Update on the Marine Environmental Consequences of Tidal Power Development in the Upper Reaches of the Bay of Fundy

Donald C. Gordon Jr.[1] and Michael J. Dadswell[2]

[1]Marine Ecology Laboratory, Ocean Science and Surveys Atlantic, Department of Fisheries and Oceans, c/o Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, N.S. B2Y 4A2

[2]Biological Station, Fisheries Research Branch, Department of Fisheries and Oceans, St. Andrews, N.B. E0G 2X0

June 1984

Canadian Technical Report of Fisheries and Aquatic Sciences No. 1256

Fisheries and Oceans Pêches et Océans

Canada

Canadian Technical Report of
Fisheries and Aquatic Sciences No. 1256

June 1984

UPDATE OF THE MARINE ENVIRONMENTAL CONSEQUENCES OF TIDAL POWER DEVELOPMENT IN THE UPPER REACHES OF THE BAY OF FUNDY

Edited by

Donald C. Gordon Jr.

Marine Ecology Laboratory
Ocean Science and Surveys Atlantic
Department of Fisheries and Oceans

Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia
B2Y 4A2

and

Michael J. Dadswell

Biological Station
Fisheries Research Branch
Department of Fisheries and Oceans
St. Andrews, New Brunswick
EOG 2X0

Proceedings of a workshop organized by the Fundy Environmental Studies Committee of APICS at the Université de Moncton on 8-10 November 1982

This is the 89th Technical Report from the Marine Ecology Laboratory, Dartmouth, N.S., and the 167th from the Biological Station, St. Andrews, N.B.

DEDICATION

This report is dedicated to Dr. Fred J. Simpson who retires in 1984 as Director of the Atlantic Research Laboratory of the National Research Council of Canada. Fred has long been an enthusiastic supporter of Fundy research and played a major role in the establishment of the Fundy Environmental Studies Committee under APICS in 1979. As Chairman of APICS from 1981 to 1984 he actively promoted and assisted Committee activities. His guidance and support will be missed.

Cat. No. Fs 97-6/1256 ISSN 0706-6457

correct citation for this publication:

Gordon, D.C. Jr. and Dadswell, M.J. 1984. Update on the marine environmental consequences of tidal power development in the upper reaches of the Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. No. 1256: vii+686p.

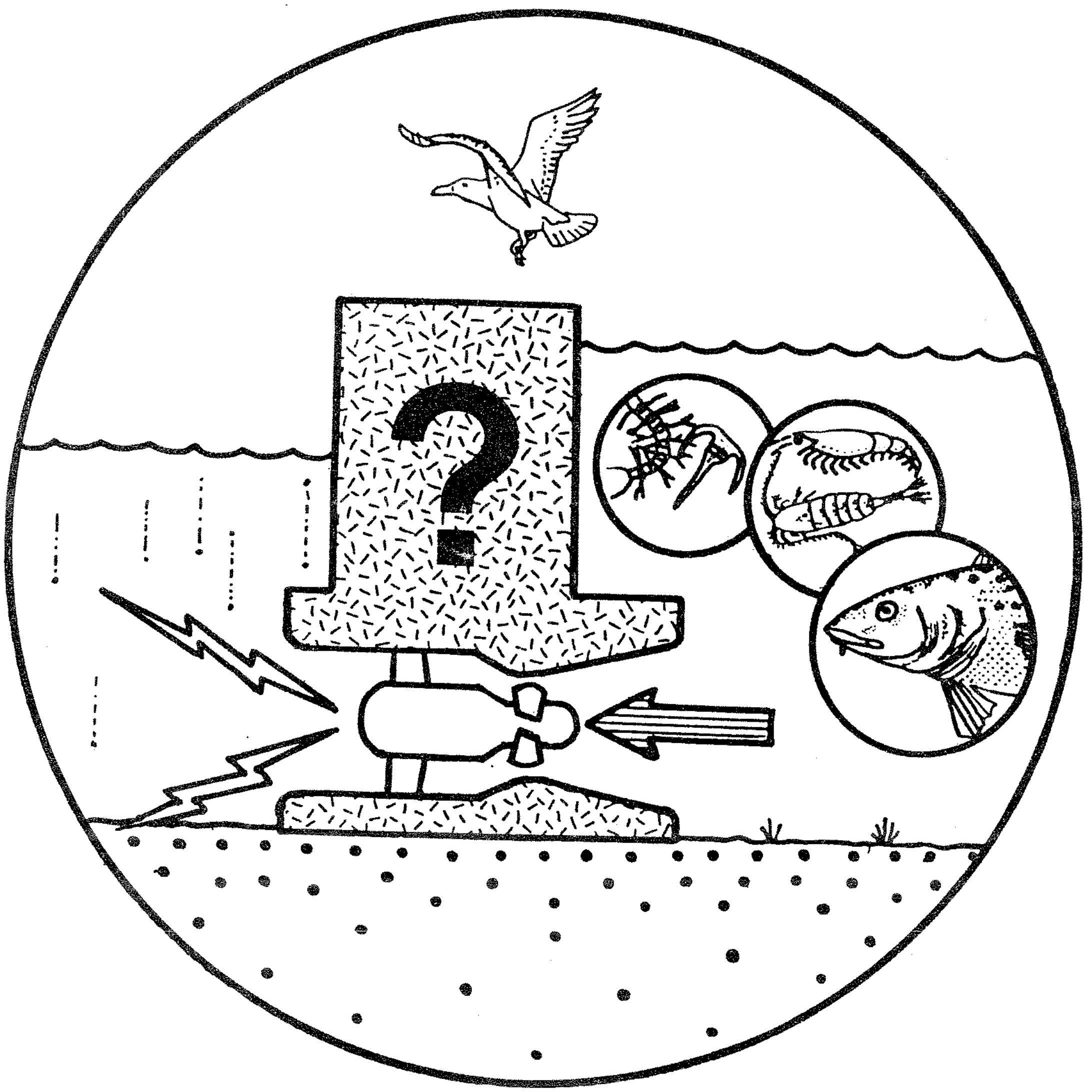


TABLE OF CONTENTS

Page

ABSTRACT

Gordon, D.C. Jr. and Dadswell, M.J. 1984. Update on the marine environmental consequences of tidal power development in the upper reaches of the Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 1256: vii+686p.

This report contains the proceedings of a workshop held at the Universite de Moncton on 8-10 November 1982 which reviewed the current knowledge of possible environmental impacts of large scale tidal power development in the upper reaches of the Bay of Fundy. Session I presented an up-to-date review of basic environmental research in the region with emphasis on research conducted since 1976. Engineering details of the most probable tidal power projects were presented in Session II. In Session III, scientists offered their predictions on how the proposed projects could alter environmental conditions in the Fundy region. Finally, Session IV featured a roundtable discussion which considered the adequacy of the environmental studies conducted to date plus the requirements and responsibilities for future work.

Key words: Bay of Fundy, tidal power development, environmental impacts

RÉSUMÉ

Gordon, D.C. Jr. and Dadswell, M.J. 1984. Update on the marine environmental consequences of tidal power development in the upper reaches of the Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 1256:vii+686p.

Le présent rapport renferme les actes d'un atelier organisé par l'APICS Fundy Environmental Studies Committee pour réévaluer les conséquences possibles sur le milieu marin par suite des aménagements marémoteurs dans les rentrants nord de la baie de Fundy. La première section contient onze études bibliographiques qui résument les recherches environnementales effectuées dans la baie de Fundy depuis 1976. Dans la section II, l'auteur présente certains détails techniques des projets marémoteurs les plus susceptibles de voir le jour. Les vingt-deux contributions formant la section III font état des perceptions de la communauté scientifique concernant la façon par laquelle une centrale marémotrice pourrait porter atteinte au milieu naturel. Cette section renferme de nombreuses opinions spéculatives et plusieurs questions, bien qu'elles soient de mieux en mieux comprises, ne trouvent pas encore de réponses satisfaisantes. La section IV, présentée à la fois en français et en anglais, contient la transcription corrigée d'une discussion-forum concernant l'à-propos des études environnementales menées jusqu'à ce jour ainsi que les exigences et les responsabilités relatives aux travaux à venir.

INTRODUCTION

Donald C. Gordon Jr. and Michael J. Dadswell

BACKGROUND

Tidal power development in the Bay of Fundy has been given serious consideration for over 60 years. Before 1970, all proposals were abandoned because they could not be economically competitive with conventional power producing schemes. The situation, however, changed in the 1970s due to the rapid escalation of world oil prices. The Bay of Fundy Tidal Power Review Board (1977) concluded that tidal power had become economically feasible and recommended that a pre-investment design program be carried out for the proposed Cumberland Basin project. More recent update studies (Nova Scotia Tidal Power Corporation 1982) reconfirmed the economic viability of a tidal power project and favoured the development of the larger Cobequid Bay site. Further precommitment studies seem highly likely but their initiation depends upon a number of political and economic factors. As an indication of the serious consideration currently being given to tidal power development, the Nova Scotia Tidal Power Corporation has constructed a pilot project at Annapolis Royal which is expected to be operational in 1984.

Constructing a tidal power project in either Cumberland Basin or Cobequid Bay, which would be a major engineering undertaking on the scale of the Dutch Delta Project, would have far reaching environmental consequences. Recognizing this, a workshop was held at Acadia University in November, 1976 to examine in a preliminary way the environmental implications of possible projects (Daborn 1977). In 1977, the hypothetical project was referred to the Federal Environmental Assessment and Review Office (FEARO). Subsequently a joint federal and provincial environmental assessment panel was created and draft guidelines drawn up. No further formal action will take place on a large scale project until there is a more definite proposal. However, an environmental impact assessment of the Annapolis Royal pilot project was conducted (Martec 1980). The general scope of possible environmental impacts are briefly reviewed by Gordon and Longhurst (1979) and Gordon (1983).

The 1976 Acadia workshop was a major event in the history of Bay of Fundy environmental research. Not only did it bring together the regional scientific community and force them to look at the Bay of Fundy as a complete system, but it clearly emphasized the very serious gaps that existed in our understanding. The proceedings (Daborn 1977) contained many recommendations for research that must be conducted before the impacts of tidal power can be accurately evaluated. The workshop also led to the formation of the Fundy Environmental Studies Committee, under the Atlantic Provinces Council for the Sciences (APICS). This Committee, which is composed of over 100 scientists and engineers who are actively conducting or managing environmental research in the Bay of Fundy, promotes information exchange by organizing workshops such as this, preparing bibliographies and conducting inventories.

Fortunately, many of the recommendations made at the 1976 Acadia workshop were acted upon and numerous research projects have been conducted in the Bay of Fundy during the past six years. They have covered all scientific displines and involved government, university and consulting industry scientists. Most of the research was conducted at the initiative of individual research scientists who were able to get financial support from on-going government programs or granting agencies. Some of the data generated have been tabulated by Loucks (1979) and published papers have been documented in a series of bibliographies (Moyse 1978; Anon. 1979, 1981, 1983).

In 1981 the Fundy Environmental Studies Committee organized the Symposium on the Dynamics of Turbid Coastal Environments in order to review some of the recent Fundy research before an international audience and to learn about comparable work being pursued in similar environments elsewhere in the world. The proceedings (Gordon and Hourston 1983) were strictly scientific and deliberately avoided the issue of tidal power environmental impacts. Therefore the Committee decided that there should be a major followup workshop of regional focus which offered a more complete review of recent Fundy environmental research and reconsidered the possible impacts of the latest tidal power proposals. This workshop was organized at the Universite de Moncton on 8-10 November 1982. It was attended by over 100 people including scientists from France, the Netherlands and the USA.

WORKSHOP PURPOSE AND STRUCTURE

The purpose of Session I was to review as completely as possible in the time available all the basic environmental research that had been conducted in the Bay of Fundy since 1976. Eleven review papers were presented, most of which dealt with biological aspects. The topics were broad and authors had to summarize the work of many scientists, much of which was unpublished. Authors prepared and circulated outlines before the workshop to minimize overlap, identify omissions and encourage cross-referencing. The basic research summarized in this session forms the essential foundation upon which environmental assessment of tidal power development can be built.

Session II presented the up-to-date design and construction details of the most probable tidal power project(s) currently under consideration for the upper reaches of the Bay of Fundy. It also included a discussion of expected changes in tidal regime both behind and seaward of proposed barrages. This information is necessary to determine the type of environmental impacts that can be expected.

These two sessions provided the background for Session III in which scientists presented their own predictions of how the proposed project(s) would alter environmental conditions in the Bay of Fundy as they are understood at the present time. Some were quite well developed and based on considerable research while others were more "gut feeling". The purpose was not to come up with final and unequivocal answers for that is impossible at the present time and must await the formal FEARO environmental assessment exercise. Rather it was to update opinions and provoke discussion which is a necessary step in the long and complicated process of determining environmental impacts of such a massive engineering project. Speculation was considerable and some predictions were in conflict with others which is to be expected at the present stage of understanding.

Finally, Session IV featured a roundtable discussion which considered the adequacy of the environmental studies conducted to date plus the requirements and responsibilities for future work. The panelists came from a wide variety of backgrounds to ensure that environmental impacts were considered in the broadest of terms including political, social and economic.

CONTENT OF REPORT

All speakers in Sessions I-III were requested to submit manuscripts immediately after the workshop and all of these, after editing, are included in this report. Because of their nature and the effort that went into their preparation, the Session I papers are quite thorough, well-balanced and complimentary. With minor changes, many of them would be suitable for primary publication. In contrast, the content of Session III papers varies immensely. For very good reasons, some authors were able to say little and were hesitant to write a short contribution. Others were able to prepare quite detailed contributions based on considerable effort. Editing in most cases was limited to format in order to insure the "individuality" of contributions.

The roundtable discussion in Session IV was recorded on tape and later transcribed and edited. Simultaneous French translation was available during the session and the edited transcript was translated into French after the workshop. Both English and French versions are included in this report.

Most of the contributions in Session III focus upon tidal power development in the upper reaches of Fundy, the theme of the workshop. Some consider a specific project, Cumberland Basin or Cobequid Bay, while others address both. Several contributions deal specifically with the environmental impacts of the Annapolis pilot project. They were included because some of the experience gained at Annapolis can be applied to a large scale project in the upper reaches of the Bay.

As should be evident from reading the individual contributions, this document should not be viewed as the final work on environmental impacts of tidal power development. As the title indicates, it is only an "update", incorporating new data and ideas developed since the 1976 Acadia workshop, a summary of our understanding as of late 1982. Further work is necessary and much is currently underway. Many contributions are already out of data because of additional research done after the workshop. If a commitment is made to proceed with the final planning studies of tidal power development in the upper reaches of the Bay of Fundy, this document will serve as the basis for planning the environmental components. Some time in the future it is hoped that the Session I papers can be expanded into a monograph on the Bay of Fundy similar to that recently published for the Quoddy Region (Thomas 1983).

ACKNOWLEDGMENTS

First and foremost we thank the many authors who prepared contributions for this report and the roundtable discussion participants who presented their opinions. Funding for the workshop was provided by the Atlantic Provinces Council on the Sciences (APICS) and the Universite de Moncton. Dixi Lambert from the Office of the Minister, Fisheries and Oceans Ottawa, arranged for and funded the French translation services. Peter Cranford prepared the English transcript of Session IV and Michel Joanis, Fisheries and Oceans Ottawa, translated it into French. In planning the workshop we were assisted by two other members of the Steering Committee, J. Lakshminarayana and George Baker. The Universite de Moncton provided an excellent environment for the workshop and all local arrangements were efficiently handled by J. Lakshminarayana and Patrick Maltais, assisted by many students. Finally, we wish to thank the B.I.O. Word Processing Unit and Publications Services for their excellent assistance in preparing this lengthy report.

REFERENCES

Anon. 1979. Bay of Fundy Bibliography: Supplement I. Proc. N.S. Inst. Sci. 29: 313-314.

Anon. 1981. Bay of Fundy Bibliography: Supplement II. Proc. N.S. Inst. Sci. 31: 181-185.

Anon. 1983. Bay of Fundy Bibliography: Supplement III. Proc. N.S. Inst. Sci. 33: 101-105.

Bay of Fundy Tidal Power Review Board. 1977. Reassessment of Fundy tidal power. Ottawa, 516 p.

Daborn, G.R. ed. 1977. Fundy tidal power and the environment. Acadia Univ. Inst. Publ. No. 28, 304 p.

Gordon, D.C. Jr. 1983. Integration of ecological and engineering aspects in planning large scale tidal power development in the Bay of Fundy, Canada. Water Sci. Tech. 16: 281-295.

Gordon, D.C. Jr. and A.S. Hourston (ed.) 1983. Proceedings of the Symposium on the Dynamics of Turbid Coastal Environments. Can. J. Fish. Aquat. Sci. 40 (Suppl. 1): 1-365.

Gordon, D.C. Jr. and A.R. Longhurst. 1979. The environmental aspects of tidal power project in the upper reaches of the Bay of Fundy. Mar. Pollut. Bull. 10: 38-45.

Loucks, R.H. Oceanology Ltd. 1979. Bay of Fundy environmental data inventory. Atlantic Regional Laboratory Tech. Rept. No. 24 (NRCC No. 17746), 155 p.

Martec Ltd. 1980. Annapolis tidal power project environmental assessment. Halifax, N.S.

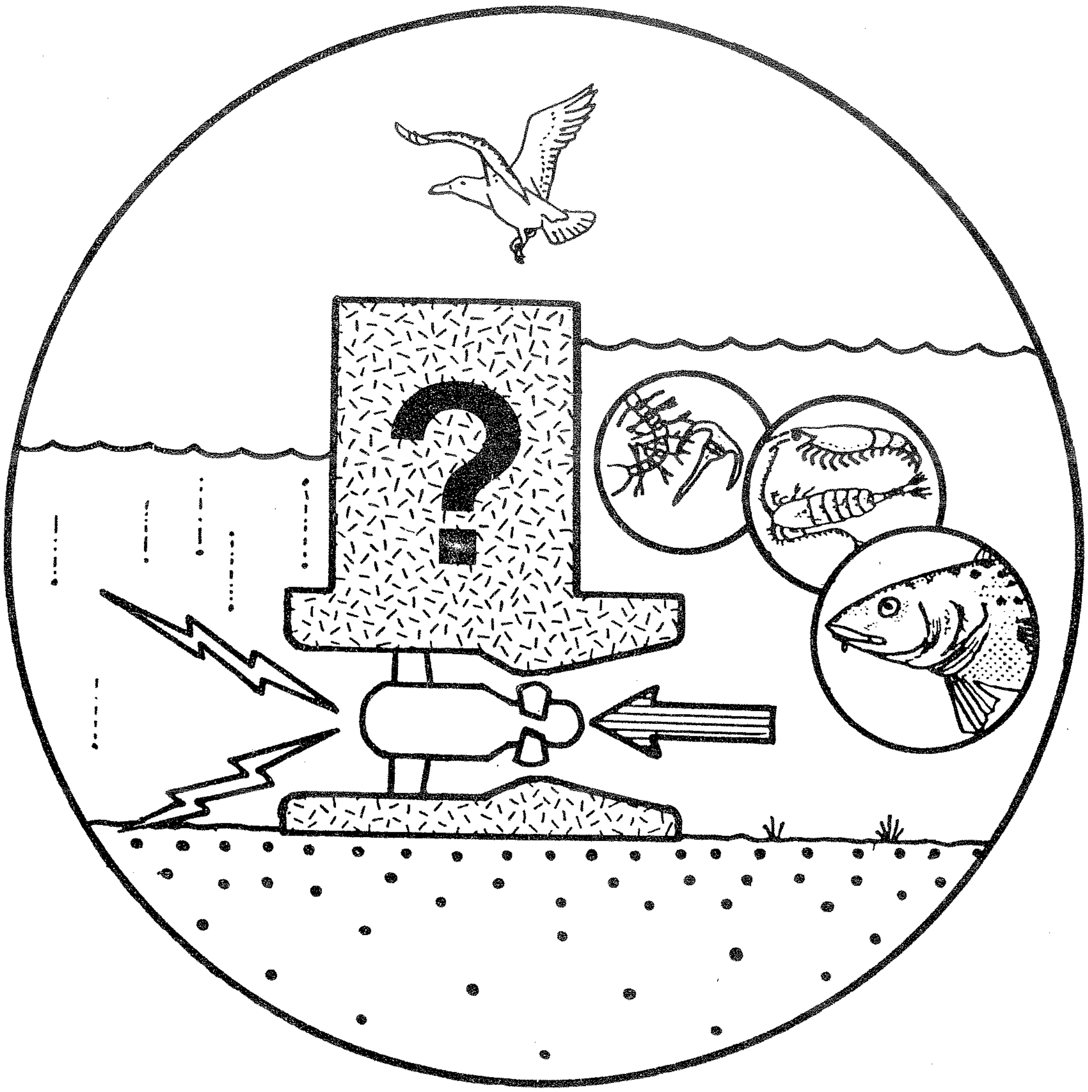
Moyse, C.M. 1978. Bay of Fundy environmental and tidal power bibliography. Fish. Mar. Ser. Tech. Rept. No. 822, 123 p.

Nova Scotia Tidal Power Corporation. 1982. Fundy tidal power; Update '82. Halifax, N.S. 41 p.

Thomas, M.L.H. (ed.) 1983. Marine and coastal systems of the Quoddy Region, New Brunswick. Can. Spec. Publ. Fish. Aquat. Sci. No. 64, 306 p.

SESSION I

Review papers of basic environmental research conducted since 1976.



A Review of the Physical Oceanography of the Bay of Fundy

David A. Greenberg

Coastal Oceanography
Bedford Institute of Oceanography
P.O. Box 1006, Dartmouth, N.S. B2Y 4A2

ABSTRACT

The physical oceanography of the Bay of Fundy is examined. The large tides and tidal currents, attributable to a resonance effect, are a dominant force in the system. Variations in water levels and currents are caused by the predictable variability in the tidal generating forces, and by the less predictable meteorological forcing and fresh water input. The large tides give rise to unusual effects such as tidal bores and reversing falls. The potential and kinetic energy and dissipation levels associated with the tides are all very large. Examinations of hydrographic data and modelling results have indicated strong vertical mixing caused by the tides, but horizontal exchange in the system is low compared to low-tide, open-sea situations. The mean currents in the upper Bay are largely tidally-driven, but in the lower Bay, fresh water runoff plays a major role. The ice characteristics are also greatly influenced by the tidal range and tidal currents. Wave information in the Bay is sparce, but wave energy typically is not large.

Key words: physical oceanography, Bay of Fundy, tidal dynamics, numeric model studies

RÉSUMÉ

L'océanographie physique de la baie de Fundy fait l'objet du présent rapport. De fortes marées et d'énormes courants tidaux attribuables à un effet de résonance, constituent une force dominante dans le système. Certaines variations du niveau de l'eau et des courants sont causées par la variabilité prévisible des forces génératrices de la marée astronomique, ainsi que par le forçage météorologique direct et l'apport en eaux douces. Les grandes marées donnent lieu à des phénomènes particuliers comme le mascaret et les chutes réversibles. L'énergie potentielle et cinétique de même que les niveaux de dissipation associés aux marées sont tous très élevés. L'examen des données hydrographiques et des résultats de modélisation ont révélé l'existence d'un mélange vertical très fort, lequel est dû aux marées, tandis que l'échange horizontal est faible dans le système comparativement à ce qui existe dans les zones littorales de faible marée et de mer libre. Dans la baie du Nord, les courants moyens sont généralement mus par les marées, mais dans la baie du Sud, l'écoulement des eaux douces joue un rôle de premier plan. Les caractéristiques glacielles sont aussi dominées par le marnage et les courants tidaux. On ne sait pas grand chose de la houle qui règne dans la Baie, mas l'énergie des vagues est singulièrement faible.

INTRODUCTION

There are many processes important in the physical oceanography of the Bay of Fundy. One picture is obtained by thinking in terms of the dominant M_2 tidal signal of 12.42 hrs, the annual signal and the annual means of current and hydrographic parameters. Although this would cover most of the dynamics of the system, much of interest is attributable to the variability in these signals. The very predictable variations in tides and the less predictable annual and short time scale variations in meteorology are of great importance to the synoptic picture of the Bay and significant to many non-physical aspects of the environment. This paper attempts to briefly describe what is known about the dominant processes in the Bay of Fundy and indicate some important areas of variability in these processes.

THE SEA LEVEL TIDAL REGIME

Prior to the late 1960's the large tidal oscillations in the Bay of Fundy were thought to be caused by the near resonance between the M_2 tide (period 12.42 hours) and the natural period of the Bay. Defant (1961), for example, referring to the Bay, stated "the resonance condition is almost completely fulfulled". However, when a detailed calculation was made (Rao 1968), the free period of the Bay of Fundy alone was found to be about 9 hours which could amplify the tides, but is far from resonance. Later, Garrett (1972, 1974) showed that the entire Gulf of Maine and Bay of Fundy (Fig. 1) combined to form one resonant system with a period of close to 13 hours. Duff (1981) has suggested that "frequency entrainment" - a process by which a system forced near to natural period will convert energy to this natural period from the forced period, - may also play a part in the large Fundy tides.

Figure 2 shows the amplification of the tide incident on the shelf edge. The tidal range increases from the shelf edge by a factor of 2 1/2 to Boston, 3 to Yarmouth, 6 to Saint John, 10 to Upper Chignecto and 12 in upper Minas. Greenberg (1979) demonstrated that most of the energy enters via the Northeast channel and the northern shelf, with some entering through Great South Channel.

The above describes the M_2 component of the tide - the largest single constituent with a period of 12.42 hours and representing 90% of the tidal energy. It can reasonably be considered by itself to represent the "mean tide". The amplitude of the next two largest constituents, N_2 (period 12.66 hrs) and S_2 (period 12.00 hrs) are a factor of 4.7 and 6 smaller than M_2 respectively. The ratio of these terms is fairly constant throughout the Bay of Fundy and Gulf of Maine (Garrett 1972). It is principally the beating of these three frequencies that provides the spring-neaps variation over the course of 15 and 29 days. Beating results from the superimposing of two waves of different frequencies, which leads to a maximum combined range when the waves are in phase, and to a minimum when the waves are out of phase. The diurnal variation in this system is caused by two main constituents: K_1 (period 23.94 hrs) and O_1 (period 25.82 hrs). These are far enough from the natural period that they lead to no resonant

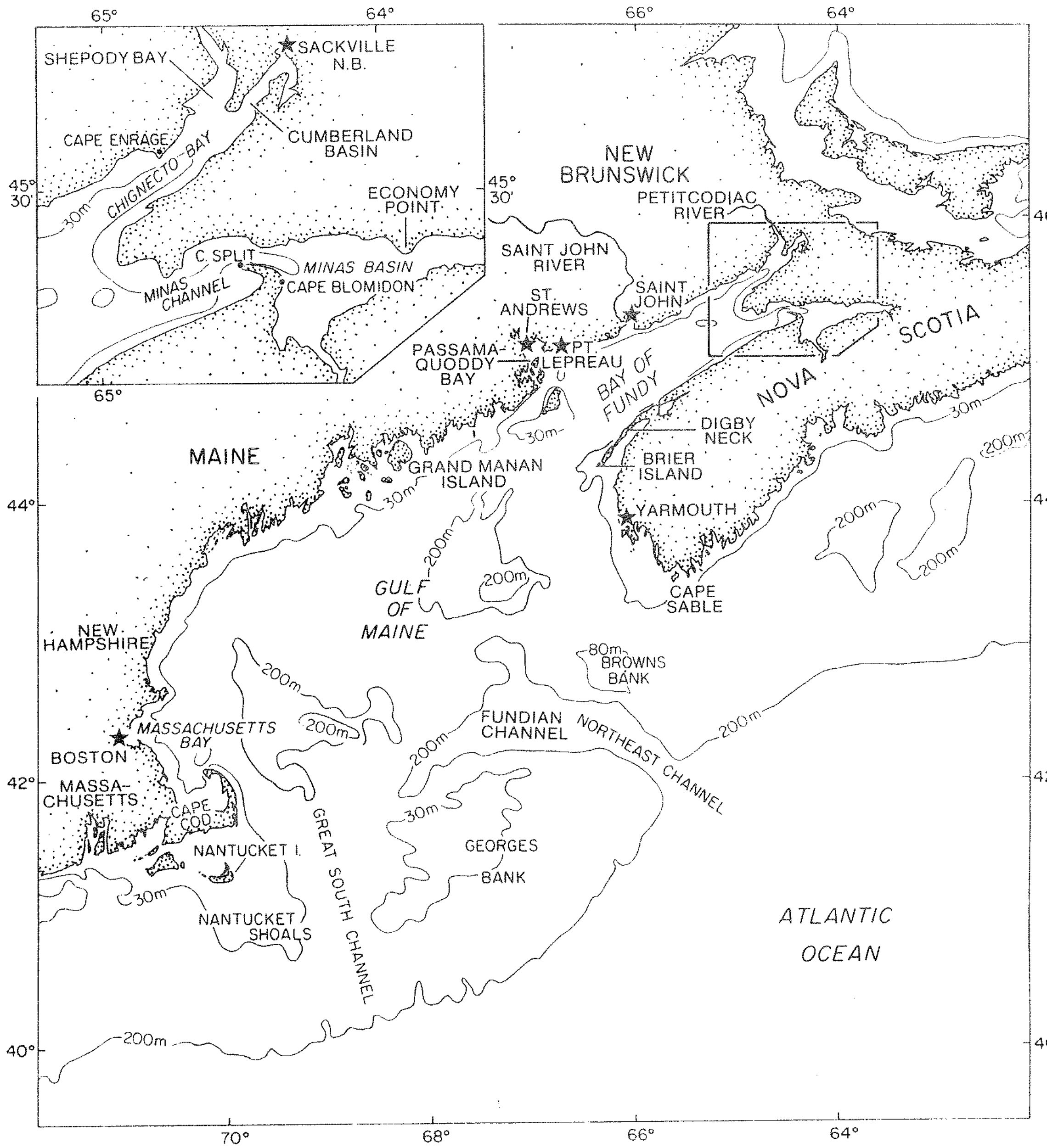


Fig. 1. Location Map for the Bay of Fundy and Gulf of Maine.

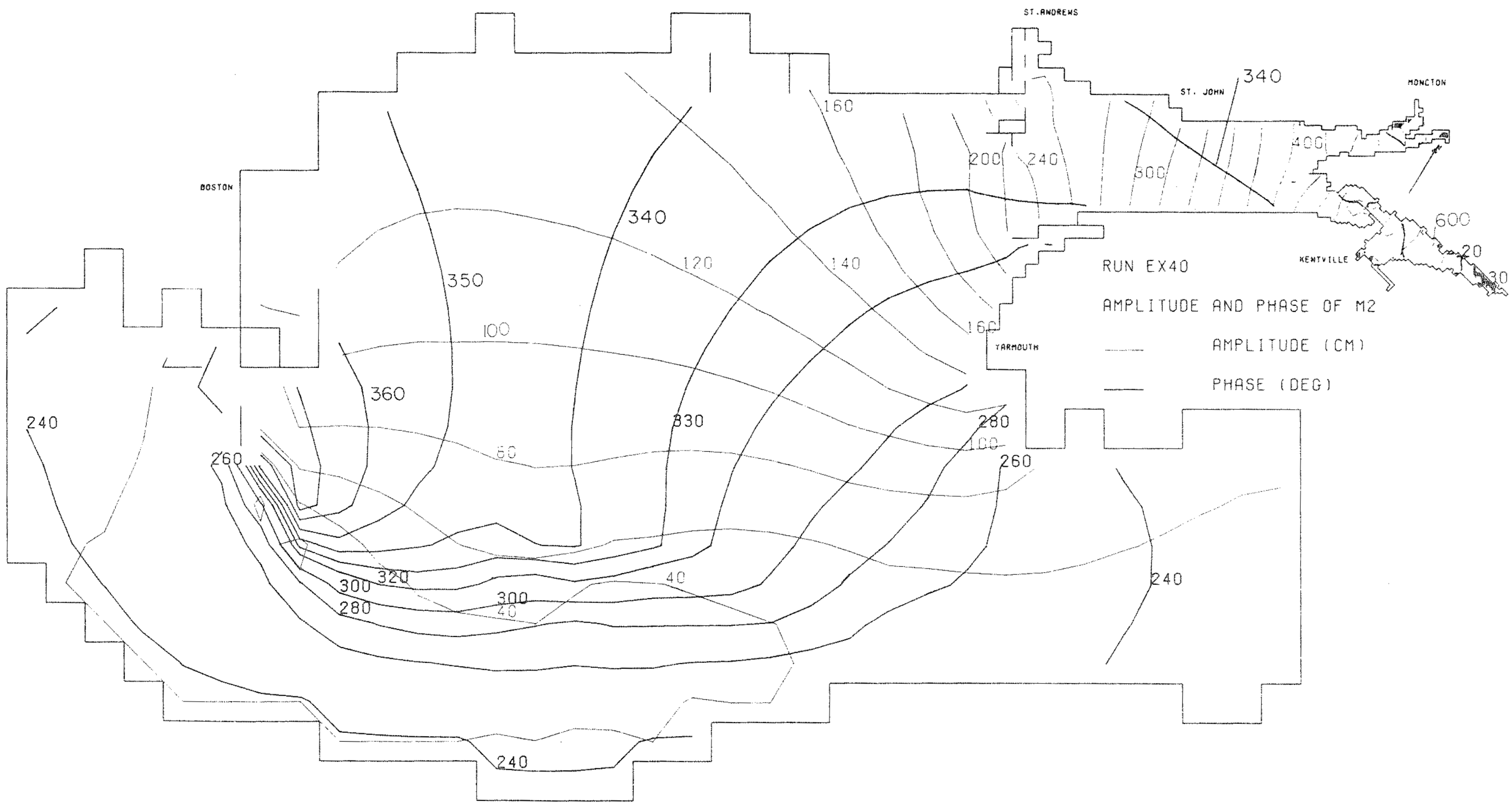


Fig. 2. The M_2 tidal regime from Greenberg (1979). Phases are relative to time zone +4. The M_2 tide can be considered the mean tide in the Bay of Fundy and Gulf of Maine.

amplification. The amplitude of these constituents is fairly constant throughout the Bay and Gulf at 10-15 cm. The beating of these two signals also leads to a spring-neaps cycle. The beat frequencies of the semi-diurnal and diurnal tides themselves beat, creating a third beat frequency that leads to two times a year when higher than normal tides are experienced. In the Bay of Fundy and Gulf of Maine the ratio of the highest tide range of the year to lowest is about 2:1. This is small compared to some areas, such as near the French tidal power plant at La Rance where the ratio is about 6:1. The largest and smallest tides are typically seen twice yearly, but the major part of the variability occurs over the 15 day and 29 day cycle (see Fig. 3 below).

Over the longer period the tides are amplified by an 18.6 year nodal variation. The effect is to change the different constituents by different percentages. The largest effect in the Fundy-Maine system is from the ±3.7% variation in M_2 amplitude. It is thought that frictional effects and the competing effect from diurnals which have a nodal variation out of phase with the semi-diurnals, would reduce this to ±2.6% (Garrett 1977).

TIDAL CURRENTS

Much of what has been said about variability in tidal elevation applies to tidal currents. It is harder to get accurate tidal constituents from current observations for three reasons. Simple continuity tells us that the tidal current will be closely related to tidal elevation, but vary with basin configuration and topography. A general hourly picture of mean tidal currents is given in the Atlas of Tidal Currents (CHS 1981), based on the numerical model described in Greenberg (1979). Some general observations, can be made. The currents are of the order 1 $m.s^{-1}$ around Southwest Nova Scotia and over Georges Bank. The rest of the Gulf of Maine has lower tidal currents - about 0.5 $m.s^{-1}$ and even lower in the western corner of the Gulf. The tidal currents increase from 0.75 to 1. $m.s^{-1}$ from the mouth of the Bay to Cape Chignecto and continue fairly uniformly at that level in Chignecto Bay. On the Nova Scotia side, the entrance to Minas Channel has tidal currents of 1 to 1.5 $m.s^{-1}$ increasing to as high as 4 $m.s^{-1}$ in the narrows by Cape Split then decreasing to a typical strength of 1.5 $m.s^{-1}$ in the Minas Basin.

TIDAL BORES AND REVERSING FALLS

Tidal bores are found in some shallow rivers that flow into the head of Chignecto Bay and Minas Basin such as the Petitcodiac River. They occur when a large amplitude tidal wave travels over shallow water. The speed at which a tidal wave moves is proportional to the depth of water over which it travels. In very shallow water, the amplitude of the tidal wave is significant with respect to the depth of the water. Thus the leading and trailing edges of the wave are retarded as they move. The typical shallow water tide rises quickly on the flood and receeds slowly on the ebb. In a tidal bore situation, the wave steepens to the extent that it

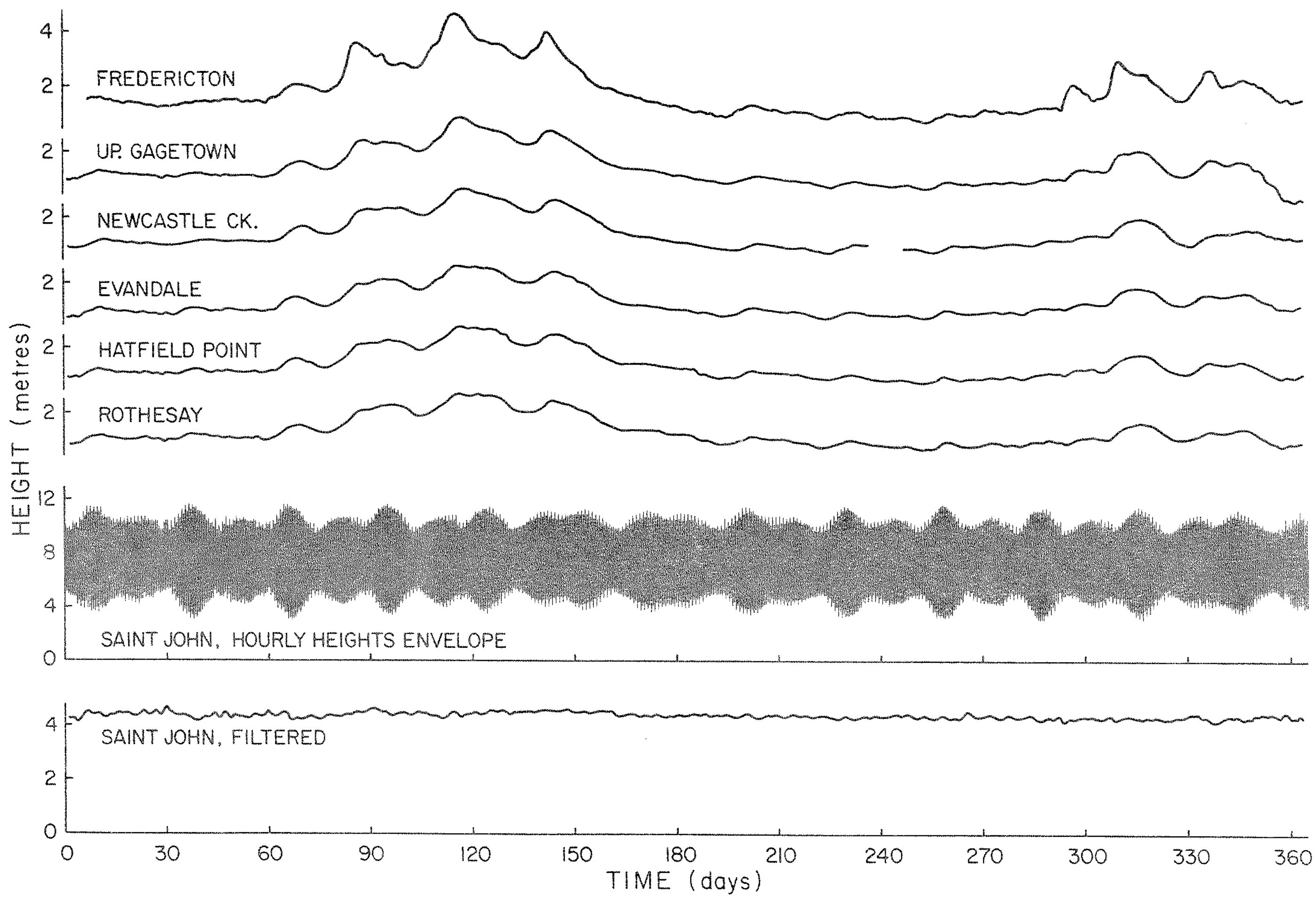


Fig. 3. Filtered hourly water levels of the lower St. John River upstream of Reversing Falls and the unfiltered and filtered water levels in St. John Harbour. The unfiltered harbour data show spring-neaps variations typical of the Bay of Fundy and Gulf of Maine. The river levels reflect variations in high tide levels in the harbour. There is no obvious correlation between the mean harbour level and the mean river level.

breaks. Much energy is dissipated in a tidal bore so it cannot continue indefinitely over the shallow water. Thus the Petitcodiac bore does not penetrate as far upstream following the siltation resulting from the completion of Moncton Causeway.

Reversing Falls, found at the mouth of the Saint John River, is driven by the combinations of high tides and river runoff over a shallow, narrow, restriction. At times of normal river flow, high water in the harbour causes an inflow past the Falls and low water causes an outflow. The mean level of the river behind the Falls is more variable and always higher than the mean level of the harbour. During times of high runoff, the level of the river is so high the falls do not reverse. The outflow at the falls at low water is "critical", meaning that it is flowing at its maximum rate, and lowering low tide would not increase the flow. At high water the inflow is not as restricted for normal river levels. Although there is no inflow during high runoff, the outflow at this time is retarded. A consequence of this regime is that the mean level in the reservoir tends to reflect the high tide levels in the harbour (Fig. 3). At times of high runoff, (inferred from the Fredericton record) the effects are more pronounced downstream at spring tides. At low runoff times, river levels seem to peak during the higher spring tides. Flooding situations caused by high runoff could be more severe when the peak runoff occurs at times of higher than normal tides.

ENERGY CHARACTERISTICS

The partitioning of tidal energy is described in Greenberg (1979) from which the following is excerpted.

Values of mean energy and mean work rates are given in Table 1. The distribution of kinetic energy and frictional work is shown in Fig. 4, and 5. The potential energy is, predictably, highest in the upper reaches of the Bay of Fundy, where the tidal range is greatest. In these areas, in particular, and generally in the Bay of Fundy, the mean potential energy is higher than the mean kinetic energy. In the Gulf of Maine the kinetic energy is greater than the potential energy, and is concentrated in a wide band from around the Nantucket area, through Georges Bank, across the Fundian Channel, and into the Bay of Fundy. There are local maxima through Great South Channel, Northeast Channel and at the entrance to the Bay of Fundy. The mean kinetic energy of the New Hampshire corner of the Gulf of Maine is very low. The kinetic energy per unit area reaches a maximum in the narrows by Cape Split, where there are strong currents through the deep channel. The mean kinetic energy in Chignecto is in comparison, very low. The frictional dissipation in the Gulf of Maine is concentrated in a band similar to that of the mean kinetic energy, but with maxima over the shallow areas. There is very little dissipation in the New Hampshire corner of the Gulf. The frictional dissipation increases gradually from the body of the bay into Chignecto Bay. There is a dramatic increase from Cape Chignecto into Cape Split, then a reduction in dissipation in the Minas Basin, although values are still relatively high.

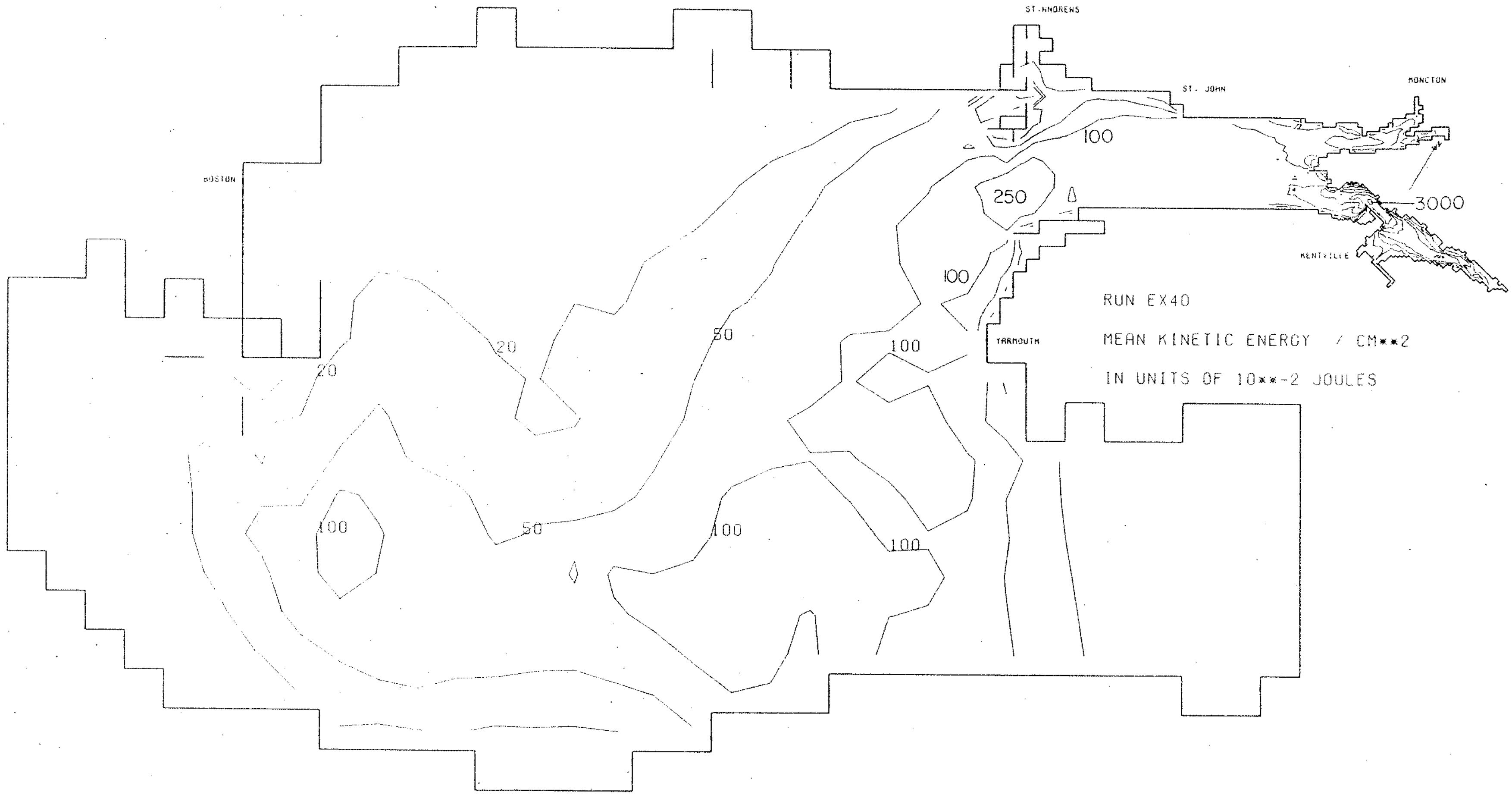


Fig. 4. The mean kinetic energy of the Bay of Fundy and Gulf of Maine from a numerical model simulation of the M_2 tide (Greenberg 1979).

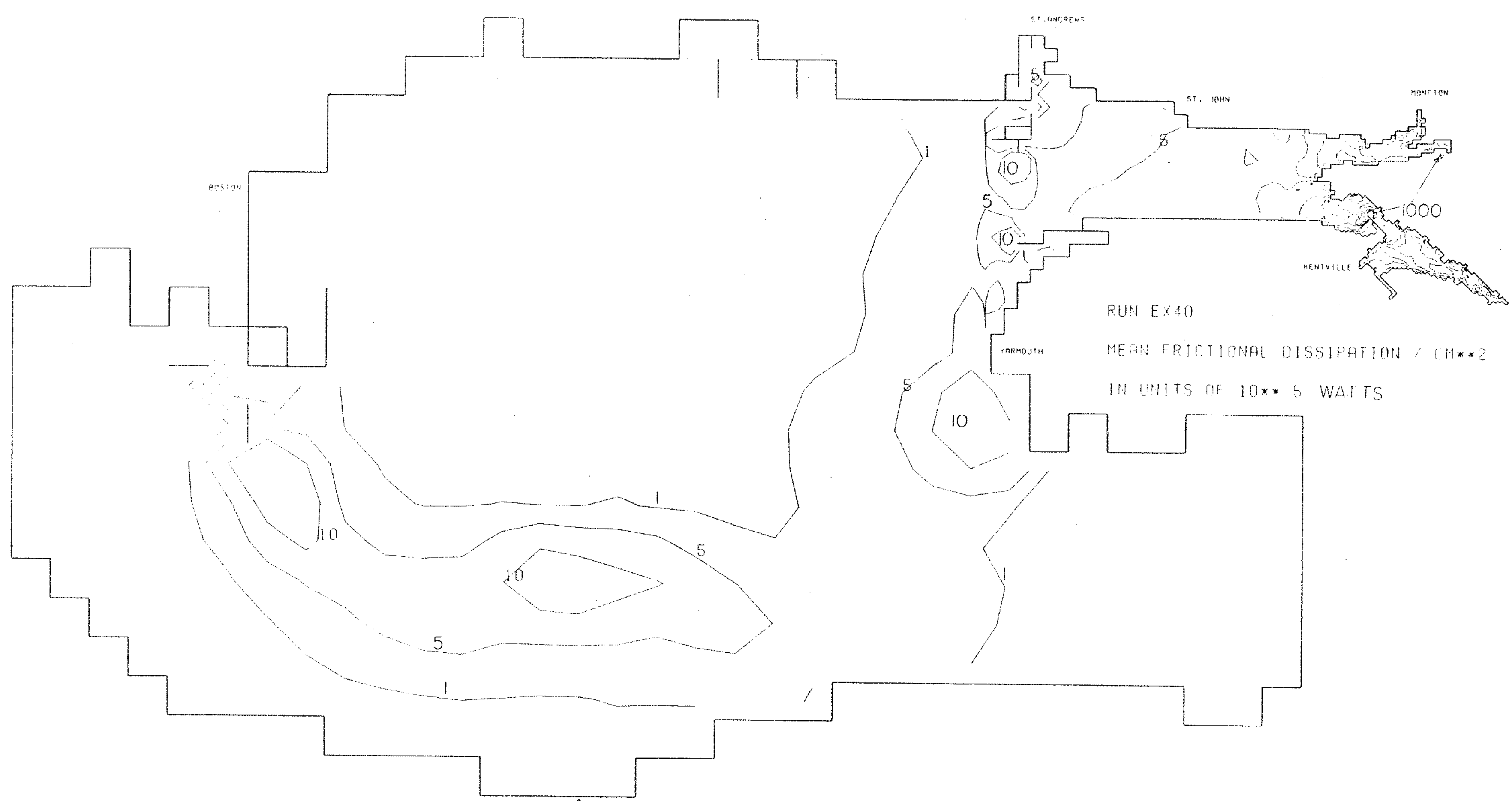


Fig. 5. The mean frictional dissipation in the Bay of Fundy and Gulf of Maine, from a numerical model simulation of the M_2 tide (Greenberg 1979).

Using the values in Table 1, the dissipative Q, where $Q = \frac{\text{Frequency x energy}}{\text{Dissipation rate}}$, was found to be 5.0 for the entire system and for the Gulf and Bay considered separately. Q is a measure of the damping of the system.

TEMPERATURE AND SALINITY CHARACTERISTICS

An integrated study of the temperature and salinity characteristics for the entire Bay of Fundy remains to be done. We can, however, put together a picture that gives us some idea of the hydrography of the region from different studies, recognizing year to year variability most noteably from variations in fresh water runoff in the St. John River (Bumpus 1960) and to some extent from meteorological effects. The data used for this outline comes from Hachey (1952), Bailey (1954), Bailey et al. (1954) who looked in detail at aspects at the mouth of the Bay; Amos and Joice (1977) who examined the Minas area; Amos and Asprey (1981) who looked at Chignecto Bay; and Kate Kranck (personal communication) and Don Gordon (personal communication) who surveyed the main body of the Bay.

Bailey (1954) studied long term measurements across a transect from St. Andrews to Digby Neck. He found data from the years 1950-1952 to be very similar, but quite different from the 1917 data in which similar salinities were observed, but temperatures were 2.0° C colder. He identified tidal mixing, vernal warming, runoff, and autumn and winter cooling to be important processes in the seasonal hydrographic picture. The analysis of data from a station north of Grand Manan Island (Bailey et al. 1954) from three depths showed sinusoidal variations over the year. Salinity reached a maximum near bottom (about 33 ‰) with little seasonal variation and a minimum at the surface in the spring (about 30 ‰) where the seasonal variation was greater. The temperature minimum of near 0°C was noted at the surface in the winter and the maximum at this station was 13°C in the late summer, found at all depths.

The spatial variation of salinity and temperature in the Bay can be pieced together from several sources of data. At the mouth of the Bay where there is extensive stratification the salinity in summer is about 33 ‰, but fresher at the surface. The surface salinity falls regularly from the mouth to near 31 ‰ by Cape Chignecto. In Chignecto Bay values of 30 ‰ have been found and in upper Minas Basin 28 ‰ has been observed. In the fall and winter, when there is less fresh water runoff, the salinities tend to be higher and more spatially uniform. Surface temperatures in the late summer show a pattern of colder 11°C water at the mouth of the Bay warming to 14°C at Cape Chignecto and rising further to 17°C in Chignecto and 21°C in upper Minas Basin. In the fall, the temperatures are spatially more uniform and cooler than in summer. In the winter, the gradient is reversed, with the coldest (0°C) water at the head of the Bay and 3°-4°C water at the mouth.

TABLE 1. Mean energy and work for an M_2 tidal cycle for different areas.

(1) From the head of Minas to Cape D'Or.

(2) From the head of Chignecto to a line midway between Cape Enrage and Cape Chignecto.

(3) Covering the head of the bay before it divides into Chignecto and Minas.

(4) The Bay of Fundy area covered by the medium mesh.

(5) The Gulf of Maine and continental shelf area covered by the coarse mesh.

The dissipative Q of each region is also given.

(from Greenberg 1979)

Area	Mean Potential Energy 10^{14} Joules	Mean Kinetic Energy 10^{14} Joules	Mean Total Energy 10^{10} Joules	Mean Rate of Friction Dissipation 10^{10} Watts	Q
1. Minas	1.15	.38	1.53	1.02	2.1
2. Chignecto	.38	.03	.41	.06	9.6
3. Upper Fundy	.65	.21	.86	.22	5.5
4. Lower Fundy	2.39	1.59	3.97	.60	9.3
Total Fundy	4.57	2.20	6.77	1.90	5.0
5. Gulf of Maine	4.34	8.45	12.79	3.60	5.0
Total Fundy-Maine	8.91	10.65	19.65	5.50	5.0

HORIZONTAL AND VERTICAL MIXING

Although some studies of horizontal mixing have been made, there is much scope for identification of the important processes in, and quantifying of, the water exchange in the Bay. Ketchum and Keen (1953) analyzed hydrographic data for the Bay of Fundy and concluded that during times of heavy runoff in the St. John River the flushing time was about 76 days. When runoff is less important the flushing time would be much longer. Holloway (1981) analyzed salinity and runoff data and found the eddy diffusivity in the Minas Basin to be related to the tidal friction along the axis of the Basin. The estimated values were of the order 200 $m^2 . s^{-1}$. This is a value similar to what one would expect in a typical open coastal area.

Tidal currents cause much of the vertical mixing in the Bay of Fundy and Gulf of Maine. Garrett et al. (1978) found that for the summer months below a critical value of the ratio of depth to tidal dissipation the water was vertically well mixed; while above that value, water could be stratified (Fig. 6a, b). Most of the Bay northeast of Saint John is well mixed as are areas around Grand Manan Island, Brier Island and southwest Nova Scotia. When summer heating is reduced and meteorological forcing increased, in the late fall, winter and early spring, the stratification is reduced throughout the Bay (Bailey 1954).

From the above and to some extent from the data in the previous section, we can see that the tides are very effective at vertically mixing the Bay, but that horizontal exchanges are comparatively low, even with the existing large tidal excursions.

MEAN CURRENTS

Numerical model studies (Tee 1976, Greenberg 1983) have indicated that the barotropic residual circulation at the head of the Bay is largely driven by the tides. This is also supported by observations (Godin 1968, Tee 1977). Strong residuals and four gyres have been identified around Cape Split and Cape Blomidon (Fig. 7). Around Cape Chignecto, Cap D'Or and in Chignecto Bay, model results show distinct mean current patterns but there are not sufficient observations to verify them. Some observations suggest that in parts of Chignecto Bay, the mean current varies in magnitude and direction with depth. In the main body of the Bay of Fundy some of the mean currents seem to be tidally generated while others, such as the principal counterclockwise gyre in the lower Bay seem to be driven baroclinically, principally from the fresh water input from the Saint John River. The computer model agrees with observations of a tidally driven gyre off St. John and strong seaward flow northeast of Grand Manan (Fig. 8). The model does not adequately resolve the rapid changes in topography at the mouth of the Bay, so the irregular pattern should only be thought of as evidence that tides do generate strong mean currents there. The seasonal wind stress does not seem to play a major role in determining the mean circulation pattern.

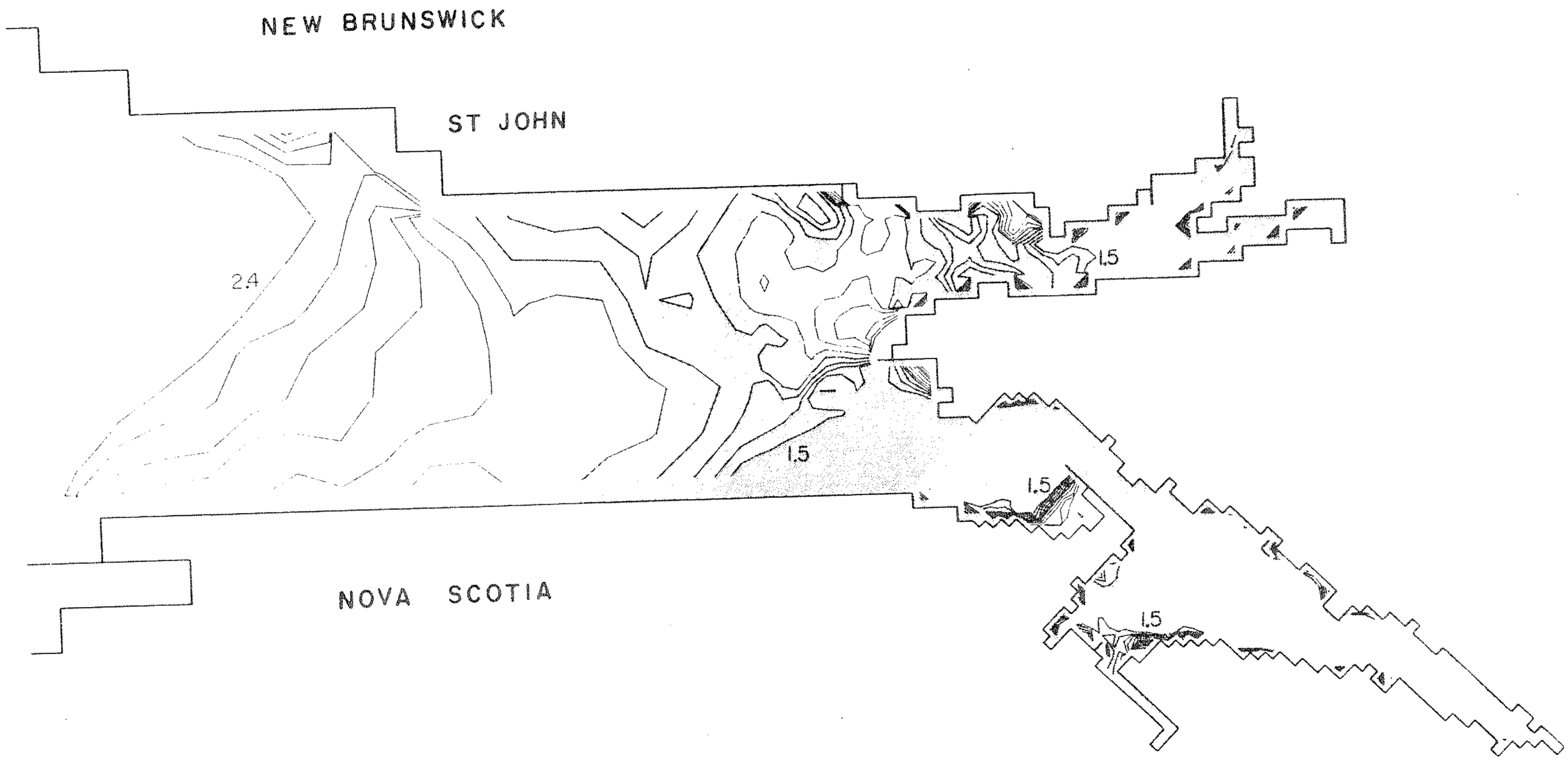


Fig. 6a. Contours of the mixing parameter $\log_{10}$ (depth/dissipation) for the Bay of Fundy. Observations from the Bay of Fundy indicated that when the parameter was less than 1.9 (shaded area), the water was well-mixed (Garrett et al. 1978).

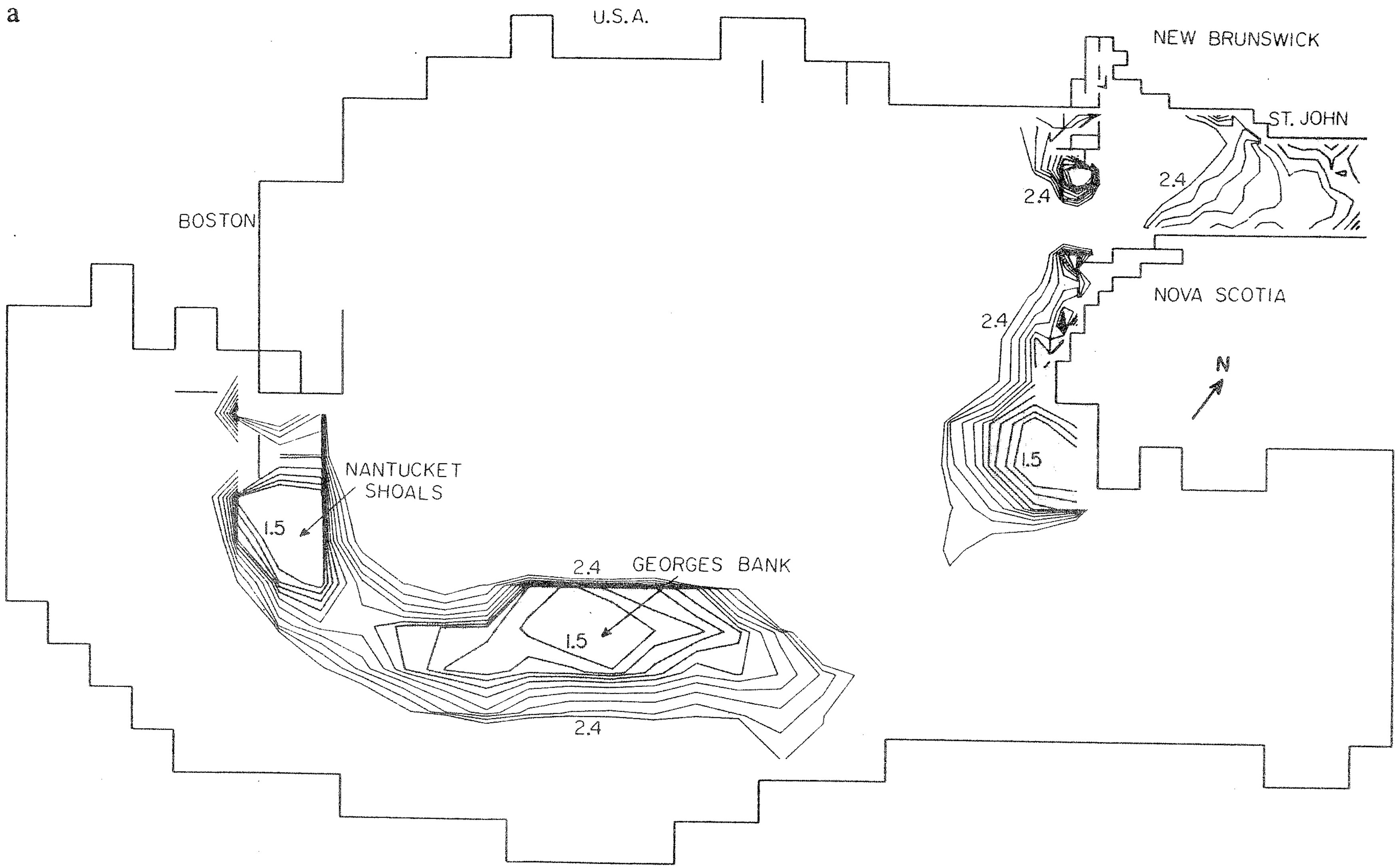


Fig. 6b. Contours of the mixing parameter $\log_{10}$ (depth/dissipation) for the outer Bay of Fundy and Gulf of Maine. Water is well-mixed when the parameter is less than 1.9 (shaded area) (Garrett et al. 1978).

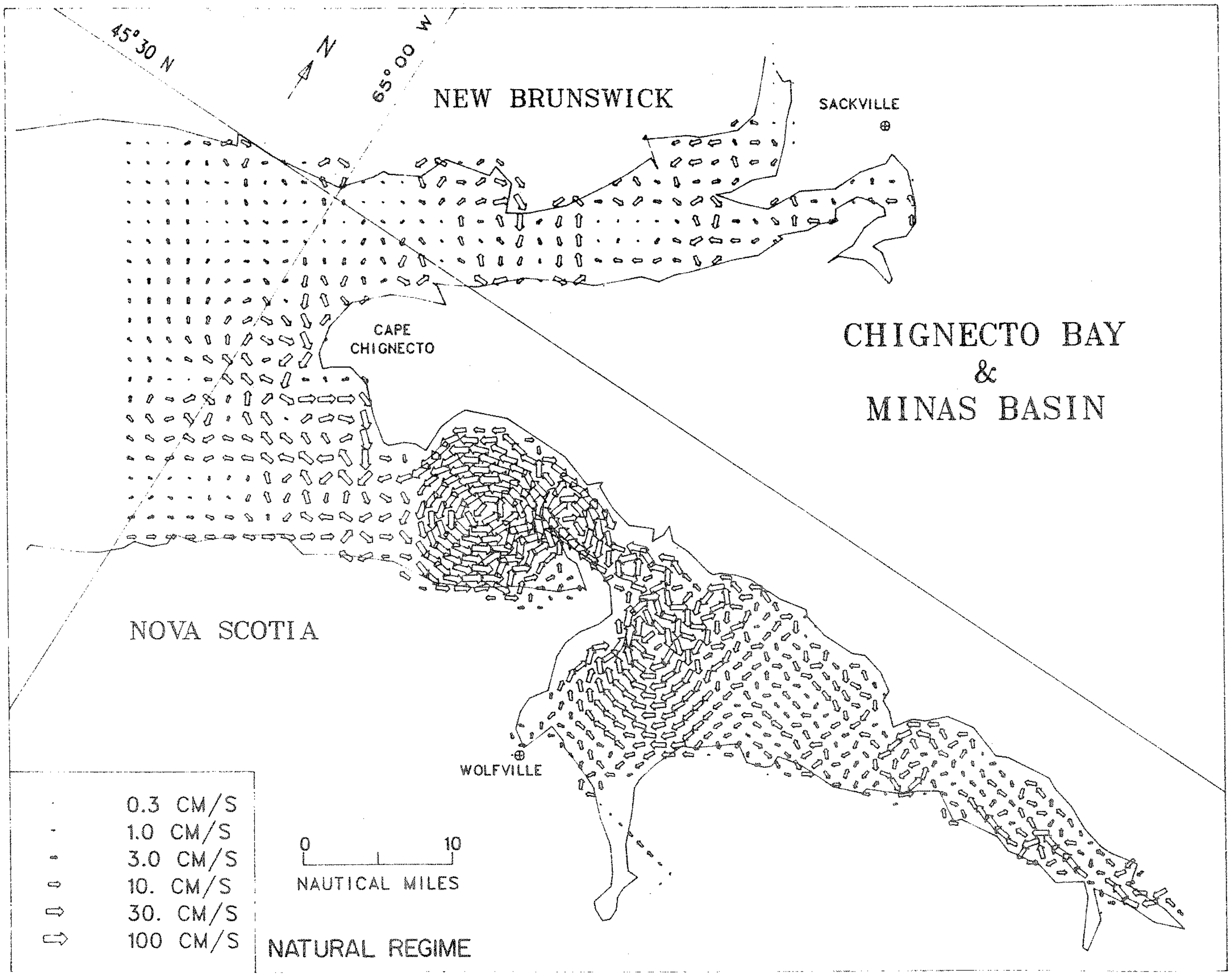


Fig. 7. Model predicted mean currents in the upper Bay of Fundy (Greenberg 1983).

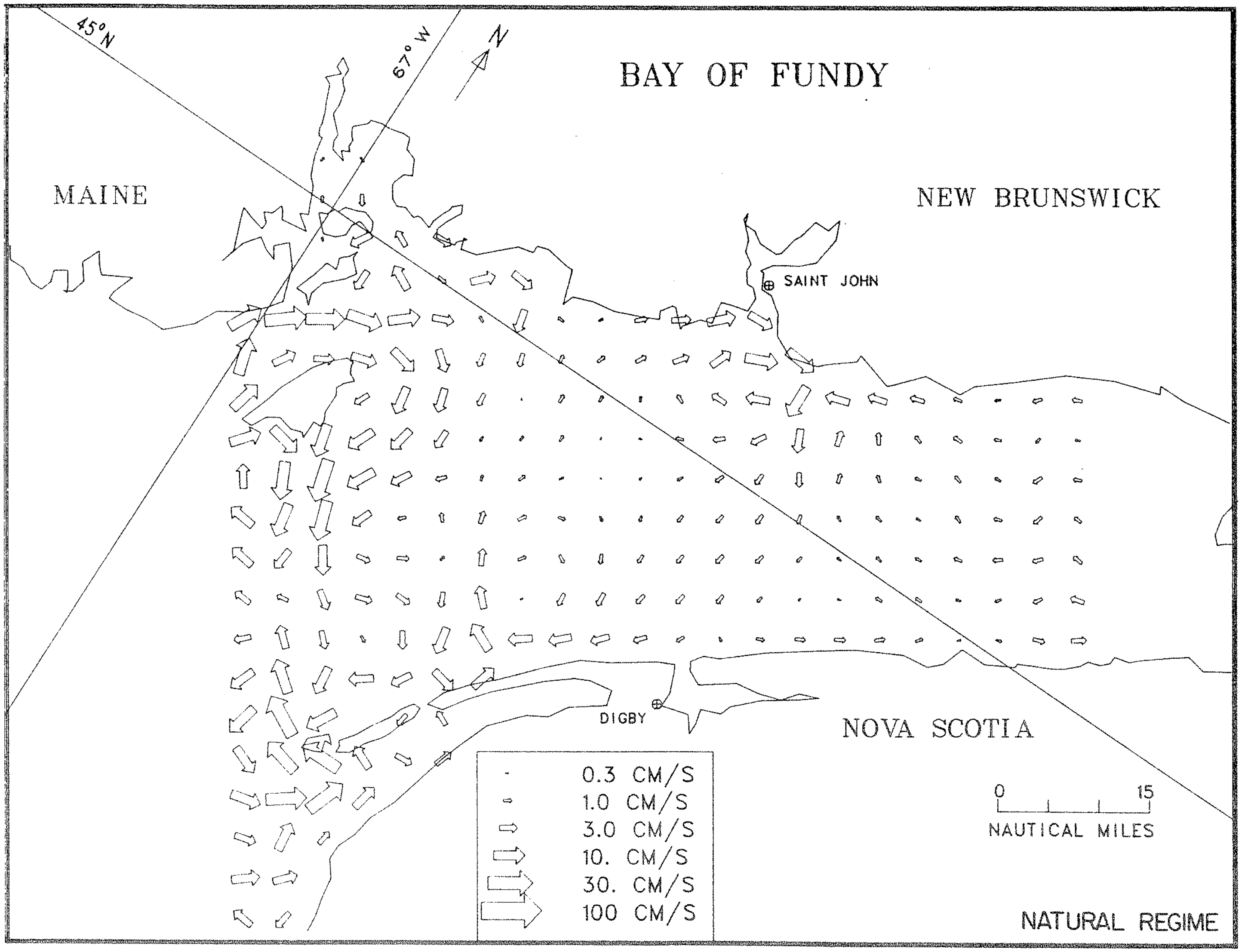


Fig. 8a. Model predicted mean currents in the lower Bay of Fundy (Greenberg 1983).

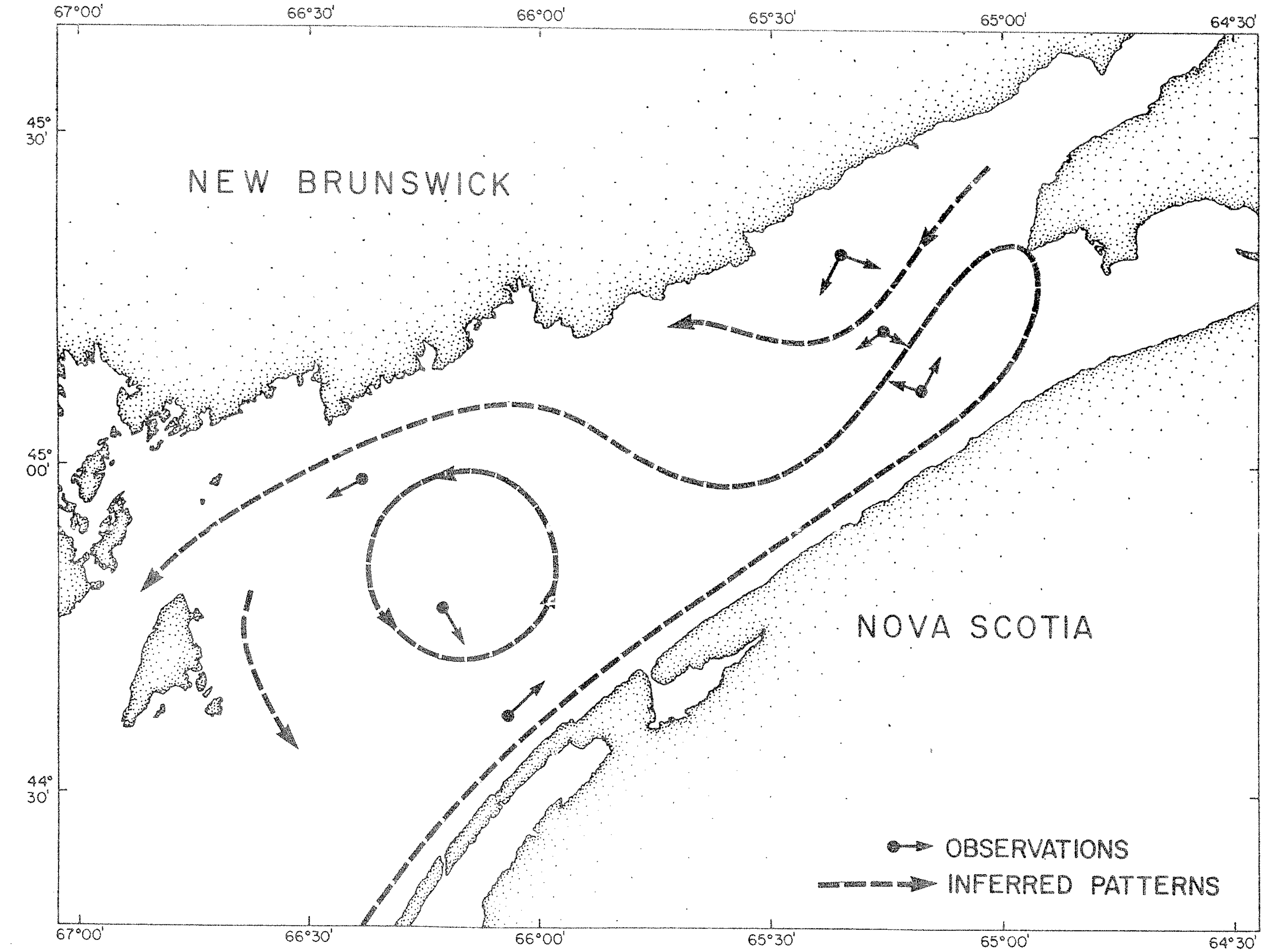


Fig. 8b. Mean current patterns from Godin (1968).

ICE, WAVES AND STORM SURGES

Ice observations are not routinely made in the Bay of Fundy. References to ice in the Bay of Fundy Sailing Directions (Anon 1982) deal as much with the Gulf of St. Lawrence as with the upper Bay. From the Sailing Directions and from ATPPB (1969), Greenberg (1977) concluded that at times, Cumberland Basin and Sheopody Bay are covered with fast ice. The only recent systematic ice study (Gordon and Desplanque 1983) contradicts this. They found that the breaking effects of the tidal range and movement by the tidal currents kept the ice in pieces and in motion most of the time. The reader is referred to Gordon and Desplanque (1983) for a detailed study including ice effects on sediment and on biology.

There have been some wave measurements in the upper Bay, but winter observations are difficult because of ice conditions. Observations in the lower Bay reported in Neu and Vandall (1976) at Tyner Pt. (near Pt. Lepreau) indicate that the significant wave height from November to April exceeds 1 m 25% of the time and exceeds 2 m 4% of the time. From May to October wave energy is reduced, reaching minimum values - approximately half the winter heights - during the late summer. There were two distinct wave periods noted: - a 9 second period attributed to sea swell generated outside the area, and a 5 second period from local generation. Longer period waves have been observed during bad storms (e.g. 16 sec during the "Groundhog Day" storm of 1976). Observations from Minas Basin (Amos and Joice 1977) show lower energy levels than observed in the lower Bay, with the significant wave height exceeding 0.6 m only 10% of the time. The observations suggest that larger waves group around a 4-5 second period. Observations from Chignecto Bay (Amos and Asprey 1981) are similar except that they do indicate some longer period, higher waves in central Chignecto.

Wave amplitude and wave period are known to increase with the duration, fetch and strength of the wind (Hasselmann et al. 1973). Wave development is also influenced by the strength of tidal streams (Phillips 1977). Wave amplitude is amplified when winds oppose currents and is decreased when wind and currents run in the same direction. There is also an apparent frequency shift from the Doppler effect of the waves moving in the current. Wind data compiled by Environment Canada (Anon 1982b) at Moncton Airport and Debert Airport for March and August are shown in Fig. 9. They represent periods of strong and weak winds respectively. It can be seen where some dominant wind directions align with the axes of the basins which would lead to increased wave energy and might interact with tidal streams. (More recent data from Sackville, N.B., which would be more relevant to Cumberland Basin, have yet to be compiled. An initial comparison of some simultaneous data, indicates that there are differences between these and the Moncton and Debert data).

Storms can cause deviations from predicted tide heights, with surges of 2 m or more observed in this area. The duration and height depends on the characteristics of the generating storm (wind, pressure, storm track, etc.). The elevation anomolies can last a few hours and might set up an oscillation that would not die down until well after the storm

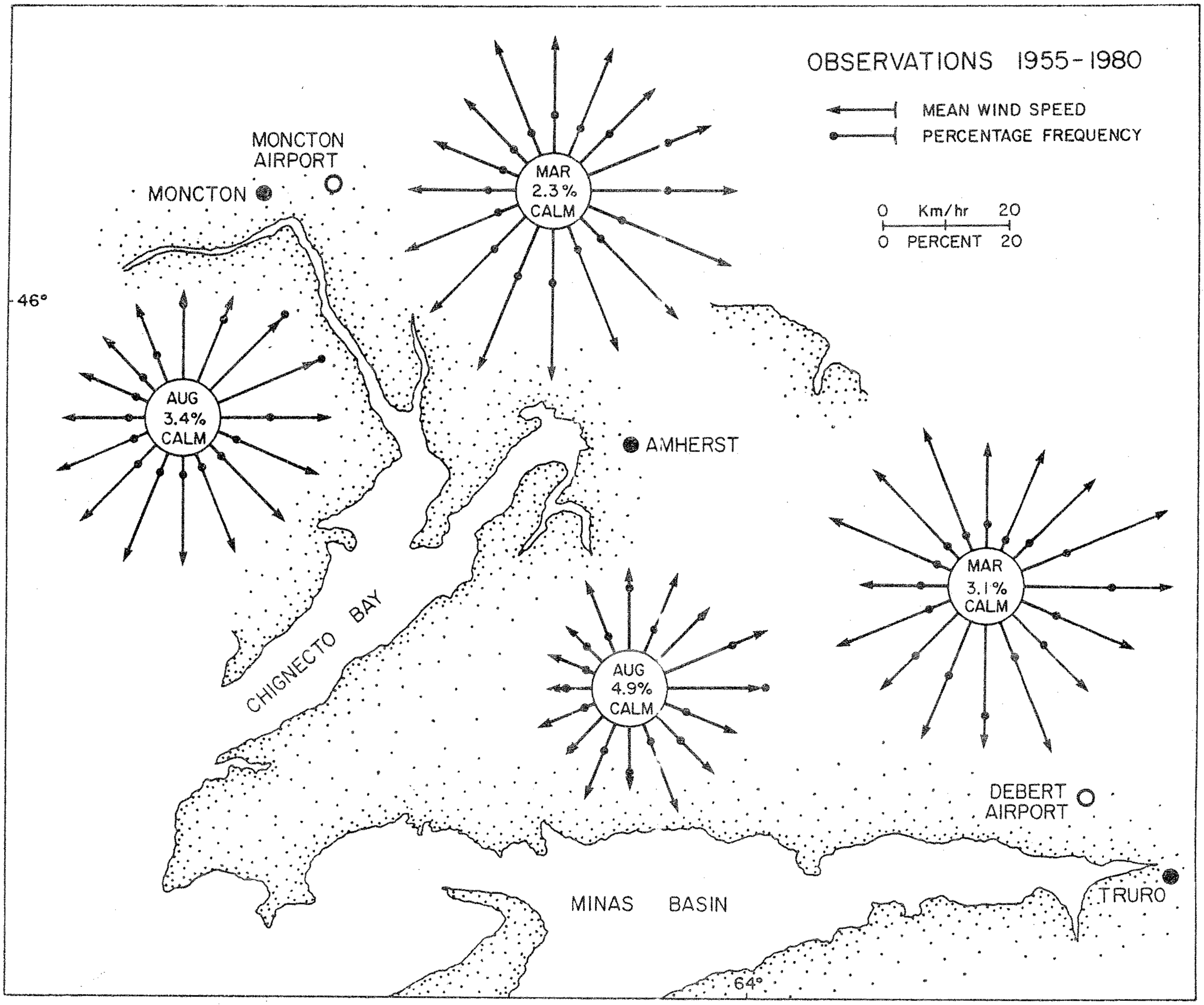


Fig. 9. Mean wind strengths and frequencies for different wind directions for a high wind month (March) and a low wind month (August). Averages are from 6 years data at Debert Airport and 26 years data at Moncton Airport.

had passed. In the Bay of Fundy, such surges are most significant if they arrive at a time of high water when areas outside the normal tidal range would be at risk. Although rare, such flooding has been reported, causing damage to some of the dyked lands around the upper Bay.

CONCLUDING REMARKS

In the above, tides have been emphasized due to their dominance in the system and perhaps also due to the author's perspective. In this brief description of the physical oceanography, the predictable (mean, seasonal and tidal) processes have been exposed and the importance of the variability in these processes has been emphasized. Some of the areas where work needs to be done have been indicated.

REFERENCES

Amos, C.L. and G.H.E. Joice. 1977. The sediment budget of the Minas Basin, Bay of Fundy, N.S., Bedford Institute of Oceanography Data Series, BI-D-77-3, 411 p.

Amos, C.L. and K.W. Asprey. 1981. An interpretation of oceanographic and sediment data from the upper Bay of Fundy. Bedford Institute of Oceanography Report Series, BI-R-81-15, 143 p.

Anon 1982. Sailing directions, Nova Scotia (SE coast) and Bay of Fundy. Canadian Hydrographic Service, Fisheries and Oceans, Ottawa. 303 p.

Anon 1982a. Canadian climate normals. Vol. 5 Wind. 1951-1980. Canadian Climate Program Atmospheric Environment Service, Environment Canada 283 p.

ATPPB (Atlantic Tidal Power Programming Board) 1969. Feasibility of tidal power development in the Bay of Fundy. Board Report and Committee Report Halifax, Nova Scotia.

Bailey, W.B. 1954. Seasonal variations in the hydrographic conditions of the Bay of Fundy. Manuscript report (Biological series), Fish. Res. Bd. Can. No. 2, 56 p.

Bailey, W.B., D.G. McGregor and H.B. Hachey. 1954. Annual variations of temperature and salinity in the Bay of Fundy. J. Fish. Res. Bd. Can. 11: 32-47.

Bumpus, D.F. 1960. Sources of water contributed to the Bay of Fundy by surface circulation. J. Fish. Res. Bd. Canada. 17: 181-197.

CHS (Canadian Hydrographic Service) 1981. Atlas of tidal currents, Bay of Fundy and Gulf of Maine. Department of Fisheries and Oceans, Ottawa. 36 p.

Defant, A. 1961. Physical oceanography. Volume 2. Pergamon Press, London, 598 p.

Duff, G.F.D. 1981. A gulf and ocean model of the Bay of Fundy tides, and their response to barrier construction and operation. Utilitas Math. 19: 3-80.

Garrett, C.J.R. 1972. Tidal resonance in the Bay of Fundy and Gulf of Maine. Nature 238: 441-443.

Garrett, C.J.R. 1974. Normal modes of the Bay of Fundy and Gulf of Maine. Can. J. Earth Sci. 11: 549-556.

Garrett, C.J.R. 1977. Tidal influences on the physical oceanography of the Bay of Fundy and Gulf of Maine. In: Daborn, G. R. ed. Fundy tidal power and the environment. Acadia University Institute Publication No. 28, pp. 101-115.

Garrett, C.J.R., J.R. Keeley and D.A. Greenberg. 1978. Tidal mixing versus thermal stratification in the Bay of Fundy and Gulf of Maine. Atmosphere-Ocean 16: 403-423.

Godin, G. 1968. The 1965 current survey of the Bay of Fundy - a new analysis of the data and an interpretation of results. Manuscript Rept. Ser. No. 8, Marine Sciences Branch, Dept. of Energy Mines and Resources, Ottawa.

Gordon, D.C. Jr., and C. Desplanque. 1983. Dynamics and environmental effects of ice in the Cumberland Basin of the Bay of Fundy. Can. J. Fish. Aquat. Sci. 40: 1331-1342.

Greenberg, D.A. 1977. Effects of tidal power development on the physical oceanography of the Bay of Fundy and Gulf of Maine. In: Daborn, G.R. ed. Fundy tidal power and the environment. Acadia University Institute Publication No. 28, pp. 200-232.

Greenberg, D.A. 1979. A numerical model investigation of tidal phenomena in the Bay of Fundy and Gulf of Maine. Marine Geodesy 2: 161-187.

Greenberg, D.A. 1983. Modelling the mean barotropic circulation in the Bay of Fundy and Gulf of Maine. J. Phy. Oceanog. (in press).

Hachey, H.B. 1952. The general hydrography of the waters of the Bay of Fundy. Manuscript report (Biological series), Fish. Res. Bd. Can., No. 455, 100 p.

Hasselman, K., T.P. Barnett, E. Bouws, H. Carlson, D.E. Cartwright, K. Enke, J.A. Ewing, H. Gienapp, D.E. Hasselmann, P. Kruseman, A. Meerburg, P. Müller, D.J. Olbers, K. Richter, W. Sell, H. Walden. 1973. Measurements of wind-wave growth and swell decay during the Joint North Sea Wave Project (JONSWAP) DHI Zeitschrift (Special Issue), 95 p.

Holloway, P.E. 1981. Longitudinal mixing in the upper reaches of the Bay of Fundy. Est. Coast. Shelf Sci. 13: 495-515.

Ketchum, B.H. and D.J. Keen. 1953. The exchange of fresh and salt waters in the Bay of Fundy and in Passamaquoddy Bay. J. Fish. Res. Bd. Can. 10: 97-124.

Neu, H.J.A. and P.E. Vandall Jr. 1976. Review of the environmental forces for the design of the Tyner Point oil terminal. Bedford Institute of Oceanography Report Series BI-R-76-7, 19 p.

Phillips, O.M. 1977. The dynamics of the upper ocean, second edition. Cambridge University Press, 309 p.

Rao, D.B. 1968. Natural oscillations of the Bay of Fundy. J. Fish. Res. Bd. Can. 25: 1097-1114.

Tee, K.T. 1976. Tide induced residual current, a 2-D nonlinear numerical tidal model. J. Mar. Res. 34: 603-628.

Tee, K.T. 1977. Tide induced residual current-verification of a numerical model. J. Phy. Oceanog. 7: 396-402.

QUESTIONS AND COMMENTS

M. Dadswell: Are you aware of the weather station set up several years ago at Fort Beausejour (head of Cumberland Basin) by AES? The winds are quite different than those recorded at Moncton Airport.

N. Greenberg: NO

An Overview of Sedimentological Research in the Bay of Fundy

Carl L. Amos

Atlantic Geoscience Centre,
Geological Survey of Canada,
Bedford Institute of Oceanography,
P.O. Box 1006,
Dartmouth, N.S. B2Y 4A2

ABSTRACT

The Bay of Fundy has been the site of a number of key studies in the field of sedimentology ranking it as one of the better studied tidal estuaries. Such studies developed concepts which have widespread application. In particular, the generic classification of flow transverse bed forms by Dalrymple et al. (1978) developed in Cobequid Bay is now applied in many regions. Relationships between tidal processes and sediment transport in the Bay of Fundy are viewed by petroleum geologists as keys to the interpretation of geologically preserved "tidalite" deposits, so often important in the exploration for oil. During the last 6 years, the field of applied sedimentology has progressed considerably. The development of techniques to interface sedimentation models and numeric hydraulic models has improved the capability to hindcast or predict sedimentation patterns. Such models are however first order; they do not account for waves, storms, ice or biological effects, yet they provide valuable information for environmental impact analysis or engineering design. A number of new techniques have been tested and perfected in the Bay. Radioisotope tagged sands were successfully used to monitor sand transport in Minas Basin; thefirst such experiment in Canada. Complementing that study, the quantitative transport and distribution of suspended particulate matter was evaluated by the calibration of the Landsat Multispectral Scanner to suspended sediment concentration. One of the most intriguing set of contributions has been the development of concepts related to sea level rise and tidal changes since deglaciation of the region. Based on these studies it now appears that large estuarine tides are ephemeral features which can develop and decay within several millenia.

Key words: sedimentation patterns, bedforms, suspended sediment, bedload, numeric simulation, post-glacial stratigraphy, sea level change.

RÉSUMÉ

La baie de Fundy a fait l'objet d'un certain nombre d'étudesclés dans le domaine de la sédimentologie qui en font un des estuaires à marées les mieux étudiés. De telles études permettent d'élaborer des concepts aux applications très répandues. En particulier, la classification générique des formes du font transversales à l'écoulement mise au point pour la baie

de Cobequid par Dalrymple et coll. (1978) est maintenant appliquée dans us grand nombre de régions. Les relations entre les processus tidaux et le transport des sédiments dans la baie de Fundy sont considérés par les géologues pétroliers comme des éléments clés de l'interprétation des sédiments indurés de type "tidalite" qui sont si souvent importants pour l'exploration pétrolière. Au cours des 6 dernires années le domaine de la sédimentologie appliquée a connu des progrès considérables. La mise au point de méthodes permettant de relier les modèles de sédimentation aux modèles hydrauliques numériques a amélioré les possibilités de prévision à postériori ou de prévision des configurations de sédimentation. Ces modèles sont toutefois de premier ordre et ne tiennent pas compte des vagues, des tempêtes, de la glace our des effets biologiques, mais fournissent néanmoins des renseignements précieux pour les analyses des répercussions écologiques ou la conception des ouvrages de génie. Un certain nombre de nouvelles méthodes ont été éprouvées et perfectionnées dans la baie. On a utilisé avec succès le marquage de sables au moyen de radio-isotopes pour la surveillance des déplacements du sable dans le bassin des Mines, ce qui constituait la première expérience du genre au Canada. A titre de complément à cette étude on a évalué quantitativement le déplacement et la répartition des particules de matière en suspension par l'étalonnage du balayeur multispectral du Landsat en fonction de la concentration de matières en suspension. Un des ensembles d'apports les plus intriguants a été l'élaboration de concepts reliés à l'élévation du niveau de la mer et aux modifications des marées depuis la déglaciation de la région. D'après ces études il semble maintenant que les marées estuariennes importantes sont des entités éphémères qui peuvent apparaître et disparaître en moins de plusieurs millénaires.

INTRODUCTION

A great many studies have been carried out related to the sedimentology of the Bay of Fundy. Klein (1970) was perhaps the first to describe in detail the nature of the intertidal sediments and the processes which control their transport and distribution. Since that time sedimentologic research has dealt with a number of aspects including: animal/sediment relationships; sedimentation dynamics; bedform morphology and genesis; intertidal and subtidal stratigraphy; sea level changes; and man's influence on sedimentation.

Many of the studies are applicable to the identification of lithified sedimentary structures and sequences and in the reconstruction of the ancient depositional environments in which they formed. Even today, the identification of such preserved "tidalite" deposits is often ambiguous and studies of Bay of Fundy sedimentology contribute increasingly to our knowledge.

A number of fundamental relationships between tidal dynamics and sedimentation (or erosion) have been evaluated and applied to predictive models of siltation. These studies have illustrated the complexity of the sediment/fluid interaction and the contributing effects of waves, ice and biological activity.

The sum total of the above research has resulted in a large number of publications. This paper will briefly review the most significant findings since 1976 when a workshop on the environmental implications of Fundy tidal power was held (Daborn 1977).

ENVIRONMENTAL AND GEOLOGICAL SETTINGS

The Bay of Fundy system is located within the Appalachian Orogenic Physiographic Province (Williams et al., 1972). The bedrock geology within the region exhibits Triassic half-graben basinal development which overprinted earlier Ordovician to Carboniferous tectonic events which began 430 million years ago. The half-graben basin is composed of Triassic sandstones and volcanic rocks which underlie much of the region (King and Maclean 1976). Bedrock flexuring during earth movements upthrusted and folded much of the material presently comprising the erosive cliffs surrounding the Bay. The "basement" structure took 100-200 million years to evolve between the Ordovician and Triassic periods. The stratigraphic section is composed of fluvial and deltaic sediments with associated volcanics producing the complex stratigraphy observed today.

The present day sedimentary character of the Bay of Fundy reflects the lithology of the local bedrock which has been modified to varying degrees by glacial erosion and deposition. These glacially derived sediments comprise much of the seabed of the Bay (Fader et al. 1977), and show local differences in composition, especially between Minas Basin and Chignecto Bay. Minas Basin is typically a sandy estuary, with wide expanses of sand flats and sand bars. Despite its silt-ladened waters, the proportion of silt and clay rich depositional environments (mudflats and salt marshes) is low. These environments are restricted to sheltered embayments.

The abundance of sand in Minas Basin is the result of wave erosion of Triassic sandstone cliffs which predominate the shoreline, supplemented by the input of glacial outwash sand which is ubiquitous. A total of 3×10^6 m^3 of sand is introduced to the system annually, released by cliff recession which varies from 0.55 m a^{-1} to 1.5 m a^{-1}. The finer grained silt and clay, derived principally from the reworking of seabed sediments, is limited because of an ice rafted, gravel lag which overlies and protects it from the erosive force of the existing strong tidal currents.

Chignecto Bay, in contrast to Minas Basin, is surrounded by erosive cliffs of Paleozoic siltstones and shales. Furthermore, the Bay has a greater exposure to ocean swell and therefore is subject to greater wave attack which causes a release of silt-size material from the seabed and through cliff erosion. The resulting aggregate is transported principally in suspension. The cliffs, which erode at rates up to 1 m a^{-1}, supply 1×10^6 $m^3 a^{-1}$ of fine-grained sediment. A further source of fine grained material is from seabed erosion. Repeated bathymetric surveys show that a tidal channel off Cape Enragé has been scoured 30 m since 1870 releasing into the water column over 60×10^6 m^3 of sediment.

The suspended sediment concentration in Chignecto Bay is an order of magnitude higher than in Minas Basin, and has resulted in the accumulation of expansive mudflats in Shepody Bay and Cumberland Basin. These deposits have largely been reclaimed for agricultural purposes, with the result that very few areas remain where the peak bottom stress is low enough to allow mud deposition. The Causeway across the Petitcodiac River at Moncton with its associated mudflat demonstrates the speed and degree of sedimentation that will result when such low energy environments are created. In this case the upper estuary, seaward of the causeway, infilled within 5 years, leaving only a small drainage channel for the outflow of fresh water.

Chignecto Bay exports sediment to the outer Bay of Fundy, distributing it in a zone which extends along the north-western part of the Bay. In contrast, sediment is imported into Minas Basin, eroded from the seabed of southwest Bay of Fundy.

The open Bay of Fundy, which is dominated principally by storm waves and tidal currents, is floored with glacial and postglacial deposits (Fader et al. 1977). These deposits are presently being eroded during storms and reworked slowly by tidal currents associated with tidal amplification over the last 6000 years. The resulting sedimentation patterns are the product of complex and dramatic sea level fluctuations in the region since glacial times. Raised marine strandlines, inferred to be 13,000-14,000 years old, have been observed at elevations up to 73 m above present sea level (Gadd 1973). Fader et al. (1977) show that by 6000-7000 years B.P. sea level had dropped to 37 m below present sea level and was beginning again to transgress the adjacent shoreline. These changes in sea level have left their imprint on the seabed sediments which is expanded upon below.

The limnic (below low water) sediments show a complex pattern of sediment types reflecting both relict and modern environments. In general, the sequence shows morainic material overlain by glaciomarine outwash and fine grained lagoonal type sediments. These lagoonal type sediments, deposited 6000-9000 years B.P., are overlain by laminated silt and sand which in turn grades upward into coarse sand or a winnowed lag which constitutes the present surface. This complex stratigraphy reflects a shift in environmental conditions from continental glaciation, to quiet water lagoonal conditions, and finally to tidally active conditions influenced by storm waves and winter ice rafting.

In general, the intertidal zone is characterized by a wave-cut rock terrace, or by a fining upwards sequence of telmatic (intertidal) deposits. Yeo and Risk (1981) have identified seven distinct physical-biological facies characterizing the intertidal zone. These are: salt marsh, beach, upper and lower mudflat, mixed mudflat, sand flat, channel lag and sand bar. Each exhibits a unique suite of sedimentary structures and biological communities.

The region may be summarized as being in a period of adjustment between the destructive forces of a rising sea level and amplifying tidal range and the constructive processes leading to sediment progradation.

OVERVIEW OF RECENT RESEARCH

Since the first Fundy tidal power environmental workshop held in 1976, a considerable amount of sedimentological research has been carried out in the Bay of Fundy. A description of the general environment and a review of work prior to 1976 was given by Dalrymple et al. (1975). The more recent research has been both pure and applied in scope and indeed some globally applicable principles have evolved.

Sedimentary cores taken from the centre of Minas Basin (Amos 1978) followed up by biological data of Bleakney et al. (unpublished data) and thereafter by modelling work of Scott and Greenberg (in prep.) have shown a progressive increase in tidal range over the last 6000 years. Large-tides (greater than 4 m in range) appear to be fugitive phenomena which can appear and reappear over several millenia leading to a complex "tidalite" stratigraphy. This concept, based on well developed physical concepts, can potentially be applied to any embayment, and thus have radical effects on interpretations of archeology, biology and geology in the regions bordering such tidal environments. Certainly, this history of sea level change has contributed greatly to the present day character of the Bay.

The Ph.D. theses of Dalrymple (1977), Knight (1977) and Lambiase (1977) have evaluated specific sand bars, their superimposed bedforms and the transport of sand under tidal flow. This work, together with the subsequent papers by Middleton and Davies (1979), Dalrymple et al. (1978), and Lambiase (1980a and b) have put forward some fundamental concepts of sediment response to high energy tidal flow.

Lambiase (1980a), working in the Avon Estuary, Minas Basin, showed that there is an inverse relationship between mean grain size and current speed, and that textural parameters do not directly reflect hydralic conditions. This finding is very important to the interpretation of geologically preserved sediments where indeed a direct relationship between grain size and current speed is inferred. He also dissected grain size cumulative curves from Minas Basin sandy sediments, relating inflection points of these curves to different modes of sediment transport. He inferred (i) tractive load, (ii) intermittant suspension and (iii) suspended load.

Collins (in prep.) examined the speculative theory of intermittent suspension described in part by Lambiase (1980a) by water sampling immediately above the seabed over a sand bar in Cobequid Bay. His results suggest that indeed this phenomenon does occur, but only during periods of wave stirring. It thus appears that relatively small waves superimposed on strong tidal currents can have a significant effect on seabed stability, sediment mobility and sediment distribution.

Yeo (1977) carried out a detailed study on animal/sediment relationships in Minas Basin. He demonstrated the use of *Corophium volutator* Lebensspuren to indicate periods of erosion or deposition associated with storms. These traces may be valuable in the reconstruction of the environment of deposition. The organisms have been interpreted to respond in a predictable fashion to storm events.

Risk and Moffat (1977) looked specifically at the distribution and abundance of Macoma baltica, and the effect of this bivalve on sedimentation. They concluded that 10,000 m^3 of fecal material is produced daily by these organisms in the Minas Basin and that they contribute significantly to the fixation of intertidal mud through the process of pelletization.

Loucks (pers. comm.) has recently carried out a survey on coastal erosion along the north shore of Minas Basin. His findings on this chronic problem has shown that the effects of ground water seepage and freeze/thaw mechanical heaving can contribute as much to the erosion problem as wave erosion. His research pointed out the significance of sheet flow in transporting coarse material across the intertidal zone during periods of high rainfall. He also considers the embayments along the north shore of Minas Basin to conform with logarithmic, spiral-type bays usually associated with wave dominated coast lines. The shape of these bays, when fully developed, minimize coastline erosion and longshore transport of sediment. His results should be of great value in the design of coastal protection schemes which have been long overdue in this region.

The Chignecto Bay system, in contrast to Minas Basin and Cobequid Bay, was sedimentologically unknown in 1976. Since that time a number of major studies have been carried out. These include a geophysical survey and sediment budget analysis, a review of which is given in Amos and Asprey (1979). The results show that this system is quite different from Minas Basin, comprising much higher quantities of finer sediments in suspension which occur in an unflocculated state. The associated sedimentary column shows a post-glacial lithostratigraphy which reflects the bedrock geology (siltstones and mudstones) and contrasts from the Triassic sandstone/ glacial outwash derived, sandy sediments of Minas Basin. Indeed, contrasts of this type are of great interest to petroleum geologists concerned with paleo-reconstruction of "tidalite"/estuarine and marginal marine systems. A more detailed analysis of the stratigraphy of surficial Bay of Fundy deposits is to be made by a geologist formally from Gulf Canada Resources Ltd.

Sediment coring in the subtidal region of Chignecto Bay has shown the existance of fresh water peats 30 m below present mean sea level. These peats have been dated to be 7000 years old and provide evidence of an oscillation in post-glacial relative sea level in keeping with the local periferal bulge concept (Quinlan and Beaumont 1982). This information can be used to calibrate rheological models of crustal movement under ice loading, which then can be used predictively in those regions where no data are available. These findings also demonstrate the rapid changes in sea level which have occurred since deglaciation of the region approximately 13,500 years B.P.

The characterization of suspended sediment transport and distribution has been achieved using two of NASA's environmental satellites: Landsat (MSS) and Nimbus-7 (CZCS). A calibration relating Landsat spectral radiance to suspended sediment concentration (SSC) has been derived over a concentration range of 2 to 1000 mg L^{-1} (Amos and Alfoldi 1979). Thematic plots of SSC have been generated using this calibration showing oceanographic and sedimentological phenomena. For example, turbid ribbons in Chignecto Bay have been recognized which are several kilometres in length and are bound laterally by distinct fronts. Such ribbons have recently been observed in the Oosterschelde Estuary, Holland and indicate the complexity of sediment transport pathways and the difficulty of representative sampling (Kohsiek, unpublished data). Optical work has been carried out to develop a theoretical framework for the satellite calibration to sediment concentration (Topliss, in prep). The work suggests that the calibration is applicable to other areas, and indeed the results have been applied to an analysis of the Mackenzie River sediment plume in the Beaufort Sea. A company is now commercially implemented this calibration, providing users with thematic maps of suspended sediment concentration. A second, similar calibration is being generated using Nimbus-7 which has a much larger field of view. The calibration covers a sediment concentration range of 20 to 150 mg L^{-1} and will be used in the outer Bay of Fundy where overpasses are daily. This will allow short term studies to be made of aspects of water mass movement such as the development and decay of turbid plumes and the ultimate dispersal of suspended material.

The upper Bay of Fundy has a number of solid fill causeways which have resulted in the formation of mudflats to their seaward side. Two of these have been studied in detail. Bray et al. (1982) has documented the Peticodiac Causeway mudflat accretion, while Amos et al. (1980) and Job Corps Project (1980; under the sponsorship of the Atlantic Regional Laboratory of the National Research Council of Canada) have documented the accretion of the Windsor Causeway mudflat. These mudflats are good calibration points for sedimentation models where processes of accretion are accelerated. It was shown that the summertime accretion of Windsor mudflat was 6.7 cm. This result was then compared to the calculated accretion, estimated using the formulation in the predictive, numeric model of Greenberg and Amos (1983). The comparison showed good agreement (within 30%). This work was supplemented by flume tank studies by Mosher (1983) on the erosion characteristics of Bay of Fundy mud. His results show a markedly higher resistance to current erosion than given elsewhere in the literature. The work is continuing but does provide valuable information to the accurate prediction of siltation.

Samples collected by helicopter in the upper waters of Chignecto Bay (Gordon et al. unpublished data) show a well established logarithmic decrease in sediment concentration down the estuary. This gradient represents a balance between the process of headward transport of sediment resulting from an asymmetric tide and the seaward dispersion due to horizontal diffusion. By observation of the sediment gradient and a knowledge of the horizontal eddy diffusivity, the residual transport of sediment can be estimated. This is very significant in the estimation of mass balance of sediment, as results of repeated measurements of suspended sediment transport show that direct sampling is subject to considerable error (Amos and Asprey, 1981).

The nature of suspended sediment in the outer Bay of Fundy and its residual transport has been examined by Kranck (unpublished data). These results show that sediments are derived from the southeastern Bay of Fundy and transported counterclockwise to the northwestern part of the Bay. She also observed a net inward transport of suspended solids presumed eroded from seabed sediments of the outer Bay. Residual transport observations in Chignecto Bay (Amos and Asprey 1981), substantiated by results of numeric modelling of silts (Amos and Greenberg 1980), show that sediment is transported inwards during calm periods but dispersed seawards during storms or spring thawing.

The effect of storms on suspended solids transport is more significant in Chignecto Bay than in Minas Basin due to it being more exposed to wave attack. In Chignecto Bay (unlike Minas Basin), suspended solids are stratified showing an increase in concentration with depth. Concentrations of several grams per litre can be found close to the bed which could indeed control the mass balance of solids and associated constituents. Such nepheloid layers have been observed in parts of the Dutch Wadden Sea (Kohsiek, unpublished data) and in the Bristol Channel, U.K. (Kirby and Parker 1975).

Hussain (1980) carried out an analysis of the distribution and nature of both clay minerals and heavy minerals in the bottom sediments of Chignecto Bay. His results showed that the clays are principally derived from Paleozoic shales surrounding the Bay. In addition he observed that heavy minerals comprise 2.5% (by weight) of the bottom sediments. There is a predominance of pyroxenes in the heavy mineral suite which appears to be derived from the basalts of southeastern Bay of Fundy. The high proportion of amphipole (also found) is interpreted to signify local erosion of the seabed. The importance of Hassain's findings relates to the mechanics of mineral concentration. If minerals are suspended and dispersed then no concentrations will result. If minerals are moved by traction along the seabed then concentration is possible, potentially leading to placer-type deposits of commercial significance. These concepts are presently being developed to provide input to Canadian Oil and Gas Lands Administration in defining the offshore potential of non-fuel mineral resources.

Loring (1979, 1982) has examined the trace metal composition of bottom sediments in the outer Bay of Fundy. His results clearly show a differentiation of sediment type about a median line parallel to the long axis of the Bay. There is a strong correlation between the concentration of trace metals and the volume of sediment less than 2 microns in diameter. Concentration of trace metals are normal and are associated with fine-grained sediments. A slight increase in concentration occurs in the vicinity of Saint John.

Pertaining to Minas Basin, a regional evaluation has been completed of (1) the sedimentary character (Amos and Long 1980), (2) the post-glacial evolution (Amos 1978), and (3) the siltation effects of tidal power development (Amos and Greenberg 1980) at the B9 Site (Bay of Fundy Tidal Power Review Board, 1977). In the latter evaluation, the tidal model of Greenberg (1979) has been interfaced to various sedimentation parameters evaluated in items (1) and (2) above to provide a predictive capability of sedimentation resulting from tidal power development (Greenberg and Amos 1983). The results are given elsewhere in this volume (Amos 1984).

Finally, it appears that the Bay of Fundy is attractive as a resource from two standpoints other than tidal power development. Firstly, an assessment is being made of the basement hydrocarbon potential of Chignecto and Cobequid Bays. Secondly, the thick deposits of clean, well sorted sand in the Cobequid Bay intertidal zone are potentially of value as road grade, cement mix or in the glass making industry. The significance of this resource is demonstrated by the non-fuel Mineral Group of Canadian Oil and Gas Lands Administration who have included this resource in their inventory of the Canadian offshore. Thus the Bay of Fundy may have excellent resource potential from several standpoints.

CONCLUSION

In conclusion, the Bay of Fundy is a natural laboratory in which many sedimentological, glacio-isostatic and hydraulic processes have interacted and from which a number of innovative theories have evolved. Two of the more important results of this work are (1) that it provides confidence to the interpretation of the mechanics of sediment motion and (2) it provides a model for the post-glacial evolution of the Bay.

ACKNOWLEDGMENTS

I would like to thank the following people for input into this manuscript: Dr. D.C. Gordon, Jr. and Mr. B.A. Zaitlin for manuscript review and the BIO Word Processing Office for manuscript production.

REFERENCES

For the sake of completeness, many sources of information are included in the bibliography which have not been quoted in the text.

Amos, C.L. 1978. The post glacial evolution of the Minas Basin, N.S.: A sedimentological interpretation. J. Sed. Petrol. 48: 965-982.

Amos, C.L. 1984. The sedimentation effect of tidal power development in the Minas Basin, Bay of Fundy. In this report.

Amos, C.L. and T.T. Alföldi. 1979. The determination of suspended sediment concentration in a macrotidal system using Landsat data. J. Sed. Petrol. 49: 159-174.

Amos, C.L. and K.W. Asprey. 1981. An interpretation of oceanographic and sediment data from the upper Bay of Fundy. Bedford Institute of Oceanography Rept. Series/BI-R-81-15, 143 p.

Amos, C.L. and K.W. Asprey. 1979. Geophysical and sedimentary studies in the Chignecto Bay system, Bay of Fundy - A progress report. Current Research, Part B, Geological Survey of Canada, paper 79-1B, 245-252.

Amos, C.L., D.E. Buckley, G.R. Daborn, R.W. Dalrymple, S.B. McCann and M.J. Risk. 1980. Trip 23: Geomorphology and sedimentology of the Bay of Fundy. Publ. Geol. Assoc. Can. 82 p.

Amos, C.L. and D.A. Greenberg. 1980. The simulation of suspended particulate matter in the Minas Basin, Bay of Fundy - A region of potential tidal power development. In: Canadian Coastal Conference. Publ. National Research Council, pp. 2-20.

Amos, C.L. and B.F.N. Long. 1980. The sedimentary character of the Minas Basin, Bay of Fundy. In: McCann, S.B. ed. The coastline of Canada, Geol. Sur. Can. Paper 80-10: pp. 153-180.

Bay of Fundy Tidal Power Review Board. 1977. Reassessment of Fundy tidal power. Ottawa, 516 p.

Bray, D.I., D.P. Demerchant and D.L. Sullivan. 1982. Some hydrotechnical problems related to the construction of a causeway in the estuary of the Petitcodiac River, New Brunswick. Can. J. Civil Eng. 9: 296-307.

Cant, G.P. 1977. Net deposition of sediment off Cape Maringouin. Internal Note No. 4. Mount Allison University, 8 p.

Daborn, G. (ed.) 1977. Fundy tidal power and the environment. Acadia University Inst. Publ. No. 28, 304 p.

Dalrymple, R.W. 1979. Wave-induced liquifaction: a modern analogue from the Bay of Fundy. Sedimentology 26: 835-844.

Dalrymple, R.W. 1977. Sediment dynamics of macrotidal sand bars, Bay of Fundy. Ph.D. thesis, McMasters University, 635 p.

Dalrymple, R.W., C.L. Amos and S.B. McCann. 1983. Excursion 6A: Beach and nearshore depositional environments of the Bay of Fundy and southern Gulf of St. Lawrence. Publ. Internat. Assoc. Sedimentologists, 116 p.

Dalyrmple, R.W., R.J. Knight and G.V. Middleton. 1975. Intertidal sand bars in Cobequid Bay (Bay of Fundy). In: L.E. Cronin, ed. Estuarine Research. Academic Press, New York, Vol. 2, pp. 293-307.

Dalrymple, R.W., R.J. Knight and J.J. Lambiase. 1978. Bedforms and their hydraulic stability relationships in a tidal environment, Bay of Fundy, Canada. Nature 275: 100-104.

Fader, G.B., L.H. King and B. MacLean. 1977. Surficial geology of the eastern Gulf of Maine and Bay of Fundy. Geol. Survey Can. Paper 76-17, 23 p.

Featherstone, R.P. and M.J. Risk. 1977. Effect of tube-building polychaetes on intertidal sediments of the Minas Basin, Bay of Fundy. J. Sed. Petrol. 47: 446-450.

Gadd, N.R. 1973. Quaternary geology of southwest New Brunswick with particular reference to Fredericton area. Geol. Survey Can. Paper 71-34, 31 p.

Greenberg, D.A. 1979. A numerical model investigation of tidal phenomena in the Bay of Fundy and Gulf of Maine. Mar. Geodesy 2: 161-187.

Greenberg, D.A. and C.L. Amos. 1983. Suspended sediment transport and deposition modeling in the Bay of Fundy, N.S. A region of potential tidal power development. Can. J. Fish. Aquat. Sci., 40 (Suppl. 1): 20-34.

Hussain, M. 1980. Textural and mineralogical analysis of Chignecto Bay sediments, Canada. M.Sc. thesis, Acadia University, 138 p.

Job Corps Project. 1980. Windsor mudflat study. Internal report, Atlantic Geoscience Centre, Bedford Institute of Oceanography, 69 p.

King, L.H. and B. MacLean. 1976. Geology of Scotian Shelf and adjacent areas. Marine Science Paper 7: 31 p.

Kirby, R. and W.R. Parker. 1975. Sediment dynamics in the Severn Estuary: A background for studies of the effects of a barrage. In: Shaw, T.L. ed. An Environmental Appraisal of the Severn Barrage, pp. 35-46.

Klein, G. deV. 1970. Depositional and dispersal dynamics of intertidal sand bars. J. Sed. Petrol. 40: 1095-1127.

Knight, R.J. 1980. Linear sand bar development and tidal current flow in Cobequid Bay (Bay of Fundy), Nova Scotia. In: McCann, S.B. ed. The Coastline of Canada. Geol. Survey Can. Paper 80-10: pp. 153-180.

Knight, R.J. 1977. Sediments, bedforms and hydraulics in a macrotidal environment, Cobequid Bay (Bay of Fundy). Ph.D. thesis, McMaster University, 693 p.

Lambiase, J.J. 1980a. Hydraulic control of grain-size distributions in a macrotidal estuary. Sedimentology 27: 433-446.

Lambiase, J.J. 1980b. Sediment dynamics in the macrotidal Avon River estuary, Bay of Fundy, Nova Scotia. Can. J. Earth Sci. 17: 1628-1641.

Lambiase, J.J. 1977. Sediment dynamics in the macrotidal Avon River estuary, Nova Scotia. Ph.D. thesis, McMaster University, 415 p.

Long, B.F.N. and J.R. Belanger. 1978. Bedform movement studies by remote sensing balloon technique in Minas Basin, Bay of Fundy. In: Current Research, Part A, Geol. Survey Can. Paper 78-1A: pp. 503-508.

Loring, D.H. 1982 Geochemical factors controlling the accumulation and dispersal of heavy metals in the Bay of Fundy sediments. Can. J. Earth Sci. 19: 930-944.

Loring, D.H. 1979. Baseline levels of transition and heavy metals in the bottom sediments of the Bay of Fundy. Proc. N. S. Inst. Sci. 29: 335-346.

Middleton, G.V. and P.M. Davis. 1979. Surface textures and rounding of quartz sand grains on intertidal sandbars, Bay of Fundy, Nova Scotia. Can. J. Earth Sci. 16: 2071-2085.

Quinlan, G. and C. Beaumont. 1982. The deglaciation of Atlantic Canada as reconstructed from the postglacial relative sea-level record. Can. J. Earth Sci. 19: 2232-2246.

Risk, M.J. and J.S. Moffat. 1977. Sedimentological significance of fecal pellets of Macoma baltica in the Minas Basin, Bay of Fundy. J. Sed. Petrol. 48: 1425-1436.

Risk, M.J. and R.K. Yeo. 1980a. Animal-sediment relationships in the Minas Basin, Bay of Fundy. In: McCann, S.B. ed. The coastline of Canada. Geol. Survey Can. Paper 80-10: pp. 189-194.

Risk, M.J. and R.K. Yeo. 1980b. Bay of Fundy organism-sediment relationships. In: Sedimentary processes and animal-sediment relationships in tidal environments. Geol. Assoc. Can. Short Course Notes, 1: 133-152.

Thomas, F.C. and C.T. Schafer. 1982. Distribution and transport of some common foraminiferal species in the Minas Basin, Eastern Canada. J. Foraminiferal Res. 12: 24-38.

Wagner, F.J.E. 1980. A faunal interpretation of tidal evolution in Minas Basin, Nova Scotia. Geogr. Phys. Quar. 24: 253-257.

Wightman, D.M. 1981. Glaciofluvial and glaciomarine sedimentation on the north side of the Minas Basin. Geol. Assoc. Can. (Abstracts) 6: A-61.

Wightman, D.M. 1980. Late Pleistocene glaciofluvial and glaciomarine sediments on the north side of the Minas Basin, Nova Scotia. Ph.D. thesis, Dalhousie University, 444 p.

Williams, H., J.J. Kennedy and E.R.W. Neale. 1972. The Appalachian structural province. In: Price, L.A. and Douglas, R.J.W. eds. Variations in tectonic style in Canada. Paper II, pp. 181-261.

Yeo, R.K. 1977. Animal/sediment relationships and the ecology of the intertidal mudflat environment of Minas Basin, Bay of Fundy, Nova Scotia. M.Sc. thesis, McMaster University, 396 p.

Yeo, R.K. and M.J. Risk. 1979. Intertidal catastrophes: effect of storms and hurricanes on intertidal benthos of the Minas Basin, Bay of Fundy. J. Fish. Res. Bd. Can. 36: 667-669.

Yeo, R.K. and M.J. Risk. 1981. The sedimentology, stratigraphy and preservation of intertidal deposits in the Minas Basin system, Bay of Fundy. J. Sed. Petrol. 51: 245-260.

QUESTIONS AND COMMENTS

D. Wildish: What is the maximum depth to which the wave effect is significant on cohesive sediments in the Bay of Fundy such as the LaHave clay?

C. Amos: Its obviously probabilistic if you are looking at it predictively as we are currently doing on the edge of the continental shelf. If you have a probability function for the wave height you can in fact estimate the velocity at the seabed using some sort of first order approximation like Airy theory. There are methods of relating sediment type to the critical velocity for sediment erosion which can in turn be related to the critical stress for erosion. A lot of work has been done on the stability of cohesive sediments so its not too difficult to come out with the first order probability of having a particular velocity at the seabed and indicating whether or not there is likely to be any erosion.

G. Daborn: Could the differences in predicted sedimentation patterns between the Minas Basin and Bristol Channel schemes be caused by the fact that the latter tends to move the tidal system away from resonance and the post-barrage flow conditions will be much less.

C. Amos: No. The UK workers did not look at the detailed velocity field distribution but just a range of peak stresses and I think they assumed that anywhere subject to a stress less than 10 dynes cm^{-2} would be areas of mud accumulation. From the information I have they did not look at post-barrage conditions in more detail. My feeling is that their assumption about the sediment distribution in relation to peak stress is probably wrong.

M. Dadswell: Does the sedimentation model have a temperature component? Our observations in Cumberland Basin indicate that considerable sediment settles out when the water temperature reaches 16-18 C.

C. Amos: No. We have done a sensitivity analysis on temperature and found that temperature appears to be a second order effect and therefore has not been considered further. Perhaps the changes you see are due to advection of different water parcels or biological effects. I doubt if flocculation is important because its more dependent on salinity than temperature.

A brief overview of recent chemical research in the Bay of Fundy

Paul D. Keizer

Atlantic Oceanics Company Ltd.
46 Fielding Avenue
Dartmouth, N.S. B3B 1E4

Donald C. Gordon, Jr.

Marine Ecology Laboratory
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, N.S. B2Y 4A2

and

Ernest R. Hayes

Department of Chemistry
Acadia University
Wolfville, N.S. B0P 1X0

ABSTRACT

A considerable amount of chemical research has been conducted in the Bay of Fundy since 1976. Extensive field programs have sampled the water column and sediments in most parts of the Bay over tidal and seasonal cycles. The principal variables measured were heavy metals, inorganic nutrients, plant pigments and organic carbon and nitrogen. Concentration ranges and spatial and temporal variations are now reasonably well defined and work is continuing on understanding chemical fluxes. Most Bay of Fundy water originates from the continental shelf. Freshwater input is relatively low and salinity gradients are small. Water chemistry in the outer part of the Bay is influenced by high biological productivity. In contrast, chemical processes in the macrotidal upper reaches appear to be controlled primarily by physical factors, especially the very high and variable concentrations of suspended sediment which suppress biological production.

Key words: Bay of Fundy, chemical oceanography, heavy metals, nutrients, chlorophyll, organic carbon and nitrogen

RÉSUMÉ

On a effectué une quantité considérable de recherches en chimie dans la baie de Fundy depuis 1976. D'importants programmes sur place ont

permis d'échantillonner la colonne d'eau et les sédiments dans la plupart des parties de la baie pendant toute la durée des cycles des marées et des saisons. Les principales concentrations mesurées ont été celles des métaux lourds, des éléments nutritifs inorganiques, des pigments végétaux et du carbone organique ainsi que de l'azote. Les étendues des concentrations et leurs variations dans l'espace et dans le temps sont maintenant raisonnablement bien connues et les travaux visant à comprendre les mécanismes chimiques se poursuivent. Pour la plus grande partie les eaux de la baie de Fundy proviennent du plateau continental. Les apports en eau douce sont relativement faibles et les gradients de salinité sont peu importants. La chimie de l'eau de la partie extérieure de la baie est influencée par une productivité biologique élevée. Par contraste, les processus chimiques des parties macrotidales intérieures semblent principalement déterminés par des facteurs physiques et en parjticulier par les concentrations très élevées et variables de matières en suspension qui étouffent la production biologique.

INTRODUCTION

Chemical oceanographic research in the Bay of Fundy is very recent. Because of the absence of data, chemical papers were not included in the program of the 1976 Acadia Workshop and the report from the chemistry discussion group (Hayes and Stiles 1977) expressed concern about the lack of information on water quality, nutrient dynamics and other chemical topics. A literature review for the entire Bay of Fundy conducted in 1978 (Moyse 1978) identified only 22 chemical references most of which dealt with rather specific pollution studies.

Largely as the result of the Acadia Workshop a number of chemically-oriented investigations were begun in the late 1970's and a large data base has been collected (partly tabulated by Loucks 1979). Several reports have already appeared and a considerable amount of work is in progress. The purpose of this review is to identify the chemical oceanographic studies undertaken since 1976, especially those involving large field programs, and to present some of the data in a preliminary fashion. This review is not exhaustive and is only intended to illustrate the kind of progress currently being made to improve our understanding of the chemical oceanography of the Bay of Fundy.

CHEMICAL VARIABLES STUDIES

Chemical oceanographic studies have focused on heavy metals, nutrients, plant pigments and organic carbon and nitrogen. Heavy metals analyzed in sediments include Hg, Cd, Zn, Cu, Pb, Co, Ba, Ni, Cr, Be, V, As and Se. Nutrients include nitrate, nitrite, ammonia, phosphate and silicate. Pigment studies have focused on chlorophyll a. Organic carbon measurements have included both dissolved and particulate components. Temperature and salinity have also been widely determined but only a few measurements of dissolved oxygen have been made. Suspended sediment exerts a major influence on seawater chemistry and concentrations have been measured in most water samples collected. Particle-size distributions of surface and suspended sediments have also been determined for a large number of samples.

MAJOR FIELD PROGRAMS

Bay of Fundy Proper

A number of cruises were made by the Bedford Institute of Oceanography (BIO) between 1977 and 1980 covering all major seasons. Most of the chemical work on these cruises was conducted by the Marine Ecology Laboratory (MEL) and the Atlantic Oceanographic Laboratory (AOL). Sediment was collected at hundreds of stations spread fairly evenly over the Bay. Water samples throughout the water column were collected principally at the sixteen stations identified in Fig.1. Anchor stations (marked with open circles in Fig. 1) were sampled at hourly intervals over at least one complete tidal cycle (low water to low water).

Chignecto Bay/Cumberland Basin

A large number of subtidal sediment samples were collected in Chignecto Bay in August 1978. Anchor stations (Fig. 1) were sampled at different seasons and locations across the channels. During 1979 and 1980, surface water and intertidal sediment samples were collected at low tide in Cumberland Basin approximately monthly by MEL with the assistance of a C.C.G. helicopter at the stations shown in Fig. 2. A large number of chemical investigations have also been conducted year-round between 1978 and 1980 by MEL at Pecks Cove on both intertidal sediment and water flooding the mudflat at high tide.

Minas Basin/Cobequid Bay/Southern Bight

Subtidal sediments in the entire Minas Basin system were sampled on a 3-km grid in August 1979. At the same time anchor stations were occupied (Fig. 1.). A limited number of chemical variables were measured year-round by MEL in the intertidal zone at Anthony Park during 1977 and 1978 (eg. Hargrave 1978). During 1979, two Job Corps programs coordinated by Acadia University and the Atlantic Regional Laboratory (ARL) conducted a variety of chemical studies involving both sediment and seawater in the intertidal zone of the Southern Bight near Wolfville; observations were restricted to the summer months. Between April and October 1981 MEL collected, at monthly intervals, intertidal sediment samples for chemical analysis at nine transects around the entire Minas Basin system using a C.C.G. helicopter (Fig. 3).

GENERAL DISTRIBUTION OF CHEMICAL VARIABLES

Sediment

Loring (1979 and 1982) has shown that heavy metal concentrations in Fundy sediments vary regionally and with textural differences. Concentrations are highest in the fine sediments in the North Outer Bay region (Fig. 1) and are generally at or near natural levels in relation to source rocks. Sediment pigment and organic carbon/nitrogen concentrations also show an inverse relationship with grain-size in both sub- and intertidal sediments. Preliminary data on sediment organic chemistry at the Pecks Cove mudflat have been reported by Gordon et al. (1980) while Roberts (1982) has studied the composition of sediment organic matter. Intertidally the highest concentrations occur in Cumberland Basin and the Southern Bight which are dominated by muddy sediments. Intertidal sediment chlorophyll data are discussed in more detail by Hargrave et al. (1983) and Prouse et al. (1984).

Seawater

General distribution patterns during summer are illustrated in Table 1. Salinity is just over 32°/₀₀ at the mouth of the Bay and decreases to less than 30°/₀₀ in the upper reaches because of freshwater input from numerous small rivers. The lowest salinities are found in Cobequid Bay and the Southern Bight where samples were collected in a mudflat drainage channel (Table. 1). In the open Bay salinities are slightly greater on the Nova Scotia side reflecting the inward transport of Shelf Water (residual circulation is counter-clockwise). Salinity can vary several °/₀₀ over a tidal cycle in the upper reaches (e.g. Fig. 4).

During the summer, temperatures are much greater in the upper reaches because of the shallowness and turbidity of the water. In winter however temperatures are less and extensive ice can form (Gordon and Desplanque 1983). An indication of the seasonal range of temperature is given in Table 2.

There is little or no stratification of the water column in the inner part of the Bay because of the limited freshwater input and the intense vertical tidal mixing (Garrett et al. 1978). Stratification near the mouth of the Bay varies seasonally and is strongest during summer.

Only a few dissolved oxygen measurements were made at the first anchor stations and they consistently indicated values at or near saturation (Table 1).

Nutrient concentrations show some spatial variablility and are substantial even during the summer months (Table 1). Primary production studies (Prouse et al. 1984) have shown that the major limiting factor is light. Only nitrate approaches limiting concentrations and that is during the summer near the mouth of the Bay (North Outer portion, Fig. 1) when thermal stratification is greatest (data for nitrate in the Southern Bight shown in Table 1 are not comparable with other data because of their source).

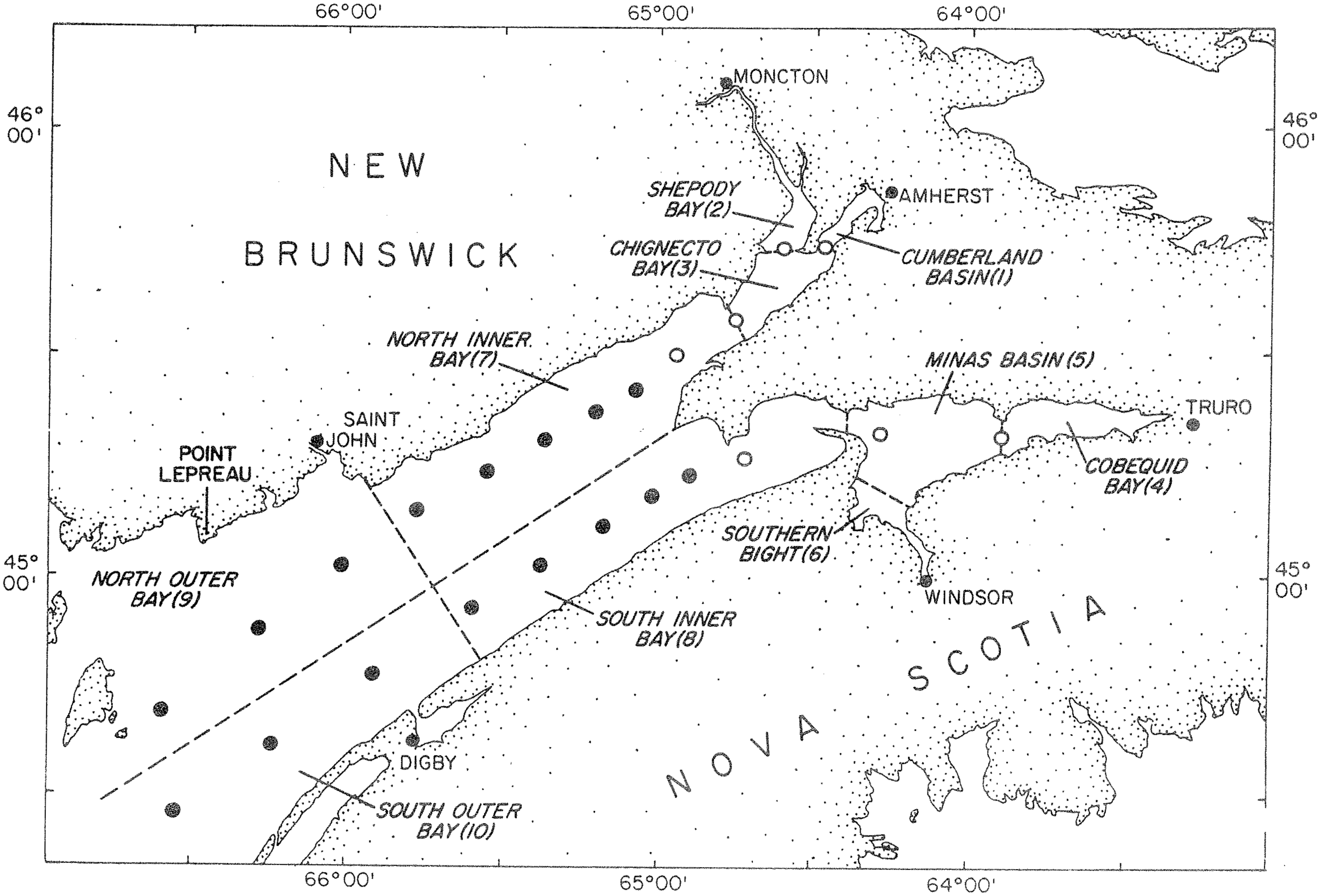


Fig. 1. Map of the Bay of Fundy showing the location of principal stations where water chemistry data were collected by ship. Open circles in the upper parts of the Bay denote anchor stations. Also shown are the boundaries used in dividing the Bay into different regions (Table 1).

TABLE 1. Geographic variation of some chemical oceanographic properties in the Bay of Fundy. Numbers represent average concentrations in surface samples collected during the month of August. Only high tide data were used from anchor stations (Fig. 1). All data were collected by the Marine Ecology Laboratory using ships with the exception of the Southern Bight where data were collected by Acadia University in a mudflat drainage channel.

Property	Cumberland Basin (1)	Shepody Bay (2)	Chignecto Bay (3)	Cobequid Bay (4)	Minas Basin (5)	Southern Bight (6)	North Inner(7)	South Inner (8)	North (Outer 9)	South (Outer 10)
Salinity (°/oo)	30.16	30.30	30.95	29.15	31.09	28.1	31.44	32.08	32.30	32.64
Temperature (°C)	17.10	16.3	14.0	17.1	14.4	ND	12.9	11.83	11.39	11.20
Dissolved Oxygen (mL L^{-1})	9.5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ammonia (ugat L^{-1})	ND	ND	ND	0.75	0.90	ND	2.11	.33	.53	.52
Nitrite (ugat L^{-1})	0.60	0.30	.48	0.26	0.26	ND	0.30	.27	.03	.16
Nitrate (ugat L^{-1})	5.55	4.10	2.62	4.72	3.71	0.0	3.22	4.88	.33	3.88
Phosphate (ugat L^{-1})	0.90	0.60	.72	0.86	1.10	2.2	.91	.94	.91	1.35
Silicate (ugat L^{-1})	9.55	6.30	2.57	11.10	8.10	2.2	8.49	15.94	12.57	19.33
DOC (mg L^{-1})	1.37	1.30	1.35	2.13	3.60	1.16	1.96	1.89	1.89	1.72
POC (mg L^{-1})	0.250	0.160	.164	0.154	0.085	.664	.102	.108	.342	.282
PN (mg L^{-1})	0.036	0.015	.022	0.020	0.006	ND	.009	.011	.039	.032
Chlorophyll (μg L^{-1})	1.19	1.00	.75	1.53	0.93	2.92	0.89	.92	3.25	3.67

ND = not determined

TABLE 2. Seasonal variation in some chemical oceanographic properties at the mouth of the Cumberland Basin. Numbers represent average concentration in surface samples collected near the time of high water on anchor stations. Data collected by the Marine Ecology Laboratory.

	March 1979	August 1978	October 1979	February 1980
Salinity °/oo	29.58	30.17	33.60	30.5
Temperature (°C)	1.8	18.3	10.9	2.0
Ammonia (ugat L^{-1})	ND	ND	0.0	2.1
Nitrite (ugat L^{-1})	0.05	0.7	ND	ND
Nitrate (ugat L^{-1})	12.7	5.5	5.3	12.7
Phosphate (ugat L^{-1})	1.2	0.8	1.1	1.2
Silicate (ugat L^{-1})	26.1	9.4	10.0	26.1
DOC (mg C L^{-1})	2.3	1.4	1.7	1.6
POC (mg C L^{-1})	0.44	0.25	0.30	2.72
PN (mg N L^{-1})	0.03	0.04	0.04	0.40
Chlorophyll (μg L^{-1})	1.05	1.19	1.09	1.72

ND = not determined

The pronounced seasonal variations in dissolved nutrients are typical of north temperate coastal waters. Concentrations are highest in winter and early spring and lowest in summer (Table 2). Seasonal variation is greatest at the mouth of the Bay where the highest primary productivity occurs (Prouse et al. 1984).

Particulate organic carbon and nitrogen concentations are highest in the outer part of the Bay and in the more productive estuaries such as Cumberland Basin and the Southern Bight (Table 1) (concentrations for the Southern Bight are probably exaggerated somewhat because samples were collected from a drainage channel). In the outer Bay, concentrations decrease with depth. The opposite occurs in the upper reaches because of the resuspension of sediment. Concentrations vary over a tidal cycle and are greatest near low tide when the concentrations of suspended sediment are also greatest (Amos and Asprey 1981). Seasonal variations in the upper reaches are also related to sediment resuspension, and concentrations are greatest in the winter (Table 2) when intertidal sediments are subjected to heavy ice scouring (Gordon and Desplanque 1983).

Concentrations of dissolved organic carbon show considerable variability (Table 10). The complete data base must be analyzed to determine if significant spatial or seaonal patterns exist. There are no apparent temporal variations over a tidal cycle at any location.

Chlorophyll concentrations during the summer are greatest in the outer part of the Bay (Table 1) reflecting the high phytoplankton productivity (Prouse et al. 1984). Despite the turbidity of the water in the upper reaches appreciable chlorophyll concentrations do occur, in part because of the resuspension of intertidal sediment and the associated abundant microalgae. There is little seasonal variation at the mouth of Cumberland Basin (Table 1) presumably because of greater sediment resuspension during the winter.

SMALL SCALE VARIABILITY

Sediment

Chlorophyll and organic carbon/nitrogen concentrations in intertidal sediments are consistently greater in the upper intertidal zone at all locations (Fig. 2 and 3) presumably due to longer exposure times. Concentrations decrease with depth in the upper few cm and surface sediment samples must be collected carefully to prevent mixing with deeper sediment.

In September 1980 MEL examined the small scale spatial variability of numerous chemical and biological variables in surface sediment across the Pecks Cove mudflat. Chlorophyll displays pronounced variablility over horizontal distances of just a few cm (Fig. 5) while the variability of organic carbon/nitrogen is considerably less. This spatial variability must be considered when data based on few replicates are interpreted.

Analysis of surface water samples collected in the Cumberland Basin by helicopter (Fig. 2) gives some information on small-scale chemical vari-

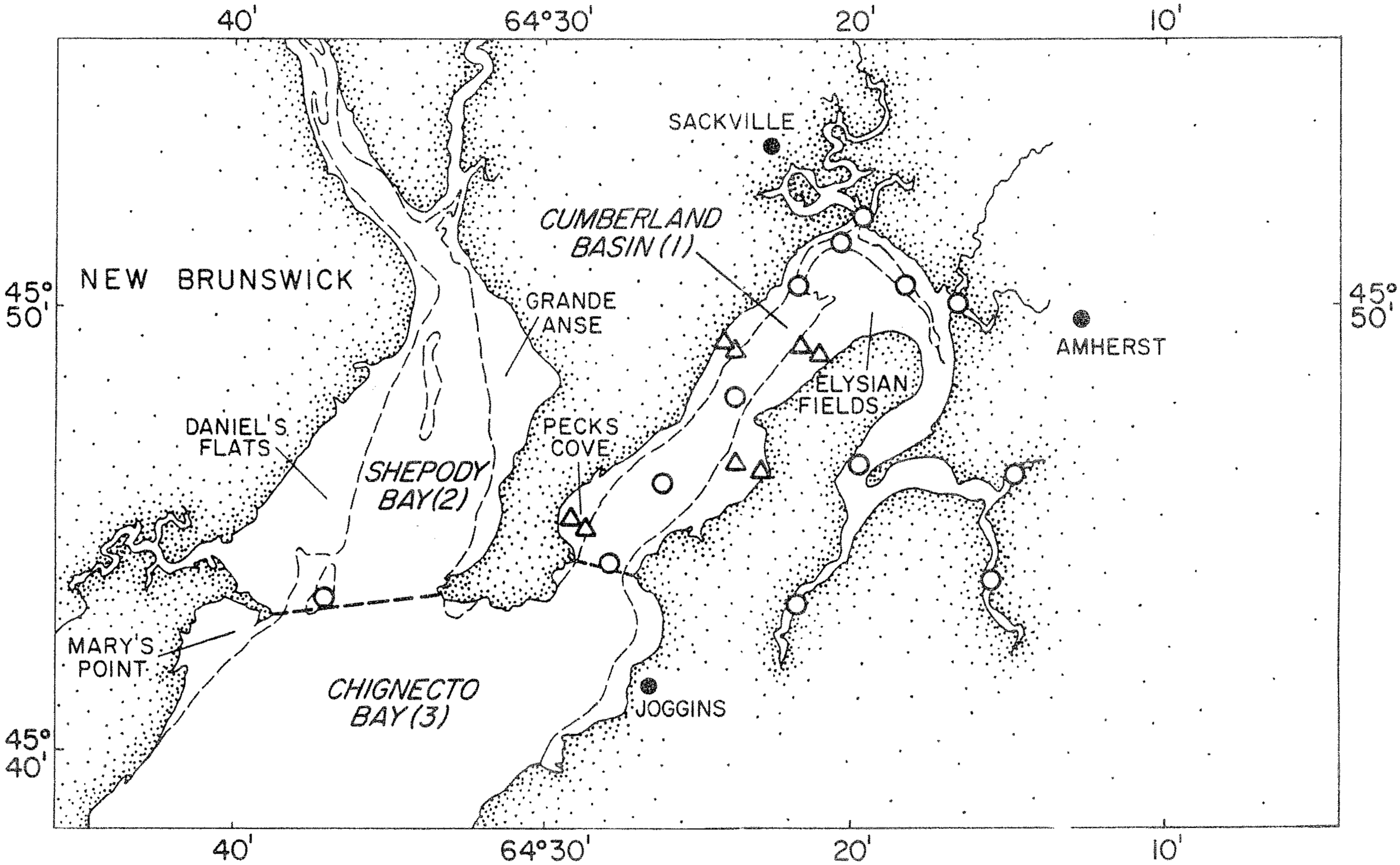


Fig. 2. Map of the upper Chignecto Bay region showing the location of stations sampled by helicopter in Cumberland Basin. Circles denote water samples and triangles sediment samples. Dashed line indicates the approximate location of mean low water.

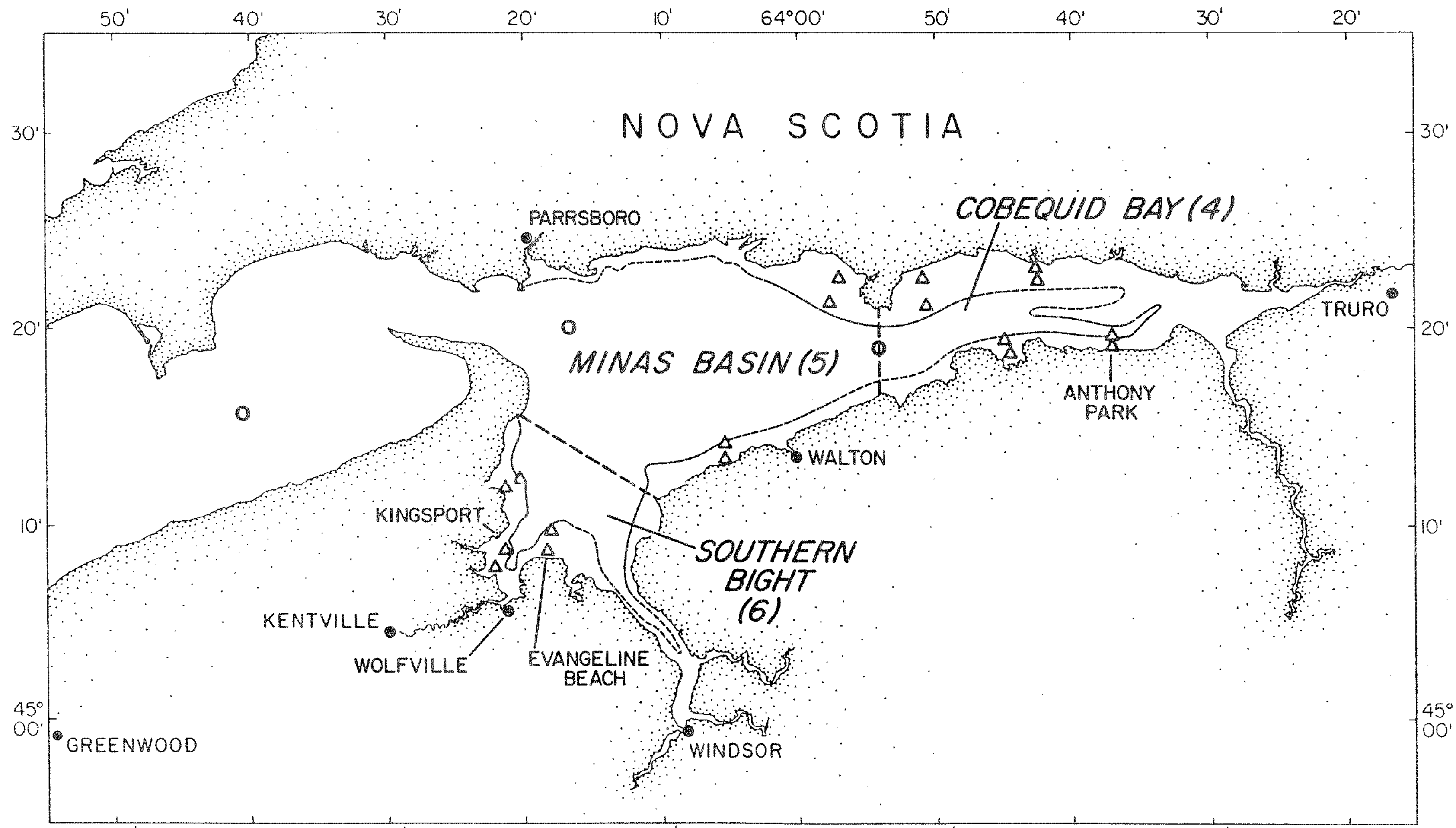


Fig. 3. Map of the Minas Basin region showing the location of various intertidal chemical studies and the sites where sediment samples were collected by helicopter. Dashed line indicates the approximate location of mean low water. Open circles denote anchor stations occupied in August 1979.

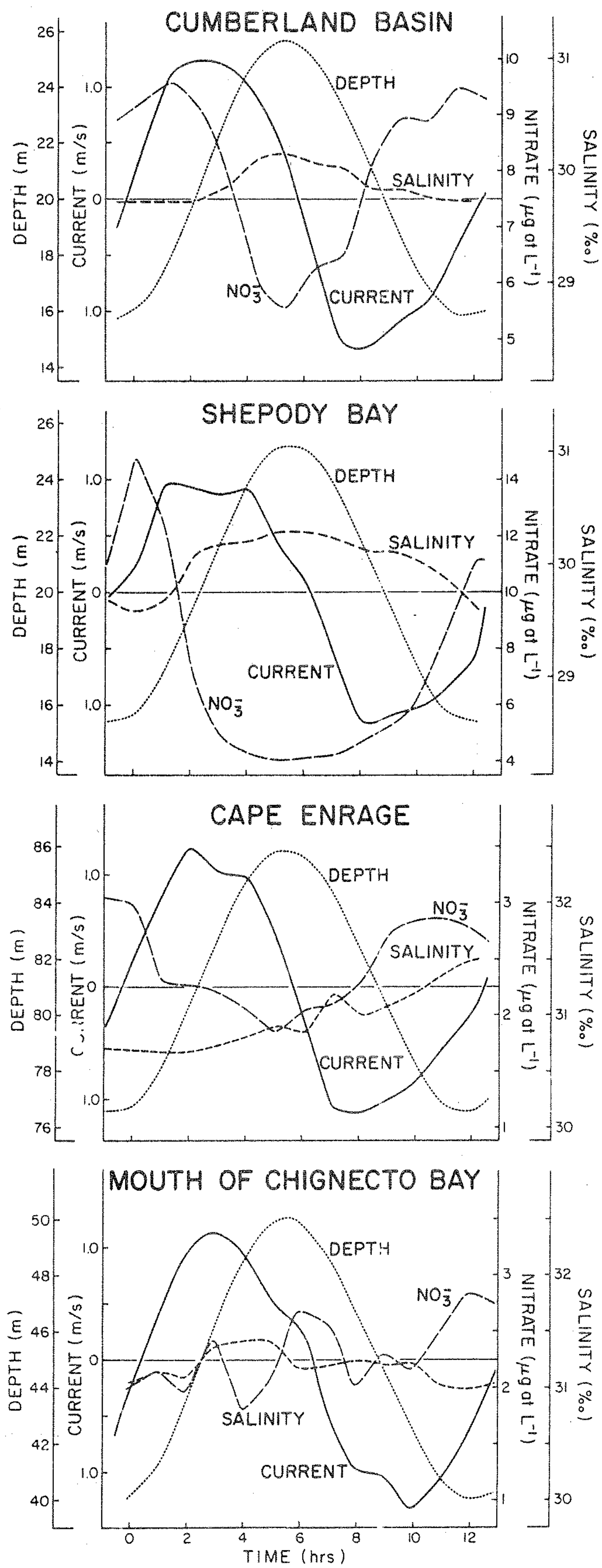


Fig. 4. Typical tidal cycle variations of depth, current velocity, salinity and nitrate in Cumberland Basin, Shepody Bay, Cape Enrage and Chignecto Bay (August 1978).

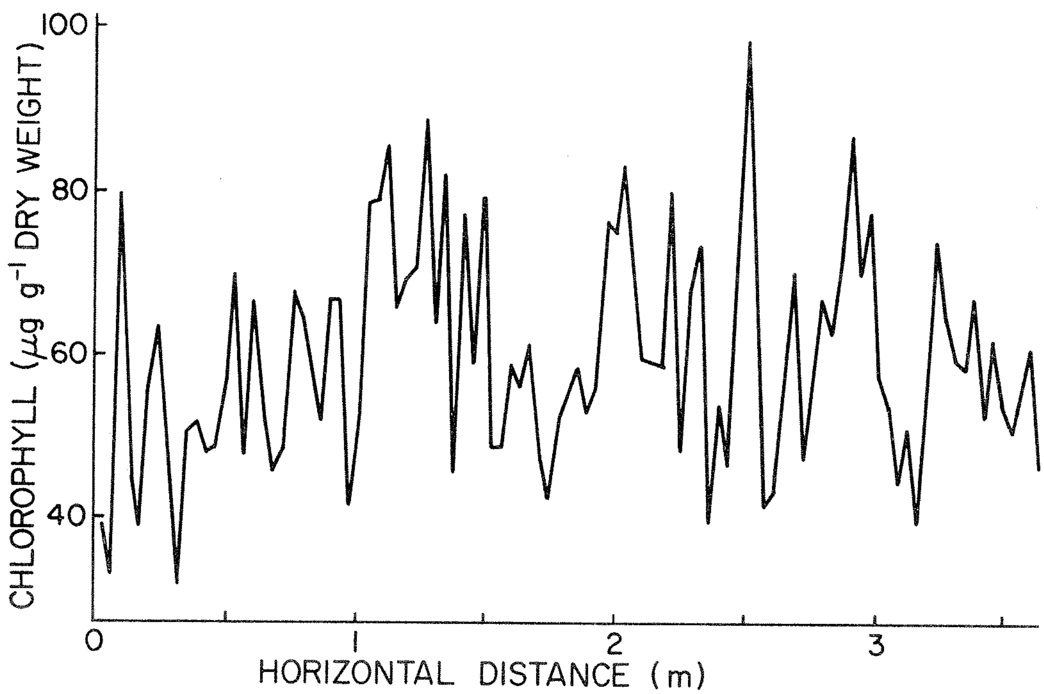


Fig. 5. Small-scale horizontal variability of chlorophyll in surface sediment at Pecks Cove (September 1980).

ability in the upper estuaries. These samples were collected at or near low tide and salinity ranged from near 30°/₀₀ at the mouth of the Basin to almost 0°/₀₀ in the small tidal rivers (salinity at these sites would be at least 20°/₀₀ when the tide was high). Nutrient concentrations were highly variable reflecting the influence of numerous factors including season, location and river discharge. Concentrations of chlorophyll and particulate organic carbon/nitrogen generally increased up the axis of the estuary as did suspended sediment concentrations. Helicopter data from the mouth of the Basin agreed with anchor station data from the same location (Table 2).

During 1979, water samples were collected by MEL over the upper part of the Pecks Cove mudflat during the four hour flooding period with a portable pumping system. Concentrations of particulate variables were higher at the beginning and end of flooding episodes because of resuspension as the water edge moved across the mudflat. The degree of resuspension was dependent upon wind and wave activity which varies considerably day to day.

CHEMICAL DYNAMICS

Input Processes

Although freshwater input is minor in the upper Bay compared to tidal flushing (Garrett et al. 1978) it does have a measurable effect on seawater chemistry. Salinities are lower at the head of the Bay, even at high tide (Table 1), and concentrations of nitrate and silicate vary inversely with salinity over the tidal cycle at the anchor stations (eg. Fig. 4). These observations suggest that horizontal mixing in the upper reaches is less intense than vertical mixing.

Chemical exchanges between water and sediment are expected to be very important in the upper reaches of Fundy. A number of exchange experiments have been conducted at Pecks Cove by MEL using different methods, under both turbulent and static conditions, and sediments have been found to release nutrients to the water column. Surficial and suspended sediments have also been identified as the site of intense microbial activity which remineralizes organic nitrogen to ammonia. Acadia University has studied the capacity of sediment to bind and release nutrients at several sites in the Southern Bight area and some typical results, adapted from De Marco et al. (1979), are shown in Table 3. Uptake occurs under some conditions while release can occur under other conditions. Similar observations have been made at Pecks Cove.

Because of the relatively small freshwater input most of the water in the Bay of Fundy is derived from the shelf and the counter-clockwise residual circulation is well-reflected in the distribution of temperature, salinity and nutrients.

TABLE 3. Distribution of nutrients in intertidal sediments, suspended particulate material (SPM) and the water column at Evangeline Beach in the Southern Bight (Fig. 3) (ug at L^{-1}). Data gathered by Acadia University (DeMarco et al. 1979).

Nutrient	Water Column	SPM	Sediment
Ammonia	0.0 -14.0	1.0 - 5.0	0.2 - 0.5
Nitrate	0.2 - 0.4	0.1 - 0.3	0.004 - 0.005
Nitrite	0.3 - 2.3	0.0 - 2.3	0.01 - 0.02
Reactive Phosphorus	0.0 - 8.0	0.0 - 3.0	1.0 - 2.0
Pyrophosphate	1.0 - 8.0	0.0 - 3.0	2.0 - 4.0
Total phosphorus	0.0 - 9.0	0.0 - 3.0	2.0 - 4.0
Reactive silicate	0.0 - 0.4	0.0 - 1.0	0.1 - 0.5
Total silicate	0.0 - 2.0	0.0 -10.0	0.0 - 0.3
Sulfate	0.0 - 0.1	2.5 -15.0	0.04 - 0.05
Sulfite	1.01 - 0.1	0.02 - .04	0.1 - 0.4
Sulfide	0.0 - 0.1	0.0 - 0.1	0.0 - 0.3

Horizontal Fluxes

The anchor station program was undertaken to determine the magnitude, direction and importance of horizontal fluxes between the upper reaches and the lower parts of the Bay. Initial attempts to calculate nutrient fluxes through Chignecto Bay suggest a seaward transport. These results are very tentative however because of uncertainties in current reversal times and residual circulation patterns. Different approaches to analyzing the data are available and will be tried. Reasonable estimates of horizontal fluxes should be possible from the existing data base.

OTHER STUDIES

Ackman et al. (1979) have studied the lipids and fatty acids of *Corophium voluator*. Brown et al. (1981) have compared fluorescence and spectrophotometric methods for measuring chlorophyll in sediment. Using comparisons with the results obtained using more precise high-pressure liquid chromatography they demonstrated that the spectrophotometric method generally gives more reliable results. The fluorescence method usually over-estimates chlorophyll concentrations, sometimes by as much as 70%. MEL used both methods when analyzing the Minas Basin system sediment samples collected by helicopter and found that differences between the results of the two methods were less and varied seasonally. Hawkins and Keizer (1982) developed an automated laboratory method to measure ammonia excretion rates of *Corophium* and other marine organisms. Schwinghamer et al. (1983) have studied stable carbon isotopes in the Cumberland Basin ecosystem.

A number of chemical studies by ARL have focused on salt marshes in the Southern Bight. A large body of tidal water data is reported by Walker et al. (1981). Mackinnon and Walker (1979) have studied the carbon content of saltmarsh sediment and pore water while Smith et al. (1979) investigated nitrogen fixation rates. Two Job Corps final reports also contain chemical data gathered from the Southern Bight area (DeMarco et al. 1979; and Walker et al. 1979).

Pollutants in Cumberland Basin sediments have been studied. Petroleum hydrocarbon concentrations are very low in intertidal sediments (Keizer, unpublished data) and Pocklington (unpublished data) was unable to detect any chlorinated hydrocarbons.

Finally, a very extensive radionuclide monitoring program has been conducted in the north Outer Bay region (Fig. 1) around Point Lepreau (Smith et al. 1981).

ACKNOWLEDGMENTS

We thank Peter Cranford for preparing data for this review.

REFERENCES

Ackman, R.G., D.M. Nash and J. McLachlan. 1979. Lipids and fatty acids in *Corophium volutator* from Minas Basin. Proc. N.S. Inst. Sci. 29: 501-516.

Amos, C.L. and K.W. Asprey. 1981. An interpretation of oceanographic and sediment data from the upper Bay of Fundy. Bedford Institute of Oceanography Rept. Series, BI-R-81-15, 143 p.

Brown, L.M., B.T. Hargrave and M.D. MacKinnon. 1981. Analysis of chlorophyll a in sediments by high-pressure liquid chromatography. Can. J. Fish. Aquat. Sci. 38: 205-214.

DeMarco, A.C. (Project Leader). 1979. Nutrient distribution in the intertidal waters of the Minas Basin. Final Report for Job Corps Program, Dept. of Chemistry, Acadia University.

Garrett, C.J.R., J.R. Keeley and D.A. Greenberg. 1978. Tidal mixing versus thermal stratification in the Bay of Fundy and Gulf of Maine. Atmos.-Ocean 16: 403-423.

Gordon, D.C., Jr. and C. Desplanque. 1983. Dynamics and environmental effects of ice in the Cumberland Basin of the Bay of Fundy. Can. J. Fish. Aquat. Sci. 40: 1331-1342.

Gordon, D.C., Jr. P.D. Keizer, J. Dale and P.J. Cranford. 1980. Pecks Cove mudflat ecosystem study: observations in 1978. Can. Tech. Rept. Fish. Aquat. Sci. No. 928, 17 p.

Hargrave, B.T. (ed.) 1978. Geochemical and biological observations in intertidal sediments from Cobequid Bay, Bay of Fundy, Nova Scotia. Fish. Mar. Ser. Tech. Rept. No. 782, 43 p.

Hargrave, B.T., G.A. Phillips, P.A. Neame and N.J. Prouse. 1982. Benthic microalgal primary production and community respiration at intertidal sites in Minas Basin and Cumberland Basin, Bay of Fundy. Can. Data Rept. Fish. Aquat. Sci. No. 354, 179 p.

Hawkins, C.M. and P.D. Keizer. 1982. Ammonia excretion in *Corophium volutator* using an automated method. Can. J. Fish. Aquat. Sci. 39: 640-643.

Hayes, E.R. and D.A. Stiles. 1977. Chemical considerations. In: Daborn, G.R. ed. Fundy tidal power and the environemnt, Acadia University Inst. Publ. No. 28, pp. 294-295.

Loring, D.H. 1979. Baseline levels of transition and heavy metals in the bottom sediments of the Bay of Fundy. Proc. N.S. Inst. Sci. 29: 335-346.

Loring, D.H. 1982. Geochemical factors controlling the accumulation and dispersal of heavy metals in Bay of Fundy sediments. Can. J. Earth Sci. 19: 930-944.

Loucks, R.H. 1979. Bay of Fundy environmental data inventory. Nat. Res. Coun. Can., Atl. Reg. Lab. Tech. Rept. No. 24, 155 p.

Mackinnon, M.D. and A.D. Walker, 1979. Comparison of carbon content of the sediments and their pore waters in saltmarshes of Kingsport and Grand Pre, Minas Basin, Bay of Fundy, Nova Scotia. Proc. N.S. Inst. Sci. 29: 373-379.

Moyse, C.M. 1978. Bay of Fundy environmental and tidal power bibliography. Fish. Mar. Ser. Tech. Rept. No. 822, 125 p.

Prouse, N.J., D.C. Gordon Jr., B.T. Hargrave, C.J. Bird, J. McLachlan, J.S.S. Lakshminarayana, L. Sita Devi and M.L.H. Thomas. 1984. Primary production: organic matter supply to ecosystems in the Bay of Fundy. In this report.

Smith, D.L., J. McLachlan and D.G. Patriquin. 1979. Nitrogen fixation as determined by acetylene reduction in two salt marshes of Minas Basin. Proc. N.S. Inst. Sci. 29; 381-392.

Smith, J.N., K. Ellis and F.J. Bishop. 1981. Pre-operational environmental monitoring report for the Point Lepreau, N.B., nuclear generating station 1980. BIO Rept. Series, BI-R-81-10.

Walker, A. (Project Leader) 1979. Some biological, chemical and geological investigations conducted at various locations on the Bay of Fundy. Final Report for Job Corps Program, Atlantic Regional Laboratory.

Walker, A., T. Ackles, J. Perkyns, M.D. MacKinnon, P.D. Keizer and J. McLachlan. 1981. The chemistry of tidal waters of a salt marsh of Minas Basin (Bay of Fundy) Kings County, Nova Scotia. Atl. Res. Lab. Tech. Rept. No. 29, 84 p.

QUESTIONS AND COMMENTS

D. Greenberg: Is there any reason why nutrient concentrations would be expected to change over a tidal cycle or can the observed variations be explained by a gradient moving back and forth?

P. Keizer: There is a gradient of nitrate and other nutrients along the axis of the Bay with higher concentrations in Cumberland Basin. Basically the tidal variations are caused by the pushing back and forth of this slug of more nutrient-rich water coupled with some dilution by incoming seawater.

G. Daborn: Do you know anything about the rates at which chlorophyll decays in turbid waters? We have found very high chlorophyll concentrations in the Cornwallis Estuary and are uncertain of their origin. Do you have any idea of the turnover rate of chlorophyll?

P. Keizer: No, but we do have a mechanism for determining decay rates now. The common method for estimating chlorophyll has been fluorescence spectroscopy which does not provide detailed information on degradation products. Spectrophotometric methods are not much better. However the high pressure liquid chromatographic method (HPLC) used by Brown, Hargrave and MacKinnon is capable of resolving the various photosynthetic pigments and their degradation products, making it possible to estimate decay rates.

G. Brown: Why does the correlation coefficient between fluorescence and spectrophotometric estimates of chlorophyll vary seasonally?

P. Keizer: I am not absolutely certain that everything shown in that slide is statistically true. If it is true, the reason would be that the actual determination is based on the inserting of two numbers into an equation which looks at the fluorescence or absorption of a sample under two different conditions. The equation is an empirical one developed using samples which were 100% chlorophyll a. Therefore estimates are based on the assumption that all chlorophyll measured is chlorophyll a and the only degradation product is phaeophytin. Under varying conditions, the equation can be more or less accurate. You can expect to see seasonal and geographic variations, sometimes sampling when chlorophyll a is in fact the primary pigment and other times when it is not, so the equations can become very inaccurate. You can see all sorts of variation simply because what you say you are measuring is not what you really are measuring in most instances.

G. Brown: Are the differences shown by the two methods for estimating chlorophyll really important?

P. Keizer: Probably not. As chemists, we tend to look at any variation greater than 10% as disgusting and figure something is wrong with the method. We try to hone methods to give precision in the range of 1-5%. However, in this case we must keep in mind that we are looking at biological systems which have a tremendous amount of variability and where the variation between two replicate samples can be 100°% or more. So why be concerned about 20% differences in chlorophyll estimates based on the techniques we are using.

P. Schwinghamer: Fluorescence may not be a good method to estimate spectrophotometric chlorophyll but it does seem to be a good estimator of microalgal biomass (or volume) in sediments.

P. Keizer: Yes. If the estimates obtained by fluorescence are reasonably correlated with other methods, then as a biological indicator nothing is wrong with them. You are still going to get a good correlation. The only thing is that there is an unknown k in there and it really doesn't matter what it is as long as it is relatively constant.

J. Lakshminarayana: What are the ranges of trace metal concentrations in sediments?

P. Keizer: I don't know. The data were taken from Loring's paper. Concentrations are typical for unpolluted coastal areas and reflect source rock composition.

J. Lakshminarayana: What do you mean by the buffering capacity of sediments?

P. Keizer: Basically its not unlike traditional chemical buffering but instead of involving an equilibrium coefficient there is an adsorption and desorption of chemically charged species in the water column, in this case nutrients, with sediment particles. The direction of the flux is a function of many chemical factors such as the nutrient concentration in the water surrounding the particle, pH, and the ionic strength of the solute. It has been determined, particularly in estuarine areas, that fine-grain sediments have a strong buffering capacity for phosphate, silicate and nitrate.

Primary Production: Organic Matter Supply to Ecosystems in the Bay of Fundy

N.J. Prouse, D.C. Gordon Jr., B.T. Hargrave

Department of Fisheries and Oceans
Marine Ecology Laboratory
Bedford Institute of Oceanography
P.O.Box 1006,
Dartmouth, N.S. B2Y 4A2

C.J. Bird, J. McLachlan

National Research Council of Canada
Atlantic Research Laboratory
1411 Oxford Street
Halifax, N.S. B3H 3Z1

J.S.S. Lakshminarayana, J. Sita Devi

Department of Biology
Université de Moncton
Moncton, N.B. E1A 3E9

and

M.L.H. Thomas

Department of Biology
University of New Brunswick
Saint John, N.B. E2L 4L5

ABSTRACT

Studies from 1976 to 1982 of primary production by salt marsh, seaweeds, benthic microalgae and phytoplankton in the Bay of Fundy are reviewed and annual production for different regions and the entire Bay is estimated. The outer Bay accounts for 86% of the total annual production of 1124 x 10^3 tonnes C of which 96% is derived from phytoplankton. In this region, fucoids are locally very abundant on rocky shores and net production of 845 g C m^{-2} y^{-1} has been measured. The upper reaches, typified by high turbidity, strong tidal currents and no stratification of the water column, have lower but significant production (up to 44 g C m^{-2} yr^{-1} average for all sources in the Cumberland Basin) which supports moderate populations of invertebrates, fish, and birds. The majority of this primary production is derived from extensive areas of mudflats supporting benthic microalgae and large tracts of salt marsh.

Key words: primary production, Bay of Fundy, salt marsh, seaweeds, benthic microalgae, phytoplankton

RÉSUMÉ

On effectue un examen critique des études de la production primarie d'herbes marines, de micro-algues benthiques et de phytoplancton dans les marais salés de la baie de Fundy de 1976 à 1982 et on estime la production annuelle pour différentes régions ainsi que pour l'ensemble de la baie. La partie extérieure de la baie produit 86% de la production annuelle totale de C qui s'élève à 1124 x 10^3 tonnes de C dont 96% provient du phytoplancton. Dans cette région les fucoïdes sont très abondants par endroits sur les rivages rocheux et on a mesuré une production annuelle nette de 845 g de C par m^2. Les parties intérieures, caractérisées par une turbidité élevée de l'eau, la présence de forts courants de marée et l'absence d'une stratification de la colonne d'eau présentent une production importante (atteignant jusqu'à 44 g de C par m^2 par année en moyenne pour toutes les sources dans le bassin de Cumberland) qui supporte des populations nombreuses d'invertébrés, de poissons et d'oiseaux. La plus grande partie de la production primaire provient des régions étendues de vasières supportant des micro-algues benthiques ainsi que des grands marais salés.

INTRODUCTION

Organic material in the Bay of Fundy is produced through photosynthesis by seaweeds, salt marshes, benthic microalgae and phytoplankton. Prior to 1976, few direct measurements of primary production had been made in this area, the emphasis until then being on species distributions mainly in the outer Bay. Since then, a number of investigations have been initiated especially in the more turbid upper reaches where the potential for tidal power is recognized. Presented here is a preliminary résumé of the work of numerous scientists completed to date with the aim of arriving at some estimates of production for all parts of the Bay. Many of these values are the result of limited sampling and are not to be considered absolute; they are given as a means to distinguish important areas of production as well as identify major primary producers. The data will be expanded and refined in future publications.

The Bay of Fundy has been divided arbitrarily into a number of regions (Fig. 1). In each, the areas of water (at different tidal levels), salt marsh, flats and ledges have been measured by planimetry (Table 1) so that estimates of total biomass and production could be calculated. Thus the Inner and Outer Bay typified by stratified water can be compared with the more turbid upper reaches such as Cumberland Basin and Cobequid Bay.

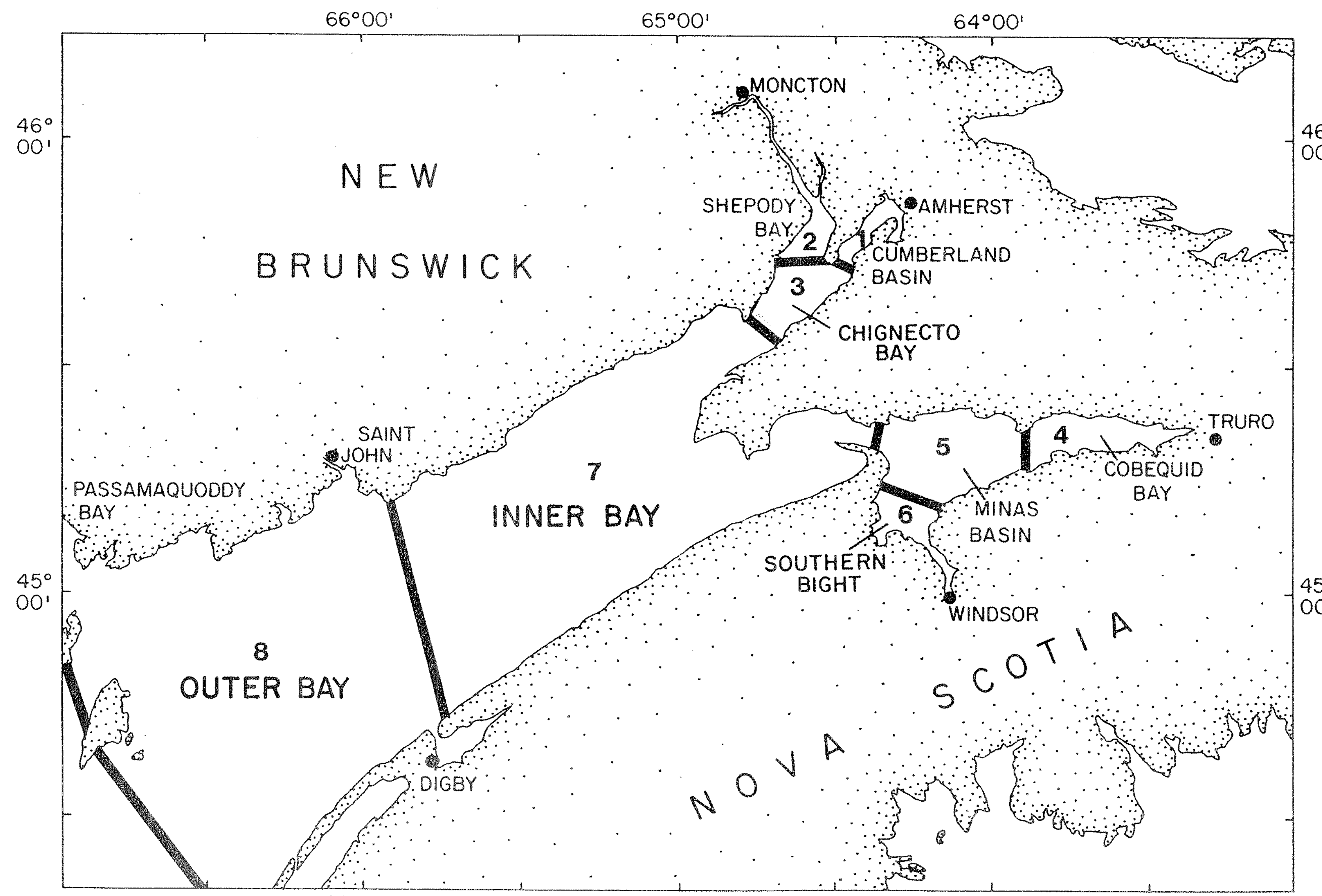


Fig. 1. Bay of Fundy indicating different regions.

TABLE 1. Estimated areas of water, saltmarsh, flats and ledges in the Bay of Fundy (ha). Unless otherwise indicated, areas tabulated by P. Cranford using maps and planimeter or estimated by difference. The estimates are weakest for the Inner and Outer Bay. Numbers of regions indicate location in Fig. 1.

Region	Mean Tidal Range (m)	LLW	HHW	Intertidal	% Intertidal of HHW	Saltmarsh Total	Saltmarsh High	Saltmarsh Low	Flats/Ledges
Cumberland Basin(1)	10	3850	11810	7960	67	1714[1]	948	766	6246
Shepody Bay (2)	10	7320	15710	8390	53	911[2]	-	-	7479
Chignecto Bay (3)	9	27070	29020	1950	7	270[1]	-	-	1680
Cobequid Bay (4)	12	12280	29840	17560	59	373[1]	226	147	17187
Minas Basin (5)	11	55950	65660	9710	15	290[1]	188	102	9420
Southern Bight (6)	12	10100	21350	11250	53	2037[1]	960	1077	9213
Inner Bay (7)	8	462818	467950	5132	1.1	435[2]	-	-	4697[3]
Outer Bay (8)	5	695047	700180	5133	0.7	436[2]	-	-	4697[3]
Total			1341520			6466			84484

1 Spence (unpublished data)
2 Pearce and Smith (1973)
3 Combining mudflat area from Pearce and Smith (6194 ha) (1973) with rocky ledge area calculated by Thomas (3200 ha) (unpublished data) assuming an even split between Inner and Outer Bay.

PHYTOPLANKTON

Distribution & Area

Phytoplankton are distributed in the water column throughout the Bay of Fundy. They can be holoplanktonic (free floating), meroplanktonic (littoral and associated with coastline) or tychopelagic (mostly bottom living).

Structure & Composition

Prior to 1976 most studies concentrated on species identification and distribution in the lower Bay of Fundy, especially the Quoddy region (Davidson 1934; Gran and Braarud 1935). Since then, Lakshminarayana and Sita Devi (unpublished report) have examined 1077 water samples collected on four cruises in the entire Bay (1979-80) and at Pecks Cove, Cumberland Basin. Identified were 127 species in 42 genera representing diatoms (113 species in 35 genera), dinoflagellates (12 species in 5 genera), and green algae (1). The benthic diatom *Paralia sulcata* is very common as is *Actinoptychus senarius*, an oceanic diatom. Many euryhaline species known to occur in coastal waters associated with littoral areas are present such as *Biddulphia aurita*, *B. laevis*, *Fragilaria shulzi*, *Gyrosigma baltica*, *Navicula cryptocephala*, *N. granulata*, *Pinnularia ambigua*, *Synedra affinis*, and *Chaetoceros affine*. There appears to be a definite seasonal distribution of phytoplankton typical of a temperate coastal region resulting in winter, spring, summer and fall populations (Table 2). Species like *Rhizosolenia alata*, *R. stolterfothii*, *Thalassionema nitzschioides*, *Thalassiosira nordenskioldii*, *Ceratium fusus* and others as described by Marshall (1978) as occurring in the Gulf of Maine and surrounding Atlantic waters are represented among the species recorded for the Bay of Fundy region. This indicates an input of water into the Bay. There are also distinct variations in distribution and frequency of phytoplankters between the inner and outer Bay.

The upper reaches are especially rich in diatoms. Dominant forms in the inner Chignecto Bay, Cumberland Basin, Shepody Bay and Minas Basin are listed in Table 3.

Biomass and Productivity

Studies of production and biomass in the Bay of Fundy include those of Gran and Braarud (1935) and Subba Rao (1974) in the lower Bay plus our own investigations over the entire Bay (Hargrave et al. 1983, Prouse 1983). Using standard radiocarbon methods, as outlined by Strickland and Parsons (1968), we have arrived at net production values by *in situ* measurements at Pecks Cove, Cumberland Basin and simulated *in situ* measurements (deck incubations) on four cruises throughout the Bay. Additional light saturation experiments were performed to study the relationship between light and carbon assimilation. Production data are summarized in Table 4.

TABLE 2. Phytoplankton species present along the transect of stations of Bay of Fundy. Data summarized from unpublished observations by J.S.S. Lakshminarayana and J. Sita Devi.

O.B. = Outer Bay F = frequent
I.B. = Inner Bay D = Dominant

	Cruises							
	Spring 79-004		Summer 79-023		Fall 79-034		Winter 80-003	
	I.B.	O.B.	I.B.	O.B.	I.B.	O.B.	I.B.	O.B.
Actinocyclus octonarius	F							
Asterionella japonica			D	D	F		F	
Bacillaria paxillifer								F
Biddulphia aurita	D				F			
B. pulchella				D				
B. mobiliensis			D		F			
Caloneis westii							F	
Chaetoceros affine	F	F		F				
Ch. compressum				F				
Ch. decipiens	F	D	D	D	F			
Ch. diadema	D	F		F				
Ch. gracile	D	F						
Ch. radicans	D	F						
Ch. subtile	F							
Ch. tires	F							
Coscinodiscus asteromphalus					D	F		F
C. centralis		F					F	F
C. concinnus						D		
C. eccentricus			D	D	D	D	F	
C. radiatus	F	F					F	F
Cyclotella meneghiniana							F	
C. striata								F
Diploneis didyma							F	
Ditylum brightwellii		F		D	F	F		
Eucampia radiatus	D							
Fragilaria sp.								
Licmophora gracilis							F	
Leptocylindrus danicus				F				
Melosira moniliformis	F				F	D	F	D
M. nummuloides	D			D	F	D	D	D
M. sulcata							D	D
M. westii							F	
Navicula maculosa							F	D
Nitzschia angularis								
N. closterium						D	F	D
N. longissima				F				
N. seriata			D		F			
Paralia sulcata							D	D
P. cruciformis								
Pleurosigma aestuarii				F				

TABLE 2. CONT'D.

	Cruises							
	Spring 79-004		Summer 79-023		Fall 79-034		Winter 80-003	
	I.B.	O.B.	I.B.	O.B.	I.B.	O.B.	I.B.	O.B.
Rhizosolemia hebetata								
forma *semispina*	D	F	D				D	
R. robusta							D	
R. setigera	F				F	D		
Skeletonema costatum		D		D				
Streptotheca tamesis					D	D		
Thalassionema nitzschioides	F						F	F
Thalassiothrx frauenfeldii	F					D		
Thaassiosira decipiens								
Th. nordenskioldii		F						
Ceratium furca				F				
C. longipes			D	D	F	D		
C. macroceros					F	F		
C. tripos	F		D		F	F		
Prorocentrum micans				F				
Protoperidinium depressum					F			

TABLE 3. Dominant phytoplankton species collected from the inner Bay of Fundy. Minas Basin samples collected from summer only. Data summarized from unpublished observations by J.S.S. Lakshminarayana and J. Sita Devi.

	Inner Chignecto Bay	Cumberland Basin	Shepody Bay	Minas Basin
Actinoptychus senarius	X	X	X	
Biddulphia mobiliensis	X	X	X	
B. aurita	X		X	X
Ceratium tripos		X	X	
Coscinodiscus centralis		X	X	X
C. concinmus	X	X	X	X
C. eccentricus				X
Cyclotella meneghiniana		X	X	
Eucampia zodiacus		X	X	
Fragilaria oceanica	X	X	X	
Gonyaulax tamarensis	X	X	X	
Gyrosigma fasciola	X	X	X	
Melosira nummulloides	X			X
Navicula vanhöffenii	X			
Nitzschia seriata	X		X	X
Paralia sulcata	X	X	X	
Pinnularia quadrateria	X			
Pleurosigma normanii	X			
Rhizoselenia alata	X		X	
RL. styliformis	X	X	X	
Surirella fastuosa	X			
S. ovata	X	X	X	
Synedra affinis	X	X	X	
Thalassiosira decipiens		X	X	
Thalassiothrix longissima			X	

TABLE 4. Summary of phytoplankton production data. Numbers of regions indicate location in Fig. 1.

Region	Area at Mean Sea Level (ha x 10^3)	Annual Production (g C m^{-2} yr^{-1})	Estimated Total Annual Production (tonnes C yr^{-1} x 10^3)
Cumberland Basin (1)	7.8	15(5-25)	1.2(0.4-2.0)
Shepody Bay (2)	11.5	15(5-25)	1.7(0.6-2.9)
Chignecto Bay (3)	28.0	15(5-25)	4.2(1.4-7.0)
Cobequid Bay (4)	21.1	17(15-19)	3.6(3.2-4.0)
Minas Basin (5)	60.1	17(15-19)	10.3(9.1-11.6)
Southern Bight(6)	15.7	15(5-25)	2.4(0.8-3.9)
Inner Bay (7)	465.4	27	125.7
Outer Bay (8)	697.6	133	927.8

Average annual phytoplankton production in the water covering the Pecks Cove mudflat, which is flooded only half of the day, is estimated by in situ methods to be 7 g C m^{-2} (Hargrave et al. 1983) with twice this production (15 g C m^{-2}) for the water mass permanently present in the Basin. Annual rates of carbon assimilation estimated from deck incubation experiments in the Cumberland-Shepody region ranged from 5-25 g C m^{-2}, in close agreement with in situ values. These rates compare with a production estimate of 13 g C $m^{-2}y^{-1}$ in the Dollard Estuary, Netherlands, which experiences high turbidity from pollution (Cadée and Hegeman 1974a).

Although radiocarbon measurements were made only on one summer cruise in the Minas Basin, a ratio between these values and those measured for the same period in the Cumberland Basin provides an estimate for the entire year. By this method a range of 15-19 g C $m^{-2}y^{-1}$ is derived, slightly higher and less variable than for the Cumberland Basin. This difference is due in part to the lower amount of suspended sediment allowing greater light penetration. However in the more turbid areas such as Cobequid Bay and the Southern Bight production values are probably similar to the Cumberland Basin.

In the open Bay of Fundy, annual production is estimated at 27 g C m^{-2} in the inner Bay and 133 g C m^{-2} in the outer Bay (Table 4). The latter is typified by a stratified water column and negligible turbidity. By comparison annual primary production in St. Margarets Bay, Nova Scotia, is between 125-155 g C m^{-2} (Platt and Irwin 1968).

Seasonally, highest production is observed in all areas in summer when light conditions are optimal. Although the stratified water of the Outer Bay has the potential for nutrient limitation, this does not appear to happen, perhaps because of upwelling off Yarmouth. Our summer measurements of production in the surface water at the mouth of the Bay (≈12 mg C $m^{-3}h^{-1}$) were the highest recorded and are in agreement with those observed by Subba Rao (1974) in the same area. Lowest production appeared to be in fall; winter values were slightly higher but this might have been the result of limited sampling. Limited sampling might also explain the absence of a noticeable spring bloom in the Bay of Fundy as has been observed during March-April in adjacent temperate waters (Platt 1971; Platt et al. 1973). More frequent sampling at Pecks Cove during this time period showed that production is low in April but increases rapidly in May and June (Hargrave et al. 1983). Perhaps the high turbidity in this area suppresses active growth of phytoplankton until a "threshold" amount of light is received in late spring. Sinclair (1978) has noted a similar phytoplankton response and absence of a spring bloom in the turbid waters of the lower St. Lawrence Estuary.

The annual variation in abundance of phytoplankton is reflected in the chlorophyll distribution throughout the Bay of Fundy. Maximum average biomass in surface water calculated on the basis of four seasonal cruises occurred in summer at the mouth (3.3 µg L^{-1}) with minimum concentration in winter and early spring (0.5 µg L^{-1}). However average biomass in the surface waters of the Cumberland-Shepody area is similar throughout the year (1.3-1.8 µg L^{-1}). This might be a reflection of the high turbulence which resuspends large numbers of algal cells, including benthic diatoms, into the water column.

Gran and Braarud (1935), in their study of phytoplankton abundance for pre-tidal power assessment in the Quoddy region, concluded that turbulence and turbidity were the main factors influencing phytoplankton production in the Bay of Fundy. Light, as influenced by turbidity, is clearly the most important factor. High concentrations of suspended material in the Cumberland Basin limits the photic zone to only 1-2 m so that production integrated over depth is low. On one occasion, at Pecks Cove, for example, as a result of high turbidity (greater than 2 g L^{-1}) and low incident radiation, irradiance could not be measured below the surface during the flood tide and net production was zero (dark fixation also exceeded light fixation). At this site, we found that photosynthetically available radiation decreased an average of 96% while phytoplankton production decreased 59% from the surface to 1 m depth (Hargrave et al. 1983). The dissimilarity can be explained by the non-linear response of phytoplankton to light as well as only instanteous measurements of radiation over the incubation period. Comparison of the photosynthetic efficiency by phytoplankton and benthic microalgae shows that the former assimilate carbon less efficiently per unit incident light as a result of shading from suspended particles.

The photic zone is much deeper in the Minas Basin (4-8 m) because of lower turbidity. Similarly, very low concentrations of suspended material (<5 mg L^{-1}) in the Outer Bay allows photosynthesis and net production to occur to a depth of about 18 m.

The extreme turbulence as a result of strong tidal currents influences not only distribution but production and biomass as well. This turbulence causes the high turbidity which has been shown to limit production and also allows nutrients to be swept into the photic zone so that they are not limiting (Keizer et al. 1983). It is not known how water movement in the upper reaches might affect the exposure of phytoplankton to light; at one instance algal cells might be in the photic zone and then swept below. Marra (1978a, b), in a laboratory study of photosynthesis under constant and fluctuating light intensities, suggests that phytoplankton might utilize light as efficiently at one depth as moving through the water column. In a turbulent environment, optimal light could be well utilized during short exposure so that integral production over depth is enhanced. From measurement of *in situ* irradiance and light saturation data, optimal light can occur in the surface water of the upper reaches (Prouse 1983). In the much clearer water of the Outer Bay there might also be some photoinhibition in the surface.

Chemosynthetic production has not been considered in the calculations for total annual phytoplankton production. This is the amount of carbon dioxide assimilated by autotrophic bacteria for the production of organic material using simple inorganic compounds such as ammonia for an energy source. This process readily occurs in the dark and rates of carbon assimilation can exceed photosynthetic fixation (Seki 1968, Morris et al. 1971, Petersen 1979, Taguchi and Platt 1977). There can be additional dark assimilation through heterotrophic processes by bacteria and algae. Our studies at Pecks Cove indicate that non-photosynthetic biological uptake, that is the difference between dark uptake and uptake in dark mercuric chloride-poisoned bottles, could be as much as 48% of the gross amount fixed in light. This chemosynthetic production was positively correlated with the amount of suspended material in the water. Seki (1968) observed the greatest dark assimilation in the spring in the water column of a shallow inlet in Japan because of strong seasonal winds stirring up the benthic microorganisms. In areas of the Bay of Fundy with high turbidity, such as the Cumberland Basin and Cobequid Bay, there are large numbers of microorganisms at all times which would account for high dark fixation values. Indeed the upper reaches have the highest concentration of bacterial cells in the Bay of Fundy, 98% of which are attached to suspended particles (Cammen and Walker 1982). Measurements in the Outer Bay with fewer bacterial cells and negligible turbidity showed lower rates of dark uptake. As chemosynthetic production is independent of light and hence depth, there could be a considerable quantity of carbon assimilation throughout the water column in areas of high turbidity. Thus, total organic carbon production for turbid areas of the Bay might be much greater than estimated from measurements of phytoplankton production alone.

Fate of Production

Most if not all of the production is rapidly utilized in pelagic and benthic food webs.

BENTHIC MICROALGAE

Distribution and Area

Benthic diatoms are ubiquitous in intertidal sediments in the Bay of Fundy. Because of the extensive tidal range, the intertidal region is very large, especially in the upper reaches (Table 1). More than half of the total area of Cumberland Basin, Shepody Bay, Cobequid and the Southern Bight is intertidal and composed of sand- and mudflats.

Structure and Composition

The vertical distribution of chlorophyll in intertidal sediments indicates that diatoms can occur to depths of at least 15 cm. Cadée and Hegeman (1974b) have made similar observations in intertidal sediments from the Dutch Wadden Sea. However, diatoms can only carry out photosynthesis in the upper few millimetres of surface sediment where light is available. Cells are able to migrate vertically in the surface layer seeking optimal light intensities. Wave activity associated with advancing and receding tides can suspend cells along with surface sediment such that benthic species are frequently encountered in water samples.

At least 16 genera of benthic diatoms occur in Cumberland Basin and the three most common are Gyrosigma, Coscinodiscus and Rhaphoneis (Palmer, personal communication). Numbers and diversity change markedly over an annual cycle. Schwinghamer et al. (1983) found *Gyrosigma* to be the predominant genus at Pecks Cove during the summer months.

Biomass and Productivity

Benthic diatom biomass (volume) has been measured directly at Pecks Cove by Schwinghamer (1981). Maximum and minimum biomass occurred in September and February/March respectively. Similar seasonal maxima and minima at sites in Cumberland Basin, Cobequid Bay, Minas Basin and the Southern Bight were observed by measuring the chlorophyll concentration in surface sediments (Gordon et al. unpublished data). Average annual concentrations for various sites are listed in Table 5 and pronounced variations are noted. In general, concentrations are greater in finer sediments. Reduced chlorophyll concentrations at lower intertidal zone stations imply that diatom biomass is less at sites which are flooded longer and therefore receive less light than upper intertidal zone stations (about 8 h versus 4 h on each tide at Pecks Cove). Using a carbon to chlorophyll ratio of 20 (determined empirically) benthic microalgae at Pecks Cove constitute about 7% of the organic carbon in surface sediment averaged over a year. This percentage can exceed 50% during bloom conditions.

Production of benthic microalgae was measured by Hargrave et al. (1983) at two intertidal sites using an *in situ* oxygen production method. They estimated gross annual production to be 73.0 (62.5-83.5) and 26.6 (20.2-32.0) g C m^{-2} at Pecks Cove (Cumberland Basin) and Anthony Park (Cobequid Bay), respectively. Net production would be approximately 10% lower than these values. Both estimates are based on data gathered over a two year period and are in the range reported for studies in other intertidal areas. Schwinghamer (1981) estimated production from microalgal biomass and a turnover ratio calculated from a regression of P/B on cell volume. He derived an estimate of 46 g C m^{-2} for net annual production at Pecks Cove, somewhat lower than the value calculated by Hargrave et al. (1983).

At least three factors appear to control the productivity of benthic diatoms. The most important is probably light. Because of water turbidity, no photosynthesis occurs when the flats are flooded. Maximum productivity occurs during the summer months when incident solar radiation (and temperature) are greatest. The data of Hargrave et al. (1983) suggest that production is less in the lower intertidal zone where chlorophyll concentrations are generally lower (Table 5) presumably because of light limitation. Cadée and Hegeman (1977) report a strong correlation between elevation and benthic microflora production in the intertidal region of the Dutch Wadden Sea, an environment similar to the upper reaches of the Bay of Fundy, which they explain by light availability.

Intense grazing by microalgal-feeding herbivores such as *Corophium volutator* appears to depress productivity during certain periods of the year (Hargrave et al. 1983). Although there is an abundance of nutrients in the water all seasons of the year (Keizer et al. 1984) nutrient limitation may occur since only a thin film of water is present on the sediment surface when photosynthesis takes place. The possible importance of

TABLE 5. Average annual concentrations (median of 12 monthly means) of chlorophyll in the surface 1 cm of intertidal sediment measured fluorometrically. Numbers in parentheses indicate regional location in Fig. 1.

Location	mg chlorophyll a m^{-2} Upper Intertidal	mg chlorophyll a m^{-2} Lower Intertidal
Pecks Cove (1)	215	180
Minudie (1)	124	62
Elysian Fields (1)	79	61
Allen Creek (1)	58	43
Economy East (5)	20	20
Portapique (5)	27	43
Anthony Park (5)	56	23
Noel (5)	54	20
Economy West (6)	27	24
Cambridge (6)	10	10
Pereau (7)	70	153
Starrs Point (7)	96	52
Evangeline Beach (7)	80	65

physical stress resulting from tidal suspension and re-deposition is unknown.

Cadée and Hegeman (1977) found a very strong correlation between annual benthic microflora production and annual average concentrations of chlorophyll in surface sediment. Hargrave et al. (1983) also reported lower concentrations of chlorophyll at Anthony Park than at Pecks Cove averaged over the year. Annual production was also about one third of that at Pecks Cove. Therefore we have estimated annual diatom production at other intertidal areas from the annual average chlorophyll concentrations (Table 5) using the average annual production/chlorophyll ratio observed by Hargrave et al. (1983) (0.54 g C per mg chlorophyll). Values averaged for different regions are presented in Table 6 along with estimates of total annual production.

Fate of Production

All evidence indicates that benthic diatom production is utilized very rapidly, either by consumption or respiration in the surface sediment or in the water column (Hargrave et al. 1983). All major consumers at the Pecks Cove mudflat have $\delta^{13}C$ ratios in the same range as benthic microalgae (approximately -12 to -15°/₀₀) indicating their importance as a food source (Schwinghamer et al. 1983).

SALT MARSH

Distribution and Area

The distribution and area of salt marshes in the Bay of Fundy are summarized in Table 1. The largest tracts of salt marsh occur in Cumberland Basin and the Southern Bight (58%). Only 6% of the total salt marsh area is found in Cobequid Bay. Before the arrival of European settlers in the seventeenth century and subsequent diking, the salt marshes at the head of the Bay of Fundy were more extensive, approximately 28 x 10^3 hectares (Ganong 1903). About 90% of the original salt marsh has been reclaimed in Cumberland Basin.

Structure and Composition

Patriquin (1981) has reviewed the general biology of salt marshes in Nova Scotia. Salt marsh properties are influenced profoundly by elevation and the frequency of immersion by tidal waters. This is especially the case near the head of the Bay of Fundy where the elevation of high water can vary several meters over a spring-neap cycle and the number and timing of high spring tides change from year to year. Fundy marshes are also influenced by a steady rise in highwater level of about 0.3 m per century (Amos 1978).

Generally speaking, Fundy salt marshes can be divided into two categories on the basis of elevation:

TABLE 6. Summary of gross benthic microalgal production. Net production would be approximately 10% lower. See text for derivation of annual production estimates. Numbers in parentheses indicate regional location in Fig. 1.

Region	Area of Mud and Sand Flat (ha x 10^3)	Annual Production (g C m^{-2} yr^{-1})	Annual Production (tonnes C yr^{-1} x 10^3)
Cumberland Basin (1)	6.2	38(23-116)	2.4
Shepody Bay (2)	7.5	38(23-116)[1]	2.8
Chignecto Bay (3)	1.7	14(11-30)[2]	0.2
Cobequid Bay (4)	17.2	14(11-30)	2.4
Minas Basin (5)	9.4	9(5-15)	0.8
Southern Bight(6)	9.2	45(28-84)	4.1
Inner Bay (7)	3.0	14(11-30)[2]	0.4
Outer Bay (8)	3.2	14(11-30)[2]	0.4

[1] assuming same as Cumberland Basin.
[2] assuming same as Cobequid Bay.

High marsh - That portion of salt marsh well above mean high water (MHW) that occupies a narrow vertical zone of about 1 m. It is very flat and can be dissected in places by creeks and man-made ditches. It is flooded infrequently by only the highest spring tides (about 25 to 50 times a year). When flooding occurs, immersion is brief and the maximum water depth is about 1 m. The dominant plant is Spartina patens, but Puccinellia americana is also common in some locations. Juncus gerardi and Spartina pectinata are sometimes found along the landward edge where drainage is poor and freshwater collects. High marsh represents the mature stage of salt marsh development (Redfield 1973).

Low marsh - That portion of salt marsh ranging from just above MHW to about 2 m below. It is generally sloped. Sheltered portions are found along creeks and ditches that penetrate high marsh areas and around saline pools. Exposed portions occupy the sloping surfaces seaward of high marsh tracts and terminate in mudflats. Except for the upper portions on neap tides, low marsh is flooded twice daily. The depth of water flooding low marsh is commonly several meters, often with sizeable waves, and immersion times can be as long as 4 h. Vegetation is almost exclusively Spartina alterniflora. Low marsh, representing early stages in salt marsh evolution, can develop into high marsh if the rate of sediment accumulation exceeds rise in sea level.

Total marsh areas are divided into high and low categories (Table 1). In general, high marsh areas are slightly greater in aerial extent in all regions of the upper reaches of the Bay of Fundy. In Cumberland Basin and the Southern Bight, the regions with the greatest marsh areas, the relative areas of high marsh are 55 and 47% respectively. As only high marsh has been diked, the original area of high marsh must have been was much greater.

Productivity

Three salt marsh productivity studies have been conducted in the Bay of Fundy. Morantz (1976) studied four sites in the John Lusby Marsh near Amherst, the single largest salt marsh in Cumberland Basin. He estimated net above-ground annual production to be 483 g dry wt m^{-2} (including high and low marsh assemblages). Two salt marshes in the Minas Basin were studied by Smith et al. (1980); one (Grand Pré) was entirely low marsh while the other (Kingsport) was a mixture of high and low. Net above-ground annual production for both marshes was about 500 g dry wt m^{-2}. They noted the higher productivity of Spartina alterniflora (low marsh) compared with other species. Most recently, Gordon and Cranford (in prep.) studied eight salt marshes around the perimeter of Cumberland Basin, including the John Lusby Marsh. They estimate the net above-ground annual production to be 634 and 406 g dry wt m^{-2} for low and high marsh, respectively.

Despite differences in location and methods, all rates are remarkably similar and suggest that 500 g dry wt m^{-2} (or 215 g C m^{-2}) is a reasonable estimate of the net above-ground annual production of Fundy salt marshes. This value is lower than observed in salt marshes along the Atlantic coast of Nova Scotia and further south in the USA (Hatcher and

Mann 1975). The total salt marsh production is considerably greater because of below-ground growth (Smith et al., 1980). Estimates of net aboveground production are presented in Table 7.

Elevation plays a key role in controlling salt marsh productivity. Morantz (1976), Smith et al. (1980) and Gordon and Cranford (in prep.) all noted the general greater productivity of Spartina alterniflora compared to high marsh species. Within the low marsh zone, Gordon and Cranford (in prep.) have observed a very close inverse relationship between the productivity of S. alterniflora and elevation with the most luxuriant growth occurring about MHW where plants are flooded on the average of only a few minutes twice a day (but with considerable variability from day to day).

The lower productivity of high marsh is probably caused by nutrient limitation, especially nitrogen (Smith et al. 1980). High concentrations of combined nitrogen (ammonium, nitrite and nitrate) are found in estuarine waters (Smith et al. 1980, Keizer unpubl. data) but these are not readily available to high marsh plants because of the infrequency of flooding. Rates of nitrogen fixation are also low and can supply only a few percent of the total nitrogen requirements of marsh plants (Smith et al. 1979).

Nutrient limitation is less significant in low marsh because of the much greater frequency of flooding. However, the limiting effects of physical stress become more important. As elevation decreases the time of exposure to wave and current activity increases. Light limitation may also become important at the lowest elevations of Spartina alterniflora which can be flooded as much as 4 h per tide. Moving drift ice during the winter months may also limit the seaward growth of low marsh by damaging underground rhizomes.

Odum and Fanning (1973) postulated that tides provide an energy subsidy which increases saltmarsh production. Steever et al. (1976) have demonstrated a strong positive linear correlation between Spartina alterniflora production and tidal range, but they recognized that a point of diminishing returns is probably reached where the physical stress of higher tidal range outweighs the benefits. This is clearly the case for the lower elevation stands of S. alterniflora in Fundy marshes.

In conclusion, the frequency and duration of flooding play a paramount role in controlling the productivity of Fundy marshes. On high marsh where flooding is infrequent and brief, growth is limited primarily by a shortage of nutrients. At the lowest elevations of Spartina alterniflora, where flooding occurs twice daily for several hours, physical stress plays a key role. Optimal growth conditions occur in between, at and immediately below MHW.

Fate of Production

The fate of salt marsh production, both above-and belowground, is poorly understood and currently a topic of considerable scientific interest (for example Nixon 1979 and Marinucci 1982). While some saltmarshes are net consumers of material from tidal waters (for example Woodwell et al.

TABLE 7. Summary of low salt marsh production data (net above-general production). Numbers of regions indicate position in Fig. 1.

Region	Area of Low Marsh (ha x 10^3)	Annual Production (g C m^{-2} yr^{-1})	Estimated Total Annual Production (tonnes C yr^{-1} x 10^3)
Cumberland Basin (1)	0.76	215	1.6
Shepody Bay (2)	0.39[1]	215	0.8
Chignecto Bay (3)	0.11[1]	215	0.2
Cobequid Bay (4)	0.15	215	0.3
Minas Basin (5)	0.10	215	0.2
Southern Bight(6)	1.08	215	2.3
Inner Bay (7)	0.2[1]	215	0.4
Outer Bay (8)	0.2[1]	215	0.4

[1] estimated assuming 43% of total area is low marsh which is probably too high for the Outer Bay.

1977), all three production studies of Fundy marshes have demonstrated sizeable export of plant material to estuarine waters. Schwinghamer et al. (1983) have shown that saltmarsh detritus is widely distributed in the sediments and water column of Cumberland Basin. Most of the export appears to take place from low marsh areas where physical stress is greatest. A large portion of the aboveground production disappears by late fall and that present throughout the winter usually disappears by the following growing season. In contrast, high marsh appears to export very little of its production, in part because of infrequent and brief flooding. The biomass of dead material from previous year's growth often exceeds annual production and its rate of disappearance is probably controlled more by decomposition processes than export.

We conclude that because of high tidal energy, a large fraction of Fundy salt marsh production is exported and widely distributed throughout the local estuaries at the head of the Bay. The dynamics of this pool of organic matter and its importance in estuarine foodwebs are poorly understood and warrant further study in the Bay of Fundy. As high marshes appear to function largely as closed systems, only low marsh areas are used to calculate potential carbon supply to estuarine ecosystems (Table 7).

SEAWEED

Distribution and Area

Seaweeds are distributed along rocky shores on both sides of the open Bay of Fundy and in isolated patches in the upper reaches. Approximately 35% of the shoreline of the open Bay is entirely rock and, in addition, 55% of the remaining shoreline has some rock. The average width of the rocky shore is 40.7 m and the total length is about 1605 km. The total rocky area suitable for seaweed is about 1156 ha along the Nova Scotia Fundy coast and 2044 ha in New Brunswick, or a total of 3200 ha.

Structure and Composition

The floristics of Fundy seaweeds are relatively well documented (Edelstein et al. 1970, Wilson et al. 1979), and an extensive survey has been made of the distribution of species along vertical transects spaced around the Bay (Trick 1977, Smith 1978). The biomass is dominated by only a few species. Within the littoral zone, the predominant species are fucoids, especially *Ascophyllum nodosum*, with lesser amounts of *Fucus vesiculosus*, *F. edentatus* and *F. spiralis*. The extreme lower littoral and sublittoral zones are dominated by the kelps, *Laminaria digitata*, *L. longicruris*, *Alaria esculenta*, and *Agarum cribrosum*.

Biomass and Production

Production and biomass for the New Brunswick shore of the Bay of Fundy have been studied by Thomas (unpublished data). Biomass distributions as dry weight have been determined for over 30 locations from the United States border to Point Wolf. All collections or measurements were taken at a series of six tidal heights: 0, 20, 40, 60, 80, and 100% of mean tidal range (0=MLW, 100=MHW). Results are summarized in Table 8. Along the Nova Scotian coast of the Bay of Fundy, qualitative assessments, including perusal of aerial photographs, indicate a paucity of vegetation northeast of the Digby Neck area with the exception of sites where the flora is locally abundant (Bird and McLachlan, pers. comm.). Along the Digby Neck, there are significant stands of fucoids with up to 20 kg m^{-2} (dry) standing stock recorded. The overall estimates of biomass have been reported by Loucks Oceanology (1980) and are summarized in Table 9. Kelp densities are not high as there is a major limitation of suitable substrate (Tremblay and Chapman 1980).

The production studies of Thomas have focused on a primary field site at Musquash Head, New Brunswick (just west of Saint John). The area is typical in terms of community structure, biomass, zonation, slope and aspects. Production determinations were divided into emerged and submerged phases separately. Fucus spiralis dominated the 100% level and F. endentatus the 0% level with Ascophyllum nodosum the overall dominant.

Annual mean net production for submerged and emerged phases at each tidal level are summarized for the New Brunswick Shore in Table 10 and for all regions of the Bay of Fundy in Table 11. Using the mean net production figure of 845 g C m^{-2} y^{-1}, total anual production is estimated at 27 x 10^3 tonnes C in the Bay of Fundy. Gross macrophyte production amounts to 33 x 10^3 tonnes C annually which would include the loss of dissolved organic matter.

Several conclusions can be drawn from this study of seaweed production. The rocky intertidal zone of the Bay of Fundy is moderately productive and the bulk of the production takes place during the exposed phase because of light limitation when intertidal algae are submerged. Intertidal fucoid algae have significant net primary production at all temperatures from -10°C to 30°C and at all stages of dessication from 0% to 70%. The majority of production takes place in the middle of the intertidal zone between the tidal levels of 30 and 90% of mean tidal range, most by the knotted wrack, Ascophyllum nodosum.

Fate of Production

Much of the seaweed can be broken down into detritus and soluble organic material which can be utilized by organisms. Dadswell (pers comm.) suggests this occurs when seaweed, such as Ascophyllum, is sloughed off by tidal currents and washed ashore. At Musquash Head, Thomas and Page (1983) found that net production of Fucus edentatus during summer averaged 61 g m^{-2} day of which 52 g was retained as biomass with remainder exported as detached plants or dissolved organics. For material washed ashore there is active breakdown by amphipods and Diptera with further reworking by bacteria so that a humus-like substance containing feces and water soluable organics is produced. This material could eventually re-enter the water column through action of the tides.

TABLE 8. Mean dry weight biomass of seaweeds along the New Brunswick coast of the Bay of Fundy in 1979-1982 (g/m^2). (M. Thomas, unpublished data).

Tidal Level	Total Flora	Fucoids
0%	248	129
20%	1423	1264
40%	2520	2195
60%	1892	1743
80%	2304	2276
100%	240	240

TABLE 9. Biomass of fucoids along the Nova Scotia shore of the Bay of Fundy. (Loucks Oceanology, 1980)

Site	Distance (km)	Area (ha)	Range tonne/ha (wet wt)	Total biomass tonnes wet wt.)
Pond Cove- Digby Gut	110	365	45-125	>38,000
Digby Gut- Delap Cove	16	40	45-125	> 4,500
Delap Cove- Scotsman Bay	52	610	18-87	>31,000

Estimated average = 75,000 tonne wet weight

Standard error of uncertainties = 50% (assume for lack of further informaion)

Uncertainty for temporal variability = 20%

Resultant ± standard error = 75,000 tonnes (1±0.54)

TABLE 10. Summary of yearly net seaweed production on rocky shores along the New Brunswick coast of the Bay of Fundy (g C m^{-2} yr^{-1})

Tidal Level	Submerged Phase	Emerged Phase	Total
0%	261	38	299
20%	19	411	43
40%	317	996	1313
60%	196	895	1091
80%	347	1123	1497
100%	75	364	438
		Mean	845

TABLE 11. Summary of seaweed net production data. (Average production rate calculated in Table 10). Numbers of regions indicate position in Fig. 1.

Region	Rocky Intertidal Area (ha)	Net Annual Production ($g\ C\ m^{-2}\ yr^{-1}$)	Estimated Total Annual Production ($tonnes\ C\ yr^{-1} x10^{3}$)
Cumberland Basin (1)	Trace	-	-
Shepody Bay (2)	Trace	-	-
Chignecto Bay (3)	Trace	-	-
Cobequid Bay (4)	Trace	-	-
Minas Basin (5)	Trace	-	-
Southern Bight(6)	Trace	-	-
Inner Bay (7)	1600	845	13.5
Outer Bay (8)	1600	845	13.5

SUMMARY

Production estimates of each plant type are summarized in Table 12 for all regions in the Bay of Fundy. Total annual production for the entire Bay is 1124 x 10^3 tonnes C. Of this about 96% is derived from phytoplankton with seaweed, benthic microalgae, and salt marsh responsible for about 2%, 1% and 0.6% of the total production respectively. The dominance of phytoplankton production reflects the large area of water compared to other habitats as well as the very high phytoplankton productivity rates in the less turbid Outer Bay. Regionally, the Outer Bay which has the greatest area provides about 85% of the total production followed by the Inner Bay which provides about 12%. All other regions account for 1% or less of the total annual production for the Bay of Fundy, largely because of their relatively small areas (Fig. 1).

When production is expressed as an average on a unit area basis (Table 12) it is clear that primary production in the upper reaches, such as the Cumberland Basin (44 C m^{-2} y) and the Southern Bight (41 g C m^{-2} y^{-1}), is moderate despite high energy and light limitation. Approximately half of the production in the upper reaches stems from benthic microalgae because of the extensive sand- and mudflats. Extensive salt marshes, especially in the Cumberland Basin and Southern Bight, are also important local components of the total production. These turbid upper regions are much more productive than was originally predicted and supply organic material to support large populations of invertebrates, fish, and birds.

ACKNOWLEDGMENTS

We thank Peter Cranford for the determination of areas used in our calculations as well as the Canadian Wildlife Service, Sackville, N.B., for providing saltmarsh area data. We are also grateful to Andy Palmer for diatom identificiation.

REFERENCES

Amos, C.L. 1978. The post glacial evolution of the Minas Basin, N.S. A sedimentological interpretation. J. Sed. Petrol. 48: 965-982.

Cadée, G.C., and J. Hegeman. 1974a. Primary production of phytoplankton in the Dutch Wadden Sea. Neth. J. Sea Res. 8: 240-259.

Cadée, G.C., and Hegeman. 1974b. Primary production of the benthic microflora living on tidal flats in the Dutch Wadden Sea. Neth. J. Sea. Res. 8: 260-291.

Cadée, G.C. and J. Hegeman. 1977. Distribution of primary production of the benthic microflora and accumulation of organic matter on a tidal flat area, Balgzand, Dutch Wadden Sea. Neth. J. Sea Res. 11: 24-41.

TABLE 12. Summary of annual primary production estimates in various regions of the Bay of Fundy. Gross production is given for benthic microalgae while net values are given for the other three primary producers. Numbers of regions indicate position in Fig. 1.

Region	Tonnes C y^{-1} x 10^3					Average
	Phytoplankton	Marsh	Benthic Microalgae	Seaweeds	Total	(g C m^{-2} y^{-1})
Cumberland Basin (1)	1.2(23%)	1.6(31%)	2.4(46%)	-	5.2 (0.5%)	44
Shepody Bay (2)	1.7(32%)	0.8(15%)	2.8(53%)	-	5.3 (0.5%)	34
Chignecto Bay (3)	4.2(92%)	0.2(5%)	0.2(4%)	-	4.6 (0.4%)	16
Cobequid Bay (4)	3.6(57%)	0.3 (5%)	2.4(38%)	-	6.3 (0.6%)	21
Minas Basin (5)	10.3(91%)	0.2 (2%)	0.8(7%)	-	11.3 (1.0%)	17
Southern Bight (6)	2.4(27%)	2.3(26%)	4.1(47%)	-	8.8 (0.8%)	41
Inner Bay (2)	125.7(90%)	0.4(0.3%)	0.4(0.3%)	13.5(10%)	140.0(12.5%)	30
Outer Bay (8)	927.8(98%)	0.4(0.04%)	0.4(0.04%)	13.5(2%)	942.1(84.9%)	135
TOTAL	1076.9(95.8%)	6.2(0.6%)	13.5(1.2%)	27.0(2.4%)	1123.6	

Cammen, L. M., and J.A. Walker. 1982. Distribution and activity of attached and free-living suspended bacteria in the Bay of Fundy. Can. J. Fish. Aquat. Sci., 39: 1655-1663.

Davidson, V.M. 1934. Fluctuations in the abundance of planktonic diatoms in the Passamaquoddy region, New Brunswick, from 1924 to 1931. Contr. Can. Biol., NS; 8: 359-407.

Edelstein, T., L.C-M. Chen, and J. McLachlan. 1970. Investigations of the marine algae of Nova Scotia. VIII. The flora of Digby Neck, Bay of Fundy. Can. J. Bot. 48: 621-629.

Ganong, W.F. 1903. The vegetation of the Bay of Fundy salt and diked marshes: an ecological study. Bot. Gazette 36: 161-186.

Gran, H.H., and T. Braarud. 1935. A quantitative study of the phytoplankton in the Bay of Fundy and the Gulf of Maine (including observations on hydrography, chemistry and turbidity). J. Biol. Bd. Can., 1: 279-432.

Hargrave, B.T., N. J. Prouse, G.A. Phillips, and P.A. Neame. 1983. Primary production and respiration in pelagic and benthic communities at two intertidal sites in the Upper Bay of Fundy. Can. J. Fish Aquat. Sci. 40 (Suppl. 1): 229-243.

Hatcher, B.G., and K.H. Mann. 1975. Above-ground production of marsh cordgrass (Spartina alterniflora) near the northern end of its range. J. Fish. Res. Bd. Can. 32: 83-87.

Keizer, P.D., D.C. Gordon Jr. and E.R. Hayes. 1983. A brief review of recent chemical research in the Bay of Fundy. In this report.

Loucks Oceanology. 1980. A literature and photoassessment of the marine plant biomass of eastern Canada. Unpublished contract report to the National Research Council, Halifax.

Marinucci, A.C. 1982. Trophic importance of Spartina alterniflora production and decomposition to the marsh-estuarine ecosystem. Biol. Conservation 22: 35-58.

Marra, J. 1978a. Effect of short term variations in light intensity on photosynthesis of a marine phytoplankter: a laboratory simulation study. Mar. Biol. 46: 191-202.

Marra, J. 1978b. Phytoplankton photosynthesic response to vertical movement in the mixed layer. Mar. Biol. 46: 203-208.

Marshall, H.G. 1978. Phytoplankton distribution along the eastern coast of the U.S.A. Part II. Seasonal assemblages north of Cape Hatteras, North Carolina. Mar. Biol. 45: 203-208.

Morantz, D.L. 1976. Productivity and export from a marsh with a 15 m tidal range and the effect of impoundment of selected areas. M.Sc. thesis, Dalhousie Univ., 77 p.

Morris, I., C.M. Yentsch, and C.S. Yentsch. 1971. Relationship between light carbon dioxide fixation and dark carbon dioxide fixation by marine algae. Limnol. Oceanogr., 16: 854-858.

Nixon, S.W. 1979. Between coastal marshes and coastal waters - a review of twenty years of speculation and research on the role of salt-marshes in estuarine productivity and water chemistry. In: P. Hamilton and K.B. MacDonald, eds., Estuarine and wetland processes, Plenum, pp. 437-526.

Odum, E.P. and M.E. Fanning. 1973. Comparison of the productivity of Spartina alterniflora and Spartina cynosuroids in Georgia coastal marshes. Bull. Georgia Acad. Science 31: 1-12.

Patriquin, D.C. 1981. The general biology of salt marshes. In: A. Hatcher and D.G. Patriquin, eds., Salt marshes in Nova Scotia, Institute for Resource and Environmental Studies, Dalhousie Univ. pp. 4-27.

Pearce, P.A., and A.D. Smith. 1973. The potential influence on waterfowl of port and tidal power development in the Bay of Fundy. Can. Wild. Ser. Rep. Ser. No. 29, pp. 91-100.

Petersen, G.H. 1979. On the analysis of dark fixation in primary production computations. J. Cons. Int. Explor. Mer, 38: 326-330.

Platt, T. and B. Irwin. 1968. Primary production measurements in St. Margaret's Bay, 1967. Fish. Res. Bd. Can. Tech. Rept. No. 77, 123 p.

Platt, T. 1971. The annual production by phytoplankton in St. Margaret's Bay, Nova Scotia. J. Cons. Int. Explor. Mer, 33: 324-333.

Platt, T., B. Irwin, and D.V. Subba Rao. 1973. Primary productivity and nutrient measurements on the spring phytoplankton bloom in Bedford Basin, 1971. Fish. Res. Bd. Can. Tech. Rept. No. 423, 44 p.

Prouse, N.J. 1983. Primary production measurements in the Bay of Fundy from March 1979 to November 1980. Can. Tech. Rept. Fish. Aquat. Sci. No. 1167, 82 p.

Redfield, A.C. 1972. Development of a New England saltmarsh. Ecol. Mono. 42: 201-237.

Schwinghamer, P. 1981. Size distribution of benthic organisms in the Bay of Fundy, Canada. Ph. D. thesis, Dalhousie University, 122 p.

Schwinghamer, P., F.C. Tan, and D.C. Gordon, Jr. 1983. Stable carbon isotope studies on the Pecks Cove mudflat ecosystem in the Cumberland Basin, Bay of Fundy. Can. J. Fish. Aquat. Sci., 40 (Suppl. 1): 262-272.

Seki, H. 1968. Relationship between production and mineralization of organic matter in Aburatsubo Inlet, Japan. J. Fish. Res. Bd. Can. 25: 625-637.

Sinclair, M. 1978. Summer phytoplankton variability in the lower St. Lawrence Estuary. J. Fish. Res. Bd. Can. 35: 1171-1185.

Smith, D. 1978. Productivity and nitrogen flow in a Minas Basin saltmarsh and distribution of macroalgae in the Bay of Fundy (New Brunswick shore). Project 16-01-001, Federal Youth Summer Job Corps. National Research Council of Canada, Halifax.

Smith, D.L., C.J. Bird, K.D. Lynch, and J. McLachlan. 1980. Angiosperm productivity in two saltmarshes of Minas Basin. Proc. N.S. Inst. Sci. 30: 109-118.

Smith, D.L., J. McLachlan, and D.G. Patriquin. 1979. Nitrogen fixation as determined by acetylene reduction in two saltmarshes of Minas Basin. Proc. N.S. Inst. Sci. 29: 381-392.

Steever, E.Z., R.S. Warren, and W.A. Niering. 1976. Tidal energy subsidy and standing crop production of Spartina alterniflora. Est. Coast Mar. Sci. 4: 473-478.

Strickland, J.D.H., and T.R. Parsons. 1968. A practical handbook of sea-water analysis. Fish. Res. Bd. Can. Bull. No. 167, 311 p.

Subba Rao, D.V. 1975. Phytoplankton production, nutrients and density structure in the shelf area of Nova Scotia and Georges Bank during August, 1974. Tech. Rept Can. Fish. Mar. Ser. No. 524, 272 p.

Taguchi, S., and T. Platt. 1977. Assimilation of $^{14}CO_2$ in the dark compared to phytoplankton production in a small coastal inlet. Est. Coast. Mar. Sci., 5: 679-684.

Thomas, M.L.H., and F.H. Page. 1983. Herbivory by the gastropod Lacuna vincta in the lower intertidal area at Musquash Head, New Brunswick, Canada. J. Mar. Biol. Assoc. U.K., in press.

Tremblay, C., and A.R.O. Chapman. 1980. The local occurrence of Agarum cribrosum in relation to the presence or absence of its competitors and predators. Proc. N.S. Inst. Sci. 30: 165-170.

Trick, C. 1977. Environmental study of Bay of Fundy and waters of the Fundy approaches (Yarmouth to Cumberland Countries, Nova Scotia). Project 03D-001, Federal Youth Summer Job Corps. National Research Council of Canada, Halifax.

Wilson, J.S., C.J. Bird, J. McLachlan, and A.R.A. Taylor. 1979. An annotated checklist and distribution of benthic marine algae of the Bay of Fundy. Memorial Univ. Nfld. Occas. Pap. Biol. 2: 1-65.

Woodwell, G.M., D.E. Whitney, C.A.S. Hall, and R.A. Houghton. 1977. The Flax Pond ecosystem study: exchanges of carbon in water between a salt marsh and Long Island Sound. Limnol. Oceanogr. 22: 833-838.

QUESTIONS AND COMMENTS

G. Brown: When is the greatest influx of detritus from the saltmarshes?

N. Prouse: Our experience in Cumberland Basin suggests during the summer months.

G. Brown: Is there a direct relationship between phytoplankton production in the outer and inner parts of the Bay? Can production in the outer Bay be imported to the inner Bay?

N. Prouse: There might be some relationship dependent upon the general circulation pattern in the Bay. Some typically oceanic phytoplankton species do reach the inner parts of the Bay. I think that most of the secondary production in the upper part of the Bay results from *in situ* primary production. Import is unlikely but export may occur.

C. Amos: Are the production estimates you give typical of other similar estuaries in the world and of what significance are your observations?

N. Prouse: Yes, they are typical of other areas with turbid water and extensive intertidal sediments such as the Wadden Sea. Phytoplankton and seaweed production values seem typical. However, salt marsh production is somewhat lower than found along the Atlantic coast. The significance is that as the water gets more turbid, there is less phytoplankton production. The Bay of Fundy is rather unique because of its great tidal amplitude which produces vast areas of mudflat which are ideal for either benthic microalgae or saltmarsh production. These can contribute a lot of production and help offset the decline in phytoplankton production.

D. Gordon: Comparing our knowledge now to what it was six years ago, it is clear that phytoplankton and saltmarsh production are important production sources in the upper reaches. At the Acadia Workshop they were thought to be very minor and the consensus was that benthic microalgal production dominated the system. It is important, contributing about 50% of the total production, but these other sources are important too. We have learned that the production is more diversified than earlier thought.

A Review of Subtidal Benthic Ecological Research in the Bay of Fundy: 1976-1982

David J. Wildish

Fisheries and Environmental Sciences
Department of Fisheries and Oceans
Biological Station, St. Andrews
New Brunswick Canada E0G 2X0

ABSTRACT

A brief review of benthic ecological research in the Bay of Fundy in the period 1976-1982 is presented.

Key words: subtidal benthos, Bay of Fundy, production

RÉSUMÉ

On présente un bref examen critique des recherches en écologie benthique effectuées dans la baie de Fundy pendant la période de 1976 à 1982.

INTRODUCTION

The possibility that a large tidal power project could start in the Bay of Fundy stimulated an interest in predicting what kinds of effects might result from such development. The major question, as far as subtidal benthic animals are concerned, is how the changed environment will affect benthic production (Wildish 1977a) and the transfer of this production to the tertiary trophic level.

It should be remembered that there are a number of additional contemporary practical reasons (Wildish 1977b) for studying the benthos usually carried out by different, isolated, groups and which will dictate the direction such studies take. The groups include:

- recent sedimentary geologists who study benthic/sedimentary interactions in order to understand the process of sediment burial and thus the stratigraphic record;

- fisheries biologists who study benthic production because it is a major contributor to commercial groundfish production;

- and environmental biologists who utilize benthic distribution patterns to indicate the spatial extent of municipal or industrial pollution, dredging and dumping activity.

BENTHIC DISTRIBUTION AND CONTROLLING FACTORS

Knowledge of the taxonomy and geographic distribution of benthos in the Bay of Fundy is still far from complete although most of the papers appearing in the review period concern this subject. Taxonomic and physical features of some estuaries have been described (Metcalfe et al. 1976, Wildish and Kristmanson 1979, Wildish 1983) as well as the soft-sediment macrofauna of the lower Bay (Peer et al. 1980) and upper Bay (Wildish et al. 1983). The epifauna of hard bottoms has been studied in the Western Isles at the mouth of the Bay of Fundy (Noble et al. 1976, Page 1981, Logan et al. 1983).

The hard-bottom benthic fauna down to Scuba diving depth (40 m) has been subjectively described as consisting of two major biotic communities:

- *Terebratulina septentrionalis* community
- Crustose coralline algae community

by Logan et al. (1983). An objective analysis of epifaunal data down to a depth of 26 m yielded five major clusters (Page et al. in prep.):

- shallow zone
  - crustose coralline algae
  - *Petrocelis middendorfi*
- mid-depth
  - upward facing surfaces of crustose coralline algae
  - shaded, steeply inclined faces consisting of a *Terebratulina*-dominated communmity
- deep zone
  - *Terebratulina* community, with the greatest diversity of macrofauna

The soft-bottom benthic macrofauna has been studied at all depths (to >200 m) in the Bay of Fundy. In contrast to the hard-bottom macrofauna, soft sediments of the lower Bay have been described on a functional basis utilizing the trophic group concept (Wildish and Peer 1983). The reason for this lies in the belief that the community concept is of dubious value in benthic work (Wildish 1977). A similar analysis of subtidal benthic data in the upper Bay, Chignecto Bay and Minas Basin, is being prepared (Wildish et al. 1983).

One interesting feature of the soft sediment work is that a benthic assemblage similar to the *Terebratulina septentrionalis* community of Logan et al. (1983) is present over nearly one-third of the southeastern corner of the lower Bay. In this region the sediment is a poorly sorted mixture inclusive of sand, silt/clay, boulders, cobbles, and pebbles described by Fader et al. (1977) as Scotian Shelf drift. This sediment is preglacial and the oldest of three major types present and may be regarded as transitional between hard and soft bottoms. Its presence renders a clear distinction between hard- and soft-bottom macrofaunal associations as problematical to define.

A satisfactory conceptual basis from which to explain subtidal macrofaunal composition biomass and productivity, free of tautology and useful to the aims given in the Introduction, has been suggested by Wildish

(1977). Included in the multiple limiting factor theory are physical factors, e.g. salinity, temperature, current speed, oxygen availability, sediments and water/sediment exchange phenomena and biotic factors, e.g. food supply, colonizing larval supply, and interspecific competition.

Current speed and food supply are the only factors currently being studied experimentally in testing the hypothesis of Wildish and Kristmanson (1979) that they control productivity of suspension feeders. Unpublished experiments already completed confirm the presence of a seston depleted layer downstream from a mussel bed and ongoing experiments are designed to derive a relationship between the turbulent supply of seston and mussel growth. Circumstantial evidence (Wildish et al. 1981) also supports the idea that the turbulent supply of seston (X) controls suspension feeder production (Y) because these are related by the relationship:

$$\text{Log } Y = 0.0124X + 0.0163$$

with a correlation coefficient of 0.86 which is significant at $P > 95\%$. Suspension feeder production at some stations in the Bay does not obey this relationship (Wildish et al. 1981) and is "impoverished" due to a physical limitation linked to sediment erosion/deposition cycles. It has been suggested that it is repeated sediment erosion itself which prevents larval settling or adult growth, the direct effect of high current speeds, or the effect of high concentrations of inorganic materials suspended in water (Wildish and Kristmanson 1979).

BENTHIC PRODUCTION

Crude estimates of benthic production based on wet biomass values times an empirically derived P:B ratio have been made for ≈300 soft-sediment stations in the Bay. The results will be reported separately as maps of production for the lower (Wildish and Peer 1983) and upper Bay (Wildish and Peer, in prep.). The P:B ratios used in these analyses depend on life span in years (Robertson method) or mass in Kcal (Banse and Mosher method).

An independent estimate of crude benthic production has been made at 15 subtidal stations in the lower Bay using the novel method introduced by Schwinghamer (1981). The results of this analysis are in essential agreement with the findings of Wildish and Peer (1983).

As a check on the empirically derived P:B ratios, a more detailed study of production by some Amphipoda was attempted. *Pontoporeia femorata*, *Leptocheirus pinguis*, and *Casco bigelowi* in the Digdequash estuary could not be assessed for production purposes because of emigration from, and immigration to, the sampling location during the 2-yr sampling period (Wildish 1980, Wildish and Peer 1981). However, a more stable deep population at 80 m in the lower Bay of Fundy yielded four species for which production and P:B values have been calculated (Wildish, unpubl. data) including: *Haploops fundiensis*, *Harpinia propingua*, *Photis reinhardi*, and *Casco bigelowi*. The results are in general agreement with the empirically derived values of P:B calculated by Robertson or Banse and Mosher methods.

No production data are available for hard-bottom benthos.

THE WORM'S EYE VIEW: ON BEING PREYED UPON

A prospectus for a study of the relationship between benthic prey and their predators which are chiefly demersal fish might include:

- predator stomach analysis
- prey mortality curves
- adaptations of the prey to avoid predators involving color and vision, smell, and cryptic odors or altered prey reproductive strategies
- energy exchange between the prey and predator

By these criteria, such studies in the Bay of Fundy are woefully inadequate with a little information on only the first two categories.

A study of benthic food resources utilized by five species of demersal fish has been made by MacDonald (1982). The predator species studied included cod, ocean pout, winter flounder, and American plaice. MacDonald et al. (1982) showed experimentally that these species digest different species of food items at different rates and that the evacution rate of different prey should be considered in estimating daily rations from fish sampled in field. Utilized this method daily, feeding chronology and ration calculations were made from a field experiment (MacDonald and Waiwood, in prep.) with maximum rations (% body wt day^{-1}) found as follows: winter flounder (1.65), cod (1.66), ocean pout (1.25), and plaice (0.69). In laboratory experiments, Tyler and Dunn (1976) showed that the maintenance ration for winter flounder was 7.9 cal g^{-1} day^{-1}. The gross conversion efficiency depended on ration varying from 1.16%

Indirect life-history evidence (Wildish, unpubl. data) shows that <u>Haploops fundiensis</u> is a remarkable biannual ampeliscid with little mortality occurring early in the life history in contrast to most other well known amphipods where considerable mortality occurs in the early juvenile stages (Wildish 1982).

NEW METHODS

Schwinghamer (1981) has examined the size distributions of micro-organisms, microfauna, and macrofauna and found that when biomass concentration is expressed as a $\log_2$ function of organism size (equivalent spherical diameter) a characteristic spectrum emerges. Biomass is determined as volume displacement (V) of individual specimens or groups of similarly sized individuals of the same species. The organism volumes are then converted to the equivalent spherical diameter (D) by:

$$D = 2 \sqrt[3]{\frac{3V}{4\Pi}}$$

and the total biomass for the size-class expressed as cm^3 m^{-2} sediment surface area. One useful property of the spectrum is that it can be used to

(1977). Included in the multiple limiting factor theory are physical factors, e.g. salinity, temperature, current speed, oxygen availability, sediments and water/sediment exchange phenomena and biotic factors, e.g. food supply, colonizing larval supply, and interspecific competition.

Current speed and food supply are the only factors currently being studied experimentally in testing the hypothesis of Wildish and Kristmanson (1979) that they control productivity of suspension feeders. Unpublished experiments already completed confirm the presence of a seston depleted layer downstream from a mussel bed and ongoing experiments are designed to derive a relationship between the turbulent supply of seston and mussel growth. Circumstantial evidence (Wildish et al. 1981) also supports the idea that the turbulent supply of seston (X) controls suspension feeder production (Y) because these are related by the relationship:

$$\text{Log } Y = 0.0124X + 0.0163$$

with a correlation coefficient of 0.86 which is significant at $P > 95\%$. Suspension feeder production at some stations in the Bay does not obey this relationship (Wildish et al. 1981) and is "impoverished" due to a physical limitation linked to sediment erosion/deposition cycles. It has been suggested that it is repeated sediment erosion itself which prevents larval settling or adult growth, the direct effect of high current speeds, or the effect of high concentrations of inorganic materials suspended in water (Wildish and Kristmanson 1979).

BENTHIC PRODUCTION

Crude estimates of benthic production based on wet biomass values times an empirically derived P:B ratio have been made for ≈300 soft-sediment stations in the Bay. The results will be reported separately as maps of production for the lower (Wildish and Peer 1983) and upper Bay (Wildish and Peer, in prep.). The P:B ratios used in these analyses depend on life span in years (Robertson method) or mass in Kcal (Banse and Mosher method).

An independent estimate of crude benthic production has been made at 15 subtidal stations in the lower Bay using the novel method introduced by Schwinghamer (1981). The results of this analysis are in essential agreement with the findings of Wildish and Peer (1983).

As a check on the empirically derived P:B ratios, a more detailed study of production by some Amphipoda was attempted. *Pontoporeia femorata*, *Leptocheirus pinguis*, and *Casco bigelowi* in the Digdequash estuary could not be assessed for production purposes because of emigration from, and immigration to, the sampling location during the 2-yr sampling period (Wildish 1980, Wildish and Peer 1981). However, a more stable deep population at 80 m in the lower Bay of Fundy yielded four species for which production and P:B values have been calculated (Wildish, unpubl. data) including: *Haploops fundiensis*, *Harpinia propingua*, *Photis reinhardi*, and *Casco bigelowi*. The results are in general agreement with the empirically derived values of P:B calculated by Robertson or Banse and Mosher methods.

No production data are available for hard-bottom benthos.

THE WORM'S EYE VIEW: ON BEING PREYED UPON

A prospectus for a study of the relationship between benthic prey and their predators which are chiefly demersal fish might include:

- predator stomach analysis
- prey mortality curves
- adaptations of the prey to avoid predators involving color and vision, smell, and cryptic odors or altered prey reproductive strategies
- energy exchange between the prey and predator

By these criteria, such studies in the Bay of Fundy are woefully inadequate with a little information on only the first two categories.

A study of benthic food resources utilized by five species of demersal fish has been made by MacDonald (1982). The predator species studied included cod, ocean pout, winter flounder, and American plaice. MacDonald et al. (1982) showed experimentally that these species digest different species of food items at different rates and that the evacution rate of different prey should be considered in estimating daily rations from fish sampled in field. Utilized this method daily, feeding chronology and ration calculations were made from a field experiment (MacDonald and Waiwood, in prep.) with maximum rations (% body wt day^{-1}) found as follows: winter flounder (1.65), cod (1.66), ocean pout (1.25), and plaice (0.69). In laboratory experiments, Tyler and Dunn (1976) showed that the maintenance ration for winter flounder was 7.9 cal g^{-1} day^{-1}. The gross conversion efficiency depended on ration varying from 1.16%

Indirect life-history evidence (Wildish, unpubl. data) shows that Haploops fundiensis is a remarkable biannual ampeliscid with little mortality occurring early in the life history in contrast to most other well known amphipods where considerable mortality occurs in the early juvenile stages (Wildish 1982).

NEW METHODS

Schwinghamer (1981) has examined the size distributions of microorganisms, microfauna, and macrofauna and found that when biomass concentration is expressed as a $\log_2$ function of organism size (equivalent spherical diameter) a characteristic spectrum emerges. Biomass is determined as volume displacement (V) of individual specimens or groups of similarly sized individuals of the same species. The organism volumes are then converted to the equivalent spherical diameter (D) by:

$$D = 2 \sqrt[3]{\frac{3V}{4\Pi}}$$

and the total biomass for the size-class expressed as cm^3 m^{-2} sediment surface area. One useful property of the spectrum is that it can be used to determine productivity by multiplying the biomass for a given section of the spectrum by the appropriate Banse and Mosher P:B ratio. Comparisons between the two methods used in the Bay are facilitated by the assumption that 1 cm^3 = 1 g wet wt and, as mentioned, suggest concordance in the results obtained.

Both the size-class method of Schwinghamer (1981) and the conventional method used by Wildish and Peer (1982) are recognized to be crude attempts involving numerous approximations and errors and for that reason more refined measures on a single population of a given species of amphipod have been attempted as a check. Two minor technique changes, introduction of the size frequency method for marine amphipods where cohorts are not distinguishable in size/frequency data and a back-calculation method to overcome sampling bias of early life-history stages of amphipods,have been suggested (Wildish and Peer 1981). The importance of knowing the life-history details of a given population (Wildish 1982) is emphasized when individual population production estimates are to be made.

New sampling techniques for the study of Bay of Fundy benthos include the UNB benthic camera and MEL large modified Van Veen grab of 0.5 m^2, neither of which have yet had time to make their mark on benthic studies. Further improvements in field and experimental methods are of critical importance to the future development of benthic work.

New developments in the taxonomy of Bay of Fundy benthos include keys to adult (Appy et al. 1980) as well as larval polychaetes (Lacalli 1980) and a checklist for the Minas Basin and Channel (Bromley 1979). New species described from the Bay include the amphipods *Haploops fundiensis* (Wildish and Dickinson 1982), a new species of *Melita* (Brunel and Dadswell, in prep.), and a new polychaete *Aglophemus neotenus* (Noyes 1980).

CONCLUSIONS

As found earlier in a general review of benthic studies (Hargrave and Levings 1975) on the Canadian Atlantic Coast, benthic work is still in its infancy in 1982 in the Bay of Fundy.

With the available evidence at hand can we answer the question regarding the environmental effects of a tidal barrage on benthic production? The answer is a qualified yes. Tidal current speeds resulting from barrage construction can be predicted from Greenberg's (1979) model and this parameter can be used to predict the suspension feeder production expected at a given location from the relationship derived from these two parameters. A difficulty remains in that suspension feeding is known to be a ramp function of current speed and the exact limiting factor in tidally impoverished areas is still unknown. Secondly, the relationship applies only to suspension feeders and not deposit feeders which are the other major trophic group present. The factors controlling deposit feeding production remain conjectural.

There is little information regarding the transfer of benthic production to demersal fish although some guesses about this have been made (Wildish and Peer 1982). Only 11.7% of total lower Bay benthic production is considered as available to demersal fishes such as cod, haddock and pollock as a food resource. A calculated transfer exchange between the benthos and dermersal fish yields a value of 14%.

One other possibility resulting from changed tidal dynamics is the redistribution of resting cysts of red-tide organisms away from the present "sediment traps" (LaHave clay in the southwest corner of the Bay). This might result in large toxic dinoflagellate blooms (Reid 1980) in areas presently free of paralytic shellfish poisoning.

REFERENCES

Appy, T.D., L.E. Linkletter and M.J. Dadswell. 1980. A guide to the marine flora and fauna of the Bay of Fundy: Annelida: Polychaeta. Fish. Mar. Serv. Tech. Rep. No. 920, 124 p.

Bromley, J.E.C. 1979. A preliminary check list of marine fauna of Minas Basin and Minas Channel. Proc. N.S. Inst. Sci. 29: 517-541.

Fader, G.B., L.H. King and B. MacLean. 1977. Surficial geology of the eastern Gulf of Maine and Bay of Fundy. Geol. Survey Can. Mar. Sci. Paper No. 19.

Greenberg, D.A. 1979. A numerical model investigation of tidal phenomena in the Bay of Fundy and Gulf of Maine. Marine Geodesy 2: 161-187.

Hargrave, B.T. and C.D. Levings. 1975. A prognosis for Canadian benthic biological oceanography. J. Fish. Res. Board Can. 32: 2268-2275.

Lacalli, T.C. 1980. A guide to the marine flora and fauna of the Bay of Fundy: polychaete larvae from Passamaquoddy Bay. Can. Tech. Rep. Fish. Aquat. Sci. No. 940, 27 p.

Logan, A., A.A. MacKay and J.P.A. Noble. 1983. Sublittoral hard substrates. In: M.L.H. Thomas ed. Marine and coastal systems of the Quoddy Region, New Brunswick. Can. Spec. Publ. Fish. Aquat. Sci. No. 64, pp. 119-139.

MacDonald, J.S., K.G. Waiwood and R.H. Green. 1982. Rates of digestion of different prey in Atlantic cod (Gadus morhua), ocean pout (Macrozoarces americanus), winter flounder (Pseudopleuronectes americanus), and American plaice (Hippoglossoides platessoides). Can. J. Fish. Aquat. Sci. 39: 651-659.

Metcalfe, C.D., M.J. Dadswell, C.F. Gillis and M.L.H. Thomas. 1976. Physical, chemical, and biological parameters of the Saint John River estuary, New Brunswick, Canada. Fish. Mar. Serv. Tech. Rep. No. 688, 42 p.

determine productivity by multiplying the biomass for a given section of the spectrum by the appropriate Banse and Mosher P:B ratio. Comparisons between the two methods used in the Bay are facilitated by the assumption that 1 cm^3 = 1 g wet wt and, as mentioned, suggest concordance in the results obtained.

Both the size-class method of Schwinghamer (1981) and the conventional method used by Wildish and Peer (1982) are recognized to be crude attempts involving numerous approximations and errors and for that reason more refined measures on a single population of a given species of amphipod have been attempted as a check. Two minor technique changes, introduction of the size frequency method for marine amphipods where cohorts are not distinguishable in size/frequency data and a back-calculation method to overcome sampling bias of early life-history stages of amphipods,have been suggested (Wildish and Peer 1981). The importance of knowing the life-history details of a given population (Wildish 1982) is emphasized when individual population production estimates are to be made.

New sampling techniques for the study of Bay of Fundy benthos include the UNB benthic camera and MEL large modified Van Veen grab of 0.5 m^2, neither of which have yet had time to make their mark on benthic studies. Further improvements in field and experimental methods are of critical importance to the future development of benthic work.

New developments in the taxonomy of Bay of Fundy benthos include keys to adult (Appy et al. 1980) as well as larval polychaetes (Lacalli 1980) and a checklist for the Minas Basin and Channel (Bromley 1979). New species described from the Bay include the amphipods Haploops fundiensis (Wildish and Dickinson 1982), a new species of Melita (Brunel and Dadswell, in prep.), and a new polychaete Aglophemus neotenus (Noyes 1980).

CONCLUSIONS

As found earlier in a general review of benthic studies (Hargrave and Levings 1975) on the Canadian Atlantic Coast, benthic work is still in its infancy in 1982 in the Bay of Fundy.

With the available evidence at hand can we answer the question regarding the environmental effects of a tidal barrage on benthic production? The answer is a qualified yes. Tidal current speeds resulting from barrage construction can be predicted from Greenberg's (1979) model and this parameter can be used to predict the suspension feeder production expected at a given location from the relationship derived from these two parameters. A difficulty remains in that suspension feeding is known to be a ramp function of current speed and the exact limiting factor in tidally impoverished areas is still unknown. Secondly, the relationship applies only to suspension feeders and not deposit feeders which are the other major trophic group present. The factors controlling deposit feeding production remain conjectural.

There is little information regarding the transfer of benthic

Noble, J.P.A. and A. Logan. 1981. Single frequency distributions and taphonomy of brachipods: a recent model. Palaeogeogr. Palaeoclimatol. Palaeoecol. 36: 87-105.

Noble, J.P.A., A. Logan and G.R. Webb. 1976. The recent Terebratulina community in the rocky subtidal zone of the Bay of Fundy, Canada. Lethaia 9: 1-17.

Noyes, G.S. 1980. The biology of Aglaophamus neotenus (Polychaeta: Nephthyidae), a new species from Maine and Canada. Biol. Bull. 158: 103-117.

Page, F.H. 1981. Structure of sublittoral hard-bottom benthic communities in the Quoddy Region, Bay of Fundy. M.Sc. Thesis, University of New Brunswick.

Peer, D., D.J. Wildish, A.J. Wilson, J. Hines and M. Dadswell. 1980. Sublittoral macro-infauna of the lower Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. No. 981, 74 p.

Reid, P.C. 1980. Toxic dinoflagellates and tidal power generation in the Bay of Fundy, Canada. Mar. Poll. Bull. 11: 47-51.

Schwinghamer, P. 1981. Size distributions of benthic organisms in the Bay of Fundy, Canada. Ph.D. thesis, Dalhousie University, 122 p.

Schwinghamer, P. 1981. Characteristic size distributions of integral benthic communities. Can. J. Fish. Aquat. Sci. 38: 1255-1263.

Tyler, A.V. and R.S. Dunn. 1976. Ration growth and measures of somatic organ condition in relation to meal frequency in winter flounder (Pseudopleuronectes americanus) with hypotheses regarding population homeostasis. J. Fish. Res. Board Can. 33: 63-75.

Webb, C.D., A. Logan and J.P.H. Noble. 1976. Occurrence and significance of brooded larva in a recent brachipod, Bay of Fundy, Canada. J. Paleontol. 50: 869-871.

Wildish, D.J. 1977a. The marine and estuarine sublittoral benthos of the Bay of Fundy and Gulf of Maine. In: Daborn, G.R. ed. Fundy tidal power and the environment. Acadia University Inst. Publ. No. 28, pp. 160-163.

Wildish, D.J. 1977b. Factors controlling marine and estuarine sublittoral macrofauna. Helgol. wiss. Meeresunters. 30: 445-454.

Wildish, D.J. 1980. Reproductive bionomics of two sublittoral amphipods in a Bay of Fundy estuary. Int. J. Invertebr. Reprod. 2: 311-320.

Wildish, D.J. 1982. Evolutionary ecology of reproduction in gammaridean Amphipoda. Int. J. Invertebr. Reprod. 5: 1-19.

Wildish, D.J. 1983. Sublittoral sedimentary substrates. In: Thomas M.L.H. ed. Marine and coastal systems of the Quoddy Region, New Brunswick. Can. Spec. Publ. Fish. Aquat. Sci. No. 64, pp. 140-155.

Wildish, D.J. and J.J. Dickinson. 1982. A new species of Haploops (Amphipoda, Ameliscidae) from the Bay of Fundy. Can. J. Zool. 60: 962-967.

Wildish, D.J. and D.D. Kristmanson. 1979. Tidal energy and sublittoral macrobenthic animals in estuaries. J. Fish. Res. Board Can. 36: 1197-1206.

Wildish, D.J. and D. Peer. 1981. Methods for estimating secondary production in marine Amphipoda. Can. J. Fish. Aquat. Sci. 38: 1019-1026.

Wildish, D.J. and D. Peer. 1983. Tidal current speed and production of benthic macrofauna in the lower Bay of Fundy. Can. J. Fish. Aquat. Sci. 40: (Suppl. 1): 309-321.

Wildish, D.J., D.D. Kristmanson and D. Peer. 1981. Effect of tidal currents on suspension-feeding benthos in the Bay of Fundy. Int. Counc. Exp. Sea CM 1981/L:33.

Wildish, D.J., D.L. Peer, A.J. Wilson, J. Hines, L. Linkletter and M.J. Dadswell. 1983. Sublittoral macro-infauna of the upper Bay of Fundy. Can. Tech. Rept. Fish. Aquat. Sci. No. 1194, 64 p.

A Review of Benthic Macrofaunal Production of the Upper Bay of Fundy Intertidal Area

Donald L. Peer

Marine Ecology Laboratory
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, N.S. B2Y 4A2

ABSTRACT

The upper reaches of the Bay of Fundy support a low diversity intertidal macrofaunal community dominated by the bivalve mollusk *Macoma balthica* and the amphipod *Corophium volutator*. *Corophium* is responsible for the largest part of the intertidal secondary production except in one part of Cobequid Bay where *Macoma* is the main macrofaunal producer. The distribution of both species and the factors that are considered to be influencing it are discussed. Estimates of *Macoma* production made at two locations by different workers are compared. *Corophium* production at three different locations measured by three different workers are compared to the total primary production.

Key words: Bay of Fundy, intertidal macrofauna, secondary production, *Corphium volutator*, *Macoma balthica*

RÉSUMÉ

Les parties d'amont de la baie de Fundy supportent une communauté macrofaunique intertidale peu diversifiée dominée par le mollusque bivalve *Macoma balthica* et l'amphipode *Corophium volutator*. Le *Corophium* est responsable de la plus grande part de la production intertidale secondaire sauf dans une partie de la baie de Cobequid ou le *Macoma* est le principal producteur macrofaunique. On examine la répartition des deux espèces et les facteurs importants qui l'influence. On compare des estimations de la production de *Macoma* effectués en deux emplacements par des travailleurs différents. La production de *Corophium* mesurée à trois emplacements par trois travailleurs différents est comparée à la production primarie totale.

INTRODUCTION

The intertidal mudflats of the upper reaches of the Bay of Fundy support a low diversity community of macrofauna dominated by three or four species (Hicklin et al. 1980). The amphipod *Corophium volutator* is responsible for most of the macrofaunal production in Cumberland Basin, Shepody Bay and the Southern Bight of Minas Basin. The bivalve mollusk *Macoma balthica* also occurs in this area in significant numbers and contributes about half the amount to production as does *Corophium*. On the south shore of Cobequid Bay Macoma accounts for a much larger part of the production.

Other species, such as the soft-shelled clam Mya arenaria and a number of species of polychaetes, are also present but either their contribution to the macrofauna is very small or they are confined to a limited area. There is a fishery for Mya along the north shore of Cobequid Bay and Minas Basin which is described by Witherspoon (1984). The following review will be confined to work done on the two ubiquitous species, Macoma and Corophium.

DISTRIBUTION OF MACOMA

On the sand flats of the south shore of Minas Basin, Yeo (1977) found that Macoma was confined to a narrow zone near neap high water extending seaward only 50-150 m. On the mudflats of the southern shore of Cobequid Bay densities are lower near shore and increase seaward reaching a maximum near the seaward edge of the mud. The Macoma in this environment are more abundant than on any other part of the upper reaches of the Bay of Fundy.

In Cumberland Basin and Shepody Bay Macoma are always confined to a narrow zone near shore, a distribution similar to that of the sandflats of Minas Basin. Within some restricted areas densities can be as high as those of Cobequid Bay but the animals are always small.

It has been suggested by both Yeo (1977) and Cranford (1980) that the Macoma distribution is the result of a conflict between the positive effects of increased submergence, hence increased feeding time, and the negative effects of erosion and deposition.

PRODUCTION OF MACOMA

Macoma production was measured on the mudflats of Cobequid Bay by Yeo (1977) and found to be 9-15 g shell-free dry weight m^{-2} y^{-1} from the upper and lower mudflats respectively. This would translate into 2.97 and 4.95 g C m^{-2} y^{-1}. The P/B (production biomass) ratio was 0.3 for the upper mudflat animals and 0.5 for the lower. This was for a population of old animals with a body weight of about 1 g. These high levels of production are somewhat anomalous as there are large intertidal areas in other parts of Cobequid Bay where Macoma is absent or found in very low numbers. As there is insufficient primary production to account for such levels of production it would seem reasonable to assume that food energy is being concentrated in areas of high secondary production.

Macoma production on the Cumberland Basin and Shepody Bay mudflats has been measured by the Marine Ecology Laboratory and found to be between 0.15 and 2.2 g C m^{-2} yr^{-1} with a P/B ratio of between 0.65 and 1.6. These populations are composed of much younger and smaller animals with average body weights of from 0.07 to 0.12 g (dry weight).

DISTRIBUTION OF COROPHIUM

Working along the southern shore of Cobequid Bay and Minas Basin, Yeo (1977) found the greatest Corophium densities on a sediment consisting of 70% very fine sand and 30% silt and clay with a 20-25% water content in the upper 5 cm. He found a rapid reduction in numbers whenever the grain size was over 3.5 phi units (about 100 μm).

Gratto (1979) found that in the Southern Bight of Minas Basin the maximum densities were on the lower half of the mudflats where the preferred type of sediment was most commonly found. In both Shepody Bay and Cumberland Basin, Hicklin et al. (1980) found Corophium to be abundant between high and low neap tide level with no particular seaward or shoreward trend. Densities were considerably less on the sandflats of the Elysian Fields in the Cumberland Basin.

Corophium shows large fluctuations in density with time. Highest densities are found in July and September in all areas. The rapid reduction in numbers during August is due to the tens of thousands of shorebirds that pass through and feed at this time. Another rapid drop in density can often be seen in late May and early June, when the sample spacing is adequate, and is thought to the result from fish predation.

PRODUCTION OF COROPHIUM

The production of Corophium was measured at three locations in the upper reaches of the Bay of Fundy: Cobequid Bay (Yeo 1977), the Southern Bight of Minas Basin (Gratto 1979) and Pecks Cove, Cumberland Basin (Peer et al. in prep.). Annual production was 2.41, 6.3 and 1.74 gm C m^{-2}, respectively. Another estimate, one year later, from Pecks Cove was 0.62 gm C m^{-2} which gives an indication of the amount of inter-annual variation to be expected. Annual P/B ratios are also given in these studies and found to vary between 2.6 and 5.8.

P/B ratios have been used by ecologists to estimate production in the absence of growth and mortality rates when biomass data alone are available. The extreme temporal and seasonal variation in biomass of Corophium in this area makes the estimation of a mean annual biomass difficult to determine and results in unreliable and variable P/B ratios. For this reason, I have constructed a series of ratios of production/mean July biomass. The month of July was chosen because at this time the heavy fish predation which causes a rapid biomass loss during late May and early June is over (or at least the population has reached a stable equilibrium with it) and Corophium is in a state of uniform growth. The arrival of large numbers of shorebirds in early August causes a precipitous drop in biomass and maintains it at a low level until September.

The July P/B ratios were found to be quite consistent among the four measurements available (Table 1). They ranged from 1.4 to 1.9 with a mean of 1.6.

TABLE 1. Biomass and P/B ratios of *Corophium* at three sites in the upper reaches of the Bay of Fundy.

	Mean July biomass (g C m^{-2})	Annual biomass (g C m^{-2})	July P/B
Pecks Cove (1978)	0.9	1.74	1.9
Pecks Cove (1979)	0.45	0.62	1.4
Mungo Brook	1.66	2.41	1.4
Avonport	3.68	6.3	1.7

Good summer biomass data are available from 22 different mudflats from the upper Bay of Fundy. An annual unit production is calculated for each from the mean July P/B ratio (Table 2). From these data a mean annual unit production was calculated for the intertidal area of the major regions in the upper Bay (Table 3). *Corophium* production was closely related to total primary production (Prouse et al. 1984) (Fig. 1). Although the exact nature of the food of *Corophium* is not known (Hawkins, in prep.), this relationship indicates that their food may be derived directly from the total primary production.

REFERENCES

Cranford, P.J. 1980. Growth and seasonal cycle of *Macoma balthica* (L.) at Pecks Cove in the Bay of Fundy. Honours thesis, Dalhousie University, 43 p.

Gratto, G. 1979. The biology of the amphipod *Corophium volutator* (Pallas) in the Western Minas Basin. M.Sc. thesis, Acadia University.

Hicklin, P.W., L.E. Linkletter and D.L. Peer. 1980. Distribution and abundance of *Corophium volutator* (Pallas), *Macoma balthica* (L.) and *Heteromastus filiformis* (Clarapede) in the intertidal zone of Cumberland Basin and Shepody Bay, Bay of Fundy. Can. Tech. Rept. Fish. Aquat. Sci. No. 965, 55 p.

Prouse, N.J., D.C. Gordon Jr., B.T. Hargrave, C.J. Bird, J. Mclachlan, J.S.S. Lakshminarayana, J. Sita Devi and M.L.H. Thomas. 1984. Primary production: organic matter supply to ecosystems in the Bay of Fundy. In this report.

Witherspoon, N. 1984. A survey of the commercial soft shell clam *Mya Arenaria* population on the north shore of the Minas Basin of the Bay of Fundy. In this report.

Yeo, R.K. 1977. Animal-sediment relationships and the ecology of the intertidal mudflat environment, Minas Basin, Bay of Fundy, Nova Scotia. M.Sc. thesis, McMaster University, 396 p.

QUESTIONS AND COMMENTS

B. Wilson: What was the Y-axis on your last figure?

D. Peer: Primary production (g C m^{-2} y^{-1}) averaged for the entire region.

N. Witherspoon: Is there a similar relationship between primary production and *Macoma* production?

TABLE 2. Calculated annual secondary production of *Corophium* at 22 sites in the upper reaches of the Bay of Fundy.

	July Biomass	Annual Production ($g\ cm^{-2}$)
Elysian Fields	0.01	0.02
Joggins	1.81	2.90
Minudie	1.71	2.74
Pecks Cove (1978)	0.90	1.44
Pecks Cove (1979)	0.45	0.72
Grand Anse	1.04	1.66
Danials Flats	0.64	1.02
Marys Point	1.33	2.13
Sterling Brook	0.40	0.64
Anthony Park	0.31	0.50
East Noel	0.74	1.18
Kings Creek	0.80	1.28
Salter Head	0.33	0.53
Tennycape	0.10	0.16
Walton	0.22	0.35
Starrs Point	0.36	0.58
Evangeline Beach	0.03	0.05
Avonport	3.57	5.71
Starrs Point	1.49	2.38
Evangeline Beach (1978)	0.62	0.99
Avonport	3.68	5.89

TABLE 3. Mean values of secondary production by *Corophium* in different regions in the upper reaches of the Bay of Fundy.

Region	Annual Production (g C m^{-2})
Cumberland Basin	1.78 (including Elysian Fields)
	2.36 (excluding Elysian Fields)
Shepody Bay	1.60
Cobequid Bay	0.80
Minas Basin	0.26 (1977)
Southern Bight	2.11 (Evangeline Beach data)
	3.09 (1978 Evangeline Beach data)

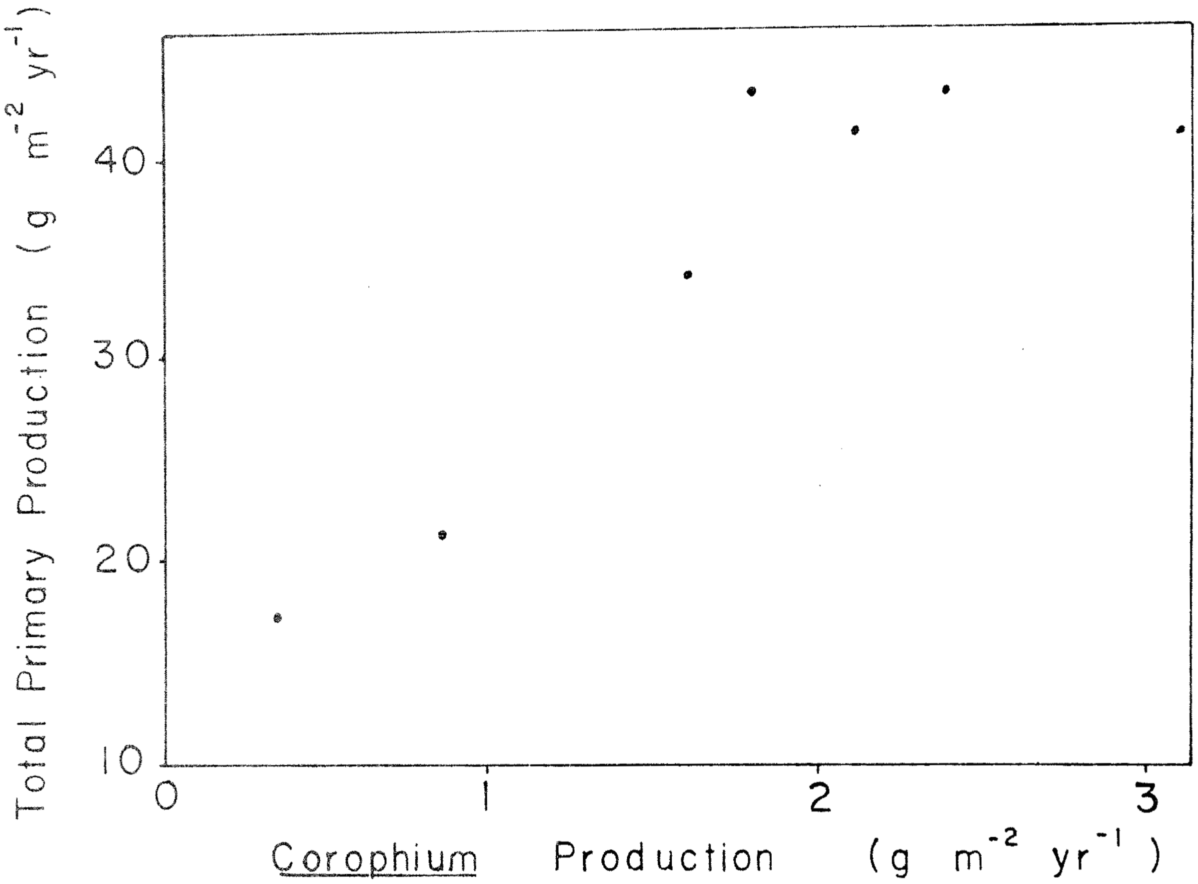


Fig. 1. Relationship between total primary production (Prouse et al. 1984) and secondary production of Corophium averaged for major regions in the upper reaches of the Bay of Fundy.

D. Peer: No. *Macoma* appears to reach disporportionally high biomasses and production up in that one little pocket of Cobequid Bay. In the Chignecto Bay region, *Macoma* production seems to be quite variable depending upon the state of the population. I think they are periodically wiped out by storms and probably living under stress.

D. Gordon: Isn't it fair to add that Yeo's data come from areas where *Macoma* is most abundant and that areas with low abundance were not sampled. The figures you give are averaged for all of Cobequid Bay and therefore may be on the high side.

D. Peer: Yes, the entire Selma Bar and north shore are mostly sand and have few *Macoma*. Distribution is very patchy and some areas have no *Macoma* at all.

M. Majka: Is there any evidence to support your suggestion that the drop in *Corophium* abundance in June is due to fish predation?

D. Peer: Yes. Mike Dadswell reports a very massive migration of tomcod onto the tidal flats about this time and if your sampling straddles this period you can see quite a drop in *Corophium*.

M. Dadswell: We found tomcod feeding on polychaetes during the winter but switching to *Corophium* in May-June.

K. Mann: Do you have any coherent theory on the ecology of *Macoma* to explain its distribution? For example, I am thinking about some polychaetes which shed their larvae when the tide is out and settlement occurs near the high water mark. Is it possible that *Macoma* larvae settle near high water while the reproducing population is in deeper water.

D. Peer: No, I don't think so. I have not seen too many *Macoma* in deeper water. The distribution around high tide seems to be related somewhat to mudflat stability. Its a question of where the sediment is unstable their chances of becoming eroded or buried become greater and greater and so there are less and less of them until you reach the state of almost sand wave situation where *Macoma* is unable to survive. I don't know how *Macoma* is able to maintain production in some areas such as Cobequid Bay, perhaps because other animals can't survive. There may be import of food from other parts of the mudflat so what you may have is an exaggerated estimate of production confined to one little spot which can't occur elsewhere.

G. Brown: Has any work been done on the production of *Mya* (soft-shelled clam).

D. Peer: Yes. Ross Yeo did some production estimates along the north shore of Cobequid Bay in his thesis. I did not include them here for that is the only place where they seem to be abundant. I don't believe we have ever found significant numbers of *Mya* anywhere in Shepody Bay or Cumberland Basin.

Microbial Ecology of the Bay of Fundy[1]

Leon M. Cammen

Bigelow Laboratory for Ocean Sciences
West Boothbay Harbor, Maine 04575

ABSTRACT

Largely qualitative studies of fungi in the Bay of Fundy have resulted in the isolation and identification of almost 60 species. Some information is available about their nutrition, but little is known of their quantitative significance. Free-living bacteria (unattached to particles) dominated the open water of the lower Bay in all seasons, but attached cells were more abundant in the upper reaches. Both the abundance and proportion of cells attached were strongly correlated with the concentration of suspended particulate matter. Bacterial activity generally followed the same pattern as cell numbers. Bacteria in subtidal sediments accounted for 1 to 2% of the total organic carbon and ranged from 0.03 to 0.5 g C m^{-2}. Bacteria in intertidal sediments were generally more abundant on a per g sediment basis high in the intertidal zone than low in the intertidal, but numbers per cm^3 were similar. Biomass ranged from 1.6 to 2.8 g C m^{-2}. Bacterial numbers per unit sediment organic carbon doubled in the fall during the benthic microalgal bloom. Numbers of attached bacteria per unit carbon were higher in the water than in the sediment. There are significant gaps in our knowledge of microbial ecology in the Bay including a quantitative assessment of the role of microbes in general, and protozoans in particular, in energy and nutrient cycling.

Key words: Bay of Fundy, marine fungi, suspended bacteria, attached bacteria, free-living bacteria, heterotrophic activity, sediment bacteria, mudflat.

RÉSUMÉ

Des études en grande partie qualitatives des champignons dans la baie de Fundy ont permis d'en isoler et d'en identifier près de 60 espèces. Certains renseignements sont disponibles quant à leur alimentation, mais on ne sait que peu de choses sur leur importance quantitative. Les bactéries vivant à l'état libre (non attachées à des particules) dominent dans les eaux libres de la partie aval de la baie en toutes saisons, mais les cellules, parasites sont plus abondantes dans les segments plus en amont. L'abondance et la proportion de cellules parasites présentaient de fortes corrélations avec la concentrtion des particules de matières en suspension. L'activité bactérienne présente en général les mêmes caractéristiques que les nombres de cellules. Les bactéries présentes dans les sédiments sub-

[1]Bigelow Laboratory for Ocean Sciences Contribution No. 82038

tidaux renferment de 1 à 2% du carbone organique total et environ 0,03 à 0,5 g de C par m^2. Dans les sédiments intertidaux les bactéries sont généralement plus abondantes, par gramme de sédiments, à la partie supérieure de la zone intertidale qu'à sa partie inférieure, mais les nombres par cm^3 sont comparables. La biomasse varie de 1,6 à 2,8 g de C par m^2. Les nombres de bactéries par unité de carbone organique dans des sédiments doublent à l'automne pendant le pullulement des microalgues benthiques. Les nombres de bactéries parasites par unité de carbone sont plus élevés dans l'eau que dans les sédiments. Notre connaissance de l'écologie microbienne de la baie présente des lacunes importantes dont une évaluation quantitative du rôle des microbes en général, et des protozoaires en particulier, dans le cycle de l'énergie et de l'alimentation.

INTRODUCTION

The Bay of Fundy, with its large tidal range, extensive mudflats and turbid waters presents a unique environment for the study of microbial processes. Unfortunately our knowledge of microbial ecology in this area is rather limited. In fact, it was not difficult to limit this review to work after 1975, since virtually all we know has come from studies carried out after 1978. I have organized this review into two sections, one dealing with marine fungi and the second with bacteria; within the bacteria section I have discussed open water, subtidal sediments and intertidal areas including both the sediment and overlying water at high tide.

FUNGI

Studies of marine fungi in the Bay have been largely qualitative, but it is possible that numbers of geofungi may be higher in the Bay than in other marine areas because of the high tides and the degree of freshwater input (Miller and Whitney 1981b). About 60 species of fungi have been isolated and identified from seawater samples and from littoral marine algae (Miller and Whitney 1981 a, b). Some information is available from these studies on suitable organic substrates for the fungi, but we do not yet have an indication of the importance of their role in degradative processes in the Bay.

BACTERIA

Open Water

The only information we have about bacterial populations and activity in the open water of the Bay comes from a series of three cruises throughout the Bay in spring, summer and fall of 1979 (Fig. 1; Cammen and Walker 1982). That study attempted to show the relationship between bacteria and suspended particulate matter (SPM).

Bacterial abundance in surface water of the Bay of Fundy ranged from 0.2 to 4.0 x 10^6 cells mL^{-1} (Fig. 2). Distribution of free-living

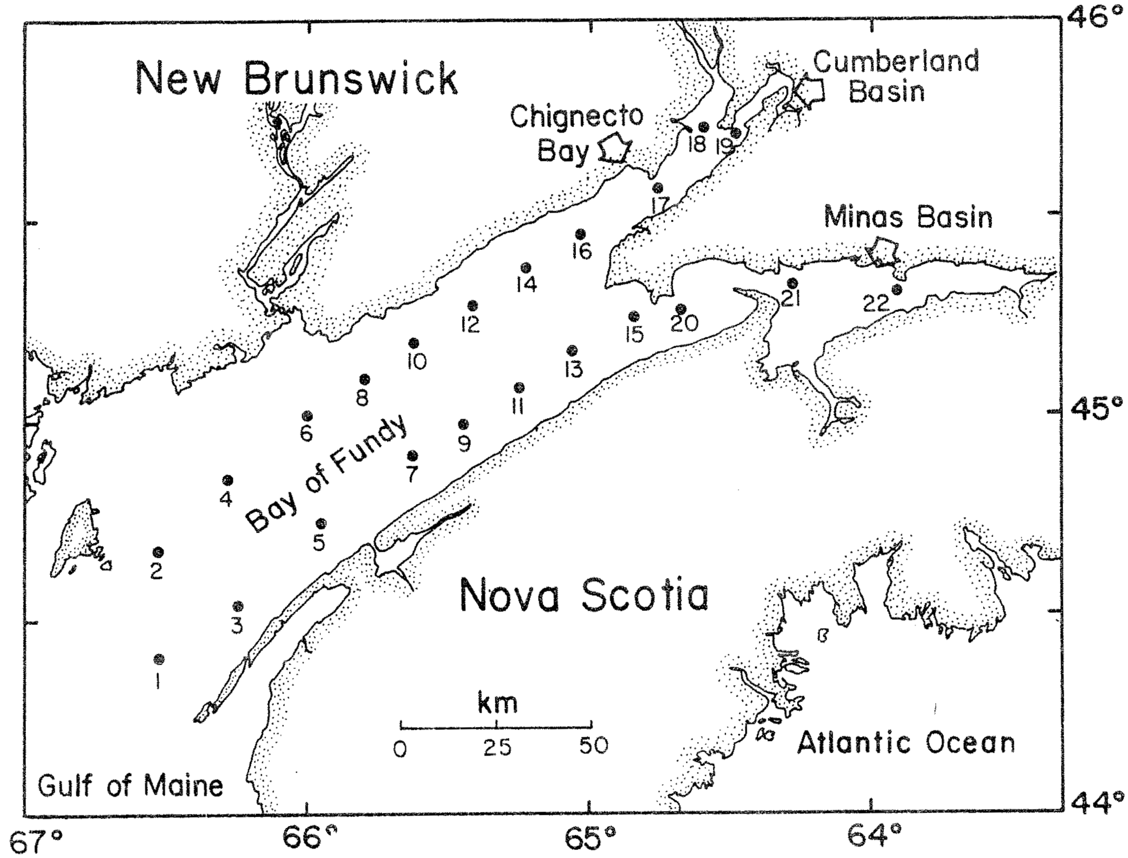


Fig. 1. Location of cruise stations in the Bay of Fundy (reproduced from Cammen and Walker 1982).

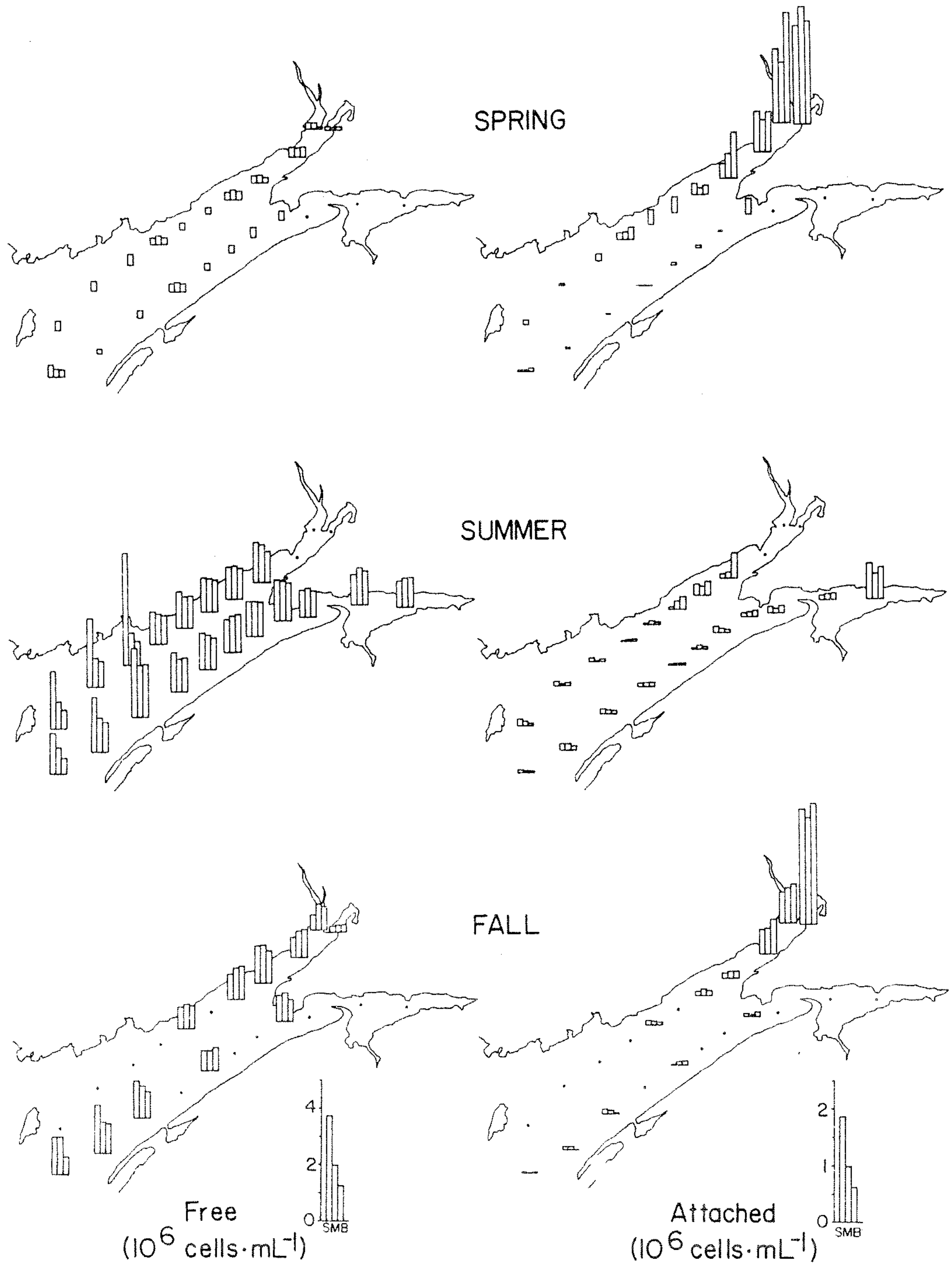


Fig. 2. Abundance of free-living and attached suspended bacteria (x 10^6 mL^{-1}) in the Bay of Fundy. Only one bar is present when only surface water was sampled (reproduced from Cammen and Walker 1982).

bacteria (unattached to particles) was fairly uniform within the lower Bay of Fundy with the exception of Stations 2-6 during the summer where numbers were higher; Station 6, located just off Saint John, New Brunswick, had the highest numbers of free-living bacteria recorded during the three cruises. In general, free-living bacteria were most abundant in the summer and least abundant in the spring. Abundance was reduced in the upper reaches of the Bay (Chignecto Bay and Minas Basin) during all three seasons. The distribution of bacteria attached to particles was also quite uniform in surface water during summer and fall in the lower Bay. In the spring, however, there was a marked discrepancy between the northern and southern sides of the Bay, with higher numbers on the northern side except near the mouth of the Bay. In all three seasons the numbers of attached bacteria were much higher in the upper reaches than in the lower Bay: 67-94% of the cells in the upper reaches were attached in the spring, 8-40% in the summer and 37-89% in the fall.

The abundance of bacteria in the midwater and bottom water of the Bay generally followed that of the surface water (Fig. 2). The major exception was in the summer when high numbers of free-living bacteria in the surface water of Stations 2-6 were not reflected in the deeper waters. As in the surface waters, free-living bacteria were generally more abundant in the summer than in the spring and fall and in the lower Bay than in the upper reaches. Numbers of attached bacteria were higher along the north side of the Bay than along the south side in the summer in both mid- and bottom water.

Both the distribution and activity of suspended bacteria in the Bay of Fundy reflect the general anti-clockwise circulation pattern of flow in from the Gulf of Maine along the southern or Nova Scotia coast and out along the northern new Brunswick coast (Bailey 1957). For example, the distribution of free-living bacteria during the summer (Fig. 2) shows an initial stratification as water enters the Bay along the southern coast followed by relatively complete mixing so that distribution becomes uniform with depth. As the water flows out along the northern coast, the distribution remains uniform with depth until past the Saint John River outflow where a pulse of bacteria appears in the surface water; this pulse remains evident in the more seaward stations. Similarly, the distribution of attached bacteria in the spring shows the influence of SPM carried out of Chignecto Bay along the northern coast. Thus, in some respects, bacteria appear to be a conservative tracer of water masses in the Bay.

The proportion of suspended bacteria that are attached in the Bay of Fundy varies with the area sampled and appears to depend on the amount of SPM in the water. Hanson and Wiebe (1977) point out that in the open ocean most bacteria are free-living, in coastal waters the proportion of attachment appears to vary, and in estuary-salt marsh systems most of the bacteria seem to be attached. The Bay of Fundy apparently has similarities to all these systems with the relatively open mouth, adjacent to the Gulf of Maine, dominated by free-living bacteria and the turbid upper reaches dominated by attached cells. The relation between numbers of attached bacteria and detrital SPM (SPM with living algal biomass subtracted) was consistent regardless of season or depth (Fig. 3, $r^2=0.94$, $N=116$, $P<0.01$).

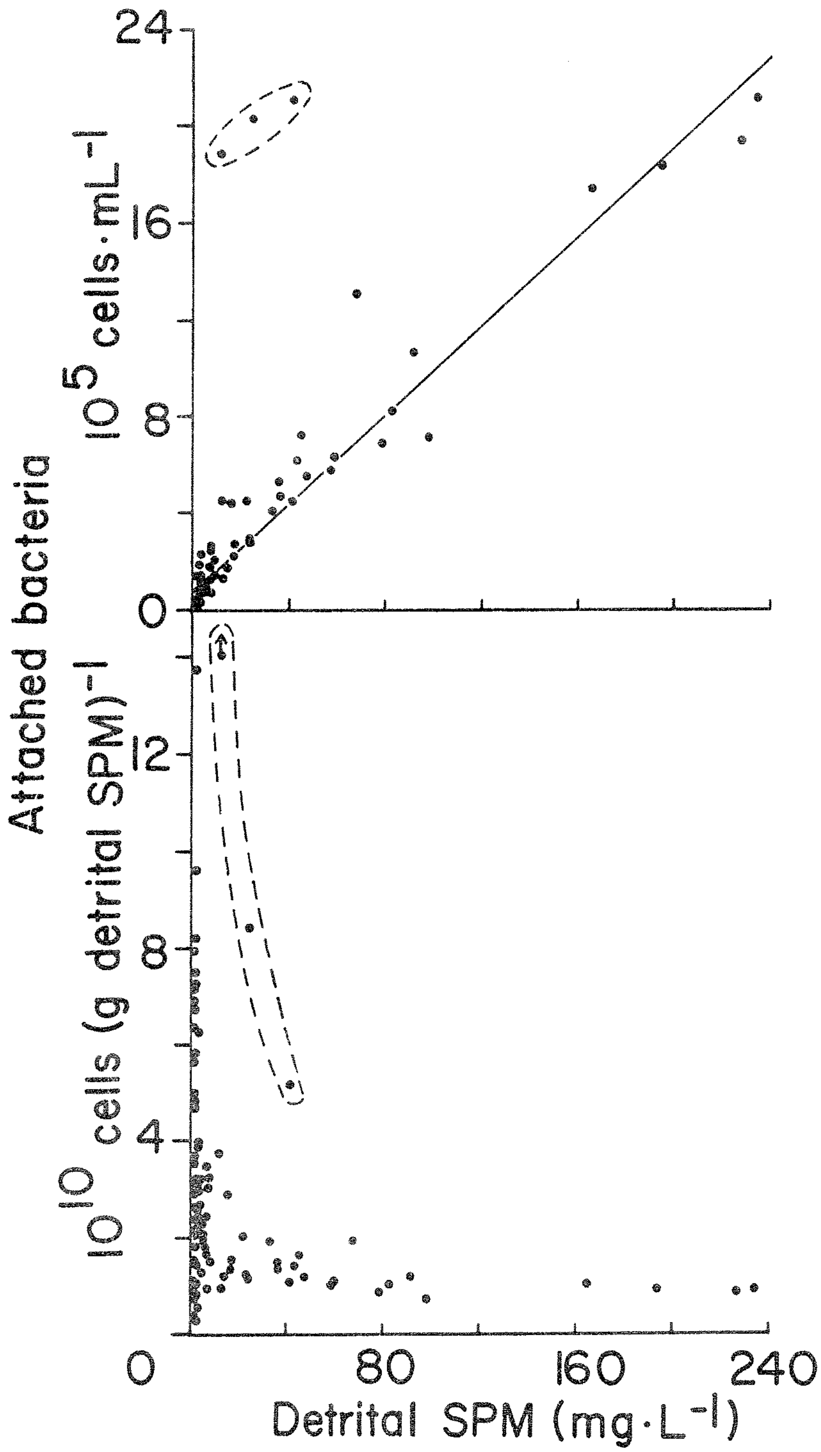


Fig. 3. Total numbers of attached bacteria (upper) and number of attached bacteria per unit detrital SPM (lower) as a function of detrital SPM concentration for all samples. Values within dashed lines are from Station 19 on the fall cruise (reproduced from Cammen and Walker 1982).

There was only a minor effect of quality of the detrital SPM (measured as percent carbon) on numbers of attached bacteria (g detrital SPM)$^{-1}$ (r^2 = 0.13, N = 110, P<0.05). Although the number of attached bacteria per unit weight of detrital SPM was highly variable for detrital SPM concentrations less than 15 mg L^{-1} (N = 94, Fig. 3), ranging from 0.3 to 13.7 x 10^{10} cells (g detrital SPM^{-1}), the variability was much less at higher detrital SPM concentrations. For samples with 15 to 70 mg detrital SPM L^{-1} (N = 17), the numbers of attached cells (g detrital SPM)$^{-1}$ were between 1 and 2 x 10^{10} and for detrital SPM concentrations greater than 75 mg L^{-1} (N = 8), there were consistently 1 x 10^{10} cells (g detrital SPM)$^{-1}$.

There was no significant difference in bacterial cell volume between spring and summer or with depth in the summer. The mean cell volume for surface water from four stations in the spring was 0.11 μm^3 (SE ± 0.02), equivalent to about 1.0 x 10^{-14} g C cell^{-1}. For five summer stations overall mean cell volume was 0.09 μm^3 (SE ± 0.01), equivalent to 0.8 x 10^{-14} g C cell^{-1}. Mean cell volumes (μm^3) for surface, mid-, and bottom water for these five stations were: 0.08 ± 0.01, 0.09 ± 0.01, and 0.09 ± 0.02, respectively.

Heterotrophic activity of the bacteria was also determined by use of ^{3}H-glutamic acid in the summer and fall. Activity was greater in the summer than in the fall and was dominated by free-living bacteria throughout the Bay. In the fall, free-living bacteria still accounted for most of the heterotrophic activity in the lower Bay but the proportion of activity due to attached bacteria was substantially greater than during the summer. Activity in the upper reaches in the fall was dominated by attached bacteria. On a per cell basis, the geometric mean ratio of attached:free-living activity in surface water was 0.56 in the summer and 2.32 in the fall. Thus, free-living bacterial cells were about twice as active as attached cells in surface water during the summer, but only half as active during the fall.

Subtidal sediment

The only available data on subtidal bacterial populations come from a single cruise in summer 1979 (Schwinghamer 1981b). Bacterial biomass (0.25 - 4 μm cells) ranged from 0.03 to 0.5 g C m^{-2}, accounting for 1-2% of the total organic carbon in the sediments. There were generally 1-10 cells for each 100 μm^2 of sediment grain surface, greater than the densities found by Dale (1974) in samples along the Atlantic coast of Nova Scotia. Using these data plus a few additional intertidal stations, Schwinghamer (1981b) found a very close relationship between the log of bacterial biomass and an index derived from the log of the percent silt-clay in the sediment times the percent organic carbon (r^2 = 0.812).

Intertidal sediment and overlying water

There have been two studies of intertidal bacteria in the Bay of Fundy, one already published on Minas Basin (Tunnicliffe and Risk 1977) and one unpublished on Pecks Cove in Cumberland Basin (Cammen and Walker, unpublished data). I will mention the former study only briefly since it is available elsewhere, but will discuss the latter in more detail.

Minas Basin

Tunnicliffe and Risk (1977) were interested in the relation between densities of the bivalve Macoma balthica and intertidal bacterial populations. They found that Macoma density was highly correlated with bacterial density. Bacterial densities ranged from about 0.5 x 10^9 to 2 x 10^{10} cells per g dry sediment. Although they suggest that bacteria could account for an average of 33 and as much as 100% of the total sediment organic carbon, their conversion factor for carbon per cell appears to be in error; a more reasonable conversion factor gives an average of 2.5%, similar to that for subtidal sediments.

Pecks Cove

The second intertidal area that was studied in the Bay of Fundy was Pecks Cove, located at the mouth of Cumberland Basin in the upper Bay of Fundy (Fig. 4) (Cammen and Walker, unpublished data). Tidal range in this area averages about 11 m; salinity rages from 20 to 28°/₀₀ and water temperature from the freezing point to 23°C. Station A was located in the upper intertidal zone of a 1 km wide mudflat and was exposed an average of 16 h per day; average water depth at high tide was about 3 m. Station B was located in the lower intertidal zone and was exposed an estimated 4 h per day; average water depth at high tide was about 10 m. Dominant macrofauna in this area were the amphipod Corophium volutator, the polychaete Heteromastus filiformis, and the snail Hydrobia minuta; the bivalve Macoma balthica was also abundant in areas near Station A. The uppermost portion of the mudflat (just above Station A) supported a narrow band of Spartina alterniflora marsh and diatoms were abundant on the sediment surface of the entire mudflat. The sediment at both these stations was predominantly silt, but organic carbon content was quite low, 0.3-1.5%.

Samples for determination of bacterial abundance were taken from the mudflat sediment at Stations A and B by coring and from the water flooding the mudflat with a pumping system either monthly or biweekly between 20 April and 12 December 1979. Bacterial numbers were determined for the water and sediment by direct epifluorescent counting. The water samples were analyzed for suspended particle matter (SPM), particulate organic carbon (POC), chlorophyll a and particle size. Sediment samples were also analyzed for organic carbon, chlorophyll a and particle size.

Sediment

Numbers of bacteria g^{-1} were generally greater at the high intertidal Station A than at the low intertidal Station B, but numbers cm^{-3} were similar (Fig. 5). Little seasonal variation was apparent although numbers of bacteria cm^{-3} at the surface seemed to be higher in the late spring and summer than in the fall for both stations. With an average cell carbon content of 1.2 x 10^{-14} g for Station A and 1.1 x 10^{-14} g for Station B along with the numbers of bacteria cm^{-3} from Fig. 5, bacterial carbon m^{-2} in the top 5 cm ranged from 2.0 to 2.8 g at Station A and 1.6 to 2.3 g at Station B during the sampling period.

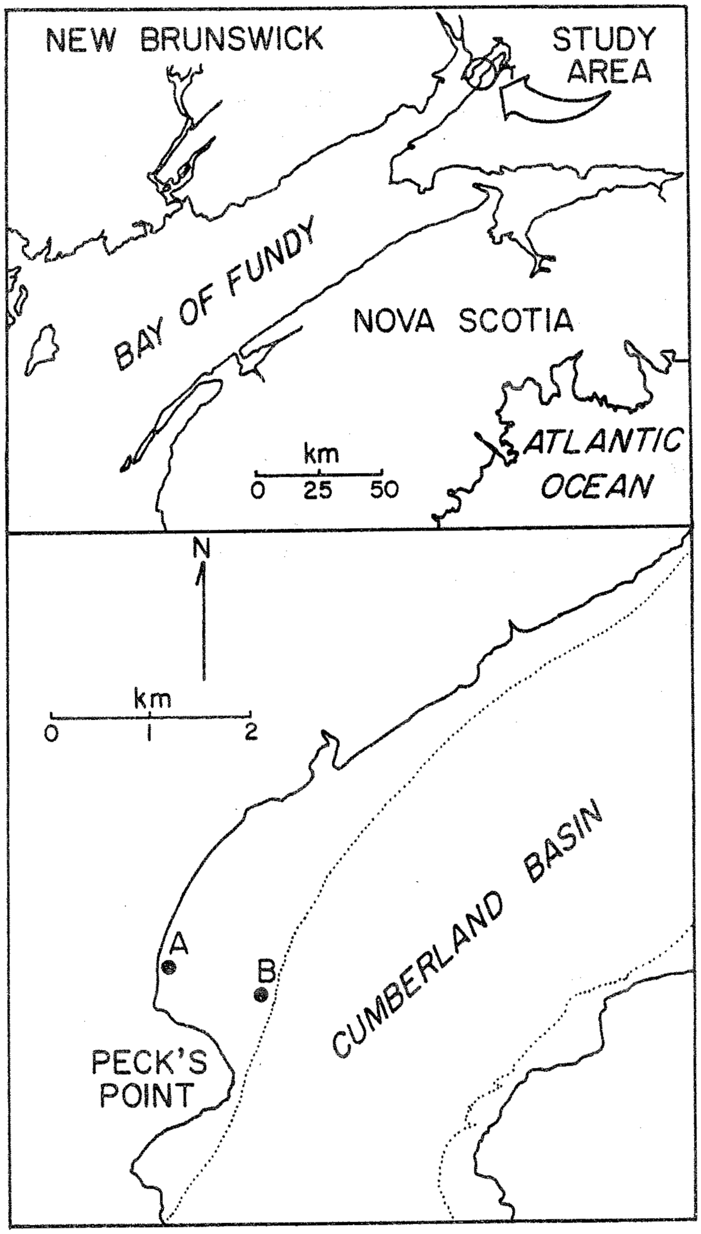


Fig. 4. Location of the Peck's Cove mudflat.

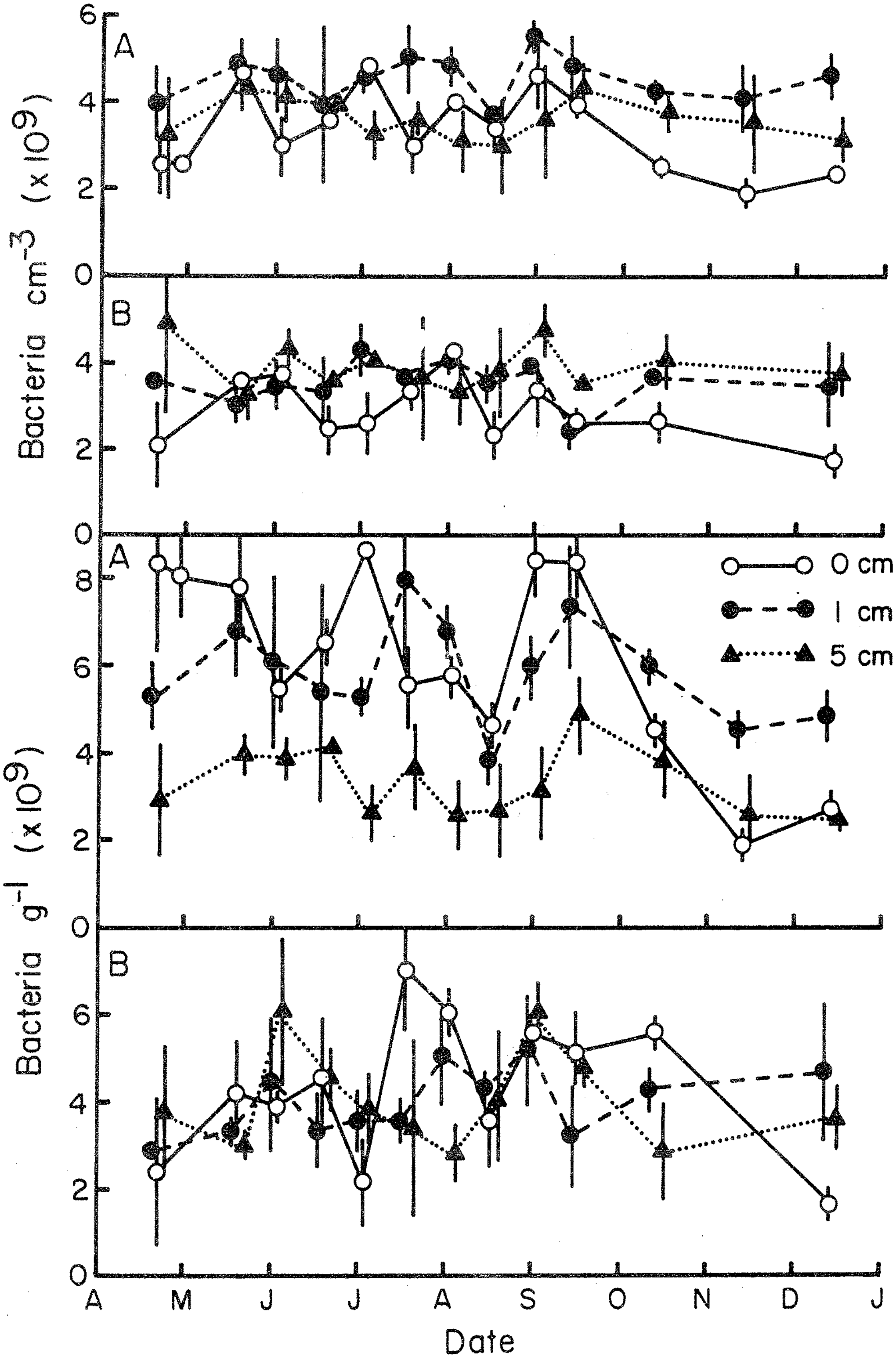


Fig. 5. Seasonal variation in bacterial abundance in the Peck's Cove mudflat. Abundance is given cm^{-3} (upper two panels) and g^{-1} (lower two panels) for stations A and B. Vertical bars are ± 1 SE.

There was a close relationship between bacteria and chlorophyll a concentrations in the sediment at Station A throughout the sampling period (Fig. 6c, d); bacterial and algal carbon were not included in the sediment carbon values when calculating bacteria (g C)$^{-1}$. Values of bacteria (g C)$^{-1}$ for Station A were consistently about 9 x 10^{11} cells (g C)$^{-1}$ (Fig. 6c) until early September when there was a marked increase. This increase came just after the start of an algal bloom on the sediment surface (Fig. 6d). Similarly, the subsequent decline in algal biomass was followed closely by a decrease in bacteria (g C)$^{-1}$. The overall correlation for all sampling dates was r = 0.83 (P<0.01). Station B did not have a marked algal bloom during our sampling period and bacteria (g C)$^{-1}$ remained fairly constant throughout the year. Both bacteria (g C)$^{-1}$ and chlorophyll a (g^{-1}) were similar for both stations except during the period of the algal bloom.

Overlying water

There was little seasonal variation in total suspended bacteria in the samples taken at slack water from the high intertidal Station A and numbers were generally lower than those found in the water that initially flooded the station (Fig. 7). From 66 to 89% of the bacteria in the initial samples and from 55 to 82% of the bacteria in the slack water samples were attached to particles. Free-living bacterial abundance was usually about 0.5 x 10^6 cells ml^{-1} in the initial samples, but in the slack water samples values were higher in the summer, reaching a peak of 1.2 x 10^6 cells ml^{-1} on 8 August. Attached bacterial numbers generally were about 2.0 x 10^6 cells ml^{-1} in the initial water samples and about 1.5 x 10^6 cells ml^{-1} in the slack water samples.

Numbers of attached bacteria (g POC)$^{-1}$ varied widely in successive samples and were higher when tidal range was lower (Fig. 6b,c). There was a significant inverse correlation between bacteria and the amount of POC in the water at slack high tide (r = -0.88, P<0.01) (Fig. 6b, c) the same relation was found for bacteria (g SPM)$^{-1}$ and the SPM concentration (r = -0.92, P<0.01). However, unlike the sediment, there was no apparent relation between microalgal biomass in the water column (measured by chlorophyll a) and bacteria.

Suspended bacterial cells were slightly smaller than those in the sediment. Cell volumes were equivalent to about 1.0 x 10^{-14} g C per cell. Taking into account the bacterial concentration, bacterial biomass in the overlying water ranged from 13 to 30 μg C L^{-1}.

Factors controlling bacterial abundance in sediment and overlying water

Although there were no pronounced seasonal cycles for total bacterial abundance (per volume of sediment or water - Figs. 5, 7), there was significant variation when bacterial numbers were expressed on a per gram dry weight of sediment (Fig. 5) or per gram carbon (Fig. 6c) basis. In particular, numbers of attached suspended bacteria (g POC)$^{-1}$ were highest although variable in the summer (Fig. 6c), even though the numbers mL^{-1} remained fairly constant throughout the year (Fig. 7). Similarly, the peak in bacteria (g C)$^{-1}$ in the fall at Station A (Fig. 6c) was not reflected in numbers cm^{-3} (Fig. 5).

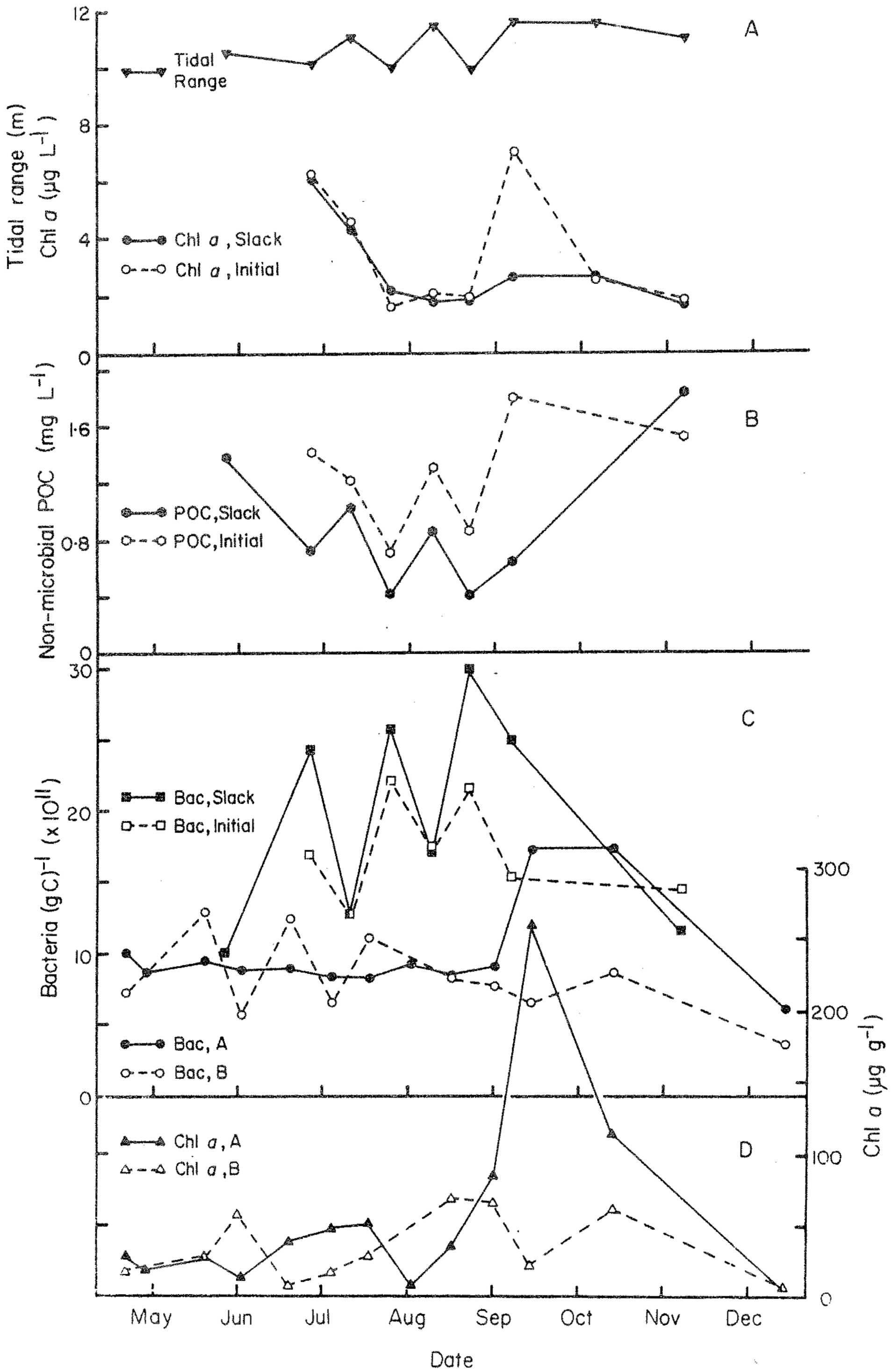


Fig. 6. Relationships between bacteria, organic carbon and chlorophyll a in the water and sediment throughout the sampling period. Chlorophyll a in the water and the predicted tidal range are given in A. POC in the water is given in B. Bacterial abundance (g C)$^{-1}$ in the water for both initial and slack high water samples and in the sediment for Stations A and B is presented in C. Chlorophyll a abundance in the sediment at Stations A and B is given in D.

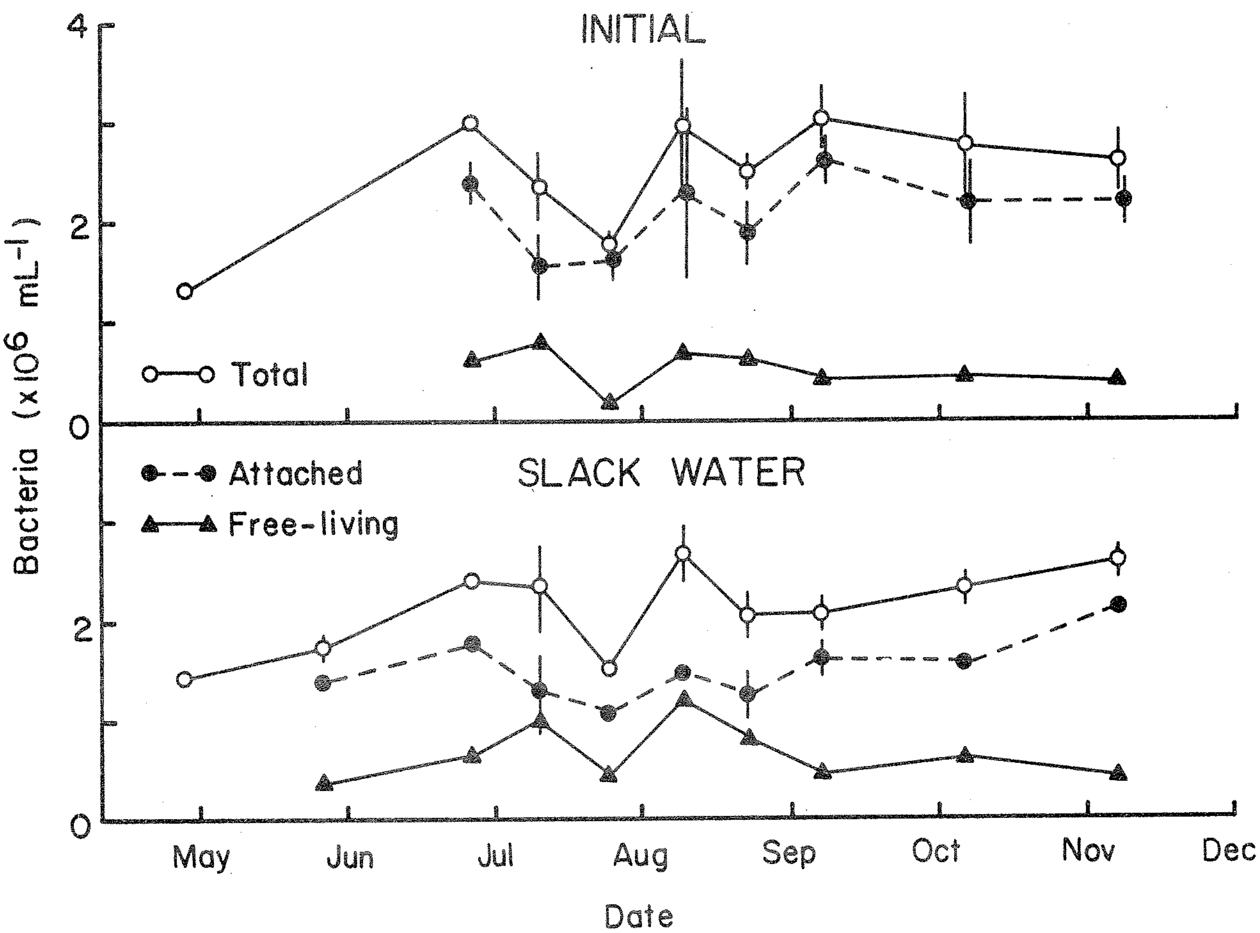


Fig. 7. Seasonal variation in bacterial abundance in the water flooding Peck's Cove mudflat. Data are given for both the initial samples from the pump and for samples taken at slack high water. Vertical bars are ± 1 SD.

There was little difference in bacterial abundance in surface sediment between the high intertidal Station A and the low intertidal Station B during most of this study. Until the time of the algal bloom at Station A in September, numbers cm^{-3} were generally from 3 to 4 x 10^9 and numbers $(g\ C)^{-1}$ averaged about 9 x 10^{11}; as soon as the algal bloom began at Station A, however, the similarity disappeared and numbers $(g\ C)^{-1}$ became higher at Station A than at Station B. The similarity most of the year was surprising since Station A was exposed about 16 hours each day, while Station B was exposed only about 4 hours. This difference in exposure time may explain why there was no algal bloom at Station B (Admiraal and Peletier, 1980). Station A showed virtually no erosion or accretion of sediment throughout the sampling period, but there was a steady accretion of sediment at Station B, resulting in an increase of 17.4 cm sediment from April to September (Gordon and Desplanque 1983). Although this rapid accretion may explain why the differences in bacterial abundance with depth (bacteria g^{-1}) consistently observed at Station A were not seen at Station B (Fig. 5), it did not result in a large difference in surface grain size (as measured by Coulter Counter) between the two stations (Gordon and Desplanque 1983).

It is not obvious why the apparent link between microalgal biomass and bacterial abundance in the sediment during the sampling period (Fig. 6c, d) was so strong. The amphipod *Corophium* has been implicated in control of microalgal populations on the mudflat since the algal bloom (Fig. 6d) occurs just after the *Corophium* population declines sharply due to shorebird predation (Boates and Smith 1979, Schwinghamer 1981b); a causal model developed for this mudflat also supports this view (Schwinghamer 1981b). The question then is whether the bacteria population may also have been limited by the same grazer, or whether the bacteria may simply have responded to changes in the production of algal exudates, or whether some other explanation may be needed. Bacterial biomass and activity are related to the abundance and activity of phytoplankton in the water column (Fuhrman et al. 1980, Wolter 1982) and a similar relationship has been shown between primary production and community respiration in intertidal flats, although there was a lag of 1 to 2 months (van Es 1982). In order for the apparent relationship between microalgae and bacteria at Peck's Cove to be due solely to cropping by *Corophium*, then *Corophium* would have to be a major grazer of both bacteria and algae. While *Corophium* is capable of grazing on and digesting both bacteria and microalgae (Fenchel et al. 1975, Lopez and Levinton 1978), it is unlikely that the *Corophium* population represents a major consumer of bacteria (Schwinghamer et al. 1983). The microbial community made up of ciliates, microflagellates and others, and the mesofauna (= meiofauna), probably consume bacteria at a much higher rate than the *Corophium* population. Cammen and Walker (unpublished data) suggested that an increase in algal standing stock, due to a reduction in feeding pressure by *Corophium*, led to an increased production of extracellular organic compounds, which in turn shifted the steady-state existing between bacterial production and consumption toward production, resulting in an elevated standing stock. Later in the fall as both temperature and light began to decrease, microalgal production declined and bacterial standing stock also decreased; there was certainly no evidence that these declines were due to increased feeding activity by *Corophium*.

There were more bacteria (g C)$^{-1}$ attached to particles in the water column that in the sediment during most of the sampling period (Fig. 6b) and the difference may be explained by available surface area. There is a gross inverse correlation between particle size and bacterial abundance which has been attributed to surface area available for bacterial attachment (Hargrave 1972, Dale 1974), although on a finer scale this relationship does not always hold (Cammen 1982). Inorganic grain size analysis gave a mean surface:volume ratio of 1.50 ± 0.07 (SD) for the slack water SPM between 25 June and 6 September. Sediment samples taken on 18 June, 3 and 16 July, and 30 August from Stations A and B had a mean surface:volume ratio of 0.60 ± 0.25. Thus, for a given volume of particles, the water samples had potentially 2.5 times more surface area than the sediment which could account for most of the difference in bacterial abundance simply by considering available surface areas.

The data from the water samples suggest that resuspension from bottom sediments may be significant in controlling bacterial abundance in the water flooding the mudflat. There are apparently three general mechanisms which control resuspension in this area. Two are large scale, operating throughout the Cumberland Basin on an order of days, and result in the variation seen in the slack water samples (Fig. 6b). The first of these large-scale factors is tidal exchange which varies throughout the lunar tidal cycle as tidal range changes. The second large-scale factor is the occurrence of storms (Amos and Asprey 1981). The third factor is small scale, operating at the front of the advancing water as small-amplitude waves on an order of minutes (Anderson 1980); this factor would be responsible for the difference between the slack water and initial water samples (Fig. 6b). If we assume that during the periods with greater amounts of POC (Fig. 6b) or SPM in the water, the mean particle diameter was also greater, then the variations in bacteria (g POC)$^{-1}$ (Fig. 6c) or (g SPM)$^{-1}$ can be explained as a result of variation in the available surface area of the SPM. The two occasions during the summer that the amount of POC in the slack water samples was relatively high (9 July, 8 August - Fig. 6b) were also the only times that there was no difference in bacteria (g POC)$^{-1}$ for the initial and slack water samples. It is likely that on these two dates the difference in mean particle size between the slack water SPM and the material suspended by the advancing flood-water was the least of the summer sampling dates and thus the change in surface:volume ratio as the newly suspended material settled out between the initial and slack water samples would have been minimal.

An additional explanation for the wide fluctuations in bacterial abundance (g POC)$^{-1}$ between consecutive water samples may be that the abundance of bacteria in the water was linked to phytoplankton production in a manner analagous to the sediment. The periods when bacterial abundances were particularly low were also the periods of high SPM loading (Fig. 6b, c) and presumably increased turbidity when phytoplankton production would have been reduced.

In summary, bacterial abundance in the Pecks Cove sediment-water system appears to be controlled by both surface area available for colonization and the presence of microalgae in agreement with Schwinghamer

(1981a). The major difference observed between sediment and water bacterial abundance appears to be mainly due to the greater surface area available in the water per volume of particles. Within the sediment, variation appears to be linked to the presence of benthic microalgae; possibly an analagous situation occurs in the water, but there is no evidence to show this.

CONCLUSIONS

Although the studies reported in this review have begun to give us basic information on fungal and bacterial populations, there are significant gaps in our knowledge that will need to be addressed if we are to gain an understanding of microbial activity in the Bay. We need quantitative information about the role of fungi in heterotrophic processes and more such information for the bacteria. We know almost nothing about the protozoans in terms of their abundance and their role in the cycling of energy and nutrients. Truly the field of microbial ecology is a wide-open area for investigation in the Bay of Fundy.

REFERENCES

Admiraal, W. and H. Peletier. 1980. Influence of seasonal variations of temperature and light on the growth rate of cultures and natural populations of intertidal diatoms. Mar. Ecol. Prog. Ser. 2: 35-43.

Amos, C.L. and K.W. Asprey. 1981. An interpretation of oceanographic and sediment data from the upper Bay of Fundy, BIO Report Series BI-R-81-15, 143 p.

Anderson, F.E. 1980. The variation in suspended sediment and water properties in the flood-water front traversing the tidal flat. Estuaries 3: 28-37.

Bailey, W.B. 1957. Oceanographic observations in the Bay of Fundy since 1952. Atlantic Oceanographic Group, St. Andrews, New Brunswick.

Boates, J.S. and P.C. Smith. 1979. Length-weight relationships, energy content and the effects of predation on *Corophium volutator* (Passas) (Crustacea:Amphipoda). Proc. N.S. Inst. Sci. 29: 489-499.

Cammen, L.M. 1982. Effect of particle size on organic content and microbial abundance within four marine sediments. Mar. Ecol. Prog. Ser. 9: 273-280.

Cammen, L.M. and J.A. Walker. 1982. Distribution and activity of attached and free-living suspended bacteria in the Bay of Fundy. Can. J. Fish. Aquat. Sci. 39: 1655-1663.

Dale, N.G. 1974. Bacteria in intertidal sediments: Factors related to their distribution. Limnol. Oceanogr. 19: 509-518.

Fenchel, T., L.H. Kofoed and A. Lappalainen. 1975. Particle-size selection of two deposit feeders: the amphipod Corophium volutator and the prosobranch Hydrobia ulvae. Mar. Biol. 30: 119-128.

Fuhrman, J.A., J.W. Ammerman and F. Azam. 1980. Bacterioplankton in the coastal euphotic zone: Distribution, activity and possible relationships with phytoplankton. Mar. Biol. 60: 201-207.

Gordon, D.C. Jr. and C. Desplanque. 1983. Dynamics and environmental effects of ice in the Cumberland Basin of the Bay of Fundy. Can. J. Fish. Aquat. Sci. 40: 1331-1342.

Hanson, R.B. and W.J. Wiebe. 1977. Heterotrophic activity associated with particulate size fractions in a Spartina alterniflora salt-marsh estuary, Sapelo Island, Georgia, USA, and the continental shelf waters. Mar. Biol. 42: 321-330.

Hargrave, B.T. 1972. Aerobic decomposition of sediment and detritus as a function of particle surface area and organic content. Limnol. Oceanogr. 17: 583-596.

Lopez, G.R. and J.S. Levinton. 1978. The availability of microorganisms attached to sediment particles as food for Hydrobia ventrosa Montagu (Gastropoda:Prosobrahcnia). Oecologia 32: 263-275.

Miller, J.D. and N.J. Whitney. 1981a. Fungi from the Bay of Fundy. II. Observations on fungi from living and cast seaweeds. Bot. Mar. 24: 405-411.

Miller, J.D. and N.J. Whitney. 1981b. Fungi from the Bay of Fundy. III. Geofungi in the marine environment. Mar. Biol. 65: 61-68.

Schwinghamer, P. 1981a. Characteristic size distributions of integral benthic communities. Can. J. Fish. Aquat. Sci. 38: 1255-1263.

Schwinghamer, P. 1981b. Size distributions of benthic organisms in the Bay of Fundy, Canada. Ph.D. thesis, Dalhousie University. 122p.

Schwinghamer, P., F.C. Tan and D.C. Gordon. 1983. Stable carbon isotope studies on the Pecks Cove mudflat ecosystem in the Cumberland Basin, Bay of Fundy. Can. J. Fish. Aquat. Sci. 40 (Supp. 1): 262-272.

Tunnicliffe, V. and M.J. Risk. 1977. Relationships between the bivalve Macoma balthica and bacteria in intertidal sediments: Minas Basin, Bay of Fundy. J. Mar. Res. 35: 499-507.

Van Es, F.B. 1982. Community metabolism of intertidal flats in the Ems-Dollard estuary. Mar. Biol. 66: 95-108.

Wolter, K. 1982. Bacterial incorporation of organic substances released by natural phytoplankton populations. Mar. Ecol. Prog. Ser. 7: 287-295.

QUESTIONS AND COMMENTS

B. Hargrave: Did you ever count bacteria on flocculent detrital particles or pieces of *Spartina* debris? Correct me if I am wrong, but most of your counts are made on fine suspended particles and not coarse debris collected with a net.

L. Cammen: The only fractionation work I have done is on surface sediment where the largest size fraction was particles greater than 243 µm. In Cumberland Basin, the bacterial concentrations are greatest on the smaller particles (Cammen 1982). I have counted bacteria in sediments from other areas and the concentration in the largest size fraction was always relatively low. I have not done this in the water column.

B. Hargrave: Large particles may be small in numbers and mass but they may be micro-sites of decomposition.

L. Cammen: What I did not show was if the total sediment weight is taken into account, then in the spring, most of the bacteria are associated with particles in the 10-40 µm range, a little larger. Only 4-6% are found on particles larger than 102 µm. However, these are counts on surface sediment, as shallow as possible. My data deal only with standing stock, not activity, so the large particles could be more important in terms of decomposition.

G. Daborn: I endorse your remark about needing more work on the activity of bacteria. Gail Brown and Mike Brylinski started some preliminary experiments this year on heterotrophic uptake in the Cornwallis Estuary where the suspended sediment concentrations are in excess of 500 mg L^{-1}. On the first couple of runs they could not saturate the system. The bacteria were capable of turning over all the glucose added, so obviously they were extremely active.

L. Cammen: The greater the suspended sediment concentration, the greater the potential for heterotrophic activity due mostly to the increased numbers of bacteria.

K. Mann: I am not clear about your comparison of bacteria in water and sediment normalized to carbon. It seems to me that carbon is going to be very much more dilute in the water column. To explain it, you relate to the amount of surface area available and I would have thought that per unit volume the surface area of sediment was much greater than in the water column. At this stage it seems like a funny basis for comparison. Can you clarify that?

L. Cammen: These are attached bacteria, not all bacteria. In terms of a given weight of particles, a given amount of carbon in the water will have more bacteria associated with it than a given amount of carbon in the sediment. The reason is that the given amount of carbon in the water is in the form of much smaller particles which have more surface area. The point of normalizing for carbon is that invariably you will find that numbers of bacteria are closely correlated with the amount of carbon available. The problem is that the amount of carbon available is also a function of particle size and we really don't know which factor is more important. What I have done here is first eliminate the amount of carbon as a factor and then make my comparison. This suggests that suspended particles are finer than surface sediment. I am not really comparing a volume of water to a volume of sediment. I am comparing a volume of particles in water to an equal volume of particles in sediment.

M. Majka: Have you attempted to identify the bacteria or do laboratory studies?

L. Cammen: I made no attempt to do any taxonomy. This was the very first microbial study to be done and it is only baseline data. I was primarily interested in the relation of bacteria to the rest of the system. I thought it was most important to get some knowledge of numbers and rates in the field. When you work with laboratory cultures, you are studying bacteria under unusual conditions and it is hard to extrapolate that data to the field. Such data may be valuable in some instances, but they do not answer the kind of questions I would like to see addressed.

Zooplankton Studies in the Upper Bay of Fundy since 1976

Graham R. Daborn

Department of Biology
Acadia University
Wolfville, N.S. B0P 1X0

ABSTRACT

Extensive collections of zooplankton have been made in the Bay of Fundy in association with larval fish studies. Within the upper portions of the Bay of Fundy system, collections have been made with a variety of gear, for several months during the year, utilising sequential time-series sampling over whole tidal cycles and general surveys. Zooplankton diversity declines with distance up the Bay toward the inner reaches. Abundance and biomass decline to a minimum in Chignecto Bay and Minas Basin where suspended sediment levels are <50 mg L^{-1}, but rise dramatically in extremely turbid waters (>500 mg L^{-1}). The zooplankton of inner waters is dominated by small estuarine species such as *Eurytemora herdmani* and *Acartia tonsa*. High biomass in extremely turbid waters suggests the plankton food web is detritus-based. Visual feeders are absent and vertical movements eliminated, except in the clearer waters of Chignecto Bay and Minas Basin. Specific studies of *Eurytemora herdmani* and *Neomysis americana* indicate high production in the most turbid waters, and both species are utilized extensively by fish. In moderately turbid areas fish feed primarily on benthic organisms.

Key words: zooplankton, suspended sediment, diversity, productivity, copepods, tidal cycles, vertical migrations, trophic relationships.

RÉSUMÉ

Dans le cadre d'études sur les larves de poissons on a effectué d'importantes collectes de zooplancton dans la partie intérieure de la baie de Fundy. Dans les parties d'amont du réseau de la baie de Fundy on a effectué ces collectes au moyen d'une gamme diversifiée d'instruments, pend nt plusieurs mois de l'année et dans le cadre d'échantillonnages échelonnés dans le temps sur des cycles complets des marées ainsi que de dénombrements généraux. La diversité du zooplancton diminue en fonction de la distance dans la direction de l'amont dans la baie. L'abondance et la biomasse diminuent jusqu'à un minimum dans la baie de Chignectou et le bassin des Mines où les concentrations de matières en suspension sont inférieures à 50 mg par L, mais augmente dramatiquement dans les eaux extrêmement turbides où les concentrations de matières en suspension sont supérieures à 500 mg par L. Les petites espèces estuariennes comme *Eurytemora herdmani* et *Acartia tonsa* sont les espèces dominantes du zooplancto des eaux les plus intérieures. La présence d'une grande quantité

de biomasse dans les eaux extrèmement turbides suggère que le plancton vit dans un milieu riche en matériaux décomposés. Les espèces qui dépendent de la vue pour se nourrir sont absentes et les déplacements verticaux sont éliminés sauf dans les eaux plus claires de la baie de Chignectou et du bassin des Mines. Les études spécifiques d'Eurytemora herdmani et de Neomysis americana indiquent une production élevée dans les eaux les plus turbides et les deux espèces sont largement utilisées par le poisson. Dans les secteurs modérément turbides la plupart des poissons se nourrissent principalement d'organismes benthiques.

SURVEYS IN THE BAY OF FUNDY

Prior to 1976 studies of plankton in the Bay of Fundy system had primarily concerned the outer region of the Bay, particularly the Quoddy region and the upwelling systems between Grand Manan and Brier Island. A number of publications provide an extensive coverage of zooplankton in the Gulf of Maine - outer Bay of Fundy region (e.g. Bigelow 1926; Fish 1936a, b, c; Fish and Johnson 1937; Legaré and MacLellan 1960). Only one publication, however, deals with the inner Bay of Fundy (defined for convenience as the Bay northeast of the Digby-Saint John line to Cape Chignecto) and Minas Basin. Jermolajev (1958) presented an account of analyses of 99 plankton tows taken in 1920 (86) and 1951 (13) at 28 stations in the inner Bay, Minas Basin and Cobequid Bay. These collections were a mixture of vertical and horizontal tows using nets with mesh size of 570 or 280 μm. Although her results indicated some very high zooplankton numbers in some samples from Minas Basin and Cobequid Bay, Jermolajev (1958) was much more impressed with the sparseness of zooplankton in the inner Bay. She concluded: "The extreme paucity of plankton in the inner Bay as well as the poor condition of the few immigrants there leaves no doubt that fish larvae and larger fish that depend upon plankton for food will be little apt to grow and survive if they remain there."

In the last decade, sampling activity in the Bay of Fundy has increased greatly and some of this activity has included the two subsystems at the head of the Bay - Chignecto Bay and Minas Basin. Since 1969 larval herring surveys have involved plankton tows at 116 stations covering the entire Bay of Fundy, and including one station in Minas Basin (No. 116) and three (Nos. 103-105) in Chignecto Bay (Fig. 1). Because of the length of time required to traverse Minas Channel, the Five Islands Station (No. 116) has only been visited once in the last five years (Power, personal communication). In general all other stations have been visited 2-4 times each year in a programme that is continuing at the present time.

Primary objectives of this survey relate to larval herring distributions. Zooplankton collections are made with paired Bongo nets fitted with 505 and/or 333 μm mesh. Both mesh sizes retain adults of many copepod species, although immature stages are allowed to pass through. A preliminary analysis of zooplankton samples taken in 1969 shows that maximal densities (>20 m^{-2}) of the euphausiids Meganyctiphanes norvegica and Thysanoessa inermis are primarily encountered at the mouth of the Bay and in the Quoddy region (Fig. 2). A second centre of abundance in the inner

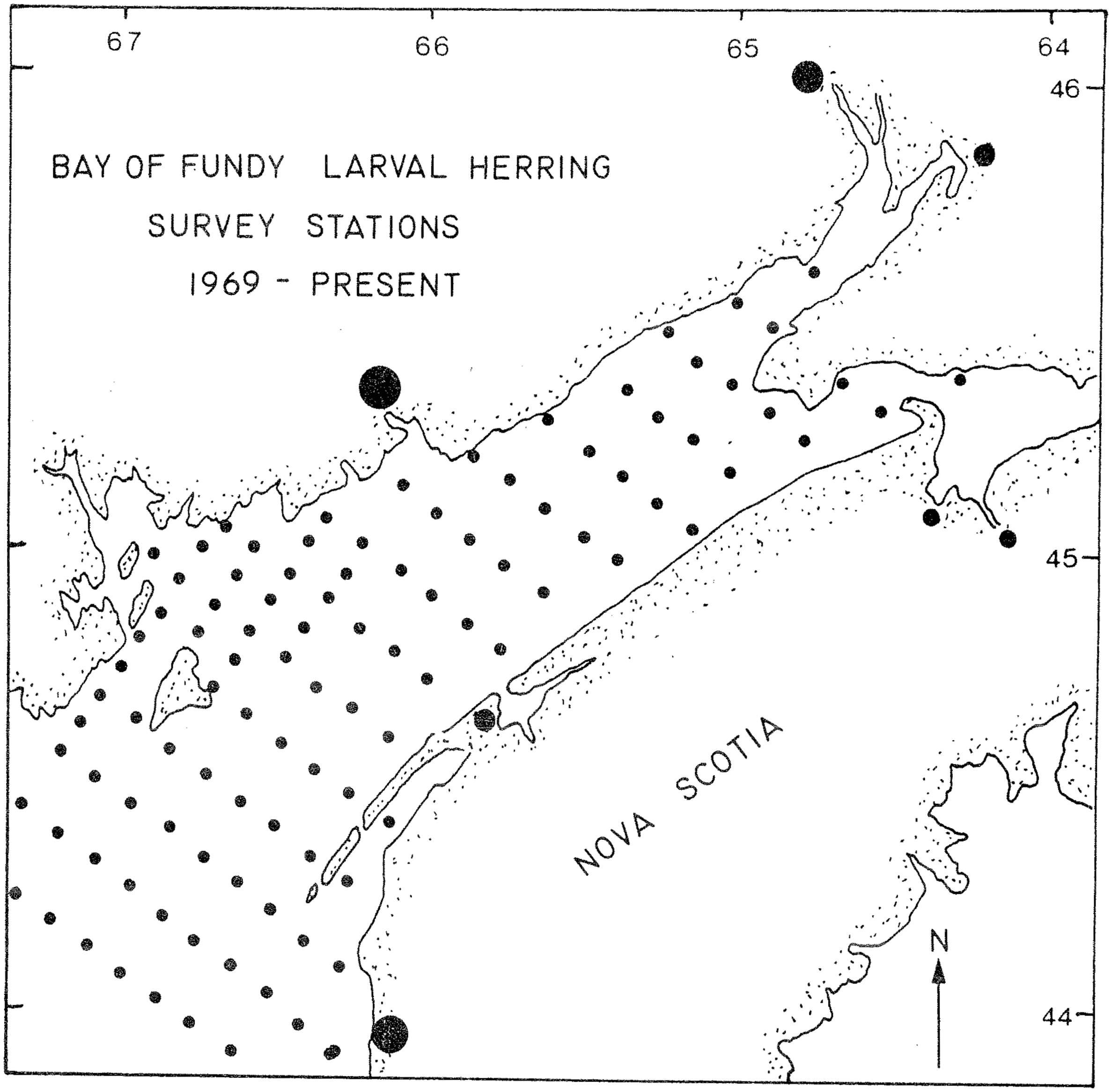


Fig. 1. Larval herring sampling stations in the Bay of Fundy, 1969-82.

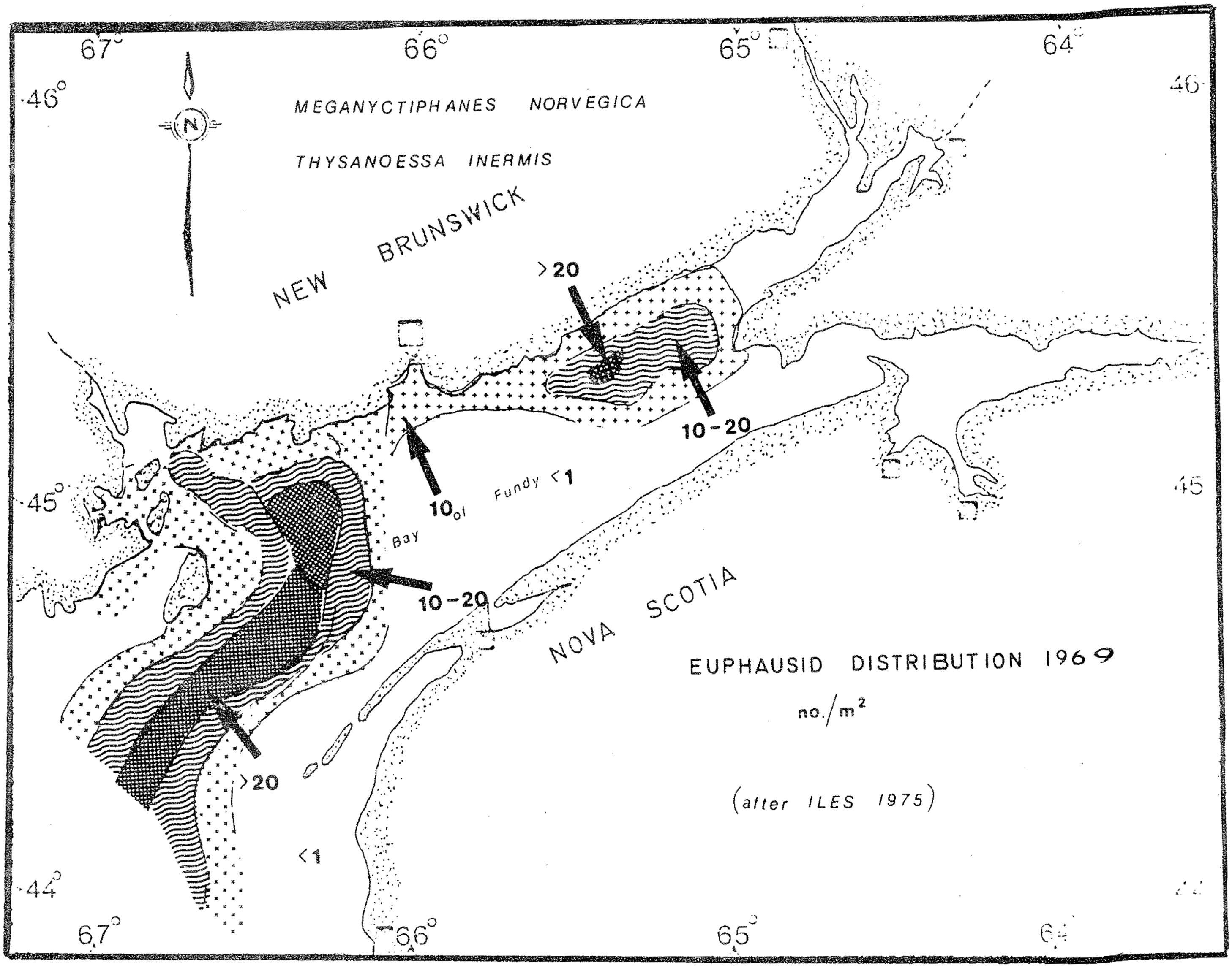


Fig. 2. Distribution of euphausiids in the Bay of Fundy (after Iles 1975).

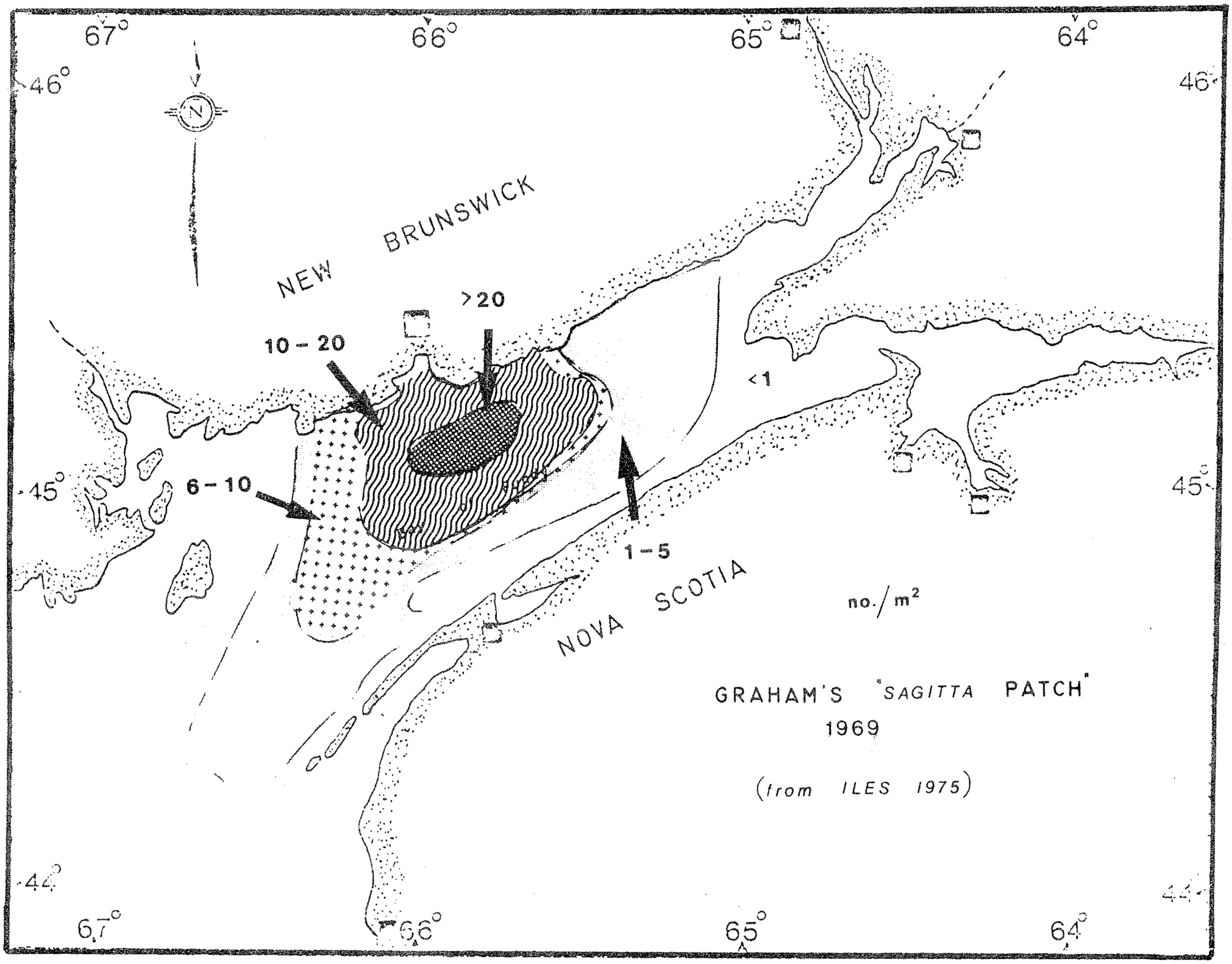


Fig. 3. Michael Graham's Sagitta patch (after Iles 1975).

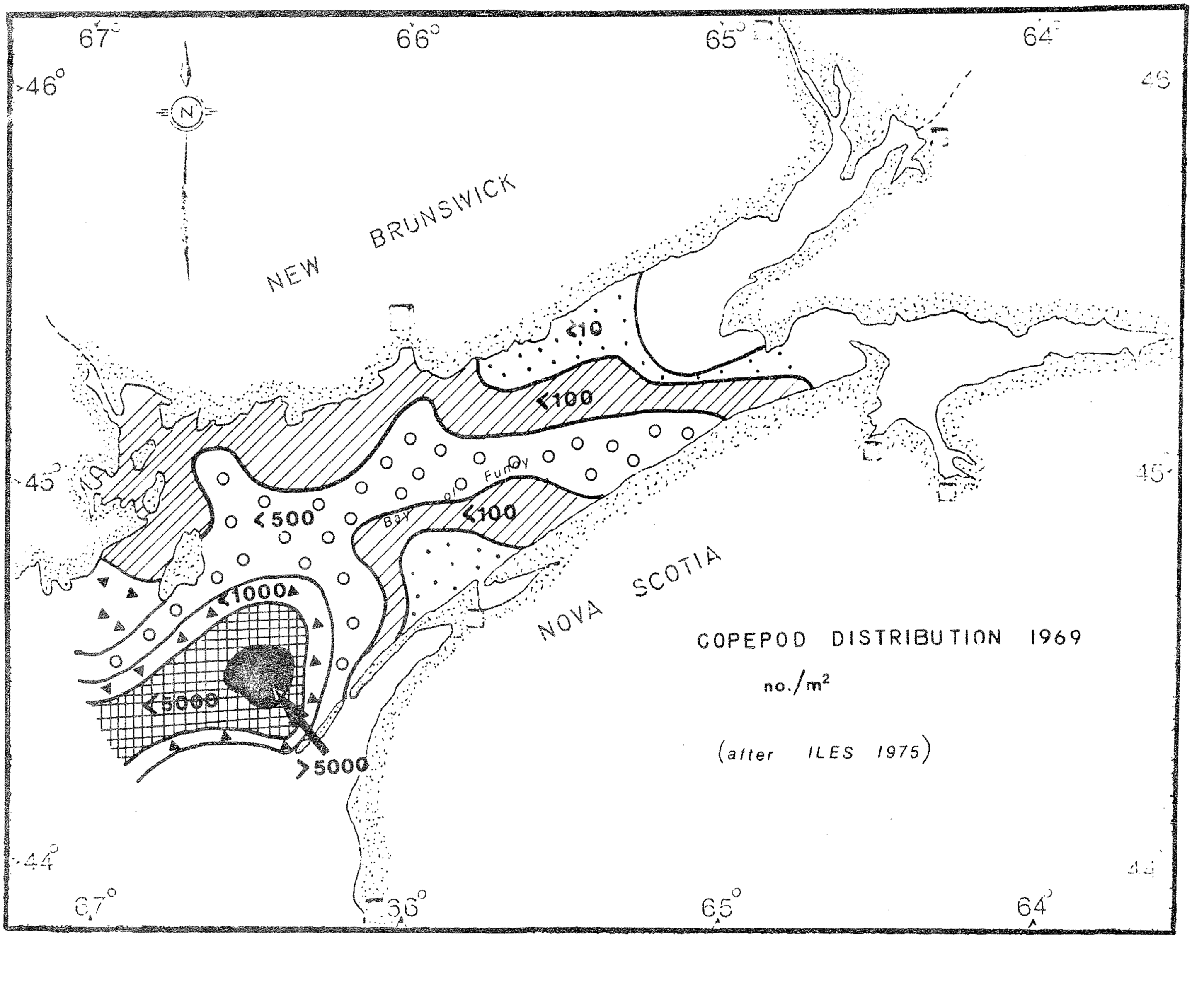


Fig. 4. Copepod distributions in the Bay of Fundy (after Iles 1975).

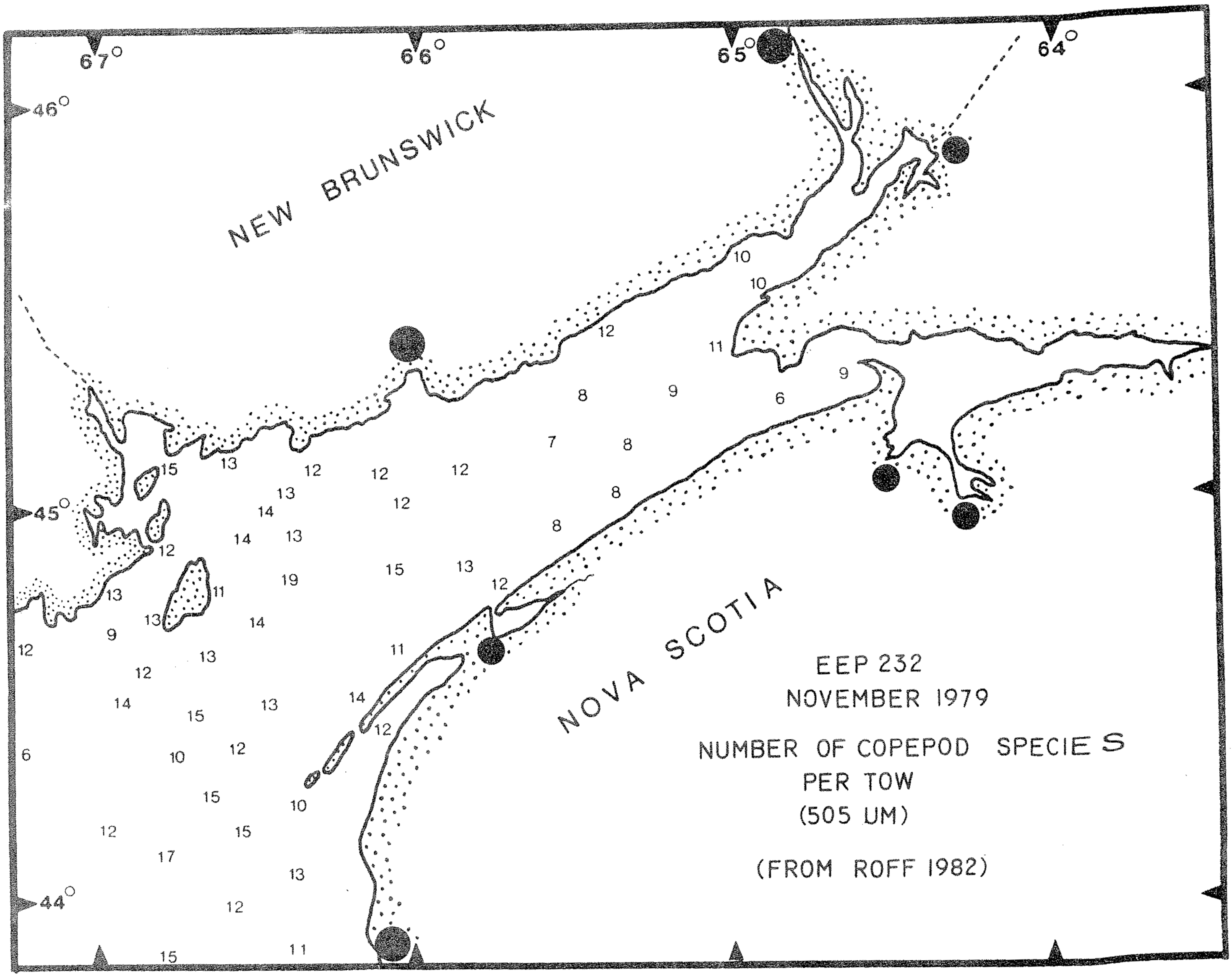


Fig. 5. Copepod diversity in the Bay of Fundy (after Roff, unpublished data).

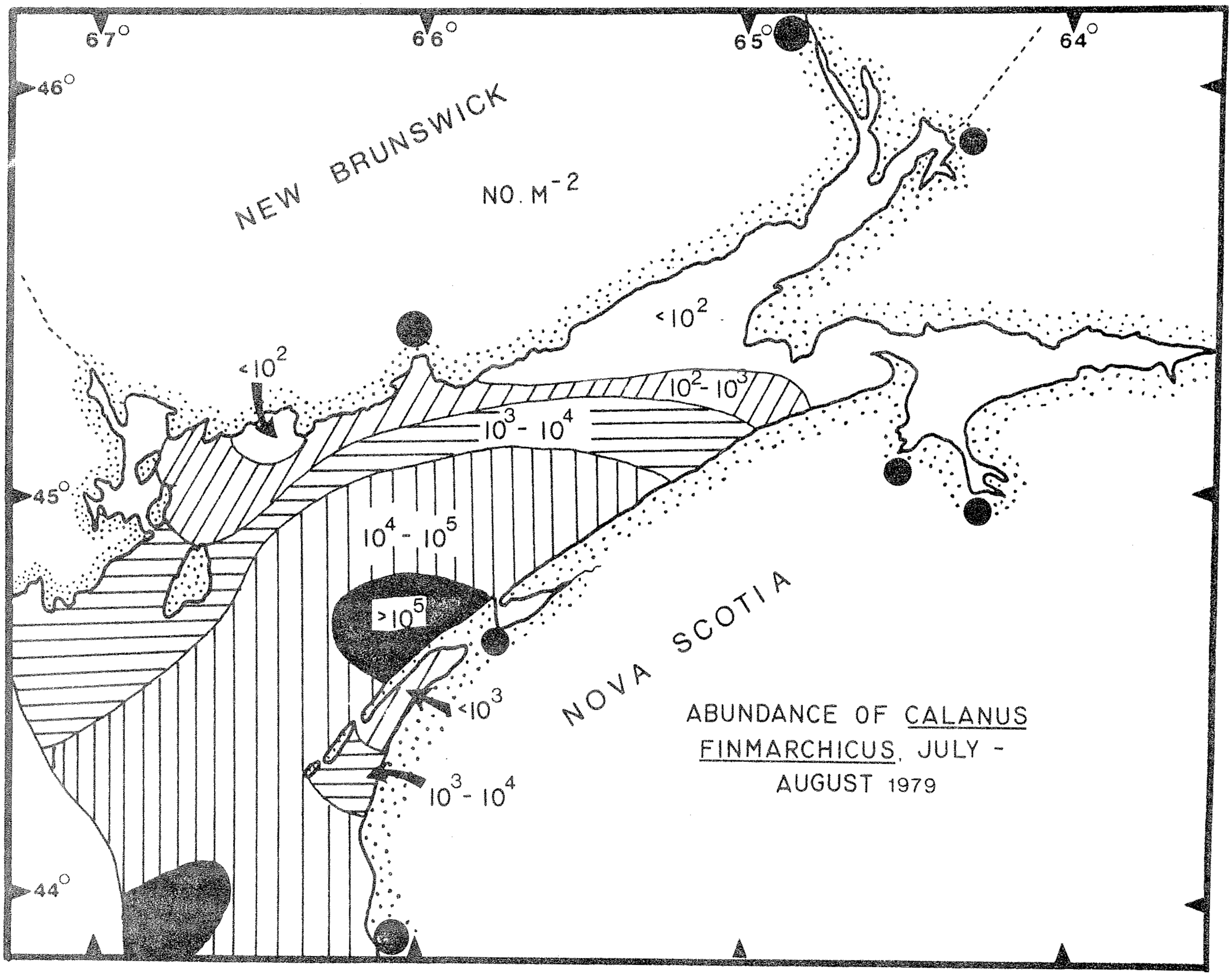


Fig. 6. Distribution of Calanus finmarchicus in the Bay of Fundy (after Roff, unpublished data).

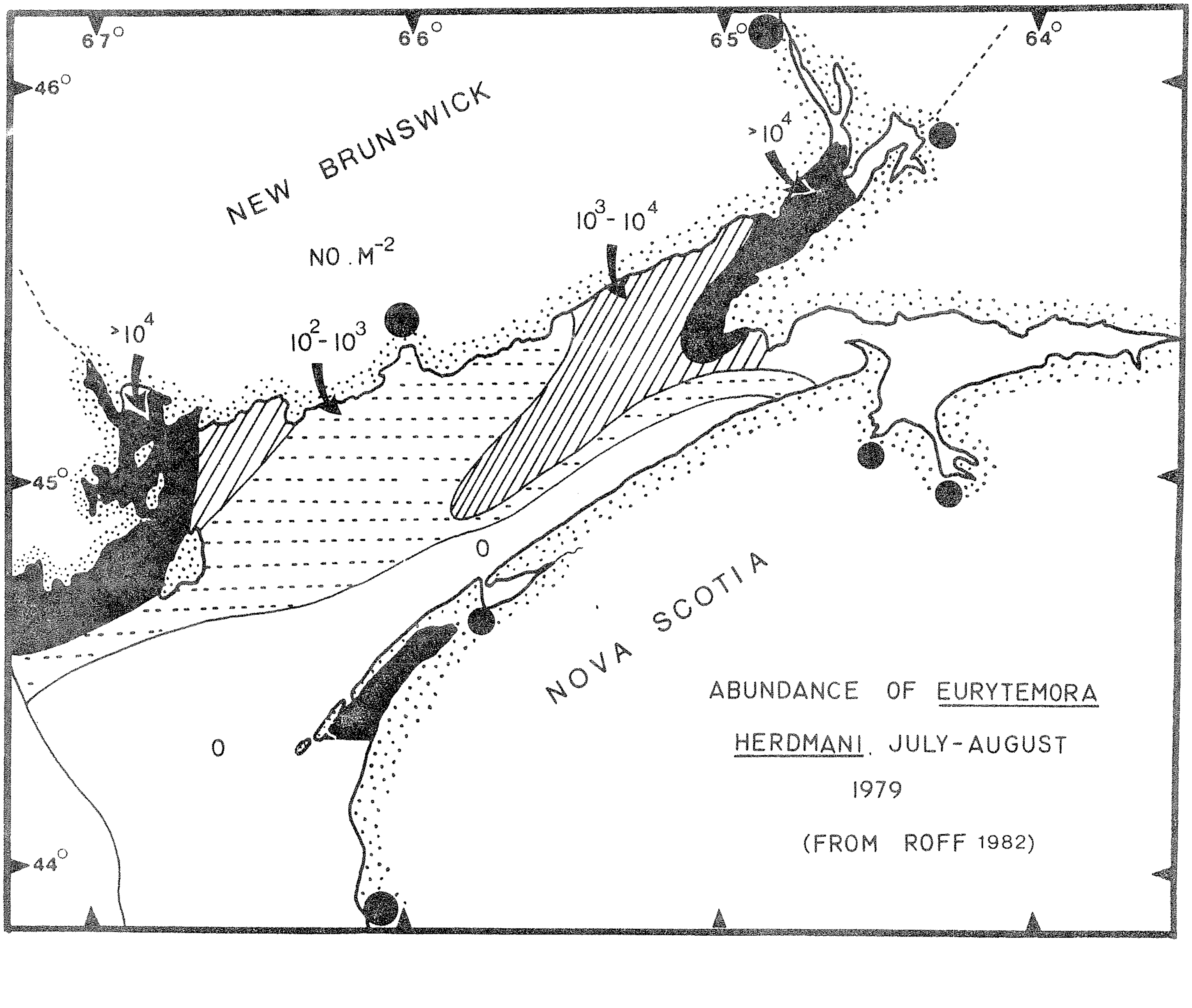


Fig. 7. Distribution of Eurytemora herdmani in the Bay of Fundy (after Roff, unpublished data).

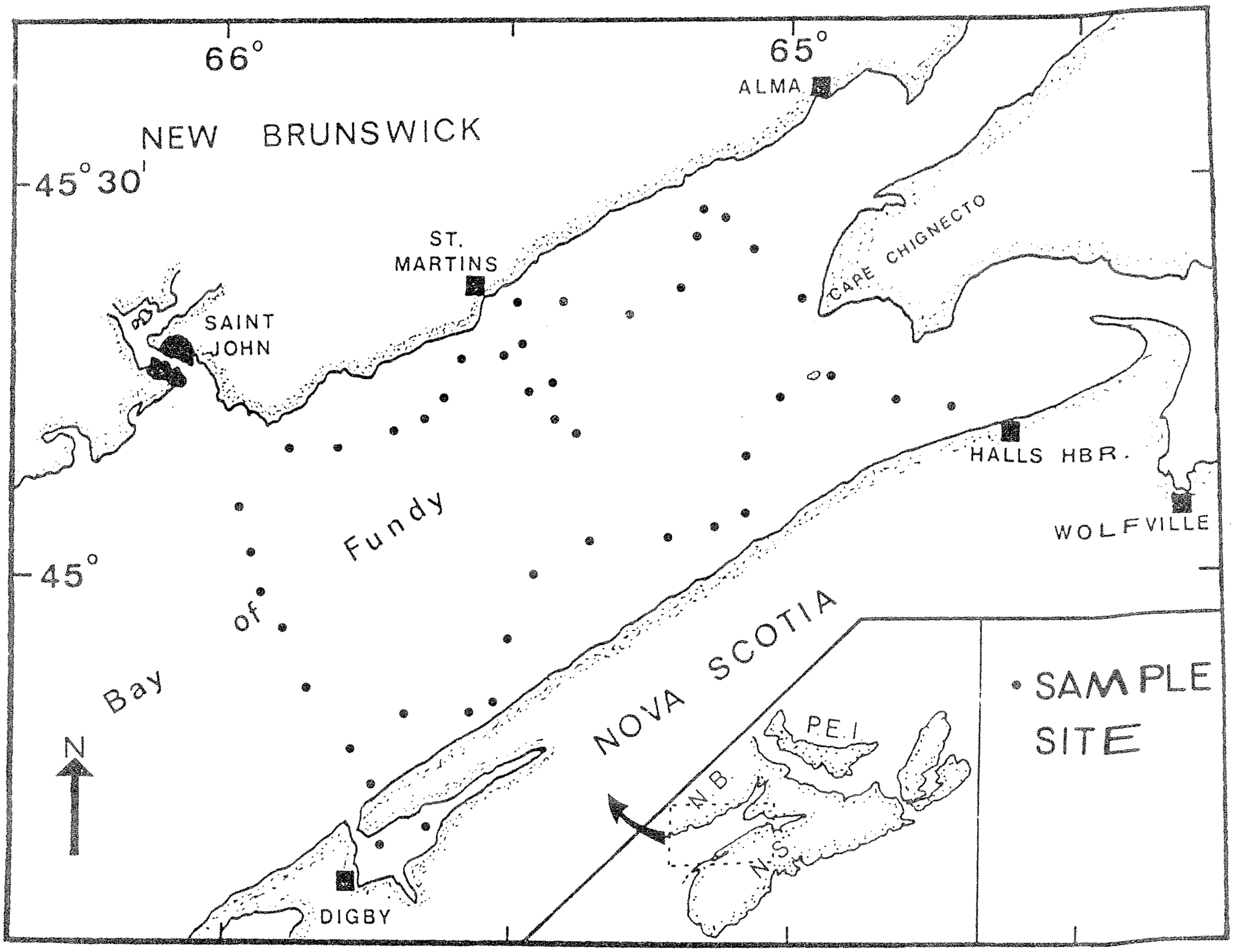


Fig. 8. Neuston sampling stations of the inner Bay of Fundy, 1979.

TABLE 1. Zooplankton study programmes in the Bay of Fundy since 1976.

Programme	Year(s)	Region(s)	No. Stations	No. Cruises	Months	Techniques	Agency
Larval Herring Surveys	1969-P	Bay of Fundy	116	20	Jan-Dec	10 min. oblique tows 65 cm dia. Bongo nets 505 & 303 μm mesh Occasional neuston tows	St. Andrews Biol. Stn. (Iles)
M/V Oran II	1978	Shepody Bay	2A	1	June	10 min fixed-depth tow 30 cm dia. net 246 μm mesh	B.I.O. (Hildebrand)
C.S.S. Dawson	1978-80	Bay of Fundy Chignecto, Shepody	16T	5	Feb, Mar-Apr	Vertical haul + occasional Fixed depth tow	
		Cumberland Minas Basin	3-5A	5	Aug, Oct-Nov	30 cm dia. metered net 160 μm (+occ. 330,560, 1050 μm)	Acadia/BIO (Daborn)
C.S. Hart	1978	Cumberland	1A	1	Dec	Vertical haul 30 cm dia 60 μm + 160 μm Horizontal tow 560 μm	Acadia/ St. Andrews (Daborn)
M/V Miss Patti II	1979	Bay of Fundy	44	3	July-Oct	Neuston tows 1 m & 4 m dia 1170 μm mesh	Acadia/ St. Andrews
						Vertical hauls 160 μm mesh	(Daborn/ Stasko)
M/V Scoter	1980	Minas Basin	5	4	Jun-Sept	Vertical hauls 30 cm dia 160 μm mesh	Acadia (Daborn)
Annapolis Estuary	1981-82	Annapolis Estuary	10	18	Mar-Dec	Vertical hauls 30 cm dia 160 μm mesh 30 cm dia 64 μm mesh	Acadia (Redden)
Cornwallis Estuary	1981-82	Cornwallis Estuary	1		Jan-Dec	Vertical & horizontal tows 30 cm diam 160 μm mesh	Acadia (Brown)

P = present; T = transect station; A = 13+ h anchor station

Bay off St. Martin's is probably primarily Thysanoessa and may occur only occasionally. The life histories and distributions of euphausiids in the Bay of Fundy have been studied by Corey and colleagues at the University of Guelph and described in several publications (Kulka and Corey 1978, 1982; Kulka et al. 1982a, b).

Chaetognaths and ctenophores frequently seem to be concentrated in a patch (Graham's Sagitta patch) south of Saint John (Fig. 3), a phenomenon that Iles (1975) suggests is a consequence jointly of hydrographic forces of the environment and behavioural characteristics of the plankton. Copepods on the other hand tend to show a more regular distribution in the Bay, having maximal densities (>5000 m^{-2}) between Grand Manan and Brier Island (Fig. 4) and declining steadily at stations further up the Bay.

According to Iles (personal communication) these general patterns of distribution are shown in subsequent surveys. Analysis of samples is not complete for all cruises and all stations, and generally does not involve identification below family or order level (Frost, personal communication). More detailed examination of these samples has been carried out recently by Roff and Corey and their students at the University of Guelph. Roff (unpublished data) has developed the first general account of the microcrustacea, principally the copepods, occurring over the main Bay of Fundy. As one would expect, the diversity (as indicated by number of species) tends to be considerably less in the inner Bay, inside the Digby-Saint John line where the water column is essentially unstratified (Fig. 5). The number of species increases, however, as one approaches Chignecto Bay where it is augmented by estuarine and perhaps benthic forms such as the harpacticoids. Calanus finmarchicus becomes progressively less abundant (Fig. 6) and is represented primarily by copepodid stages III-V. As Jermolajev (1958) observed, this species probably cannot maintain itself within the Bay, but drifts inward with tidal and residual circulation of water. The estuarine copepod Eurytemora herdmani, however, exhibits the reverse pattern, with maximum abundance in turbid, shallow areas such as St. Mary's, Passamaquoddy and Chignecto Bays (Fig. 7).

A survey of near-surface and neustonic plankton was carried out in the Inner Bay as a joint project between St. Andrews Biological Station and the Department of Biology at Acadia Univeriesty in 1979. Sampling was conducted using 1 m and 4 m diameter neuston nets towed at 4 and 2 kts, respectively, at 44 stations (Fig. 8) during each of 3 cruises. When the 1 m neuston net was towed it was paired with a 1 m diam. conical net set at a mean depth of 1 m. All samples were fitted with 1179 Nitex mesh and thus collected only macrozooplankton. The survey, although limited, provides some information on distributions of macrozooplankton but perhaps of greater interest is the indication that a well-developed neustonic component is to be found in the Inner Bay (Table 1). Several species, particularly the amphipod Calliopius laeviusculus, the copepods Anomaloceraopalus and Harpacticus chelifer and several fish are more abundant in the top 15-20 cm of the water column during the daytime than they are at a depth of 50-150 cm. Our results failed to show a direct correlation of abundance with the presence of floating wrack (mostly Ascophyllum nodosum), but determination of the quantity of the latter could not be made in this study and would repay much more investigation.

TABLE 2. Mean numbers of organisms/1000 m^3 captured in neuston and subsurface nets.

	Neuston net[1]	Subsurface net[1]	Ratio of Neuston to Subsurface
Isopods	13.10	0.15	83.3
Gammarid Amphipods	364.63	5.76	63.3
Lumpfish	2.08	0.13	16.0
Lobster Larvae	0.52	0.04	13.5
Fourbeard Rockling Larvae	15.43	1.39	11.1
Threespined Stickleback Larvae	15.56	2.76	5.6
Hake	0.34	0.06	5.7
Pleurobrachia	125.34	23.03	5.4
Hyperiid Amphipods	50.47	10.91	4.6[n.s.]
Chaetognatha	6.17	1.54	4.0[n.s.]
Crab Larvae	590.98	175.20	3.4
Polychaetes	1.57	0.84	1.9
Copepods	881.60	563.28	1.6[n.s]
Herring Larvae	3.89	3.08	1.3[n.s.]
Anomalocera	0.04	0.08	0.5[n.s.]
Caridea	0.32	0.75	0.4
Euphausids	0.94	3.13	0.3[n.s.]

[1] No. of paired samples = 120

[n.s.] Indicates no significant difference between means at 0.05 level.

STUDIES IN THE INNER BASINS

Zooplankton collections in the southern bight of Minas Basin have been carried out by Acadia University personnel, commencing in 1976. These early studies included distributional surveys within the Southern Bight and tidal studies (Pennachetti 1978, Daborn and Pennachetti 1979b), and involved examination of suspended sediment concentrations and particle size distributions (Daborn and Pennachetti 1979a). After some experimentation, a mesh size of 160 μm was adopted for plankton samplers since this mesh retains many juvenile stages of the dominant copepods while permitting most of the suspended particulate matter to pass through. Since much finer nets have been used, the results are not entirely comparable with those of Jermolajev (1958) but do lead to the same general conclusions: zooplankton populations in the Southern Bight are highly contagious, at times very abundant, and usually dominated by small (<1 mm length) estuarine copepods such as Eurytemora herdmani, Acartia tonsa and Pseudodiaptomus coronatus. Meroplanktonic components such as trochophore, cyphonautes and veliger larvae are frequently very numerous (>1000,000 m^{-3}). Studies at a fixed anchor station often showed striking changes in absolute and relative abundance with time over a tidal cycle (Daborn and Pennachetti 1979b).

Hildebrand (1981) occupied two anchor stations in the mouth of Shepody Bay in June 1978 (Fig. 9) sampling at fixed depths of 1-5 m with a 30 cm diam. net of 246 μm mesh. Samples were of 10 min duration each half hour for 13 hours. Hildebrand recognised two distinct planktonic associations: an estuarine one consisting mainly of A. hudsonica, E. herdmani, C. hamatus and meroplanktonic larvae, which formed most of the biomass present near low tide, and a second community dominated by Pseudocalanus sp. and Sagitta elegans around high tide. Maximum biomass values of >50 mg m^{-3} are comparable to those that can be derived from Jermolajev's (1958) data for Cobequid Bay (50-75 mg m^{-3}). There was no clear indication in Hildebrand's collections that light influenced abundance of most species with the possible exception of Pseudocalanus. The 1% light level was estimated to be at 1-2 m, and SPM levels always exceeded 100 mg L^{-1}; hence vertical migrations were not identifiable in the mouth of Shepody Bay (Hildebrand 1981).

Following this early work, zooplankton collections were made on each of five cruises of C.S.S. Dawson (Table 1). Most collections were made during anchor stations at Cape Enragé (Stations 6, 7, 8, 16, 23), Shepody Bay (9, 18) and Cumberland Basin (10, 17, 24). In August 1979 the Dawson occupied three anchor stations in Minas Channel (22), Minas Basin (21) and Economy Point (20). At each hour of the anchor station simultaneous vertical tows were taken with a 30 cm diam. Clarke-Bumpus sampler fitted with 160 μm mesh and a 1 m diam. conical net with 1050 μm mesh. During the February 1980 cruise this was replaced by a trio of 30 cm diam. metered samplers fitted with 160, 330 and 510 μm mesh nets.

This series of collections has been analysed to provide an account of the composition and abundance of microzooplankton for the inner waters of the Fundy system. Although procedural features limit the reliability of the data thus obtained, some general conclusions can be made. More than

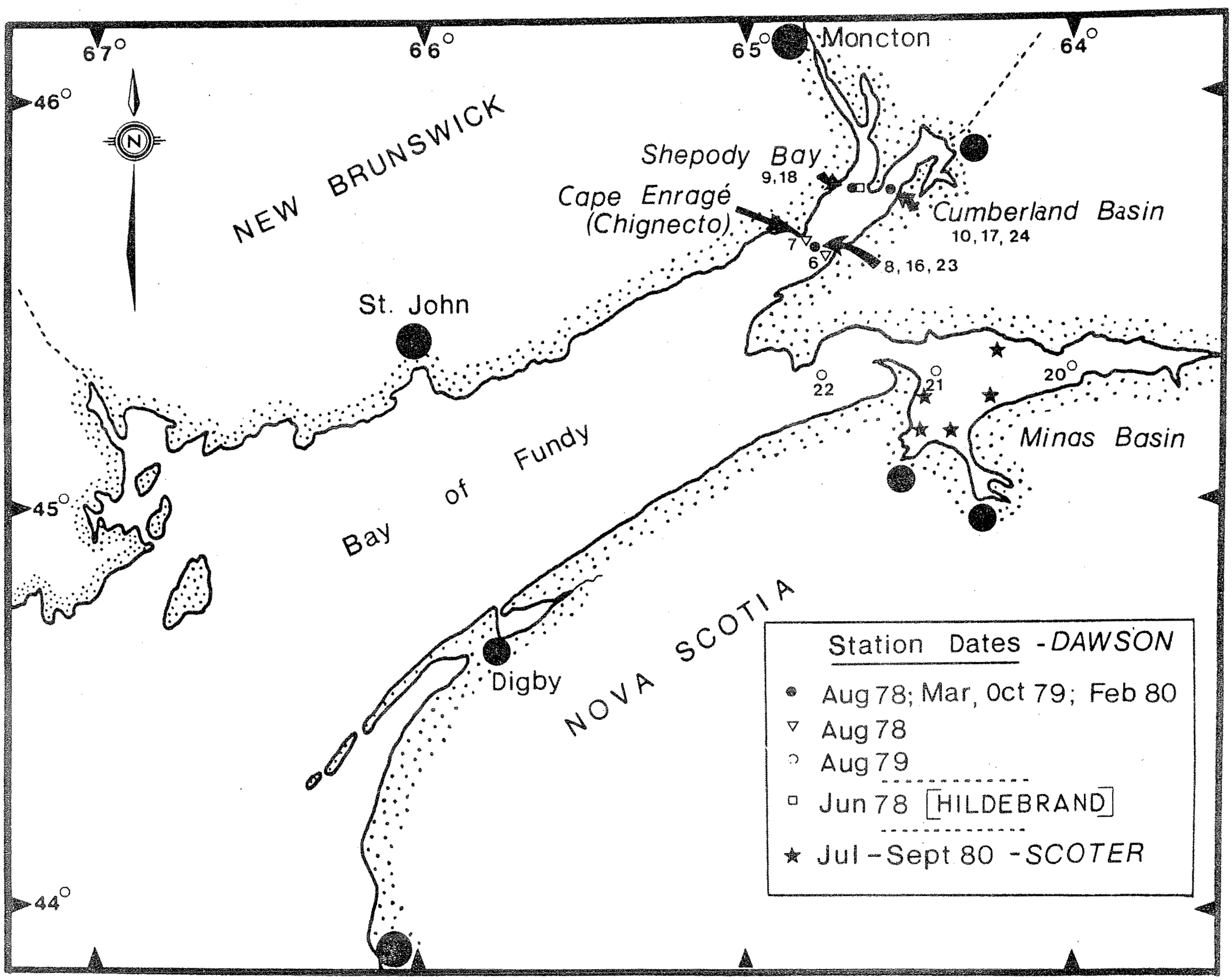


Fig. 9. Anchor stations of the inner Bay of Fundy, 1978-1980.

100 taxa have been recorded, many of them in numerous samples. Relative abundance is extremely irregular, often changing substantially from hour to hour. In all areas the plankton is dominated on most occasions by relatively small (<1.5 mm) estuarine copepods that are common to all areas (Fig. 10). Eurytemora herdmani, however, was notably absent from most Cumberland Basin samples, although one of the major dominants at all other sites. Furthermore, whereas Acartia hudsonica was more common in the Chignecto Bay subsystem (including Shepody and Cumberland), A. tonsa was the major form in the Minas subsystem. These differences are consistent with other reports (Jermolajev 1958, Daborn and Pennachetti 1979b, Hildebrand 1981) and it is tempting to ascribe the dominance of A. tonsa in the Minas Basin to the higher summer temperatures prevailing there.

The outermost stations in Chignecto Bay (6-8, 11-14, 18, 23), Minas Channel (22) and Cape Blomidon (21) are in regions of mixing between faunas derived from the Bay of Fundy and from the more turbid inner bays. The Fundy association includes Pseudocalanus sp., Oithona similis, Centropages typicus and immature Calanus finmarchicus. At these deeper, clearer and more saline stations, also, meroplanktonic larvae were less important numerically than at the shallow, turbid stations nearer shore. At the latter large swarms of trochophore or veliger larvae occasionally dominated samples. As a consequence of this, and patchiness in the holoplankton, diversity was generally lower at the inner stations, and lowest of all at the mouth of Cumberland Basin.

At all stations, distinct differences were evident between samples taken during the flood and those taken at corresponding stages of the ebb tide. These differences became extreme at the innermost stations. The 13-16 h duration of a station involved both day and night samples and at the relatively less turbid (<25 mg L^{-1} SPM) stations in Minas and Chignecto, some of the flood-ebb differences are attributable to vertical movements of the plankton. In all areas, perhaps particularly in Shepody Bay and Cumberland Basin, the samples indicate extreme patchiness of the plankton.

Direct measurements of biomass have not usually been made because of the large quantities of detritus present in most samples. Estimates based on abundance and mean individual weight have been made where estuarine copepods dominate the samples (Table 3). The values indicate that biomass of microcrustacea in these turbid waters is considerable and, since the estimates do not include macroscopic forms such as mysids, the total plankton bionass is really much greater.

A major limitation of the Dawson series is the long time interval between cruises. Brown (personal communication) has carried out a detailed survey of microzooplankton, suspended sediments and heterotrophic activity in the Cornwallis Estuary over a 1.5 year period. Samples were taken with a 160 μm mesh net at weekly or bi-weekly intervals near high tide at Port Williams. The zooplankton community consists of Acartia tonsa, Eurytemora herdmani, Pseudodiaptomus coronatus, Labidocera aestiva and numerous meroplanktonic or vagile benthic forms including Neomysis americana. E. herdmani was the dominant form during fall and spring months, being re-

Gp 1. *ALL REGIONS*

- *Acartia tonsa*
- *Acartia clausi (hudsonica)*
- *Centropages hamatus*
- *Centropages typicus*
- *Pseudodiaptomus coronatus*
- *Pseudocalanus minutus*
- *Neomysis americana*
- *Crangon septemspinosa*
- *Sagitta elegans*
- *Calanus finmarchicus*
- Copepod larvae
- Trochophore larvae
- Brachyuran larvae
- Harpacticoida

Gp 2. *ALL EXCEPT SHEPODY*

- *Labidocera aestiva*
- *Tisbe furcata*
- *Autolytus cornutus*
- *Balanus* larvae
- Gastropod larvae

Gp 3. *ALL EXCEPT CUMBERLAND*

- *Eurytemora herdmani*

Gp 4. *CHIGNECTO & MINAS ONLY*

- *Temora longicornis*

Fig. 10. Species groups of the microzooplankton of the inner Bay of Fundy.

TABLE 3. Mean abundance and estimated biomass of microzooplankton[1] at anchor stations in the inner Bay of Fundy.

Region	Station	Date	Abundance $\bar{X}$ No m^{-3}	Abundance $\bar{X}$ No. m^{-2}	Biomass Mg m^{-3}	Biomass Mg m^{-2}	Diversity H[1]
Chignecto Bay	6	Aug 78	376	11,650	3.94	–	1.66
	7	Aug 78	562	21,931	6.63	–	1.35
	8	Aug 78	516	46.420	8.79	–	1.51
	16	Mar 79	48	2,240	0.01	–	0.60
	23	Oct 79	257	13,090	0.68	–	1.33
Cobequid Bay	20	Aug 79	167	5,187	3.48	–	1.24
Minas Basin	21	Aug 79	116	5,117	1.19	–	1.70
Minas Channel	22	Aug 79	25	1,256	0.36	–	1.82
Shepody Bay	9	Aug 78	372	9,228	4.52	–	0.56
	18	Apg 79	334[2]	8,702[2]	0.11[2]	–	0.45
Cumberland	10	Aug 78	466	11,660	9.23	116.6	0.95
Basin	17	Apt 79	92	2,120	0.01	7.3	0.56
	24	Oct 79	114	3,542	1.58	45.4	0.34

[1] Biomass estimates include copepods only, not larger plankters nor meroplanktonic forms.

[2] Estimates exclude V. large sample with >110,000 trochophore larvae at cast 7

placed by A. tonsa in the warmer months. This study represents the only detailed examination of such a highly turbid system. It reinforces the impression derived from the Dawson anchor station series that biomass of plankton increases substantially in the more turbid regions of the system.

Brown's frequent and consistent sampling allows a reasonable estimate of standing crop biomass to be made for at least the dominant copepods. Over 58 samples, average biomass of A. tonsa was 153.3 mg m^{-2} and of E. herdmani was 82.0 mg m^{-2}. These values are very high compared to other estuarine systems. Although direct determinations of production/biomass ratio have not been made, adoption of values quoted in the literature (P/B = 24 for A. tonsa, 33 for E. herdmani from Burkill and Kendall 1982) gives estimates of production of 3.7 g m^{-2} yr^{-1} and 2.7 g m^{-2} yr^{-1} for A. tonsa and E. herdmani respectively. The adopted P/B ratios may be too high; nonetheless the biomass values clearly indicate the potential for very high secondary production in the plankton of the most turbid areas. Recent measurements of primary production and heterotrophic activity in the water column have shown that the former is about nil and the latter extremely high. Since the dominant copepods are well known to be omnivorous, and the bacteria are almost all associated with suspended particles (Cammen and Walker 1982) it is clear that the high planktonic biomass is fueled by the organic matter-microflora complex in suspension. Examination of gut contents confirms that the numerically dominant copepods ingest suspended particles only.

Evidence that the trophic support for the microzooplankton is adequate or even abundant is provided by an examination of reproductive activity in E. herdmani from the Cornwallis River (Crawford, personal communication). She has shown that egg-bearing females are present from October through July, with clutch sizes <120 eggs. There are 5 or 6 generations during the year. Such reproductive output clearly suggests that food supply is more than adequate for maintenance of the population, and that productivity of this species may be quite high.

MACROZOOPLANKTON

A major limitation of the studies outlined above arises from the inadequate sampling of the larger crustaceans and fish that may readily avoid capture in slow-moving, fine-mesh nets. There is little doubt that much more of the biomass in the water column in highly turbid regions is associated with semipelagic forms, particularly the mysids (Mysis stenolepis, M. mixta and Neomysis americana) and Crangon septemspinosa, than with the abundant but small copepods. These macrozooplankters have been studied by Corey and her students in Passamaquoddy Bay (Pezzack and Corey 1979, Amaratunga and Corey 1979, Corey 1981, 1982). Occasional collections with larger and coarser nets have shown very considerable abundance of mysids in Cumberland Basin, Shepody Bay and the Cornwallis Estuary. Furthermore, examination of fish stomach contents has often shown a disproportionate amount of larger crustaceans than recorded in plankton tows because many species feed selectively on the largest particles that can be ingested. In effect some fish provide an alternative sampling method that selectively captures macrozooplankton. Both American shad, Alosa sapidissima (Dadswell, personal communication) and alewives, A. pseudoharengus, feed extensively on mysids which they effectively filter from the water column.

The only study of mysids in this area was carried out by Prouse (unpublished data) in Cumberland Basin. Midwater (5 m depth) plankton tows were made on six occasions between June 14 and October 13 1981 using a 0.5 m diam. conical net with 600 μm mesh. The survey was repeated in 1982, when samples were taken at three different depths. Prouse concluded that Neomysis americana was most abundant near the mouth of Cumberland Basin in summer, but was almost absent in October, whereas Mysis stenolepis was concentrated in upper regions of the Cumberland Basin. Size frequency distributions indicated that Neomysis had two generations per year, and Mysis one. These results correspond with those obtained from Passamaquoddy Bay (Amaratunga and Corey 1975, Pezzack and Corey 1979). It is probable that both mysids utilize detritus extensively and provide the major link between detritus of salt marsh or terrigenous origin and the abundant fish fauna of Cumberland Basin. Suitable collections are not available for Cobequid Bay, but the presence of fairly large numbers of shad and alewives in the Bay in summer (Dadswell, personal communication) suggests that some macrozooplankters must be abundant there. Analysis of stomach contents will provide a good indication of the dominant forms. Obviously, much remains to be done to evaluate the importance of the larger pelagic organisms in the upper Bay.

BIOPHYSICAL RELATIONS OF THE PLANKTON

The foregoing account briefly outlines major research activities on zooplankton in recent years in the inner regions of the Bay of Fundy system. Although systematic collections have rarely been carried out with appropriate frequency and interpretation is limited by the difficulties of adequate sampling in the extreme conditions found in the inner regions, some general features have emerged with sufficient clarity to afford tentative conclusions.

Physical parameters quite clearly exert an overwhelming influence on the zooplankton of the system. Plankton diversity and abundance decline steadily as one proceeds up the Bay of Fundy, as coastal/neritic genera such as Calanus, Metridia, Pleuromamma, Scolecithrix, Oncaea and Anomalocera disappear. The innermost turbid waters are dominated numerically by small estuarine species of Eurytemora, Acartia and Pseudodiaptomus. Along the same axis, tidal range, vertical mixing and suspended particulate matter concentrations increase while depth, light penetration and salinity decrease. Although all these physical factors are covariant and interrelated, it is probable that SPM levels are of primary importance in determining the community composition, diversity and abundance of microzooplankters. As turbidity increases, the photic zone is reduced and phytoplankton progressively diminished, removing the major food sources for obligate herbivores such as Calanus. In the innermost turbid regions extremely high concentrations of particulate matter, associated with attached bacteria, provide a different food source for omnivorous species such as Eurytemora and Acartia. In between, where SPM levels are too great to permit sufficient phytoplankton production, but too low for effective filtering, the abundance and biomass of zooplankton are much lower. The relationship appears as shown in Fig. 11.

According to this interpretation, the Bay of Fundy is a system with a production pump at each end, one associated with autotrophic production at the mouth of the Bay and the other with allochthonous production (vis à vis the water column) of the innermost macrotidal regions. The similarity between this model of planktonic secondary production and the variation in production of benthos, shorebirds, benthic algae and salt marshes (eg. Peer 1984, Prouse et al. 1984, Hicklin 1984) is striking.

Sequential sampling over complete tidal cycles sometimes indicates that specific composition varies in a consistent pattern, although this is often masked by the effects of patchiness. For example, in Minas Basin summer zooplankton populations include both Eurytemora herdmani and Acartia tonsa. Over a single tidal cycle, A. tonsa was the dominant form near low tide but was replaced by E. herdmani near high tide. When displayed as a function of SPM concentration the percentage of a sample represented by E. herdmani declines monotonically, whereas that of A. tonsa rises (Fig. 12). As noted elsewhere (Daborn and Pennachetti 1979b), it is probable that E. herdmani is restricted to deeper waters by temperature limitations rather than by SPM level since at other seasons the species tolerates much higher turbidities. A similar temporal relationship is evident in Cumberland Basin between A. hudsonica and Pseudodiaptomus coronatus (Fig. 13). Although present studies provide a valuable basis, much more needs to be done before a reasonable model of zooplankton distribution, composition and abundance in these turbid regions can be constructed.

Results from Cumberland Basin and the Cornwallis Estuary indicate that zooplankton productivity may be higher than previously expected and may even be comparable to that in clearer waters. Trophic support comes primarily through non-living organic matter and bacteria. The zooplankton is utilized by a few fish species, although most shift to feeding on the benthos when large enough. The zooplankton provides an integral link between suspended organic material and the terminal consumer. A considerable nursery role and potential is therefore indicated for these waters. An assessment of this role, however, can only come from a prolonged, consistent study of zooplankton productivity in these inner regions.

ACKNOWLEDGMENTS

I am grateful to a number of people who kindly provided references and unpublished information for use in this review: Dick Brown (CWS), Gail Brown (Acadia), Sue Corey (Guelph), Peggy Crawford (Acadia), Mike Dadswell (DFO), Lee-Anne Frost (Huntsman), Derek Iles (DFO), Mike Power (DFO), Nick Prouse (MEL) and John Roff (Guelph). In addition I am glad to acknowledge the multitude of students and colleagues who have been involved in collection and analysis of material from the Bay in recent years. Financial

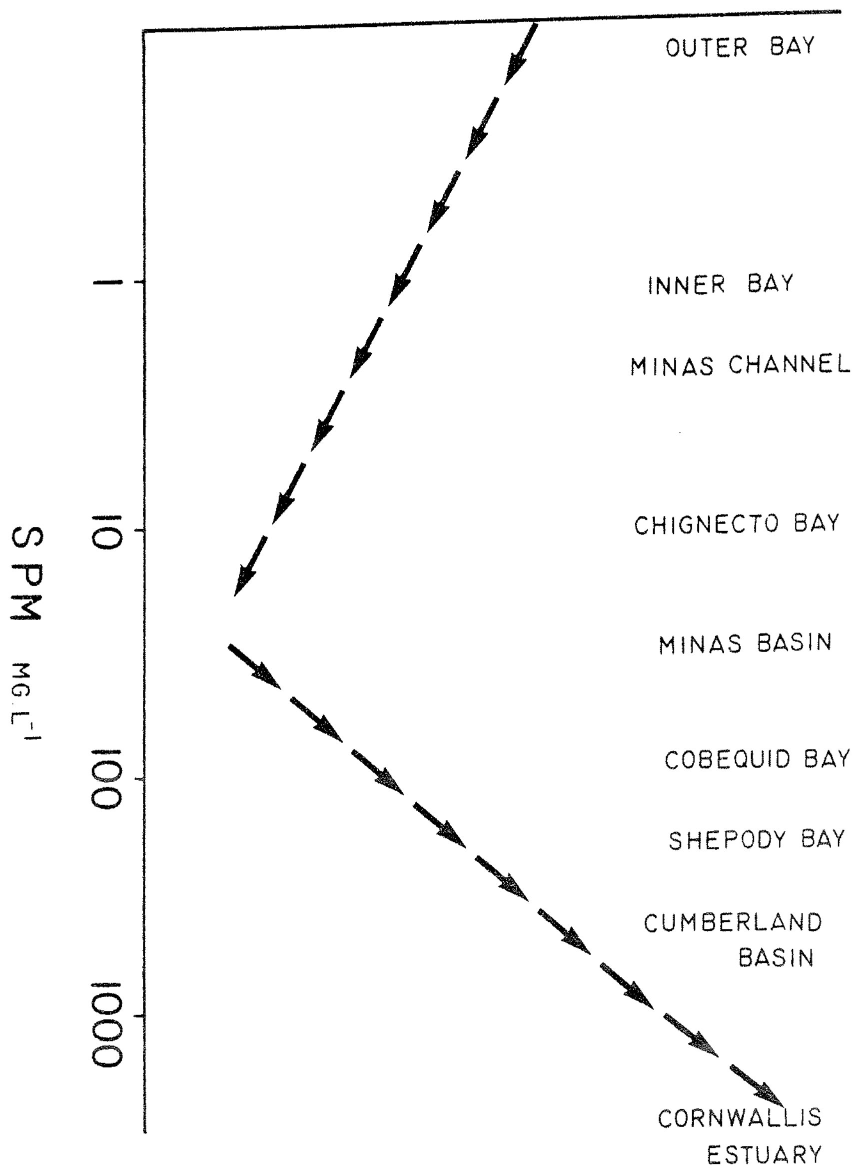


Fig. 11. Model of zooplankton: suspended particulate matter concentration in the Bay of Fundy.

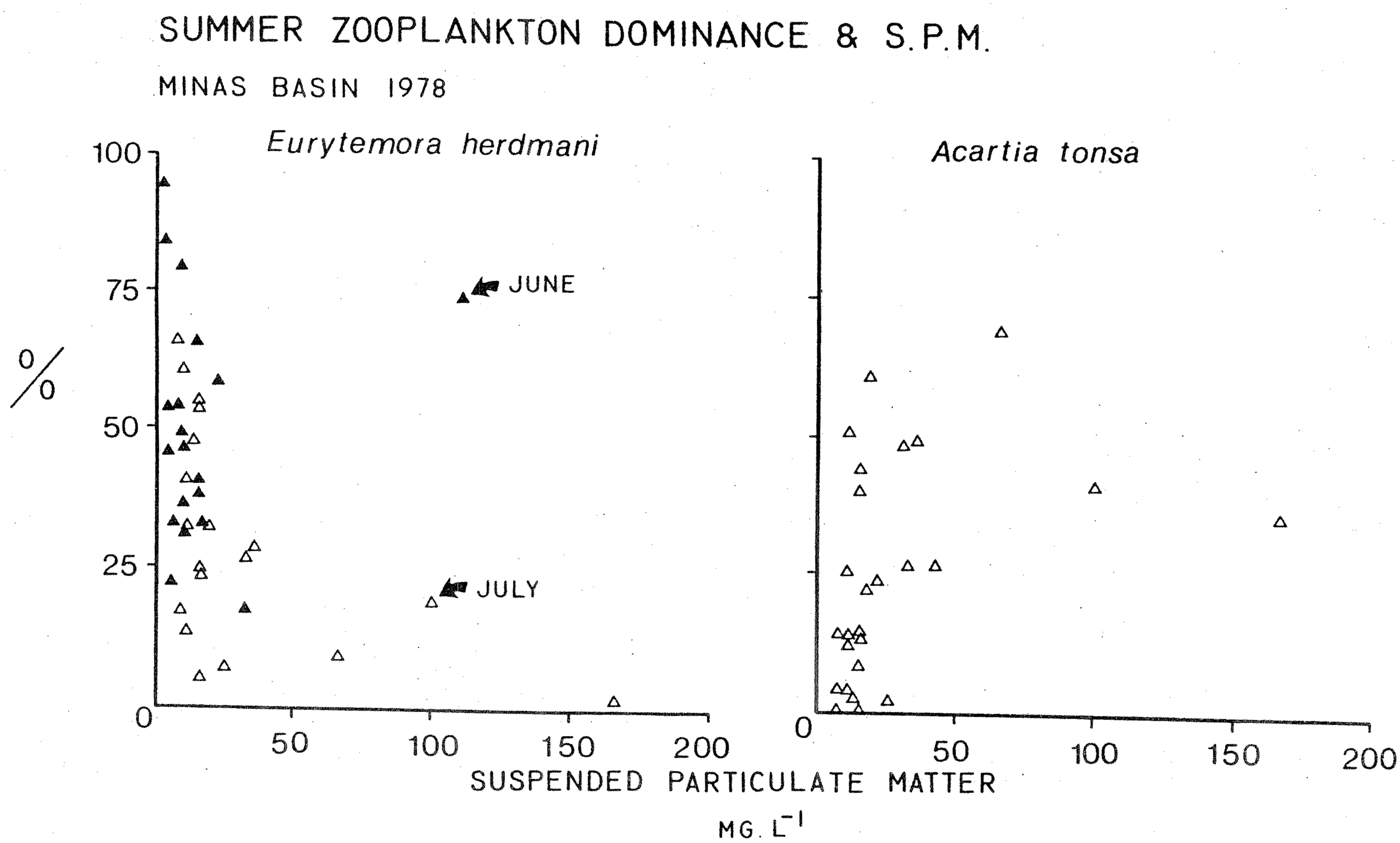


Fig. 12. Relationships between suspended particulate matter concentration and composition of zooplankton in Minas Basin, 1978.

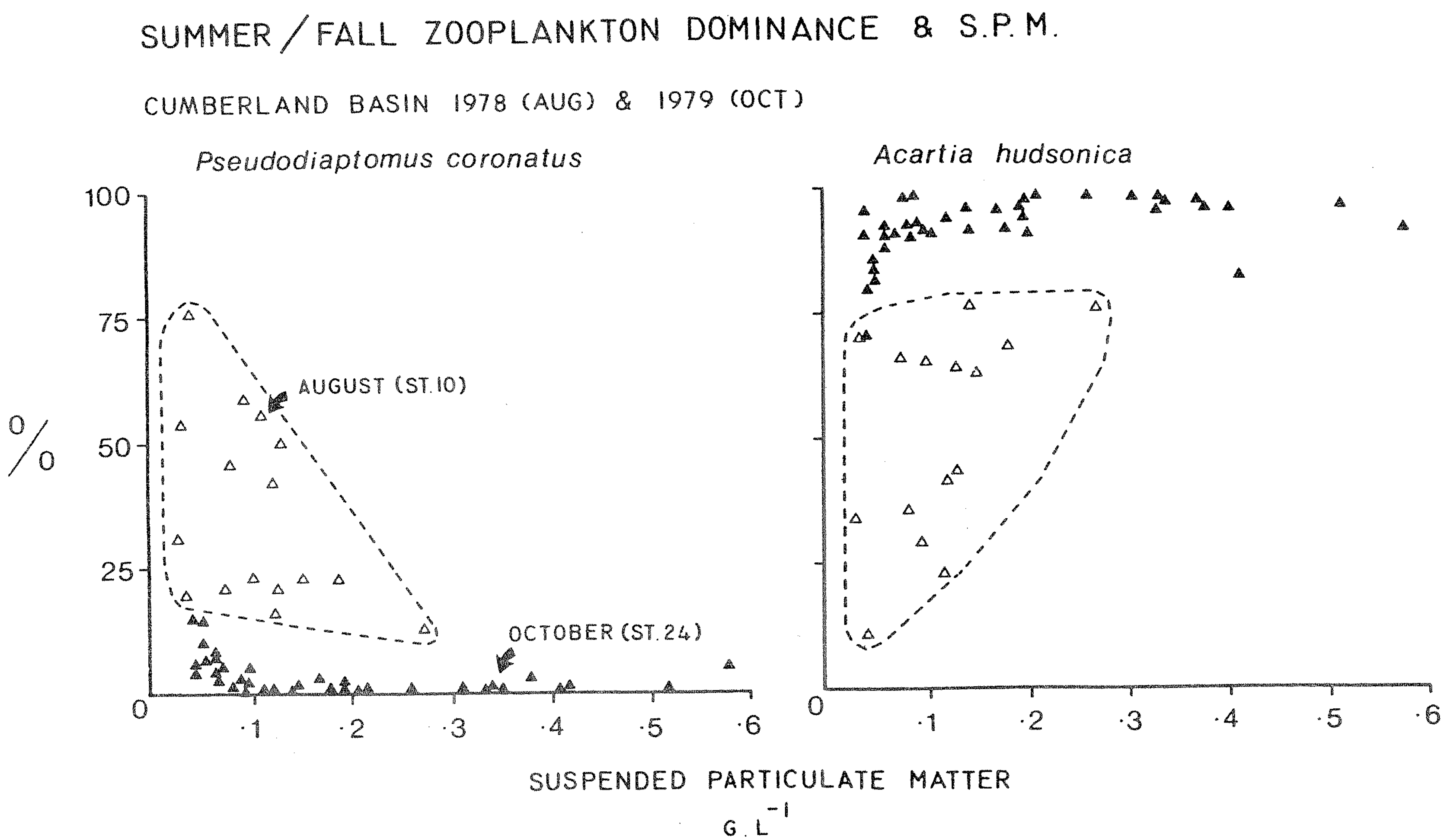


Fig. 13. Relationships between suspended particulate matter concentration and composition of zooplankton in Cumberland Basin, 1979.

support was made available through NSERC grant A9679, and logistical support through the kind of offices of Don Gordon and Carl Amos. Figures 1-4 are included by kind permission of Derek Iles (DFO). To all these I am most grateful.

REFERENCES

Amaratunga, T. and S. Corey. 1979. Development of the marsupium and the release of young in Mysis stenolepis (Crustacea, Mysidacea). Crustaceana 37: 80-84.

Bigelow, H.B. 1926. Plankton of the offshore waters of the Gulf of Maine. Bull. U.S. Bur. Fish. 40: 1-509.

Burkill, P.H. and T.F. Kendall. 1982. Production of the copepod Eurytemora affinis in the Bristol Channel. Mar. Ecol. Pro. Ser. 7: 21-31.

Cammen, L.M. and J.A. Walker. 1982. Microbial ecology of the Bay of Fundy. 1. Distribution and activity of attached and free-living suspended bacteria. Can. Fish. Aquat. Sci. 39: 1655-1663.

Corey, S. 1981. The life history of Crangon septemspinosa Say (Crustacea, Decapoda) in the shallow sublittoral area of Passamaquoddy Bay, New Brunswick. Crustaceana 41: 21-28.

Corey, S. 1982. Distribution of arctic and subarctic Cumacea in Canadian waters. Can. J. Zool. 59: 1726-1733.

Daborn, G.R. and C. Pennachetti. 1979a. Physical oceanographic and sedimentological studies in the southern bight of Minas Basin. Pro. N. S. Inst. Sci. 29: 315-333.

Daborn, G.R. and G. Pennachetti. 1979b. Zooplankton studies in the southern bight of Minas Basin. Proc. N.S. Inst. Sci. 29: 465-481.

Daborn, G.R., A.M. Redden and R.S. Gregory. 1982. Ecological studies of the Annapolis Estuary, 1981-1982. Acadia University Institute Publication No. 29, Wolfville, N.S., 80 p.

Fish, C.J. 1936a. The biology of Calanus finmarchicus in the Gulf of Maine and Bay of Fundy. Biol. Bull. 70: 118-141.

Fish, C.J. 1936b. The biology of Oithona similis in the Gulf of Maine and Bay of Fundy. Biol. Bull. 70: 168-187.

Fish. C.J. 1936c. The biology of Pseudocalanus minutus in the Gulf of Maine and Bay of Fundy. Biol. Bull. 70-193-216.

Fish, C.J. and M.W. Johnson. 1937. The biology of the zooplankton population in the Bay of Fundy and Gulf of Maine, with special reference to production and distribution. J. Biol. Can. 3: 189-321.

Hicklin, P.W. and P.C. Smith. 1984. Studies of birds in the Bay of Fundy: a review. In this report.

Hildebrand, L.P. 1981. Preliminary observations on the distribution, composition and abundance of zooplankton in Chignecto Bay during June and August 1978, with emphasis on the relationship to tidal cycles. Can. Tech. Rep. Fish. Aquat. Sci. No. 136, 40 p.

Iles, T.D. 1975. Michael Graham's Bay of Fundy Sagitta patch revisited; are there "stocks" of zooplankton animals? International Council for the Exploration of the Sea, Plankton Committee; CM 1975/L24., 12p.

Jermolajev, E.G. 1958. Zooplankton of the inner Bay of Fundy. J. Fish. Res. Bd. Can. 15: 1219-1228.

Kulka, D.W. and S. Corey. 1978. The life history of Thysanoessa inermis (Kroyer) in the Bay of Fundy. Can. J. Zool. 56: 492-506.

Kulka, D.W. and S. Corey. 1982. Parasitism in euphausiids of the Bay of Fundy region. Crustaceana (in press).

Kulka, D.W., S. Corey and T.D. Iles. 1982a. Length and weight relationships of euphausiids. J. Crustacean Biol. 2: 239-247.

Kulka, D.W., S. Corey and T.D. Iles. 1982b. Community structure and biomass of euphausiids in the Bay of Fundy. Can. J. Fish. Aquat. Sci. 39: 326-334.

Legaré, J.E.H. and D.C. MacLellan. 1960. A qualitative and quantitative study of the plankton of the Quoddy Region in 1957 and 1958 with special reference to the food of the herring. J. Fish. Res. Bd. Can. 17: 409-448.

Peer, D.L. 1984. A review of benthic macrofaunal production of the upper Bay of Fundy intertidal area. In this report.

Pennachetti, C. 1978. Plankton and suspended sediments in the southern bight of Minas Basin. Unpublished Report. Project 16-01-005. Atlantic Regional laboratory, National Research Council of Canada, Halifax, N.S., 197 p.

Pezzack, D.S. and S. Corey. 1979. The life history of Neomysis americana (Smith) (Crustacea, Mysidacea) in Passamaquoddy Bay. Can. J. Zoo. 57: 785-793.

Prouse, N.J., D.C. Gordon, B.T. Hargrave, C.J. Bird, J. McLachlan, J.S.S. Lakshminarayana, J. Sita Devi and M.L.H. Thomas. 1984. Primary production: organic matter supply to ecosystems in the Bay of Fundy. In this report.

QUESTIONS AND COMMENTS

D. Gordon: Have you any feeling whether the zooplankton production shows a direct relationship with primary production which varies by about a factor of three from the mouth of the Bay to the upper reaches?

G. Daborn: I have not attempted yet to calculate zooplankton production for the outer part of the Bay. I think however that production in the upper portions is a small fraction of what is produced in the upwelling region at the mouth of the Bay. I don't think the two are going to be dimensionally comparable.

D. Gordon: It is interesting to see that the low point in your zooplankton abundance data occurs in Chignecto Bay and Minas Basin where primary producton is lowest.

G. Daborn: I drew Fig. 11 before I realized what would be presented in the primary production paper this morning so it's somewhat coincidental, but it fits rather well.

K. Mann: The P/B ratio depends very much upon the rate of predation on the population. It's a fact that so much production is removed that it lowers the biomass and increases the P/B ratio. If, as you suggested, zooplankton are able to escape from their predators in turbid waters you might expect a much lower P/B ratio. I am suspicious of your P/B ratios.

G. Daborn: I chose a value produced for *Eurytemora* of 33 which was adopted by Burkill and Kendall (1982) for the Bristol Channel. The P/B ratios for *Eurytemora* range from a low of 16 to as high as 182 in Narrangansett Bay. I have no direct values for Fundy. There obviously is much variation. I would not attempt to justify the choice of 33 except to say that it came from a comparable environment.

K. Mann: I think you might have to look at the range of unpublished values and lower yours a bit.

M. Dadswell: You are also going to have to worry about those fish, particularly shad, that can feed without seeing.

G. Daborn: I agree.

B. Hargarve: Have you made any observations on microzooplankton, such as tintinnids?

G. Daborn: Yes, we do have records of tintinnids in the southern part of Minas Basin where the water is somewhat clearer. Gail Brown comes across tintinnids in the Cornwallis River but I don't think they are that common. The problem is some things go through a 160 μm net. If you use a finer net you can capture smaller zooplankton but it clogs up with sediment.

B. Hargrave: Tintinnids can also disintegrate if samples are preserved.

G. Daborn: It's an area we have not covered adequately, either by collecting or preservation. At the other end of the size spectrum we have also underestimated mysids which are much more abundant. Gail Brown captures very large numbers of juvenile mysids in her zooplankton collections and there are some adults present too. These are not adequately sampled by fine mesh nets.

A Review of Research on Fishes and Fisheries in the Bay of Fundy between 1976 and 1983 with Particular Reference to its Upper Reaches

Michael J. Dadswell, Rodney Bradford,
the late A.H. Leim[1], and D.J. Scarratt

Fisheries and Environmental Sciences
Department of Fisheries and Oceans
Biological Station
St. Andrews, New Brunswick EOG 2X0

G.D. Melvin

Department of Biology,
University of New Brunswick
Fredericton, New Brunswick E3B 5H1

R.G. Appy

Fundy Isles Marine Enterprises,
St. Andrews, New Brunswick EOG 2X0

ABSTRACT

Since 1976 research on fishes and fisheries in the Bay of Fundy has been concentrated in three regions: the megatidal embayments of Chignecto Bay and Minas Basin; the estuaries of the Annapolis and Saint John Rivers, and outer the Brier Island - Grand Manan - Passamaquoddy Bay region.

Fishes utilizing the intertidal and pelagic zones received the greatest attention in the upper Bay. Intertidal studies have examined the abundance and feeding relationships of tomcod, Atlantic silversides, smelt, smooth flounder and winter flounder. Pelagic fish studies included a survey of fishes and their parasites in Cumberland Basin and an assessment of the abundance and origin of alosids in these regions. Tagging and population discrimination studies (morphometics, meristics, parasites) indicate many of the American shad occurring in the upper Bay of Fundy during summer are of southern origin, this region being the northern terminus of their coastal migration route. Long-term, continuing Atlantic herring surveys conducted over the entire Bay of Fundy indicate the upper portions are important for larvae and juveniles. Additionally large numbers of juvenile and adult shad and alewife occur there and the entire region appears important as a nursery and feeding ground for planktivorous fish. Lobster research, including a tagging program, was conducted in the Alma region and movement of large lobsters was found to be extensive.

In response to the construction of a hydroelectric tidal-generating plant on the Annapolis River, fish passage structures and turbine mortality expected from the STRAFLO turbine was assessed. Additional studies are underway on larval fish ecology, the local striped bass population and the size and structure of the shad spawning population. The American shad population is large and has distinct characteristics making it a sensitive tool for assessing turbine mortality. Studies in the Saint John estuary included work on alewives, sturgeon and striped bass.

Studies in the lower Bay of Fundy include benthic fish surveys, the comparison of red and white hake biology, cod bioenergetics, and extensive lobster tagging programs. The biology of harbour porpoise has been extensively documented and recent marine mammal work indicates large numbers of cetaceans spend the summer in the outer Bay of Fundy.

Fisheries of the upper Bay of Fundy are traditionally localized with moderate levels of yield. The major fisheries are for anadromous species (salmon, shad, alewife, and striped bass) and shellfish (lobsters, softshell clams). Cod, halibut, flounder and mackerel are caught but landings are low. There is a herring purse-seine fishery in Scots Bay. Fisheries in the lower Bay of Fundy have high yields and are based on groundfish (cod, pollock, haddock, and flounders), pelagics (herring), and shellfish (lobsters, scallops).

Key words: groundfish, pelagic fish, anadromous fish, shellfish, landings, population discrimination, low-head turbines, NAFO 4X

RÉSUMÉ

Depuis 1976 la recherche sur le poisson et les peches dans la baie de Fundy a ete concentree dans trois regions: les indentations megatidales interieures de Chignectou et des Mines, les estuaries des rivieres Annapolis et Saint-Jean et la region de l'ile Brier exterieure - Grand-Manan - Passamaquoddy.

Les poissons qui frequentent les zones interdidale et pelagique ont fait l'objet de la plus grande attention dans la partie interieure de la baie. Des etudes intertidales ont examine l'abondance et les relations alimentaires du poulamon atlantique, de la capucette, de l'eperlan, de la plie lisse et de la plie rouge. Parmi les etudes sur le poisson pelagique mentionnons un recensement des especes et de leurs parasites dans le bassin de Cumberland ainsi qu'une evaluation de l'abondance et de l'origine des aloses dans ces regions. L'etiquetage et des etudes de differenciation des populations (morphonetique, traits meristiques, parasites) indiquent qu'un grand nombre des aloses canadiennes presentes dans la partie interieure de la baie de Fundy pendant l'ete viennent du sud, puisque cette baie est le termi us septentrional de leur parcours migratoire cotier. Les etudes a long terme du hareng de l'Atlantique qui se poursuivent indiquent que les parties interieures de la baie sont importantes pour les larves et les jeunes. On trouve de plus a cet endroit de grands nombres de jeunes et adultes aloses et gaspareaux et toute la region semble importante comme

aire de croissance et d'alimentation pour les poissons planctophages. Des recherches sur le homard incluant un programme d'étiquetage, ont été menées dans la région d'Alma et on a constaté que les gros homards se déplaçaient sur des distances considérables.

En réponse à la construction d'une usine marémotrice sur la rivière Annapolis on a évalué les structures permettant le passage des poissons et les taux de mortalité prévus pendant l'exploitation de la turbine STRAFLO. D'autres études sont en cours concernant l'écologie des poissons au stade larvaire, la population locale de bars d'Amérique ainsi que la taille et la structure de la population d'aloses qui fraye. La population d'aloses canadiennes est importante et présente des caractéristiques dinstinctes qui en font un instrument sensible pour l'évaluation des taux de mortalité attribuables à la turbine. Parmi les études effectuées dans l'estuarie de la Saint-Jean mentionnons des travaux portant sur le gaspareau, l'esturgeon et le bar d'Amérique.

Dans la partie extérieure de la baie de Fundy les études englobent des dénombrements des poissons benthiques, la comparaison de la biologie de la merluche-écureuil et de la merluche blanche, des recherches bioénergétiques sur la morue ainsi que d'importants programmes d'étiquetage de homards. La biologie du marsouin a fair l'objet d'études importantes et des travaux récents sur les mammifères marins indiquent que de grands nombres de cétacés passent l'été dans la partie extérieure de la baie de Fundy.

Les pêcheries dans la partie intérieure de la baie de Fundy sont depuis toujours localisées et fournissent des captures modérées. Les pêches majeures sont celles des espèces anadromes (saumon, alose, gaspareau et bar d'Amérique) ainsi que des mollusques et crustacés (homards, myes). On y prend également de la morue, du flétan, du flet et du maquereau, mais les captures de ces espèces sont faibles. Il se pratique une pêche à la senne coulissante dans la baie Scots. La pêche dans la partie extérieure de la baie de Fundy donne des rendements élevés et elle est basée sur le poisson de fond (morue, lieu, aiglefin et flets), le poisson pélagique (hareng) ainsi que les mollusques et crustacés (homards et coquilles Saint-Jacques).

INTRODUCTION

Since earliest times the fish of the Bay of Fundy have been a primary consideration for the people inhabiting its shoreline (Perley 1852, Bonnichsen and Sanger 1977, Scarratt 1977). Although the fisheries exploited and their economic values have changed over time in response to availability and market demand, their development and well-being have always been critically important (Perley 1852, Prince 1912, Caddy and Chandler 1976). Consequently, any alternation to the Bay of Fundy habitat which could effect fisheries should be thoroughly reviewed before implementation.

The Fundy Tidal Power and the Environment Workshop in 1976 was the stimulus for examining the state of knowledge concerning fish and fisheries in the Bay (Scarratt 1977). It was the general consensus that although the large and presently valuable commercial fisheries at the mouth of the Bay were in general well known, existing knowledge diminished steadily as one proceeded into the Bay (Daborn and Bleakney 1977). It was thought that the inner portions of the Bay of Fundy might serve as a nursery area and a recommendation to investigate this possibility was made. As will be seen in this review, much of the research which followed was designed to answer this question. Others thought the supposed low productivity of the inner Bay would limit its use as a nursery and was the reason there seemed to be no commercially significant fisheries in the region (Anon 1977). This latter opinion now appears incorrect on both accounts (Daborn 1984; Dadswell et al. 1983).

Fundy tidal power and its effects on fisheries have been reviewed in the past (Kerswill 1960, Martin 1960, Riley 1970), especially with respect to international development of the Quoddy region. The opinion of these authors represents fisheries in jeopardy from development in the lower Bay of Fundy.

RESEARCH

The Upper Bay of Fundy

As a region, the upper Bay of Fundy (Fig. 1) has received less research attention than most of the remainder of Atlantic Canada. Early work on fishes was confined to a summer survey on fisheries in 1850 by Perley (1852), investigations on American shad between 1919 and 1923 (Leim 1924), Atlantic salmon investigations (White 1936, Huntsman 1958, Jessop 1976a) and descriptive compliations (Leim 1931). Much of the early work by A. H. Leim remained unpublished until now or appeared in check lists (Bousfield and Leim 1958) and among fish species accounts in larger works (Leim and Scott 1966). Consequently, when Scarratt (1977) reviewed the fish and fisheries of the Bay of Fundy for the first tidal power workshop in 1976, little information was available to describe this region. After 1976 field studies became intensive and considerable information has now been accummulated.

Tidal flat fishes

To date, forty-three fish species, which can be considered regular residents of the region, have been recorded from surveys of the tidal flats (Table 1). Incidence and abundance of fishes observed in weirs or traps in the intertidal zone during 1920-1922 by Leim were virtually identical to observations during 1980-1983 by Salinas, Scully and Dadswell. Bleakney and McAllister (1973) observed some additional benthic species stranded during extreme low tides. Fish utilizing the tide flats represent two groups: those which remain along the littoral fringe at low water and can be captured by hand seine, and those which occur over the tide flats only

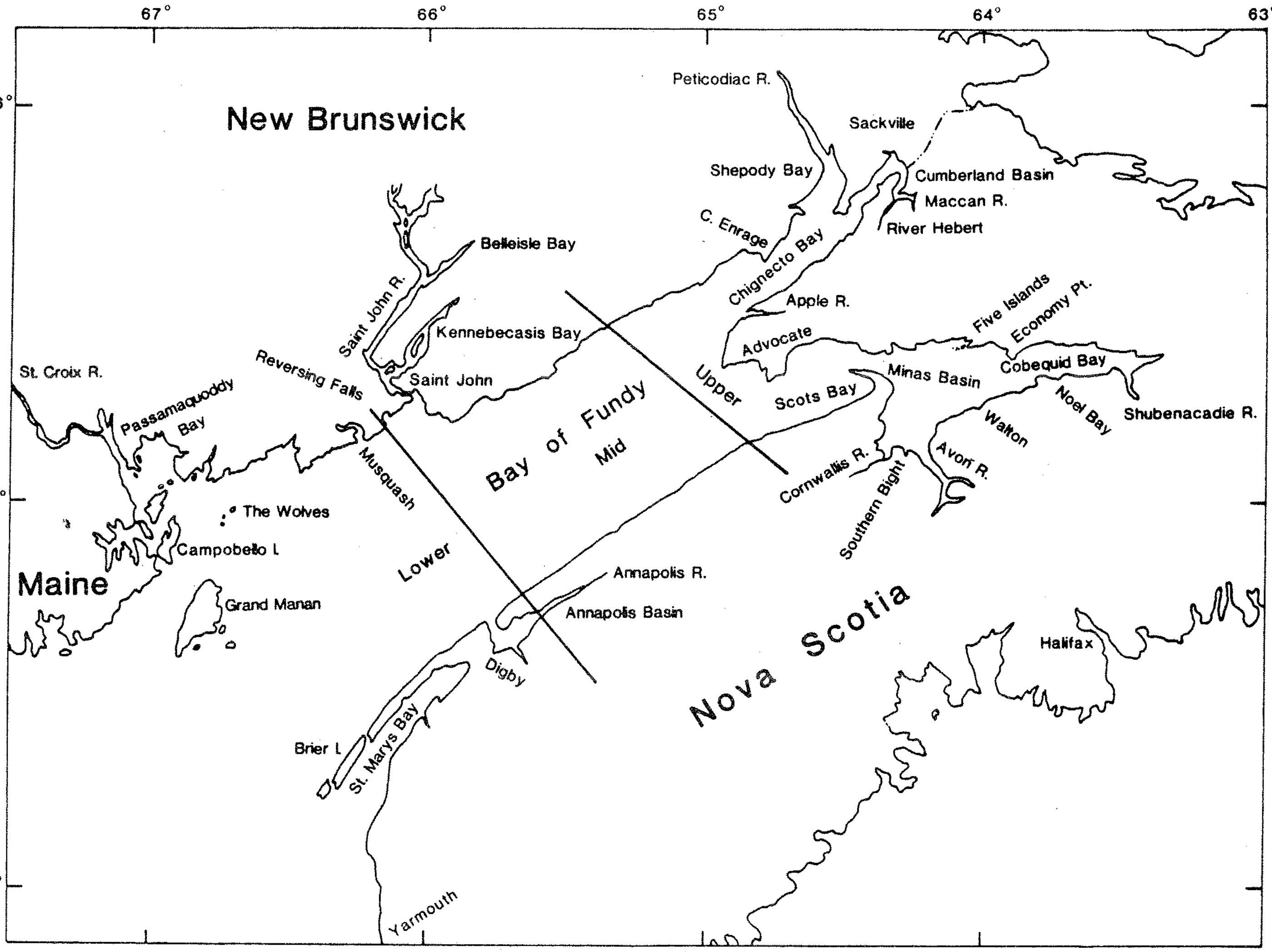


Fig. 1. The Bay of Fundy showing localities mentioned in the text and dividing lines for the regional discussion of its fish fauna.

TABLE 1. Fishes captured during surveys of tide flats in the upper Bay of Fundy. Survey in 1919-1923 was by Leim. Surveys during 1978-82 were carried out by Gillmurry, Salinas, Scully and Dadswell. Qualitative indices of abundance are: A, abundant, usually collected in large numbers at all times (100-1000); C, common, frequently collected in moderate numbers (10-100); R, rare, seldom encountered, few individuals (1-10); (-), not encountered during survey.

	Leim 1919-23 Minas Basin	Bleakney and McAllister 1973 Minas Basin	1978-83 Minas Basin	Surveys Chignecto Bay
Little skate *Raja erinacea*	C	C	C	-
Winter skate *Raja ocellata*	-	R	-	-
Barndoor skate *Raja laevis*	C	-	-	-
Thorny skate *Raja radiata*	-	-	-	C
Dogfish *Squalus acanthias*	R	-	R	R
Atlantic sturgeon *Acipenser oxyrhynchus*	R	-	R	-
Alewife *Alosa pseudoharengus*	C	-	A	C
Blueback herring *Alosa aestivalis*	C	-	A	C
American shad *Alosa sapidissima*	A	R	A	R
Atlantic herring *Clupea harengus*	A	R	C	-
Atlantic menhaden *Brevoortia tyrannus*	-	R	C	-
Atlantic salmon *Salmo salar*	R	-	R	-
American smelt *Osmerus mordax*	A	C	A	C
American eel *Anguilla rostrata*	C	-	R	A
Threespine stickleback *Gasterosteus aculeatus*	C	-	C	A
Blackspotted stickleback *Gasterosteus wheatlandi*	C	-	C	R
Fourspine stickleback *Apeltes quadracus*	C	-	R	R
Ninespine stickleback *Pungitius pungitius*	R	-	R	-
Fourbeard rockling *Enchelyopus cimbrius*	-	R	-	-
Atlantic cod *Gadus morhua*	C	R	R	R
Atlantic tomcod *Microgadus tomcod*	A	A	A	A
Silver hake *Merluccius bilinearis*	A	R	R	-
White hake *Urophycis tenuis*	C	R	C	-
Pollack *Pollachius virens*	C	-	R	-
Atlantic silverside *Menidia menidia*	A	A	A	A
Mummichog *Fundulus heteroclitus*	A	-	C	R
Banded killifish *Fundulus diaphanus*	A	-	R	-
Northern pipefish *Syngnathus fuscus*	R	R	R	-
Smooth flounder *Liopsetta putnami*	A	C	A	C

TABLE 1. CONT'D.

	Leim 1919-23 Minas Basin	Bleakney and McAllister 1973 Minas Basin	1978-83 Minas Basin	Surveys Chignecto Bay
Winter flounder Pseudopleuronectes americanus	C	A	A	C
Windowpane Scophthalmus aquosus	A	C	A	C
Atlantic halibut Hippoglossus hippoglossus	–	–	R	–
Striped bass Morone saxatilis	A	–	R	R
Sea raven Hemitripterus americanus	R	C	C	–
Shorthorn sculpin Myoxocephalus scorpius	–	R	–	–
Longhorn sculpin Myoxocephalus octodecemspinosus	R	–	R	–
Grubby Myoxocephalus aeneus	–	C	R	–
Lumpfish Cyclopterus lumpus	–	R	–	–
Atlantic seasnail Liparis atlanticus	–	C	C	–
Ocean pout Macrozoarces americanus	R	C	–	–
Rock gunnell Pholis gunnellus	–	C	–	–
Goosefish Lophius americanus	A	R	–	–
Sand lance Ammodytes americanus	R	–	–	–
Butterfish Peprilus triacanthus	R	–	C	–

at high tide and are captured by gillnets or weirs. The former grouping consists of juveniles and adults of smaller forage species and juveniles of large species; the latter, juveniles and adults of large commercial species.

Seine surveys were conducted in Cobequid Bay by Leim during August 1921, at Kingsport, Minas Basin during 1978 and 1979 (Imrie and Daborn 1981, Gilmurray and Daborn 1981), at Pecks Cove, Cumberland Basin during 1979 (Salinas 1981), and at 15 sites in the upper Bay (Fig. 2) between June and September 1978 by Dadswell. Sites in the inner portions of Minas Basin and Chignecto Bay were characterizied by mud substrate, salinities less than 30°/₀₀ and turbid water (Salinas 1981, Imrie and Daborn 1981), seaward sites had sandy-mud to gravel substrate, salinities in excess of 30°/₀₀ and clear water. Fifteen fish species were captured regularly (Table 2). During summer two fish assemblages existed: an estuarine-mudflat group of juvenile and adult tomcod, smelt, silversides and smooth flounder in the inner portions of the region (Imrie and Daborn 1981, Salinas 1981), and a seaward, oceanic-sand beach group of juvenile herring, white hake and winter flounder and adult and juvenile three-spine sticklebacks (Fig. 3) (Table 3). Most sites in the inner regions were numerically dominated by tomcod (Table 2) (Salinas 1981). Kingsport, Minas Basin appears to be a transition locality where larger numbers of smelt and silversides were found than at other inner or outer sites (Imrie and Daborn 1981, Gilmurray and Daborn 1981).

Because of the region's large tides fishermen have long favored intertidal weirs for capturing commercial species (Perley 1852, Prince 1912). These weirs are typically made of brush and are variously V-shaped with the open end facing the shore. The wings of the weir may be up to 300 m in length. In most such weirs the trap dries at low water and the fishermen drive a vehicle across the tide flat to collect the fish. In the past there were a large number of these weirs (Perley 1852). Because of declining catches and limited entry licencing policies the number of weirs is now much reduced. During 1982 none were built in Chignecto Bay and only seven in Minas Basin; four at Economy Point, two at Five Islands and one at Walton (Fig. 1).

During August 1920 and 1922 a weir in Scots Bay was visited on each low tide. This procedure was repeated for a weir at Bass River, Cobequid Bay during August 1921 and for one at Apple River in 1931. Between June and August 1982 a weir at Five Islands was visited intermittently and records of the catch/tide of shad were kept for another weir at Economy Point. Between May and August, 1983 a weir at Economy Point was visited during every low tide and one at Five Islands intermittently. Catches of commercial species consisted of shad, herring, mackerel, alewifes, Atlantic sturgeon, white hake and flounders (Table 4). We were informed that significant catches of cod occur during cold water periods (May and November), and some halibut were captured at Five Islands (Dadswell pers. ob.). During both 1920-22 and 1982-83 few striped bass were captured (four observed 1982) but in some years catches have been significant (Caddy and Chandler 1976). Fish catches in the Scots Bay weir during August and early September 1922 consisted of large juveniles and adults of the species re-

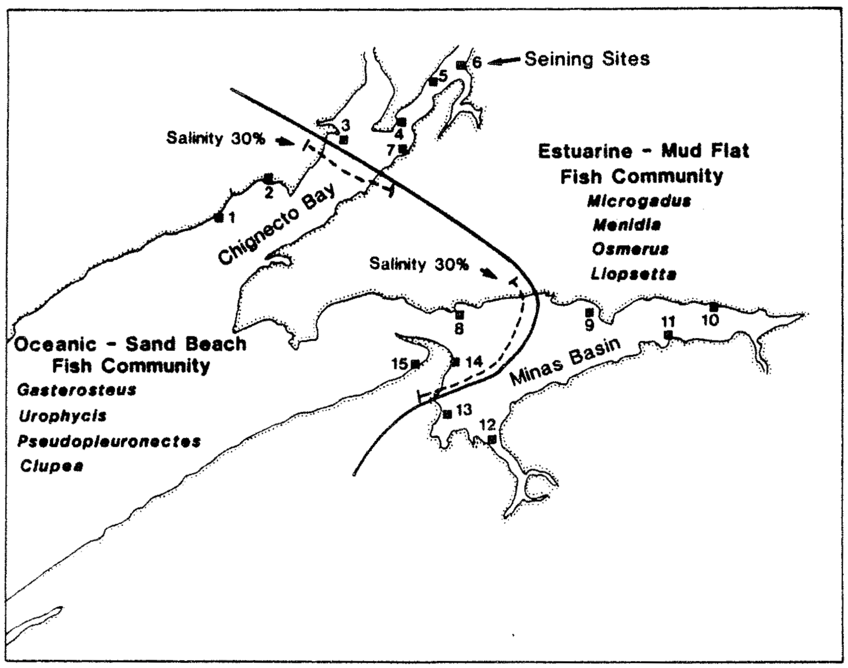


Fig. 2. Seining sites occupied in the upper Bay of Fundy during 1978 and their associated fish assemblages. Isohalines are after Bousfield and Liem (1958) and Dadswell (unpub. data).

TABLE 2. Occurrence and abundance of fishes captured during the low water period in 0-1 m depths at sites in the upper Bay of Fundy during June to September 1978 (Fig. 2). Numbers are total catch from two 5-min hauls with a 15-m seine at each site.

Species	Alma (1)		Marys Pt. (2)		Pecks (3)		Allen Ck. (5)		Joggins (7)		Parrsboro (8)		Noel Bay (11)		Avonport (12)		Kingsport (13)		Blomidon (14)		Scots Bay (15)	
	Jun	Jul	Jun	Sep	Jun	Sep	Jun	Sep	Jun	Sep	Jun	Sep	Jun	Sep	Jun	Aug	Jun	Aug	Jun	Aug	Jun	Aug
R. erinacea	-	3	-	-	-	-	-	-	3	-	-	-	-	-	2	-	-	-	-	-	-	2
A. pseudoharengus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13	-	-	-	-	-	-
C. harengus	2	-	-	-	-	-	-	-	-	-	2	4	-	-	3	-	-	-	-	-	-	-
S. salar	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
O. mordax	1	-	3	3	2	-	2	6	1	4	-	-	32	61	10	110	8	24	2	-	1	1
M. saxatilis	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A. rostrata	-	-	-	-	-	-	1	7	1	1	-	-	1	-	-	-	-	-	-	-	2	-
G. aculeatus	26	4	1	-	-	-	-	-	2	-	10	20	-	-	-	-	-	7	-	-	3	-
G. wheatlandi	-	-	-	-	2	-	-	-	-	-	1	-	-	-	-	3	4	2	-	-	1	-
G. morhua	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-
M. tomcod	-	-	6	212	119	19	125	28	15	29	-	-	2	1	13	8	-	-	-	2	24	14
U. tenuis	-	1	1	-	-	-	-	-	2	-	3	13	1	-	-	2	-	-	-	-	14	28
M. menidia	24	1	-	24	1	2	8	15	-	1	-	1	2	2	1	5	-	2	-	-	4	1
L. putnami	-	-	13	5	4	1	7	3	7	3	-	-	3	5	-	15	-	7	3	2	-	-
P. americanus	12	8	4	-	-	2	-	-	1	-	3	8	-	-	-	-	-	-	3	1	1	1

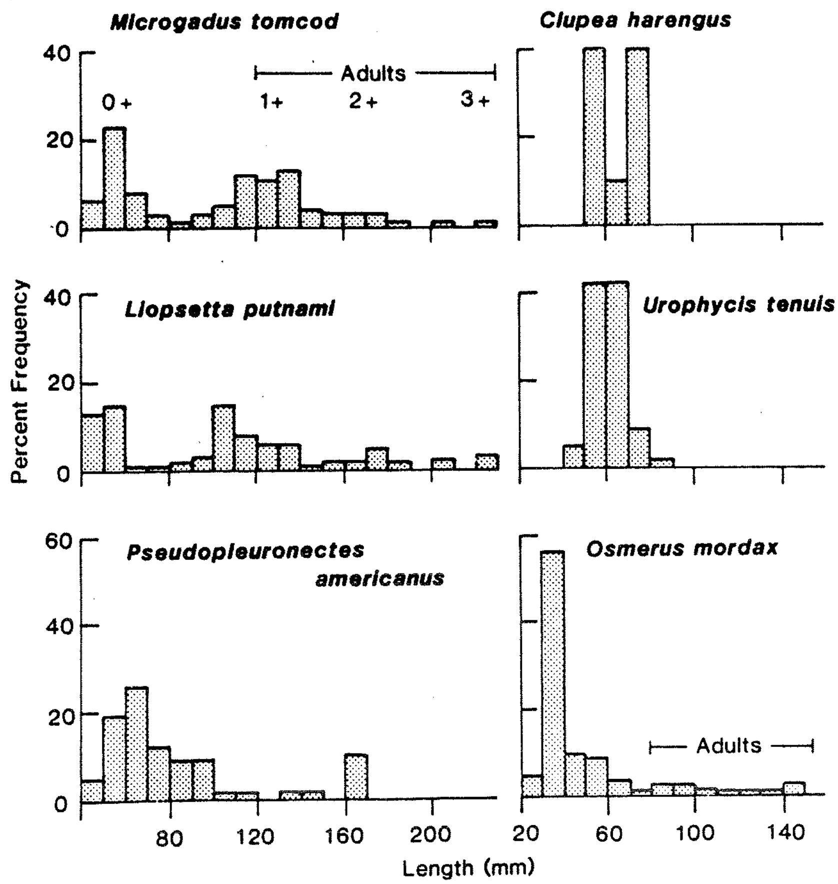


Fig. 3. Size distribution of fishes captured by seine in 0-1 m depths at low tide during June to September, 1978.

TABLE 3. Totals and percent representation of the most abundant fishes captured at 15 seining sites in the upper Bay of Fundy during June to September 1978. Estuarine-mudflat sites were characterized by salinities of 25-30°/₀₀ (Fig. 2).

Species	Estuarine Site 3-7, 9-13	Oceanic Sites 1, 2, 8, 14, 15	Total Captured
Microgadus tomcod	819 (95%)	40 (5%)	852
Osmerus mordax	198 (97%)	6 (3%)	204
Liopsetta putnami	82 (94%)	5 (6%)	87
Menidia menidia	75 (56%)	58 (44%)	133
Clupea harengus	3 (25%)	12 (75%)	15
Urophycis tenuis	6 (7%)	84 (93%)	90
Gasterosteus aculeatus	10 (14%)	63 (86%)	73
Pseudopleuronectes americanus	5 (15%)	29 (85%)	34
			1488[1] (96%)

[1] Total fish captured of all species 1545.

TABLE 4. Weir catch by week during August 1921 and 1922 at Bass River and Scots Bay, Minas Basin (Leim, unpub. data). The same species were observed at a weir at Five Islands during 1982 and 1983.

	Bass River, 1921; Dates				Scots Bay, 1922; Dates			
	8-14	15-21	22-28	Sep 29-4	5-11	12-18	19-25	Sep 26-3
Squalus acanthias	-	-	-	-	-	1	8	1
Raja erinacea	2	-	-	-	6	7	11	2
Raja laevis	-	-	-	-	5	4	0	1
Acipenser oxyrynchus	-	-	-	-	1	-	-	-
Alosa pseudoharengus	2	-	-	-	38	25	40	7
A. aestivalis	-	-	-	-	13	12	16	1
A. sapidissima	-	-	3	3	305	122	62	347
Clupea harengus	-	-	-	-	494 [2]	33 [2]	423 [2]	218 [2]
Salmo salar	-	-	-	3	2	10	0	0
Osmerus mordax	2	1	-	-	6	3	14	15
Scomber scombrus	-	-	-	-	5200 [1]	3968 [1]	2100 [1]	2
Peprilus triacanthus	-	-	4	-	1	0	0	2
Morone saxatilis	2	1	-	7	0	0	0	0
Gadus morhua	-	-	-	-	0	0	0	2
Microgadus tomcod	21	5	1	2	29	1		4
Merluccius bilinearis	2	0	0	0	-	1	-	680 [2]
Urophycis tenuis	106	1	-	1	29	21	100	20
Pollachius virens	-	-	-	-	6	6	1	1
Liopsetta putnami	12	14	12	67	0	1	0	0
Pseudopleuronectes americanus	1	2	0	8	25	13	47	12
Scophthalmus aquosus	4	16	20	5	31	42	39	1
Hemipterus americanus	-	-	-	-	2	4	11	1
Lophius americanus	-	-	-	-	6	11	7	8

[1] Estimated from cart loads.
[2] Many ripe specimens, ready to spawn.

presented (Fig. 4). Large catches of juvenile mackerel (300+), ripe adult herring (450) and ripe, adult silver hake (450) occurred (Fig. 5).

A particular characteristic of weir catches was the predominence of certain species on day tides (e.g. low tide occurs between 8 am and 8 pm) or night tides (low water, 8 pm - 8 am). During August and early September 1922, 55% of the shad, 63% of the herring and 100% of the silver hake were captured during night tides, whereas 99% of the mackerel were taken during the day (Fig. 5). During 1982, of 1706 shad captured in a weir at Economy Point, 96% were taken on night tides. Daily catches of shad in weirs at Economy Point during 1982 were greatest when low water occurred in the evening and night (8 pm - 4 am) and tides were in a neap phase (Fig. 6). Occasional large catches of night species occurred during day tides and the reverse (Fig. 5). Particular tides or weather conditions immediately preceeding the catch may have been the cause (Prince 1912).

A day-night differential utilization of the tide flats by various species was also observed during intertidal fish trapping studies at Pecks Cove in 1979. Tomcod were usually most abundant on the tide flat during day tides when the water was cool (spring-fall) and during night tides when the water was warm (summer) (Fig. 7). Smooth flounder were often most abundant on night tides during spring and fall, and on day tides in the summer (Fig. 8).

1. Tom cod (Microgadus tomcod)

Since 1976, Microgadus has been the focus of a considerable research effort in the turbid regions of the upper Bay of Fundy because of its apparent central role in the energy transfer of intertidal benthic biomass into the food chain (Schwinghamer et al. 1983) and its possible relationship as a competitor with migrant shorebirds for the amphipod, Corophium volutator (Hicklin and Smith 1984). Considerable data, mostly unpublished, have been accumulated in the Bay of Fundy by Leim in Cobequid Bay and the Shubenacadie River between 1919-1923, Cox (1933) in Passamaquoddy Bay, Dadswell in the Saint John River between 1974-76, and in Cumberland Basin by Dadswell between 1978-1979, Van Eeckhaute and Appy (1979) and Salinas (1981).

Abundance: Tomcod were the numerically dominant species in virtually every seine haul and benthic tow in Cumberland Basin (Tables 5 and 6; Fig. 9). Catches of 100-200 for a 5-min seine haul or 30-min tow were common. They were abundant in Cobequid Bay and the Shubenacadie River (Leim, unpubl. data) but less so in Minas Basin and at sites further seaward (Tables 3 and 6) (Imrie and Daborn 1981). They are so abundant in the Shubenacadie River that a large population of bald eagles (Haliaectus leucocephalus) overwinter along the river and feed almost exclusively on tomcod concentrated for spawning (Reid 1982).

During May to October, 1979 a large fykenet was used to capture intertidal fishes by blocking the seaward end of a tidal creek discharging from part of a 600,000 m^2 drainage basin of the Pecks Cove tide flat. Capture-recapture data indicated an adult tomcod population averaging

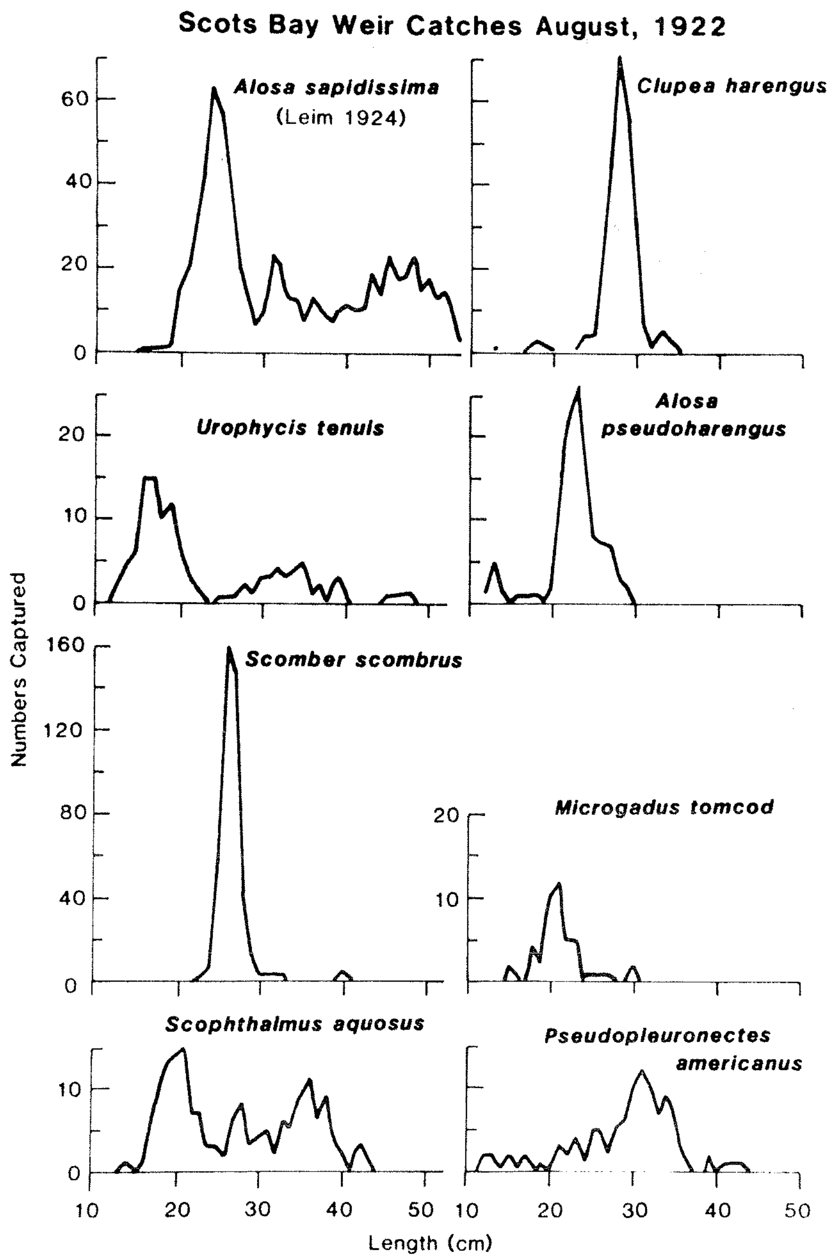


Fig. 4. Size distribution of fishes captured in a Scots Bay weir during August 1922.

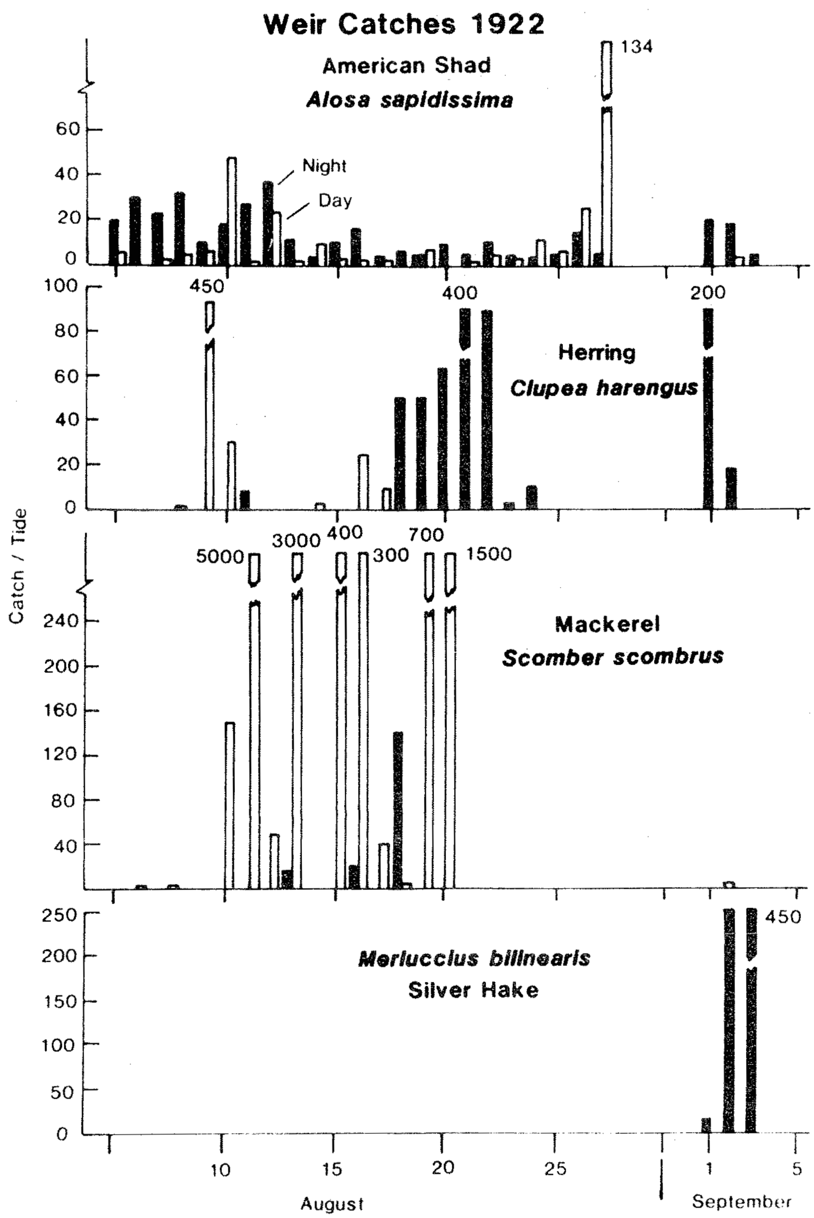


Fig. 5. Catches of commercial fishes on day tides (8 am - 8 pm low water) and night tides (8 pm - 8 am low water) in a Scots Bay weir during August 1922.

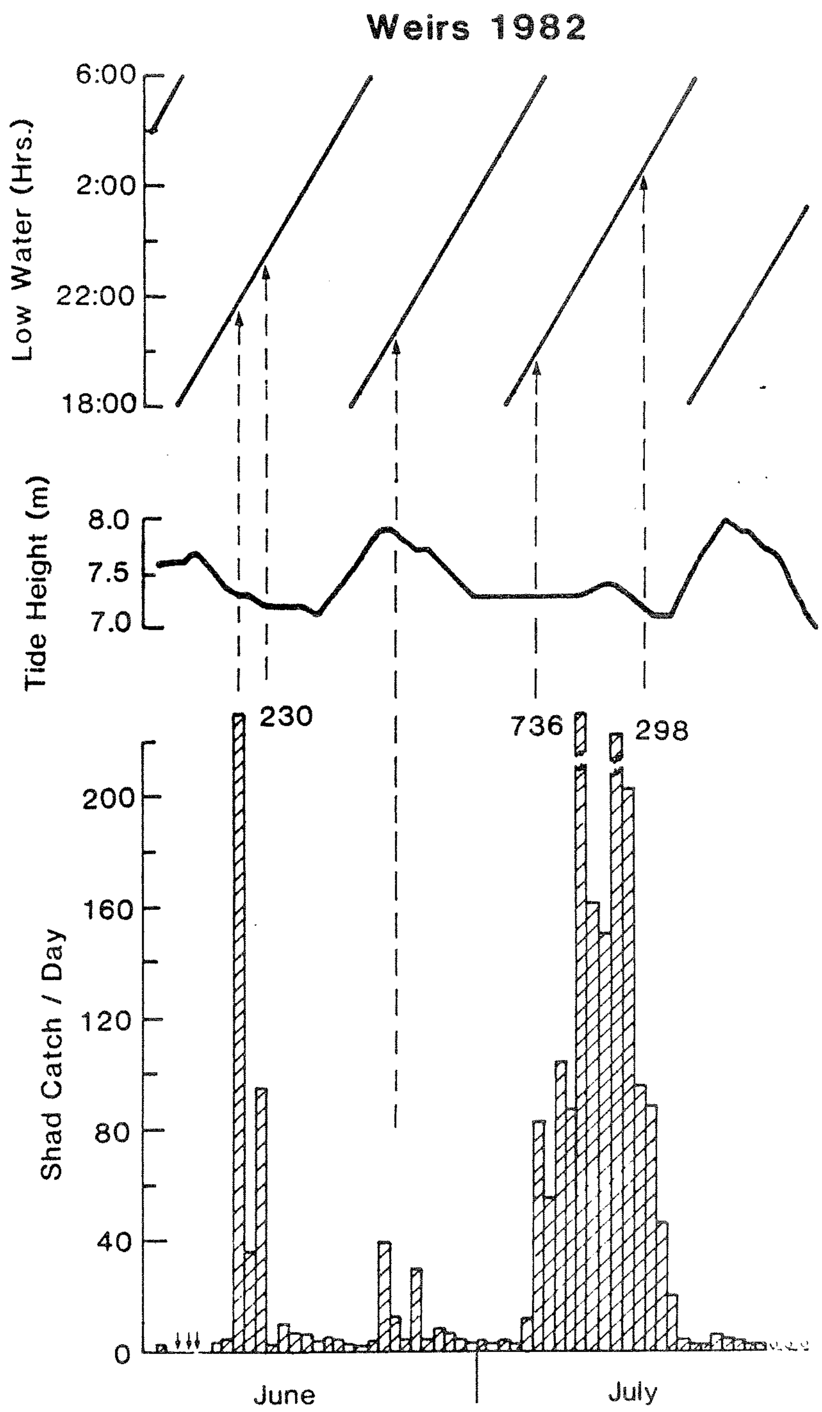


Fig. 6. Shad catch/day during 1982 for two weirs at Economy Point, Cobequid Bay in relation to daily tide height and time of low water.

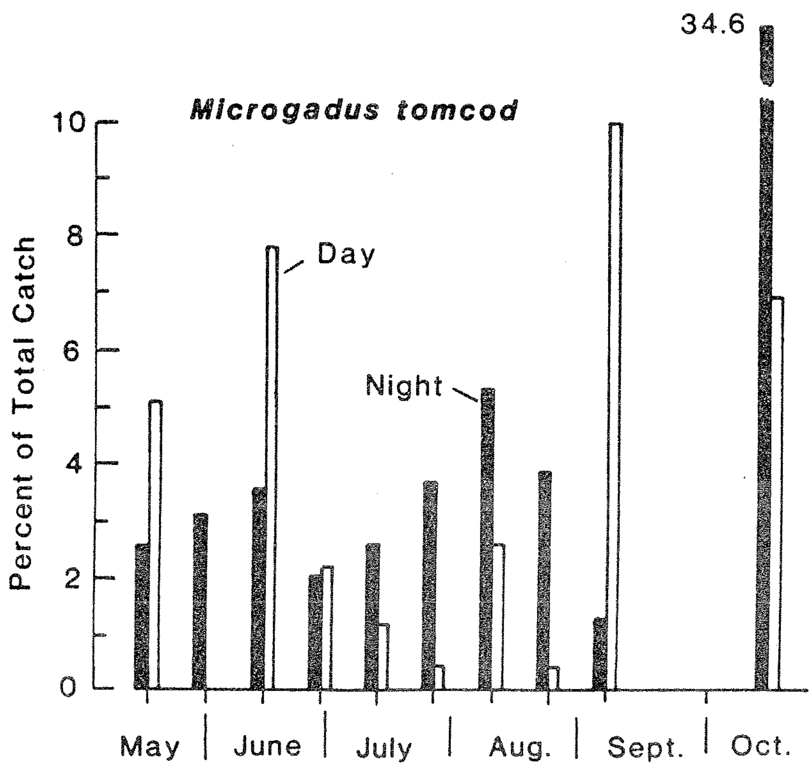


Fig. 7. Abundance of tomcod, expressed as a percent of the total summers catch, captured in a fykenet on the Pecks Cove tide flat during day (8 am - 8 pm high water) and night (8 pm - 8 am high water) tides.

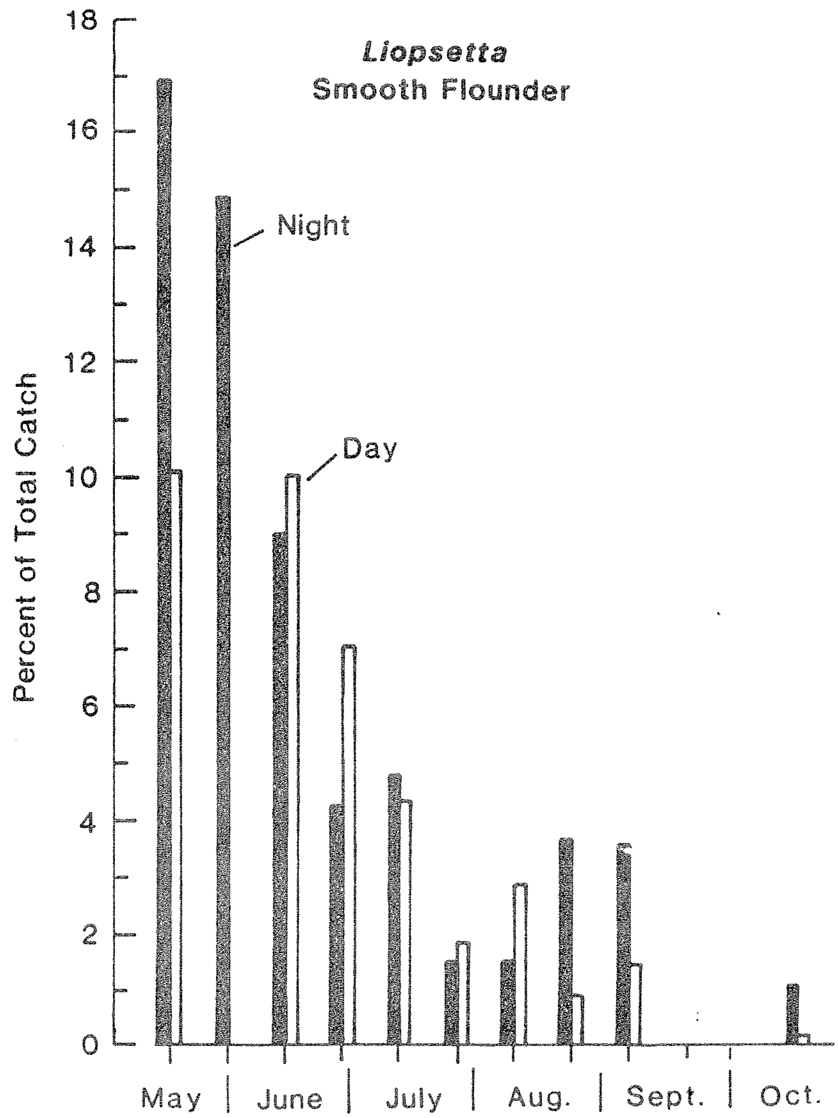


Fig. 8. Abundance of smooth flounder, expressed as a percent of the total summers catch, captured in a fykenet on the Pecks Cove tide flat during day (8 am - 8 pm high water) and night (8 pm - 8 am high water) tides.

TABLE 5. Fish catch per 5-min beach seine haul at Pecks Cove, Cumberland Basin. Hauls were in 0-1 m in depths along the littoral fringe between 1 hr before and 1 hr after low tide.

Species	Date 1979							
	March 22	May 31	June 18	July 10	July 31	Aug 15	Aug 30	Sept 11
Alosa pseudoharengus	-	-	-	53.5	0.5	-	-	-
Clupea harengus	-	-	-	-	-	-	-	-
Osmerus mordax	-	1.0	-	2.0	3.5	27.5	3.5	-
Menidia menidia	-	20.0	6.0	-	-	42.0	137.0	1.0
Anguilla rostrata	-	-	-	-	2.0	-	-	-
Microgadus tomcod	17.0	3.5	104.0	53.0	15.5	29.5	88.5	9.5
Liopsetta putnami	-	19.5	17.0	-	0.5	2.5	0.5	-
Pseudopleuronectes americanus	-	-	-	-	-	0.5	1.5	-
Hemitripterus americanus	-	-	-	0.5	-	-	-	-
Gasterosteus aculeatus	-	1.0	-	-	0.5	-	-	-

TABLE 6. Fish catch/30-min tow with a "Yankee-35" bottom trawl at Stations (see Fig. 9) in the Upper Bay of Fundy. Data from Van Eeckhaute and Appy (1979) and Dadswell (unpub. data). Station numbers in brackets are "Prince" station numbers for the same site from Bousfield and Leim (1958).

	Station																			
	Minas Basin										Chignecto Bay									
	2 (P196)		3 (P195)			4 (P194)		5 (P192)			9	6		7		13		14	15	16
Species	Jan	Sep	Jan	Jun	Sep	Jan	Sep	Jan	Jun	Sep	Sep	Jan	Sep	Jan	Sep	Jun	Sep	Sep	Sep	Sep
Squalus acanthias	–	–	–	–	–	–	–	–	–	–	–	–	14	–	22	–	–	–	–	5
Raja erinacea	4	–	3	16	–	1	–	3	28	–	–	3	–	12	45	–	–	–	–	2
Clupea harengus	–	–	–	–	–	1	–	1	–	–	–	7	–	31	–	–	1	1	–	–
Osmerus mordax	26	–	9	–	–	–	–	–	–	–	–	1	–	6	–	2	3	8	–	–
Gadus morhua	1	–	–	8	–	–	–	–	30	–	1	–	–	–	–	–	–	–	–	–
Microgadus tomcod	1	–	–	–	–	–	3	–	1	–	–	–	–	–	221	20	20	77	23	60
Urophycis tenuis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	27	3	–	18	–	3
Merluccius bilinearis	–	–	–	–	–	–	–	–	–	–	4	–	1	–	165	1	15	31	100	96
Pollachius virens	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	–
Pseudopleuronectes americanus	2	–	2	20	–	–	–	1	300	–	–	–	–	1	–	–	–	–	–	–
Scophthalmus aquosus	–	–	1	–	–	1	–	–	–	–	–	1	–	–	–	–	–	–	–	–
Hippoglossus hippoglossus	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–
Peprilus triacanthus	–	1	–	–	1	–	–	–	–	36	–	–	4	–	–	–	2	2	–	–
Hemitripterus americanus	4	1	3	4	–	38	1	4	4	–	–	11	–	–	–	–	–	–	–	–
Myoxocephalus aeneus	2	–	3	–	–	3	–	1	–	–	–	1	–	–	–	–	–	–	–	–
M. octodecemspinosus	1	–	–	7	–	–	–	1	60	–	–	1	–	–	–	–	–	–	–	–
Liparis atlanticus	–	–	–	–	–	2	–	1	–	–	–	–	–	–	–	–	–	–	–	–
Liparis coheni	–	–	1	–	–	29	1	–	–	–	–	17	–	1	–	–	–	–	–	–

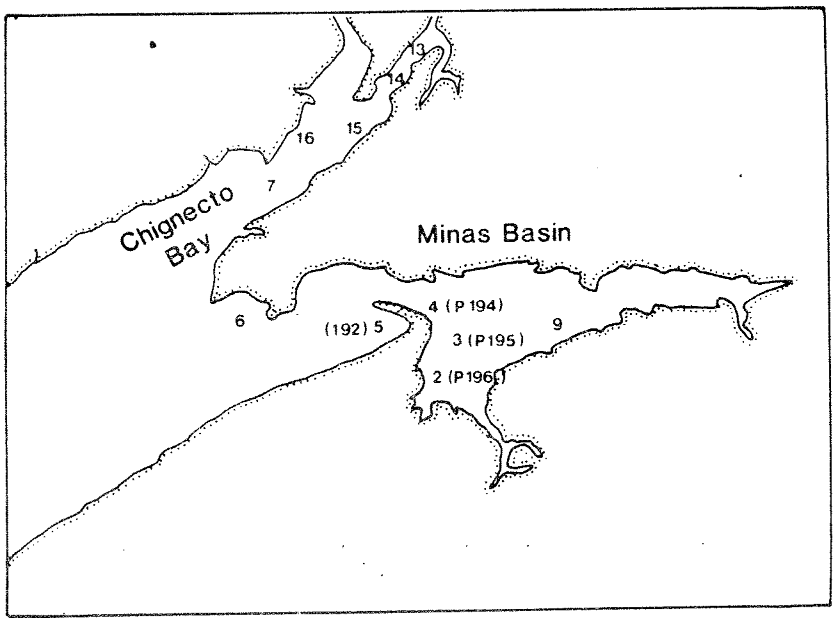


Fig. 9. Stations sampled by "Yankee-35" trawl in the upper Bay of Fundy during 1979. Numbers in brackets are the "Prince" stations occupied for bottom trawl by Leim in 1922 (Bousfield and Liem 1958).

122,000 utilized the tide flat during high tide (Table 7). A population of this size represented a standing crop of approximately 0.2 tomcod/m^2, or for the average weight of tomcod sampled in this study of 21.8 g, a tomcod biomass of 4.4 g/m^2.

Food: The amphipod, *Corophium volutator*, constituted 78-92% on a dry weight basis of the food of tomcod utilizating tide flats in Cumberland Basin during summer (Salinas 1981). During fall, winter and spring polychaetes and other benthos accounted for up to 70% by dry weight of the stomach contents (Salinas 1981). Crustaceans, particularly amphipods, are typically found as the major prey in other tomcod populations studied (Cox 1933, Grabe 1978).

Tomcod feeding on *Corophium* appear to select for the large amphipods (Fig. 10) but selection may be controlled more by availability (more large *Corophium* swimming in water column) than by preference. The mouth gape to length relationship for tomcod suggests that even 0+ tomcod (50 mm) would have little problem feeding on all sizes of *Corophium* (Fig. 11).

Between May and December 1979, weight of gut contents was 1-3% of body weight, of which 30-90% by weight was *Corophium* (Salinas 1981). This represents 35-150 *Corophium*/tomcod. Using estimated tomcod population sizes and the mean number of *Corophium* found in stomachs during 2-wk periods, it was calculated that 1.72×10^6 *Corophium* or 2.86 g dry wt m^{-2} were removed from the Pecks Cove tide flat between May and October, 1979 (Table 8). The calculated removal by tomcod represented 0.2% of the estimated *Corophium* production between May and September 1979 (Hicklin et al. 1980, Linkletter pers. comm.). Unless population size was underestimated, tomcod apparently consume only a minor portion of the annual Pecks Cove *Corophium* production.

Salinas (1981) found that tomcod feeding intensity was related to season and tide phase. Greatest food consumption occurred in summer, least in winter. Stomach fullness was greatest during mid-tide falling which suggests predation success was greatest when turbidity declined (Salinas 1981, Gilmurray and Daborn 1981). Assimilation efficiency of tomcod was approximately 90% at 10°C and 18°C but assimilation rate was greatest at higher temperatures (Salinas 1981).

Early life history: In the Bay of Fundy region tomcod spawn in freshwater streams during winter (Leim and Scott 1966). Eggs are adhesive and remain attached to the substrate until the larvae hatch in early spring (March-April) (Peterson et al. 1980). The larvae drift downstream to the ocean where they remain drifting as part of the zooplankton for the first 2-3 mo of their life. Hatching size in the Bay of Fundy is 6-8 mm (Peterson et al. 1980) and growth is slow for the first 2 mo, the larvae attaining only 12-16 mm (Fig. 12). During June growth accelerates and by late July when juvenile tomcod (0+) first appear in the intertidal zone in Cumberland Basin they average 50-60 mm in length (Fig. 13). The weight-length relationship for Saint John River larval tomcod is described by LogW = 1.22 (LogL)-5.25 where W = weight in g, L = length in mm (Fig. 14).

TABLE 7. Tabulation of marked Microgadus tomcod from bi-weekly collections in ith sample, recaptured in the hth sample, Peck's Cove, May – October, 1979 and resulting Seber-Joly population estimates.

Cycle	i	1	2	3	4	5	6	7	8	9		Totals
	n_i	545	447	1068	450	276	341	954	601	1540	2981	9203
	R_i	445	356	1038	406	248	237	895	552	97	0	4274
1		–	6	3	3	1	2	2	1	4	3	25
2			–	3	5	2	4	1	1	2	2	20
3				–	4	2	2	1	3	2	2	16
4					–	6	3	2	3	2	1	17
5						–	1	1	1	2	5	10
6							–	2	8	14	6	30
7								–	2	12	2	16
8									–	8	4	12
9										–	2	2
10											–	–
m_i		–	6	6	12	11	12	9	19	46	27	148
% recaptures			1.3	0.6	2.6	4.0	3.5	0.9	3.2	3.0	0.9	

Cycle	Proportion marked	Total marked	Total number[1] (N)	Survival probability	Immigration	Standard Error of (N)
1	–	–	–	.7754	–	–
2	.0134	344	25642	3.0926	303122	12958
3	.0056	2147	382144	.2817	-74074	193404
4	.0267	896	33587	.8354	-989	13446
5	.0399	1077	27033	.2556	2644	12164
6	.0352	336	9545	6.1992	310047	3369
7	.0094	3477	368575	.6264	-144384	159216
8	.0316	2733	86449	.3853	8840	33188
9	.0299	1259	43132	–	–	30126
10	.0091	–	–	–	–	–

[1] Mean population estimate 121,888 ± 39,321

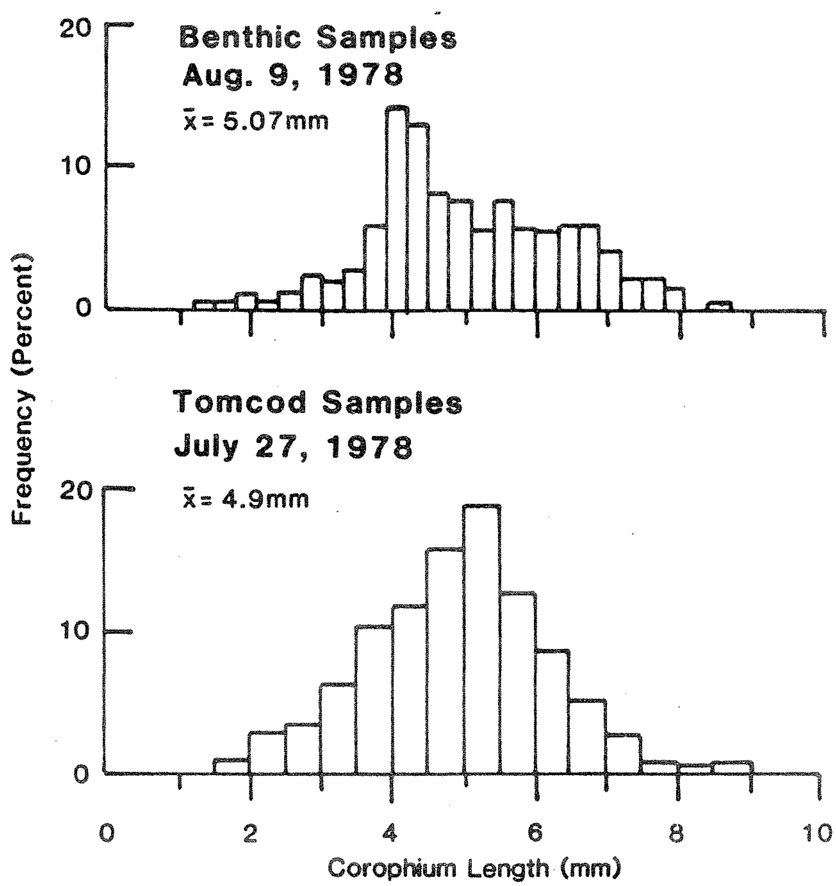


Fig. 10. Size distribution of <u>Corophium</u> in benthic samples and in tomcod stomachs from Pecks Cove, 1978.

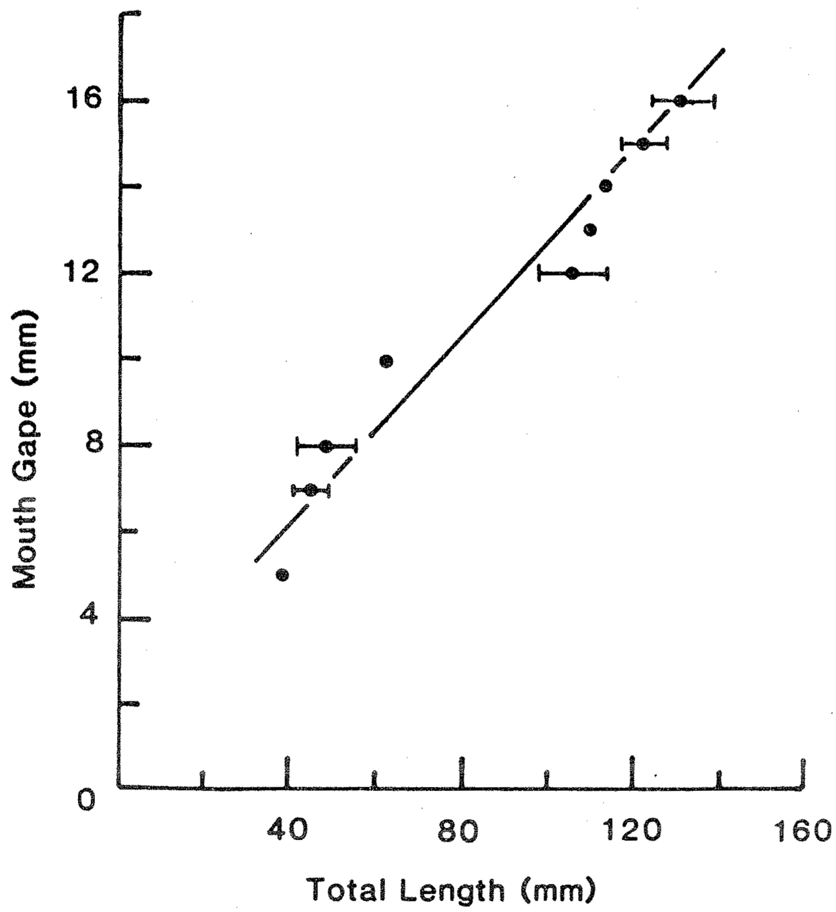


Fig. 11. Mouth gape of tomcod in relation to total length.

TABLE 8. Utilization of *Corophium volutator* by tomcod, Pecks Cove, Cumberland Basin. June 1 - October 25, 1979.

Period	*Corophium*/ tomcod	Tomcod Population $\times 10^4$	*Corophium* removed/tide $\times 10^7$	Tides of period	Total *Corophium* $\times 10^8$	*Corophium* dry wt./tomcod $\times 10^{-2}$ g	Dry wt. *Corophium* $\times 10^{-3}$ g	Total wt. *Corophium* consumed $\times 10^5$ g
June 1-13	39.7	38.2	1.52	24	3.65	4.98	1.26	4.60
June 14-27	35.5	3.36	0.12	28	0.34	4.83	1.36	0.46
June 28-July 11	52.5	2.70	0.14	28	0.39	2.18	0.42	0.16
July 12-24	145.6	0.95	0.14	26	0.36	6.70	0.46	0.16
July 28-Aug 8	68.2	36.86	2.51	30	7.53	6.26	0.96	7.23
Aug 9-22	63.2	8.64	0.55	28	1.54	5.63	0.88	1.35
Aug 23-Sept 11	76.6	4.21	0.33	40	1.32	3.02	0.39	0.52
Sept 11-Oct 25	58.0	12.19	0.71	88	6.25	2.50	0.43	2.68
							Total	17.16×10^5 g 2.86 g/m^2 dry wt.

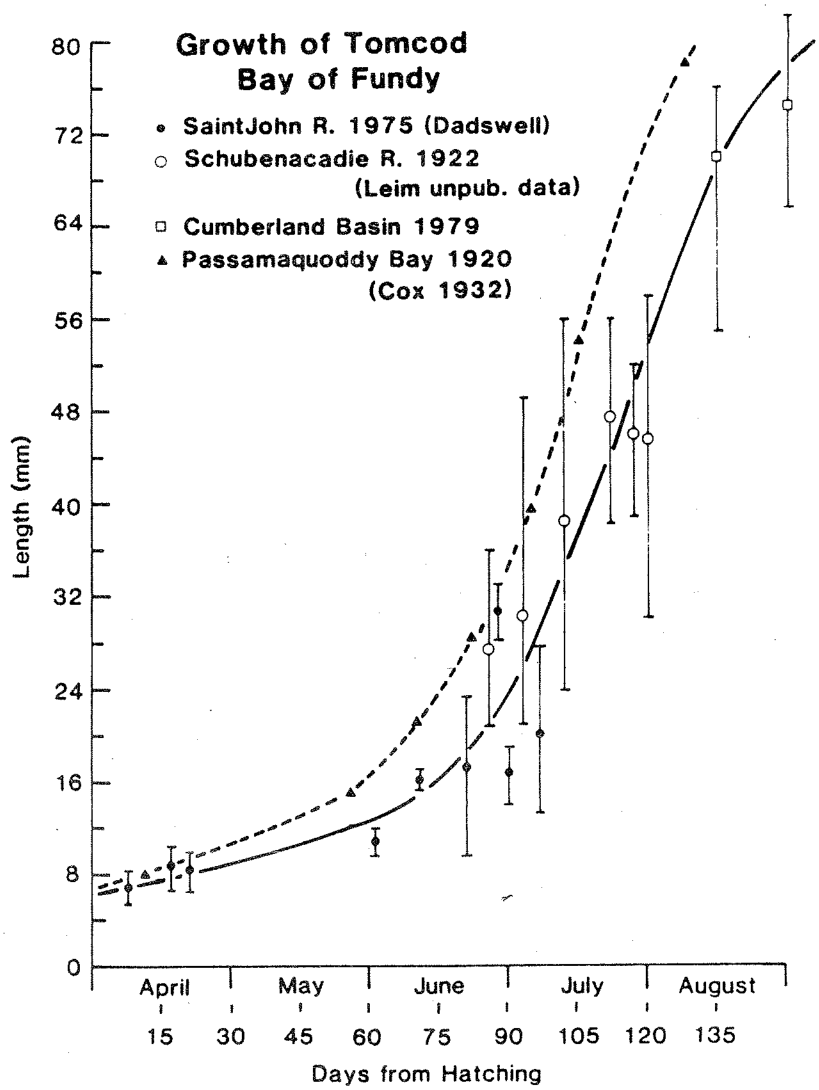


Fig. 12. Averaged growth rate during the first year of life of *Microgadus tomcod* from various localities in the Bay of Fundy.

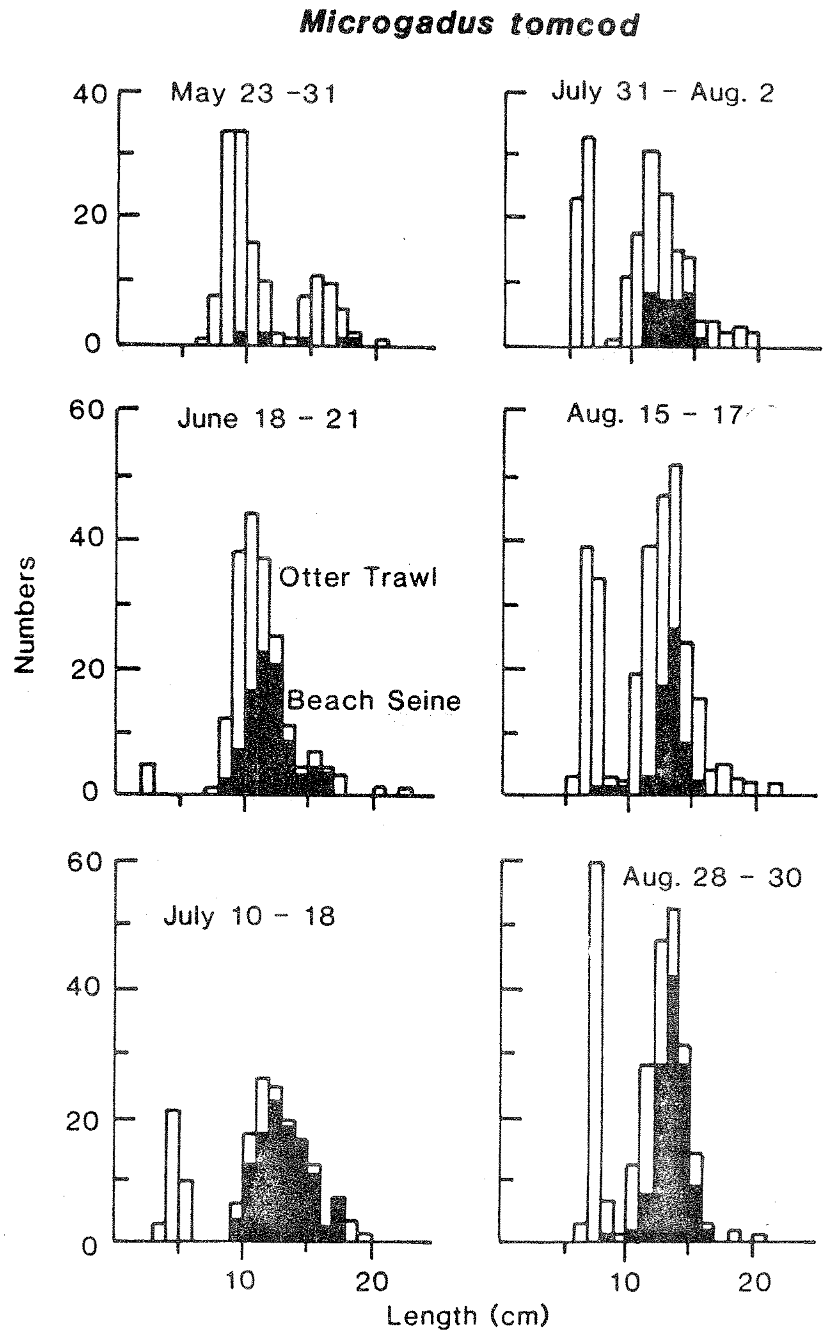


Fig. 13. Length-frequency distribution of tomcod on Pecks Cove intertidal zone and just offshore, May-August 1979, caught be beach seine (1-cm mesh) and otter trawl (3-cm mesh).

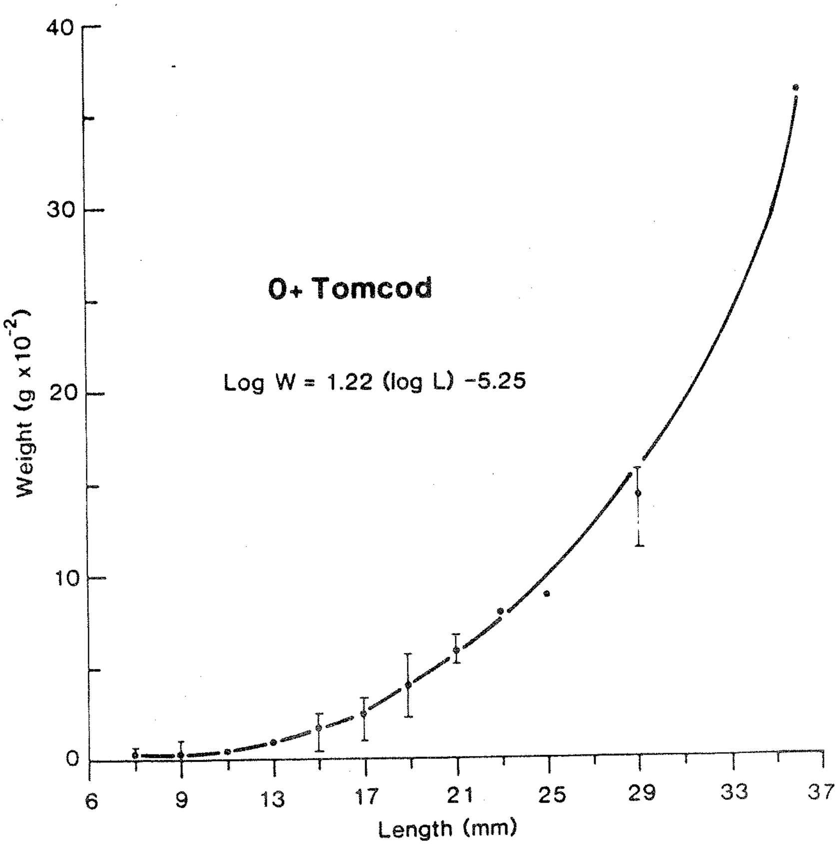


Fig. 14. Weight-length relationship for larval tomcod captured in the pelagic zone of the Saint John River estuary, 1975.

Age, growth and mortality: Tomcod are shortlived. Few captured in Cumberland or Minas Basin exceeded 4 yr of age (Fig. 15). Growth is rapid during the first two summers but slows on attainment of maturity (age 1+). The approximate von Bertalanffy growth curve for tomcod from Cumberland Basin is $L_t = 280\ (1-e^{-0.303(t+0.10)})$ where L_t = length in cm (Fig. 16). Mean size of immature 1+ fish approaches that of mature 2+ tomcod during the former's second summer and the majority of tomcod do not survive after age 2+ or second spawning (Fig. 15). The average weight-length relationship for tomcod from Cumberland Basin is LogW = 2.96(LogL) -4.05, where LogW is weight in g and LogL is length in mm (Fig. 17).

The percent of various age-class abundances from cumulative seine hauls in Cumberland Basin and Cobequid Bay indicate mortality of 0+-2+ tomcod is high (Fig. 18). Calculated instantaneous total mortality (Z) for Cumberland and Cobequid seine collections and Scots Bay weir collections are 1.87,2.13 and 0.68, respectively (Fig. 19). We suspect older tomcod are less abundant in the inner portions and young tomcod are not well represented seaward of these embayments during summer because of temperature selection. This spatial segregation creates a bias for estimated mortalities. True Z for these populations is perhaps in the range, 1.00-1.50.

Movements: After leaving the zooplankton, tomcod become part of the intertidal zone or beach assemblage of fishes (Macdonald et al. in press). Tomcod migrate onto the tide flats with the rising tide and leave on the falling tide (Salinas 1981). During summer, perhaps in response to increased temperatures in the shore zone, larger tomcod remain in deeper water or migrate to more seaward intertidal beaches (Figs. 13, 20) (Table 6), then return to the embayments in October (Fig. 7).

2. Smelt (*Osmerus mordax*)

Smelt were the second most abundant fish captured in seine hauls in the upper Bay of Fundy (Table 3). Ninety-seven percent of smelt taken during the 1979 seine survey were from estuarine sites. Smelt was also abundant in the pelagic zone of the megatidal basins and were frequently captured during trawl sampling (Van Eeckhaute and Appy 1979) and drift gillnet sampling (see pelagic section).

Food: In Minas Basin, yearling smelt (25-50 mm FL) fed predominently on *Eurytemora herdmani* and pelagic eggs; 1-2-yr-old smelt fed mainly on salt marsh insects, mysids and *Corophium* (Imrie and Daborn 1981).

Age and growth: In Cumberland and Minas Basins, yearling smelt appear in the intertidal zone in late July at a size of 20-30 mm FL (Fig. 21) (Imrie and Daborn 1981). One-year-old smelt average 65-105 mm FL and 2 yr old smelt may attain 150 mm. The largest smelt captured during the 1978 seining survey was 188 mm. Seining and benthic trawl surveys predominately captured 0+, 1+ and 2+ smelt (Van Eeckhaute and Appy 1979).

The weight-length relationship for smelt from the upper Bay of Fundy based on 92 specimens captured between June and August was LogW = 3.04 LogL - 12.29 where W = weight (g), L = fork length (mm).

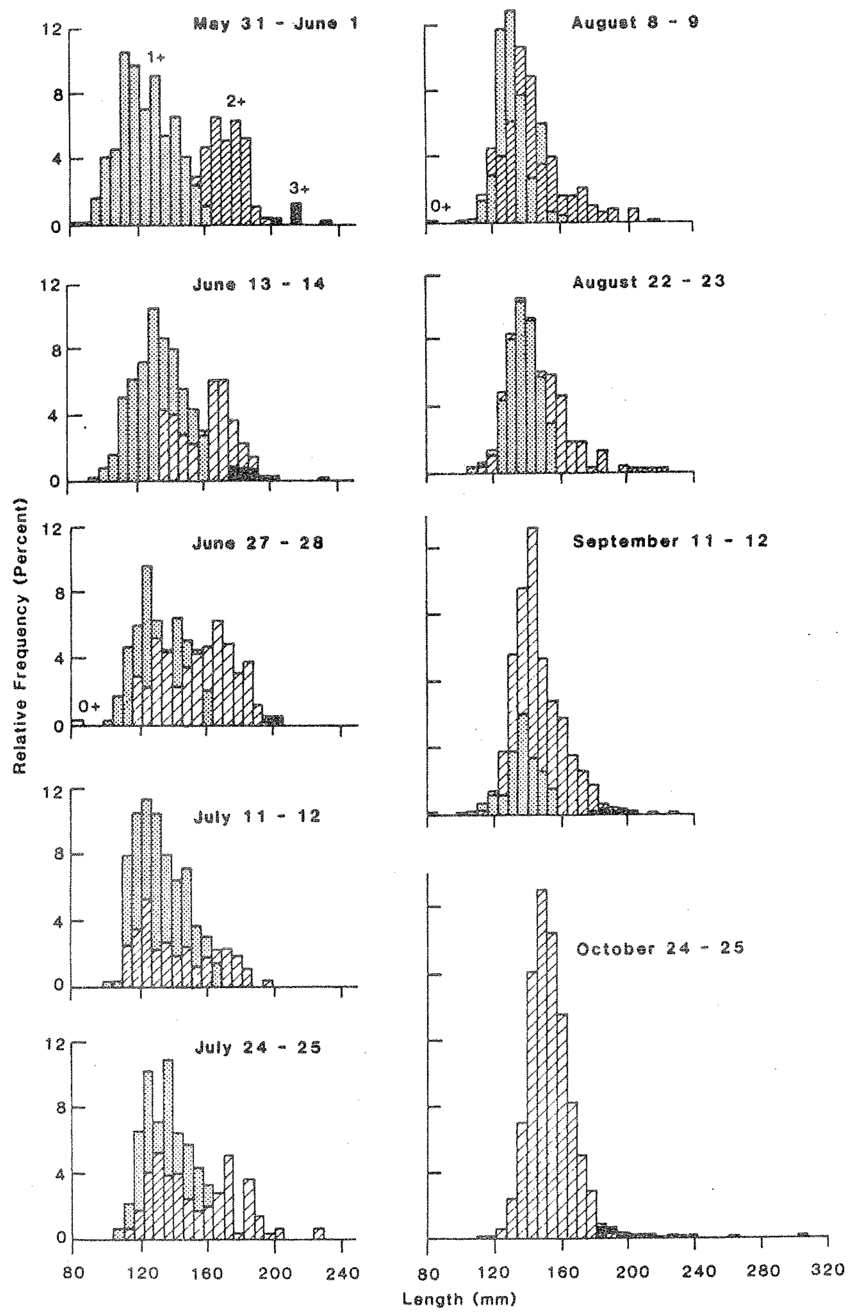


Fig. 15. Length-frequency distribution by age of tomcod captured in an intertidal fykenet (2.5-cm mesh) during May-October 1979.

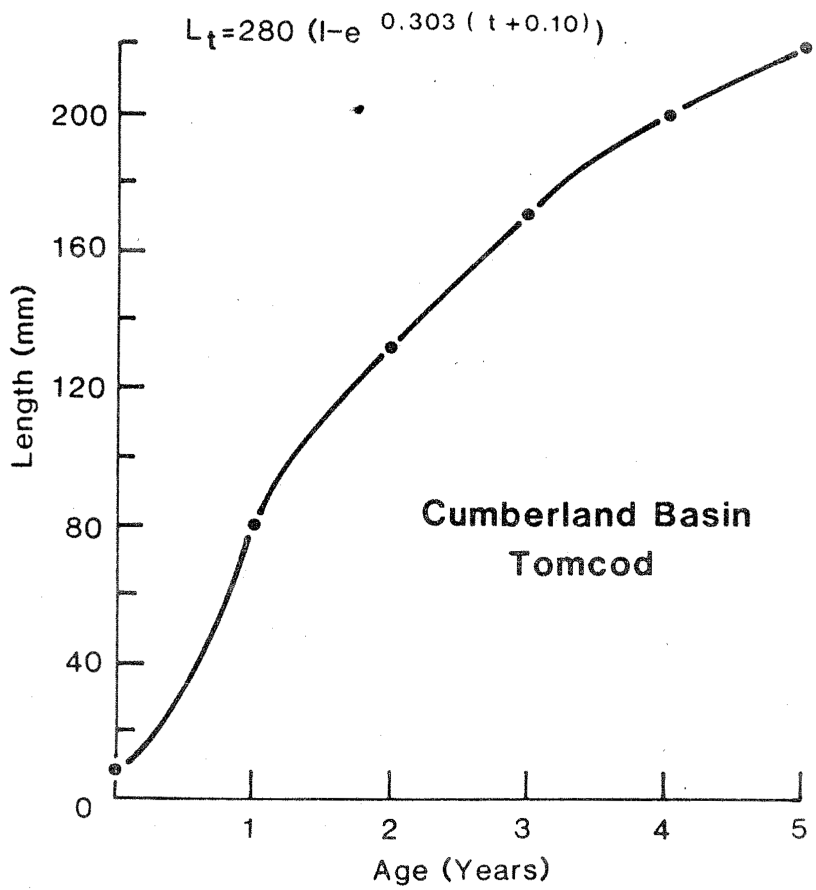


Fig. 16. Von Bertalanffy growth relationship (length vs age) for tomcod in Cumberland Basin.

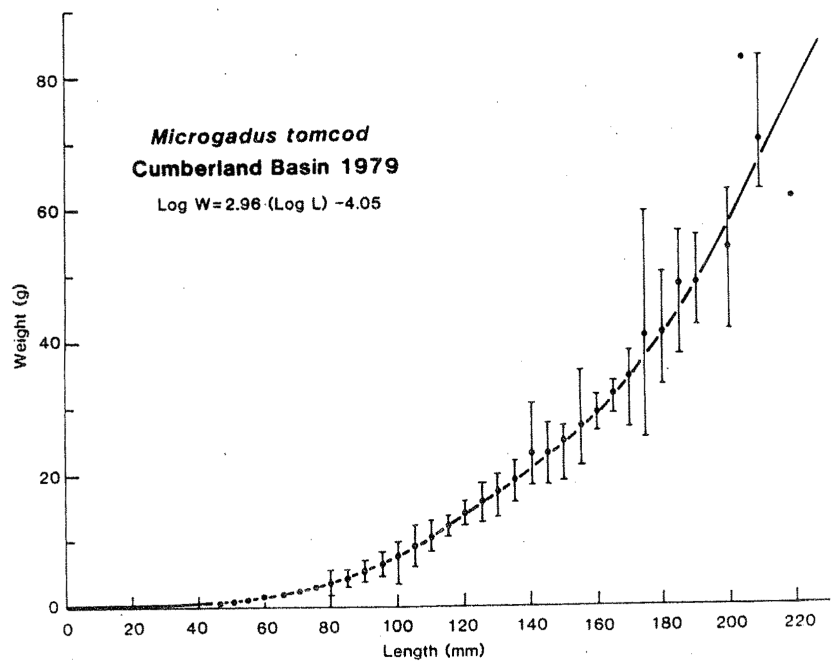


Fig. 17. Weight-length relationship for tomcod from Cumberland Basin.

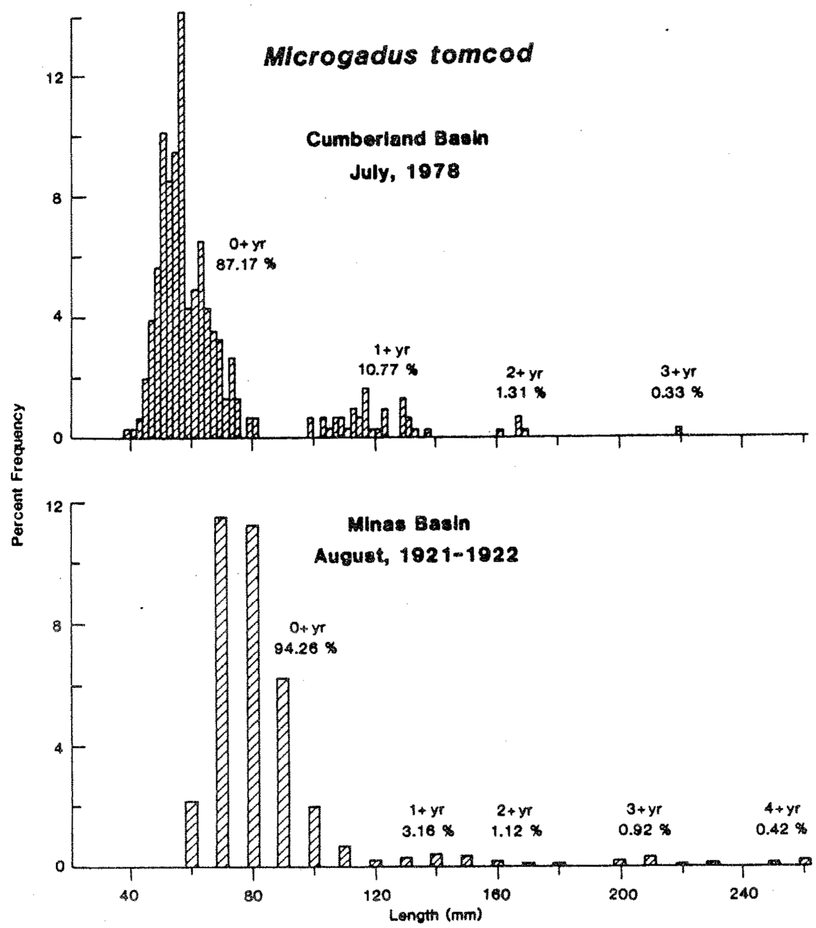


Fig. 18. Age-class abundance from cumulative seine hauls during summer in Cumberland and Minas Basins, 1978 and 1921-22.

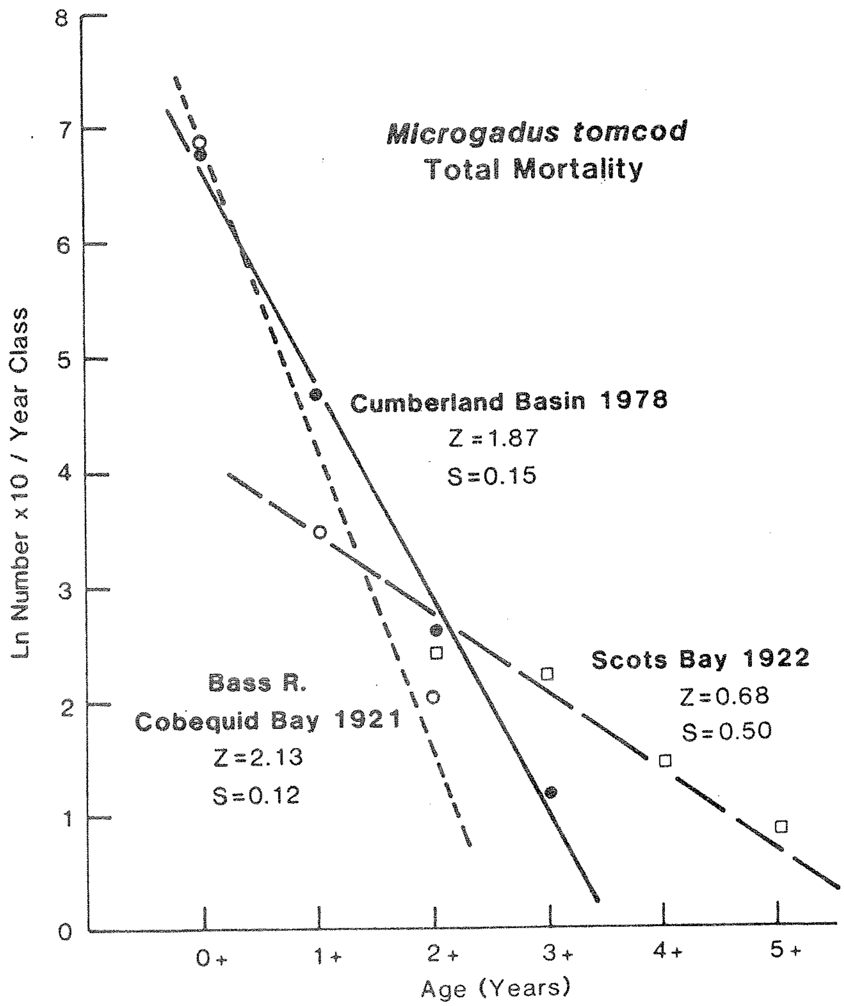


Fig. 19. Total mortality (Z) and resultant annual survivorship (S) for tomcod sampled at two warmwater sites (Cumberland Basin and Cobequid Bay) and one coldwater site (Scots Bay).

Fig. 20. Numbers of tomcod captured/seine haul in Chignecto Bay during June to September 1978. Sites in a seaward progression are Beausejour, Wood Pt., Wood Ck., Allen's Ck., Pecks Pt. and Marys Pt.

3. Silversides (*Menidia menidia*)

Menidia menidia is a common member of the beach fish assemblage in the upper Bay of Fundy (Table 3). They seem to be most abundant at sites with harder substrate (sand, gravel), high salinities and less turbid water (Table 2). Abundance of *Menidia* among beach catches tends to increase in late summer (Gilmurray and Daborn 1981) (Table 5). This is partially a response to the addition of 0+ recruits to the population, and partially because the water becomes less turbid at this time making the habitat more preferable to *Menidia*. Gilmurray and Daborn (1981) postulated *Menidia* was primarily a visual particulate feeder because the gut fullness index rose rapidly during and after high tide when turbidity was decreasing. Salinas (1981) found *Menidia* was always absent along the beach at night except during one sampling period when there was a full moon.

Food and feeding: In Cumberland Basin *Corophium* comprised the highest percentage (43-93%) of food items in the *Menidia* guts at all times of the year (Salinas 1981). Only insects approached *Corophium* in importance and then only in August and September (29-30%). The copepod *Eurytemora herdmani* was third in occurrence.

Food items occurring in the guts of *Menidia* from Minas Basin were similar but relative importance was different (Gilmurray and Daborn 1981). The copepod, *Eurytemora herdmani*, was the most common food item of all size classes except those larger than 101 mm (40-100%) and at all times of the year except mid-summer. Unlike the situation in Cumberland Basin, where there appeared to be little selection of prey type by size class of *Menidia* (Salinas 1981), small *Menidia* in Minas Basin exhibited strong selection for planktonic or neustonic prey (*Eurytemora*, Harpacticoids, *Crangon*). Larger silversides ate food similar to those in Cumberland, mainly floating or swimming large arthropods (*Corophium*, Insecta, *Diastylis*).

Although prey items were fairly similar, the feeding mode appeared to be almost exactly opposite at the two sites studied. Salinas (1981) found *Menidia* were empty at low tide and had full guts at high tide (Fig. 22). Gilmurray and Daborn (1981) found *Menidia* were least full at high tide and gut fullness increased during falling tide (Fig. 22). The results from Cumberland Basin may be partially spurious since 41 of the 50 *Menidia* used for the low tide stomach analysis were taken during a dawn low tide and Salinas (1981) contends *Menidia* do not feed at night.

Assimilation efficiency of *Menidia* was 71.5% at 10°C and 73.7% at 17°C (Salinas 1981). Evacuation times varied from 34 hr at 5°C to 10 hr at 18°C (Salinas 1981).

Age, growth and reproduction: *Menidia* in the Bay of Fundy have an annual life cycle (Leim and Scott 1966) or survive for 2 yr (Jessop 1983). Spawning occurs in May and June on Cumberland Basin (Salinas 1981) and small juveniles (20 mm) enter seine caches in August (Gilmurray and Daborn 1981). Growth is rapid. Most fish in the population each year are 1-yr-olds but a few survive into their second year (Imrie and Daborn 1981). An approximate Von Bertalanffy growth curve for these silversides is L_t =

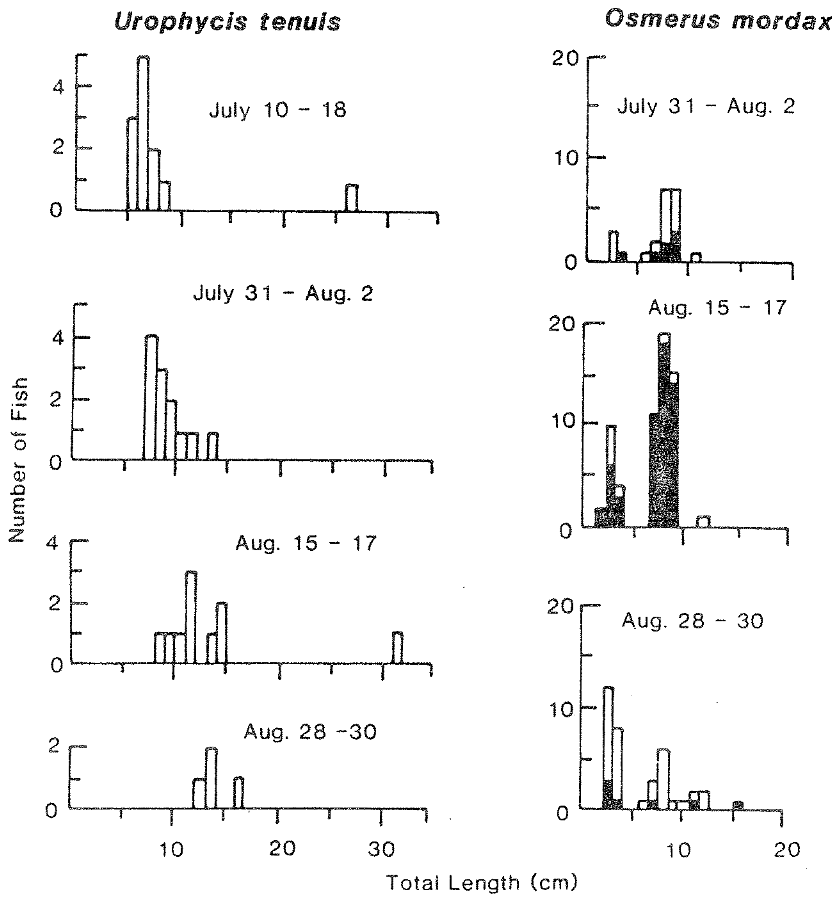


Fig. 21. Length-frequency of Urophycis tenuis and Osmerus mordax from Cumberland Basin 1979. Fish were captured with an otter trawl (opern bars) or a beach seine (shaded bars) (after Van Eeckhaute and Appy 1979).

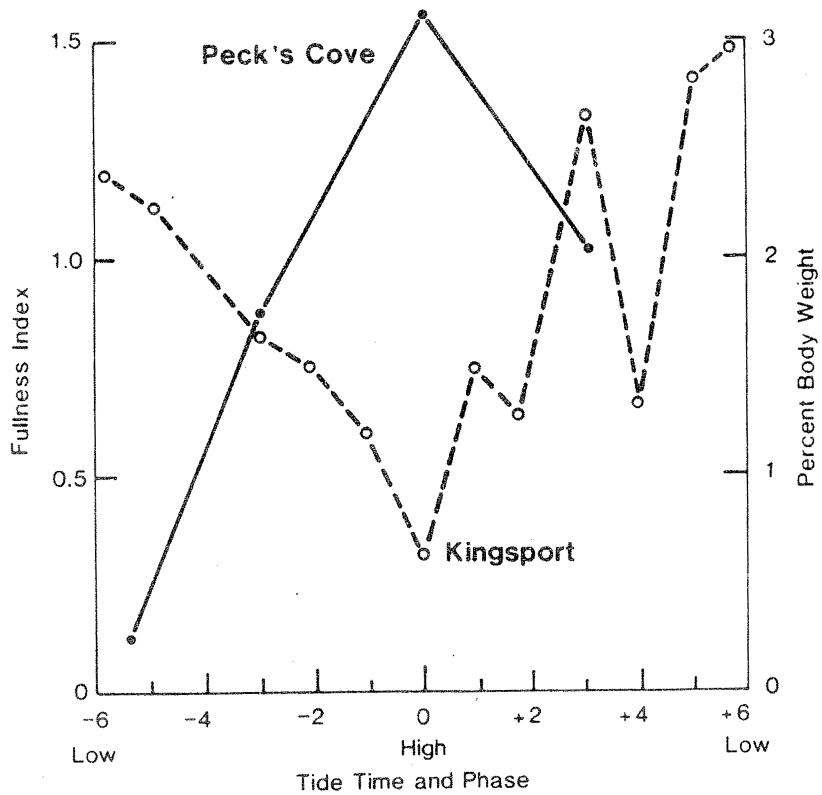


Fig. 22. Fullness index in relation to tidal time and phase for Menidia menidia in Cumberland Basin (Pecks Cove) and Minas Basin (Kingsport) (after Salinas 1981, and Gilmurray and Daborn 1981).

$126 (1-e^{0.89(t+0.22)})$ (Fig. 23). The weight-length relationship is given by Salinas (1981) as a power function. For September it is $W = 41 \times 10^{-7} L^{3.27}$ where W = dry body weight (g) and L = total length (mm). The weight- length relationship for seine captured *Menidia* during the summer was LogW = 2.94 LogL - 11.76 where W = wet weight (g), L = fork length (mm).

4. Smooth flounder (*Liopsetta putnami*)

Smooth flounder are an ubiquitous member of the beach assemblage in the upper Bay of Fundy but never occur in large numbers (Table 2). Greatest numbers, 94% of captures, were over mud flats, in warm, turbid, low salinity water (Table 3). This species is uncommon outside of estuarines in eastern Canada (Leim and Scott 1966).

Abundance: The large fykenet used to capture tomcod during the 1979 population experiments at Pecks Cove also captured considerable numbers of smooth flounder. Catches ranged from 50-300 during a 3-tide sampling cycle (Table 9). Catches were largest during spring, declined during summer and increased in the fall as 1+ juveniles began to be captured by the gear (Fig. 24). During spring and late summer largest catches of smooth flounder occurred on night tides but the pattern was reversed in mid-summer (Fig. 8). The differences, however, were barely significant (P = 90%) and may actually have been caused by tide phase, weather or gear bias.

Mark-recapture experiments at Pecks Cove during May to October, 1979 indicated the smooth flounder population was relatively sendentary and it declined from approximately 10,000 in spring to 1000 in fall (Table 9). The beach population consisted of four year classes (1+-4+) and decline in population appears related to a sharp decline in 2+ fish (Fig. 24). Whether decline was caused by emigration (which the population model suggests) or mortality is impossible to determine. Scully (1983), using a Schnabel mark-recapture experimental design, found the population of 0+ juvenile smooth flounder in a mudflat-salt marsh tide flat drainage system in Minas Basin was 1742 ± 50%.

Food: Imrie and Daborn (1981) reported that 0+ smooth flounder from Kingsport, Minas Basin fed mainly on harpacticoid copepods and mysids. Scully (1983) found 0+ flounder from a nearby site utilized *Eurytemora* in spring after which *Corophium* and polychaetes became the most important food items. Smooth flounder (1+ - 4+) from Pecks Cove, Cumberland Basin preyed only on benthos (Fig. 25). *Corophium*, polychaetes, and *Hydrobia* were the most numerous items found in the guts but *Macoma* was usually the most important by weight. Salinas (1981) reports similar findings from his study of smooth flounder guts in Cumberland Basin (they were *Liopsetta*, not *Paralichthys* as in his thesis). *Macoma* averaged 37% of the diet of all sizes of flounder but declined from a high of 81% in May when *Macoma* were abundant in the benthos to 44% in August when they were less so. Polychaetes were also important ranging from 12-65% occurrence. *Corophium* tended to be most important in the diet of flounder less than 165 mm in length. In general molluscs dominated the diet but a large proportion (57%) of the total dry gastric contents was sediment.

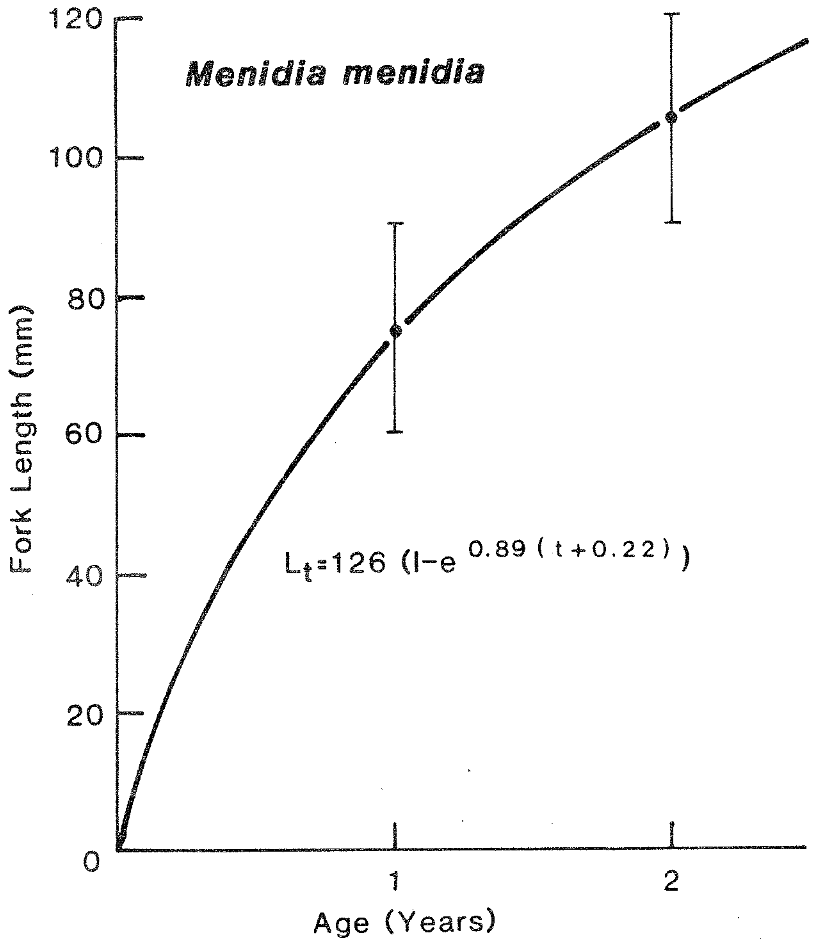


Fig. 23. Von Bertalanffy growth relationship for *Menidia menidia* from Minas Basin.

TABLE 9. Tabulation of marked Liopsetta putnami from the biweekly collections in ith sample, captured in the hth sample, Pecks Cove, May – September, 1979 and the resulting Serber-Joly population estimates.

Cycle	i										Totals
	n_i	265	292	276	155	94	56	63	87	92	1380
	R_i	265	244	201	92	68	39	40	70	13	1032
1		–	5	4	5	6	2	5	1	1	29
2			–	14	0	5	7	4	4	1	44
3				–	7	6	2	2	2	2	21
4					–	5	5	2	2	1	15
5						–	1	1	2	2	6
6							–	1	3	2	6
7								–	3	3	6
8									–	6	6
9										–	–
m_i		–	5	18	21	22	17	15	17	18	133

Where i = sample number, h = recapture sample number, n = number of captures in the ith sample, R_i = number of marked animals released in the ith sample, r_h = number of recaptures in the hth sample, m_i = number of marked animals caught in the ith sample.

Cycle	Proportion marked	Total marked	Total number (N)	Survival probability	Immigration	Standard Error of (N)
1	–	–	–	.5231	–	–
2	.0171	138	8065	1.3168	-2942	3939
3	.0652	497	7614	.4822	-1217	2483
4	.1355	328	2419	1.2776	-833	775
5	.2340	509	2176	.4052	-130	955
6	.3036	225	741	.6815	214	317
7	.2381	168	707	.8121	248	313
8	.1954	157	804	–	–	381
9	.1957	–	–	–	–	–

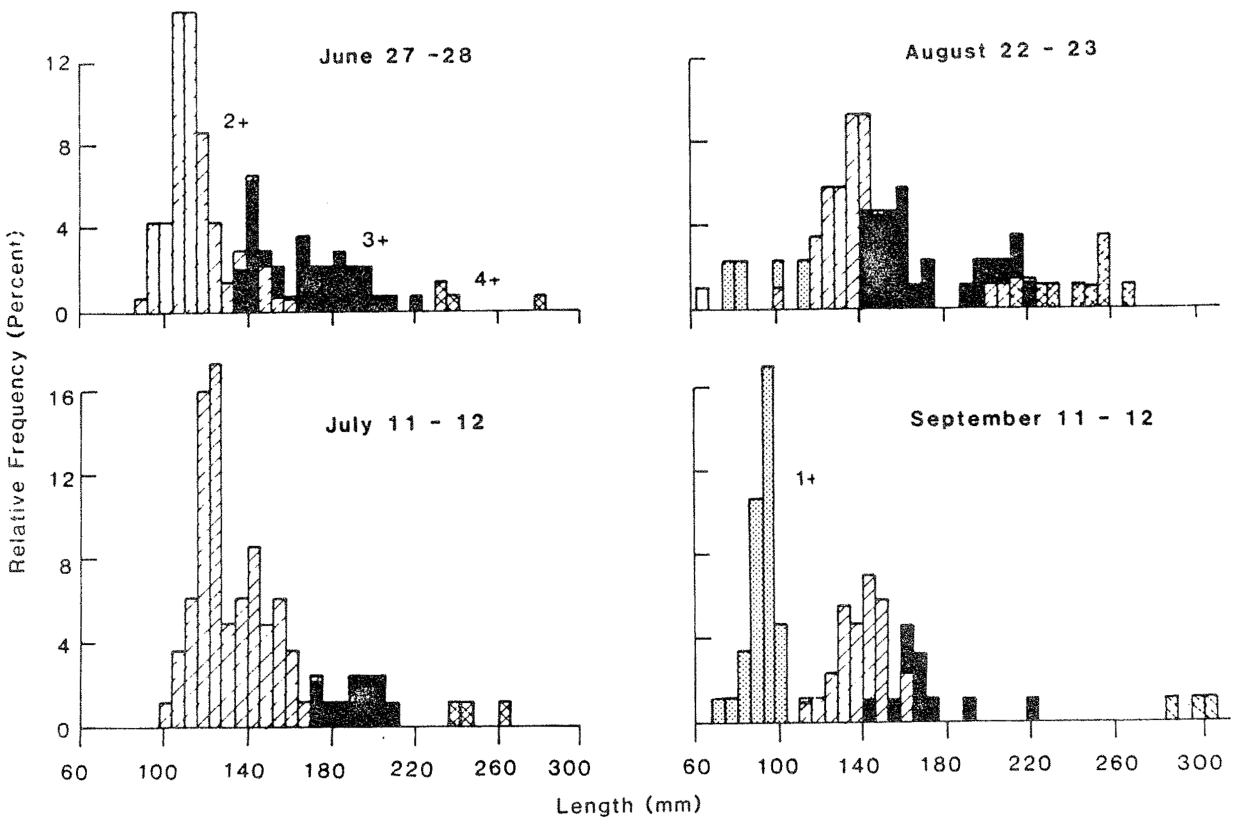


Fig. 24. Length-frequency distribution by age-class of smooth flounder captured on the Pecks Cove mudflat between June and September 1979.

Age, growth and mortality: The majority of smooth flounder occurring on tide flats in Minas Basin were young of the year (Imrie and Daborn 1981; Scully 1983). In Cumberland Basin the major age classes captured were ages 1+–3+ (Fig. 24) but these findings could be partially an artifact of the sampling gear used. No flounder more than 4+ in age was captured.

Scully (1983) found the growth relationship for 0+ smooth flounder from Minas Basin was $L_t = 112.5\ (1-e^{-0.08(t+0.513)})$ where length is in mm. The weight-length relationship for these same fish was LogW = 3.14 (LogL)-2.010 where W = weight (g), L = length (mm). The weight-length relationship for 1+–3+ smooth flounder from Cumberland Basin was LogW = 3.12 (LogL)-1.19 where W = weight (g), L = length (mm).

Using percent abundance of 1+–4+ age classes of smooth flounder captured in Cumberland Basin in July and September, 1982 (Fig. 24) total mortality (Z) of the populations was determined as 1.40–1.65 (Fig. 26). Estimated total mortality may be greater than real values because of the probable emigration of larger flounder from the beach assemblage. Further work needs to be done on all these beach species to clarify the effects of their migratory behavior on the biological population parameters obtained from sampling.

5. Sticklebacks (*Gasterosteus aculeatus* and *G. wheatlandi*)

Sticklebacks were most common at seaward sites in the upper Bay of Fundy (Table 3). Sampling in lagoons and salt-marsh pools indicate they are extremely abundant in these habitats (Bleakney and Bailey-Meyer 1979, Brown 1983). *Gasterosteus aculeatus* is a regular member of the beach community in the outer Bay of Fundy (Macdonald et al., in press).

Food: The only aspect of the biology of sticklebacks in the upper Bay of Fundy examined to date was feeding habits. *G. aculeatus* from Cumberland Basin fed largely on harpacticoids (48–77%), *Macoma* spat, insects and *Eurytemora* (Salinas 1981). *G. wheatlandi* from Minas Basin fed almost exclusively on planktonic organisms including *Eurytemora* and harpactacoids (Imrie and Daborn 1981).

6. White hake (*Urophycis tenuis*)

Juvenile white hake (0+) were common members of the beach assemblage at more seaward sites in the upper Bay of Fundy (Tables 2 and 3). These juveniles ranged from 30–70 mm TL with a mode of 60 mm (Fig. 3). Yearling white hake were common in benthic trawl catches in Cumberland Basin (Van Eeckhaute and Appy 1979). These 1+ hake grew from a mean of 50 mm in spring to 150 mm in late August (Fig. 21). Few older white hake were captured. Except for parasites no other biological data were obtained from white hake.

7. Eel (*Anguilla rostrata*)

American eel were common in seine hauls from the inner, turbid

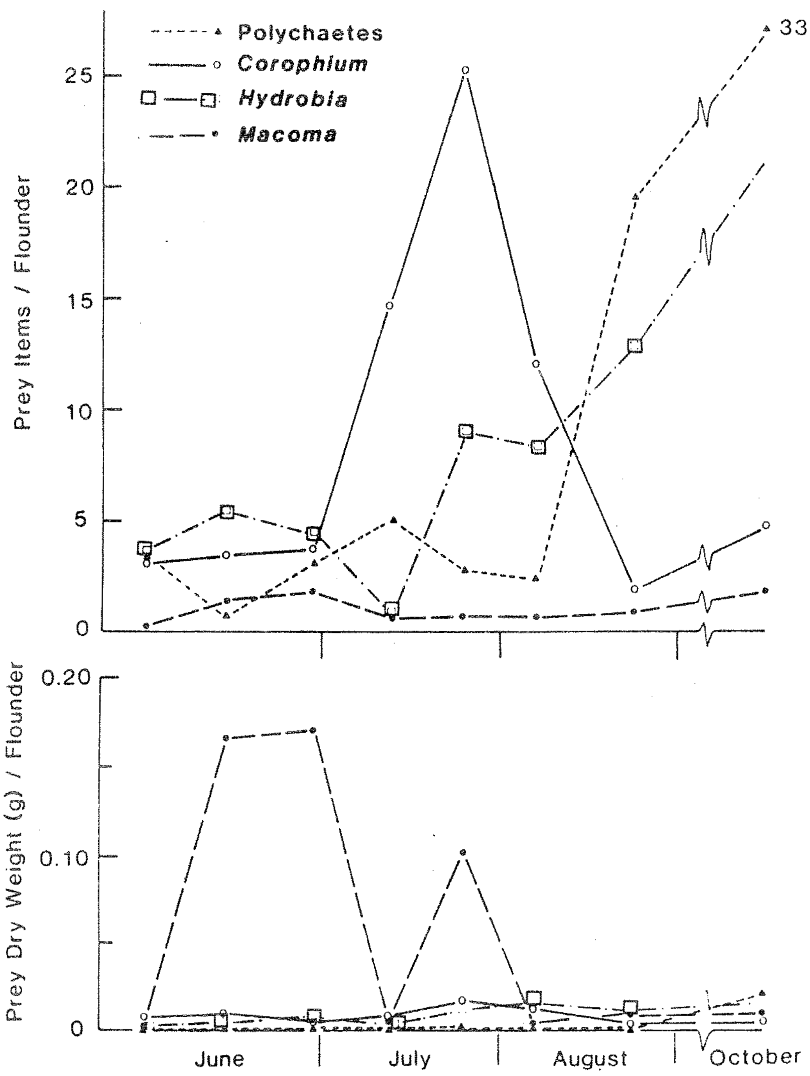


Fig. 25. Relative frequency and total dry weight of prey items by taxonomic group from stomachs of smooth flounder captured in Pecks Cove, Cumberland Basin between June and October 1979.

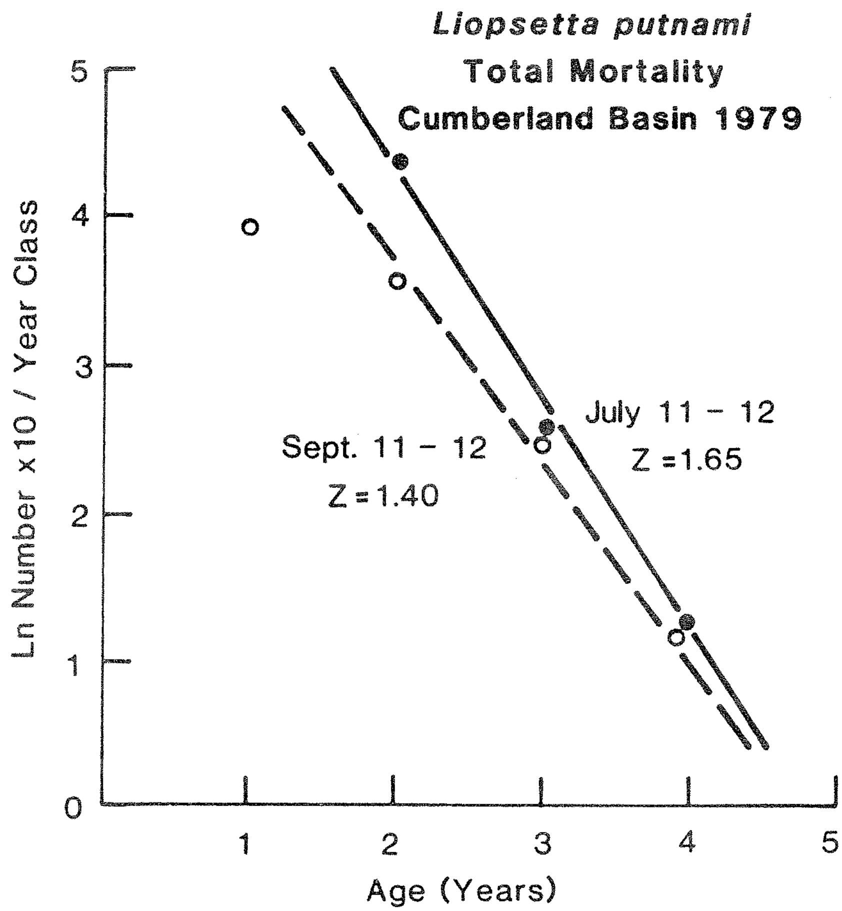


Fig. 26. Total mortality (Z) estimated by age class size analysis for smooth flounder at Pecks Cove, Cumberland Basin.

portions of the upper Bay of Fundy (Table 2), generally in habitats with reduced salinities (tidal creeks). Eels captured were mostly small to medium size green eels. No commercial fishery for eels exists in the upper Bay of Fundy but observed abundance appears sufficient to support one (Dadswell pers. obs).

8. Mummichog (*Fundulus heteroclitus*)

Mummichogs were seldom encountered during beach sampling but they are abundant in salt-marsh tide pools throughout the upper Bay of Fundy (Dadswell, pers. obs.). Bleakney and Bailey-Meyer (1979) captured 335 *F. heteroclitus* (52 g) from one 12.45 m^2 tide pool (4.18 g/m^2). Mummichogs occur in the pools in association with sticklebacks (*G. aculeatus*, *G. wheatlandi*, *Apeltes quadracus* and *Pungitius pungitius*) and American eels (*Anguilla rostrata*) (Bleakney and Bailey-Meyer 1979). Bleakney and Bailey-Meyer (1979) observed mummichogs leaving the pools during high tide to forage among the salt-marsh plants.

Brown (1983) has recently completed a study on *F. heteroclitus* from salt-marsh pools around the southern part of Minas Basin. He found four age classes of mummichog were present; the 0+-3+ age groups. Young of the year consituted approximately 70% of catches, 3+ fish, approximately 5%. The population arrives in the tide pools in June and most, except a few 0+ fish which overwinter there, leave in October.

Food: Juvenile (0+) mummichogs consumed mostly copepod nauplii (Brown 1983). Adults had detritus, diatoms, vegetation, insect larvae and *Corophium* in their stomachs. Diet varied during the year; in spring detritus, insects and copepods were most abundant, in summer, *Corophium*, detritus and insects, and in the fall, detritus and insects.

Growth: The Von Bertalanffy growth relationships for male and female mummichogs from Minas Basin were $L_t = 88(1-e^{-0.28(t+1.32)})$ for males and $L_t = 74.5\ (1-e^{-0.48(t+0.60)})$ for females where L_t is in mm (Fig. 27). The weight-length relationship for males was LogW = 3.20(LogL)-5.54 and for females, LogW = 3.26(LogL)-5.43 where W = weight (g) and L = length (mm) (Brown 1983).

9. Windowpane (*Scophthalmus aquosus*)

Windowpane were seldom captured during seining on tide flats but large specimens (20-40 cm) were often caught in weirs at Scots Bay (Fig. 4), Five Islands and Bass River in Minas Basin. The food of large windowpane captured in weirs at Bass River, Cobequid Bay in August 1921 in order of importance consisted of *Crangon septemspinosa* (71% occurence, 1-20 specimens per fish), tomcod (40%, 1-5/fish), smelt (9%, 1/fish), and striped bass, herring, silversides and mysids (all 3% and 1/fish). Small windowpane (under 20 cm) eat mysids almost exclusively (Leim and Scott 1966).

10. Other benthic fishes

Cod, *Gadus morhua*, were sometimes captured in drift gillnets (Table

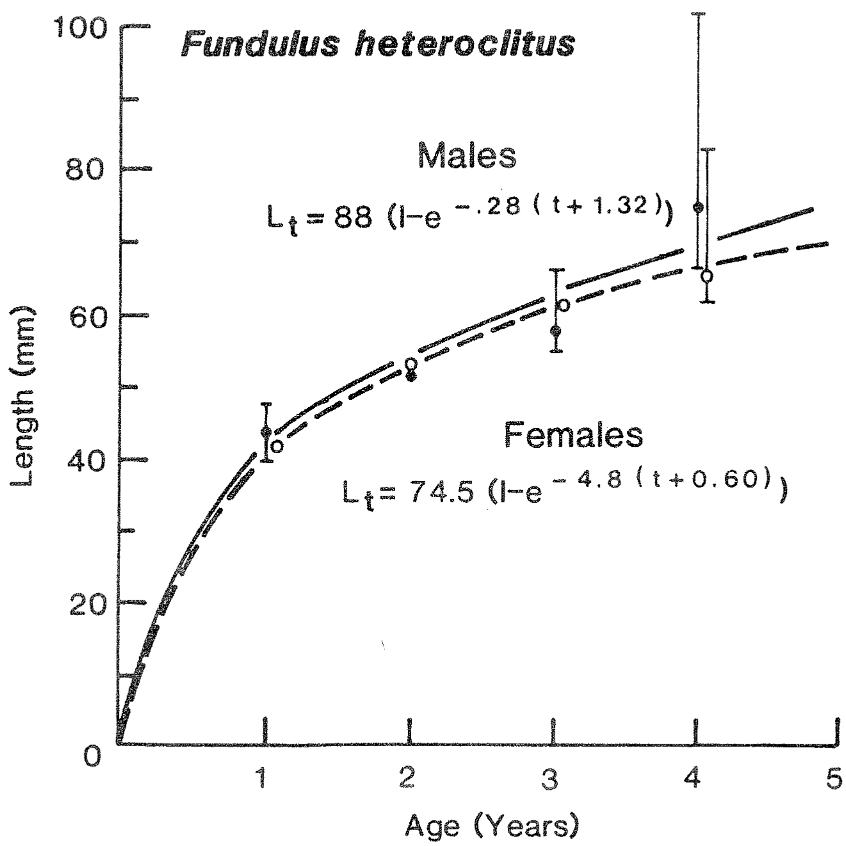


Fig. 27. Von Bertalanffy growth relationship for mummichog from Minas Basin (after Brown 1983).

10). A small set gillnet fishery existed around Pecks Point and the weir fishermen described small runs of rock cod (the local name) which occurred in Minas Basin in November. Cod were commonly caught during bottom trawl sampling in Scots Bay (Table 6).

Sea ravens, Hemitripterus americanus, were often caught during bottom trawl surveys in Minas Basin but were never encountered in Chignecto Bay (Table 6). During the summers of 1982 and 1983 they were regularly captured in the weirs at Five Islands and Economy Point.

Atlantic sturgeon, Acipenser oxyrhynchus, are common in the upper Bay of Fundy in summer. They were often captured in drift gillnets (Table 10) and by weirs. Most specimens seen were large (80-150 cm), and many were not actually handled because they tore out of the gillnets before reaching the boat. They were most abundant in the region during June and July.

Winter flounder, Pseudopleuronectes americanus, were seldom common in the surveys of the turbid water regions of the upper Bay. The only large catch was taken with a bottom trawl in Scots Bay (Table 6). The species was usually represented in catches only by juveniles. Leim (1931) reported winter flounder only moderately common during 1919-21 in Minas Basin. Weirs are built to specifically catch this species on the Economy flats but recent catches are small (Linkletter, pers. comm.). Observed catches in weirs at Upper Economy and Five Islands during 1982 and 1983 never exceeded 20 flounders/tide.

Leim (1931) reports this species eats mainly amphipods and Frame (1982) confirmed amphipods as the main dietary item. Risk and Craig (1976) described flatfish feeding traces in Minas Basin intertidal mud flats which were attributed mainly to this species.

Pelagic fish

Drift gillnets have been a favored gear in the shad and salmon fisheries of the upper Bay of Fundy since 1840 (Perley 1852, Prince 1912). Drift gillnet surveys were conducted in Chignecto Bay between 1979 and 1982 (Dadswell et al. 1983) and in Minas Basin during 1982 and 1983. Of 24 fish species recorded from commercial and survey gear approximately 18 can be considered pelagic or semi-pelagic (Table 10).

Commercial and experimental nets were set by hand from vessels in the tidal stream in or near frontal zones at points delegated by tide type (neap or spring) and phase (rising or falling). In Cumberland Basin, drifts generally began in mid-Basin (off Minudie) and proceeded 10 km to the inland (Sackville) or seaward (Joggins) ends. Inland or "high-water" drifts occurred largely over areas occupied by tide flats at low tide and had mean depths of 7-10 m at high water. In Cobequid Bay, drifts generally began off Spencer Creek at or near high water and proceeded 1-5 km inland and for 15-20 km seaward to Economy Point (Fig. 1). Sets were made during all periods of daylight or darkness.

TABLE 10. Pelagic and benthic fishes and crustaceans recorded from experimental and commercial drift gillnets in Chignecto Bay and Minas Basin in 1852 and 1979 - 1983. Meshes sizes were 6.2, 8.0, 10.0, 11.2, 12.0, 12.7 and 13.7 stretched mesh.

	Catch					
	Chignecto Bay			Minas Basin		
	1979	1980	1981[b]	1982[b]	1983[b]	Period
White shark *Carcharodon carcharias*[1]	–	–	–	–	–	Summer
Thresher shark *Alopias vulpinus*[2]	–	–	–	–	–	Summer
Porbeagle *Lamna nasus*	–	2	–	–	–	Summer
Dogfish *Squalus acanthias*	41	45	31	107	3	Spr-Summer
Atlantic sturgeon *Acipenser oxyrhynchus*	1	1	4	11	8	Spr-Summer
American shad *Alosa sapidissima*	680	3069	2831	2174	2800	Spr-Summer
Alewife *Alosa pseudoharengus*	4	15	269	450	1000	Spr-Summer
Blueback herring *Alosa aestivalis*	5	18	32	4	500	Summer
Atlantic menhaden *Brevoortia tyrannus*	30	4	81	–	400	Summer
Atlantic herring *Clupea harengus*	2	1	8	4	2	Spring
Atlantic salmon *Salmo salar*	55	34	132	76	82	Summer-Fall
American smelt *Osmerus mordax*	9	5	20	63	30	Spr-Fall
Atlantic cod *Gadus morhua*	1	0	0	1	0	Fall
Silver hake *Merluccius bilinearis*	364	8	4	1	5	Spr-Summer
White hake *Urophycis tenuis*	2	1	2	3	0	Spr-Fall
Atlantic mackerel *Scomber scombrus*	–	–	1	4	0	Spr-Summer
Weakfish *Cynoscion regalis*	1	–	–	–	0	Summer
Tautog *Tautoga onitis*[3]	–	–	1	1	0	Summer
Striped bass *Morone saxatilis*	2	0	6	2	14	Spr-Fall
Butterfish *Peprilus triacanthus*	9	7	11	(5)[4]	130	Summer
Lumpfish *Cyclopterus lumpus*	2	0	0	0	0	Fall
Bluefish *Pomatomus saltatrix*	0	0	1	1	1	Summer
Windowpane *Scophthalamus aquosus*	3	5	4	5	6	Spr-Fall
Fourspot flounder *Paralichthys oblongus*	–	–	1	–	0	Summer

TABLE 10. CONT'D.

	Catch					
	Chignecto Bay			Minas Basin		
	1979	1980	1981[2]	1982[2]	1983[2]	Period
DECAPODA						
Lady crab *Ovalipes ocellatus*	-	-	1	6	10	Spr-Fall
Toad crab *Libinia emarginata*	-	-	-	22	1	Summer

[1] Captured in commercial nets 1850-1982.

[2] Minimum mesh size reduced from 12.0 cm to 6.2 cm.

[3] Mature specimens were running ripe.

[4] Leim records butterfish (5) from drift nets, Aug 29-Sept 1, 1921. We captured none in 1982, but over a hundred in 1983.

1. Sharks (Alopias, Lamna, Carcharodon)

The appearance of large pelagic sharks in the upper Bay of Fundy was surprising. During the 1979-82 survey in Chignecto Bay, two porbeagles (Lamna nasus) were captured (Table 11) but impressive holes left in our gillnets on many occasions alluded to their continuous presence.

Three species of large pelagic sharks have been captured in the upper Bay of Fundy. Thresher shark, Alopias vulpinas, were first recorded in this region by Perley (1852). Since this is a very distinctive shark species, identification is likely correct. Confirmed reports of threshers in the Bay of Fundy are numerous (Table 11). Atlantic porbeagle, Lamna nasus, in the Bay of Fundy have not been well documented but in recent years confirmed captures are common (Table 11). Two porbeagles were captured during night time drifts in Chignecto Bay in 1980. They were both 2-2.5 m in length. Neither specimen contained anything in their stomachs but they may have regurgitated while in the gillnets. Records of white shark, Carcharodon carcharias, are more common for the Bay of Fundy as a whole but only one confirmed report is from the upper Bay (Case 1968). There is one unconfirmed report from a weir at Advocate during 1977.

Perhaps one of the most interesting aspects of large shark occurrence in the Bay of Fundy is the timing of their appearance at various points around the Bay. If all large shark capture records (including basking sharks) are considered together a distinct pattern is evident (Table 11). Records are predominantly from the Digby shore in early summer, the upper Bay in mid-summer and the Saint John shore in late summer and fall (Fig. 28).

Catches of dogfish in the Bay of Fundy exhibit a similar pattern. Dogfish were very abundant in the upper Bay during June and July (catches of 100+ in one 4-hr set) but seldom encountered thereafter. On the New Brunswick shore of the lower Bay they were uncommon before August but became abundant during September and October (Fig. 29).

These data suggest sharks migrate around the Bay of Fundy during summer in a counter-clockwise pattern similar to American shad (Dadswell et al. 1983). Whether this is in response to a moving food source, or because they utilize residual drift transport to facilitate or provide clues for migration is unknown. The Bay of Fundy appears to be a northern terminus for numerous shark species which migrate from the Caribbean or coastal USA to Atlantic Canada (Bigelow and Schroeder 1954, Casey and Stillwell 1968).

2. American shad (Alosa sapidissima)

American shad were the most abundant, large fish in the upper Bay of Fundy during summer (Table 10). Single weir catches in excess of 100,000 shad were reported before the turn of the century (Prince 1912) and total commercial catches in this region before the 1900's ranged from 1-3 million kg/yr (Leim 1924, Jeffers 1932). Recent commercial gillnet catches average 30-50 shad/hr (Dadswell et al. 1983) and present day weir catches sometimes were 500-1000 shad on a single tide (Fig. 30).

TABLE 11. Summary of large shark captures or confirmed sightings in the Bay of Fundy/Gulf of Maine.

Species	Capture Site	Date	Year-day	Source
Thresher shark	Parrsboro, N.S.	July 15, 1919	196	Liem, (unpub. data)
	Chignecto Bay	August 15, 1850[1]	224	Perley 1852
Alopias vulpinas	" "	August 15, 1950[1]	227	"
	" "	August 20, 1850[1]	232	"
	Saint John	Sept. 15, 1980	258	Telegraph Journal
	Wolves Is.	Sept. 22, 1960	265	W.B. Scott (pers. comm.)
	Deer Is.	August 28, 1936	240	Leim & Scott 1966
	Bliss Is., N.B.	Sept. 25, 1981	268	W.B. Scott (pers. comm.)
Atlantic porbeagle	Metaghan, N.S.	July 27, 1982	208	Yarmouth newspaper.
(Mackerel shark)	Chignecto Bay	August 5, 1980	217	Dadswell (unpub. data)
	" "	Sept. 3, 1980	246	" "
Lamna nasus	Passamaquoddy	August 31, 1900	243	Prince & McKay 1902
	"	October 3, 1935	276	M'Gonigle & Smith 1936
	Dipper Harbour, N.B.	July 22, 1975	203	I.D. Center Records
	" "	August 5, 1980	217	" "
	Deadsman's Harbour	Sept. 16, 1976	259	" "
	Back Bay, N.B.	Sept. 24, 1980	267	" "
	Portland, ME	Nov. 10, 1947	314	Scattergood 1949
	" "	Nov. 24, 1947	358	" "
White shark	Digby Gut, N.S.	July 2, 1932	183	Piers 1934
	Wedgeport, N.S.	July 10, 1953	191	Templeman 1963
Carcharodon	Cobequid Bay, N.S.	August 15, 1966	227	Case 1968
carcharias	Maces Bay, N.B.	August 3, 1954	215	Templeman 1963
	Campobello Is., N.B.	August 15, 1872	227	Templeman 1963
	" "	Nov. 15, 1932	319	" "
	" "	August 20, 1952	232	" "
	Deer Is., N.B.	August 24, 1949	236	" "
	Bliss Is., N.B.	August 13, 1971	225	Arnold, 1972
	L'Etete, N.B.	August 8, 1977	220	I.D. Center Records
	Casco Bay, ME	Nov. 15, 1931	319	Bigelow & Schoeder 1953
	Off Massachusetts	October 16, 1923	289	" " "
Basking shark	Yarmouth, N.S.	July 4, 1939	185	Templeman 1963
	Digby, N.S.	August 16, 1939	228	" "
Cetorhinus maximus	Musquash, N.B.	August 6, 1851	218	Perley 1852
	Maces Bay, N.B.	Sept. 21, 1934	264	Templeman 1963
	Back Bay, N.B.	August 4, 1936	216	" "
	Campobello Is., N.B.	August 23, 1947	235	" "
	St. Andrews, N.B.	Sept. 12, 1947	255	" "
	Eastport, ME	Sept. 17, 1947	260	" "
	Maces Bay, N.B.	Sept. 13, 1953	256	" "
	L'Etete, N.B.	July 29, 1954	210	" "
	Grand Manan	July 21, 1958	212	" "

[1] estimated dates based on Perley's report.

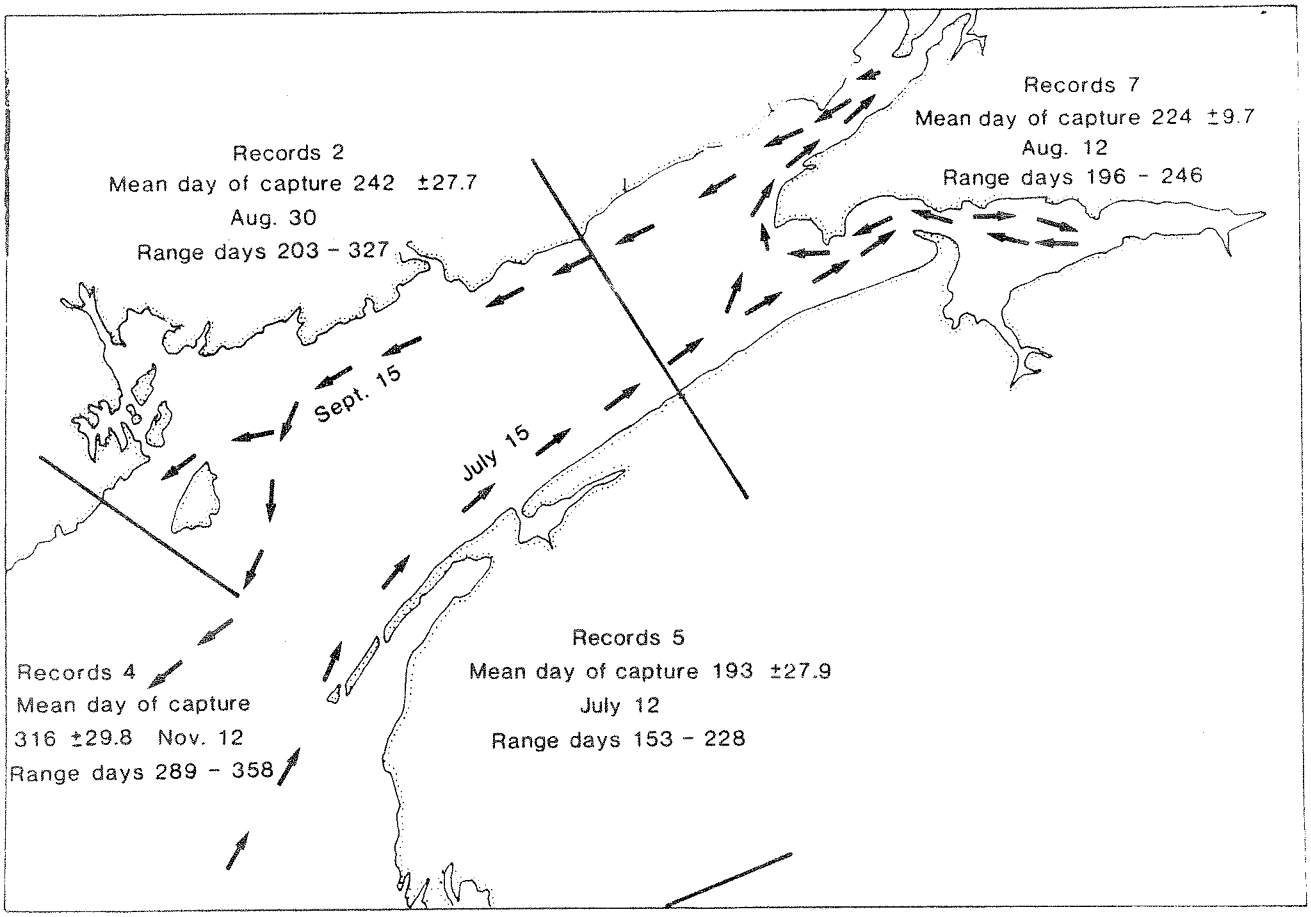


Fig. 28. Hypothetical migratory route, number of records, mean day of capture and range of days of capture for large sharks in the Bay of Fundy - Gulf of Maine (Table 11).

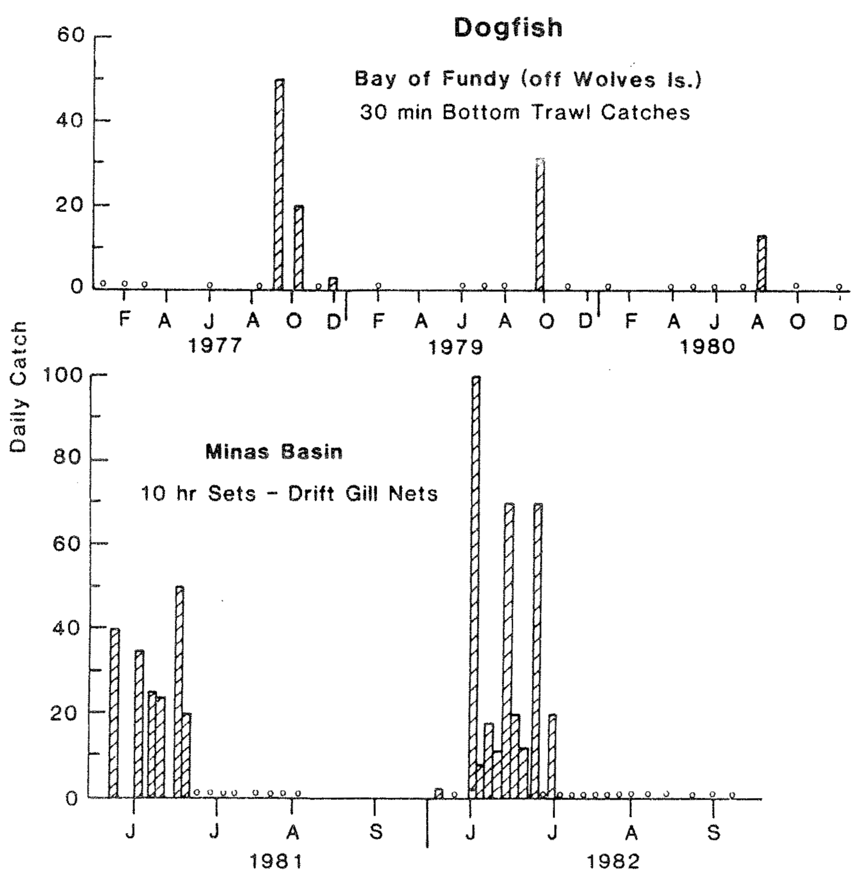


Fig. 29. Catches of dogfish by month in the lower Bay of Fundy (off Wolves Is.) and the upper Bay of Fundy (Minas Basin).

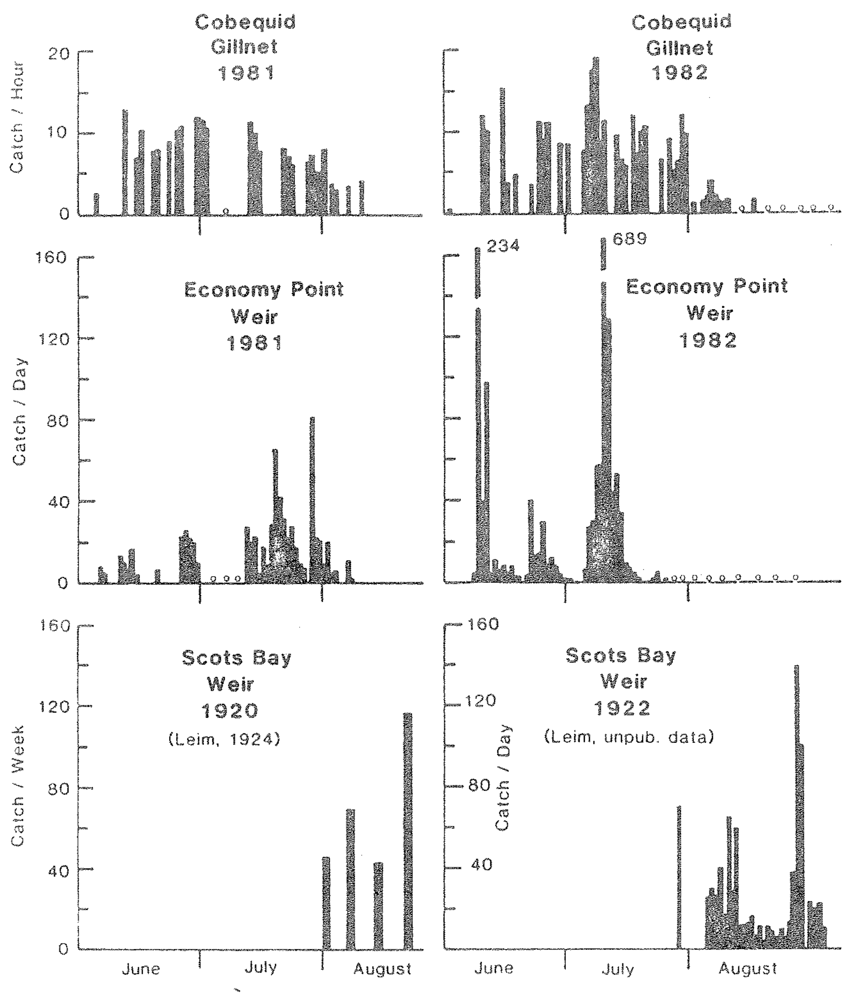


Fig. 30. Capture rate of shad during June to August from commerical gill-nets, and weirs in Cobequid Bay 1981 and 1982 and in Scots Bay 1920 and 1922. Zeros indicate fishing days when few or no shad were captured.

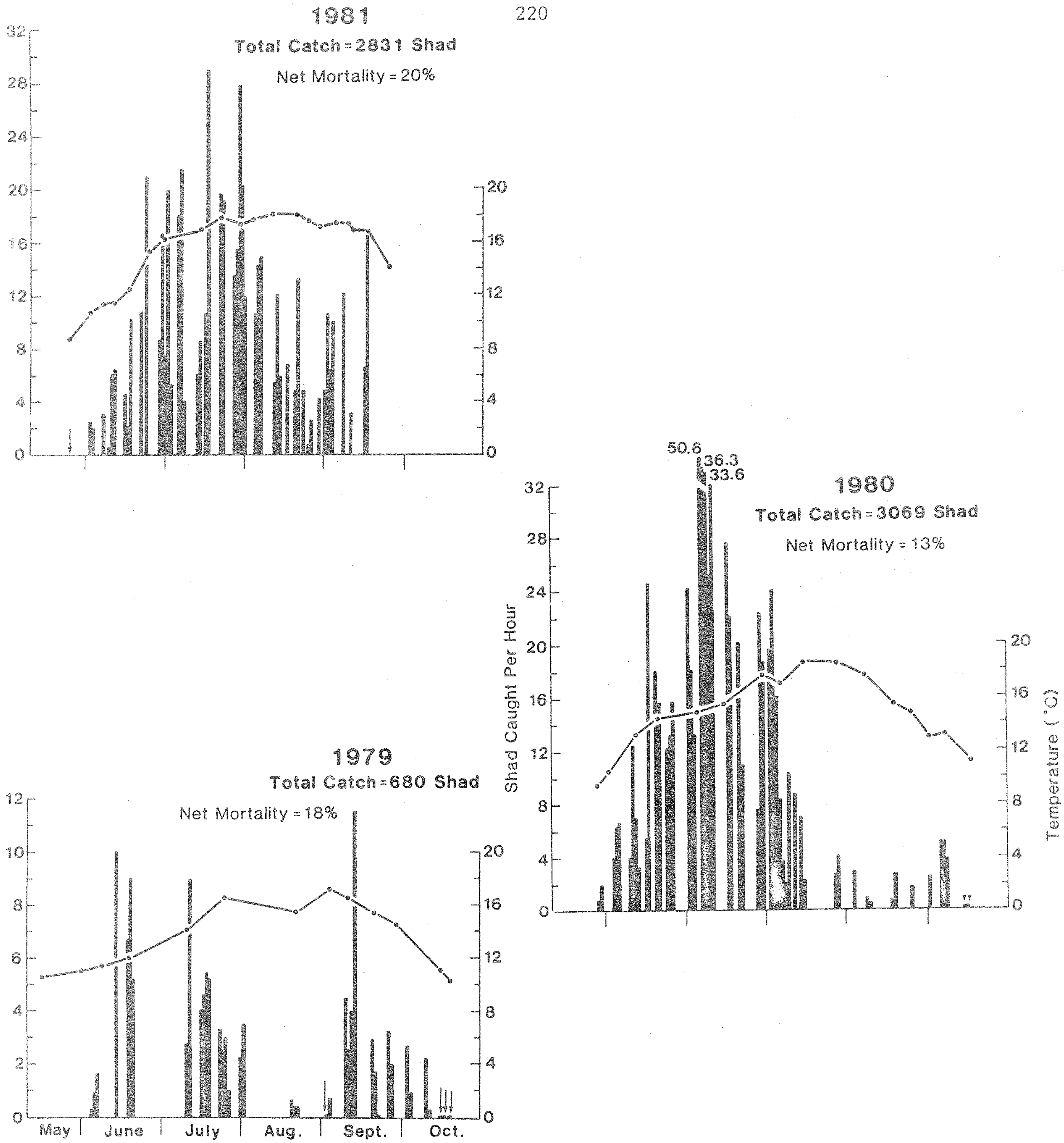


Fig. 31. Capture rate of shad during May to October from experimental gillnets in Cumberland Basin, 1979, 1980 and 1981. Arrows indicate fishing days when few or no shad were caught.

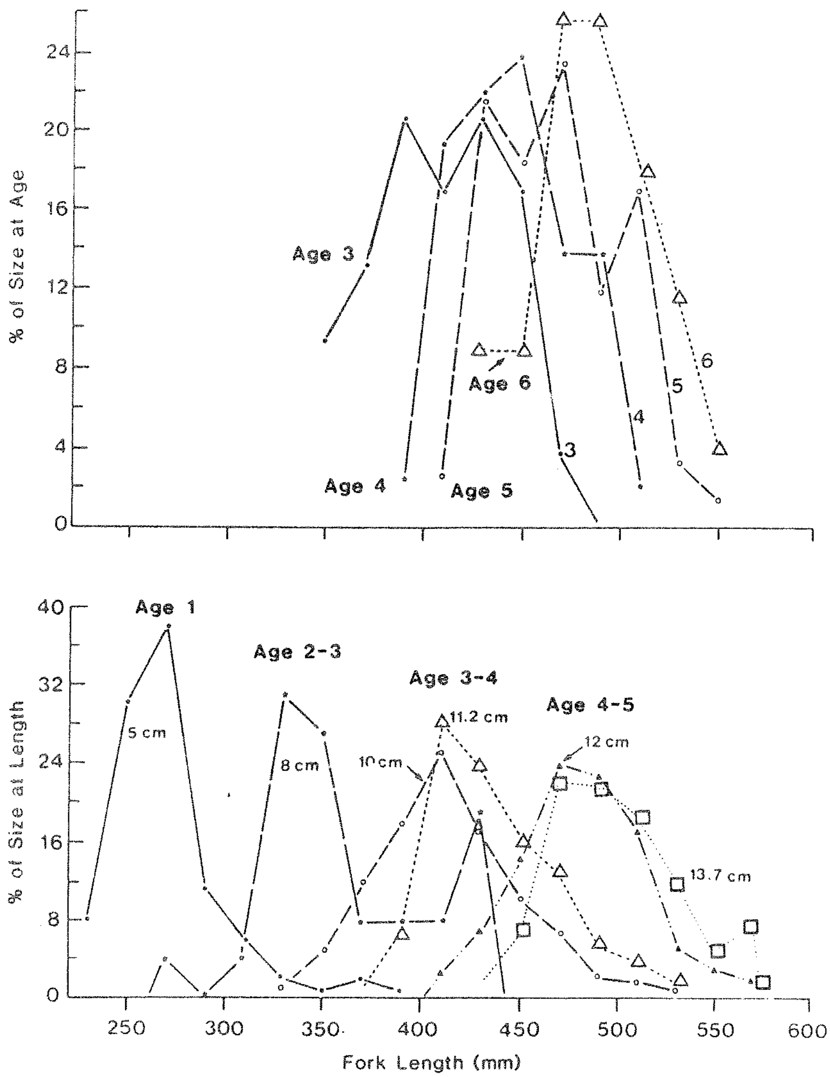


Fig. 32. Top: Length-frequency distribution by age of sampled shad from Cumberland Basin.
Bottom: Indirect selectivity of 210/6 multifiliment gillnets of various stretched mesh size (cm) for shad.

TABLE 12. Mean day of recapture by site of tagged shad in the Bay of Fundy and Gulf of Maine, 1979-82.

Capture Site	N.	Mean year-day[1]	Date	Capture-date range
Annapolis - Diby	27	138.4 ± 15.0	May 182	125-186 (May 5-Jul 5)
Head of Cobequid Bay	15	185.2 ± 12.9	Jul 4	166-212 (Jun 15-Aug 1)
Economy Point	11	189.5 ± 9.5	Jul 8	167-198 (Jun 16-Jul 17)
East Walton, Minas Basin	6	195.6 ± 5.7	Jul 16	192-203 (Jul 11-Jul 22)
Cumberland Basin[2]	34	196.0 ± 20.8	Jul 15	156-219 (Jun 5-Aug 7)
Cumberland Basin[3]	39	203.0 ± 22.8	Jul 22	156-258 (Jun 5-Sep 15)
Shepody Bay[4]	26	197.5 ± 18.8	Jul 16	163-233 (Jun 12-Aug 21)
Chignecto Bay	9	251.7 ± 20.9	Sep 9	218-271 (Aug 6-Sep 28)
Saint John - Campobello	9	237.0 ± 22.6	Aug 25	191-279 (Jul 10-Oct 6)
Grand Manan	6	252.7 ± 12.6	Sep 9	227-260 (Aug 15-Stp 17)
Brier Is.-St. Mary's Bay	5	275.2 ± 29.1	Oct 1	259-327 (Sep 16-Nov 23)
Portland ME-Cape Ann, MA	10	314.8 ± 13.5	Nov 11	288-333 (Oct 15-Nov 29)

[1] Year-day, chronological day from January 1, e.g. July 15 = day 196.

[2] Not including tags taken after Aug 15.

[3] Including tags after Aug 15.

[4] Commercial shad season closed on Aug 15, 1979-81 and Aug 31, 1982.

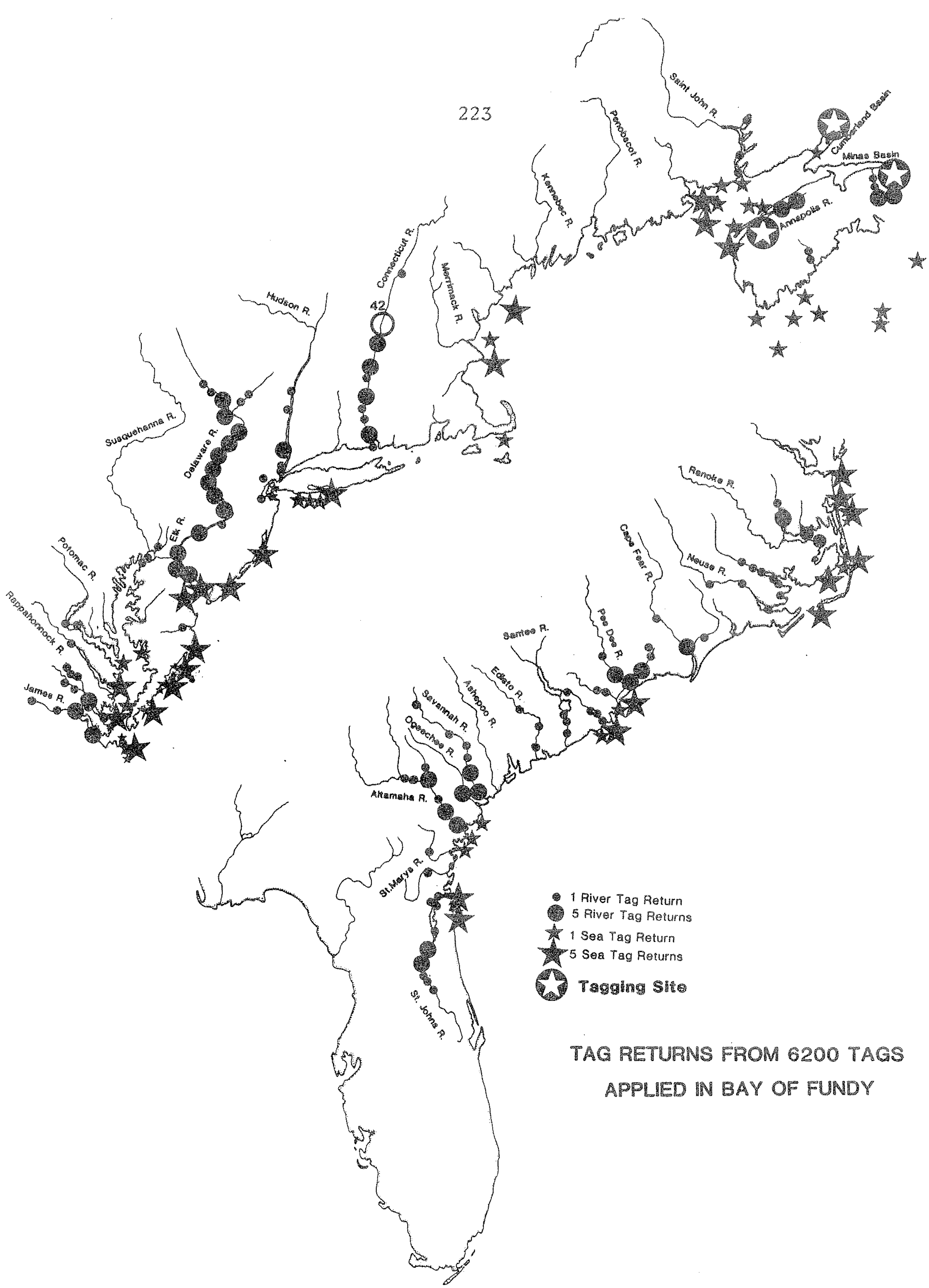


Fig. 33. Locality map for recaptures of shad tagged in Cumberland Basin and Cobequid Bay between 1979 and 1982. For tag returns from north of the Bay of Fundy see Dadswell et al. (1984).

TAG RETURNS

June	July 1-15	July 16-31	Aug. 1-15	Aug. 16-31	Sept.	
10 13%	12 15%	37 49%	9 11%	4 5%	7 9%	Cape Hatteras South
12 13%	17 19%	38 54%	14 16%	4 4%	5 5%	Cape Cod South
3 19%	7 44%	2 13%	1 6%	1 6%	2 13%	Bay of Fundy
3 33%	2 22%	2 22%	2 22%	0	0	Gulf of St. Lawrence

POPULATION DISCRIMINATION

June	July 1-15	July 16-31	Aug. 1-15	Aug. 16-31	Sept.	
2%	3%	5%	6%	9%	17%	Cape Hatteras South
8%	20%	33%	34%	33%	31%	Cape Cod South
76%	61%	51%	38%	41%	46%	Bay of Fundy
14%	16%	11%	22%	17%	16%	Gulf of St. Lawrence

Fig. 34. Top: Number of tags (upper left corner) and percent of total returns from a geographic region for weekly or monthly periods tagged in Cumberland Basin.
Bottom: Percent of total sample by period from particular geographic regions of the eastern North American coast for shad collected in Cumberland Basin. Defined universe from known sampled shad populations included 14 rivers from Florida to Quebec.

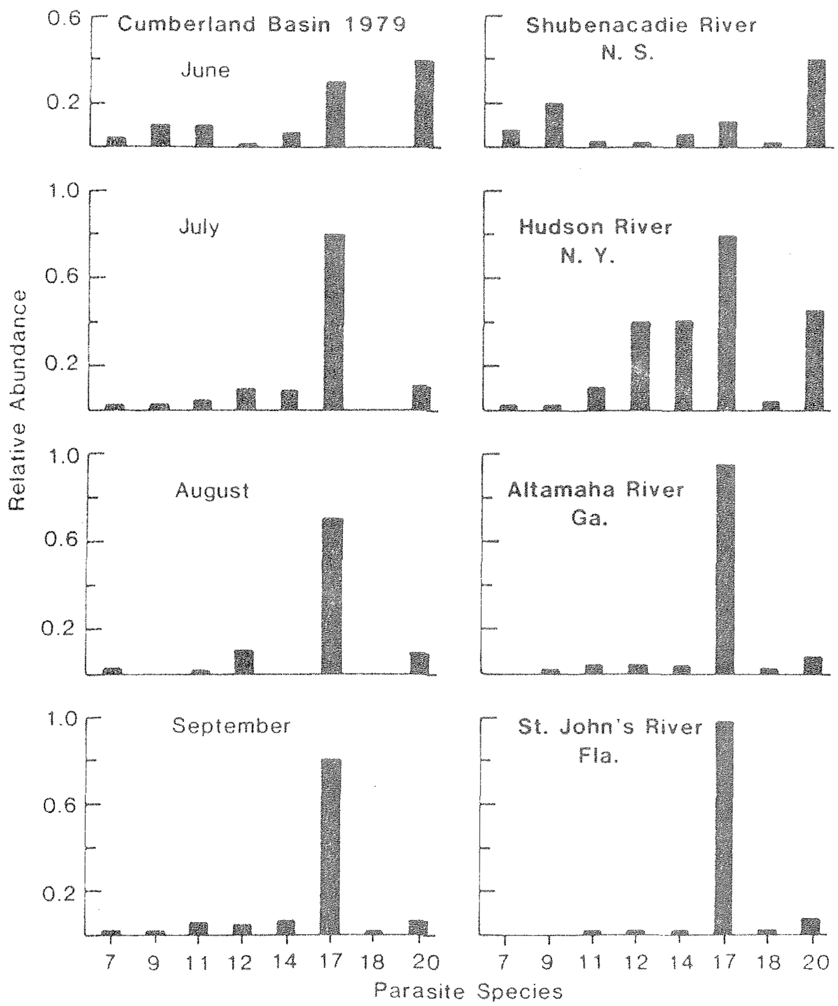


Fig. 35. Relative abundance of eight internal parasites of shad from samples taken in June, July, August and September, 1979, in Cumberland Basin and from two northern and two southern rivers during the 1980 spawning runs. Parasites are: (7) Derogenes varicus, (9) Hemiurus levinseni, (11) Lecithaster spp, (12) Genitocotyle atlantica, (14) Diplostomulum spatheceum, (17) Scolex pleuronectis, (18) large pleurocercoid, (20) Hysterothylacium aduncum.

Abundance and catchability of shad in the upper Bay appears related to migration timing, tidal amplitude and turbidity (Dadswell et al. 1983). Shad destined to spawn in local rivers first arrived in the upper Bay of Fundy during late April (Leim 1924, Melvin et al. unpubl. data). During June, immature, maturing and spent ocean-feeding shad arrived in large numbers in the upper Bay (Dadswell et al. 1983). The duration of the run of ocean-feeding fish was from June to August in Minas Basin (Fig. 30) and June to October in Cumberland Basin (Fig. 31). The ocean-feeding run was composed in a large part by 3-, 4- and 5-yr-old shad (Fig. 32). Both younger and older shad were less abundant.

Population estimates using capture-recapture models for tagged fish indicated over a million shad may occupy Cobequid Bay during each high tide at the height of the run (Dadswell et al. 1984). Tag returns showed shad migrated around the Bay of Fundy in a counterclockwise manner, occurring off Nova Scotia in spring, at the head of the Bay during summer (Dadswell et al. 1983) and off New Brunswick in the fall (Gabriel et al. 1976, Bradford 1981) (Table 12). Tag returns and population discrimination studies indicated these shad represent all populations extant in rivers of eastern North America (Dadswell et al. 1983). Of 10,500 shad tagged and released in Minas and Cumberland Basins to date, there are 32 (7%) tag returns from Canadian marine locations, 130 (28%) from coastal U.S., 32 (7%) from Canadian rivers, and 269 (59% from U.S. rivers (Fig. 33). Morphometric and meristic studies and tag returns indicated a large portion of the early shad run was composed of northern fish (rivers north of Cape Cod) but the proportion of populations shifted to southern rivers as the summer progressed (Fig. 34) (Melvin unpub. data). Stock discrimination studies using both otoliths (Williams 1981) and parasites revealed a similar pattern (Fig. 35) (Uhazy 1980). Other tagging studies (Vladykov 1955) also indicate a relationship exists between St. Lawrence estuary shad and those in the upper Bay of Fundy.

Early studies on shad in the upper Bay of Fundy are among the major works on this species concerning spawning and larval ecology (Leim 1924) and feeding (Leim 1924, Willey 1923).

3. Gaspereau (*Alosa pseudoharengus* and *A. aestivalis*)

Alewife and blueback herring were among the most common fishes captured in the upper Bay of Fundy (Tables 4, 10) but little is known about their biology in this region. Two research projects on gaspereau were initiated in 1983, a feeding study by H. Stone and G. Daborn, Acadia University, and a stock composition and migration study by R. Rulifson, Eastern Carolina University, North Carolina. B. Jessop, Fisheries and Oceans, Halifax has been studying the composition of the gaspereau spawning run in the Gaspereau River.

Exploratory surveys, reported here, were conducted by Leim (1920-21) and Dadswell (1981-83). Gaspereau were captured or observed in both weirs and gillnets in Minas Basin and Chignecto Bay from April to October. Catch rates by 6.2 cm stretched mesh drift gillnets ranged from 10-100 gaspereau/hr/100 m (Fig. 36). Capture rates peaked in late June and early

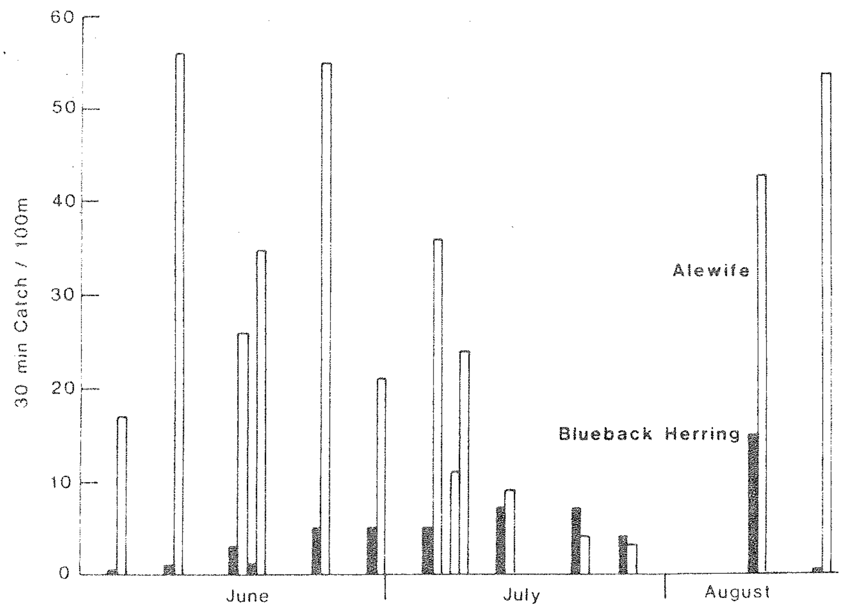


Fig. 36. Capture rate of gaspereau (alewife and blueback herring) in a 6.2 cm stretched mesh drift gillnet in Cobequid Bay during 1983.

July with a second peak in mid-August. Weir catches in excess of 1000 gaspereau/tide were observed inside Economy Point during 1983. Gillnet catches were 100% alewives during late May but the proportion of blueback herring increased during summer. A single sample taken by 6.2 cm stretched mesh gillnet in late June, 1981, consisted of 27% (16) alewives and 63% (44) blueback herring. Alewives were 2-4-yr-old and 177-234 mm fork length. Blueback herring were 2.5-yr-old and 165-255 mm FL. The weight-length relationships from this sample were LogW = 2.44 LogL - 3.6 (alewives) and LogW = 2.98 LogL - 4.8 (blueback herring) where L is FL in mm and W is weight in grams.

Gaspereau, like shad, are capable of filter feeding in turbid waters (Janssen 1982). Their presence in these regions during summer may be as a response to optimum habitat. Neves (1981) found gaspereau were least often caught by trawl surveys on the Scotian Shelf during summer whereas they were moderately common over southern regions (mid Atlantic Bight) in fall and spring. Like shad, the upper Bay of Fundy could be a northern terminus of gaspereau migrating along the Atlantic coast.

4. Atlantic menhaden (*Brevoortia tyrannus*)

Menhaden were a regular component of the pelagic fish assemblage each summer in the upper Bay (Table 10). Large, adult menhaden were most common in late June and through July. Gillnet catches of 5-10/yr and weir catches of 15/tide were observed. These menhaden were mature adults, 30-40 cm in length and were often running ripe during late July. During late August, 1983, in Cobequid Bay, large catches of juvenile menhaden were made daily with a 6.2 cm stretched mesh gillnet. These menhaden were about 20 cm FL. Catches averaged 70 menhaden in 100 m of net per 1/2-hr set.

Menhaden are filter feeders and can utilize phytoplankton and detritus (Durbin and Durbin 1981). Their presence in these turbid wates in large numbers was unexpected. Whether they represent a separate stock (running ripe adults) or were only a northward extension of U.S. coastal stocks remains to be resolved.

5. Atlantic herring (*Clupea harengus*)

Leim (1931) lists herring as a very abundant species in the upper Bay of Fundy and recent surveys by us confirm this opinion. Leim (1931) reported spawning herring in Scots Bay and later work identified these as a major summer spawning stock (Iles and Sinclair 1982, Sinclair et al. 1982). July spawning herring have been reported from Chignecto Bay (White 1932) and a June spawning population from the Parrsboro shore of Minas Basin (Perley 1852, D. Pettis, pers. comm).

Leim (1931) reported large numbers of 1+ herring (50-90 mm) from a weir at Bass River and we observed a similar occurrence in 1983 at upper Economy (100-1000 0+ and 1+ herring in weir/tide). Herring of this size were uncommon in Scots Bay during August (Fig. 4) but were moderately abundant in Minas Channel and Chignecto Bay (Koeller 1979). Surveys with a mid-water Boris trawl took 100-1000 0+ and 1+ herring/ 1/2-hr tow in these regions during August and February (Koeller 1979). Large spawning herring (25–35 cm) were abundant in Scots Bay during August (Fig. 4) and off Parrsboro in May (Perley 1852, Bradford, unpub. data). Herring larvae were abundant in Minas Basin off Blomidon in September 1920 and 1921 (Leim 1931) and throughout Minas Basin and Cobequid Bay in July 1983 (Bradford, unpub. data). Many of the larvae taken in July 1983 were in the yolk sac stage.

6. Atlantic salmon (Salmon salar)

Atlantic salmon pass through the basins in the upper Bay of Fundy on their way to spawn in local rivers (Huntsman 1958, White 1936, Dominey 1970a, b, Semple 1979). This region once supported a large commercial salmon fishery (see fisheries section) but it has mostly disappeared lost due to blocking of rivers (Semple 1979, Wildsmith 1981) and restrictions on commercial salmon licenses. The sports catch from many rivers, however, remains significant and is often greater than the commercial catch (Table 13).

The salmon in the upper Bay were characteristically grilse (1+ sea-year fish average weight 2kg.) (Table 13) (Huntsman 1958, Dadswell, unpub. data). Our drift gillnet surveys took salmon consistently from late June until late October. Large salmon (2+ sea-year fish) and large grilse were present in July catches and small grilse were abundant in fall (October). Yearly catches with experimental nets varied from 34 to 132 salmon/yr (Table 10). Tag returns of salmon released by us averaged 2-3/yr and all were from either commercial drift netters in the upper Bay or from anglers fishing local spawning rivers (Maccan, Shubenacadie). Tagging data also indicated salmon may remain in the sea in this region for up to a month (Dadswell et al. 1984) presumably while they wait for proper conditions for stream ascent.

7. American smelt (Osmerus mordax)

This species is common in the pelagic zone of the turbid regions of the upper Bay of Fundy but was not adequately sampled by our drift net gear. No directed work has been done on the species in this region (except intertidal studies) but it appears to be an important component of the community.

Larval smelt were extremely abundant in Minas Basin plankton samples (Bradford, unpub. data). In September these larvae are 28–58 mm long. Two length modes were common in weir catches 3–7 cm and 7–12 cm, presumably 1+ and 2+ fish (Leim 1931). Specimens as long as 27 cm were observed.

8. Silver hake (Merluccius bilinearis)

Specimens from 15–20 cm were common in weirs at Bass River and Economy Point throughout the summer. The species was extremely abundant in Cumberland Basin during the summer of 1979 (Table 10). These 15–20 cm specimens entangled themselves by their teeth in large mesh gillnets.

TABLE 13. Commercial and sports landings of Atlantic salmon in the upper Bay of Fundy 1973-81.

	Kings Co.				Cumberland, Colchester, Hants				Westmorland-Albert			
	Commercial	Sports			Commercial	Sports			Commercial	Sports		
Year	kg	kg	#fish	kg/fish	kg	kg	#fish	kg/fish	kg[1]	kg	#fish	kg/fish
1973	970	22	5	4.4	500	2626	1181	2.2	92	279	124	2.2
1974	2011	23	11	2.1	1160	5717	2554	2.2	210	586	258	2.3
1975	3386	79	24	3.3	422	2292	1042	2.2	39	194	92	2.1
1976	2419	17	4	4.2	1463	4921	2331	2.1	150	352	180	1.9
1977	2703	89	26	3.4	450	3244	1116	2.9	264	248	135	1.8
1978	985	9	5	1.8	1264	4008	2875	1.4	164	134	68	2.0
1979	1477	32	9	3.5	2129	2442	624	3.9	18	29	9	3.2
1981	91	121	37	3.3	2985	3143	1318	2.4	23	168	86	1.9

[1] By-catch during salmon closure period (very unreliable).

Large catches of adult silver hake 23-51 cm were taken in the weir at Scots Bay in September 1922 (Fig. 5). Many of these fish were in spawning condition.

9. Mackerel (Scomber scombrus)

This species was not abundant in the turbid regions of the upper Bay. Our gillnet surveys in the turbid regions (Secchi visibility 10-100 cm) rarely captured any (Table 10). On the other hand, weirs which captured fish from the clear water regions (Scots Bay, Chignecto Bay) made large catches of "tinker" mackerel of 23-33 cm in length (Fig. 4) (White 1932, Leim 1931). This suggested the mackerel avoided the turbid regions during their migration through the upper Bay.

10. Striped bass (Morone saxatilis)

Striped bass were formerly very common in Minas Basin (Leim and Scot 1966) and well known in Chignecto Bay (Bayne 1930, M. Snowden, pers. comm.). The maximum number we captured in our drift gillnets in one summer was 14 in 1983 (Table 10), but observations indicated we would have captured many more if sets had been made along the shore in shallow water.

The species is known to spawn in the Shubenacadie River (Leim and Scott 1966, Jessop and Vithayasai 1979) and may spawn in other rivers at the head of the Bay. Growth of larvae and juveniles in the Shubenacadie River is rapid (Fig. 37) and these fish appear to migrate into Cobequid Bay at a length of 5-11 cm (Leim 1921).

Medium sized specimens (17-26 cm) were present in Cobequid Bay weirs at 1921 and 1983. Large specimens (50-100 cm) were caught occasionally in our drift gillnets (Table 10) and many of this size were observed in Shubenacadie River during the springs of 1979 and 1980 (Melvin and Dadswell, unpub. data). Medium sized and large striped bass were also common in Shubenacadie Lake during winter (Alexander 1975, Melvin 1978). This lake appears to be an important overwintering site for the species in the upper Bay of Fundy region. Possibly bass from rivers other than the Shubenacadie occur there also. Two bass, which were tagged while spawning in the Annapolis River during 1982, were recaptured in the Shubenacadie River during the early spring of 1983 (Table 14). Growth of bass in the Shubenacadie River was similar to that reported for other Fundy rivers (Jessop and Vithayasai 1979).

The entire question of origin and migration of striped bass in the Bay of Fundy is intriguing and begs study. Incidental tagging by researchers during the course of studies in the Bay of Fundy and the occasional recapture of bass tagged on spawning grounds in the mid-Atlantic United States suggests many of the bass occurring in the Bay of Fundy and its upper reaches are not of local origin (Table 14). Large catches of bass in the Bay of Fundy during the 1960's and early 1970's (Caddy and Chandler 1976), which corresponded with peak year-class production of bass in Chesapeake Bay (Kohlenstein 1981), adds further evidence to this possibility. Although tag returns of bass spawning in Bay of Fundy tributaries

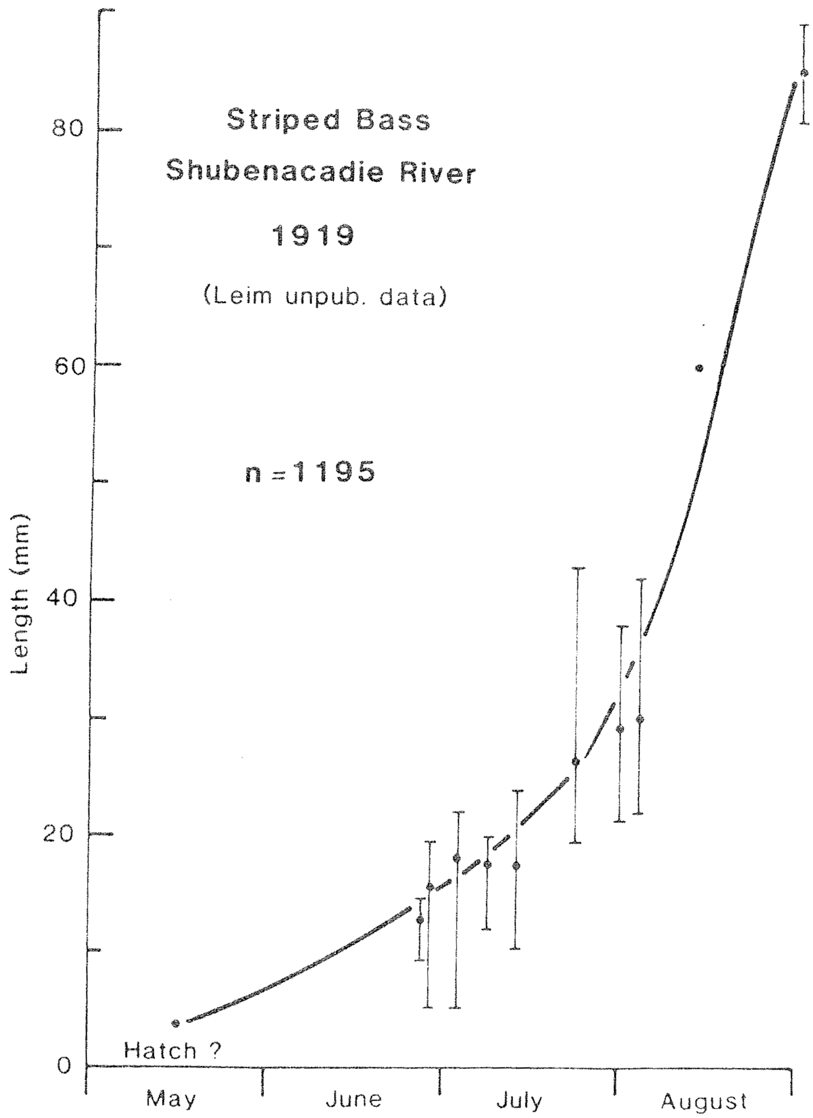


Fig. 37. Growth of young-of-the-year striped bass from Shubenacadie River in 1979.

TABLE 14. Sites and dates of tagging and recapture for migrant striped bass associated with the Bay of Fundy.

Tagging Site	Date	Recapture Site	Date	Days at large	Source
Potomac R., Maryland	Feb/59	Walton, Minas Basin, N.S.	Sep/59	159	Nichols and Miller 1967
" "	Apr/60	Bear R., N.S.	Jul/60	99	" "
" "	Apr/61	Annapolis Royal, N.S.	Jul/61	127	" "
Annapolis R., N.S.	14 Jul/75	Potomac R., VA	25 Mar/76	255	Underwater Naturalist, 1976
" "	29 Aug/66	Rockingham, N.C.	24 Jun/67	308	Moss 1971
Cheboque R., N.S.	13 Jul/69	Long Beach Is., N.J.	22 Apr/70	283	" "
" "	13 Jul/69	Sakonnet R., R.I.	10 Jun/70	342	" "
" "	4 Sep/66	Indian R., Del.	13 Mar/67	178	" "
" "	12 Aug/66	Patcong Ck., N.J.	15 Jul/67	337	" "
Nanticoke R., MD	14 Apr/73	Reversing Falls, N.B.	25 Oct/76	1279	Boone, MD Fish & Game
Darlings Lake, N.B.	5 Jun/69	Montauk, N.Y.	19 Nov/69	167	Underwater Naturalist
Westfield, N.B.	12 Sep/72	Blackstone R., R.I.	23 Oct/72	36	Williamson 1974
Reversing Falls, N.B.	7 Aug/73	Southampton, N.Y.	Nov/73	90?	Dadswell 1976
Annapolis R., N.S.	17 May/82	Shubenacadie R., N.S.	12 May/83	360	Dadswell, unpub. data
" "	20 May/82	" "	31 May/83	376	" "

were seldom from outside their river of origin (Dadswell 1976 and unpub. data) population discrimination studies by Melvin (1978) indicated Bay of Fundy spawning populations were most closely akin to Chesapeake Bay stocks, rather than to the Hudson River fish, geographically a closer but less migrant population (McLaren et al. 1981).

Timing of tagging and recapture of bass in the Bay of Fundy, originating from southern populations, suggests bass may migrate around the Bay during summer in a fashion similar to that of sharks and shad as already discussed. The bass appeared to concentrated along the Nova Scotia shore from early- to mid-summer and on the New Brunswick shore during late summer and fall (Table 14).

11. Butterfish (Peprilus triancanthus)

This species was abundant in Cobequid Bay during mid-summer and rare to common in Cumberland Basin (Table 10). Most specimens were captured in the 6.2 cm gillnet and ranged from 10-15 cm inlength. Catches of this size range varied from 5-20 butterfish in a 1/2-hr set during August 1983. Larger individuals were less common but mature, running ripe adults, 15-25 cm long, were captured in Cumberland Basin during 1981. The maximum sized individual captured was 27 cm long.

Virtually nothing is known about this species in Canada and the origin of the fish in the upper Bay can only be guessed at. The species supports a large commercial fishery in the Gulf of Maine (Leim and Scott 1966) and those occurring in the upper Bay may be part of this stock.

12. Southern fishes

A persistent character of the fish catches in the upper Bay of Fundy is the incidence of summer occurrence of typically southern fishes from the Virginian biogeographic province (Table 15). The fairly regular occurrence of elements of the eastern United States turbid estuary community contrasts sharply with the intermittent occurrence of tropical, Gulf Streamfishes on the Atlantic coast of Nova Scotia (Leim and Scott 1966) and suggests active migration to the Bay of Fundy. Persistence of warm water in the upper Bay of Fundy (Fig. 38) and an abundance of prey species may influence fishes such as the bluefish to remain long enough to be captured.

Invertebrates

1. American lobster (Homarus americanus)

Biology of American lobster is poorly known for the upper Bay of Fundy. The first directed study for the region is the work by Campbell (1984). In general terms the upper Bay appears less important in terms of fisheries than it does as a nursery. For whatever reason, large adult lobsters migrate into Chignecto Bay to release larval and extrude eggs (Campbell 1984). The eventual fate of these larvae is unknown. Tagging of the adult lobsters has revealed they make extensive coastal migrations. Some have been captured as far south as Massachusetts.

TABLE 15. Incidence of southern fishes in the upper Bay of Fundy during summer.

Species	Capture Site	Date	Source
Cynoscion regalis Weakfish	Economy Pt., Minas Basin	Sept 1955	Leim and Scott (1966)
	Cumberland Basin	July 1979	Dadswell (unpub. data)
Pogonias cromis Black drum	Halls Harbour, N.S.	1947	Bleakney 1963
Tautoga onitis Tautog	Scots Bay	July 12 1902	Vladykov & Mackenzie 1935
	Cranberry Head Cumberland Co.	1912	Fowler 1915
	Cumberland Basin	Aug 1981	Dadswell (unpub. data)
Prionotus carolinus Northern searobin	Minas Channel	July 1951	Leim (unpub. data)
Paralichthys oblongus Fourspot flounder	Cumberland Basin	July 1981	Dadswell (unpub. data)
Sphoerides maculatus Northern puffer	Kingsport, Minas Basin	July 1951	Leim & Day 1959
Pomatomus saltatrix Bluefish	Minas Basin Five Islands	July 1951	Leim & Scott 1966
	Cumberland Basin	July 24, 1978	Dadswell (unpub. data)
	Cumberland Basin	July 1981	" "
	Black Rock, N.S.	Aug 12, 1957	I.D. Center Records, St. Andrews
	Five Islands, Minas Basin, N.S.	July 23, 1982	Dadswell (unpub. data)
	Spencer Ck., Cobequid Bay, N.S.	July 20, 1983	Dadswell (unpub. data)

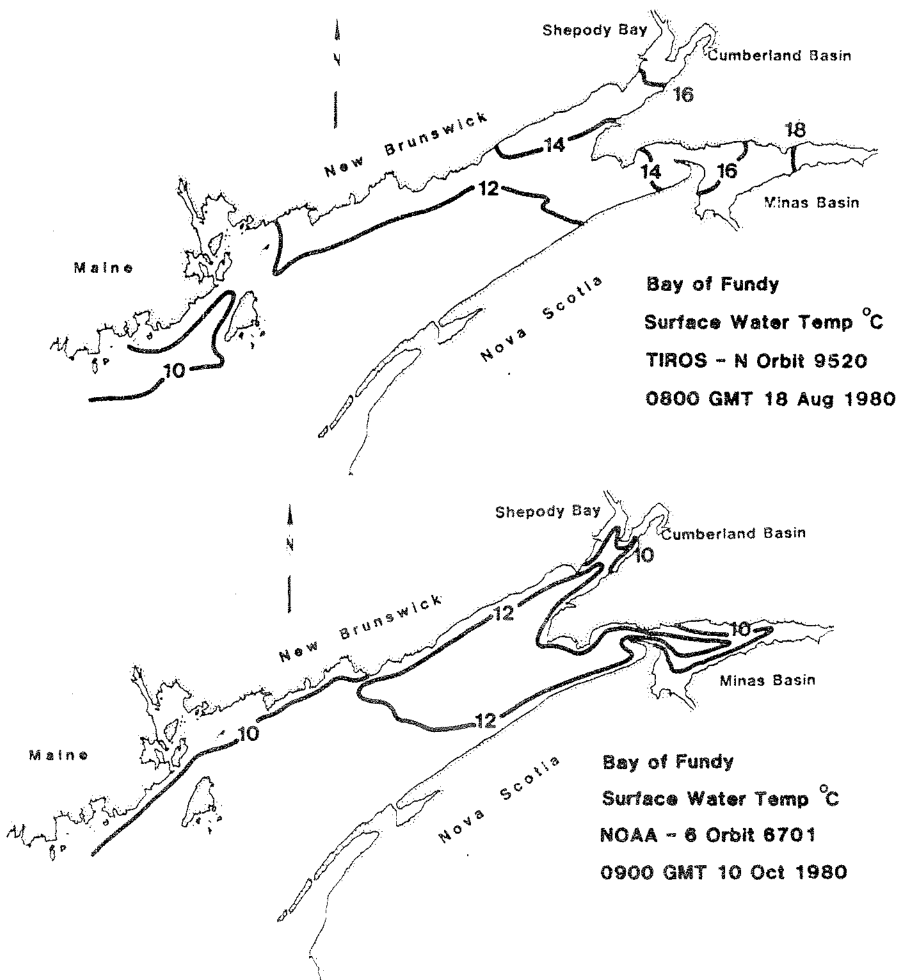


Fig. 38. Temperature structure of the upper Bay of Fundy August and October 1980.

2. Soft-shell clams (Mya arenaria)

Soft-shell clams support the largest dollar value fishery in the upper Bay of Fundy ($0.5 million, 1982). Except for the work by Witherspoon (1984) very little is known about the biology of the species in the region. The fishery is valuable to the Bay of Fundy region because it is not affected by toxic dinoflagellate blooms and can supply the market when the rest of fishery is closed for this reason (Reid 1980).

Along the north shore of Minas Basin environmental conditions have been favorable for development of highly productive clam flats. In other areas of the upper Bay this species is either lacking or exists in less than commercial quantities. Lack of soft-shell clams in many of intertidal areas of the upper Bay may be caused by high sediment loads in the water, high sedimentation rates or extensive ice scour during winter (Risk et al. 1977, Yeo 1978).

Many of the flats have clams with slow growth rates and show signs of stunting (Witherspoon 1984). This resource may be existing very close to its limits of biological tolerance and even subtle environmental changes might cause the loss of the fishery.

The Mid Bay of Fundy

Research on fishes in the middle Bay of Fundy has been largely limited to the estuarine and anadromous fishes in the two major estuaries of this region, the Saint John and Annapolis Rivers (Fig. 1), and to scallops, the region's major fishery. The Marine Fish Division of Fisheries and Oceans conducts groundfish and larval fish cruises in this region each year, the results of which are used to produce descriptive reports (Scott 1979), and provide a data base for assessment of commercial fish stocks. Recent work on zooplankton relationships in this region resulted in a description of lumpfish juveniles (Cyclopterus lumpus) which were associated with the surface waters (Daborn and Gregory 1983) and aspects of the biology of adult lumpfish (Gregory and Daborn, in press). The paper on lumpfish juveniles contains the first description of their prey preferences.

Scallops (Placopecten magellanicus)

Scallops are the most valuable fishery in the Maritimes. In 1982 landings exceeded $12 million. One of the largest and best known scallop beds in Atlantic Canada lies off Digby between 44°30'N - 45°00'N and 65°40' - 66°30'W (Dickie 1955). This bed has been fished since the 1920's and the long term catch data available demonstrates an underlying regularity to the marked fluctuations in landings (Caddy 1979). The catches oscillate with a periodicity of 9 yr which Caddy (1979) thought was linked to the lunar apsides cycle. Whether scallop recruitment was linked to this cycle through temperature variations, tidal circulation or unknown environmental factors, could not be resolved.

The Annapolis Estuary

The Annapolis estuary has attracted considerable interest in recent years because of the decline in the river's striped bass population (Jessop and Vithayasai 1979) and the construction of Canada's first tidal hydroelectric generating station on the estuary at Annapolis Royal (Douma and Stewart 1981).

The fish fauna of the estuary is dominated by anadromous and euryhaline marine species and is depauperate in freshwater species (Table 16) (Jessop 1976, Daborn et al. 1979). Lack of freshwater species probably has zoogeographic reasons since the Shubenacadie River, which is closer to the source of freshwater dispersal routes, has a more diverse freshwater assemblage (Alexander 1975) (Table 16).

Graduate students of Acadia University have contributed much to the knowledge of fish life histories in the Annapolis. Williamson (1974) and Williams (1977) examined aspects of striped bass biology and O'Neill (1978) studied the life history of white perch in the river. Creel surveys and biological studies on striped bass in the estuary by the Dept. of Fisheries and Oceans during the last 10 yr (Phenney 1973, Jessop and Doubleday 1976, Jessop and Vithayasai 1979, Jessop 1980) indicate this population is declining. Studies on reproduction of bass in the river showed eggs were viable (Parker and Doe 1981, Wiles 1979) but egg production was extremely variable (Williams 1977). Angling catches in recent years were dominated by large mature fish (Fig. 39). Mean age and length of bass in creel surveys increased from 6.0 yr and 56 m in 1972 to 10.9 yr and 80 cm in 1978 (Jessop 1980). What portion of the angling catch from the river was contributed by bass of southern origin is unknown (Table 14) but Annapolis and Chesapeake stocks have declined in unison (Van Winkle et al. 1979).

Annapolis River striped bass weigh less at comparable lengths than Saint John River bass (Williamson 1974) but length at age is identical (Fig. 40) (Dadswell 1976, Jessop 1980). What proportion of this similarity and difference is due to mixing of southern fish in the samples of both stocks is unknown and results should be viewed with caution.

Other anadromous fishes of the Annapolis have received some or no attention. Atlantic salmon have almost disappeared from the system since construction of dams on the main tributary streams (Wildsmith 1981). In 1951 the sports catch of salmon from the Annapolis system was 455 fish. In recent years it has seldom exceeded 10 salmon/yr (Swetnam and Bernard 1981). At present the shad stock of the Annapolis River is large (Melvin 1982, Melvin et al. unpub. MS) and it ranks as the major sports and commercial fishery on the river. The spawning population was estimated at between 100,000 and 200,000 adults and because of the mode of the commercial fishery (no selective gear allowed) it approaches a virgin shad stock in nature. It was thought that this stock may act as a sensitive monitor for tidal power turbine mortality on fish stocks of the river (Melvin and Dadswell 1984). Jessop (1983) produced a very complete study of the life history of the silverside population in the Annapolis. He characterized the silversides in this estuary as typical r-strategists and suggests they could support a moderate fishery.

TABLE 16. Fishes captured by hand seine from estuaries of the Bay of Fundy. Data compiled from Leim (unpub. 1919-1922), Shubenacadie; Jessop 1976; Daborn et al. (1979), Annapolis; Gorham (1965), Squires and Gorham (1966, 1967) and Dadswell (unpub.), Saint John; Melvin (MS 1976), Passamaquoddy (Waweig, Digdequash and Sam Orr Pond). Abundance is A, Abundant (+100 during study); C, common (10-100); R, rare (1-10); (-) never encountered.

Species	Shubenacadie	Annapolis	Saint John	Passamaquoddy
Petromyzon marinus	C(30)	-	C(52)	-
Raja erinacea	-	R(40)	R(2)	R(2)
Alosa pseudoharengus	C(17)	A(?)	A(500)	C(15)
Alosa aestivalis	-	?	A(400)	R(2)
Alosa sapidissima	A(223)	A(?)	R(3)	-
Clupea harengus	-	-	R(3)	A(150)
Brevoortia tyrannus	-	-	R(1)	-
Salmo salar	R(3)	-	R(3)	-
Salvelinus fontinalis	R(2)	R(1)	R(2)	-
Coregonus clupeaformis	-	-	R(1)	-
Osmerus mordax	A(114)	A(203)	C(55)	C(12)
Esox niger	-	-	R(3)	-
Catostomus commersonii	A(158)	A(100)	C(82)	-
Catostomus catostomus	-	-	R(4)	-
Notemigonus crysalencas	C(32)	-	C(87)	-
Semotilus atromaculatus	R(3)	C(16)	R(2)	-
Semotilus corporalis	R(1)	-	C(17)	-
Hybopsis plumbea	R(4)	-	C(73)	-
Rhinichthys atratulus	-	-	R(5)	-
Notropis cornutus	C(61)	-	A(237)	-
Notropis heterolepis	-	-	R(6)	-
Ictalurus nebulosus	-	-	C(45)	-
Anguilla rostrata	R(4)	A(542)	C(40)	C(25)
Fundulus diaphanus	C(33)	A(297)	A(125)	R(5)
Fundulus heteroclitus	R(5)	C(64)	R(2)	A(115)
Tautogolabrus adsperus	-	R(9)	-	R(2)
Morone americana	-	A(529)	C(10)	R(1)
Morone saxitilis	A(977)	R(3)	R(2)	-
Lepomis gibbosus	-	-	C(10)	-
Perca flavescens	R(2)	-	C(14)	-
Menidia menidia	C(28)	A(13,000)	A(110)	A(152)
Cyclopterus lumpus	-	-	R(1)	R(3)
Urophycis tenuis	R(2)	-	C(24)	C(12)
Microgadus tomcod	A(400)	R(3)	A(152)	C(16)
Pollachius virens	-	C(10)	-	C(17)
Syngnathus fuscus	-	R(7)	R(2)	C(15)
Pseudopleuronectes americanus	R(8)	C(91)	C(23)	C(12)
Liopsetta putnami	-	-	-	C(13)
Apeltes quadracus	C(10)	A(1800)	A(105)	C(15)
Gasterosteus aculeatus	C(22)	-	A(236)	A(156)
Gasterosteus wheatlandi	-	-	--	C(22)
Pungitius pungitius	C(13)	C(33)	R(2)	R(5)

TABLE 16. CONT'D.

Species	Shubenacadie	Annapolis	Saint John	Passamaquoddy
Pholis gunnellus	–	–	–	R(1)
Hemipterus americanus	–	–	–	R(3)
Myoxocephalus aenus	–	–	–	R(6)

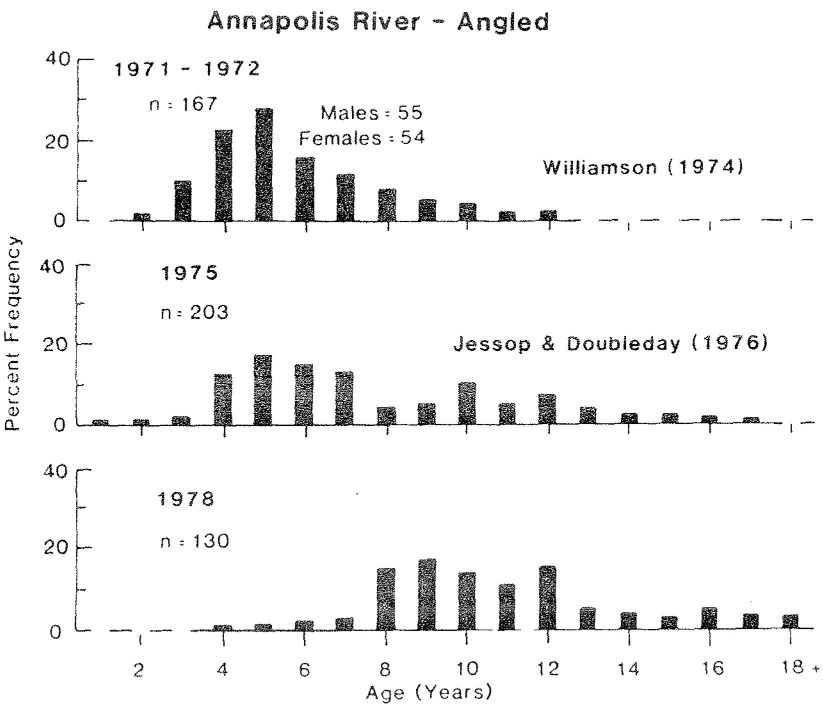


Fig. 39. Age structure of striped bass from the Annapolis River and its changes between 1971 and 1978.

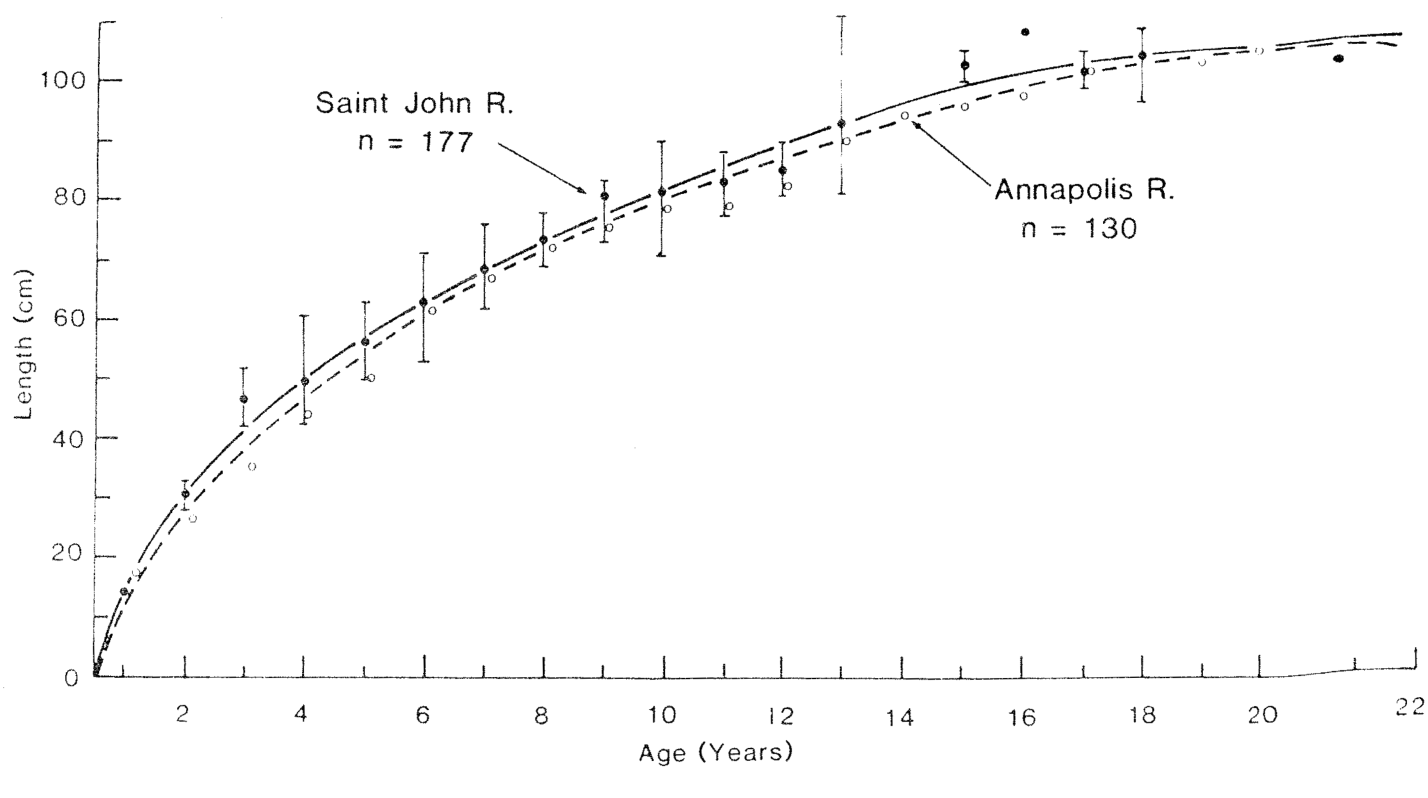


Fig. 40. Growth of striped bass from the Saint John and Annapolis Rivers

Construction of the tidal power station led to questions of fish passage facilities, many of which were addressed in a report by Martec Ltd. (Anon. 1980a).

The Saint John Estuary

The Saint John River is the second longest river on the east coast of North America after the Saint Lawrence and has a drainage area of 55,000 sq km. Its estuary forms a complex series of interconnected channels, bays and lakes covering 500 km^2 and extending inland 120 km (Trites 1960). The estuary is unique for this region in that the Reversing Falls sill, 5 m below mean hightide level of the Bay of Fundy, restricts circulation between the estuary and the Bay and dampens tidal amplitude within the estuary (Trites 1960). As a result mean summer temperatures in the estuary average 9°C warmer than the Bay. This set of conditions sets up a complex array of habitats in the estuary ranging from fjords with permanently cold and saline deep water to tidal freshwater lakes (Metcalfe et al. 1976). The resulting fish fauna is diverse, ranging from oligohaline redfish (Sebastes mentella) (Squires and Gorham 1966) through the only known Canadian population of shortnose sturgeon (Acipenser brevirostrum) (Dadswell 1979) to a diverse assemblage of warm-and cold-water freshwater species (Table 16). Its estuarine fisheries are among the largest and most valuable in the Maritimes (Meth 1972, Dadswell, in press).

Recent research on fishes in the Saint John estuary has been largely confined to the anadromous species: sturgeon, shad, gaspereau, salmon and striped bass. Although not known to exist in the Saint John before 1959 (Liem and Day 1959) subsequent research has revealed the shortnose sturgeon population in the river is one of the largest in eastern North American (Dadswell 1979, Taubert and Dadswell 1980). The species is anadromous, spawning in the upper reaches of the estuary in spring (Anon. 1980), feeding in mid-estuary and wintering in the lower estuary or in the Bay of Fundy (Dadswell 1979). Atlantic sturgeon also occur in the estuary and support a small commercial fishery (see fisheries section) but their biology in this river system is virtually unknown.

The American shad is one of the better studied fish from the Saint John. The fishery for this species was large in times past (200,000 - 400,000 kg/yr) but during the last 20 yr has declined significantly, part of the reason for which may be construction of Mactaquac Dam (Jessop 1975). The decline prompted considerable study. Carscadden and Leggett (1975) determined that shad from each of the Saint John tributary rivers were distinguishable and had unique life histories. Most Saint John River shad spawn at age 4 or 5 and average 41 cm in length. Repeat spawners are abundant (76.8%) and average 2.8 spawnings/fish (Carscadden and Legget 1975). An interesting aspect of shad biology on the Saint John is the occurrence of a "fall run" (Gabriel et al. 1976). The "fall run" was thought to consist largely of Saint John shad (Gabriel et al. 1976) but recent work indicates the majority may originate from other rivers on the east coast during their migration out of the Bay of Fundy (Bradford 1981, Dadswell, unpub. data).

Gaspereau (alewifes and blueback herring) biology has been examined by various workers but most information is not yet available in published form (Jessops, pers. comm.). Messiah (1977) described the population structure and biological characteristics of both alewife and blueback herring from the spawning run. Dadswell (in press) described the fishery.

Atlantic salmon once supported the most valuable fishery of the Saint John River but this fishery has since declined in value because of reduced population and imposed quotas (see fisheries section). The salmon population has been severely impacted by damming and pollution of the river (Fig. 41) (Dominey 1973) and aerial spraying of insecticides (Elson 1967). Ruggles and Watt (1975) described the attempts to revitalize the salmon run but results have not been encouraging. However, presence of the Mactaquac Dam and the associated hatchery to replace salmon parr production lost in the drowning of the river has resulted in considerable research on hydro-electric development and its effect on this species (Carey 1970, Macdonald and Hyatt 1973, Ruggles 1980).

Striped bass research on the Saint John has been sporadic. Williamson (1974) and Dadswell (1976) described growth and population characteristics and Melvin (1978) studied the morphometric, meristic and protein characteristics of the population. This bass population, similar to the Annapolis River one, appears to be genetically related to Chesapeake Bay populations (Melvin 1978). What proportion of actual Chesapeake bass were in the study samples is unknown but this may well have influenced results.

The angling catch of bass in the Saint John was high during the 1960's (O'Donnell 1963) coincident with the peak of Chesapeake fish. In 1976 a 28 kg specimen, 21-yr-old was captured at Reversing Falls. This was probably a southern fish since local striped bass seldom exceed 20 kg at this age (Dadswell 1976). Tag returns also indicate southern bass spend part of the summer in the Saint John region (Table 14). Since 1973 there has been a lack of younger age classes present in the Saint John (Fig. 42) and the population has declined to low levels resulting in a closure of the commercial fishery.

The Saint John estuary has one of the few populations of lake whitefish (Coregonus clupeiformis) in the Maritimes (Scott and Crossman 1973). The population size is not known but the fish can be seasonally abundant during spawning and feeding migrations (Meth 1972, Dadswell 1976). Age and growth characteristics of the population were similar to other studied populations (Dadswell 1976).

Graduate students of the University of New Brunswick (Fredericton) have made numerous studies on parasites of fishes in the estuary. A new species of sturgeon parasite (Capillospirura pseudoargumentosa) was described (Appy and Dadswell 1978) and its life cycle determined (Appy and Dadswell 1983).

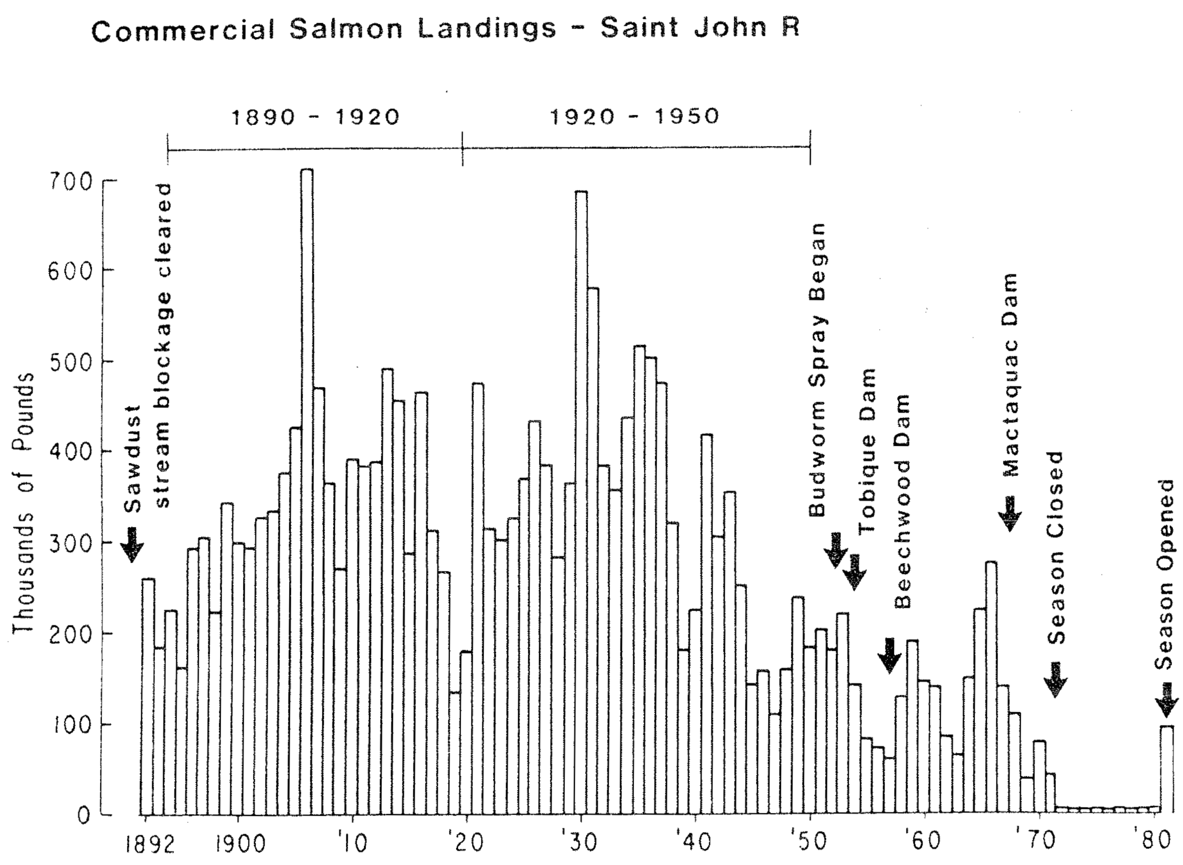


Fig. 41. Saint John River Atlantic salmon commercial landings between 1982 and 1981 and the period of first impact by various human endeavors.

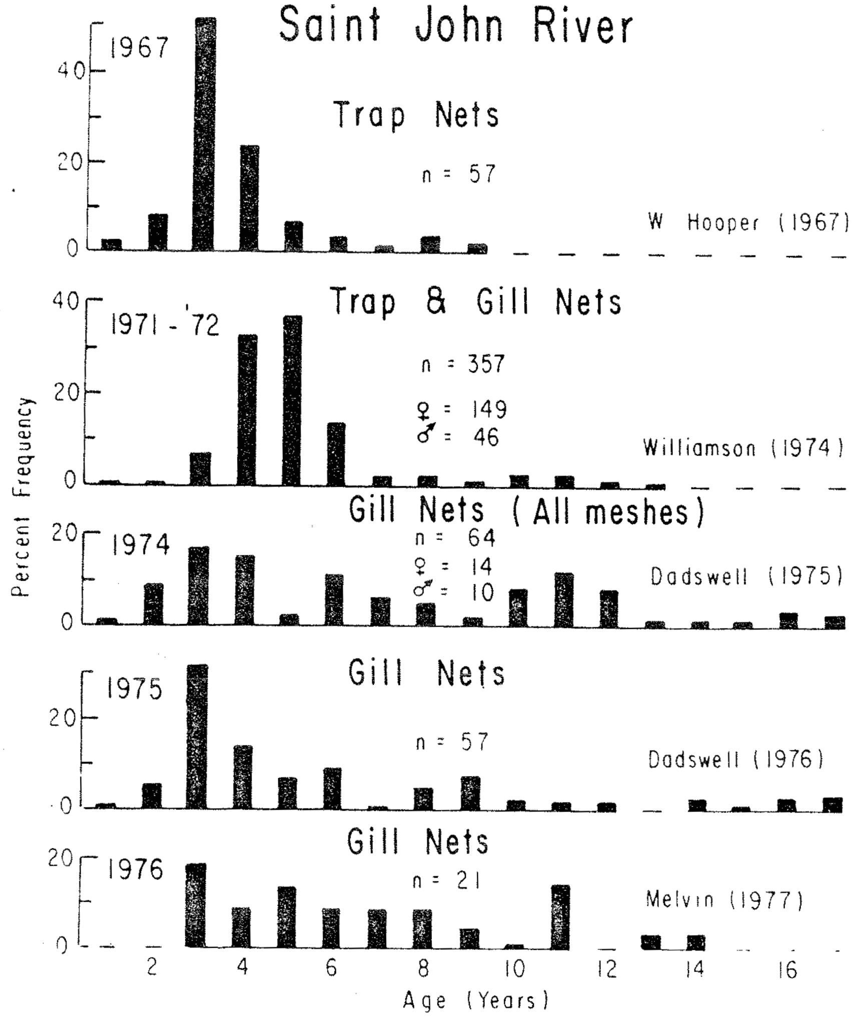


Fig. 42. Percent frequency of catch-by-age for Saint John River striped bass between 1967 and 1976.

The Lower Bay of Fundy

The biology of fishes in the lower Bay of Fundy is perhaps the most studied and best known in the Maritimes (Daborn and Bleakney 1977). The outer region is also the site of the most valuable fisheries in the Bay (Scarratt 1974, 1977). Recent fisheries research has concentrated on groundfish, herring, lobsters, fish physiology and aquaculture, cetaceans, and fish taxonomy.

Most groundfish research is conducted by the Marine Fish Division of Fisheries and Oceans. Recent areas of concentration are the bio-energetics of cod and haddock. Each year, annual or biannual groundfish assessment cruises are conducted at standard stations in the Bay of Fundy and the Scotian Shelf (NAFO 4X subdivision) (Scott 1976). These are largely to assess stock size, age composition, distribution and recruitment of the commercially exploited species of gadoids and pleuronectids. The exploitation, growth and stock identification of cod (Beacham 1982a), haddock (Beacham 1982b), pollock (Beacham 1982c) and plaice (Beacham 1982d) have been addressed for stocks occurring in the Bay of Fundy and Gulf of Maine. Long-term sampling for groundfish at reference localities on a finer time scale has occurred in Passamaquoddy Bay and close-by in the Bay of Fundy (Tyler 1971, 1972, Macdonald et al. in press). Subsidiary studies of fish from these localities have included the life histories of red and white hake (Markle et al. 1982), description of cod parasites (Appy and Burt 1982) and the fish leech fauna of the region (Appy and Dadswell 1981).

Herring is one of the most important fisheries in the outer Bay of Fundy and research has been conducted over a long time period. Herring tagging studies (McKenzie and Tibbo 1961, Stobo 1976) and juvenile herring surveys have been directed at determining the movements and stock relationships of post-metamorphosis herring. Results indicate the Bay of Fundy is an important feeding area for pre-recruit herring from stocks occurring in the Gulf of Maine and Bay of Fundy (Das 1968). Significant contributions to invertebrate, as well as, larval herring ecology have been made since the onset of ichthyoplankton surveys conducted annually during March, August and November since 1969. Vertical oblique plankton tows (paired 505 Bongo nets) are conducted at 116 standard stations throughout the Bay of Fundy (not including the inner portions of Minas and Chignecto Bay). Results indicate discrete aggregations of ctenophores (Iles 1975) chaetognaths (Hurley 1980) and euphausids (Kulka et al. 1982). The concepts of the larval transport-retention mechanisms and the seasonal and area distribution of herring larvae described by Das (1968) and Iles (1972, 1979) have been modified recently to account for the spawning population in the Scots Bay area. Three discrete retention areas for the larvae from the spawning populations of Grand Manan, southwest Nova Scotia and Scots Bay were identified (Bradford 1982). Messiah (1975) described the growth of otoliths in young herring from the Bay of Fundy.

Lobster research has emphasized aquaculture and physiology (Aiken 1980, Aiken and Waddy 1978), parasitology (Leslie et al. 1981) and lobster stock biology and assessment (Campbell and Duggan 1980). Long distance movements of lobster from the Bay of Fundy along the United States coast were verified by an extensive tagging program (Campbell 1984).

Fish physiology studies have been directed towards Atlantic salmon aquaculture and have lead to the establishment of a small aquaculture industry in the region. Studies have included selective breeding (Bailey et al. 1980, Glebe et al. 1980), the development of rapid growing parr (Johnston and Saunders 1981, Saunders and Henderson 1978, Wedemeyer et al. 1980) and procedures for aquaculture (Saunders 1983, Saunders et al. 1982, Saunders et al. 1983, Sutterlin et al. 1981).

The physiological process of hatching of fish eggs has been examined with respect to osmoregulation (Peterson et al. 1980), acid precipitation and low pH (Peterson et al. 1980, Peterson and Martin- Robichaud 1983) and cadmium pollution (Peterson et al. 1983). The impact and physiological effect of dionoflagellate toxins on finfish was described and delineated (White 1977, 1980, 1981, 1982a) and a continuing intensification of Gonyaulax blooms and shellfish toxicity in the lower Bay of Fundy detailed (White 1982b, 1982c).

Since the early 1970's a group of researchers have been working on the tidally generated ecosystem at the mouth of Passamaquoddy Bay and off Brier Island (Fig. 1). Because of the concentrating mechanisms of tidally induced current fronts, the region is important for herring (Huntsman 1953, Jovellanos and Gaskin 1983), birds (Brown et al. 1979, Braune and Gaskin 1982a, 1982b) and cetaceans (Neave and Wright 1968, Arnold and Gaskin 1972, Gaskin et al. 1975, Gaskin and Blair 1977, Gaskin and Smith 1979). Recent studies indicate the region supports a summer nursery of Atlantic right whales (Eubalaena glacialis) and if population estimates are correct, half the north Atlantic population of this species is in the Gulf of Maine region each summer (Kraus and Prescott 1983, Reeves et al. 1983). Much of this work was made more urgent by the possibility for construction of a large oil refinery at Eastport, ME and the potential for oil spills and their environmental impact (Scarratt 1979).

Maintenance of the taxonomic research collection for the Biological Station became the responsibility of the Identification Center in 1973. Since then the identified collection of fishes has grown to over 500 species. The collection also includes approximately 2000 species of invertebrates. Initiation of taxonomic studies has lead to publications on polychaetes (Appy et al. 1980), copepods (Roff 1978), polychaete larvae (Lacalli 1980), and larval gadoids (Markle 1982).

FISHERIES

Fisheries of the Bay of Fundy (NAFO or ICNAF 4X sub-division) have been summarized in numerous reports during the last 10 yr (Hare 1977, Scarratt 1977, Campbell 1979, Iles 1979, Kohler 1979, Peacock 1979). Interest has centered mainly on the high volume, high value species of the lower Bay so these will be only briefly reviewed here. Fisheries of the upper Bay and the estuaries have received scant attention and will be reviewed in more detail with some historical prospective. Commercial landings for the Bay of Fundy region were recorded by Statistics Canada by county before 1947 and by Statistical District after 1947 (Fig. 43). Both geographic grouping methods will be used in the following analysis.

The Bay of Fundy fisheries are valuable. The landings of all invertebrate species in 1981 was approximately 6,000 metric tons (MT) valued at $41 million (Table 17). The 1981 marine plant landings were 11,000 MT valued at $1 million (Table 18). Herring landings over the last 10 yr have averaged 110,000 MT valued at $20 million (Iles 1979) and groundfish landings in 1981 were 32,000 MT valued at $14 million (Table 19). Shad, salmon, alewifes and other diadromous species landings average 1,500 MT (Table 20) valued at approximately $1 million (Dadswell, in press). In sum, the annual value of fisheries in the Bay of Fundy without considering secondary values for the whole Bay of Fundy was estimated at $92 million in 1978 (Peacock 1979) but was probably closer to twice that in 1982. It must be remembered, however, that all compiled statistics are reported landings. In the case of marine plants, groundfish and herring where most or all of the catch is processed in central plants, the statistics may be approximately accurate. For other species, especially those sold off the boat directly to the consumer (salmon, lobster, clams), reported landings will be less than real landings. Consequently real value of the fisheries are probably considerably more than estimated.

The Upper Bay of Fundy

Fisheries in the upper Bay of Fundy have traditionally been for anadromous species, herring, clams and lobsters.

American shad

The shad fishery of the upper Bay of Fundy has existed since the earliest arrival of Europeans in the region. Perley (1852) identified the start of a weir fishery on the tide flats by 1750. Prince (1912) writing for the Dominion Shad Commission (1908-1910) described the abundance of shad in this region during the 1800's and the relative ease with which primitive and/or simple capture methods (brush weirs) could capture 50,000 - 100,000 shad on a single tide. The shad fishery was so important to the economy of the inner Bay of Fundy that a special act of the Nova Scotia Legislature was passed in 1840 for its regulation (Perley 1852). After 1840 drift gillnets became the major means of capturing shad and at the same time a large export trade in salt shad began with the eastern United States (Perley 1852). Between 1870 and 1900, annual shad landings for Minas Basin and Chignecto Bay were 1.0-2.0 x 10 kg/yr (Fig. 44) and constituted two-thirds of total Canadian shad landings. After 1900, landings declined drastically as a result of markedly decreased shad abundance (Prince 1912) and have remained at low levels up to the present. Although abundance has increased since 1970 (Dadswell et al. 1984) landings remain low because of reduced effort (Table 20).

The comparative importance of shad to the fisheries in the upper Bay when shad were abundant is amply demonstrated by comparing the relative contribution of shad and herring to the total fishery in each county around

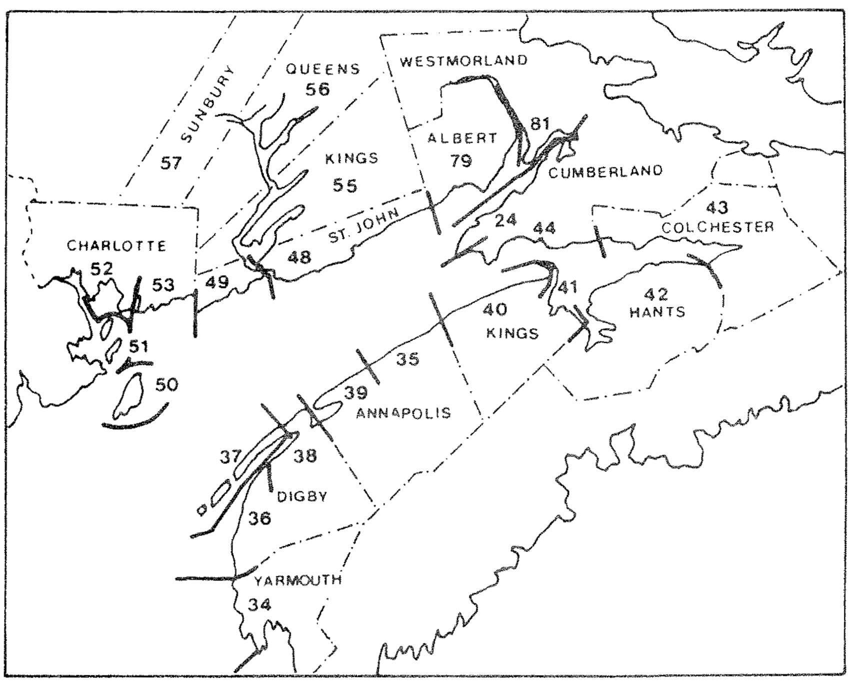


Fig. 43. Statistical districts and counties bordering the Bay of Fundy.

TABLE 17. Annual commercial landings (kg x 10^3) and landed values ($ x 10^3) of invertebrates in the Bay of Fundy (minus statistical districts 34 and 36).

Year	Lobsters kg	Lobsters $	Scallops kg	Scallops $	Soft-shelled clams kg	Soft-shelled clams $	Shrimp kg	Shrimp $
1976	2,095	9,456	549	1,853	619	217	-	-
1977	2,948	14,467	1,052	3,256	1,365	547	-	-
1978	2,378	14,824	770	3.950	1,372	614	1	1
1979	2,761	15,024	820	5,998	-	-	-	-
1980	2,285	15,390	952	8,555	-	-	-	-
1981	3,053	19,914	1,834	18,113	1,400	1,000	-	-

TABLE 18. Annual commercial landings (kg x 10^3) and landed values ($ x 10^3) of marine plants in the Bay of Fundy.

	Dulse		Irish Moss		Rockweed	
Year	kg	$	kg	$	kg	$
1973	24	32	4,795	327	-	-
1974	45	80	10,213	1,143	253	5
1975	49	97	7,838	798	463	8
1976	25	52	5,555	538	694	17
1977	79	103	5,404	577	-	-
1978	45	88	5,944	778	-	-
1979	14	41	8,275	1,127	4,622	129
1980	26	61	5,669	781	3,879	81
1981	16	58	5,581	901	5,306	114

TABLE 19. Annual commercial landings of groundfish from Bay of Fundy ports. Landings (kg x 1000); values ($ x 1000).

Year	Cod		Haddock		Redfish		Hake		Pollock		Plaice		Flounder[1]	
	Landings	Value	Landings	Value	Landings	Value	Landings	Value	Landings	Value	Landings	Value	Landings	Value
1968	8,995	859	12,419	1,685	105	6	763	58	5,499	374	6	-	1,448	168
1969	6,676	707	7,547	1,384	514	28	771	46	4.968	360	11	5	1,801	222
1970	5,345	740	6,024	1,430	1,008	73	761	58	3,831	331	17	1	1,711	239
1971	5,078	828	5,163	1,221	1,089	79	1,341	130	3,631	383	2	-	1,612	230
1972	5,287	920	3,390	1,089	228	18	1,573	169	4,355	471	7	1	1,494	260
1973	4,685	1,041	2,351	889	46	5	1,741	211	10,119	1,148	33	6	1,381	300
1974	4,798	1,342	4,447	1,571	10	1	1,764	249	5,508	718	10	2	1,424	317
1975	4,931	1,364	5,819	2,123	64	6	1,581	227	5,261	775	13	3	1,389	364
1976	3,655	1,107	3,659	1,645	57	8	1,106	186	4,890	704	15	6	1,092	328
1977	7,586	2,366	5,118	2,484	27	3	822	148	4,372	792	72	19	1,749	564
1978	6,459	2,329	8,805	4,068	10	2	775	182	3,709	773	252	100	1,715	613
1979	7,911	3,409	8,874	4,427	7	2	963	328	6,579	1,998	405	176	1,881	929
1980	11,900	5,011	10,048	5,893	22	6	983	319	7,812	2,669	434	201	2,917	1,416
1981	11,036	5,682	11,059	5,066	32	9	1,083	390	5,700	2,026	206	93	3,048	1,488
1982														

[1] All species.

TABLE 20. Landings (kg) of the major anadromous fish species between 1979 and 1981 in the Bay of Fundy region.

	1979			1980			1981		
Stat D.	Alewives	Salmon	Shad	Alewives	Salmon	Shad	Alewives	Salmon	Shad
24	<1 [1]	<1	9,000	1,000	<1	22,000	1,000	<1	31,000
33	<1	<1		36,000	<1			<1	
34				49,000		<1			
35		<1	6,000	2,000	<1	7,000			14,000
36		<1		4,000	<1				
37		<1			<1				
38									
39									
40		1	<1	81,000	2,000	<1		<1	<1
41	248,000		2,000	134,000		6,000	53,000		
42	5,000	<1	3,000	218,000	1,000	1,000	4,000	2,000	
43	500,000	1,000	14,000	32,000	1,000	39,000	1,000	<1	5,000
44		<1							
48		<1		525,000	1,000	44,000	16,000	19,000	<1
49		<1		72,000	1,000		88,000	16,000	5,000
50									
51									
52	11,000	<1			<1				
53									
79		<1							
81		<1		6,000	<1			<1	
Total	>764,000	>1000	>40,000	1,154,000	>8,000	119,000	163,000	>37,000	>55,000

[1] <1 = less than 1 metric ton.

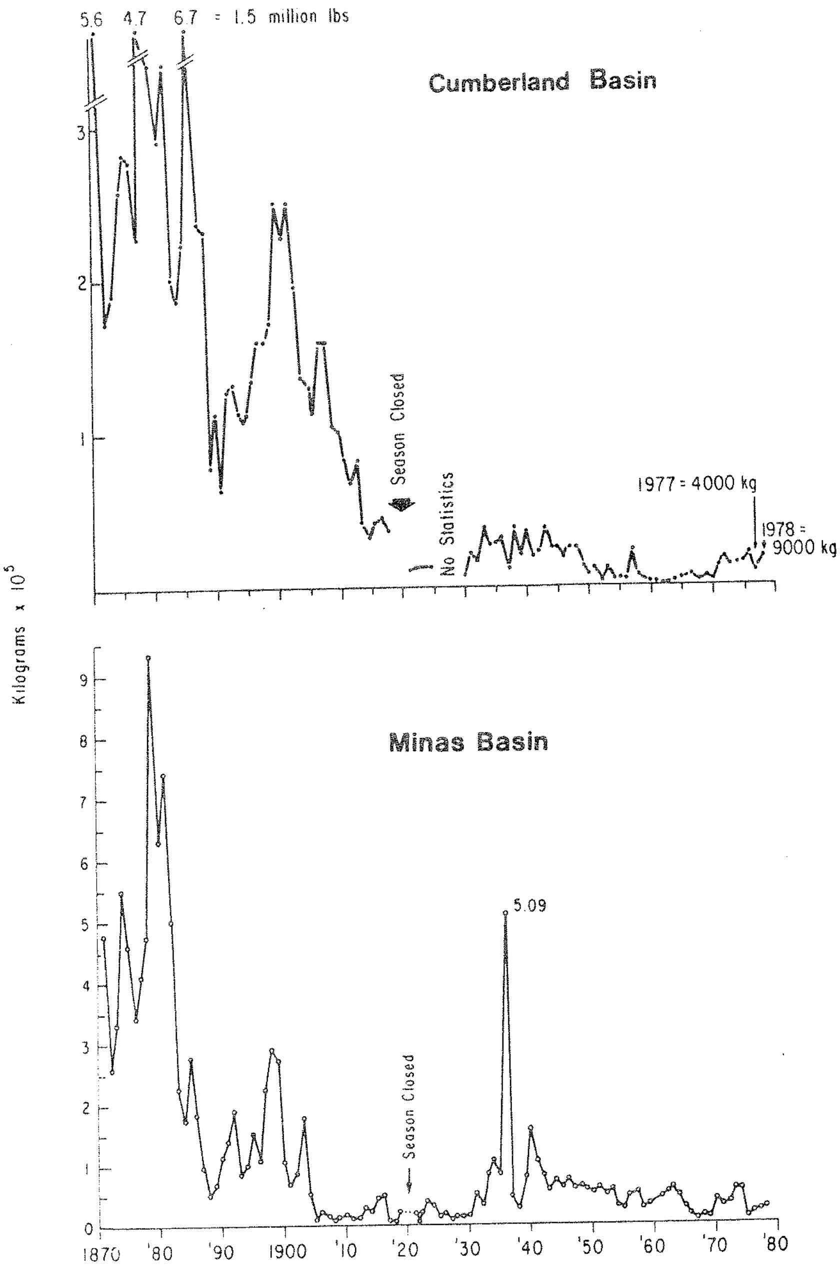


Fig. 44. Annual commercial landings of shad for Cumberland and Minas Basins from 1870-1978.

the Bay of Fundy during the period 1879-1884 (Fig. 45). Herring contributed nearly 100% of landings in Charlotte Co. and Kings Co. but shad contributed a like portion in Colchester and Westmorland Counties. Admitedly the total landings of shad and/or all fish in the upper Bay of Fundy was an order of magnitude less than the lower Bay during this period (Table 21), but when the regions were compared in terms of mean landings over 10-yr periods for the area of ocean fronting their shore (similar to the analysis by Huntsman 1952) the landings in kg/hectare were not appreciably different except for Charlotte Co. (Fig. 46).

In the upper Bay of Fundy two methods are used to capture shad, drift gillnets with a minimum allowable mesh size of 12.5 cm stretched and intertidal weirs. Three fishermen are licensed to drift net for shad in Minas Basin and approximately 30 in Chignecto Bay. There are four licensed weirs which capture shad in Minas Basin, one at Five Island, two at Economy Point and one at Walton. There are no weirs in Chignecto Bay.

At present the shad fishery of upper Bay of Fundy remains small. Landings seldom exceed 50 MT/yr (Table 20). However, each year for the past twenty the United States has been restoring more of their rivers for potential shad spawning and shad stocks are increasing (Leggett 1976, Miller et al. 1982). If restoration plans proceed as planned shad abundance in the upper Bay of Fundy could reach historical levels. Even at existing stock levels considerable scope for increasing the fishery exists.

Atlantic salmon

Atlantic salmon contributed to fisheres in the upper Bay of Fundy both through commercial and sports catches. Reported commercial landings in recent years have seldom exceeded 4 MT and in most counties sports landings have often exceeded commercial landings (Table 13). In the past, however, commercial landings often totaled 100 MT/yr (Fig. 47). Weirs in Kings Co. (Scots Bay) and the drift net fishery in Cobequid Bay were the major fisheries (Fig. 47) (Huntsman 1958). Salmon captured in the Kings Co. fishery were from many sources, even those as far away as the Mirimichi River (Saunders 1969, Jessop 1976). Catches oscillated in unison with Saint John River landings (Figs. 41, 47) which suggests a relationship either in the stocks fished or some overall environmental control of salmon production in the Bay of Fundy Basin.

The upper Bay of Fundy has some excellent salmon rivers. The total drainage basin area of Minas Basin is 4500 km^2 most of which is accessible to salmon (Martin, pers. comm.) compared to approximately 11000 km^2 for the Saint John. The sport catch in the Shubenacadie River ranges between 500 and 1000 salmon a year (Morantz 1978).

Gaspereau (Alewife and blueback herring)

Major gaspereau fisheries in the region are situated on rivers and capture fish using scoop or trap nets. Yearly landings from the upper Bay average 500 MT/yr. The largest fisheries exist in the Gaspereau River (SD 41), the Shubenacadie River (SD 42, 43) and rivers at the head of

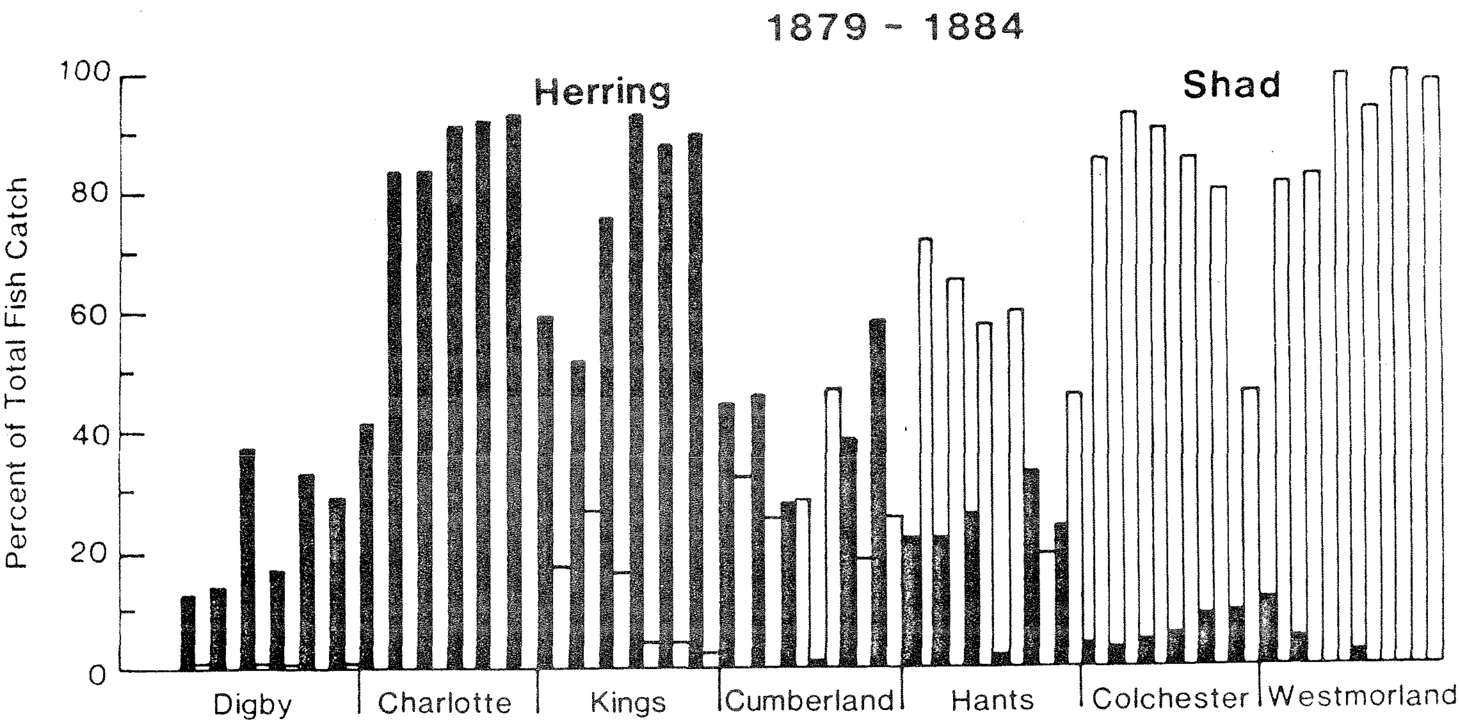


Fig. 45. Percent of total fish landings that were either herring or shad during the period 1879-1884 from counties bordering on the Bay of Fundy.

TABLE 21. Landings of herring and shad in the Bay of Fundy between 1879 and 1884 in relation to all fish landings.

Year	Digby	Kings	Hants	Cumberland	Colchester	Charlotte	Westmorland
				Herring kg x 1000			
1879	540	1,101	91	191	14	19,252	43
1880	503	372	90	168	15	27,292	13
1881	2,367	1,194	121	94	31	34,519	-
1882	2,608	2,752	6	1	24	45,135	5
1883	1,932	1,546	35	268	26	54,111	-
				Shad kg x 1000			
1879	6	314	303	139	316	-	302
1880	-	192	272	92	457	-	278
1881	50	249	270	96	588	-	353
1882	50	122	220	78	360	-	220
1883	-	68	59	98	202	-	211
1884	19	47	67	117	130	-	151
				Total landings (all species) kg x 1000			
1879	4,232	1,837	421	429	371	46,483	373
1880	3,597	724	418	367	493	32,707	300
1881	6,281	1,579	472	344	653	41,385	353
1882	15,318	2,973	370	169	422	50,057	234
1883	7,867	1,587	307	541	253	55,382	212
1884	6,664	1,725	148	461	282	58,261	154

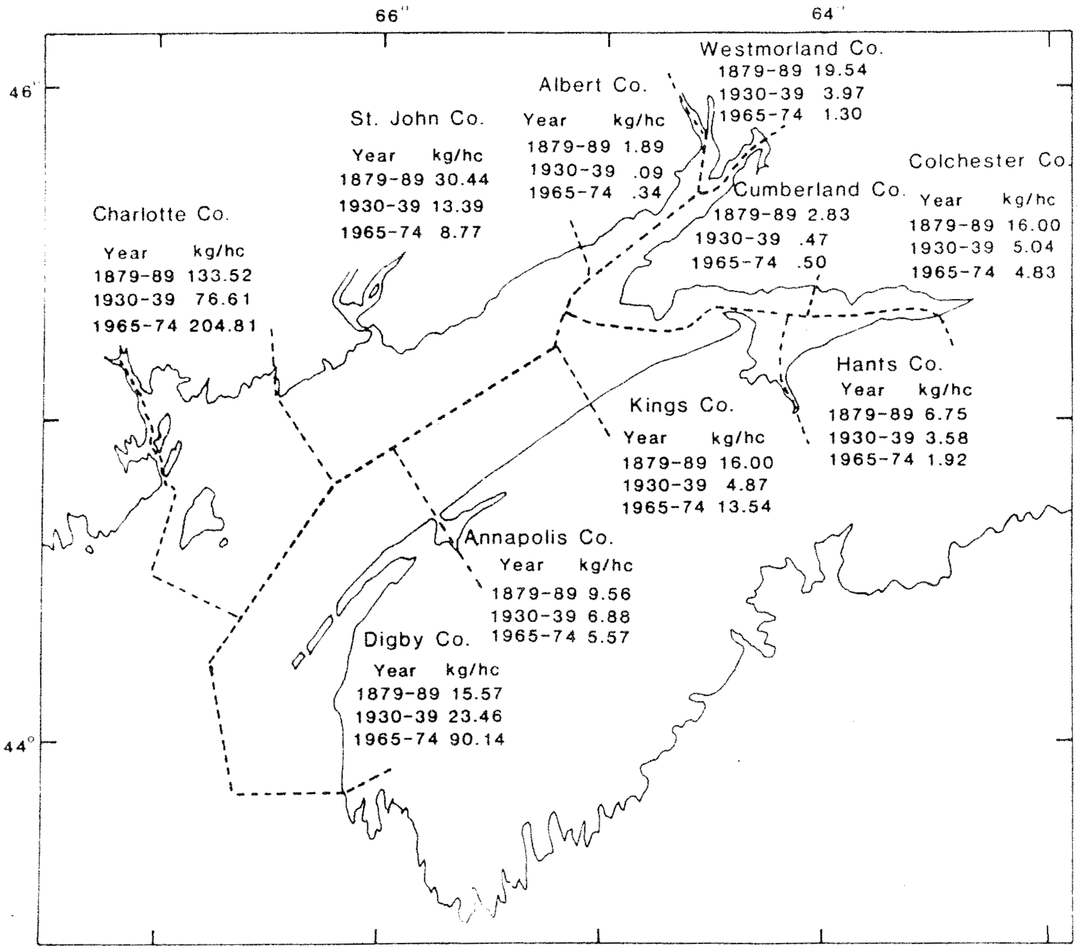
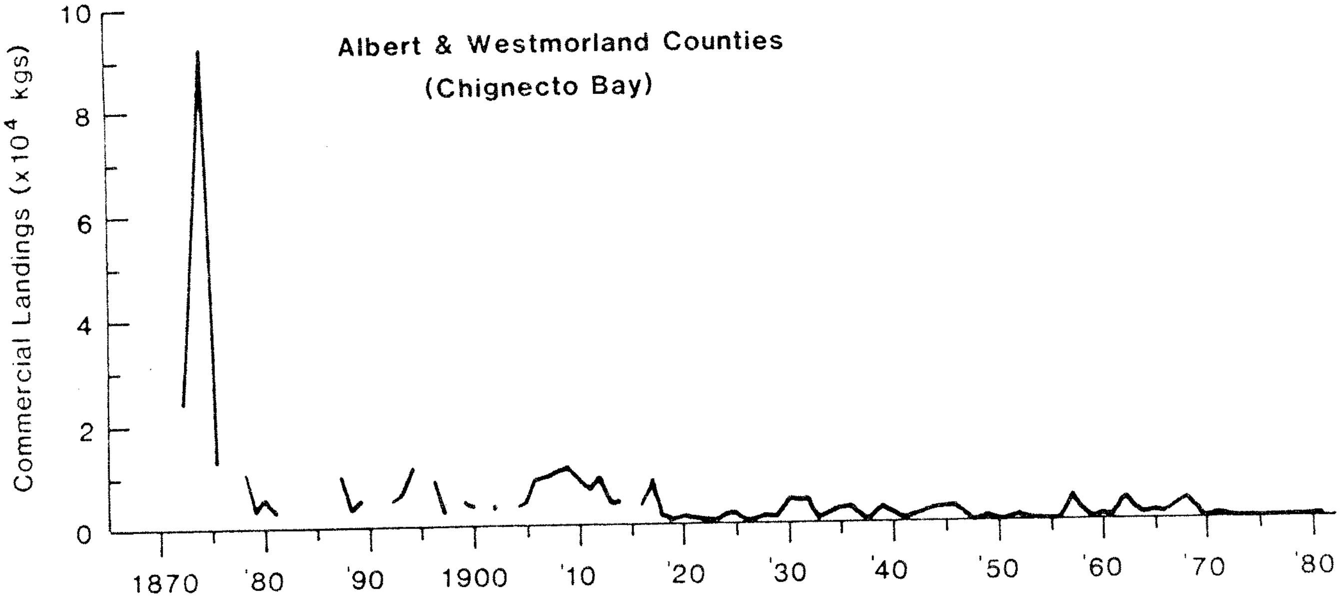
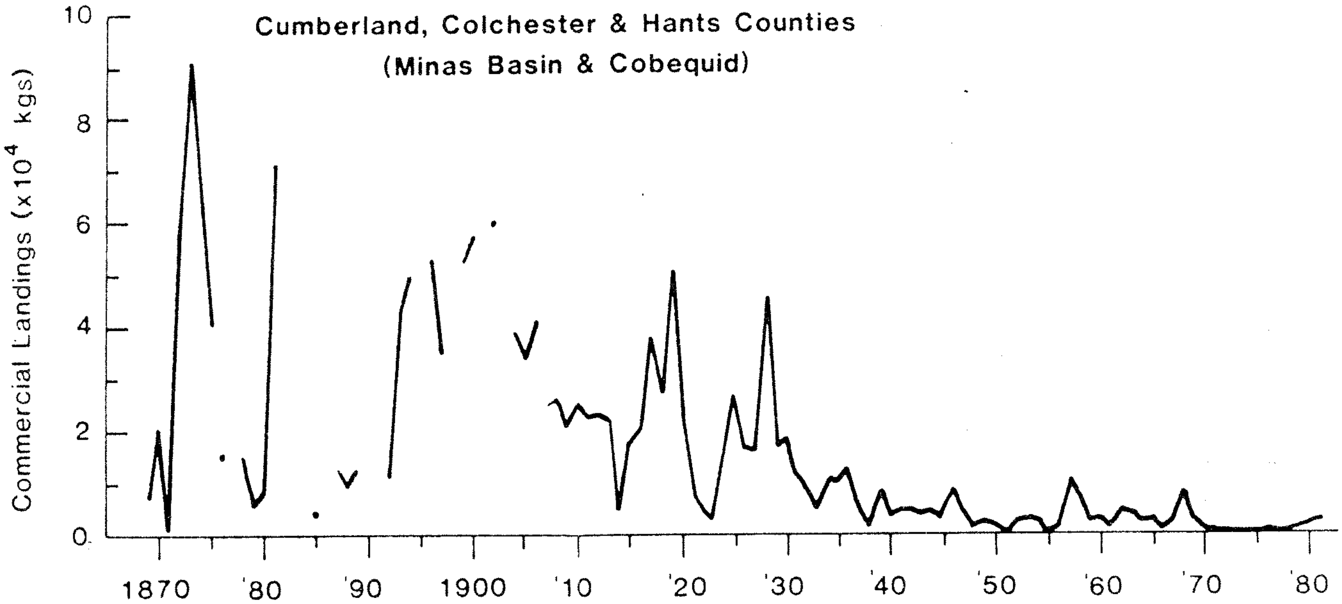


Fig. 46. Productivity of the ocean area fronting the counties of the Bay of Fundy for three 10-yr periods between 1879 and 1974. Productivity is expressed in kilograms of all fisheries landings (except plants) per hectare of ocean area.





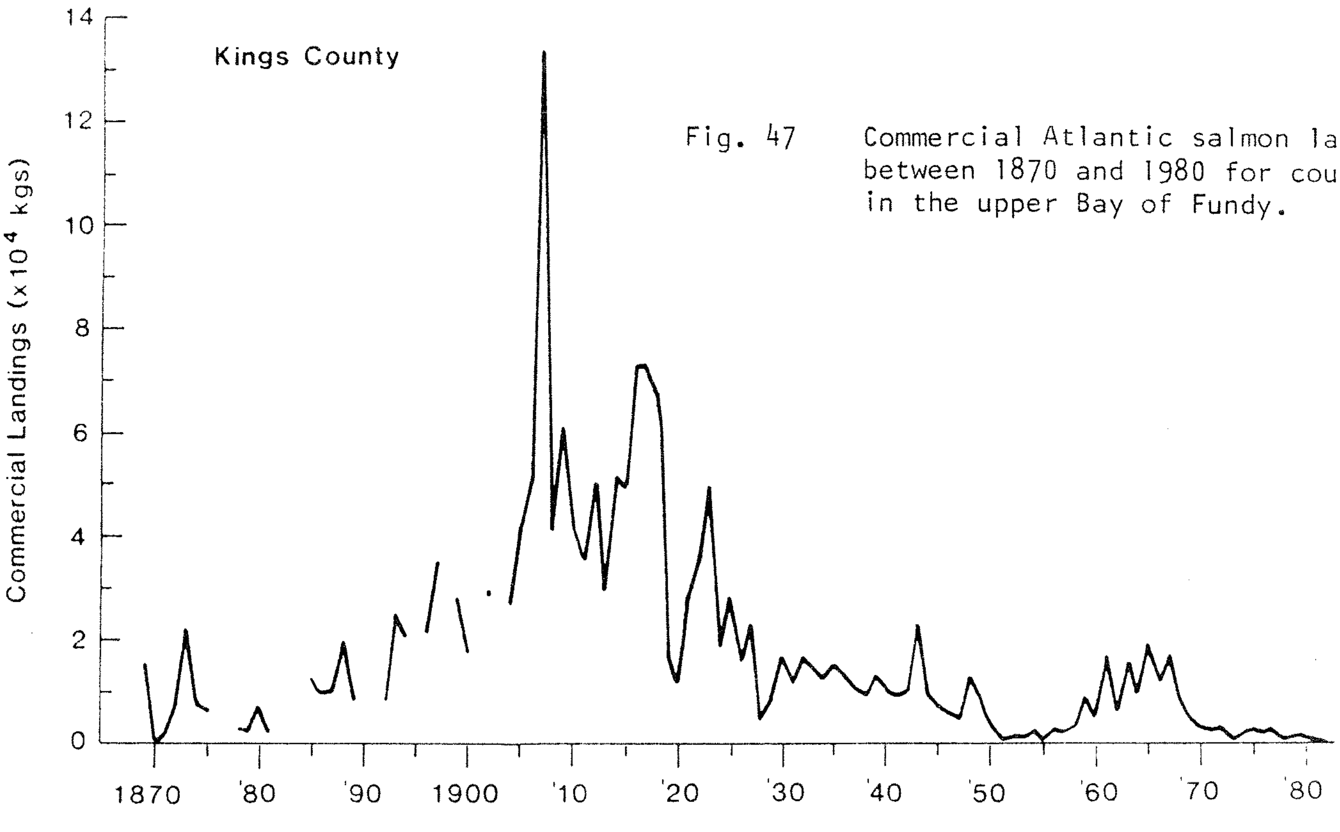


Fig. 47 Commercial Atlantic salmon landings between 1870 and 1980 for counties in the upper Bay of Fundy.

Cumberland Basin (SD 24, 81) (Table 20). The Cumberland Basin fishery has declined in recent years from 50,000 kg/yr to a few thousand kg (Table 20) (Caddy and Chandler 1976) perhaps as a result of control structures (tidal dams) placed on local rivers for agricultural development of marshlands.

Herring

Herring are an important fishery for Kings Co. in the Cape Split region. During the 1880's reported landings equalled or exceeded Digby Co. landings in some years (Table 21) and represented more than 50% of the landings in this region in most years (Fig. 45). Previously all herring were taken in intertidal weirs, but since 1960 a purse seine fishery has been responsible for most catches. The purse seine catches are mostly landed in Charlotte Co. (C. Dickson pers. comm.), which obscured the relative importance of Kings Co. to the herring fishery of the Bay until a system of reporting catches on a catch location basis was established (Iles 1979).

A small gillnet fishery in Minas Basin for adult spawning herring occurs each spring during April to June from Walton to Parrsboro (Perley 1852, commercial fishermen, pers. comm.). The fishery begins inside Minas Basin and the last catches are made in the Advocate area. Size and spawning location of this population appears unknown.

Lobsters

Campbell (1984) has discussed the lobster fishery. By all standards it is a small fishery but landings have been increasing in recent years. The value of the catch at $5.50/kg was 0.24 million in 1982 compared to 3.75 million for the whole Bay of Fundy.

Soft-shell clams

The soft-shell clam fishery in the upper Bay of Fundy is situated between Advocate and Bass River on the north shore of Minas Basin (SD 24, 44, 43). Landings have increased to over 500 MT in recent years representing about 30% of Nova Scotia landings and about 50% of the Bay of Fundy landings (Witherspoon 1984, Campbell 1979). The value of Colchester Co. fisheries has increased appreciably in recent years because of the clam fishery and between 1965 and 1974 ranked third in value in the Bay of Fundy ($/hectare) because of clam landings (Fig. 48).

The Mid Bay of Fundy

Fisheries of the middle Bay of Fundy include scallops, lobsters, groundfish and estuarine fisheries for anadromous species.

Scallops

Scallops have become the most valuable fishery in the Maritimes because of the high price offered for this commodity. During 1983 prices rose to $16/kg. The major fishery is still located off Digby but new

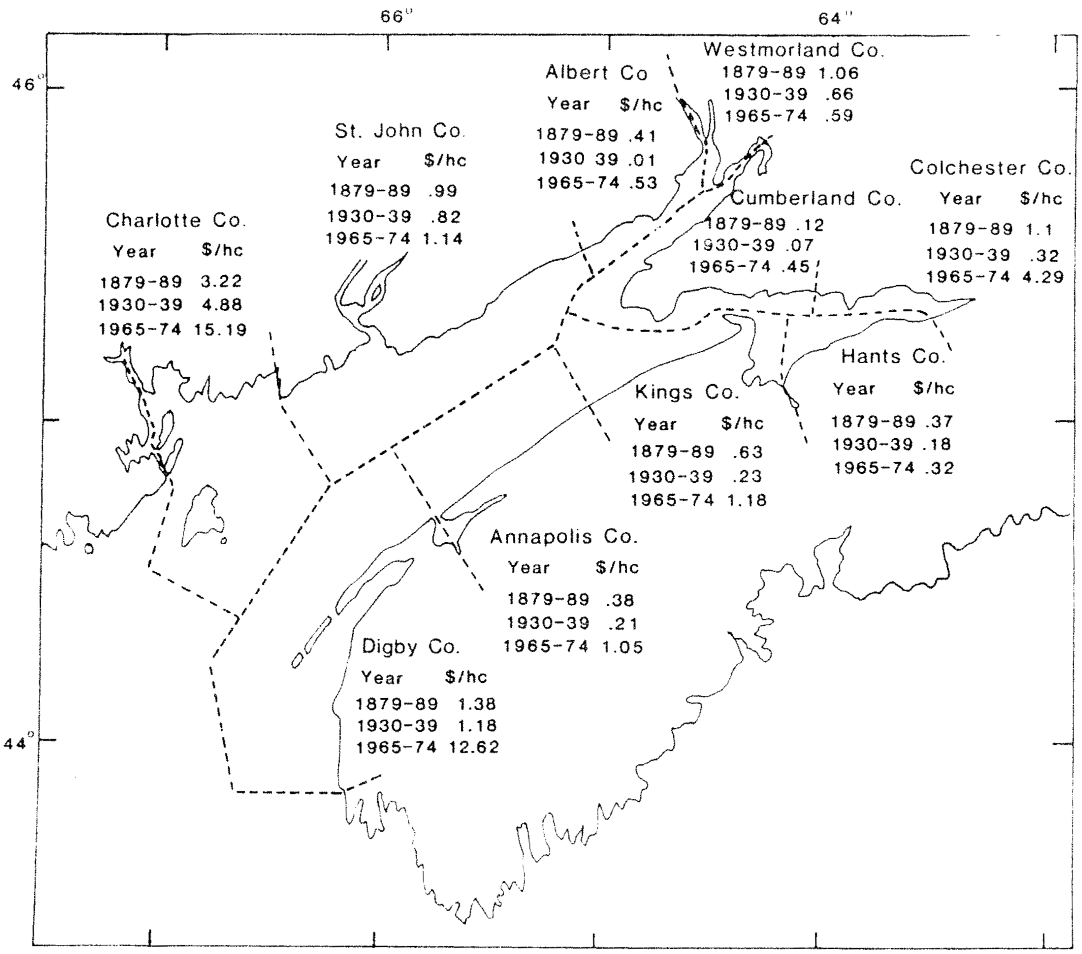


Fig. 48. Value/hectare (dollars) of all fisheries landings (except plants) for counties fronting the Bay of Fundy during selected 10-yr periods between 1879 and 1974.

fisheries are developing in Charlotte Co. and off Grand Manan (Jamieson et al. 1979).

Scallop catches from the Digby bed have fluctuated between 200 and 800 MT/yr of meats (Caddy 1979). Present landings are high due to an excellent spat settlement in 1974 and 1975 (Fig. 49) (Chandler, pers. comm.).

Lobsters

The mid Bay of Fundy supports a good lobster fishery but landings are less than for the lower Bay. Landings tend to fluctuate in response to long term warming and cooling trends in the environment (Fig. 50).

Groundfish

(See following section on lower Bay).

Estuarine fisheries

Because of legislation to protect salmon enacted before 1900, there are no commercial estuarine fisheries in the Annapolis River although the fish populations there are large enough to support such activity (Melvin et al. in press). Shad are the sole species exploited commercially in the Annapolis River but, since the fishery is restricted to the use of scoop nets two nights a week, catches seldom exceed 10,000 kg/yr (Melvin et al. in press).

The major estuarine fishery in the region is in the Saint John River. The major species exploited in present day order of landed value are eels, gaspereau, salmon, shad and sturgeon. The striped bass commercial fishery was closed in 1978 because of low population level. Annually, the Saint John produces about 60% of the New Brunswick catch of gaspereau, 20-30% of the eels, 25% of the shad, and 5% of the salmon. Virtually all the sturgeon landed in the Maritimes come from the Saint John.

The eel fishery has only been significant in size since 1969 (Fig. 51) partially in response to salmon fishermen seeking other species because of the salmon closure. Landings average about 50,000 kg/yr.

The gaspereau fishery has the largest landings of all species in the estuary, averaging 2000 MT/yr (Fig. 52). Landings were once concentrated in the harbour region (SD 49) but since 1965 the major landings have been from a trap net fishery in the lake-like portions of the estuary (Dadswell, in press).

Atlantic salmon were formerly the most valuable fishery for the estuary but implementation of the commercial salmon fishing ban in 1972 and a quota when the season reopened in 1981 has restricted landings (Fig. 41). Salmon catches are strongly influenced by water levels on both a short- and long-term basis (Scarnecchia 1981, Gee and Radford 1982) and this fact is

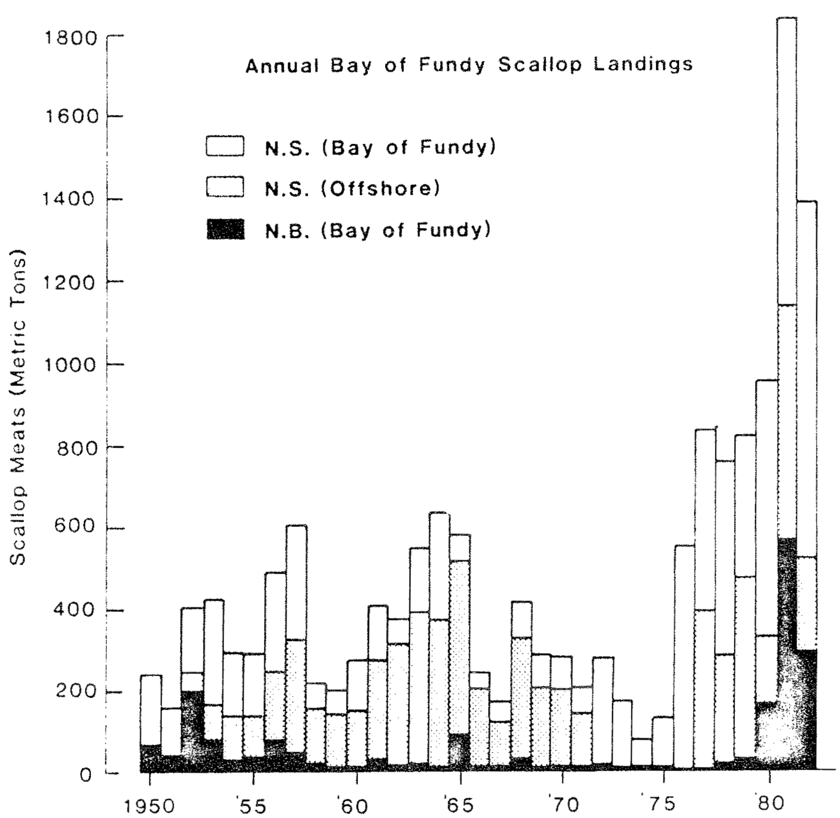


Fig. 49. Scallop landings in the Bay of Fundy. Nova Scotia offshore signify landings from the middle of the Bay of Fundy outside a 6-mi inshore/offshore dividing line.

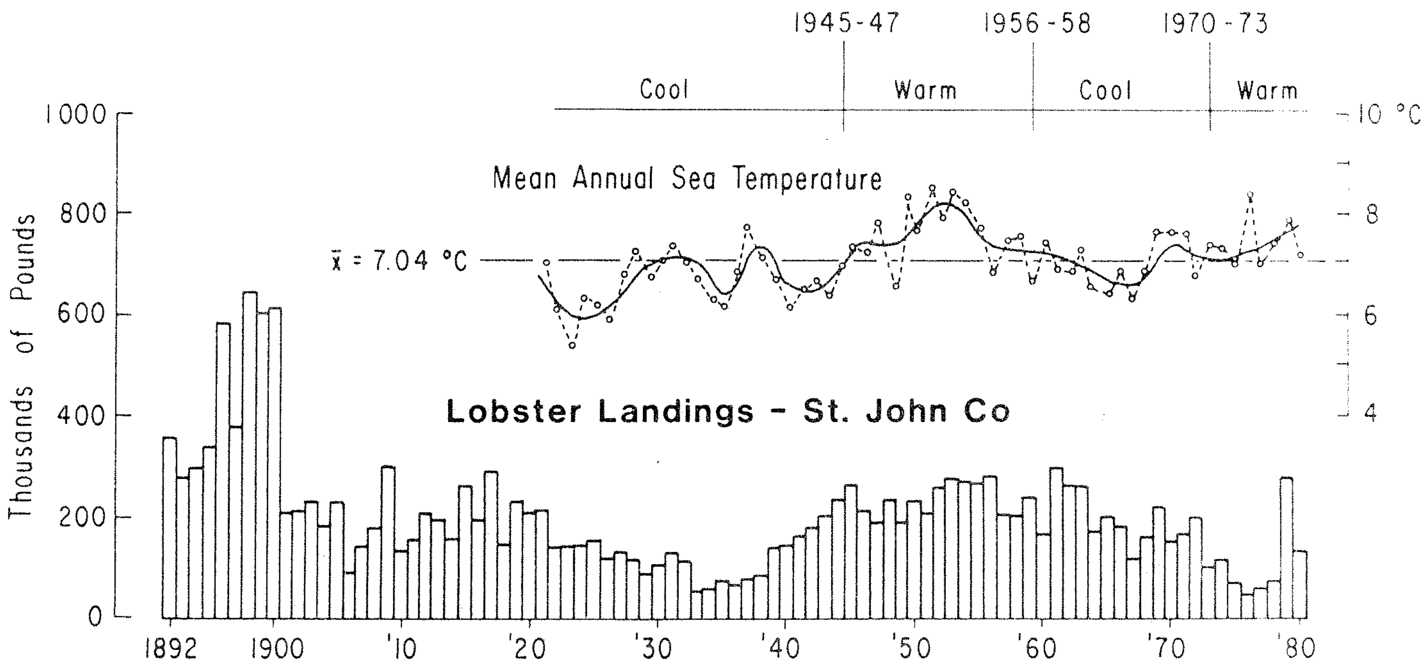


Fig. 50. Lobster landings for Saint John County, New Brunswick between 1892 and 1981 in relation to the mean annual sea temperature (Prince 5, Head Harbour). During this period effort in terms of traps was quite stable.

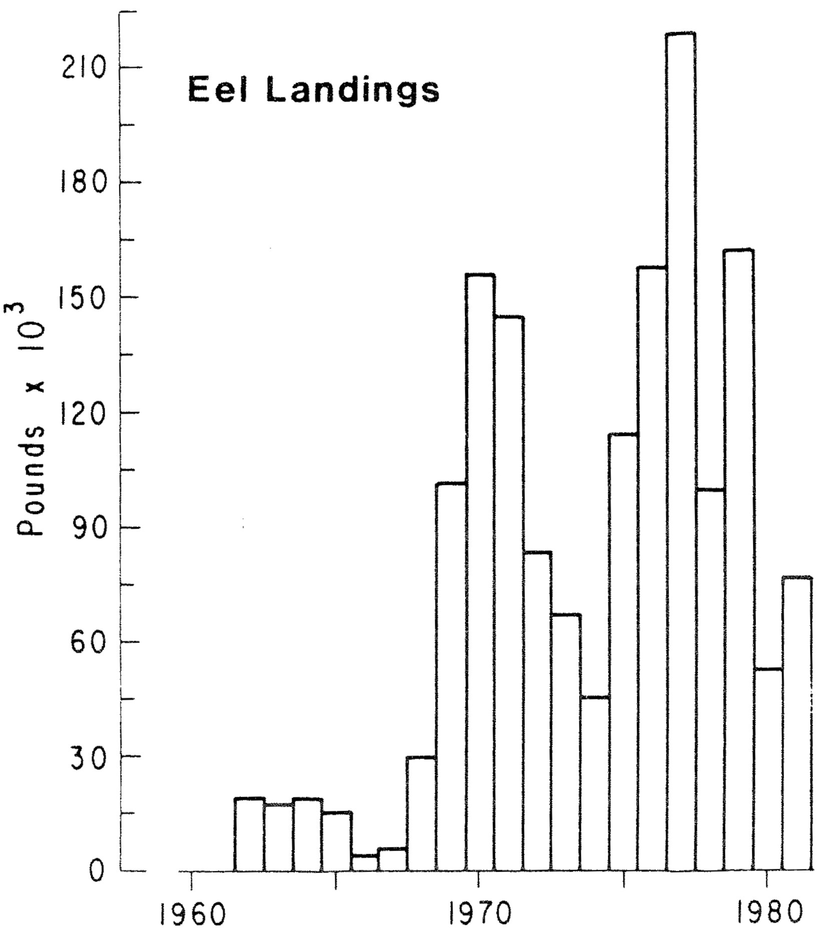


Fig. 51. Eel landings for the Saint John estuary 1962-1982.

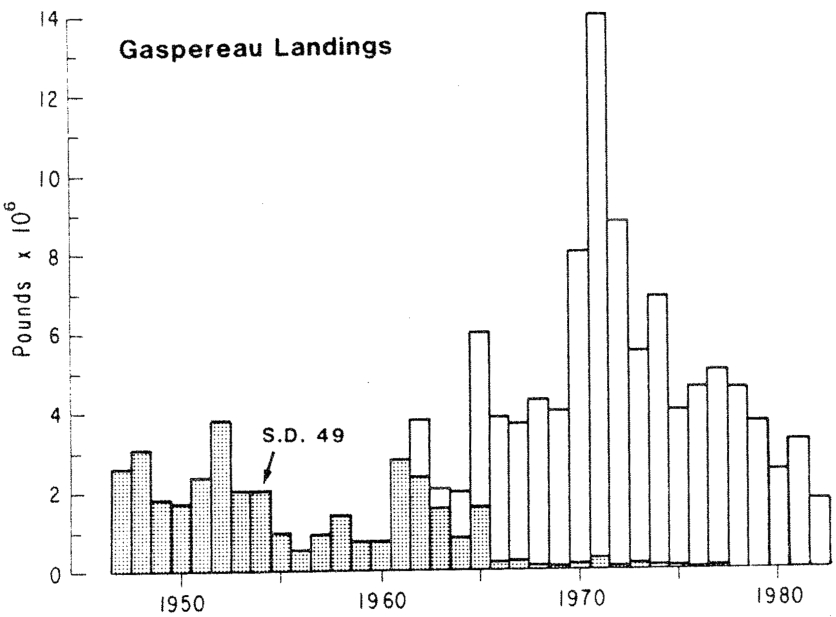


Fig. 52. Gaspereau landings in the Saint John Harbour and estuary 1947-1982.

demonstrated in the Saint John catches. Water levels in a given summer can led to good catches by either commercial or sports fishermen and lead to preceived levels of salmon abundance regardless of actual abundance. High discharge during August reduces the commercial catch because salmon move upstream rapidly but increases sport catches because salmon take well when the water is high (Fig. 53). Low summer flows have the reverse effect and when coincident with a peak in the abundance cycle (i.e. 1966) result in large commercial catches (Fig. 53). Actual size of an Atlantic salmon run, on the other hand, appears to be most closely related to mean annual discharge during the period of the 0+ year-class. Years with high average discharge (1958-1963) lead to high salmon abundance and landings after a lag period of 6 yr (1964-68) (Fig. 54).

Shad landings on the Saint John have gone through period of high and low abundance in roughly 30-yr cycles (Fig. 55). The last period of abundance was 1930-1960 and landings peaked at 450 MT.

Except for a brief period during the late 1880's when the virgin stock was first fished (Rodgers 1936) sturgeon landings on the Saint John have seldom exceeded 10,000 kg/yr (Fig. 56). Recently effort has increased because of market demand for this product and landings are higher.

The commercial fishery for striped bass in the Saint John River was closed in 1978 as a result of low population levels. Previous to 1975 landings fluctucated between 5,000 - 10,000 kg/yr with occasional peaks of 50,000 kg (Fig. 57). The actual origin and proportion of populationscontributing to this fishery is unknown.

The Lower Bay of Fundy

Herring, groundfish and lobster are the important fisheries in the lower Bay of Fundy, but many species of plants and animals are harvested in the diverse fisheries of this region (Scarratt 1977, Campbell 1979). Since these fisheries have been amply reviewed as recently as 1979 (Scarratt 1979) we will only attempt to highlight some of the more recent developments.

Herring

Several developments since the early 1970's have led to the increased value and improved management of the recognized, commercially exploitable herring stocks in the Gulf of Maine and Bay of Fundy. The responsibility for allocating national shares of the total allowable catch (TAC) for each stock was assumed by ICNAF in 1972 but 4X herring became a Canadian domestic fishery on extension of jurisdiction in 1977 (Iles 1979). Canada, having coastal state preference (4X subdivision) and the facilities to catch and process the major part of the TAC, was able to capitalize on the collapse of the northeast Atlantic herring fishery and supply Europe with a marketable food product hereby increasing both the landed and processed value of the fish (Iles 1979). In 1976 a program was initiated to reduce the proportion of adult fish supplying the meal industry (82% in

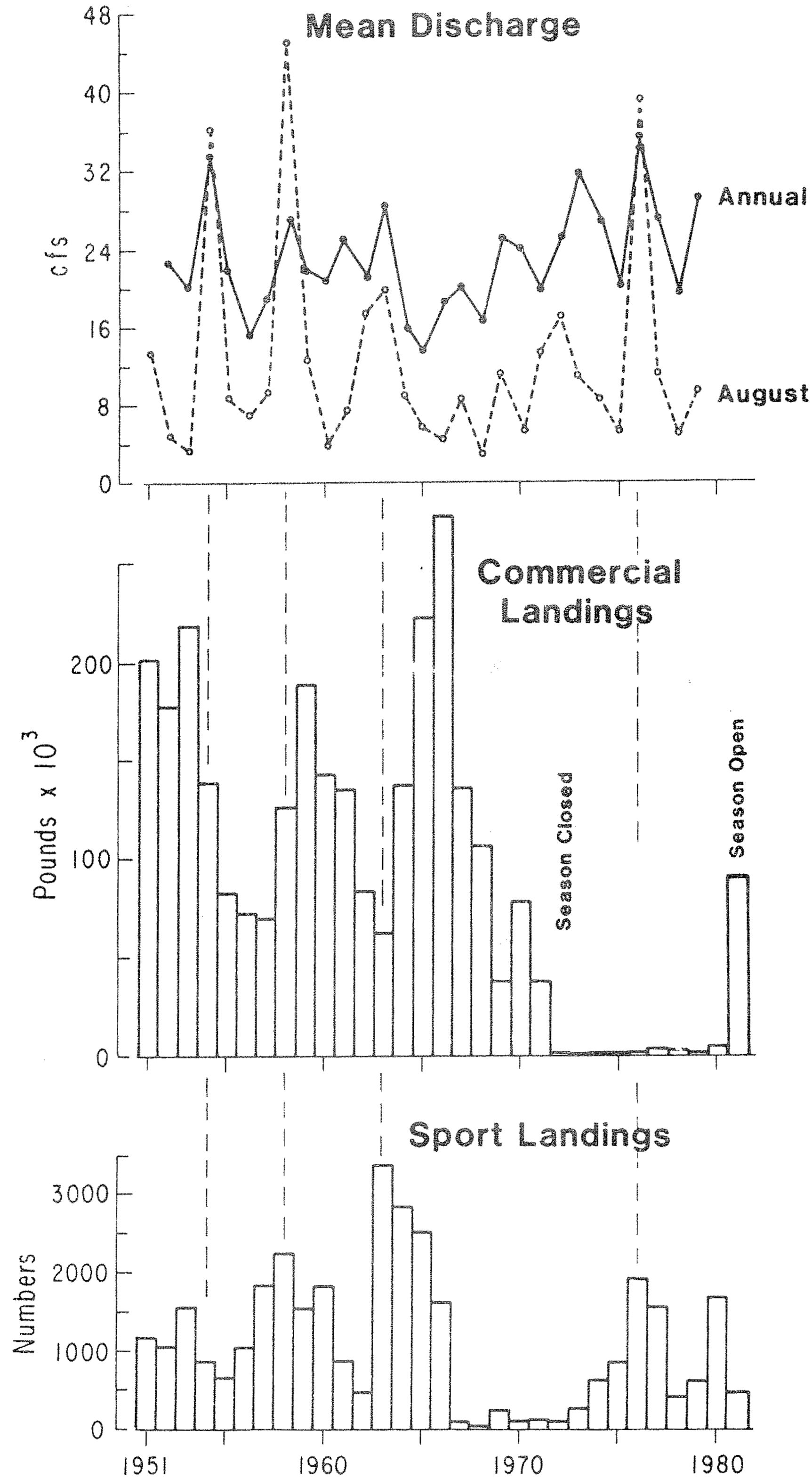


Fig. 53. Mean annual and mean August discharge of the Saint John River and commercial and sports Atlantic salmon catches in the same year between 1951 and 1981.

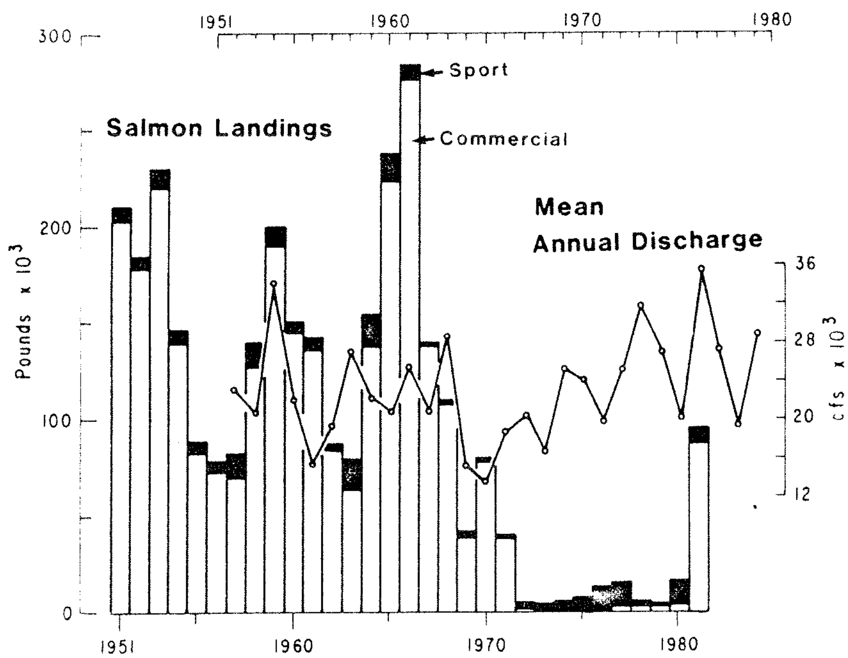


Fig. 54. Total Atlantic salmon landings for the Saint John River in relation to mean annual discharge lagged 6 yr (e.g. high flows 1958-1963 result in high landings 1956-1968).

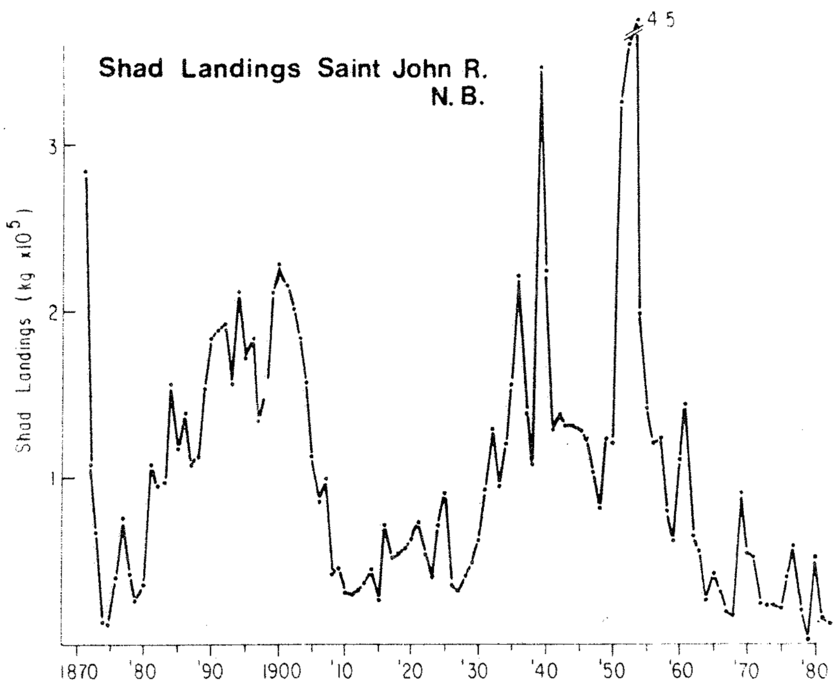


Fig. 55. Landings of American shad for the Saint John River and harbour since 1870.

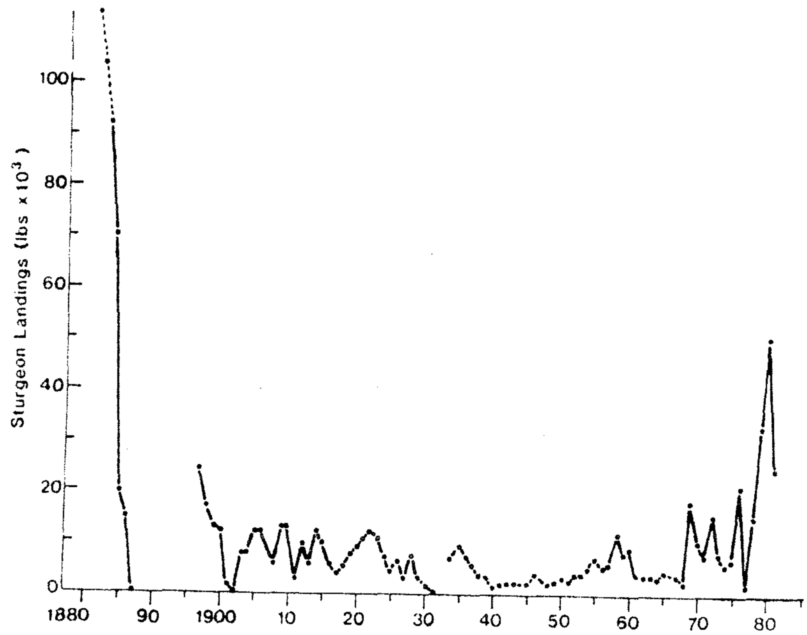


Fig. 56. Sturgeon landings for the Saint John estuary since 1880. Fluctuation in catches since 1930 is largely a representation of fishing effort rather than stock size.

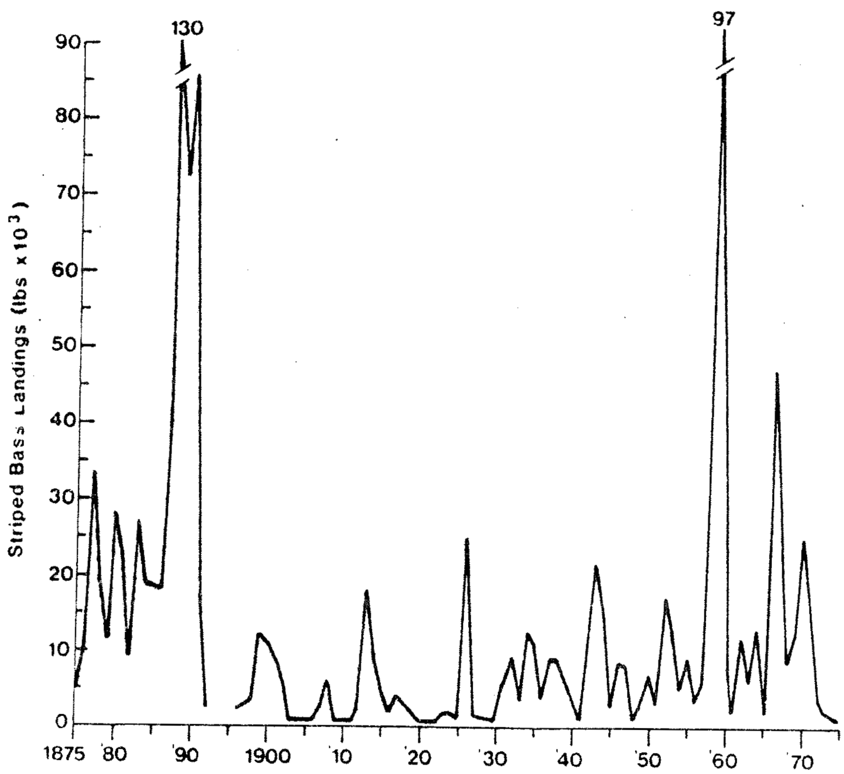


Fig. 57. Striped bass commercial landings for the Saint John estuary 1875-1975.

1975) and create a more valuable food fishery. Subsequently, price rose from $50-$90/MT to between $150-$250/MT (Table 22) (Iles 1979). At the same time a new system of reporting and sampling catches on a catch location basis replaced that of reporting by port of landing, which gave a potential for substantially improved both statistical and biological resolution of the stocks but misreporting of catch by some fleet sectors continues to present serious stock assessment problems (Iles 1979). In the last few years over-the-side sales to foreign trawler-processors has helped maintain a high price for landed herring.

Groundfish

Landings of groundfish from the outer Bay of Fundy peaked during the mid-1960's coincident with succeeding years of good recruitment for haddock (Clark et al. 1982) but then declined to low levels during the early 1970's (Table 19) (Hare 1977). Quota regulation and incidental catch limitations have allowed the haddock stock to increase and landings have improved (Table 19). The fishery is diverse and fish are taken with many different types of gear including long-line, gillnets and trawls.

Lobsters

Good summaries of the fishery and landings are found in Campbell (1979) and Campbell and Duggan (1980). The lobster is the most valuable invertebrate fishery in the outer Bay of Fundy region (Campbell 1979). Landings in recent years have remained stable at about 500 MT.

Shrimp

In the late 1960's and early 1970's a shrimp (*Pandalus borealis*) fishery existed in the lower Bay of Fundy. Catches reached a peak of over 800 MT in 1970 but steadily decreased in subsequent years and ceased altogether in 1975 as harvestable year-classes failed to materialize (Toews 1980).

Soft-shelled clams

Soft-shell clams support one of the larger fisheries in the Charlotte Co. region. Average landings between 1976-1978 were 343 MT and exceeded all other invertebrate landings. This fishery is just emerging from a long period of restricted harfesting because of high paralytic shellfish toxin levels (White 1982b) and landings should be expected to increase in the next few years.

Marine plants

Three marine plants dulse (*Rhodymenia palmata*), Irish moss (*Chondrus crispus*) and rockweek (*Ascophyllum nodosum*) are commercially harvested in the lower Bay of Fundy coastal zone. Dulse harveting occurs predominantly around Grand Manan and the adjacent mainland. The harvesting of Irish moss occurs in southwest Nova Scotia. Sharp and Roddick (1982) examined catch and effort trends for the period 1978-1980. Because of the

TABLE 22. 4X herring stock catches in Bay of Fundy

Year	Total 4X stock (MT)	Bay of Fundy 4X stock (MT)	Bay of Fundy total catch (MT)	Bay of Fundy catch value ($ x 1000)	Purse seine gillnet price/MT	Weir $ Price/MT
1972	153428	97024	135348	4910	24.07	60.00
1973	120093	74695	101962	3626	24.22[1]	60.00
1974	139170	96162	120514	4151	24.22[1]	70.00
1975	142745	90007	126357	5209	24.38	80.00
1976	114006	73477	104304	7435	61.34	90.00
1977	110798	95781	117385	11927	104.84	110.00
1978	89363	73595	112438	20025	187.50[3]	125.00[2]
1979	59021	44948	82776	14335	203.69[3]	146.38[3]
1980	109574	100616	114141	20349	185.41[3]	152.78[3]
1981	87706	69118	88198	10528	105.16[3]	170.86[3]
1982	84733	72458	98421	12300	113.98[3]	155.64[3]

[1] Average 1972 and 1975 prices

[2] Fixed negotiated purse seine and weir fish prices

[3] Average prices as provided by Statistics Branch, Halifax, N.S.

TABLE 22. CONT'D.

4X Stock - 4X herring catches, both juvenile and adult, for all gear types - New Brunswick weirs excluded. This includes catches of the 4X stock made outside the Bay of Fundy; figures from 1978 herring assessment.

Bay of Fundy 4X stock - Directly comparable to 4X stock figure. Landings for all gears (except N.B. weirs and shutoffs) within the Bay of Fundy.

Bay of Fundy total - total figures for <u>all</u> gear types for herring landings in the Bay of Fundy. (including N.B. weir and shutoffs).

<u>Origin of Bay of Fundy Data</u>

1972-76	Dominion Bureau of Statistics catch effort tapes from Halifax
1977-78	Bay of Fundy Project data base, St. Andrews - 1977 Bay of Fundy 4X stock and Bay of Fundy total catch are from Bay of Fundy data base except for 1977 gillnet data which is from DDS data.
1979-82	1982 Herring assessment, Iles and Simon.

relatively static and low price of moss, effort by fishermen was diverted to more lucrative fisheries. Rockweek is currently harvested commercially only in southwestern Nova Scotia. Sharp (1981) evaluated the methods of harvest and its effects on standing crops. Marine plants in many parts of the Bay of Fundy region are an unexploited resource as evidenced by the 4.55 million kg standing stock of rockweek on the New Brunswick side of the Bay of Fundy (Legere 1973) which is not harvested. Landing statistics for these fisheries are summarized in Campbell (1979).

ACKNOWLEDGMENTS

We wish to thank all those who helped assemble the data used in the report and those who permitted us to present their unpublished findings. Dr. C. Medcof kindly supplied us with the unpublished field notes of Dr. A.H. Leim which were so helpful in understanding the fish and fisheries of the upper Bay.

B. Garnett typed the manuscript and Frank Cunningham produced the graphics.

REFERENCES

Aiken, D.E. 1980. Molting and growth. In: J.S. Cobb and B.F. Phillips eds. The biology and management of lobsters. Academic Press, pp. 91-163.

Aiken, D.E., and S.L. Waddy. 1978. Space, density and growth of the lobster (Homarus americanus). Proc. Ann. Meeting World Mariculture Soc. 9: 461-467.

Alexander, D.R. 1975. Sport fisheries potential on twenty lakes in the headwaters of the Shubenacadie River system, Nova Scotia. Tech. Rep. Ser. Res. Develop. Br. MAR/T-75-10, 16 p.

Anon. 1977. Reassessment of Fundy Tidal Power. Reports of the Bay of Fundy Tidal Power Review Board and Management Committee, Ottawa, 516 p.

Anon. 1980a. Annapolis tidal power project. Fish passage investigations. Martec Ltd., Halifax, N. S., 130 p.

Anon. 1980b. Studies of the early life history of the shortnose sturgeon (Acipenser brevirostrum). Washburn & Gillis Assoc. Ltd., Fredericton, N. B., 119 p.

Appy, R.G. and M.J. Dadswell. 1978. Parsites of Acipenser brevirostrum Mitchill (Osteichthyes: Acipenseridae) in the Saint John River Estuary, N. B. with a description of Caballeronema pseudoargumentosus sp. n. (Nematoda: Spirurida). Can. J. Zool. 56: 1382-1391.

________1981. Marine and estuarine piscicolid leeches (Hirudinea) of the Bay of Fundy and adjacent waters with a key to species. Can. J. Zool. 59: 183-192.

________1983. Transmission and development of Capillospirura pseudoargumentosa (Appy and Dadswell, 1978) (Nematoda: Cystidicolidae). Can. J. Zool. 61: 848-859.

Appy, R.G. and M.D.B. Burt. 1982. Metazoan parasites of cod, Gadus morhua L., in Canadian Atlantic waters. Can. J. Zool. 60: 1573-1579.

Appy, T.D., L.E. Linkletter, and M.J. Dadswell. 1980. A guide to the marine flora and fauna of the Bay of Fundy (Annelida: Polychaeta). Fish. Mar. Serv. Tech. Rep. 920, v + 124 p.

Arnold, P.W. 1972. Predation on harbour porpoise, Phocoena phocoena, by a white shark, Carcharodon carcharius. J. Fish. Res. Board Can. 29: 1213-1214.

Arnold, P.W. and D.E. Gaskin. 1972. Sight records of right whales (Eubalaena glacialis) and finback whales (Balaenoptera physalus) from the lower Bay of Fundy. J. Fish. Res. Board Can. 29: 1477-1478.

Bayne, P.M. 1930. The striped bass fishery of the Fundy area. Atl. Biol. Sta. Orig. MS 340, 4 p.

Bailey, J.K., R.L. Saunders, and M.I. Buzeta. 1980. Influence of parental smolt age and sea age on growth and smolting of hatchery-reared Atlantic salmon (Salmo salar). Can. J. Fish. Aquat. Sci. 37: 1379-1386.

Beacham, T.D. 1982a. Some aspects of growth, Canadian exploitation, and stock identification of Atlantic cod (Gadus morhua) on the Scotian Shelf and Georges Bank in the northwest Atlantic Ocean. Can. Tech. Rep. Fish. Aquat. Sci. 1069, 43 p.

________1982b. Some aspects of growth and Canadian exploitation of haddock (Melanogrammus aeglefinus) on Browns and Georges Bank's in the northwest Atlantic Ocean. Can. Tech. Rep. Fish. Aquat. Sci. 1066, 25 p.

________1982c. Growth of pollock (Pollachius virens) on the Scotian Shelf in the northwest Atlantic Ocean. Can. Tech. Rep. Fish. Aquat. Sci. 1069, 23 p.

________1982d. Some aspects of growth and exploitation of American plaice (Hippoglossoides platessoides) in the Canadian Maritimes area of the northwest Atlantic. Can. Tech. Rep. Fish. Aquat. Sci. 1080, 43 p.

Bigelow, H.B. and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. Bull. U.S. Fish. Wildl. Serv. 74, 577 p.

Bleakney, J.S. 1963. First record of the fish Pogonias cromis from Canadian waters. Copeia 1963: 173.

Bleakney, J.S. and D.E. McAllister. 1973. Fishes stranded during extreme low tides in Minas Basin, Nova Scotia. Can. Field-Nat. 83: 371-376.

Bleakney, J.S. and K. Bailey-Meyer. 1979. Observations on salt-marsh pools, Minas Basin, Nova Scotia, 1965-1977. Proc. N.S. Inst. Sci. 29: 353-371.

Bonnichsen, R. and D. Sanger. 1977. Integrating faunal analysis. Can. J. Arch. 1: 109-133.

Bousfield, E.L. and A.H. Leim. 1958. The fauna of Minas Basin and Minas Channel. Nat. Mus. Can. Contr. Zool. 166: 1-30.

Bradford, R.G. 1981. Morphometric and meristic analysis of fall run shad from the Saint John Harbour area for population origin determination. Aquatic. Industries Ltd. Rep. 2, 18 p.

________ 1982. The spawning and larval retention areas of the Atlantic herring (Clupea harengus L.) in the Bay of Fundy during 1977-78. Hons. Thesis Univ. of New Brunswick, Saint John.

Braune, B.M. and D.E. Gaskin. 1982a. Feeding methods and diving rates of migrating larids off Deer Island, New Brunswick. Can. J. Zool. 60: 2190-2197.

________ 1983b. Feeding ecology of nonbreeding populations of larids off Deer Island, New Brunswick. Auk 99: 67-76.

Brown, J.F.S. 1983. The ecology of Fundulus heteroclitus at Kingsport salt-marsh, Minas Basin, Nova Scotia. M.Sc. Thesis, Acadia Univ., 100 p.

Brown, R.G.B., S.P. Barker and D.E. Gaskin. 1979. Daytime surface swarming by Meganyctiphanes norvegica (Sars) (Crustacea, Euphausiacea) off Brier Island, Bay of Fundy. Can. J. Zool. 57: 2285-2291.

Caddy, J.F. 1979. Long-term trends and evidence for production cycles in the Bay of Fundy scallop fishery. Rapp. P-v. Reun. Cons. Int. Explor. mer. 175: 97-108.

Caddy, J.F., and R.A. Chandler. 1976. Historical statistics of landings of inshore species in the Martime provinces 1947-73. Fish. Mar. Serv. Tech. Rep. 639, 240 p.

Campbell, A. 1979. Invertebrates and marine plants commercial landings in the Passamaquoddy region and Bay of Fundy, 1973-78. In D. J. Scarratt ed. Evaluation of recent data relative to potential oil spills in the Passamaquoddy area. Fish. Marine Serv. Tech. Rep. 901, pp. 19-26.

________ 1982. Movements of tagged lobsters released off Port Maitland, Nova Scotia, 1944-80. Can. Tech. Rep. Fish. Aquat. Sci. 1136, 41 p.

________ 1984. Aspects of lobster biology and fishery in the upper reaches of the Bay of Fundy. In this report.

Campbell, A. and D.R. Duggan. 1980. Review of the Grand Manan lobster fishery with an analysis of recent catch and effort trends. Can. Tech. Rep. Fish. Aquat. Sci. 997, 20 p.

Carey, T.G. 1970. Selective breeding program at Mactaquac fish culture station, Saint John River, New Brunswick. Proc. Can. Soc. Wildl. Fish. Biol. Annu. Meeting, Fredericton, 123-134 p.

Carscadden, J.E. and W.C. Leggett. 1975. Life history variations in populations of American shad, Alosa sapidissima (Wilson), spawning in tributaries of the Saint John River, New Brunswick. J. Fish. Biol. 7: 595-609.

Case, G.P. 1968. Inland shark occurrence. Underwater Nat. 5: 20-21.

Chapoton, R. and J.E. Sykes. 1961. Atlantic coast migration of large striped bass as evidenced by fisheries and tagging. Trans. Amer. Fish. Soc. 90: 13-20.

Clark, S.H., W.J. Overholtz, and R.C. Hennemuth. 1982. Review and assessment of the Georges Bank and Gulf of Maine haddock fishery. J. Northw. Atl. Fish. Sci. 3: 1-27.

Cox, P. 1933. The life history of Microgadus tomcod (Walbaum). Atl. Biol. Sta. Orig. MS 426, 14 p.

Daborn, G.R. 1984. Zooplankton studies in the upper Bay of Fundy since 1976. In this report.

Daborn, G.R. and J.S. Bleakney. 1977. Biological considerations. In G.R. Daborn, ed., Fundy tidal power and the environment. Acadia Univ. Institute Publ. No. 28, pp. 296-298.

Daborn, G.R., J.T. O'Neil, and R.R.G. Williams. 1979. Limnology of the Annapolis River and estuary: II Fish distributions in the estuary, 1976 and 1977. Proc. N. S. Inst. Sci. 29: 173-183.

Daborn, G.R. and R.S. Gregory. 1983. Occurrence, distribution, and feeding habits of juvenile lumpfish, Cyclopterus lumpus L. in the Bay of Fundy. Can. J. Zool. 61: 797-801.

Dadswell, M.J. 1976. Notes on the biology and research potential of striped bass in the Saint John estuary, 20 p. In: Baseline survey and living resource potential study of the Saint John River estuary. Fish and Fisheries. Huntsman Mar. Lab. Vol. III.

________1979. Biology and population characteristics of the shortnose sturgeon, Acipenser brevirostrum LeSuer 1818 (Osteichthyes: Acipenseridae) in the Saint John River estuary, New Brunswick, Canada. Can. J. Zool. 57: 2186-2210.

________1983. Commercial fisheries of the Saint John Harbour, New Brunswick, Canada, 1875-1983: Estuarine fishes. Environ. Protec. Serv. Tech. Rep. (in press).

Dadswell, M.J., G.D. Melvin, and P.J. Williams. 1983. Effect of turbidity on the temporal and spatial utilization of the inner Bay of Fundy by American shad (Alosa sapadissima) (Pisces: Clupeidae) and its relationship to local fisheries. Can. J. Fish. Aquat. Sci. 40 (Supp. 1): 322-330.

Dadswell, M.J., G.D. Melvin, P.J. Williams, and G.S. Brown. 1984. Possible impact of large scale tidal power developments in the upper Bay of Fundy on certain fish stocks of the northwest Atlantic. In this report.

Das, N. 1968. Spawning, distribution, survival, and growth of larval herring (Clupea harengus L.) in relation to hydrographic conditions in the Bay of Fundy. Fish. Res. Board Can. Tech. Rep. 88, 129 p.

Dickie, L.M. 1955. Fluctuations in abundance of the giant scallop, Placopecten magellanicus (Gmelin) in the Digby area of the Bay of Fundy. J. Fish. Res. Board Can. 12: 797-857.

Dominey, C.L. 1970. Great Village River aboiteau - progress report, 1969. Can. Dept. Fish. Forest. Res. Devel. Board, Fish Serv. MS Rep. 70-4, 9 p.

________1973. Recent changes in Atlantic salmon (Salmo salar) runs in the light of environmental changes in the Saint John River, New Brunswick, Canada. Biol. Conserv. 5: 105-113.

Douma, A., and G.D. Stewart. 1981. Annapolis STRAFLO turbine will demonstrate Bay of Fundy tidal power concept. Hydro Power 1: 1-8.

Durbin, E.G. and A.G. Durbin. 1981. Assimilation efficiency and nitrogen excretion of a filter feeding planktivore, the Atlantic menhaden, Brevoortia tyrannus (Pisces: Clupeidae). Fish. Bull. 79: 601-616.

Elson, P.F. 1967. Effects on wild young salmon of spraying DDT over New Brunswick forests. J. Fish. Res. Board Can. 24: 731-767.

Frame, M. 1982. Condition of some winter flounder Pseudopleuronectes americanus (Walbaum) in the Bay of Fundy. Hons. B.Sc. Thesis Dept. of Biol. Acadia Univ., Wolfville, N.S.

Fowler, H.W. 1915. Fishes from eastern Canada. Proc. Acad. Nat. Sci. Phila. 67: 515-519.

Gabriel, W.L., C.W. Leggett, J.E. Carscadden, and D.B. Glebe. 1976. Origin and characteristics of "fall-run" American shad (Alosa sapidissima) from the Saint John River, New Brunswick. J. Fish. Res. Board Can. 33: 1764-1770.

Gaskin, D.E., G.J.D. Smith, and A.P. Watson. 1975. Preliminary study of movements of harbour porpoises (Phocoena phocoena) in the Bay of Fundy, using radio telemetric methods. Can. J. Zool. 53: 1466-1471.

Gaskin, D.E. and B.A. Blair. 1977. Age determination of harbour porpoise, Phocoena phocoena (L.), in the western North Atlantic. Can. J. Zool. 55: 18-30.

Gaskin, D.G. and G.J.D. Smith. 1979. Observations on marine mammals, birds, and environmental conditions in the Head Harbour region of the Bay of Fundy. In: D.J. Scarratt ed. Evaluation of recent data relative to potential oil spills in the Passamaquoddy area. Fish. Mar. Serv. Tech. Rep. 901, pp. 69-86.

Gee, A.S. and P.J. Radford. 1982. The regulation of stock characteristics in a simulated Atlantic salmon population. Fish. Res. 1: 105-116.

Gilmurray, M.C. and G.R. Daborn. 1981. Feeding relations of the Atlantic silverside Menidia menidia in the Minas Basin, Bay of Fundy. Mar. Ecol. Prog. Ser. 6: 231-235.

Glebe, B.D., W. Eddy, and R.L. Saunders. 1980. The influence of parental age at maturity and rearing practice on precocious maturation of hatchery-reared Atlantic salmon parr. Int. Counc. Explor. Mer., C. M. 1980/F: 8.

Gorham, S.W. 1965. Notes on fishes from the Browns Flat area, Kings County, New Brunswick. Can. Field-Nat. 79: 137-142.

Grabe, S.A. 1978. Food and feeding habits of juvenile Atlantic tomcod, Microgadus tomcod, from Haverstraw Bay, Hudson River. Fish. Bull. 76: 89-94.

Gregory, R.S. and G.R. Daborn. 1983. Biological notes on adult lumpfish, Cyclopterus lumpus L., from the Bay of Fundy. Proc. N.S. Inst. Sci. 32: 321-326.

Hare, G.M. 1977. Atlas of the major Atlantic coast fish and invertebrate resources adjacent to the Canada - United States boundary areas. Fish. Mar. Serv. Tech. Rep. 681, 67 p.

Hicklin, P.W., L.E. Linkletter, and D.L. Peer. 1980. Distribution and abundance of Corophium volutator (Pallas), Macoma balthica (L) and Heteromastus filiformis (Clarepede) in the intertidal zone of Cumberland Basin and Shepody Bay, Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 965, 56 p.

Hicklin, P.W. and P.C. Smith. 1984. Studies of birds in the Bay of Fundy: a review. In this report.

Huntsman, A.G. 1922. The fishes of the Bay of Fundy. Contrib. Can. Biol. for 1921: 51-72.

________1952. The production of life in the Bay of Fundy. Trans. Roy. Soc. Can. 46, ser. 3, Sec. 5: 15-38.

________1953. Movements and decline of large Quoddy herring. J. Fish. Res. Board Can. 10: 2-47.

________1958. Shubenacadie salmon. J. Fish. Res. Board Can. 15: 1213-1218.

Hurley, P.C.F. 1980. Species distribution and aspects of the biology of Chaetognatha in the Bay of Fundy. M.Sc. thesis, Univ. of Guelph.

Iles, T.D. 1972. The seasonal and area distribution of herring spawning off the southwest Nova Scotia coast as indicated by logbook records. ICNAF Res. Doc. 72/10, Ser. No. 2693.

________1975. The movement of sea bed drifters and surface drift bottles from the spawning area of the "Nova Scotia" herring stock and the herring larval transport - retention hypothesis. Int. Comm. Explor. Sea, Hydrography Committee, C: 37.

Iles, T.D. 1979. The ecology of the herring fisheries of the Bay of Fundy. In D.J. Scarratt, ed., Evaluation of recent data relative to potential oil spills in the Passamaquoddy area. Fish. Mar. Serv. Tech. Rep. 901, pp. 27-52.

Iles, T.D. and M. Sinclair. 1982. Stocks of Atlantic herring, their discreteness and abundance variability. Science 215: 627-633.

Imrie, D.M.G. and G.R. Daborn. 1981. Food of some immature fish of Minas Basin, Bay of Fundy. Proc. N.S. Inst. Sci. 31: 149-153.

Jamieson, G.S., H. Stone, and G. Kerr. 1979. Bay of Fundy scallop stock assessment - 1979. CAFSAC Res. Doc. 80/79, 26 p.

Janssen, J. 1982. Comparison of searching behavior for zooplankton in an obligate planktivore, blueback herring (Alosa aestivalis) and a facultative planktivore, bluegill (Lepomis machrochirus). Can. J. Fish. Aquat. Sci. 39: 1649-1654.

Jeffers, A.M. 1932. Bay of Fundy survey - The shad fishery. Original Manu. Biol. Sta. St. Andrews 354, 14 p.

Jessop, B.M. 1975. A review of the American shad (Alosa sapidissima) stocks of the Saint John River, New Brunswick, with particular reference to the adverse effects of hydroelectric developments. Tech. Rep. Ser. Res. Develop. Branch MAR/T-75-6, 23 p.

________ 1976a. Distribution and timing of tag recoveries from native and non-native Atlantic salmon, (Salmo salar) released into Big Salmon River, New Brunswick. J. Fish. Res. Board Can. 33: 829-833.

________ 1976b. Physical and biological survey of the Annapolis River, 1975. Dept. of Envir. Fish. Mar. Serv. Data Red. Serv. MAR/D-76-8, 29 p.

Jessop, B.M. 1980. Creel survey and biological study of the striped bass fishery of the Annapolis River, 1978. Can. MS Rep. Fish. Aquat. Sci. 1566, 29 p.

________ 1983. Aspects of the life history of the Atlantic silverside (Menidia menidia) of the Annapolis River, Nova Scotia. Can. MS Rep. Fish. Aquat. Sci. 1694, 41 p.

Jessop, B.M. and W.G. Doubleday. 1976. Creel survey and biological study of the striped bass fishery of the Annapolis River, 1976. Fish. Mar. Serv. Dept. Environ. Tech. Rep. Ser. MAR/T-76-8, 47 p.

Jessop, B.M. and C. Vithayasai. 1979. Creel surveys and biological studies of the striped bass fisheries of the Shubenacadie, Gaspereau and Annapolis Rivers, 1976. MS Rep. Res. Br. Dept. Fish. Oceans 1532, 32 p.

Johnston, C.E. and R.L. Saunders. 1981. Parr-smolt transformation of yearling Atlantic salmon (Salmo salar) at several rearing temperatures. Can. J. Fish. Aquat. Sci. 38: 1189-1198.

Jovellanos, C.L. and D.E. Gaskin. 1983. Predicting the movements of juvenile Atlantic herring (Clupea harengus harengus) in the SW Bay of Fundy using computer simulation techniques. Can. J. Fish. Aquat. Sci. 40: 139-146.

Kerswill, C.J. 1960. Effects of proposed Passamaquoddy power project on anadromous fishes in Canadian waters. J. Fish. Res. Board Can. 17: 713-730.

Koeller, P. 1979. Distribution and movements of herring in the Bay of Fundy from juvenile surveys. CAFSAC Res. Doc. 79/32, 16 p.

Kohlenstein, L.C. 1981. On the proportion of the Chesapeake Bay stock of striped bass that migrates into the coastal fishery. Trans. Amer. Fish. Soc. 110: 168-179.

Kohler, A.C. 1979. Annual groundfish landings' and values' data for Charlotte County and Bay of Fundy ports for 1968-78, 53-56 p. In D. J. Scarratt ed. Evaluation of recent data relative to potential oil spills in the Passamaquoddy area. Fish. Mar. Serv. Tech. Rep. 901, pp. 53-56.

Kraus, S.D. and J.H. Prescott. 1983. The north Atlantic right whale (Eubalaena glacialis) in the Gulf of Maine. N. B. Naturalist, 12: 118.

Kulka, D.W., S. Corey, and T.D. Iles. 1982. Community structure and biomass of euphausiids in the Bay of Fundy. Can. J. Fish. Aquat. Sci. 39: 326-334.

Lacalli, T.C. 1980. A guide to the marine flora and fauna of the Bay of Fundy: Polychaete larvae from Passamaquoddy Bay. Can. Tech. Rep. Fish. Aquat. Sci. 940, 27 p.

Legére, J.E.H. 1973. Seaweed development. Rockweed Ascophyllum nodosum. Ann. Rep. N. B. Dept. Fish, pp. 22-23.

Leggett, W.C. 1976. The American shad (Alosa sapidissima), with special reference to its migration and population dynamics in the Connecticut River, 169-226 p. In D. Merriman and L. M. Thorpe, eds., The Connecticut River ecological study. The impact of a nuclear power plant. Amer. Fish. Soc. Mongr. 1.

Leim, A.H. 1924. The life history of the shad (Alosa sapidissima (Wilson)) with special reference to the factors limiting its abundance. Contr. Can. Biol. 2: 163-284.

Leim, A.H. 1931. The fauna of Minas Channel, Minas Basin and the Shubenacadie River. Atl. Biol. Sta. Orig. MS 278, 46 p.

Leim, A.H. and L.R. Day. 1959. Records of uncommon and unusual fishes from eastern Canadian waters, 1950-1958. J. Fish Res. Board Can. 16: 503-574.

Leim, A.H. and W.B. Scott. 1966. Fishes of the Atlantic Coast of Canada. Bull. Fish. Res. Board Can. 155, 485 p.

Leslie, H.A., A. Campbell and G.R. Daborn. 1981. Nectonema sp. (Nematomorpha: Nectonematoidea) a parasite of decapod Crustacea in the Bay of Fundy. Can. J. Zool. 59: 1193-1196.

Macdonald, J.S., K.G. Waiwood, and R.H. Green. 1982. Rates of digestion of different prey in Atlantic cod (Gadus morhua), ocean pout (Macrozoarces americanus), winter flounder (Pseudopleuronectes americanus, and American plaice (Hippoglossoides platessoides). Can. J. Fish. Aquat. Sci. 39: 651-659.

Macdonald, J.S., M.J. Dadswell, R.G., Appy, G.D. Melvin, and D.A. Methven. 1983. Fishes, fish assemblages and their seasonal movements in the lower Bay of Fundy and Passamaquoddy Bay, Canada. Fish. Bull. (in press).

MacDonald, J.R. and R.A. Hyatt. 1973. Supersaturation of air in water after passage through hydroelectric turbines at Mactaquac Dam, Saint John River, New Brunswick. J. Fish. Res. Board Can. 30: 1392-1394.

Markle, D.F. 1982. Identification of larval and juvenile Canadian Atlantic gadoids with comments on the systematics of gadid sub-families. Can. J. Zool. 60: 3420-3438.

Markle, D.F., D.A. Methven, and L.J. Coates-Markle. 1982. Aspects of spatial and temporal occurrences in the life history stages of the sibling hakes, Urophysis chuss (Walbaum 1772) and Urophysis tenuis (Mitchell 1815) (Pisces: Gadidae). Can. J. Zool. 60: 2057-2078.

Martin, N.R. 1960. Predicted effects of proposed tidal power structures on groundfish catches in Charlotte County, N.B. J. Fish. Res. Board Can. 17: 169-173.

McKenzie, R.A. and S.N. Tibbo. 1961. Herring movements in the Bay of Fundy and Gulf of Maine, 1957 and 1958. J. Fish. Res. Board Can. 18: 221-252.

McLaren, J.B., J.C. Cooper, T.B. Hoff, and V. Lander. 1981. Movements of Hudson River striped bass. Trans. Amer. Fish. Soc. 110: 158-167.

M'Gonigle, R.H. and M.W. Smith. 1936. Three rare fishes from Passamaquoddy Bay. Proc. Nova Scotian Inst. Sci. 19: 160.

Melvin, G.D. 1976. A collection of fishes from Passamaquoddy Bay, New Brunswick. Huntsman Marine Laboratory Report, 27 p.

________ 1978. Racial investigations of striped bass (Morone saxatilis (Walbaum, 1772)) (Pisces: Percichthyidae) for three Canadian Atlantic Rivers: Saint John, Shubenacadie, Tabusintac. M.Sc. thesis, Acadia Univ. 143 p.

________ 1982. Report on the Annapolis River American shad. - 1981. A precontruction study. Aquatic Industries Ltd., Rep. 3, 58 p.

Melvin, G.D. and M.J. Dadswell. 1984. Possible impact of tidal power development on the spawning population of American shad (Alosa sapidissima) in the Annapolis River, Nova Scotia. In this report.

Melvin, G.D. M.J. Dadswell, and J.D. Martin. 1983. Impact of lowhead hydroelectric tidal power development on fisheries. I. A pre-operation study of the spawning population of American shad, (Alosa sapidissima) (Pisces: Clupeidae), in the Annapolis River, Nova Scotia, Canada. Can. Tech. Rep. Fish. Aquat. Sci. (in press).

Messiah, S.N. 1975. Growth of otoliths of young herring in the Bay of Fundy. Trans. Am. Fish. Soc. 104: 770-772.

________ 1977. Population structure and biology of alewives (Alosa pseudoharengus) and the blueback herring (A. aestivalis) in the Saint John River, New Brunswick. Environ. Biol. Fish. 2: 195-210.

Metcalfe, C.D., M.J. Dadswell, G.F. Gillis, and M.L.H. Thomas. 1976. Physical, chemical and biological parameters of the Saint John River estuary, New Brunswick, Canada. Fish. Mar. Serv. Environ. Can. Tech. Rep. 686, 42 p.

Meth, F.F. 1972. Ecology of the Saint John River Basin V. Status of estuary fisheries. Res. Develop. Branch Fish. Serv. Prog. Rep 6, 100 p.

Miller, J.P., F.R. Griffiths, and P.A. Thurston-Rogers. 1982. The American shad (Alosa sapidissima) in the Delaware River basin. Delaware Basin Fish. Wildl. Coop. 132 p.

Morantz, D.L. 1978. A review of existing information on the fisheries of the Shubenacadie-Stewiacke River basin. Shubenacadie-Stewiacke River Basin Board. Tech. Rep. 1, 58 p.

Moss, F.T. 1971. Sportfishing tagging report. Sportfishing Mag. Jan. 1981: 30, 36, 38.

Neave, D.J. and B.S. Wright. 1968. Seasonal migrations of the harbour porpoise (Phocoena phocoena) and other Cetacea in the Bay of Fundy. J. Mammal. 49: 259-264.

Neves, R.J. 1981. Offshore distribution of alewife, Alosa pseudoharengus, and blueback herring, Alosa aestivalis, along the Atlantic coast. Fish. Bull. 79: 473-485.

Nichols, P.R. and R.V. Miller. 1967. Seasonal movements of striped bass Roccus saxatilis (Walbaum), tagged and released in the Potomac River, Maryland, 1959-61. Ches. Sci. 8: 102-124.

O'Donnel, A. 1963. New Brunswick stripers. Rod and Gun. April 1963: 12-13.

O'Neill, J.T. 1978. The distribution and life history of the white perch Morone americana (Gmelin) in the Annapolis River, Nova Scotia. B.Sc. Hons. Thesis, Acadia Univ.

Parker, W.R. and K.G. Doe. 1981. Studies on the reproduction of striped bass Morone saxatilis (Walbaum) from the Annapolis River, Nova Scotia. Surveillance Rep. Environ. Protec. Serv. Lab. Ser. Div. EPS 5-AR-81-6, 89 p.

Peacock, F.G. 1979. Processing plants in Charlotte County and elsewhere in the Bay of Fundy. In: D.J. Scarratt, ed., Evaluation of recent data relative to potential oil spills in the Passamaquoddy area. Fish. Mar. Serv. Tech. Rep. 901, pp. 57-60.

Penney, G.H. 1973. A preliminary investigation of the striped bass, Roccus saxatilis, fishery resource in the Annapolis River system, and the general distribution of striped bass in other areas in southwestern Nova Scotia. Can. Dept. Fish. Forest., Res. Develop. Br. MS Rep. 73-4, 35 p.

Perley, M.H. 1852. Reports on the sea and river fisheries of New Brunswick. Queens Printer, Fredericton, N.B., 294 p.

Peterson, R.H., P.G. Daye, and J.L. Metcalfe. 1980. The effects of low pH on hatching of Atlantic salmon eggs. Proc. Int. Conf. Ecol. Impact Acid Precip., Norway 1980, SNSF Project: 328.

Peterson, R.H., P.H. Johansen, and J.L. Metcalfe. 1980. Observations on early life stages of Atlantic tomcod, Microgadus tomcod. Fish. Bull. 78: 147-158.

Peterson, R.H. and D.J. Martin-Robichaud. 1983. Embryo movements of Atlantic salmon (Salmo salar) as influenced by pH, temperature, and state of development. Can. J. Fish. Aquat. Sci. 40: 777-782.

Peterson, R.H., J.L. Metcalfe, and S. Ray. 1983. Effects of cadmium on yolk utilization, growth, and survival of Atlantic salmon alevins and newly feeding fry. Arch. Environ. Contam. Toxicol. 12: 37-44.

Piers, H. 1934. Accidental occurrence of the man-eater or great white shark, Carcharodon carcharias in Nova Scotia waters. Proc. Trans. N.S. Inst. Sci. 10: 110-111.

Prince, E.E. 1912. The shad fishery of Canada and its restoration. Sea fisheries of eastern Canada. Comm. Conserv. Can. 120-136.

Prince, E.E. and A.H. MacKay. 1902. The paired fins of the mackerel shark. Notes by the Director. Sess. Pap. Atl. Biol. Sta. 22: 55-58.

Reeves, R., S. Kraus, and P. Turnbull. 1983. Right whales refuge. Nat. Hist. 92: 40-45.

Reid, C.R. 1980. Toxic dinoflagellates and tidal power generation in the Bay of Fundy, Canada. Mar. Poll. Bull. 11: 47-51.

Reid, P.R. 1982. Aspects of the winter ecology and behaviour of bald eagles (Haliaectus leucocephalus alaseanus Townsend) on the Shubenacadie River, Nova Scotia. M.Sc. Thesis, Acadia University, 131 p.

Riley, D.C. 1970. Anadromous fish passage problems associated with tidal structures. Can. Dept. Environ. Res. Develop. Br. Fish. Serv. MS Rep. 70-4, 13 p.

Risk, M.J. and H.D. Craig. 1976. Flat fish feeding traces in the Minas Basin. J. Sediment. Petrol. 46: 411-413.

Risk, M.J., R.K. Yeo, and H.D. Craig. 1977. Aspects of the marine ecology of the Minas Basin relevant to tidal power development, 164-179 p. In G. R. Daborn, ed., Fundy tidal power and the environment. Acadia Univ. Institute Publ. No. 28, pp. 164-179.

Roff, J.C. 1978. A guide to the marine flora and fauna of the Bay of Fundy: Copepods: Calanoids. Fish. Mar. Serv. Tech. Rep. 823: 29 p.

Rogers, H.M. 1936. The estuary of the Saint John River. Its physiography, ecology and fisheries. M.Sc. Thesis. Univ. of Toronto, 156 p.

Ruggles, C.D. 1980. A review of the downstream migration of Atlantic salmon. Can. Tech. Rep. Fish. Aquat. Sci. 952, 39 p.

Ruggles, C.P. and W.D. Watt. 1975. Ecological changes due to hydroelectric development on the Saint John River. J. Fish. Res. Board Can. 32: 161-170.

Salinas, I.M. 1981. Feeding strategies of Microgadus tomcod and Menidia menidia inhabiting a mudflat ecosystem in the Bay of Fundy. M.Sc. thesis, Dalhousie Univ., 86 p.

Saunders, R.L. 1969. Contributions of salmon from the northwest Miramichi River, New Brunswick, to various fisheries. J. Fish. Res. Board Can. 26: 269-278.

________ 1982. Sea ranching of Atlantic salmon in Canada. In: C. Eriksson, M. P. Ferranti, P. O. Larsson, eds., Sea ranching of Atlantic salmon. COST 46/4 Workshop Proc, pp. 5-22.

Saunders, R.L. and E.B. Henderson. 1978. Changes in gill ATPase activity and smolt status of Atlantic salmon (Salmo salar). J. Fish. Res. Board Can. 35: 1542-1546.

Saunders, R.L., E.B. Henderson, and B.D. Glebe. 1982. Precocious sexual maturation and smoltification in male Atlantic salmon (Salmo salar). Aquacuture 28: 211-229.

Saunders, R.L., E.B. Henderson, B.W. Glebe, and E.J. Loudenslager. 1983. Evidence of a major environmental component in determination of the grilse: large salmon ratio in Atlantic salmon (Salmo salar). Aquaculture 33: 107-118.

Scarnecchia, D.L. 1981. Effects of flow and upwelling on yield of wild coho salmon (Oncorhynchus kisutch) in Oregon. Can. J. Fish. Aquat. Sci. 38: 471-475.

Scarratt, D.J. 1977. Biological resources of the Bay of Fundy - Gulf of Maine system. In: G. R. Daborn (ed.) Fundy tidal power and the Environment. Acadia Univ. Inst. Publ. No. 28, pp. 131-147.

Scarratt, D.J. 1979. Evaluation of recent data relative to potential oil spills in the Passamaquoddy area. Fish. Mar. Serv. Tech. Rep. 901, 107 p.

Scattergood, L.W. 1979. Notes on the marine shark fishery. Copeia (1949) 1: 71-72.

Schwinghamer, P., F.C. Tan, and D.C. Gordon, Jr. 1983. Stable carbon isotope studies on the Pecks Cove mudflat ecosystem in the Cumberland Basin, Bay of Fundy. Can. J. Fish. Aquat. Sci. 40 (Suppl 1): 262-272.

Scott, J.S. 1976. Summer distribution of groundfish on the Scotian Shelf, 1970-74. Fish. Mar. Serv. Tech. Rep. 635.

Scully, B.W. 1983. The utilization of an intertidal salt-marsh-mudflat system as a nursery area by smooth flounder Liopsetta putnami (Gill). M.Sc. Thesis. Acadia Univ.

Semple, J. R. 1979. Anadromous fish stocks in the Petitcodiac River system and the Moncton Causeway: A status report. Can. Dept. Fish. Oceans, Fish. Mar. Serv. unpub. MS, 28 p.

________ 1984. Possible effects of tidal power development in the upper Bay of Fundy on anadromous fish passage. In this report.

Sharp, G.J. 1981. An assessment of Ascophyllum nodosum harvesting methods in southwestern Nova Scotia. Can. Tech. Rep. Fish. Aquat. Sci. 1012, 28 p.

Sharp, G.J. and D.L. Roddick. 1982. Catch and effort trends of the Irish moss (Chondrus crispus Stackhouse) fishery in southwestern Nova Scotia. Can. Tech. Rep. Fish. Aquat. Sci. 1118, 43 p.

Sinclair, M., A. Sinclair, and T.D. Iles. 1982. Growth and maturation of southwest Nova Scotia Atlantic herring (Clupea harengus harengus). Can. J. Fish. Aquat. Sci. 39: 288-295.

Squires, W.A., and S.W. Gorham. 1966. Redfish, Sebastes marinus var. mentella from the Kennebecasis River, N.B. Can. Field-Nat. 80: 253-254.

Squires, W.A., and S.W. Gorham. 1967. Silverside, Menidia menidia and northern pipefish, Syngnathus fuscus, in the Saint John River, N.B. Can. Field-Nat. 81: 280.

Stillwater, C. and J.G. Casey. 1968. Migratory habits of sharks. Prog. Sport Fish. Res. 1967: 184-185.

Stobo, W.T. 1976. Movements of herring tagged in the Bay of Fundy-update. Intern. Comm. Northw. Atl. Fish. Res. Doc. 76/48, 16 p.

Sutterlin, A.M., E.B. Henderson, S.P. Merrill, R.L. Saunders, and A.A. MacKay. 1981. Salmonid rearing trials at Deer Island, N.B. with some projections on economic viability. Can. Tech. Rep. Fish. Aquat. Sci. 1011, 28 p.

Swetnam, D. and M. Bernard. 1981. Atlantic salmon commercial catch statistics, Maritimes Region. Fish. and Oceans, Halifax, N.S.

Taubert, B.D. and M.J. Dadswell. 1980. Description of some larval short-nose sturgeon (Acipenser brevirostrum) from the Holyoke Pool, Connecticut River, Massachusetts, USA, and the Saint John River, New Brunswick, Canada. Can. J. Zool. 58: 1125-1128.

Templeman, W. 1963. Distribution of sharks in the Canadian Atlantic (with special reference to Newfoundland waters). Bull. Fish. Res. Board Can. 140, 77 p.

Toews, P.R. 1980. The Canadian Atlantic shrimp fishery and prospects from development. Can. Ind. Rep. Fish. Aquat. Sci. 117, 39 p.

Trites, R.W. 1960. An oceanographic and biological reconnaissance of Kennebecasis Bay and the Saint John River estuary. J. Fish. Res. Board Can. 17: 377-408.

Tyler, A.V. 1971. Periodic and resident components in communities of Atlantic fishes. J. Fish. Res. Board Can. 28: 935-946.

Tyler, A.V. 1971. Food resource division among northern marine demersal fishes. J. Fish. Res. Board Can. 29: 997-1003.

Uhazy, L.S. 1980. To determine the feasibility of using parasites as biological tags for determining the utilization of upper Bay of Fundy by commercially important fishes. Fundy Isles Marine Enterprises Ltd. DSS Contract 075C: FP706-8-0252, 53 p.

Van Eeckhaute, L.A. and R.G. Appy. 1979. Parasites as biological tags for determining the utilization of the upper Bay of Fundy by commercially important fishes. Fundy Isles Mar. Ltd. Prog. Rep. 2, 33 p.

VanWinkle, W., B.L. Kirk, and B.W. Rust. 1979. Periodicities in Atlantic coast striped bass (Morone saxatilis) commercial fisheries data. J. Fish. Res. Board Can. 36: 54-62.

Vladykov, V.D. 1955. Movements of Quebec shad (Alosa sapidissima) as demonstrated by tagging. Nat. Can. 77: 121-135.

Vladykov, V.D. and R.A. MacKenzie. 1935. The marine fishes of Nova Scotia. Proc. Nova Scotian Inst. Sci. 19: 17-113.

Wedemeyer, G.A., R.L. Saunders, and W.C. Clarke. 1980. Environmental factors affecting smoltification and early marine survival of anadromous salmonids. Mar. Fish. Rev. 42: 1-14.

White, A.W. 1977. Dinoflagellate toxins as probable cause of an Atlantic herring (Clupea harengus harengus) kill, and pteropods as apparent vector. J. Fish. Res. Board Can. 34: 2421-2424.

________ 1980. Recurrence of kills of Atlantic herring (Clupea harengus harengus) caused by dinoflagellate toxins transferred through herbivorous zooplankton. Can. J. Fish. Aquat. Sci. 37: 2262-2265.

White, A.W. 1981. Sensitivity of marine fish to toxins from the red-tide dinoflagellate Gonyaulax excavata and implications for fish kills. Mar. Biol. 65: 255-260.

________ 1982a. The scope of impact of toxic dinoflagellate blooms on fin-fish in Canada. Can. Tech. Rep. Fish. Aquat. Sci. 1063: 5 p.

________ 1982b. Intensification of Gonyaulax blooms and shellfish toxicity in the Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 1064, 12 p.

White, A.W. and C.M. Lewis. 1982. Resting cysts of the toxic, red-tide dinoflagellate Gonyaulax excavata in Bay of Fundy sediments. Can. J. Fish. Aquat. Sci. 39: 1185-1194.

White, H.C. 1932. Fish taken in Cairn Cove weir, Apple River, N. S. 1931. Atl. Biol. Sta. Orig. MS 375, 2 p.

________ 1936. The homing of salmon in Apple River, N.S. J. Biol. Board Can. 2: 291-400.

Wildsmith, B. 1981. Annapolis Valley tidal project. Atl. Salmon J. October 1981: 28-29.

Wiles, M. 1979. Successful rearing of striped bass *Morone saxatilis* (Walbaum) from fertilized eggs in small aquaria, with reference to environment, feeding and growth and bacterial disease. Biol. Dept. St. Mary's Univ. (unpub. MS).

Willey, A. 1923. Notes on the distribution of free-living copepoda in Canadian waters. Contr. Can. Biol. N. S., 1(16): 303-334.

Williams, P.J. 1981. Feasibility of age determination of American shad (*Alosa sapidissima*) by otoliths, with a note on stock differentiation. Hons. B.Sc. thesis, 48 p.

Williams, R.R.G. 1978. Spawning of the striped bass, *Morone saxatilis* (Walbaum), in the Annapolis River, Nova Scotia. M.Sc. thesis, Acadia Univ., 164 p.

Williamson, F.A. 1974. Population studies of striped bass (*Morone saxatilis*, in the Saint John and Annapolis Rivers. M.Sc. Thesis, Acadia Univ., 60 p.

Witherspoon, N.B. 1984. The soft-shell clam (*Mya arenaria*) resource along the north shore of the Minas Basin and potential impacts of the proposed tidal power project on its long-term productivity. In this report.

Yeo, R.K. 1978. Animal sediment relationships in the Minas Basin, Bay of Fundy. M.Sc. thesis, McMaster Univ., 396 p.

QUESTIONS AND COMMENTS

B. Silvert: Do you see any association between the fish in the Bay and the stationary zooplankton concentrations that Graham Daborn was speaking about.

M. Dadswell: We have not been looking at that. However work by Derek Iles indicates that herring larvae can be associated with patches of zooplankton, such as *Sagitta*.

G. Baker: You say all the shad will have to leave the Annapolis River through the turbine and I agree with you completely. Why then did the Department of Fisheries and Oceans require the Tidal Power Corporation to build an expensive fishway?

M. Dadswell: I recommended against it. The consultant reports showed the greatest number of fish will go with the greatest volume of water. We shall have to wait and see who is right. Behavioral studies of fish at the turbine and fishway are definitely in order.

Unknown: Do you have a ballpark figure for the net worth of the entire shad fishery along eastern North America?

M. Dadswell: That a hard figure to come up with. Reported commercial landings in the US in 1980 were only about $2 million. However, the value of the sports fishery on the Delaware and Connecticut Rivers, where about 100,000 fish are angled annually, has been estimated anywhere from 7 to 20 million dollars. This is greater than the value of the Atlantic salmon fishery in the Maritimes provinces. Before 1940, shad was the most valuable fin fish fishery on the east coast of the US.

Studies of Birds in the Bay of Fundy: A Review

Peter W. Hicklin

Canadian Wildlife Service
Sackville, New Brunswick
EOA 3CO

and

Peter C. Smith

Biology Department
Acadia University
Wolfville, Nova Scotia
BOP 1XO

ABSTRACT

This paper presents a brief summary of the major groups of birds which occur in the Bay of Fundy and discusses ecological studies of birds undertaken since 1970. Intertidal mudflats, salt marshes and areas of upwelling tidal currents near small islands are the major habitats used by birds in Fundy. Waterfowl, shorebirds (plovers, sandpipers and phalaropes) and seabirds (shearwaters, gulls and terns) are most numerous during autumn migration. Many of the studies discussed are recent and in large part remain unpublished.

Key words: Bay of Fundy, birds, ecological studies, imigration, intertidal regions, invertebrate prey, marine habitats.

RÉSUMÉ

Cette étude présente un bref résumé des principaux groupes d'oiseaux présents dans la baie de Fundy et on y examine les études écologiques entreprises sur les oiseaux depuis 1970. Dans la baie de Fundy les principaux habitats fréquentés par les oiseaux englobent les vasières intertidales, les marais salés et les régions de remontée d'eau profonde dans les courants de marée près des petites îles. Les oiseaux aquatiques, les oiseaux de rivage (pluviers, bécasses et phalaropes) et les oiseaux de mer (puffins, mouettes et sternes) sont les plus nombreux pendant la migration automnale. Un grand nombre des études examinées sont récentes et en grande partie inédites.

INTRODUCTION

Historically, little attention has been given to the Fundy avifauna. Early pioneer studies on the occurrence of birds in Fundy described, in qualitative terms, various aspects of migration, abundance and distribution in specific areas within the Bay (e.g., the Grand Manan Archipelago, Pettingill 1939) or as part of broader surveys which included it (Gilpin 1882, Squires 1976, Tufts 1898-99, Tufts 1917, 1973). It was not until the advent of serious discussions about the possible developments of tidal power and deepwater oil ports in the Bay of Fundy in the 1960's and early 1970's that researchers began to examine more seriously the avifaunal resources of the Bay of Fundy in light of these proposed developments and their potential environmental impacts (e.g. Pearce and Smith 1974, Hughson 1977, Morrison 1977). There is no single publication presently available on the distributions and abundances of birds in the Bay of Fundy, but data on populations and distributions are currently being summarized for publication (CWS, Atlantic Region).

The Bay of Fundy (Fig. 1), with its famous tides and muddy waters, provides for birds coastal, estuarine and marine habitats which are utilized by a variety of aquatic species. Some of these habitats favour particularly large numbers of a few individual species during migration.

The expansive areas of intertidal muds and their associated fauna in the upper Bay of Fundy form critical feeding grounds for migrant sandpipers (Scolopacidae) and plovers (Charadriidae) in the late summer and fall. These flats, at low tide, cover an area of about 35,000 ha of which nearly 82% is in Chignecto Bay, Minas Basin and Cobequid Bay (Fig. 2). The abundant mud-dwelling amphipod Corophium volutator (Pallas) and large polychaetes are the main food items of these migrant shorebirds (Hicklin and and Smith 1979).

Approximately 5,000 ha of salt marsh borders the Bay of Fundy and nearly 83% lies in the upper reaches (Fig. 2). Various species of dabbling ducks, geese, and certain species of shorebirds, such as the greater yellowlegs, Tringa melanoleuca, and lesser yellowlegs, T. flavipes, and the least sandpiper, Calidris minutilla, occupy these salt marshes during migration. Counts of Canada geese, Branta canadensis, and six species of dabbling ducks (black duck, Anas rubripes; mallard, A. platyrhyncos; pintail, A. acuta; green-winged teal, A. crecca; blue-winged teal, A. discors and American wigeon, A. americana) in these marshes can exceed 7,000 birds during March-May (Pearce and Smith, 1974) (Table 1a). Population turnover of these migrants is unknown and therefore much larger numbers may be utilizing the salt marshes throughout the late winter-early spring period.

Passamaquoddy Bay and the Grand Manan Archipelago contain less extensive regions of salt marsh and mudflat (180 and 280 ha, respectively) than the upper regions of Fundy. Consequently shorebirds are less numerous. Nearshore areas support upwards of 4,000 migrant brant, Branta bernicla, and nearly 13,000 migrant black ducks (Table 1a). About 7,000 pairs of common eider, Somateria mollissiama, breed in the Passamaquoddy Bay - Grand Manan region. The areas of importance to waterfowl are shown in Fig. 3.

In the lower Bay of Fundy, tens of thousands of pelagic shorebirds, the red phalarope, Phalaropus fulicaria, and red-necked phalarope, Phalaropus lobatus, congregate in the fall off Brier Island, N.S., and Deer

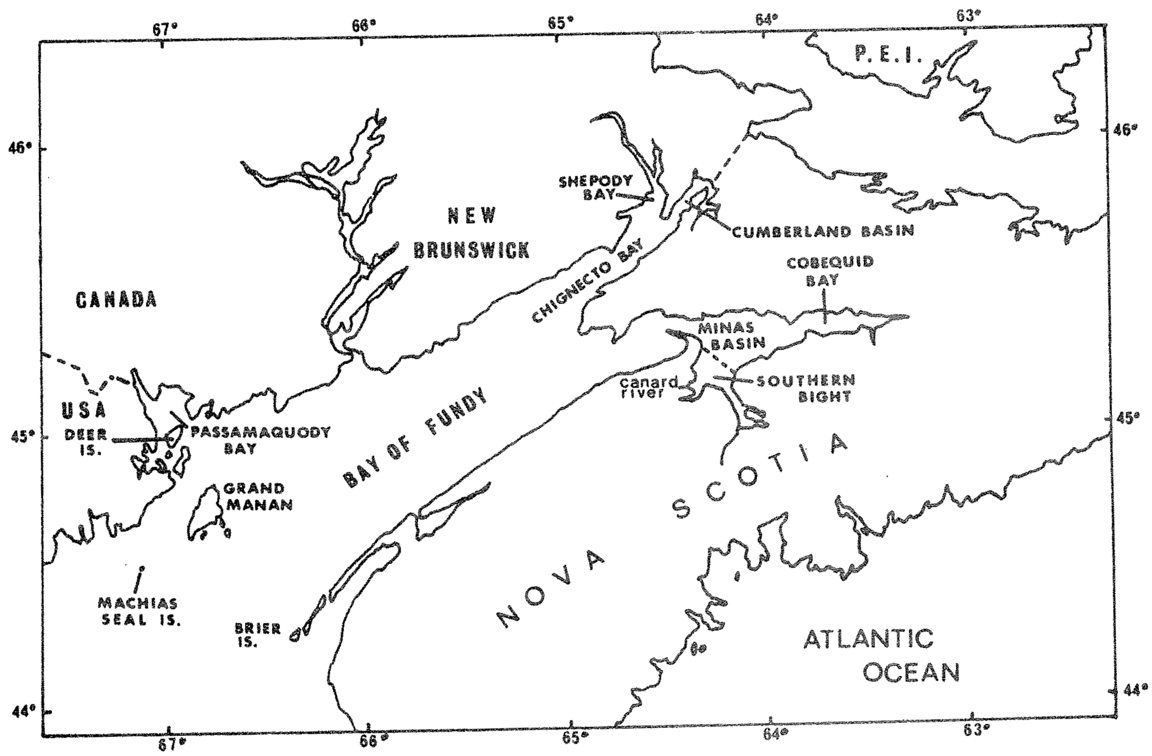


Fig. 1. The Bay of Fundy.

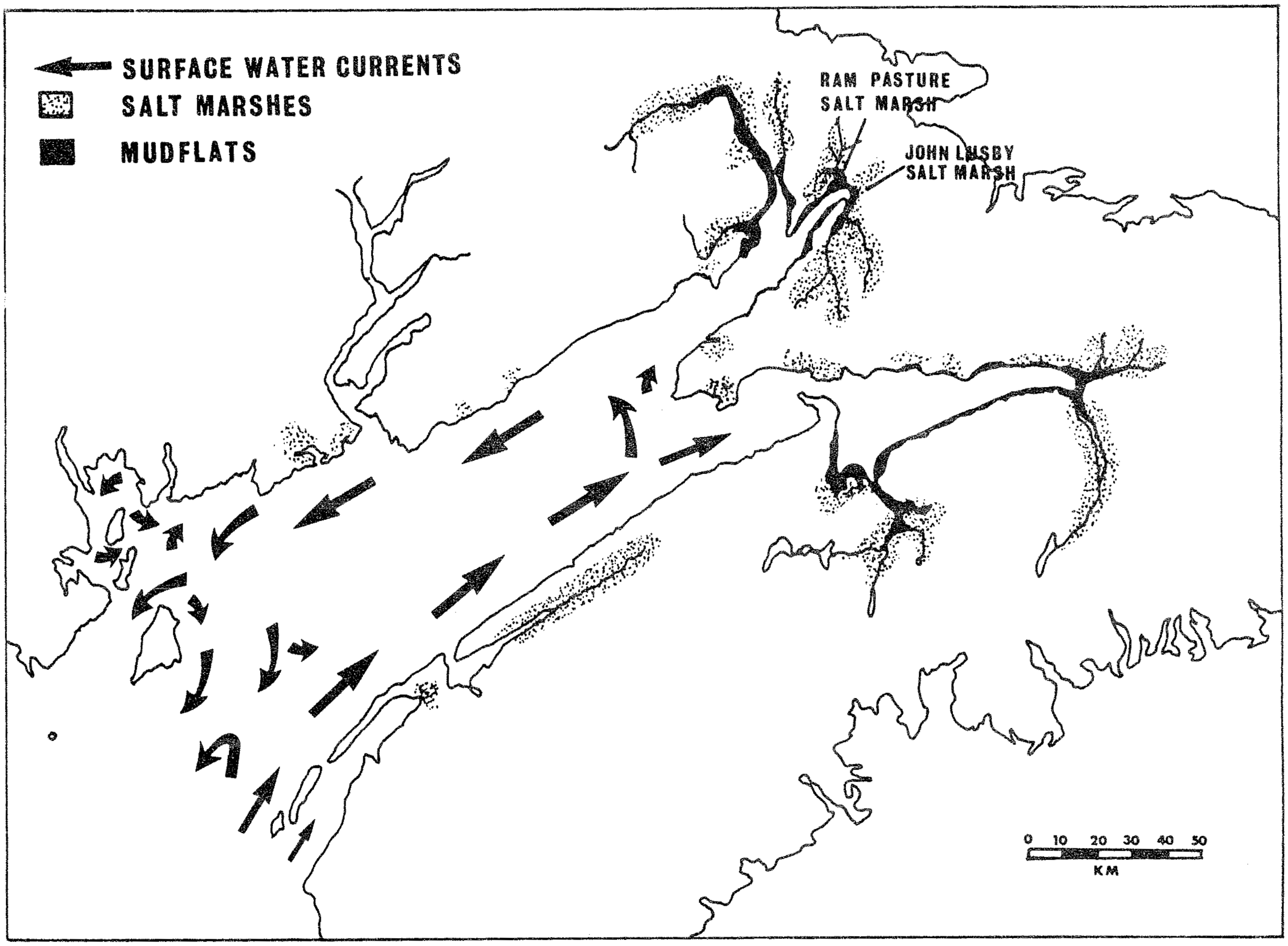


Fig. 2. Habitat types of importance to birds in the Bay of Fundy.

TABLE 1a. Maximum numbers (single day counts) of waterfowl and coastal shorebirds in Zones 1-5 (see Fig. 3) in the Bay of Fundy.

	Waterfowl[1] Zone				
	1	2	3	4	5
Canada Goose	100[3]	200[3]	6,100[3]	750[3]	200[3]
Brant	4,000[3]	350[3]	50[3]	500[3]	500[5]
Black Duck	12,500[3]	1,000[5]	1,550[4]	2,250[5]	1,050[5]
Other dabblers[6]	<25[3]	<25[3,4,5]	2,200[4]	<25[3,5]	100[4]
Divers[5]	1,300[5]	500[5]	350[3]	100[3]	500[3]
Sea ducks[8]	13,550[3]	1,200[3]	2,100[3]	50[3]	3,550[3]

	Shorebirds (July-October)[2] Zone			
	1	2	3	4
Semipalmated Plover	1,000	4,283	2,788	3,808
Black-bellied Plover	300	388	1,488	2,543
Greater Yellowlegs	75	333	154	59
Lesser Yellowlegs	50	283	1,356	59
Knot	26	2	1,447	116
White-rumped Sandpiper	55	646	707	561
Least Sandpiper	702	7,564	3,503	9,945
Dunlin	60	35	2,655	388
Short-billed Dowitcher	422	1,651	1,405	1,068
Semipalmated Sandpiper	6,366	25,094	456,355	69,550
Sanderling	200	1,909	1,150	1,151

[1] from Pearce and Smith, 1974
[2] from Morrison, 1978-1979; Elliot, 1977; R. McManus, A.J. Erskine, P. MacDonald, *pers. comm.*
[3] Mar-May
[4] Sep-Nov.
[5] Dec-Feb.
[6] Mallard, Pintail, Green-winged Teal, Blue-winged Teal, American Wigeon
[7] Ring-necked Duck, Scaup, Goldeneye, Bufflehead, Merganser
[8] Oldsquaw, Eider, Scoter

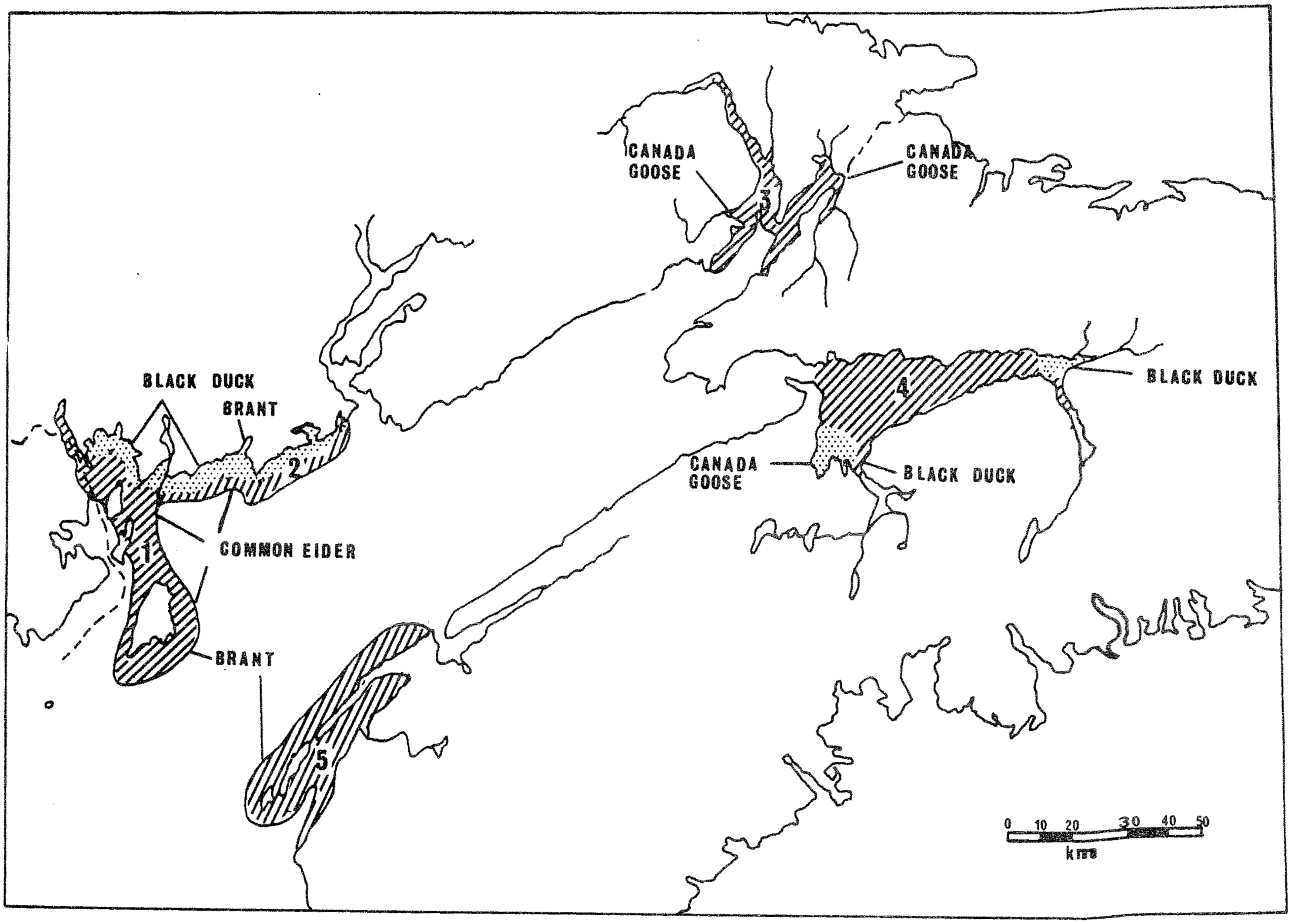


Fig. 3. Areas of importance to waterfowl in the Bay of Fundy. Zones 1-5 (hatched) are adapted from Pearce and Smith (1974). Stippled areas indicate areas of importance mainly to black ducks.

Island, N.B. Other species of pelagic birds such as the greater shearwater, Puffinus gravis, and sooty shearwater, P. griseus, are also numerous at this time particularly in the areas near Brier Island (Table 1b). Another seabird group, the alcids, including razorbills, Alca torda, and the Atlantic puffin, Fratercula arctica, breed on Machias Seal Island alongside a mixed colony of Arctic terns, Sterna paradisaea, and common terns, S. hirundo. The distributions of shorebirds and seabirds are summarized in Fig. 4.

The two extreme reaches of the Bay of Fundy are of the greatest importance to birds. The mouth of Fundy, roughly the area between Brier Island and Passamaquoddy Bay on the one hand, and the upper Bay of Fundy, Chignecto Bay and Minas Basin on the other, support large numbers of a few, ecologically quite different, species. In the former region, pelagic species, which rely on rocky islands to breed and clear water and fast currents to concentrate food for foraging, dominate whereas in the upper reaches, shorebirds and waterfowl occupy the muddy intertidal zone and salt marshes. The intervening region characterized by steep sand-stone cliffs, rocky intertidal habitats and turbid water is little used by birds.

In the sections which follow we discuss those species or groups of species given serious study from the early 1970's to the present. Since many of these studies are recent, we relied largely on unpublished information in the form of graduate theses, government reports and, where projects are not yet completed, personal communications from the investigators involved. There has been extensive work on shorebirds since 1976 but little has been published. We present here some of the pertinent findings. Since much of the work we review here is preliminary it should be treated as such by the reader.

ECOLOGICAL STUDIES OF BIRDS IN THE BAY OF FUNDY

Waterfowl

The habitats of which we know the least in terms of their utilization by birds are the salt marshes. As indicated earlier, relatively large numbers of waterfowl, dabbling ducks and geese in particular forage on the salt marshes during spring and fall migrations. Unfortunately no detailed ecological studies have been done on individual species in relation to habitat use, diets, energy consumption, fat deposition, movements, or inter-and intraspecific relationships. Hence little more can be said except that these areas may be of considerable importance to these migrants based on numbers alone. Information is especially wanting on brant in Passamaquoddy Bay and the Grand Manan Archipelago and on Canada geese in the John Lusby salt marsh, the Harvey marsh and the Canard River which are major staging grounds for grease in the Bay of Fundy.

Shorebirds

Shorebirds are especially prevalent in salt marshes in the late summer and fall. Recent studies on shorebird migration and feeding ecology

TABLE 1b. Maximum numbers (single day counts) of Shearwaters, Phalaropes, Bonaparte's Gulls and Common and Arctic Terns in Zones 1 and 5 (see Fig. 3) in the Bay of Fundy.

	Zone 1	Zone 5
Shearwaters[1]		
Greater Shearwater	≈ 500 (27 Aug. 1969)	$\approx 10^3$ (1 Sept. 1971)
Sooty Shearwater	?	$\approx 10^2$ (1 Sept. 1971)
Phalaropes[2]		
Northern Phalarope	$\approx 5 \times 10^5$ (21-22 Aug. 1974)	$\approx 5 \times 10^3$ (31 Aug. 1976)
Red Phalarope	?	$\approx 2 \times 10^4$ (3 Sept. 1972)
Gulls and Terns[3]		
Bonaparte's Gull	5,000 - 10,000 (August)	
Common and Arctic Terns	1,000 (August)	

[1] Estimates obtained from Nova Scotia Bird Society Newsletter were made by different land-based observers and are largely subjective. Numbers of these species vary greatly between years and species are often difficult to separate. Hence, orders of magnitude are most meaningful at present to designate relative abundances between zones until aerial surveys or other quantitative surveys are undertaken (R.G.B. Brown, pers. comm.).

[2] Nova Scotia Bird Society Newsletter and R.G.B. Brown (pers. comm.).

[3] Braune and Gaskin (1982a).

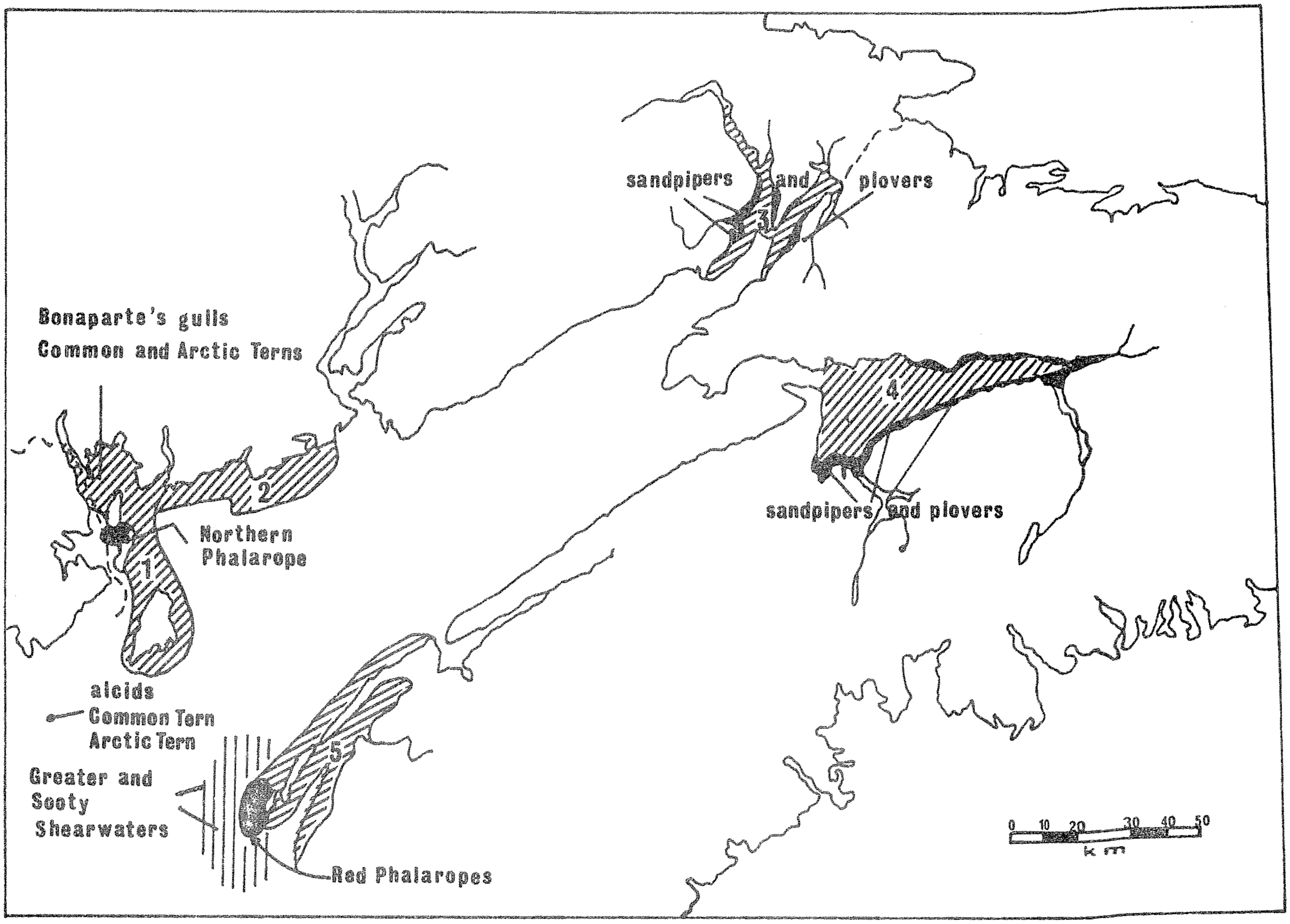


Fig. 4. Areas of importance to coastal shorebirds (sandpipers and plovers), northern and red phalaropes, greater and sooty shear waters, alcids, Bonaparte's gulls and common and Arctic terns in the Bay of Fundy. Zones 1-5 (hatched) are adapted from Pearce and Smith (1974). The dark areas specify the sites utilized by sandpipers and plovers and concentrations of phalaropes. Pointers indicate specific sites of importance within each zone to the species shown.

have concentrated primarily on mudflat foraging sites (see below). Greater and lesser yellowlegs occupy the high marshes (upper fringes of marsh flooded mainly on spring tides). The latter species is especially numerous on the Ram Pasture Salt marsh near Sackville, N.B., and large assemblages are thought to occur on the Daniel's Flats salt marshes in Albert County, N.B. (P. Hicklin, personal observation). However, surveys have never been undertaken during the migratory period to quantify the occurrence of these species in these areas and thus population estimates are not available. A preliminary unpublished study of the lesser yellowlegs in the Ram Pasture salt marsh (Hildebrand 1981) indicated that the birds did not forage in synchrony with the tidal cycle but that their feeding behaviour was more closely related to the diel cycle. The birds fed in the early morning and late evening hours and rested at mid-day unlike those shorebirds which fed on the mudflats in close association with the ebbing and rising tide. Hildebrand (1981) postulated that the yellowlegs' feeding cycle was related to the behavioural activities of macroinvertebrates in salt marsh pools. Since in some areas, particularly in Cobequid Bay, high marshes may no longer be flooded following the construction of a proposed tidal barrage, habitats of importance to yellowlegs may be lost. Conversely seaward of a tidal barrage other high marshes may become flooded daily owing to rising tide levels. A study on the comparative use of high and low marshes by shorebirds, particularly yellowlegs, would provide a clearer indication of the potential impact of tidal power developments on these birds.

Most of the birds which use the Bay of Fundy are migrants. The eastern willet, Catoptrophorus semipalmatus, is not a common species in Fundy but a few pairs breed in the Southern Bight, Minas Basin. Hansen (1978) studied the breeding biology and territorial behaviour of four pairs at Horton Landing, the only study of this species to date in the Bay of Fundy.

Since 1976, shorebirds feeding on intertidal flats have been the most intensively studied group in the Bay of Fundy. A disproportionate amount of study has been devoted to the semipalmated sandpiper, Calidris pusilla, mainly because of its higher numerical abundance and widespread distribution (Elliot 1977, Boates 1980, Hicklin 1981). Further studies on the feeding ecology of black-bellied plover, short-billed dowitcher, Limnodromus griseus, and least sandpiper are currently in progress at Acadia University. At present, the information available on the semipalmated sandpiper in Minas Basin includes foraging behaviour, energy budgets and prey (Corophium volutator) - predator relationships (Boates and Smith 1979, Boates 1980) and habitat use (Hicklin 1981). Studies on rates of energy consumption, fat deposition and effects of prey depletion in Chignecto Bay are not completed (Hicklin, unpublished data). Peach (1981) investigated the differences in energy consumption between adult and juvenile semipalmated plover, Calidris semipalmatus, in the Southern Bight, Minas Basin. There has been no work thus far on the less numerous species such as red knot, Calidris canutus, dunlin, C. alpina, and white-rumped sandpipers, C. fuscicollis.

Migration of Shorebirds in the Bay of Fundy

The southward migration of shorebirds into the Bay of Fundy occurs from mid July to mid November. Semipalmated sandpipers are most numerous in the latter part of July and the first week of August whereas plovers reach peak numbers during mid to late August (Fig. 5). Numbers of least sandpipers, short-billed dowitchers and semipalmated sandpipers peak quickly within 10-14 days following the arrival of the first flocks in July. Sanderlings and dunlins are present mainly through October and early November. The black-bellied plover is the only species which migrates to the Bay of Fundy in spring in substantial numbers (Fig. 5).

Abundance and Distribution of Invertebrate Food

The abundance of food available to birds on individual mudflats is a major factor in determining which sites are likely to be used by the largest number of birds. In 1976-1978 inclusive, the larger flats in Chignecto Bay and the Southern Bight were sampled for invertebrates (Hicklin et al. 1980, Hicklin 1981). Yeo's (1977) study on animal-sediment relationships in Cobequid Bay followed a similar sampling regime in that portion of the Bay between 1973 and 1976 inclusive. The densities (numbers m^{-2}) of the main shorebird prey species recovered from these sampling sites are shown in Figs. 6a and b. The amphipod *Corophium volutator* is by far the most numerous species with the average densities between 10,000-20,000 m^{-2} in the mid to lower regions of the flats in Chignecto Bay and the Southern Bight, Minas Basin. *Corophium* is the primary prey of semipalmated plover, dowitcher, least and semipalmated sandpipers (Hicklin and Smith 1979). Consequently, those species are particularly numerous in areas of high *Corophium* density (Figs. 7a and b).

Timing of Shorebird Migration and the Reproductive Cycle of *Corophium volutator*

The overwintering population of *Corophium volutator* releases its young in the latter part of May and the younger cohort reproduces in late July (Peer et al. unpublished data) such that the maximum abundance of this amphipod occurs during July and August (Fig. 8). Thus the arrival of birds coincides with the period of highest prey abundance. By late July, the prey population consists of two generations, the wintering population, and a younger reproductive cohort which releases its own progeny during August. Hence, this major shorebird prey in the Bay of Fundy can be considered as a renewable food resource maintaining high levels of productivity throughout the shorebird migratory period.

Fat Deposition and Predation Pressure by Migrant Shorebirds

The population of shorebirds stopping in the Bay of Fundy to accumulate fat reserves probably numbers one to two million birds. Between 90-95% of total numbers seen each year are represented by the semipalmated sandpiper. Each sandpiper requires 13-18 g of fat to accomplish the presumed non-stop transoceanic flight from Fundy to the Lesser Antilles and

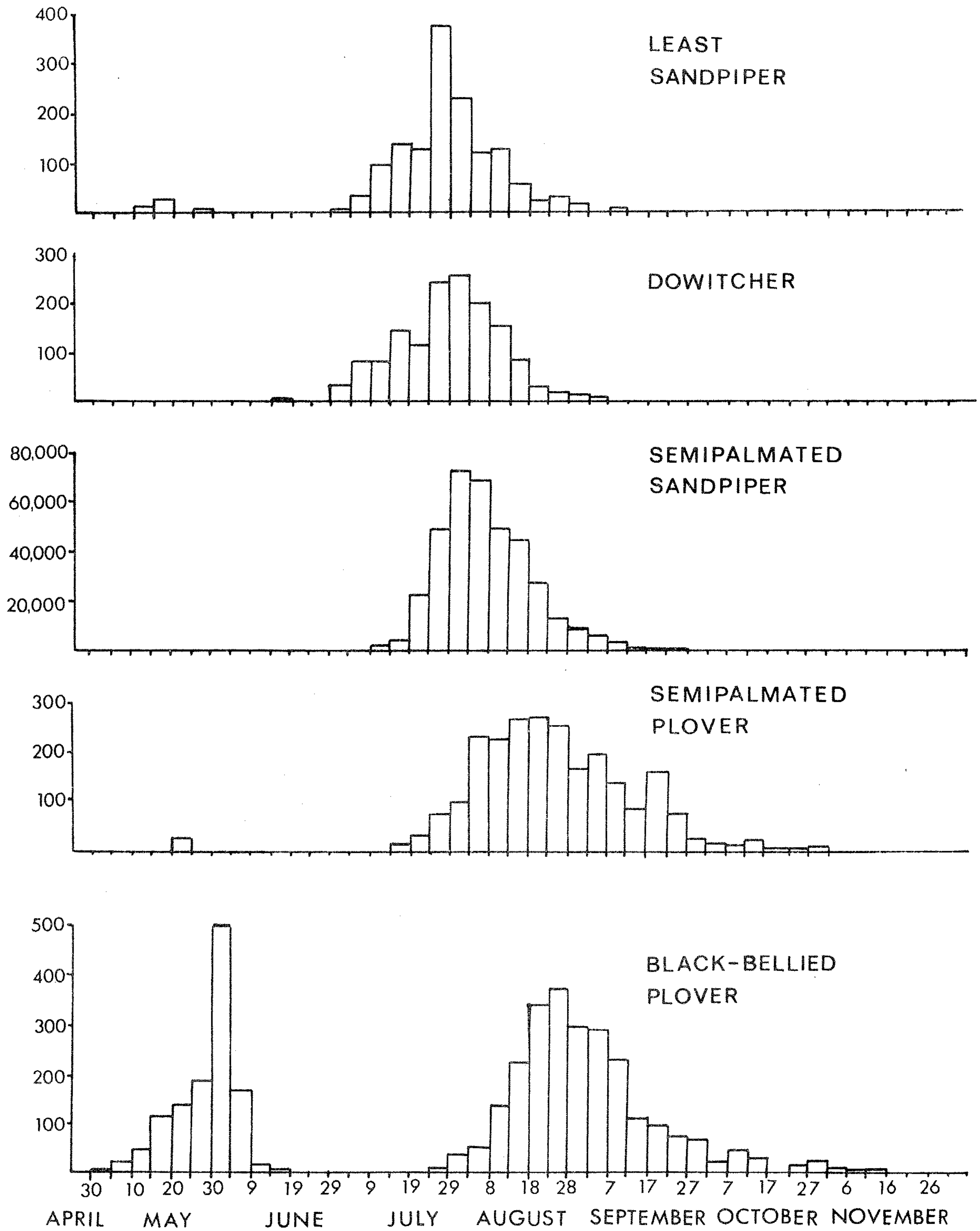


Fig. 5. Migration of the five major species of shorebirds in the Bay of Fundy between 26 April - 26 November. Each bar refers to the average number of birds per 5-day period at Evangeline Beach, Dorchester Cape and Marys Point in 1976-1983.

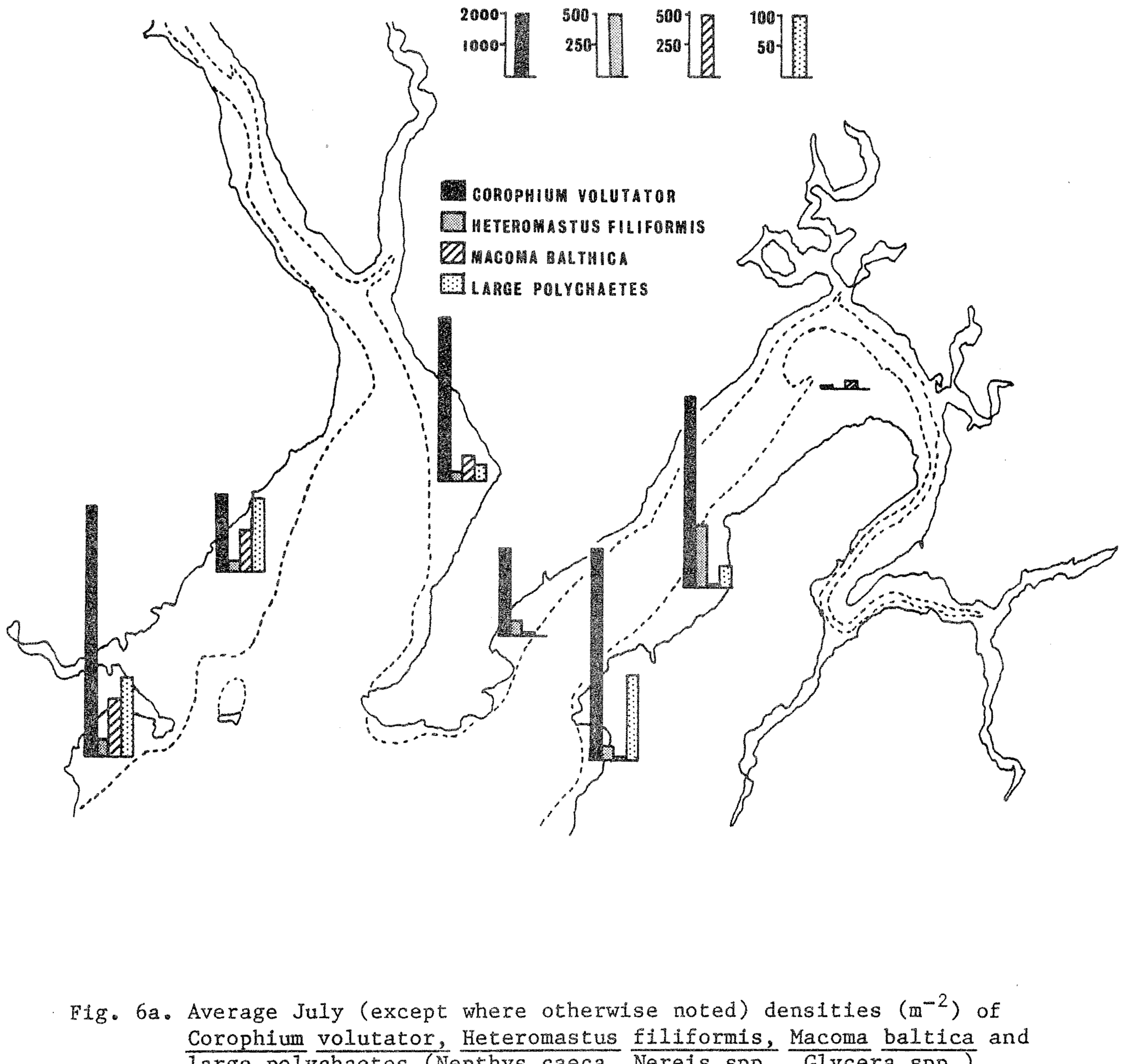


Fig. 6a. Average July (except where otherwise noted) densities (m^{-2}) of Corophium volutator, Heteromastus filiformis, Macoma baltica and large polychaetes (Nepthys caeca, Nereis spp., Glycera spp.) along linear transects in Chignecto Bay.

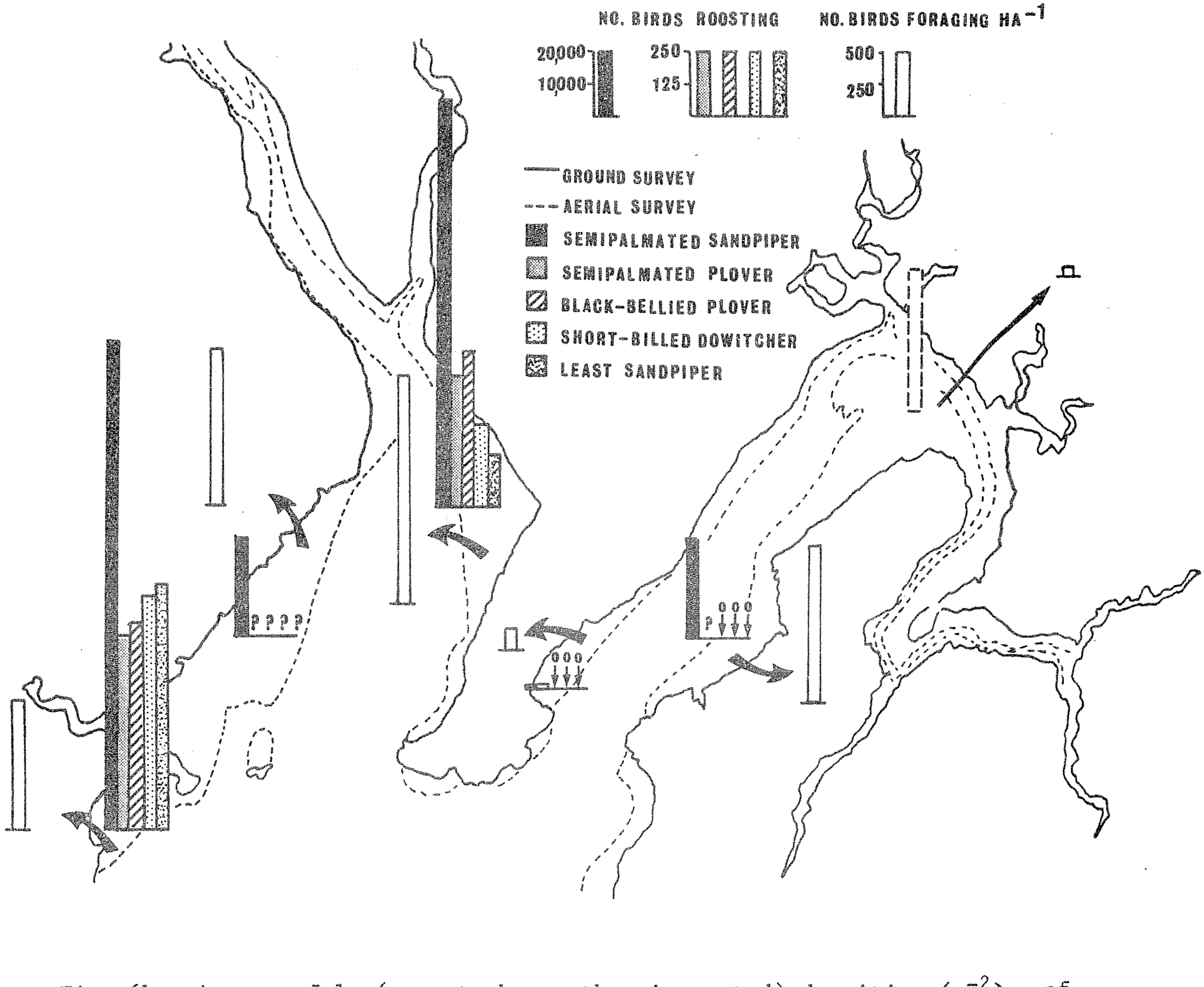


Fig. 6b. Average July (except where otherwise noted) densities (m^{-2}) of Corophium volutator, Heteromastus filiformis, Macoma baltica and large polychaetes (Nephtys caeca, Nereis spp., Glycera spp.) along linear transects in Minas Basin and Cobequid Bay.

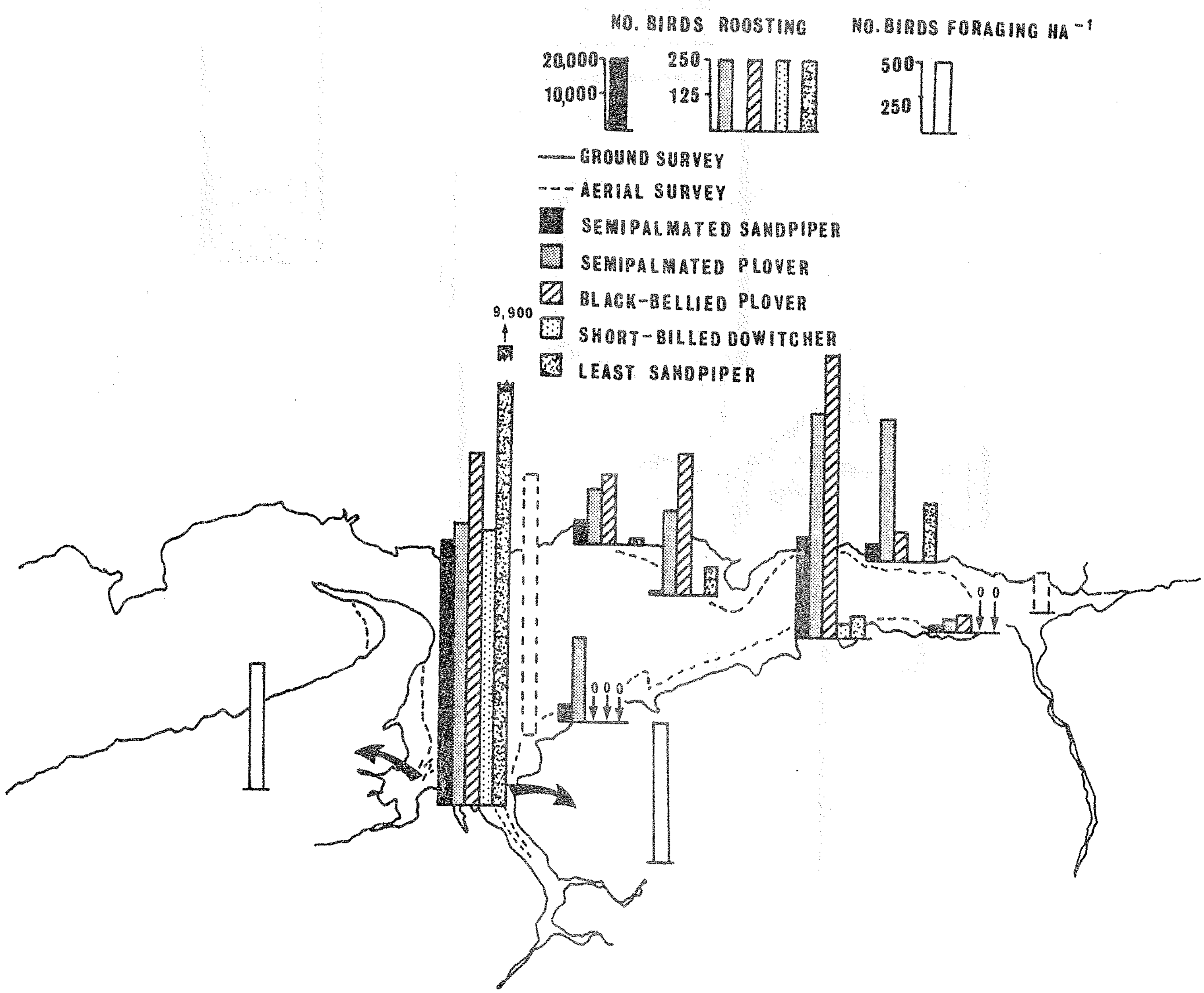


Fig. 7a. Maximum numbers at roosting sites of the semipalmated sandpiper, semipalmated plover, black-bellied plover, short-billed dowitcher and least sandpiper and densities at foraging sites in Chignecto Bay in 1976-1982. Open bars (solid and broken) refer to all species combined.

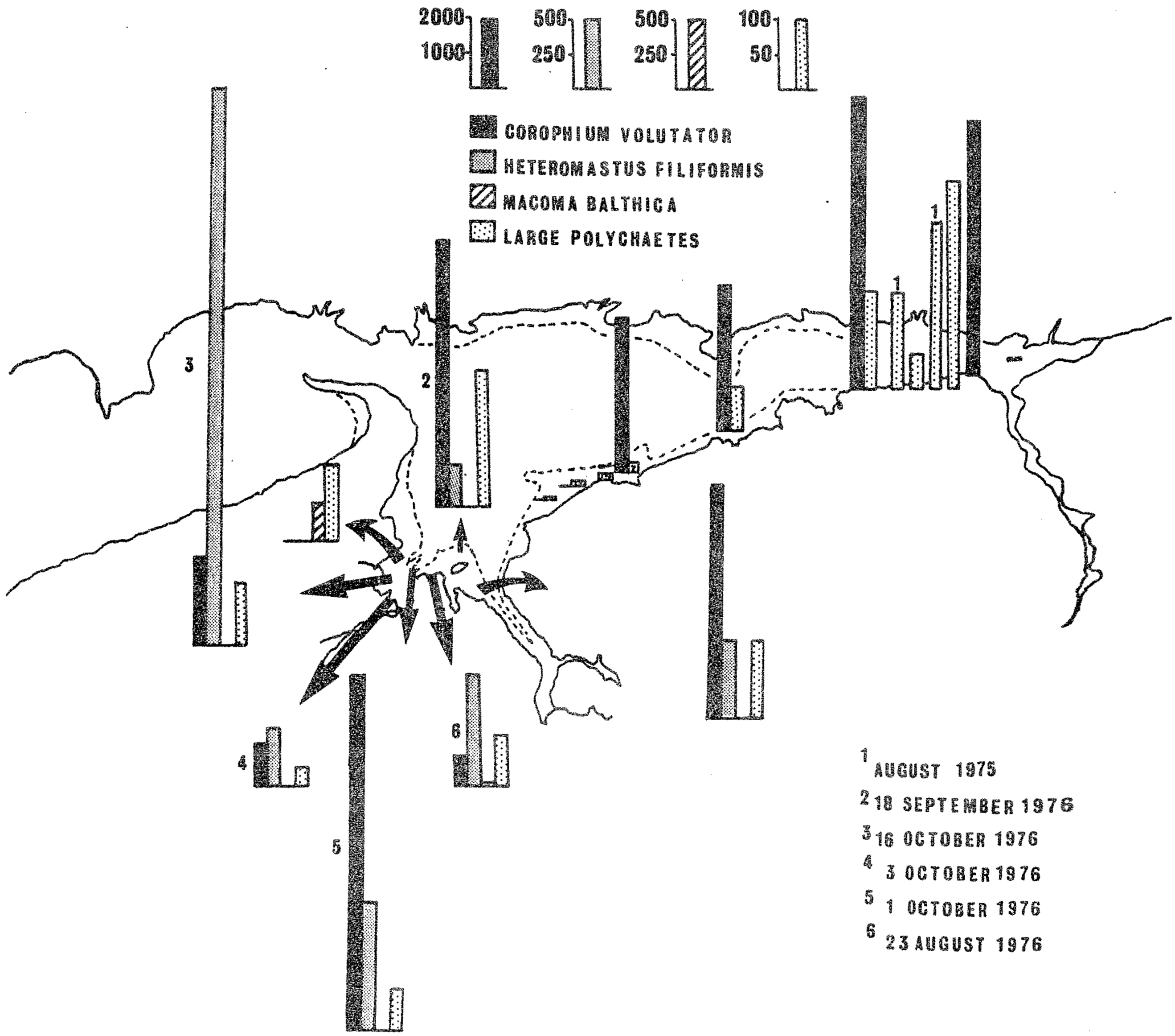


Fig. 7b. Maximum numbers at roosting sites of semipalmated sandpiper, semipalmated plover, black-bellied plover, short-billed dowitcher and least sandpiper and densities at foraging sites in Minas Basin and Cobequid Bay in 1976-1982. Open bars (solid and broken) refer to all species combined.

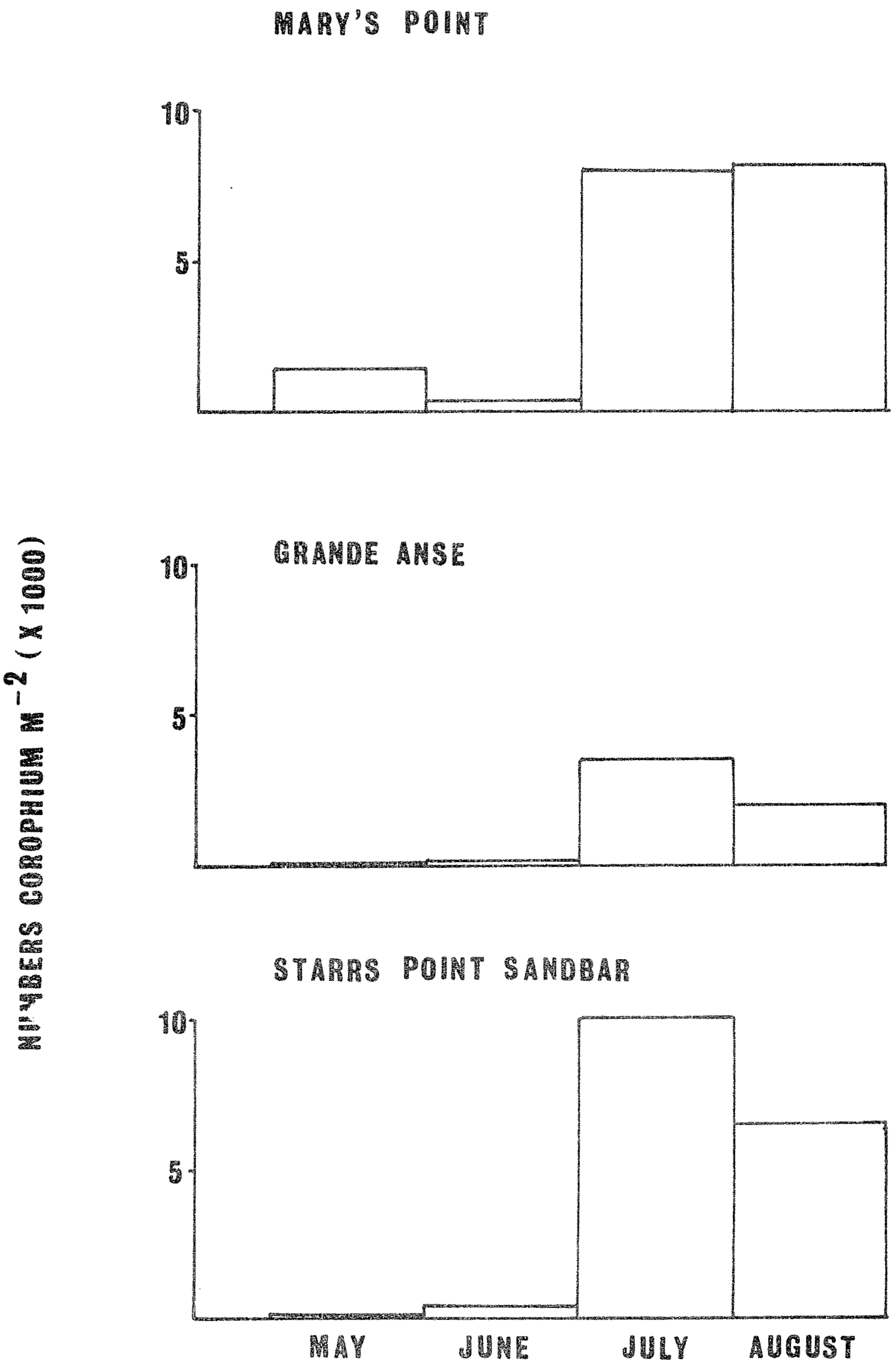


Fig. 8. Average densities of <u>Corophium volutator</u> at Mary's Point, Grande Anse and Starrs Point sandbar during the summer months.

the northern coast of South America. Of a sample of 68 semipalmated sandpipers collected on 22-30 July in 1980 (50) and 1981 (18) at Dorchester Cape, Shepody Bay, 73.5% contained between 1-20 g of fat which made up between 3.2 and 47.9% ($\bar{x}$ = 33.1%) of fresh body weight (Hicklin, unpublished data). Thus, by late July, many of the birds had stored sufficient lipid reserves for the migratory flight to South America. Observations of colour-marked semipalmated sandpipers indicated that the birds stayed in the area 10-20 days (Hicklin, unpublished data). If they arrived with low fat reserves and departed with 13-18 g of fat, they would have deposited lipid at rates of 0.65-1.88 g $bird^{-1}$ day^{-1}. The average daily increase in the mean fresh weights of semipalmated sandpipers captured between 20 July - 1 August was 1.00 g $bird^{-1}$ day^{-1}. These results are slightly higher than data obtained from observations of foraging rates in Chignecto Bay (Table 2) and the Southern Bight (Boates, 1980).

The removal of energy in the form of fat by such a large population of birds undoubtedly exerts heavy predation pressure on the invertebrate populations inhabiting those mudflats which are especially favoured by birds. Boats (1980) estimated that semipalmated sandpipers ingested 9,600-21,600 *Corophium* per bird per feeding period depending on the feeding rate, the size class of prey taken and the length of the feeding period (spring, neap or mean tides).

Peach (1981) described the diet, foraging behaviour and energy intake of adult and juvenile semipalmated plovers at the Starrs Point mudflat in Minas Basin. She found that the amphipod *Corophium volutator* was the dominant prey taken but that the polychaete *Heteromastus filiformis* was also a common prey item. The juvenile birds ingested more prey per "daylight feeding period" (time the mudflat is exposed during daylight hours) than the older ones. The energy intake of juveniles ranged from 141.5 KJ $bird^{-1}$ day^{-1} (equivalent to 1,142 worms and 12,211 amphipods) to 256.4 KJ $bird^{-1}$ day^{-1} (2,071 worms and 22,133 amphipods) on the minimal and maximal daylight feeding periods, respectively. The range for adults was 52.4 to 150.3 KJ day^{-1} $bird^{-1}$. She attributed the differences to the greater energy requirement of the immatures for growth as well as fat deposition. Black-bellied plover in the Southern Bight feed mainly on glyceran worms (A. Dubois. pers. comm.) whereas short-billed dowitcher and least sandpiper take largely *Corophium*. With the data available we have computed rough estimates of prey and energy consumption for each species during the migratory period at the Starrs Point mudflat in Minas Basin (Table 3). These values undoubtedly vary from year to year depending on the number of birds utilizing the area. The data indicate that the semipalmated sandpiper is responsible for removing 74% (1.27 KJ m^{-2}) of the total amount of energy taken by the five major species of shorebirds from the Starrs Point flat during migration. Since we have as yet no data on food consumption of juveniles of species other than the semipalmated plover, the total biomass or energy consumed may be higher if the younger age groups require more energy than the adults as shown by Peach (1981). How much energy the birds return to the system through excretion is not yet known nor is information available on the rates of food intake of red knot, Judsonian godwit, *Limosa haemastica*, and of the later arriving species such as dunlin and white-rumped sandpiper.

TABLE 2. Net energy consumption (see Appendix) and grams fat deposited by Semipalmated Sandpipers per feeding period at Dorchester Cape (Grande Anse flat), Mary's Point, Minudie and Daniel's Flats. Maxima and minima were computed using 1 standard deviation on either side of the mean.

	Grande Anse 27 July		Mary's Point 1 August		Minudie 3 August		Daniel's Flats 3 August	
	KJ	g fat deposited	KJ	g fat deposited	KJ	g fat deposited	KJ	g fat deposited
MAX	61.8	1.64	46.7	1.24	36.6	0.97	26.4	0.70
$\bar{x}$	33.2	0.88	25.6	0.68	23.3	0.62	12.1	0.32
MIN	4.5	0.12	4.9	0.13	12.1	0.32	-2.3	-0.06

TABLE 3. Estimates of prey biomass removed and energy assimilated by shorebirds at the Starrs Point mudflat during autumn migration.

	Average no. of Birds[1]	Total no. Prey Taken	Prey Biomass (g dry wt.)	Total Energy Assimilated by Birds (KJ)[2]	Energy Removed KJm^{-2}
Black-bellied Plover	132[3]	8.45×10^5	1.52×10^5	3.27×10^6	0.09
Semipalmated Plover	314[4]	1.69×10^8	8.08×10^4	1.87×10^6	0.05
Short-billed Dowitcher	300[5]	1.14×10^6	1.78×10^4	3.79×10^6	0.11
Least Sandpiper	4,400[6]	1.40×10^9	3.72×10^5	6.95×10^6	0.19
Semipalmated Sandpiper	25,500[7]	1.33×10^{10}	3.54×10^6	4.58×10^7	1.27
TOTAL		1.49×10^{10}	4.16×10^6	6.15×10^7	1.71

[1] average number of birds foraging at Starrs Point beginning when at least 10% of the peak number of birds is on the site to when 10% remains.

[2] 1 Joule=0.239 calories; assimilation efficiency is assumed to be 80% (see Boates, 1980)

[3] 3 August - 18 September 1981; adults only (Andree Dubois, pers. comm.)

[4] 27 July - 4 September 1980; adults = 264, immatures = 50 (Peach, 1981)

[5] 9 July - 3 August 1976 (Hicklin, 1981)

[6] 6 July - 14 September 1981; adults and juveniles combined (Peter MacDonald, pers. comm.)

[7] 6 July - 14 September 1981; adults and juveniles combined (Peter MacDonald, pers. comm.)

Pelagic Birds

Migrant Bonaparte's gulls, Larus philadelphia, and common and arctic terns congregate in large numbers in autumn in Passamaquoddy Bay (Table 1b). Braune and Gaskin (1982 a, b) studied the foraging ecology of these species during the late summer and fall of 1977-1979. Their results showed that the birds fed mainly during the ebbing and rising tides when tidal currents increased the availability of prey. Bonaparte's gulls fed predominantly on euphausiids and insects, and concentrated their feeding activities where these prey were most numerous. The feeding behaviour of the birds also changed with changing prey type and density (Braune and Gaskin 1982b). These studies support the findings of Brown et al. (1979) and Brown (1980) that seabirds in the lower Bay of Fundy are dependent on strong tidal streams which result in upwellings and convergences when forced to the surface over underwater ledges thus concentrating prey at the surface where they are available to birds.

In spring, large numbers of common eiders breed on many of the islands in the Quoddy Region and Grand Manan. Lock (1982) estimated that nearly 7,000 pairs of eiders were in the archipelago during the 1982 breeding season. It appears that this breeding population winters in Passamaquoddy Bay and possibly along the coast of northern Maine although there are few banding data to substantiate this belief (Erskine, pers. comm.). The diets, habitat use and energetics of eiders in southwestern New Brunswick in summer and winter have not been studied.

Off Deer Island, N.B., red-necked phalaropes can attain numbers in the hundreds of thousands in some years during the fall migration (Table 1b). The forcing of copepods and euphausiids to the upper surface layers by tidal upwellings appears to provide a highly abundant and available source of food to phalaropes (R.G.B. Brown, pers. comm.).

Machias Seal Island

Machias Seal Island situated at the mouth of the Bay of Fundy and the entrance to the Gulf of Maine contains considerable numbers of breeding puffins (800 pairs), razorbills (80 pairs), arctic terns (1,500 pairs) and common terns (100 pairs). Hawksley (1957) and Newell (unpublished data) studied the ecology of arctic terns on Machias Seal Island. Little is known of the foraging ecology of breeding birds on the island.

Brier Island

Greater and sooty shearwaters and red phalaropes are numerous in fall off Brier Island during migration (Table 1b, Fig. 4). Baker (1976) studied various aspects of the feeding ecologies of both species of shearwaters and found that the euphausiid Meganyctiphanes norvegica and squid Illex were major prey species. She found that the predominant biological phenomenon affecting the occurrence of P.gravis and P.griseus in the Brier Island region was surface swarming of M. norvegica. The physcial and biotic factors influencing the swarming of euphausiids were water temperature and tidal currents (Brown et al. 1981). The shearwaters fed mainly on the flood tide when currents carried euphausiids and squid closer to the surface. Red phalaropes similarly depended on the tidal currents, particularly at upwelling and convergences which are marked by areas of calm water termed "streaks". Along these streaks collect high densities of copepods, amphipods and pteropods upon which the phalaropes presumably feed (Brown 1980).

The studies which have been conducted on the pelagic species (shearwaters, phalaropes, gulls and terns) congregating in the lower Bay of Fundy in spring and fall have one common denominator: strong tidal currents and extensive mixing provide abundant prey at the surface, thus making prey available to the large populations of birds at critical times during northward and southward migrations.

Bald Eagles

In the Maritime Provinces, the most important wintering area for the bald eagle, *Haliaeetus leucocephalus*, is the Shubenacadie River which flows into Cobequid Bay. Reid (1982) studied their behaviour and feeding ecology during the winter months. She recorded peak numbers of 45 to 75 birds between 1977 and 1982. The tide affects the Shubenacadie river 40 km upriver from Cobequid Bay and the stretch most frequented by wintering eagles extends 16-21 km from the river mouth. The attraction for the birds is the winter spawning run of tomcod, *Microgadus tomcod*, which is especially important for the eagles' survival during January and February.

Great Blue Heron

As part of a national survey of great blue herons, Smith (1980) has documented the numbers of heronries throughout the Maritime Provinces. In 1980, 1,260 pairs of herons were present in Nova Scotia in 53 active colonies and 1,000 pairs were estimated for New Brunswick in 26 active colonies. Of those totals, 9 colonies occurred adjacent to the Bay of Fundy, with a maximum of 275 pairs or 12% of the Maritime total. The reproductive biology and foraging behaviour of great blue herons has been studied on Boot Island, Minas Basin (Quinney 1979, Quinney and Smith 1980).Ninety-eight per cent of the identified prey brought to the nestlings were flounder *Liopsetta putnami* (Quinney and Smith 1980).

Other Studies In Progress Or Planned

Graduate students and faculty at Acadia University are currently studying the feeding ecologies of black-bellied plover (Andree Dubois), short-billed dowitcher (Peter Smith) and least sandpiper (Peter MacDonald) in the Southern Bight, Minas Basin.

The Canadian Wildlife Service is planning a detailed study on the feeding ecology and bioenergetics of breeding and wintering common eider in the Passamaquoddy Bay-Grand Manan region. Preliminary studies are to begin early in 1984.

ACKNOWLEDGMENTS

We are grateful to Peter MacDonald and Andree Dubois for providing counts and information on food consumption for least sandpipers and black-bellied plovers. Counts of shorebirds at Mary's Point were undertaken and provided by Mr. David Christie and Mrs. Mary Majka. Dick Brown made helpful comments with regards to difficulties in estimating numbers of seabirds and Al Smith, A. J. Erskine and Peter Barkhouse indicated sites important to waterfowl. We thank A. J. Erskine for improving an earlier draft.

REFERENCES

Boates, J.S. 1980. Foraging semipalmated sandpipers Calidris puailla L. and this major prey Corophium volutator (Pallas) on the Starrs Point mudflat, Minas Basin. M.Sc. thesis, Acadia University, 199 p.

Boates, J.S. and P.C. Smith. 1979. Length-weight relationships, energy content and the effects of predation on Corophium volutator (Pallas) (Crustacea: Amphipoda). Proc. N.S. Inst. Sci. 29: 489-499.

Braune, B.M. and D.E. Gaskin. 1982a. Feeding ecology of non-breeding populations of larids off Deer Island, New Brunswick. The Auk 99: 67-76.

Braune, B.M. and D.E. Gaskin. 1982b. Feeding methods and diving rates of migrating larids off Deer Island, New Brunswick. Can. J. Zool. 60: 2190-2197.

Brown, R.G.B. 1980. Seabirds as marine animals. In: Burger, J., B.L. Olla and H.E. Winn, eds. Behavior of Marine Animals,, Vol. 4. Plenum Press.

Brown, R.G.B., S.P. Barker and D.E. Gaskin. 1979. Daytime surface swarming by Meganyctiphanes norvegica (M. Sars) (Crustacea, Euphausiacea) off Brier Island, Bay of Fundy. Can. J. Zool. 57: 2285-2291.

Brown, R.G.B., S.P. Barker, D.E. Gaskin and M.R. Sandeman. 1981. The foods of great and sooty shearwaters Puffinus gravis and P. griseus in eastern Canadian waters. Ibis 123: 19-30.

Elliot, R.D. 1977. Roosting patterns and daily activity of migratory shorebirds at Grand Pre, Nova Scotia. M.Sc. thesis, Acadia University, 155 p.

Gilpin, J.B. 1882. Shorebirds of Nova Scotia. Proc. and Trans. Nova Scotia Inst. Nat. Sci. 5: 376-387.

Hansen, 1978. Aspects of breeding biology of the eastern willet Catoptrophorus semipalmatus. Can. Wildl. Ser. Rep. Ottawa, 52 pp.

Hawksley, O. 1957. Ecology of a breeding population of Arctic terns. Bird Banding 28: 57-92.

Hicklin, P.W. 1981. Use of invertebrate fauna and associated substrates by migrant shorebirds in the Southern Bight, Minas Basin. M.Sc. thesis, Acadia University, 212 pp.

Hicklin, P.W. and P.C. Smith. 1979. The diets of five species of migrant shorebirds in the Bay of Fundy. Proc. N.S. Inst. Sci. 29: 483-488.

Hicklin, P.W., L.E. Linkletter, and D.L. Peer. 1980. Distribution and abundance of Corophium volutator (Pallas), Macoma baltica (L.) and Heteromastus filiformis (Clarapede) in the intertidal zone of Cumberland Basin and Shepody Bay, Bay of Fundy. Can. Tech. Rept. Fish. Aquat. Sci. No. 965, 56 p.

Hildebrand, K.I. 1981. Aspects of the feeding ecology of the lesser yellowleg Tringa flavipes at Ram Pasture salt Marsh. B.Sc. Hons. thesis, Mount Allison University, 58 p.

Hughson, W.B. 1977. Fundy avifauna: an overview. In Daborn, G.R., ed. Acadia University Inst. Publ. No. 28, pp. 180-186.

Lock, A.R. 1982. An aerial census of Common Eider breeding populations in Nova Scotia and southwestern New Brunswick. Can. Wild. Ser. Rept., 11 p.

Morrison, R.I.G. 1977. Use of the Bay of Fundy by shorebirds. In: Daborn, G.R., ed., Fundy tidal power and the environment. Acadia University Inst. Publ. No. 28, pp. 187-199.

Morrison, R.I.G. 1978a. Maritimes shorebird survey, 1976. Preliminary Report. Can. Wild. Ser., Ottawa.

Morrison, R.I.G. 1978b. Maritimes shorebird survey 1977. Preliminary Report. Can. Wild. Ser., Ottawa.

Morrison, R.I.G. and C.L. Gratto. 1979. Maritimes shorebird survey, 1978. Preliminary Report, Can. Wild. Ser., Ottawa.

Peach, H.C. 1981. The foraging ecology of adult and juvenile semipalmated plovers (Calidris semipalmatus, Bonaparte) on the Starrs Point mudflat, Minas Basin. B.Sc. Hons. thesis, Acadia University, 78 p.

Pearce, P.A. and A.D. Smith. 1974. The potential influence on waterfowl of port and tidal power development in the Bay of Fundy. Can. Wild. Ser. Rept. Ser. No. 29: 91-100.

Pettingill, O.S. Jr. 1939. The bird life of the Grand Manan Archipelago. Proc. N.S. Inst. Sci. 19: 193-272.

Quinney, T. E. 1979. Reproductive success, growth of nestlings and foraging behaviour of the great blue heron. M.Sc. thesis, Acadia University, 143 p.

Quinney, T.E. and P.C. Smith. 1980. Comparative foraging behaviour and efficiency of adult and juvenile great blue herons. Can. J. Zool. 58: 1168-1173.

Reid, P.R. 1982. Aspects of the winter ecology and behaviour of bald eagles (Haliaeetus leucocephalus alascanus, Townsend) on the Shubenacadie River, Nova Scotia. M.Sc. thesis, Acadia University, 131 p.

Smith, A.D. 1980. Great blue heron colonies in the Maritime Provinces. Can. Wild. Ser. Unpublished Rept., 20 p.

Squires, W.A. 1976. The Birds of New Brunswick. Second edition. New Brunswick Museum, Saint John, 221 p.

Tufts, H.F. 1898-99. Notes on the birds of Kings County, N.S. Parts I, II, and III. Reprint of Ottawa Naturalist 12 (9, 11, 12).

Tufts, R.W. 1917. Notes on the birds of the Grand Pre region, Kings County, Nova Scotia. Trans. N.S. Inst. Sci. 14: 154-199.

Tufts, R.W. 1973. The Birds of Nova Scotia. Second edition. Nova Scotia Museum, Halifax, 532 p.

Yeo, R.K. 1977. Animal-sediment relationships and the ecology of the intertidal mudflat environment, Minas Basin, Bay of Fundy, Nova Scotia. M.Sc. thesis, McMaster University, 396 p.

Analysis of the Bay of Fundy Ecosystem

Peter Schwinghamer

Marine Ecology Laboratory
Bedford Institute of Oceanography
P.O.Box 1006
Dartmouth, Nova Scotia B2Y 4A2

ABSTRACT

An argument is made for development of a holistic simulation model of the Bay of Fundy ecosystem and a simplified example given of the analytic approach required.

Key words: Bay of Fundy, ecosystem analysis

RÉSUMÉ

On présente un argument en faveur de la mise au point d'un modèle global de simulation de l'écosystème de la baie de Fundy et un exemple simplifié de la méthode analytique à appliquer.

INTRODUCTION

The explicit goal of each talk in this Session has been to review what is known about the behavior of a specific set of variables in the Bay of Fundy ecosystem, but the reason for this multidisciplinary day is to place this knowledge in a whole ecosystem context. We have seen examples of how knowledge of the environment can be incorporated into an understanding of the dynamics of sets of individual variables. From these examples, it seems to me that although there has been no formal ecosystem analysis the important determinants of many components in the Bay of Fundy ecosystem are beginning to be well understood.

These examples may be taken as analogous to a set of independently determined multiple regressions. The behavior of a dependent variable or set of variables has been explained, either mathematically or verbally, in terms of its relationship to a set of explanatory variables. In this sense, the information that has been presented in this session may be envisioned as a set of equations describing certain behaviors of the Bay of Fundy ecosystem.

The equations are interdependent. If we begin for example, with the observation that *Corophium* production is a function of local primary production (see Peer 1984 in this report) we find, in turn, other dependences. Primary production in the upper reaches of Fundy comes from three sources (Prouse et al. 1984), each determined by a separate set of factors some of which are common to all three, some interdependent, some also directly influencing Corophium production. Then in fact, analysis of the behavior of a given dependent variable in response to changes in any variable other than an independent driving variable requires the simultaneous solution of a set of interdependent equations.

To make predictions with acceptably narrow confidence limits, we must learn to devise and solve sets of "ecological equations" that are appropriate to the predictions being sought. This is one aspect of a holistic approach to ecosystem analysis. Holistic merely means "pertaining to the whole rather than its parts" and holistic ecosystem analysis seeks first to determine the behavior of the whole ecosystem, only then to infer from this the behavior of the relevant component variables. This is in contrast to reconstructing the various behaviors of the whole system by aggregating the behaviors of certain component parts. As many authors have argued (e.g. Kerr 1976, Mann 1975) this latter process is not possible, in general, because the a priori construction from isolated components lacks certain parameters - those that define the integrative features of the intact system. To use the example given by Mann (1975) knowing the properties of each and every cell of a rat won't tell us very much about the rat's behavior.

INTEGRATION OF HOLIST AND REDUCTIONIST ECOLOGICAL STUDIES

How then can we use the knowledge that we have gained about the individual components of the Bay of Fundy ecosystem to produce a picture of the ecosystem that in some useful way approximates reality? In answer, first it is necessary to realize that we must turn to some form of mathematical representation rather than a purely linguistic one in order to adequately represent the complexities that we want to include in our analysis. Otherwise we will soon become bogged down in verbiage without having produced much in the way of quantification of our knowledge. That is one very good reason why we should want to do ecosystem modelling.

However, ecologists often shy away from large-scale ecosystem modelling, being aware of some highly complex models with hundreds of state variables and interactions that, after great effort and expense, produce at best an indication of what the modellers didn't know. I would suggest that though they are often called holistic models, in general they do not fit the description that I have given of a holistic model. They really only represent a summation of the dis-integrated subsystems rather than an integrated view of the whole system. In the case of most ecosystem simulation models, the modellers can be envisioned as being presented with a bag full of jigsaw-puzzle pieces, some of which fit only imperfectly, some are redundant, and surely many are missing. The modellers have no clear idea what the final picture will look like but are expected to fit the pieces together. This is a difficult task. In the case of a holistic model, the pieces may be in a similar state but the modellers have before them a picture, at least in outline, of what the puzzle should look like when assembled. Thus poorly fitting pieces can be forced in, redundant ones discarded and holes worked around. Obtaining a final picture is then a much simpler task.

I propose that there is a relatively straight-forward way of fitting the pieces the Bay of Fundy puzzle together into a sensible picture. With present data and perhaps a relatively small but well-directed, additional data collection effort, a very useful ecosystem analysis could ensue. I will outline how I think this can be done.

A somewhat personal view of the process of concept development leading to an ecosystem model is illustrated in Fig. 1. Much of the process has been completed both in the development of perception of how the Bay of Fundy works and in the formal analysis, at least on the left-hand side of the figure. The development of our perceptions of Fundy depends, of course, upon what we abstract from our experience working on it. For most of us, while we work on our individual scientific endeavours (mostly on the left of Fig. 1), there is a constant feedback along the analytical process as well as between our quantitative knowledge on the left-hand side of Fig.1 and our non-quantitative observations and intuitions on the right. As I work through my studies on the benthos, for example, the knowledge gained is integrated not only into my plans for continued observation and experimentation but also into a continually evolving personal definition of "The Bay of Fundy". However, as I implied earlier, an adequate simulation of the Fundy ecosystem requires quantification, in some sense, not only on the left-hand side of Fig. 1 but on the right as well.

Studies that extend beyond species description, chemical measurement, or the like usually incorporate the next three steps in the formal analysis. That is, observations are analyzed either by statistical or physical experiments, hypotheses are generated, and some sort of verbal or mathematical model that explains the behavior of the object of study is then presented. In the analogous process of whole ecosystem analysis we should describe, from synoptic field observation, the behavior of some variables that we feel can represent whole system behavior in a holistic model. Identification of such variables is not easy. It is very difficult to measure, say, production of many species as functions of annual and spatial environmental changes, so holistic measures of ecosystem behavior based on population dynamics of species usually are not feasible. For similar and other more theoretical reasons (Peters 1977) trophically based measures are also difficult to obtain. In the hope of identifying suitable holistic variables, some scientists, mostly at the Marine Ecology Laboratory, the University of Toronto, and in the U.S.S.R. are pursuing the application of ecosystem description based upon an organism-size typology rather than species or trophic typologies. This work has developed out of extensive observations on pelagic biomass spectra by Sheldon and his co-workers (Sheldon and Parsons 1967, Sheldon et al. 1972) with later additions of both pelagic and benthic studies (Schwinghamer 1981, 1983, Sprules 1980, Harding et al. 1980, Tseytlin 1981). Theoretical work (Kerr 1974, Platt and Denman 1977, Silvert and Platt 1978, Sheldon et al. 1977, Sprules and Holtby 1979, Sprules and Knoechel 1983, Tseytlin 1982, Schwinghamer 1981, 1983) indicates that this approach provides a means of describing ecosystem structure from which dynamical hypotheses can be formulated. This illustrates that whole ecosystem behavior can be quantified and analyzed in a process analogous to that applied to more reductionist studies.

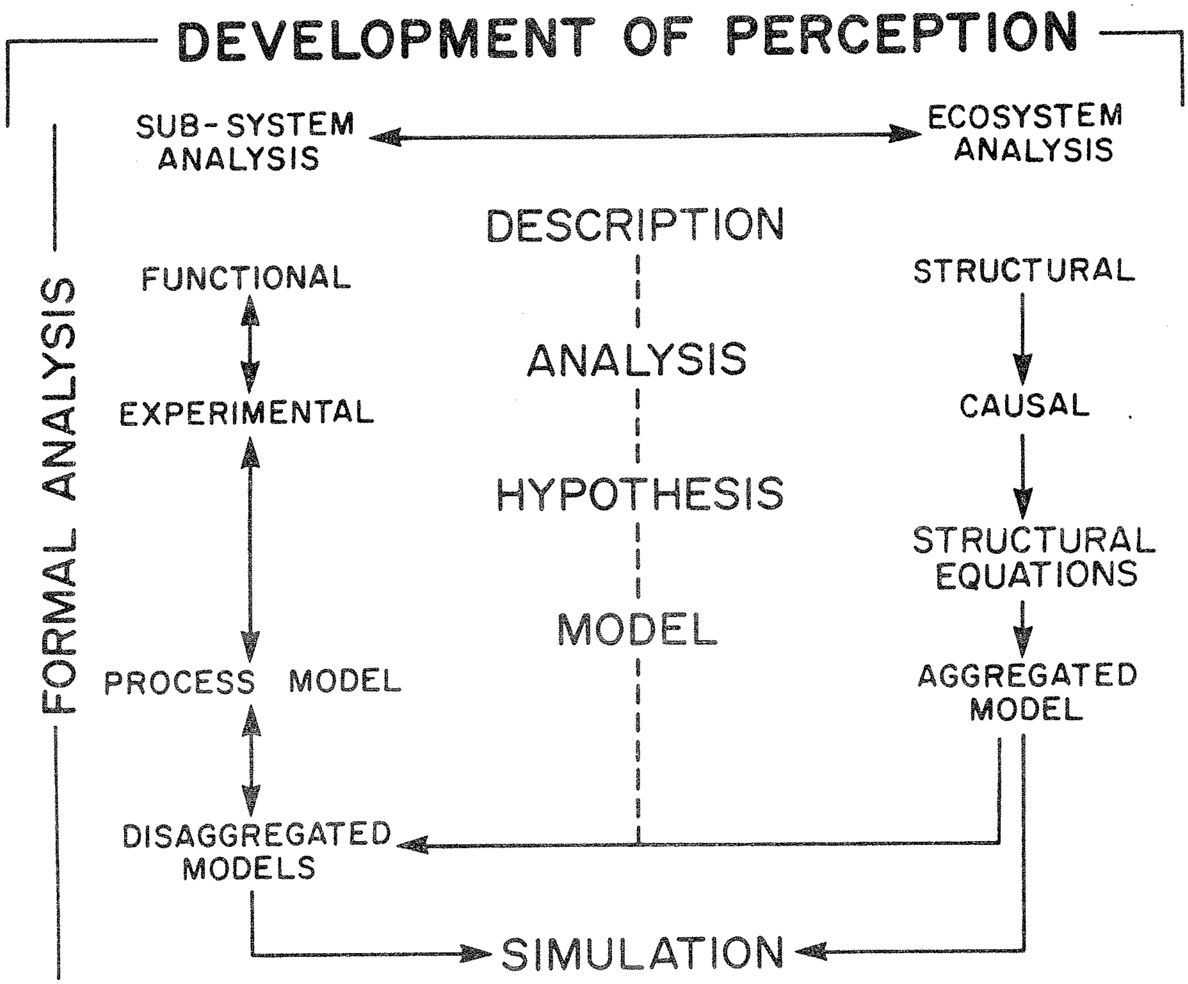


Fig. 1. A proposal for integration of holistic and reductionist ecological studies for the production of an ecosystem simulation model.

AN EXAMPLE

An example of how some aspects of the dynamics of a whole community of organisms over an annual cycle can be represented by biomass spectra is shown in Fig. 2 (from Schwinghamer 1983). Notice that the size range is from bacteria to macrofauna, that abundance in each log size class is in terms of volume per unit area of bottom and that three groups of organisms (bacteria, meiofauna, macrofauna) are well defined by their size limits and their seemingly independent dynamics. These three groups of organisms, plus benthic microalgae, were the variables of interest in an analysis of the benthic ecosystem that I undertook (Schwinghamer 1983).

The next two steps on the right in Fig. 1, holistic analysis and hypothesis formulation, can be done using quasi-statistical procedures, lumped under the rubric of "causal analysis", which provide ways of simultaneously solving a set of ecological equations (see Heise 1975 for an introduction to the subject of causal analysis). Causal analysis, by an iterative process, leads to the formulation of a most plausible hypothetical network of cause-and-effect relations among the dependent variables, and between them and the most significant explanatory variables.

A hypothetical structural model of the Peck's Cove benthic ecosystem based on causal analysis is illustrated in Fig. 3 (from Schwinghamer 1983). Certainly, it is not as complex as a species-based model would be but for our purpose it is most useful. The dependent variables (labelled "endogenous") are the total biomasses of the four groups of organisms identified earlier. The explanatory ("exogenous") variables are a small subset of all the measured environmental variables. They are the ones whose direct effects elicited strong statistical responses on the part of the endogenous variables and whose effects could be explained in some mechanistic fashion. The strengths and directions of significant (and sensible) relationships are indicated by the "paths" included in the diagram. The "path coefficients" indicate the relative strengths of relationships in this study. The arrows point to the affected variable. The statistical "fit" of this model to the data was better, in aggregate, than any other that was tried.

Causal analysis gives us a working hypothesis on which to proceed with selection of important processes for inclusion into a holistic simulation model. It is important to realize in the present example that all of the dynamics and interactions observed in the Peck's Cove benthic community must be constrained to produce an aggregate outcome such that the biomass spectrum would look like it does in Fig. 2. We are then at the level of the disaggregated model (all of the process models) on the left-hand side of Fig. 1, and the aggregated model on the right. Back to the puzzle analogy, we have the pieces (the process models) and we have the box cover with the picture on it (the biomass spectrum and causal hypotheses).

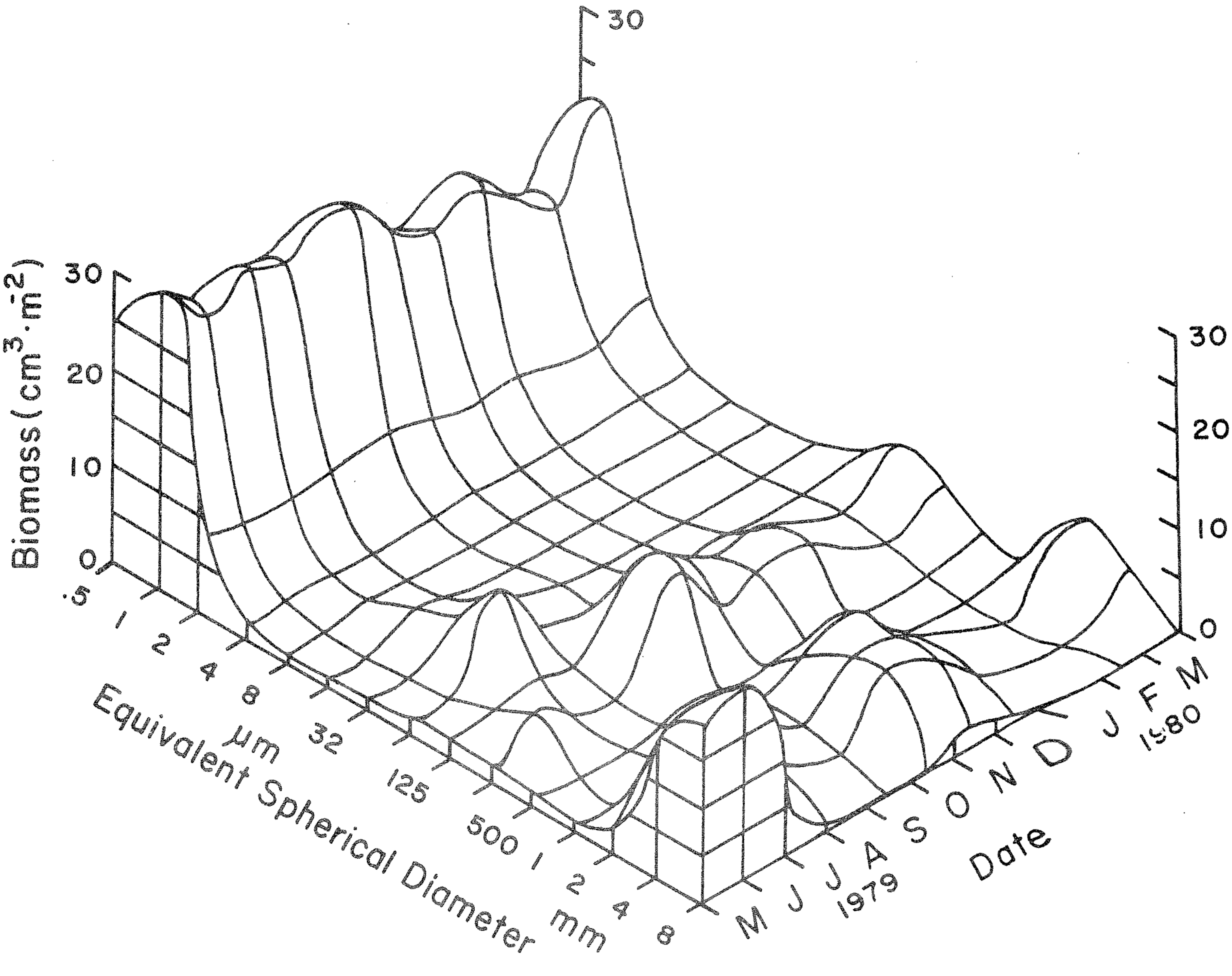


Fig. 2. Fluctuations in the biomass spectrum of the benthic community at Peck's Cove, N.B. over an annual cycle.

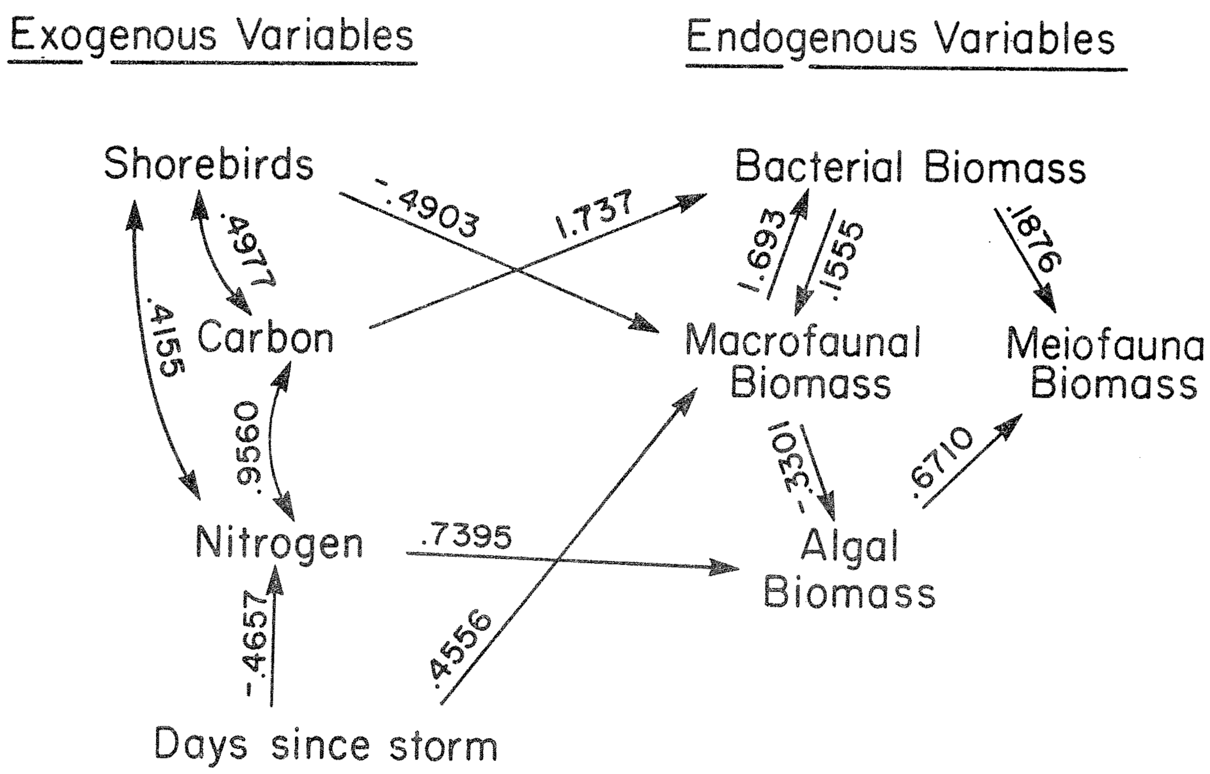


Fig. 3. Hypothetical causal model of biomass fluctuations in the Peck's Cove benthic community. The double-headed curves arrows are unanalyzed correlations. For further explanation see text.

CONCLUSION

Obviously, I have simplified the whole process of ecosystem modelling in order to make a point. However, I do think that a simulation model of the Bay of Fundy ecosystem that would provide sensible output could be achieved. Recognizing the importance of the feedbacks in the process of development, the actual simulation modelling must involve the scientists who have brought the analysis to the process model and aggregated model stage if the simulation is to be more than just mathematically correct. The example of the intensive modelling workshops of the group working on the Ems-Dollard estuary in Holland (Ruardij and Baretta 1982) would be useful to emulate in this respect.

It may be that more data are required to achieve an effective simulation model of the Bay of Fundy. However, the additional time and effort would be minimized and the results maximized if quantitative holistic analysis were developed concommitantly with the reductionist analysis of particular processes.

ACKNOWLEDGMENTS

I thank Don Gordon and Bill Silvert for their comments and ideas. Discussions with many Fundy workers, especially Barry Hargrave, Mike Dadswell, Graham Daborn, Dave Wildish and Don Peer have been most helpful.

REFERENCES

Harding, G., P. Vass, and S. Pearre. 1980. Seasonal abundance, biomass, lipid content, size composition, and mean biomass of plankton. In: Physical oceanography, dissolved nutrients, phytoplankton production, plankton biomass, and sedimentation in St. Georges Bay, N.S. 1977. Can. Tech. Rep. Fish. Aquat. Sci. No. 934, pp. 23-34.

Heise, D.R. 1975. Causal Analysis. John Wiley and Sons Inc, New York, 301 p.

Kerr, S.R. 1974. Theory of size distribution in ecological communities. J. Fish. Res. Board Can. 31: 1859-1862.

Kerr, S.R. 1976. Ecological analysis and the Fry paradigm. J. Fish. Res. Board Can. 33: 329-332.

Mann, K.H. 1975. Relationship between morphometry and biological functioning in three coastal inlets of Nova Scotia. In: Cronin, L.E. ed. Estuarine Research, Vol. 1, Chemistry, biology, and the estuarine system, Academic Press, New York, pp. 634-644.

Peer, D.L. 1984. A review of benthic macrofaunal production of the upper Bay of Fundy intertidal area. In this report.

Peters, R.H. 1977. The unpredictable problems of tropho-dynamics. Env. Biol. Fish. 2: 97-101.

Platt, T., and K. Denman. 1977. Organisation in the pelagic ecosystem. Helg. wiss. Meeresunters. 30: 575-581.

Prouse, N.J., D.C. Gordon Jr., B.T. Hargrave, C.J. Bird, J. McLachlan, J.S.S. Lakshminarayana, J. Site Devi and M.L.H. Thomas. 1984. Primary production: organic matter supply to ecosystems in the Bay of Fundy. In this report.

Ruardij, P., and J.W. Baretta. 1982. The Ems-Dollart ecosystem modelling workshop (23-27 February 1981). Biological Onderzoek Ems-Dollard Estuarium. Publicaties en Verslagen, No. 2, 46 p.

Schwinghamer, P. 1981a. Characteristic size distributions of integral benthic communities. Can. J. Fish. Aquat. Sci. 38: 1255-1263.

Schwinghamer, P. 1983. Generating ecological hypotheses from biomass spectra using causal analysis: a benthic example. Mar. Ecol. Prog. Ser. 13: 151-166.

Sheldon, R.W., and T.R. Parsons. 1967. A continuous size spectrum for particulate matter in the sea. J. Fish. Res. Board Can. 24: 909-915.

Sheldon, R.W., A. Prakash, and W.H. Sutcliffe, Jr. 1972. The size distribution of particles in the ocean. Limnol. Oceanogr. 17: 327-340.

Sheldon, R.W., W.H. Sutcliffe, Jr., and M.A. Paranjape. 1977. Structure of pelagic food chain and relationship between plankton and fish production. J. Fish. Res. Board Can. 34: 2344-2353.

Silvert, W., and T. Platt. 1978. Energy flux in the pelagic ecosystem: A time-dependent equation. Limnol. Oceanogr. 23: 813-816.

Sprules, W.G. 1980. Zoogeographic patterns in the size structure of zooplankton communities, with possible applications to lake ecosystem modelling and management. In W.C. Kerfoot ed. Evolution and ecology of zooplankton Communities. Univ. Press of New England, pp. 642-656.

Sprules, W.G., and L.B. Holtby. 1979. Body size and feeding ecology as alternatives to taxonomy for the study of limnetic zooplankton community structure. J. Fish. Res. Board Can. 36: 1354-1363.

Sprules, W.G., and R. Knoechel. 1983. Lake ecosystem dynamics based on functional representation of trophic components. In: Myers, D., and R. Strickler eds. Trophodynamics in aquatic ecosystems, AAAS Symposium, in press.

Tseytlin, V.B. 1981. Size distribution of pelagic organisms in tropical ocean regions. Oceanology 21: 86-90.

Tseytlin, V.B. 1982. Ecological effectiveness and size distribution of pelagic animals. Dokl. Akad. Nauk. SSSR. 260: 451-453.

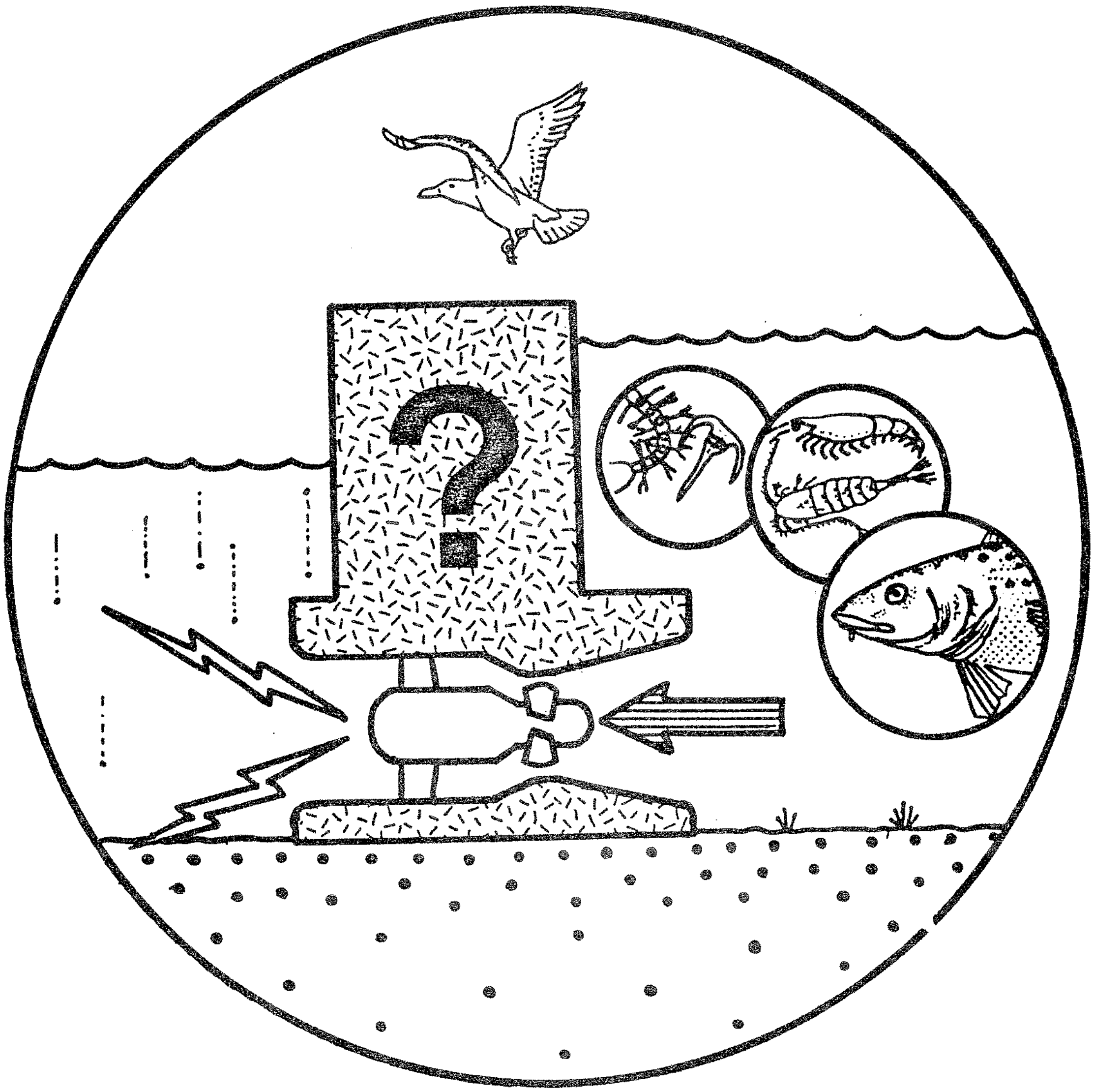
QUESTIONS AND COMMENTS

K. Mann: I think I have followed your argument for getting on with the modelling of the benthic system. Modelling the entire Bay however requires a pelagic component. Do you feel that your recommended approach can be realistically extended to the pelagic system to include and integrate the numerous surveys done along the axis of the Bay?

P. Schwinghamer: I did not want to complicate things too much by introducing compartments. The regular model formulations generally used which deal with functions within compartments and flows between compartments can use this approach quite effectively. There is no reason why compartments can't be coupled functionally with functions constrained to operate within the whole system as well as within compartments. I don't have any illusions about the whole process being very simple but I think it is a much more useful process than adding more variables and interactions to already complex models.

SESSION II

Engineering details of proposed tidal power projects.



Engineering description and physical impacts of the most probable tidal power project(s) under consideration for the upper reaches of the Bay of Fundy

George C. Baker

Nova Scotia Tidal Power Corporation
536 Main Street
Kentville, N.S.
B4N 1L3

ABSTRACT

This paper briefly describes some of the engineering details of proposed large scale tidal power developments in the upper reaches of the Bay of Fundy (Cobequid Bay and Cumberland Basin). Both construction and operation aspects are considered. It also contains predictions of changes in headpond water elevations.

Key words: tidal power development, Cobequid Bay, Cumberland Basin, engineering design.

RÉSUMÉ

Dans cet article, on décrit brièvement certains détails techniques du projet d'aménagement d'une vaste usine marémotrice dans la partie supérieure de la baie de Fundy (baie Cobequid et bassin Cumberland). On examine à la fois les détails de construction et d'exploitation. On formule aussi quelques prédictions sur les variations du niveau des eaux dans l'aire de retenue.

PREFACE

The engineering studies to date have all been of the nature of feasibility studies. They have resulted in designs which might well be altered due to economic, engineering, marketing or environmental considerations in any project actually committed for construction. The data presented here should therefore be regarded only as indicative of a probable range rather than as a set of precise specifications.

PROJECTS CONSIDERED

Developments considered economically attractive are:
Site B9 (Cobequid Bay)
Sites B9 and A8 (Cobequid Bay and Cumberland Basin) combined
Site locations are shown in Fig. 1 and the main characteristics of both possible developments are given in Table 1.

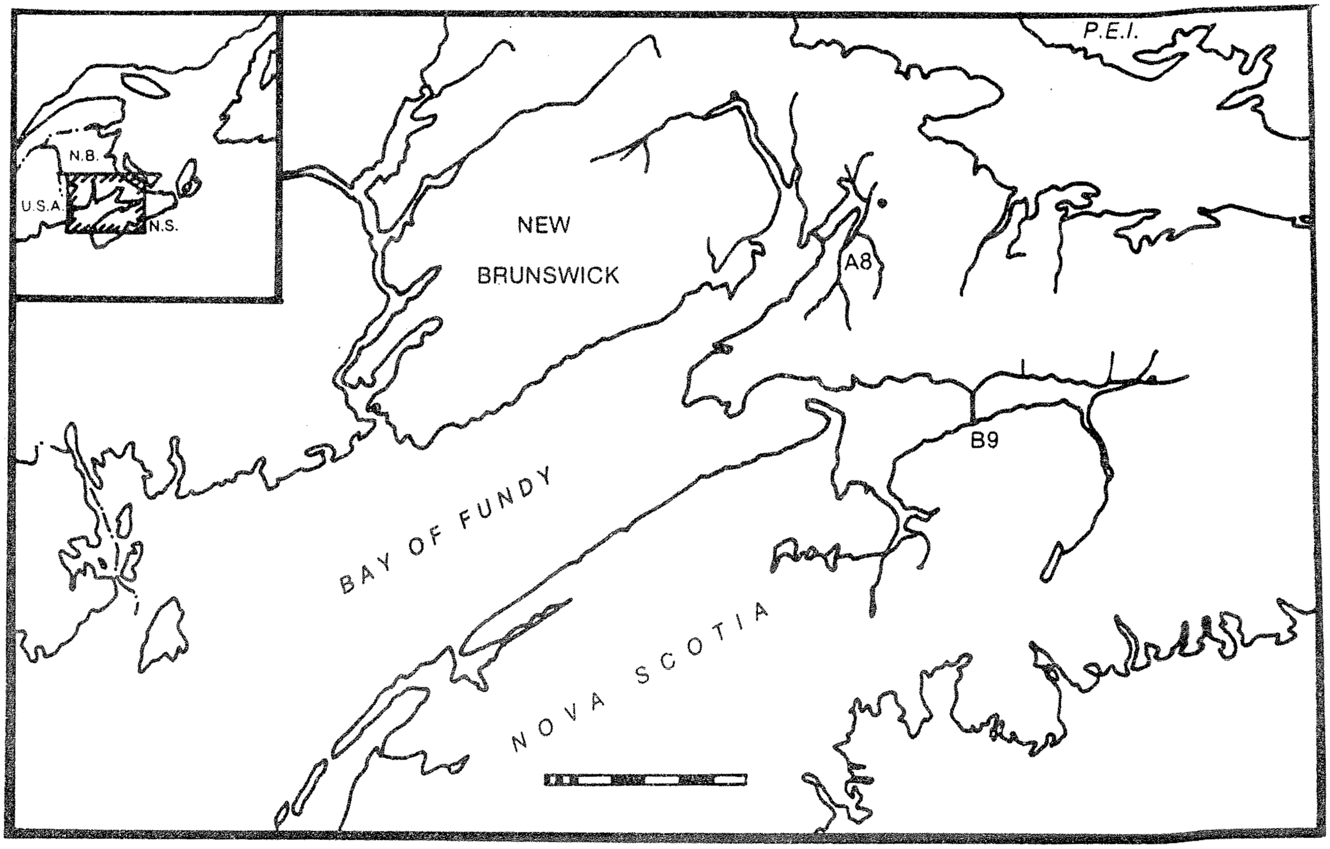


Fig. 1. Map showing location of possible tidal power development sites.

TABLE 1. Characteristics and costs (in 1981 dollars) of possible tidal power schemes in the upper reaches of the Bay of Fundy. See Fig. 1 for locations.

	SITE B9		SITE A8
	1981 New Method	1981 New Method	
Total number of powerhouse units	106	128	37
Number of Sluices (Shallow)	6	70	---
Number of Deep Sluices	44	22	---
Number of Spare Units	6	8	2
Rated unit output MVW	38	38	31
Installed Capacity MW	4028	4864	1147
Net Plant Capacity MW	3800	4560	1085
Net annual energy GWh	11766	14004	3183
Capacity Factor (%)	35.4	35.1	33.5
Cost Estimate ($\$x10^6$)			
(a) Total Direct Cost	3524	4011	1153.2
(b) Indirect and interest plus contingency	2493	3019	726.1
(c) Total Capital Cost	6017	7030	1879.3
Annual Charge (c) x .05531	332.8	388.8	103.9
Cost of Energy mills/KWh	28.3	27.8	32.6

SITE B9 CONSTRUCTION

Construction facilities are shown in Fig. 2 and barrage plan and elevation in Fig. 3. The construction method would use caissons to the greatest extent possible. These would be, in varying quantities, turbine caissons, deep sluice caissons, shallow sluice caissons, temporary sluice cribs, and blind cribs. The barrage (for 128 units) would consist of:

1200 m access dyke
24 wharf cribs
1 closure crib
6 crib sluices
12 shallow sluices
66 powerhouse caissons
15 shallow sluices
4 powerhouse caissons
5 deep sluices
8 shallow sluices
10 crib sluices
6 cribs
800 m closure dyke

Method of placement would involve excavating soft sediments, construction of berms to protect mattress, laying of sand and gravel mattress, and caisson placement. Closure dyke would be formed by end dumping on drying flats at low tide. The construction schedule is shown in Fig. 4.

More detailed information on the proposed design of dykes, cribs, slices and powerhouse units can be obtained from the Nova Scotia Tidal Power Corporation.

SITE B9 TURBINES

Choice of type is between bulb and Straflo, which would in any case be hydraulically similar. They might be fixed blade machines with wicket gate regulation, double regulated with variable pitch blades, or asynchronous (variable speed) machines without mechanical regulation. The throat diameter would probably be 7.5 m and, if synchronous, the speed would be 67.92, 69.23, 72, or 75 r.p.m.

SITE B9 OPERATION

Feasibility study designs are for single effect operation. Water elevations for mean, small and spring tides are shown in Figs. 5 and 6. Approximate changes in phase and amplitude of flows through the barrage from the start of construction to full operation are shown in Fig. 7.

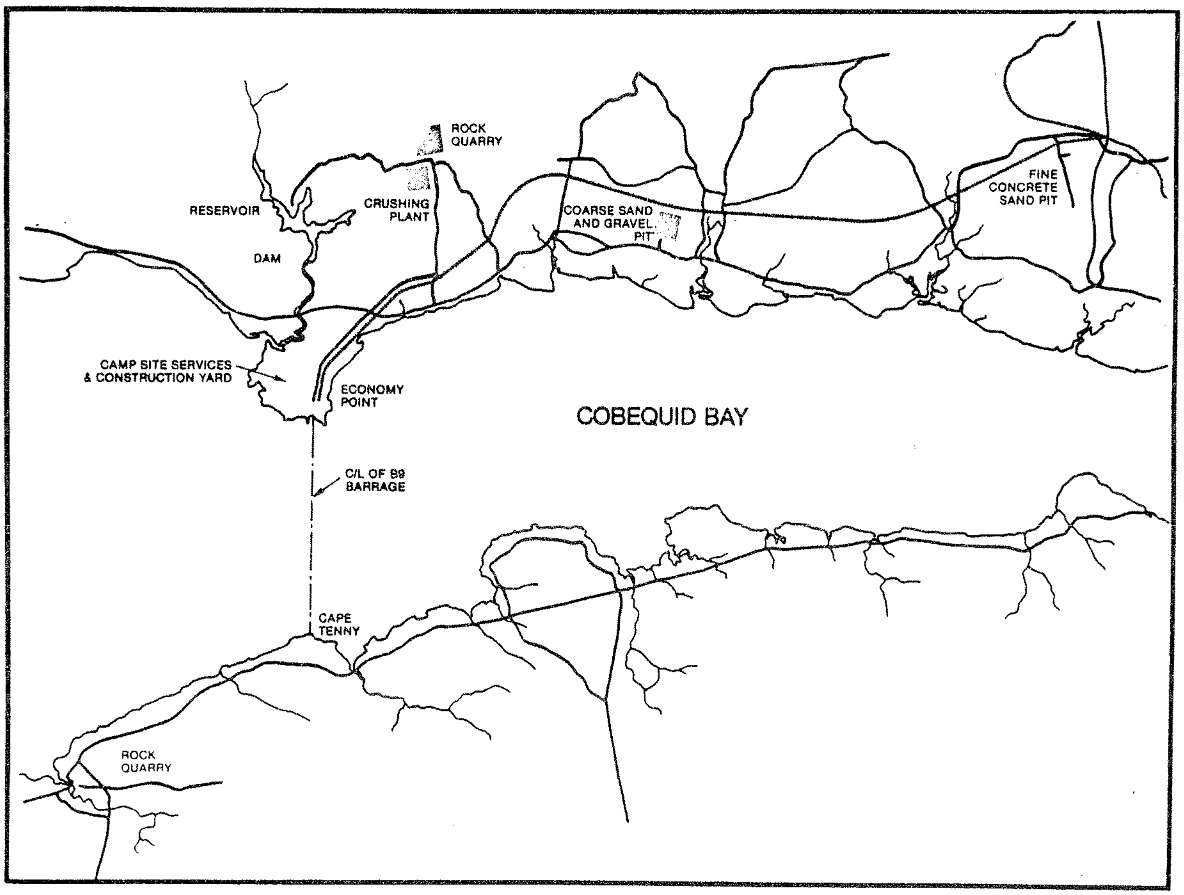


Fig. 2. Map showing proposed construction facilities for the B9 project at Economy Point/Cape Tenny.

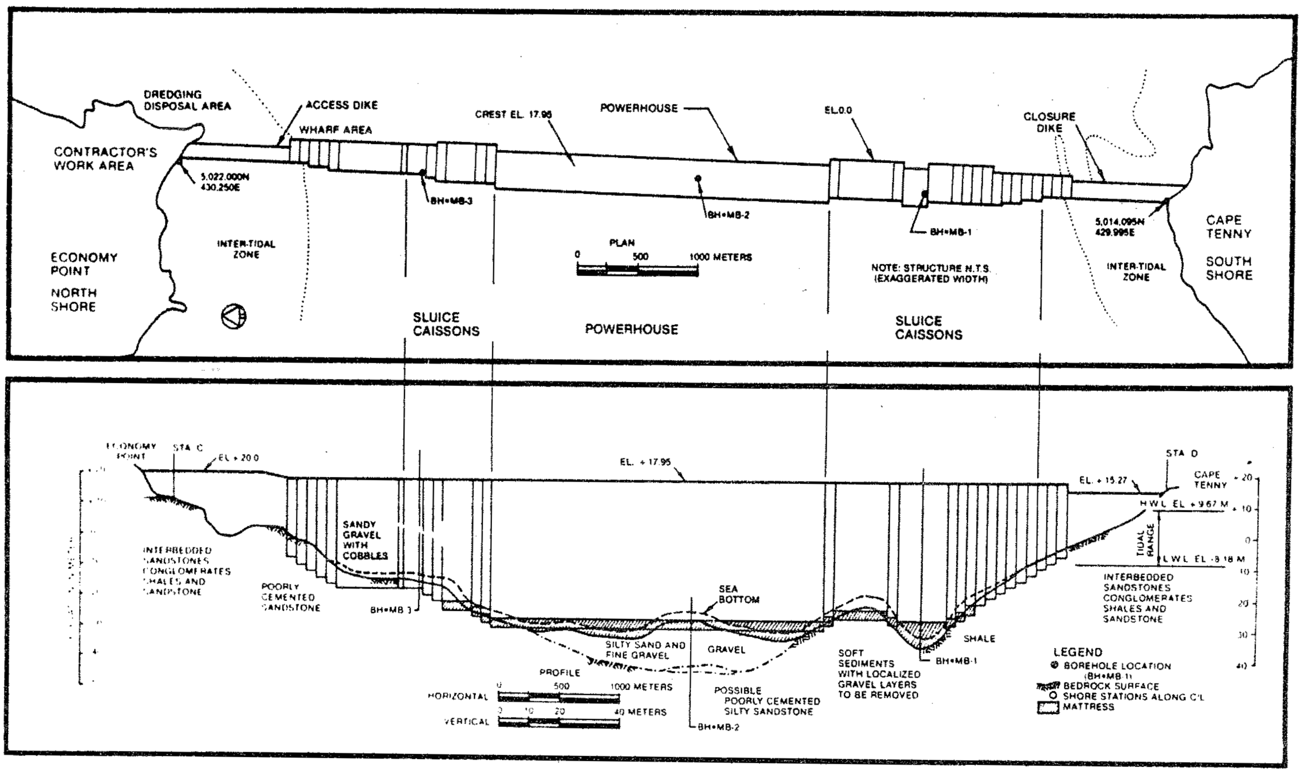


Fig. 3. Proposed barrage plan and elevation for the B9 project.

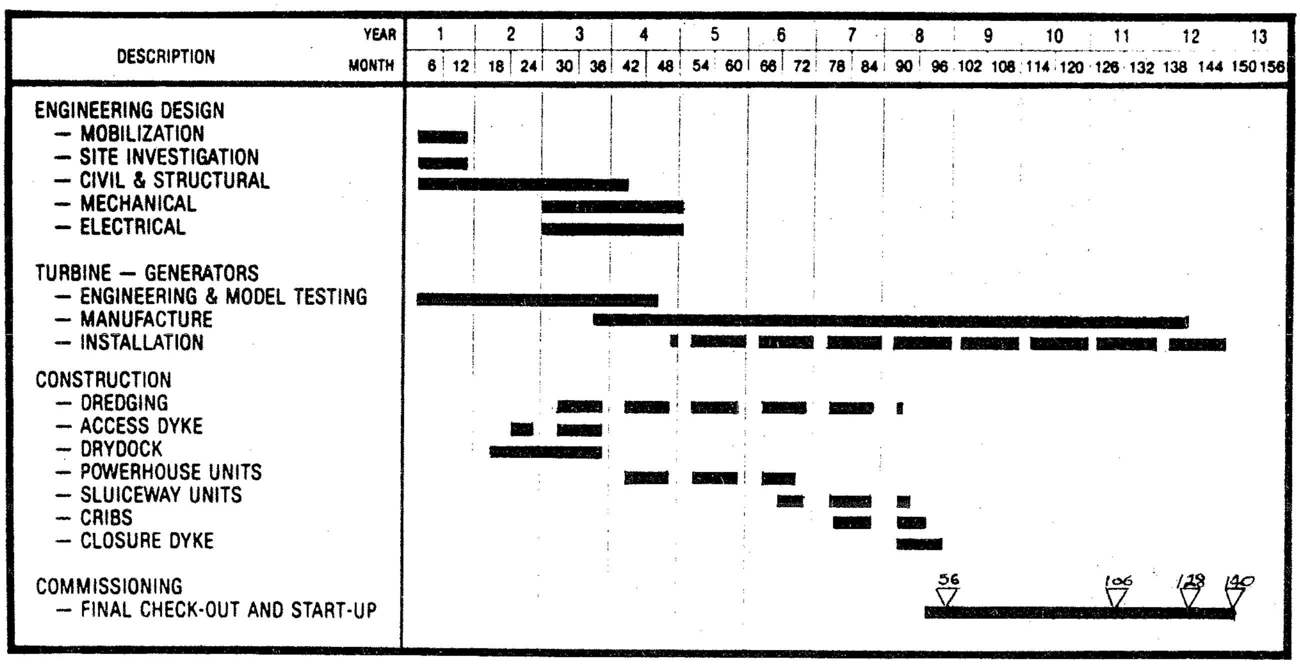


Fig. 4. Proposed construction schedule for the B9 project.

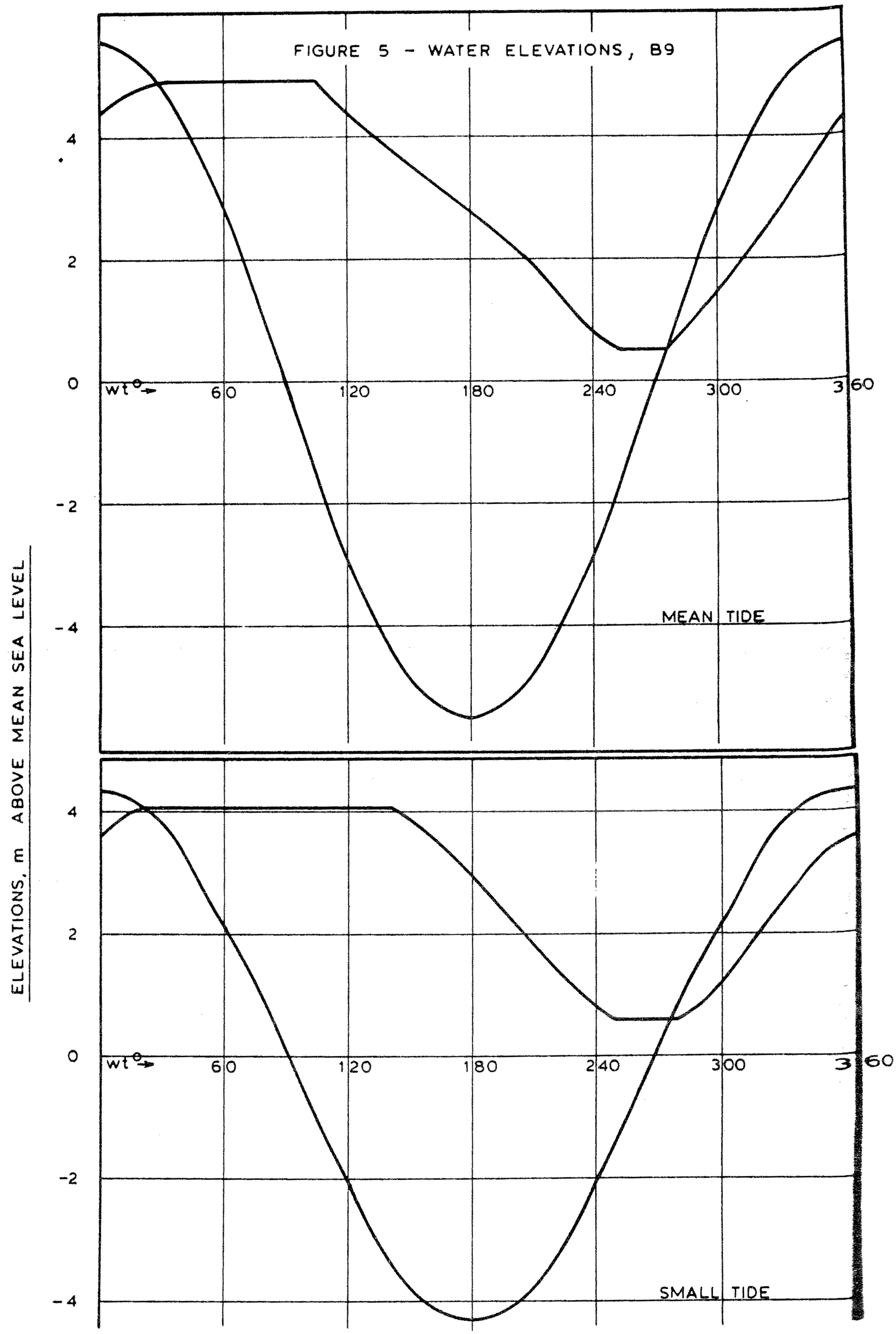


Fig. 5. Water elevations for single effect operation on small and mean tides.

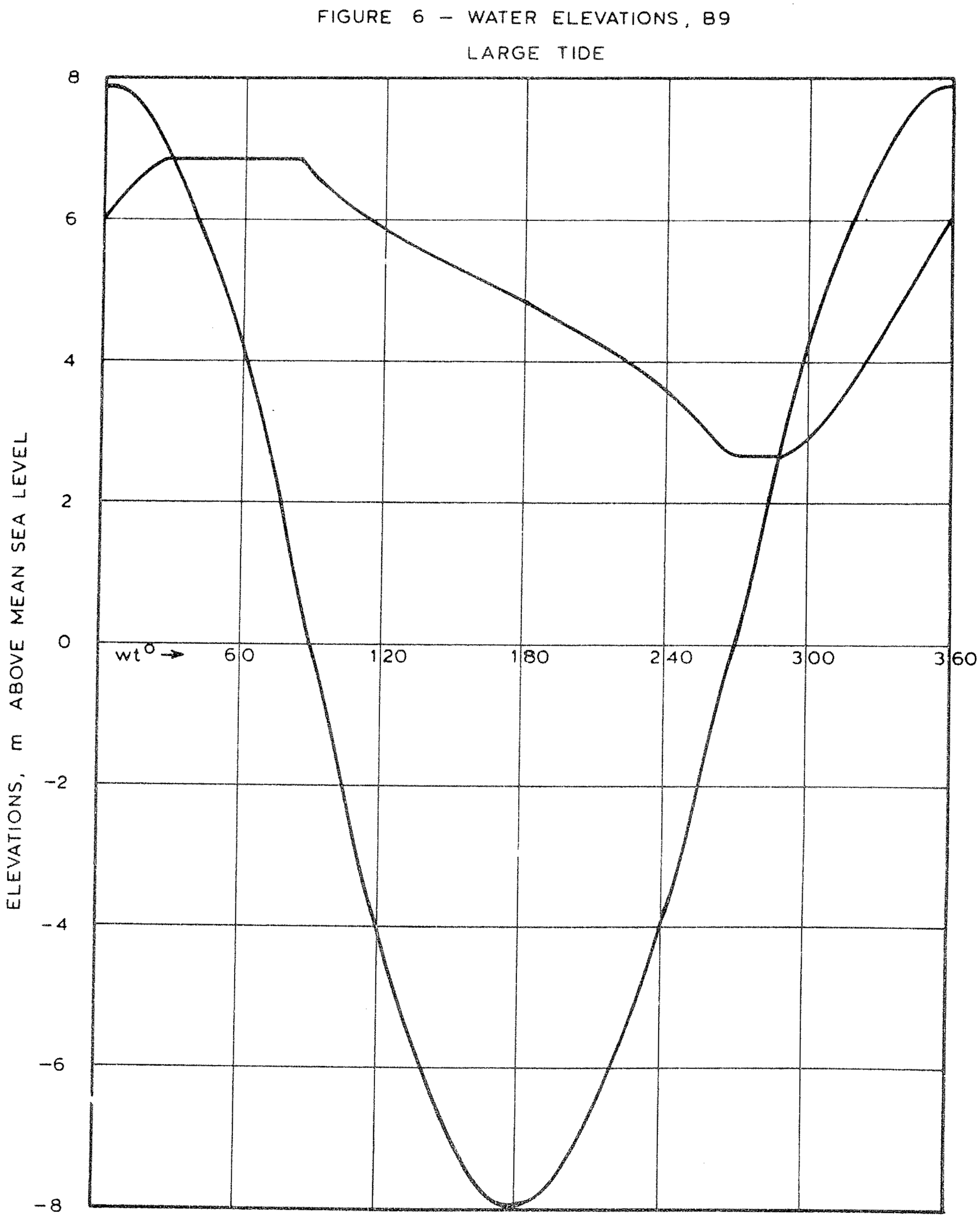


Fig. 6. Water elevations for single effect operation on a large tide.

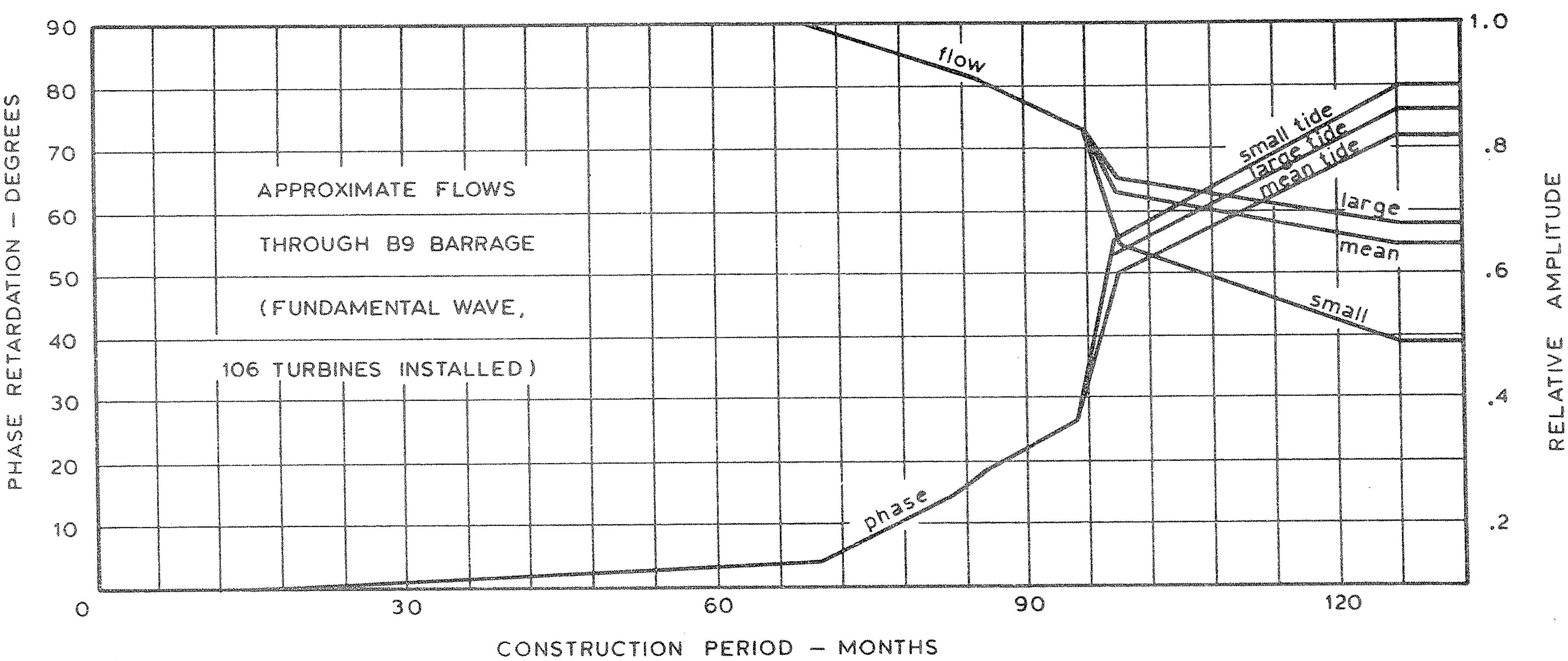


Fig. 7. Changes in phase and amplitude of flows through the B9 barrage from start of construction to full operation.

TIDAL AND BATHYMETRIC DATA

Headpond storage curves and annual tidal histograms for both sites are given in Tables 2 and 3. Mean sea level is 8.1 and 7.8 m above chart datum at B9 and A8, respectively.

SITE A8

New construction methods and schedules were developed in the most recent feasibility study with specific reference to B9. No similarly detailed work was carried out for A8. Nevertheless, it can safely be assumed that the method described above for B9 would also be used for A8.

Because of the relatively narrow mouth of Cumberland Basin, closure requirements are thought likely to limit the number of turbines at that site to 37, with approximately 24 sluices.

The caisson types and equipment types would be similar to B9. Turbines would probably be of 7.5 m diameter, but of somewhat lower rated head and slightly slower speed.

No construction schedule based on the preferred method of construction is available.

TABLE 2. Reservoir storage curves (elevations above chart datum)

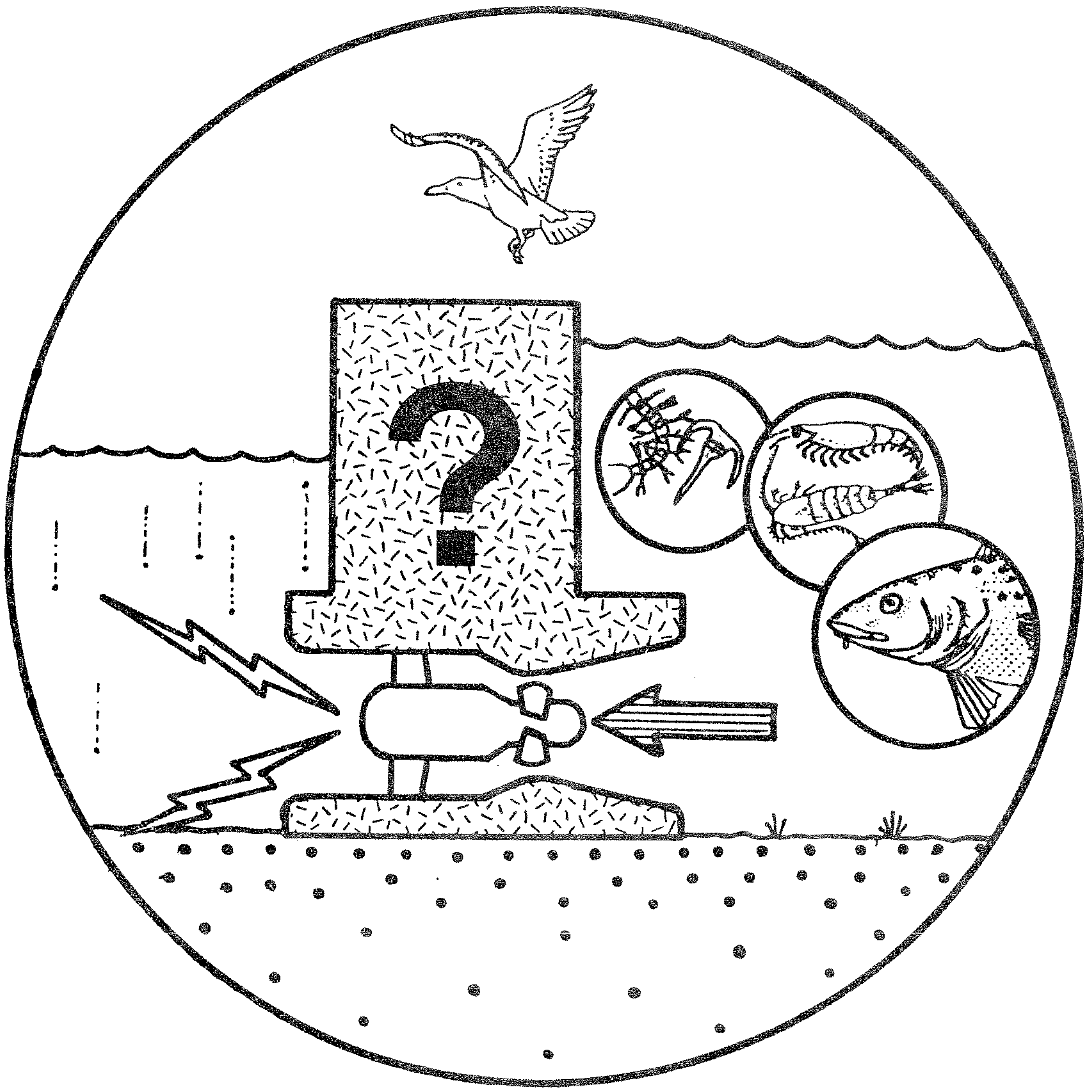
SITE B9		SITE A8	
Elevation (m)	Area (km^2)	Elevation (m)	Area (km^2)
17.270	311.320	15.996	112.150
14.220	293.960	12.948	102.300
11.170	281.530	9.900	95.312
8.130	261.590	6.852	86.247
5.080	225.590	3.804	69.412
2.030	172.750	.756	51.541
0.	118.620	-2.292	36.001
-1.020	106.970		

TABLE 3. Annual tidal histograms.

SITE B9		SITE A8	
Range (m)	Stage 2 Histogram	Range (m)	Stage 2 Histogram
7.75	0	6.75	0
8.25	0	7.25	10
8.75	2	7.75	46
9.25	33	8.25	55
9.75	71	8.75	78
10.25	62	9.25	74
10.75	79	9.75	116
11.25	82	10.25	100
11.75	99	10.75	85
12.25	101	11.25	49
12.75	51	11.75	44
13.25	35	12.25	28
13.75	25	12.75	19
14.25	32	13.25	1
14.75	18		
15.25	14		
15.75	1		

SESSION III

Preliminary predictions of possible environmental impacts resulting from tidal power development.



The Effects of Tidal Power Development on the Physical Oceanography of the Bay of Fundy and Gulf of Maine

David A. Greenberg

Coastal Oceanography
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia B3A 4A2

ABSTRACT

Predicted changes in physical oceanography due to the installation of tidal power barriers in the upper Bay of Fundy are reviewed. Away from the barrier site, the changes induced are small compared to the natural variation in the system, but in many areas still of potential significance. Changes in the vicinity of the barrier and in the headpond would be more dramatic and depend on the type and level of installation.

Key words: tidal power development, physical oceanography, Bay of Fundy, Gulf of Maine.

RÉSUMÉ

Dans le présent article, on étudie les variations prévues des conditions océanographiques physiques, qu'entraînera l'aménagement des digues d'une usine marémotrice dans la partie supérieure de la baie de Fundy. A une certaine distance du site de l'endiguement, les variations créés seront faibles par rapport aux variations naturelles du système, mais peut-être notables dans de nombreux secteurs. Aux alentours de l'endiguement et dans les eaux de retenue, les modifications risquent d'être beaucoup plus importantes, et dépendront du type d'eménagement et de son niveau.

INTRODUCTION

Although tidal power has been studied for some time, with schemes considered in Passamaquoddy (see for example IPEB 1961), and in the upper Bay of Fundy (ATPPB 1969) it was not until the study of the Bay of Fundy Tidal Power Review Board (BFTPRB 1977) that wider issues of the environmental effects of the schemes in the upper Bay were addressed (Daborn 1977). It was also realised around this time that the changes in tidal response would be more far reaching than previously thought (Heaps and Greenberg 1974).

In this paper possible changes in the physical oceanography of the Bay of Fundy due to tidal barriers are described and compared the natural variation in the system. This paper updates some of the predictions made in Garrett (1977) and Greenberg (1977). The changes in tidal sea levels, as found in numerical model studies (Greenberg 1979), are presented and some implications of these changes are discussed.

TIDAL ELEVATION

Changes in the tidal response of sea level in the Bay of Fundy and Gulf of Maine due to tidal power development have been calculated using a numerical model (Greenberg 1979). These are accounted for in terms of the free period and energy characteristics of the system. The barrier locations most favored are in upper Chignecto Bay across Shepody Bay, across Cumberland Basin and in Minas Basin at Economy Pt. (Fig. 1).

Barriers across the mouths of Shepody Bay and Cumberland Basin would give rise to very similar changes in tidal regime. The M_2 tidal amplitude of the sea level elevation (Fig. 2) decreases at the barrier and throughout the upper Bay of Fundy. The magnitude of this change diminishes from the head of the Bay changing to an increase in tidal amplitude in the lower Bay and throughout the Gulf of Maine. There seems to be little change away from the Gulf along the continental shelf.

These widespread changes are caused by the shifting of the free periods of the Bay of Fundy and of the combined Fundy-Gulf of Maine systems. Resonant amplification occurs when a system is forced near its preferred period of oscillation. The Bay of Fundy has a natural period of oscillation of about 9 hrs. (Rao 1968). A barrier which shortens the Bay, decreases this period, moving it further away from the forcing tidal period of 12.42 hours, which decreases the amplification from the mouth to the head of the Bay. The period of the Bay and Gulf combined is about 13 hours (Garrett 1972, 1974). Shortening this period brings it closer to the tidal forcing period, thus increasing the reasonant amplification. In the Bay of Fundy these two effects compete causing the tidal sea level decrease which dominates at the head of the Bay and the increase which dominates at the mouth.

A barrier in the Minas Basin at Economy Point leads to larger increases in tidal amplitude throughout the Bay and Gulf (Fig. 3) except for the area very close to the barrier. The difference in the regimes resulting from these two barrier locations is the result of the reduced transport at the Economy Point barrier site being felt downstream near Cape Split releasing energy that is dissipated by friction in the natural system. Increased capacity would necessitate more or larger turbines and greater flow. Consequently, an increase in capacity of the Economy Point barrier decreases further the tide at the barrier because increased flow leads to more energy dissipated by Cape Split. Changes in the capacity of Shepody and Cumberland barriers had little effect at the barriers and in all cases capacity changes had little effect downstream. Similarly, differences in types of generation (see "Headpond Tidal Affects" below) would have comparable effects away from the barrier site.

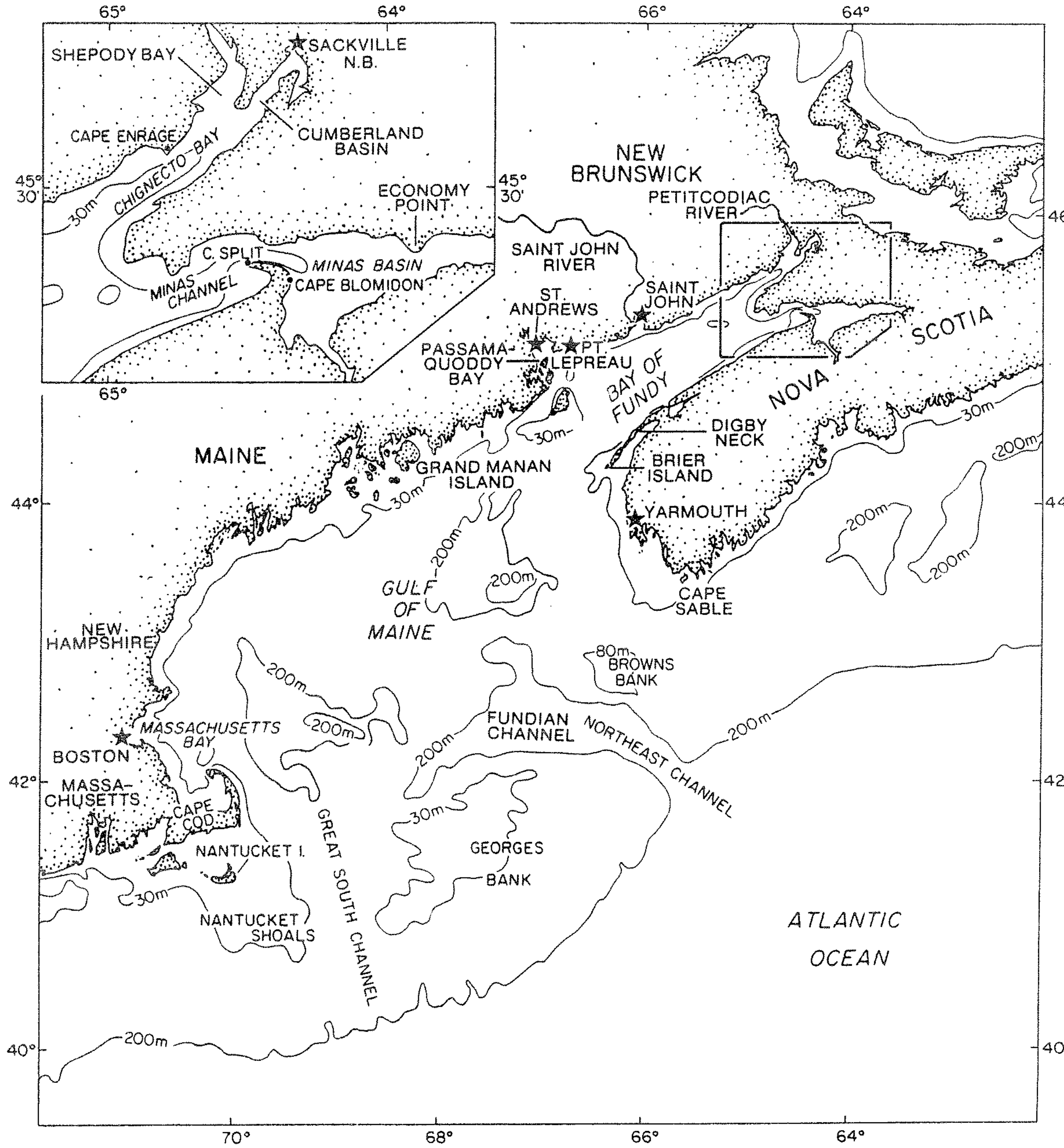


Fig. 1. The Bay of Fundy and Gulf of Maine.

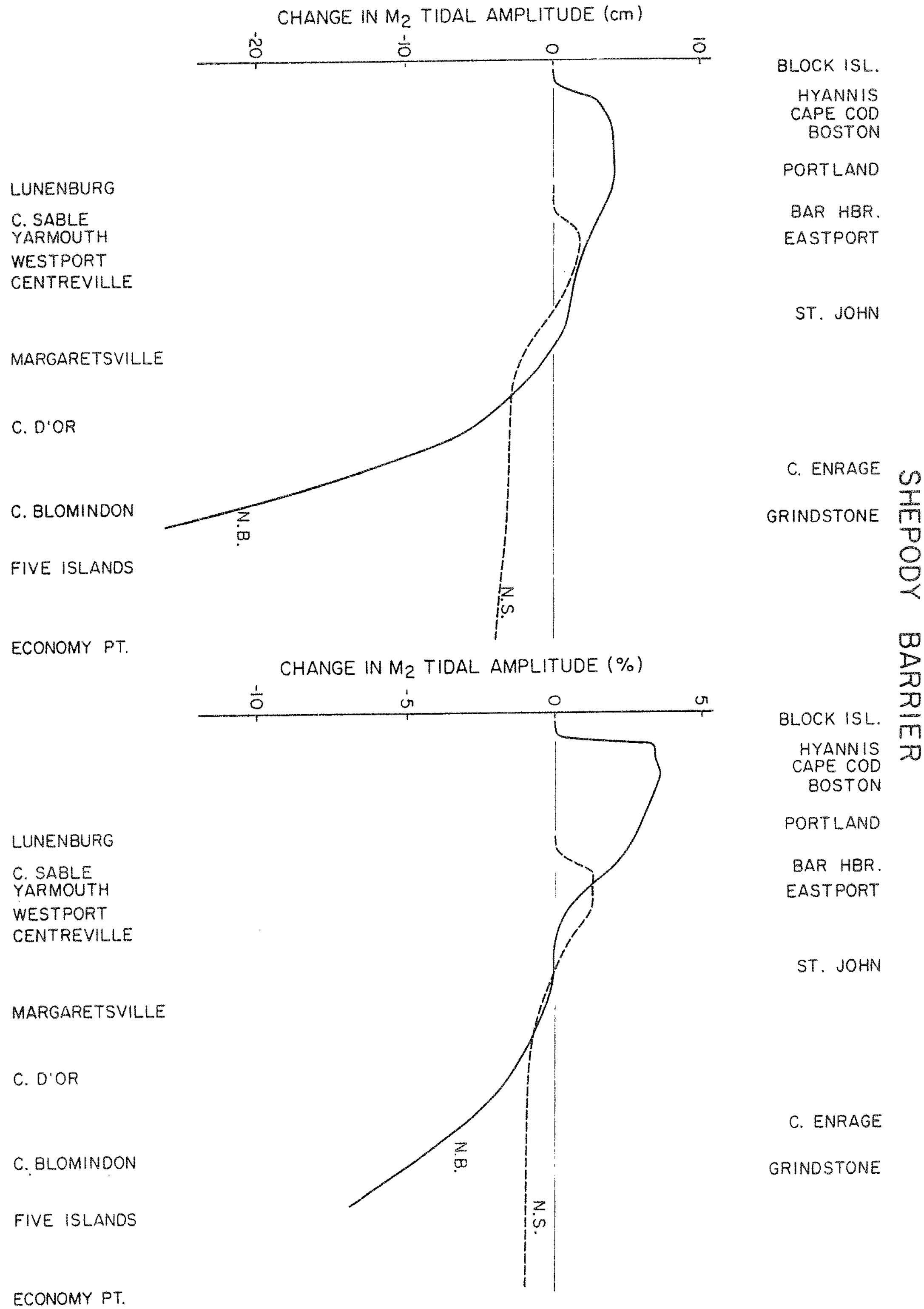


Fig. 2. Absolute and percentage change in tidal amplitude along the coast, due to a barrier installed at the mouth of Shepody Bay. The solid line is for the New Brunswick and New England coasts, the broken line is for the Nova Scotian coast.

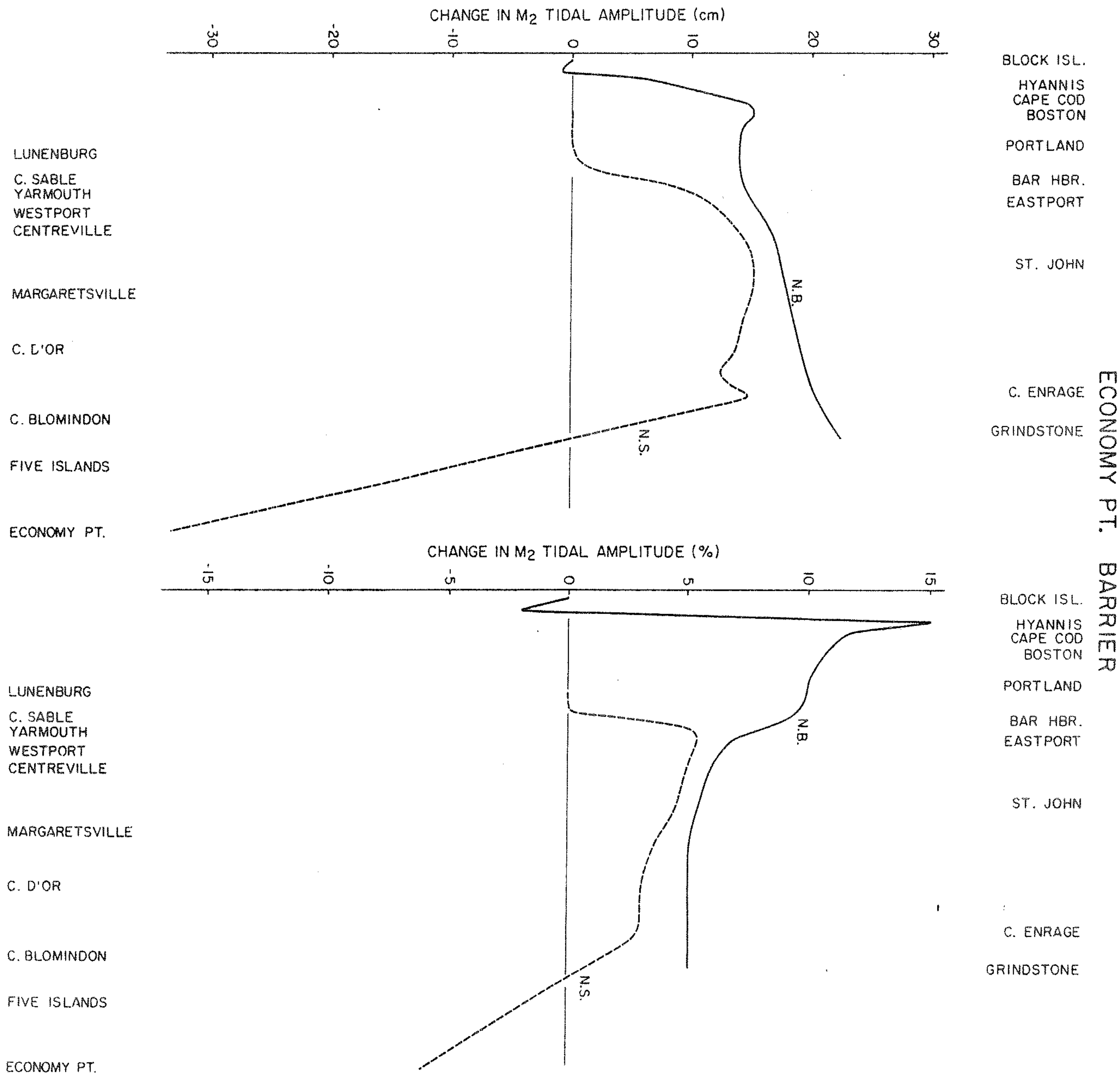


Fig. 3. Absolute and percentage change in tidal amplitude along the coast, due to a barrier installed across the Minas Basin at Economy Point. The solid line is for the New Brunswick and New England coasts, the broken line is for the Nova Scotian coast.

CONFIDENCE IN CALCULATIONS

Error limits on the changes given in Figs. 2 and 3 are difficult, if not impossible to derive. Confidence in the predictions is gained through an understanding of the physics involved, by noting the consistency of the nature of the change with other researchers, and by obtaining similar results with the progressive refining of the model. Garrett and Greenberg (1977) and Garrett and Toulaney (1979) showed that any errors due to open boundary effects would be minimal (of order 1%) for the barrier cases now under consideration. Garrett (1974) showed in his normal mode study that the shortening of the Bay of Fundy changed the shape of the Fundy-Maine oscillation. Although his grid was coarse and the equations were simplified, he predicted a reduction in amplification at the head of the Bay and an increase at the mouth and in the Gulf as is suggested in Greenberg (1979) on which this paper is based.

More recently, Duff (1981) has obtained similar patterns and percentage changes to those of Greenberg (1979) using a numerical model that telescoped to include much of the North Atlantic. This also showed minimal change along the edge of the continental shelf where Greenberg (1979) specified tidal elevations unaltered when barriers were simulated. The magnitude of the changes predicted by Duff did differ, but it is thought that this was due to poor calibration of the model, it being up to 30 cm out in amplitude and up to one hour out in phase of the tide. Duff did get results different from his full model when using a cut-down continental shelf model, using inappropriate open boundary conditions in which currents were specified not to change when barriers were simulated.

The Bay of Fundy-Gulf of Maine model referred to here has gone through a considerable development from its first trials in Greenberg (1975) (Fig. 4) to its present form (Greenberg 1979, Fig. 5). This has lead to some revision in the magnitudes of the predicted changes but little difference in the pattern of the change. Among the steps in this evolution, some of which are obvious from the diagrams, are the following:

1. The inclusion of the shallow area at the head of Cobequid Bay.
2. The inclusion of advective terms in formulations of the equations in the Minas Basin and Minas Channel.
3. The creation of a new, finer grid for the Minas Basin and Minas Channel area.
4. Recalibrations carried out along with the above three changes resulted in the lowering of the friction coefficient from an unusually high 6.4×10^{-3} to within a normal range at 2.1×10^{-3}.
5. The medium size grid was extended out to the mouth of the Bay of Fundy.
6. The coarse grid was extended out to the edge of the continental shelf and to the northeast and southwest along the shelf.
7. Variations due to map projection and the changes with latitude of the Coriolis parameter were allowed for in the coarse grid.

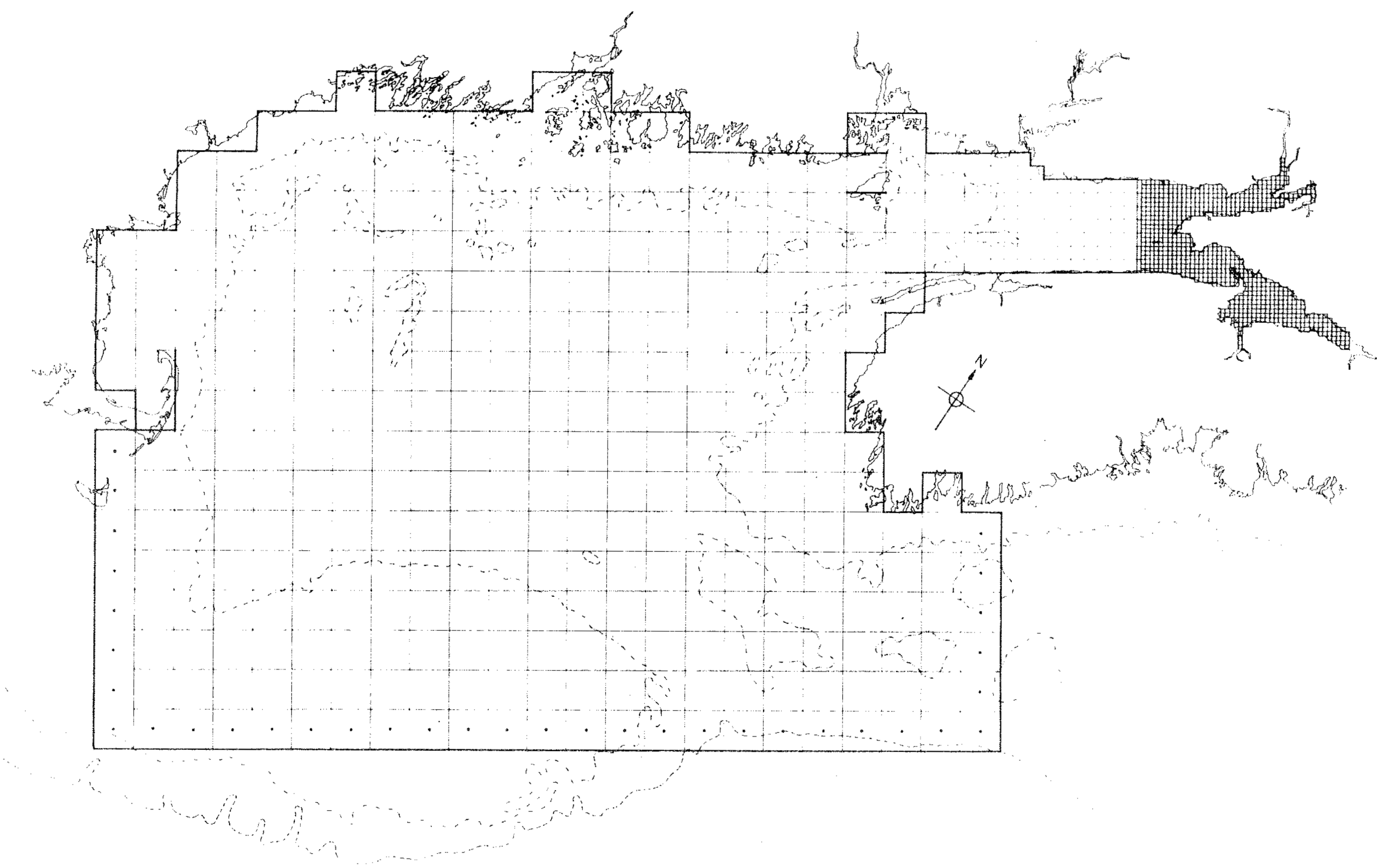


Fig. 4. The grid outline of the earliest version of the Bay of Fundy - Gulf of Maine numerical model (from Greenberg 1975).

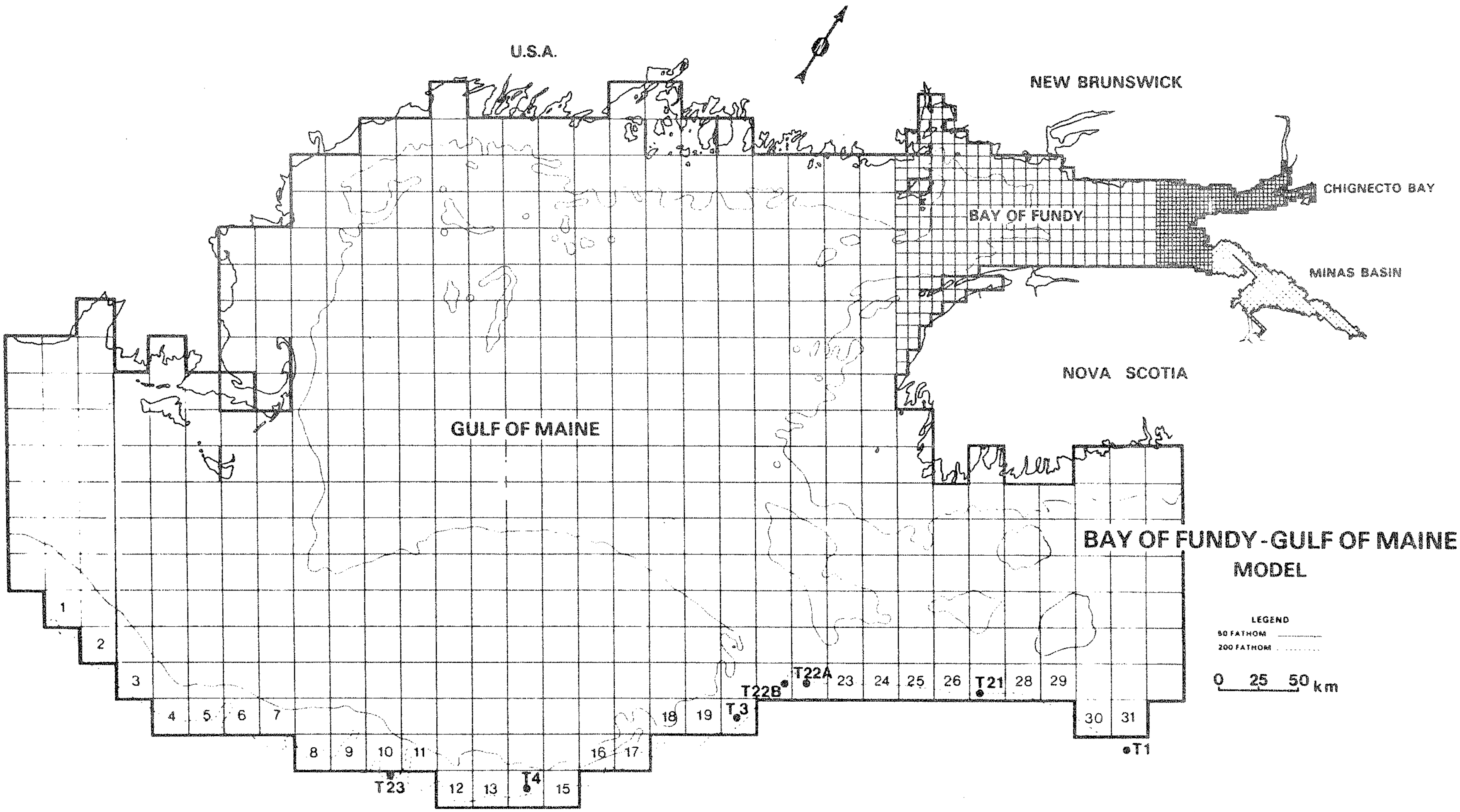


Fig. 5. The grid outline for the latest version of the Bay of Fundy - Gulf of Maine numerical model (from Greenberg 1979).

8. An extensive data collection program was undertaken which permitted a precise specification of the open boundary tides and very accurate calibration of the model.

Calculations using the above mentioned models all gave similar qualitative results, but quantitatively there was an increase in effect. The tide change at Boston, for example, increased progressively from a 6% rise to a 10% rise as the more accurate schemes were incorporated. The change in tide phase at Boston differed only from a 6 minute delay to a 4 minute delay in the later calculations.

A further test was carried out to see whether barrier effects would be poorly predicted because of the coarse resolution of the Gulf of Maine coastline. The depths around the coast of the Gulf were doubled, and simulations were run with and without barriers. The percentage change in tides due to barriers was found to be the same as predicted with realistic depths. It was reasoned that if such gross errors did not alter the predicted change, then more comprehensive modelling of the Gulf would give more detail, but not increase the accuracy of the prediction.

BARRIER EFFECTS AND NATURAL VARIABILITY

The changes in M_2 tide should be considered in conjunction with the natural variability of sea level in the system.

Computer runs have been made simulating the major tidal constituents for 30 days to examine the complete monthly variation in tides. The hourly output from the model was analyzed using a standard tidal analysis package and the simulated constituents were compared for cases with and without barriers. Times and heights of high and low water were also interpolated. The results (e.g. Table 1. Economy Pt. Barrier) indicate the largest change in amplitude for the M_2 constituent. Away from the head of the Bay, the other constitutents are changed principally in phase. Except in the immediate vicinity of the barrier, there were no changes in mean sea level. The average of the mean differences in high and low water are very close to the change in M_2 amplitude, although there are differences in the changes at high and low water. This could be real or due to inaccuracies in the interpolation scheme, particularly near the barrier, where the opening and closing of sluices and turbines could disproportionately influence results. This requires further investigation.

Changes in tidal sea level elevations of a few centimeters might tend to be camouflaged by surface waves, storm surges and even the natural tidal variation. It would be the extremes, spring and neap tides, that would be most noticeable (see Fig. 6). In a period of neap tides, low areas that would normally not be exposed and higher areas that would normally not be covered for one or more tidal cycles, would be covered and exposed respectively every tide. During a period of spring tides, areas that would never be exposed or covered by the natural tides would be included within the outer range of tidal variation.

TABLE 1. Difference between model run with an Economy Point barrier and without barriers, of high and low water heights and times, and of the major constituents simulated.

	At Barrier		Grindstone		Saint John		Boston	
HW Mean Difference	− 53.1 cm	− 31.7 min	+ 31.4	− 6.2	+ 20.9	− 2.6	+ 12.0	+ 0.9
Standard Deviation	6.8 cm	− 2.7 min	4.7	2.8	1.8	2.3	0.6	1.4
LW Mean Difference	+ 25.8 cm	− 29.3 min	− 20.0	− 8.8	− 19.7	− 6.5	− 15.8	+ 7.2
Standard Deviation	9.5 cm	− 3.0 min	3.3	1.6	2.6	2.0	1.2	3.4
O_1	12 cm	143°	12	143°	11	129°	10	142°
Difference	− 1 cm	7°	0	− 2°	0	− 1°	0	0°
K_1	15 cm	137°	15	129°	13	124°	12	136°
Difference	− 1 cm	− 8°	0	0°	− 1	+ 1°	0	0°
N_2	92 cm	336°	86	321°	58	311°	29	326°
Difference	− 1 cm	− 15°	+ 3	− 2°	+ 2	− 1°	+ 1	+ 3°
M_2	559 cm	1°	501	349°	322	340°	150	358°
Difference	− 29 cm	− 16°	+ 25	− 3°	+ 19	− 2°	+ 13	+ 3°
S_2	88 cm	46°	81	30°	51	18°	22	31°
Difference	− 1 cm	− 17°	+ 4	0°	+ 2	+ 1°	0	+ 6°

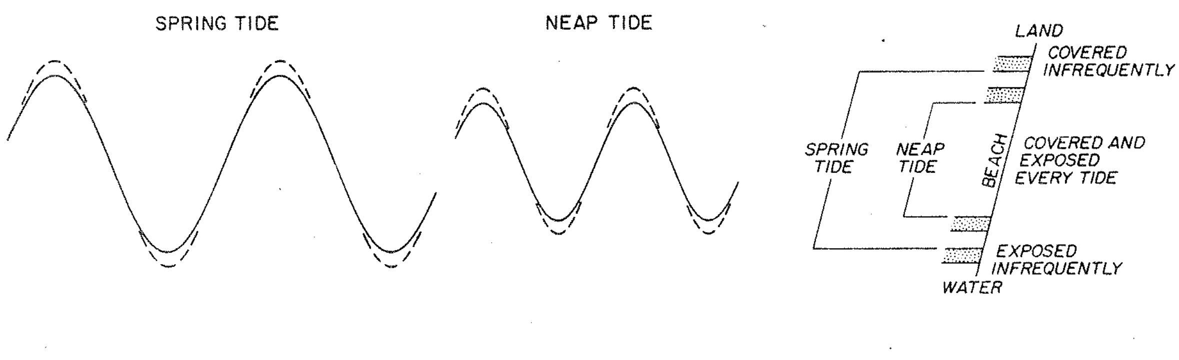


Fig. 6. The changes in spring and neap tide ranges and shoreline impact due to an increase in tidal amplitude. Changes are exaggerated for clarity.

There are many instances where increased tidal amplitudes could have an effect. Impacts which could be felt include:

1. Areas sensitive to present high water: those having low beach slope, already bothered by storm surges, salt marshes, or built up close to present high water would be most affected.
2. Shorelines sensitive to wave attack would find the waves consistently hitting higher and lower levels of the beach, but diffused over the wider tidal range.
3. Marginal ship passage would be more risky for the lower half of the tidal cycle but safer during the higher half.
4. The flood risk in the lower Saint John river valley may be more severe if higher high waters further retard high runoff in the spring.

TIDAL EFFECTS IN THE HEADPOND

The largest changes from the present regime, due to the installations of a tidal power plant, would be behind the barrier. The preferred type of installation known as ebb generation, consists of an enclosed reservoir or headpond, which is filled through sluices on a rising tide and drained through turbines on a falling tide generating electricity (Fig. 7). Other generation modes have been considered, with two way generation being a possibility, but flood generation is uneconomic. The tidal sea level changes in the headpond would be reduced to one half to one third their present range under any mode. The mean level of the reservoir depends on the particular generation mode (Fig. 8), being higher than normal for ebb generation, lower for flood generations and only slightly raised for two-way generation. The level of installed capacity also has an effect (Table 2). Greater sluice capacity tends to increase the mean headpond level, and higher turbine installation tends to increase headpond range. The mean level in ebb generation tends to mimic the variation in high water (Fig. 9) due to the higher resistance to flow of turbines compared to sluices. This effect is similar to that of Reversing Falls on the water levels in the lower Saint John River. The mean level in flood generation would tend to follow the low water variation but would vary less in two way generation.

Two-way generation is the only mode where some power can be had on demand for short periods. To achieve this, the demand must be sufficiently forecast and in such instances it might be necessary to give up some energy to have the basin level optimized at the correct time. For maximum power production, a two way scheme would be generating in an ebb generation mode during priods of low tides and in both directions during medium and high tide periods. Both of these factors could lead to a more irregular variation in mean reservoir level and in the extent of the intertidal area.

From the above, we can see that changes in the headpond tidal regime will impact the area in two different ways, by changing the mean sea level and by changing the regularity and extent of the intertidal area. Factors that could depend on the mean water level include changes in the level of, and salt intrusion into, the watertable of the surrounding land,

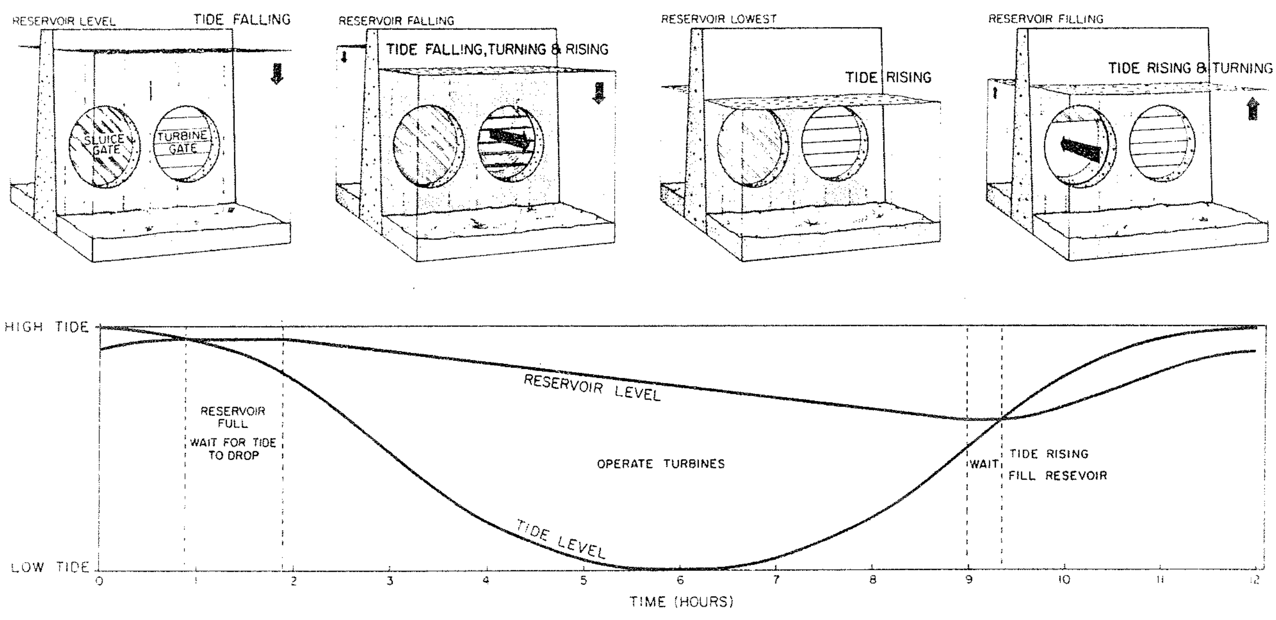


Fig. 7. The different stages of operation in an ebb generation power scheme relative to tide and reservoir levels.

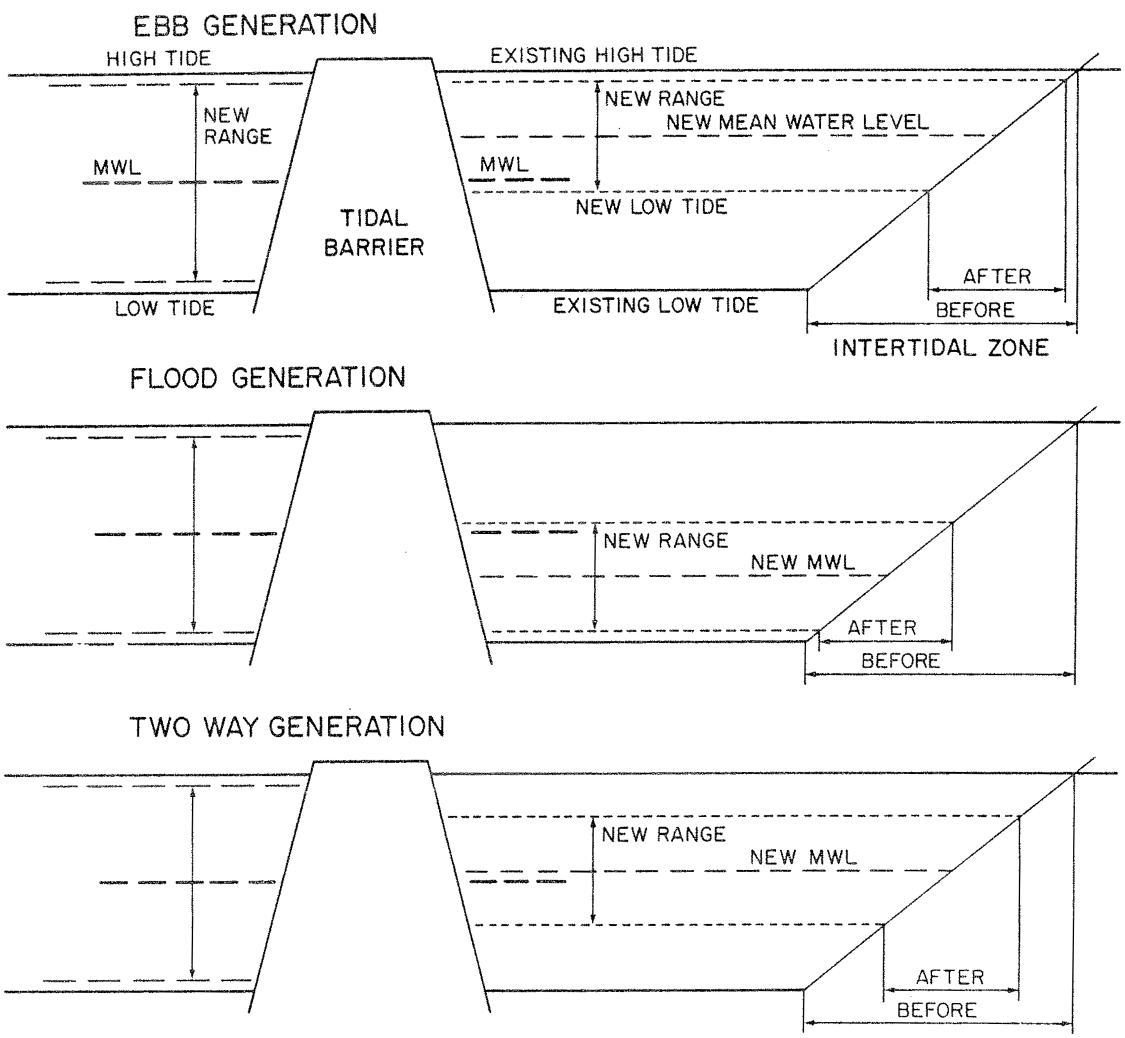


Fig. 8. Reservoir levels for different generation modes.

TABLE 2. Variations due to different installation levels. Experiments were done with an early version of the model, and barriers operating characteristics have evolved, so exact numbers would differ, but trends should be the same. Present thinking calls for even higher installation levels.

	Experiment			
	1	2	3	4
M_2 Amp in Front (cm)	548	538	563	546
M_2 Amp Behind (cm)	167	227	94	171
Mean Level Difference Across Barrier (cm)	340	277	436	373
Generation Time (min.)	364	339	402	374
Sluice Time (min.)	222	249	183	210
Number of Turbines	70	105	35	70
Number of Sluices	70	70	70	100

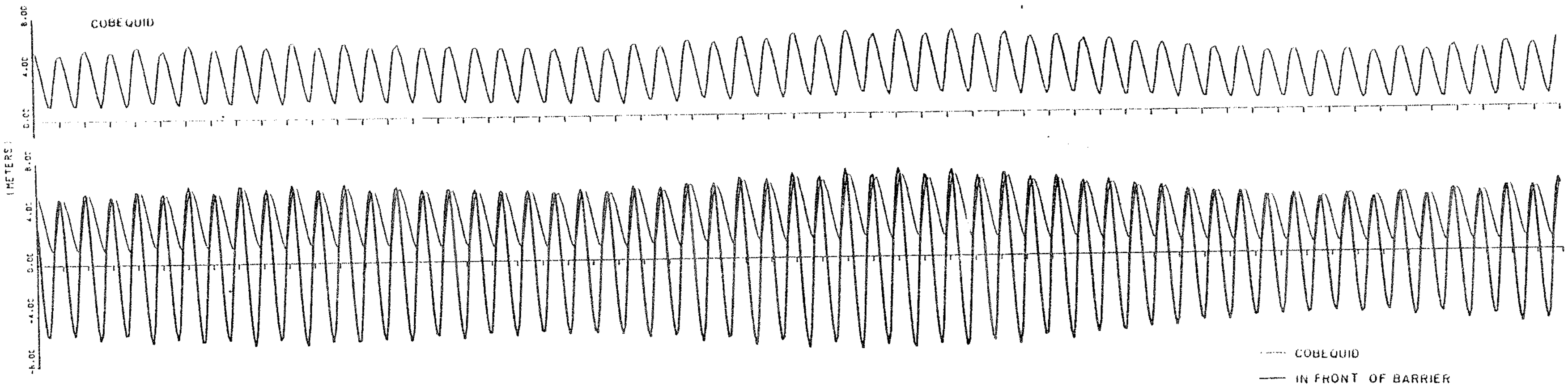


Fig. 9. Variations of tide and reservoir level at an ebb-generation tidal power barrier over a 30 day period.

and the drainage of aboiteaux. Changes in intertidal area could lead to changes in erosion, sedimentation and biology.

OTHER FACTORS

Changes in tidal currents can be expected in similar magnitudes to changes in tidal elevations. A relationship has been found connecting the strength of the tidal current and the water depth to whether or not an area is well mixed or stratified. In an analysis of tidal mixing, Garrett et al. (1978) found that the Great South Channel changed from being marginally outside the critical range for a tidally mixed area, to marginally within this range (Fig. 10) when tidal power barriers were simulated. This could have implications for water mass exchange through the Channel. The study also indicated the headpond area would tend to stratify in the summer. Holloway's (1981) study suggested a significant decrease in salinity in the headpond which would tend to increase any tendency to stratification, but little effect on salinity was predicted for the area outside of the tidal reservoir.

The placement of a barrier could have a locally significant effect on waves. The long channel fetch would be reduced, decreasing the energy level of the waves downwind from the barrier. Reflections of waves at the barrier could cause a local increase in wave energy.

Several factors relating to a barrier's installation could affect ice conditions. These include: decreased breaking forces on the ice due to lower wave activity, lower salinities, tidal range and tidal currents, limited tidal excursion due to the barrier and possibly greater ice formation due to decreased mixing. These factors could induce the present large quantities of drifting ice to form a more solid ice cover. Whether this could lead to complete fast-ice cover in the headpond has not been determined. The subject of ice is more completely covered in Gordon and Desplanque (1983).

CONCLUDING REMARKS

The predicted changes in tidal elevations and tidal currents due to the proposed installation of a tidal power dam in the upper Bay of Fundy are now fairly well understood. Although, away from the barrier, the changes may seem small compared to the natural variation in the system, they still could be significant in many areas. Good quantitative analyses on how these changes could impact flooding, shipping, mixing etc. have not been made. Perhaps estimates should be made on a site specific basis. An attempt has been made here to give some qualitative ideas on impacts based on what is quantitatively understood.

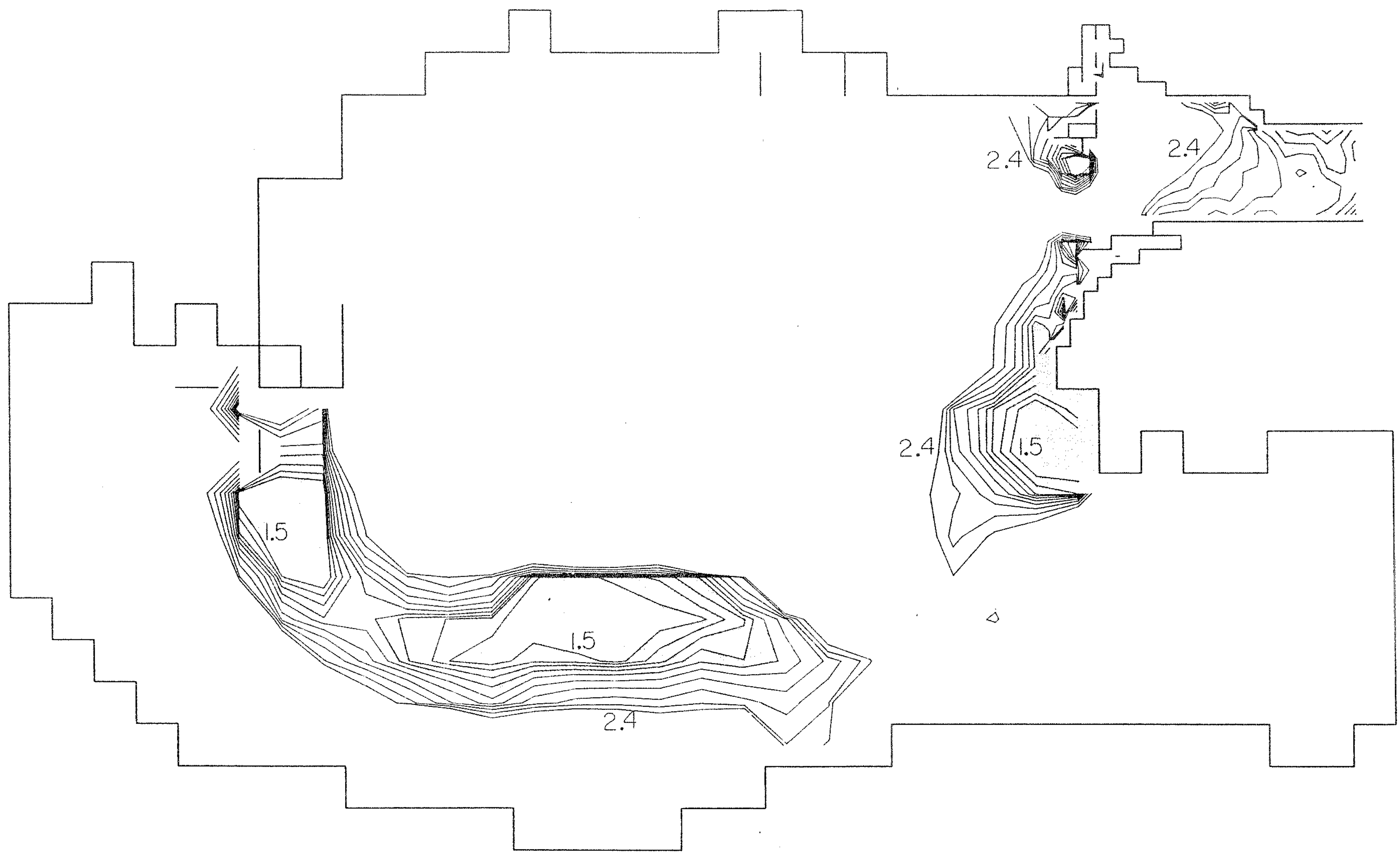


Fig. 10. The mixing parameter, Depth Dissipation, in the Gulf of Maine when a barrier is simulated at Economy Point (from Garrett et al. 1978). The Great South Channel is included in the mixed region. This should be compared to Figure 6 in Greenberg (this volume).

REFERENCES

ATPPB (Atlantic Tidal Power Programming Board). 1969. Feasibility of tidal power development in the Bay of Fundy. Board Report and Committee Report, Halifax, Nova Scotia, 5 vols.

BFTPRB (Bay of Fundy Tidal Power Review Board). 1977. Reassessment of Fundy Tidal Power. Reports of the Bay of Fundy Tidal Power Review Board and Management Committee, Ottawa, 516 p.

Daborn, G.R., ed. 1977. Fundy tidal power and the environment. Acadia Univ. Inst. Publ. No. 28, 304 p.

Duff, G.F.D. 1981. A gulf and ocean model of the Bay of Fundy tides, and their response to barrier construction and operation. Utilitas Math. 19: 3-80.

Garrett, C.J.R. 1972. Tidal resonance in the Bay of Fundy and Gulf of Maine, Nature 238: 441-443.

Garrett, C.J.R. 1974. Normal modes of the Bay of Fundy and Gulf of Maine. Can. J. Earth Sci. 11: 549-556.

Garrett, C.J.R. 1977. Tidal influences on the physical oceanography of the Bay of Fundy and Gulf of Maine. In: Daborn, G.R., ed. Fundy tidal power and the Environment. Acadia Univ. Inst. Publ. No. 28, pp. 101-115.

Garrett, C.J.R. and D.A. Greenberg. 1977. Predicting changes in tidal regime: the open boundary problem. J. Phys. Oceanog., 7: 171-181.

Garrett, C.J.R., J.R. Keeley and D.A. Greenberg. 1978. Tidal mixing versus thermal stratification in the Bay of Fundy and Gulf of Maine. Atmosphere - Ocean 16: 403-423.

Garrett, C.J.R. and B. Toulany. 1979. A variable depth Green's function for shelf edge tides. J. Phys. Oceanog. 6: 1258-1272.

Gordon, D.C. Jr. and C. Desplanque. 1983. Dynamics and environmental effects of ice in the Cumberland Basin of the Bay of Fundy. Can. J. Fish. Aquat. Sci. 40: 1331-1342.

Greenberg, D.A. 1975. Mathematical studies of tidal behaviour in the Bay of Fundy. Ph.D. thesis, University of Liverpool, 139 p.

Greenberg, D.A. 1977. Effects of tidal power development on the physical oceanography of the Bay of Fundy and Gulf of Maine. In: Daborn, G.R., ed. Fundy tidal power and the Environment. Acadia Univ. Inst. Publ. No. 28, pp. 200-232.

Greenberg, D.A. 1979. A numerical model investigation of tidal phenomena in the Bay of Fundy and Gulf of Maine. Marine Geodesy 2: 161-187.

Heaps, N.S. and D.A. Greenberg. 1974. Mathematical model studies of tidal behaviour in the Bay of Fundy. Proceedings of the IEEE International Conference on Engineering in the Ocean Environment 1: 388-399.

Holloway, P.E. 1981. Longitudinal mixing in the upper reaches of the Bay of Fundy. Est. Coast. Shelf Sci. 13: 495-515.

IPEB (International Passamaquoddy Engineering Board). 1961. Report of the International Joint Commission United States and Canada on the International Tidal Power Project, Washington-Ottawa. Rept. Intern. Joint. Comm. Docket 72, Invest. Intern. Passamoquoddy Eng. Fish. Bd.

Rao, D.B. 1968. Natural oscillations of the Bay of Fundy. J. Fish. Res. Bd. Can. 25: 1097-1114.

QUESTIONS AND COMMENTS

G. Daborn: You mentioned the possibility of stratification occuring in the headponds. Have you pinpointed the likely degree to which this might occur?

D. Greenberg: Pete Holliway did his calculation of horizontal mixing based on salinity values and he came up with a value he thought the new mean salinity would be in the headpond. Now that is a mean overall average. I am not sure of the exact numbers but it's a good four or six parts per thousand less than what are found there now. I am under the impression the change will be greater on top and less at the bottom within the stratified area at least during summer. In the winter I am sure it will be all well mixed with the exception if there is complete ice cover. Just meterology should mix it up, if it mixes the Gulf of Maine it should mix a shallow headpond.

D. Scarratt: One of your comment areas was effects on water tables and drainage but there is one thing nobody has yet addressed and that is there are a number of communities which are dependent on the ocean for sewage disposal. Has anyone begun to study the municipal engineering problems that might be created by altered and perhaps unpredictable tidal amplitudes changes?

D. Greenberg: This question may be answered by some of the later speakers, otherwise I know of no one who is examining such problems.

D. Bray: With regard to waves in the area upstream of the barrage might you not consider only the wave height but also the duration the waves will have to erode a certain length of shoreline when the level of the reservoir is held constant for three hours? What additional effect will this have on sedimentation?

D. Greenberg: Yes, this is a new departure that some of the sedimentologists can look at. There have been studies done that do suggest how things might happen when you dam a river and change the system into another regime all at once. The idea of changing a variable regime, however, has not been studied.

Fundy Tidal Power and the Coastal Resources of Maine[1]

Peter F. Larsen

and

Jerry A. Topinka

Bigelow Laboratory for Ocean Sciences
West Boothbay Harbour, Maine 04575

ABSTRACT

The development of large tidal power facilities at the head of the Bay of Fundy in Canada presents an unusual combination of potential economic benefit and environmental concern to the northeast region of the United States. This industrialized region is heavily dependent on imported oil, an undesirable situation which could be alleviated in part by the importation of tidal energy. Presently, 90% of the potential production of the Fundy project is slated for U.S. consumption. Because of the unique configuration of the Gulf of Maine - Bay of Fundy system, however, the construction of a tidal barrage at the head of the Bay of Fundy is predicted to result in tidal regime modifications throughout the tidal basin. The most marked alterations will be manifested in the western Gulf of Maine on the coasts of Massachusetts, New Hampshire and Maine, in the U.S., where the tidal range is predicted to increase by approximately 10% (30 cm) with a corresponding increase in tidal current velocities. The diverse environmental consequences range in direction from very beneficial to extremely negative and in magnitude from major to inconsequential. The Bigelow Laboratory is undertaking a preliminary study to provide objective information upon which to judge the seaward consequences of Fundy Tidal power against the impacts of other methods of electrical generation. Examples of inquiry include: loss of terrestrial habitat, storm surge damage, erosion/deposition patterns, climatic changes, patterns of productivity including red tide blooms, fishery implications, and estuarine flushing.

Key words: tidal power, tides, environmental consequences, coastal zone, New England, Gulf of Maine, Bay of Fundy

RÉSUMÉ

L'aménagement d'une usine marémotrice de grande taille à l'embouchure de la baie de Fundy au Canada, crée une situation inhabituelle, en offrant des bénéfices économiques potentiels, et en créant des problèmes environnementaux pour la région nord-est des Etats-Unis.

[1]Contribution No. 83011 of the Bigelow Laboratory for Ocean Sciences

Cette région industrialisée est très dépendante des importations de pétrole, situation indésirable à laquelle on pourrait en partie remédier par importation d'énergie marémotrice. Actuellement, 90% de la production potentielle de l'usine marémotrice que l'on prévoit d'aménager dans la baie de Fundy est destinée aux consommateurs des Etats-Unis.

En raison de la configuration unique du système golfe du Maine - baie de Fundy, on prévoit que la construction d'une using marémotrice à l'entrée de la baie de Fundy modifiera le régime des marées dans tout le bassin. Les modifications les plus prononcées se manifesteront dans l'ouest du golfe du Maine, le long des côtes du Massachusetts, du New Hampshire et du Maine (Etats-Unis), où l'on prévoit que l'amplitude des marées augmentera d'environ 10 à 15% (30 cm), en même temps que la vitesse des courants de marée. Les diverses conséquences écologiques iront de très bénéfiques à extrêmement néfastes, et, du point de vue de leur importance, de considérables à négligeables. Le laboratoire de Bigelow entreprend une étude préliminaire, pour donner une information objective permettant de juger l'incidence sur le littoral de l'usine marémotrice de Fundy, comparativement aux autres méthodes de production d'électricité. La recherche portera sur: les réductions d'habitat terrestre, les dommages causés par les marées de tempête, les cycles d'érosion et de sédimentation, les modifications climatiques, les cycles de productivité, en particulier l'apparition des "marées rouges", les répercussions sur les pêches, et l'écoulement des eaux des estuaires.

INTRODUCTION

The proposed Minas Basin tidal power facility (Bay of Fundy Tidal Power Review Board 1977) is unique because of its enormous size and its capacity to modify the tidal regime of the Gulf of Maine (Fig. 1). The large tidal range presently experienced within the Gulf of Maine-Bay of Fundy tidal basin results primarily from a resonance phenomenon in which the free period of the tidal basin is only slightly longer than the period of the forcing oceanic tide. The construction of a large tidal barrage in the upper reaches of the Bay of Fundy will shorten the basin resulting in a free period even closer to the forcing tidal period, causing increased resonance and an increased tidal range (Greenberg 1984). The magnitude of the tidal amplitude alteration (half of the tidal range) varies according to location but it has been estimated to be about 15 cm, or 10%, in the highly developed western Gulf of Maine (Fig. 2).

In spite of the possibility for environmental modifications over an extremely large area, little attention has been given to these potential far-field effects. In the United States, the lack of interest, in our opinion, exists partly because both the plans for development of Bay of Fundy tidal power and its possible impacts are not well known. Skepticism concerning construction feasibility has been fueled by a 60 year history of tidal power proposals which have never come to fruition. Some skepticism also exists within the scientific community concerning the ability of a Bay of Fundy barrage to alter the Gulf of Maine tidal regime. For these reasons, much of our effort since 1979 has been directed toward public educa-

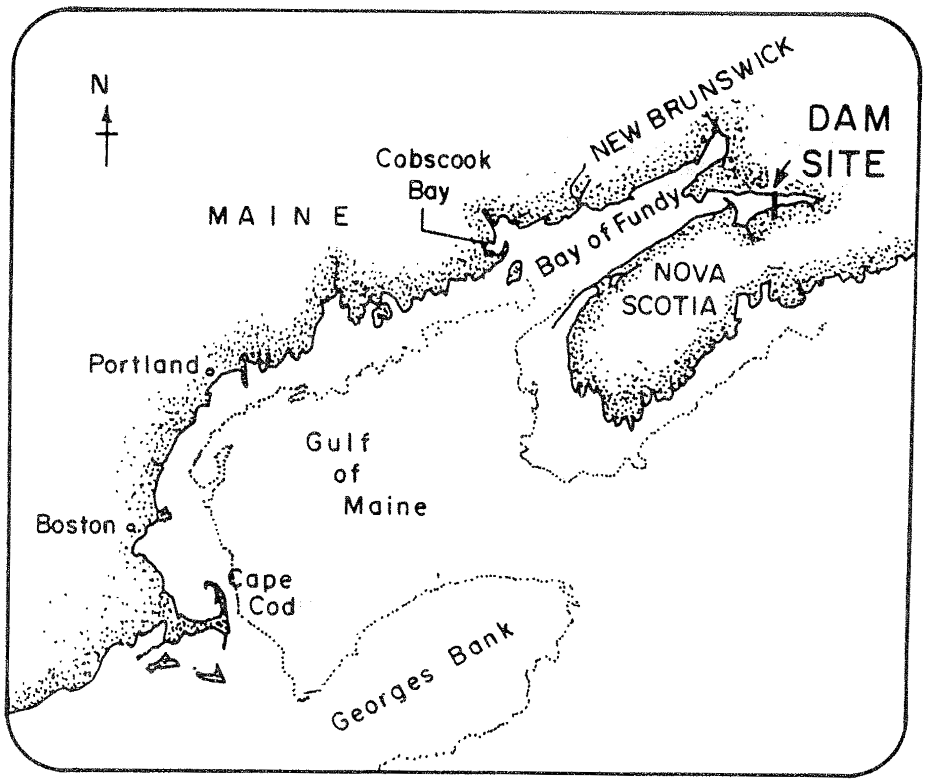


Fig. 1. The Gulf of Maine-Bay of Fundy region with the location of the proposed Minas Basin tidal barrage indicated.

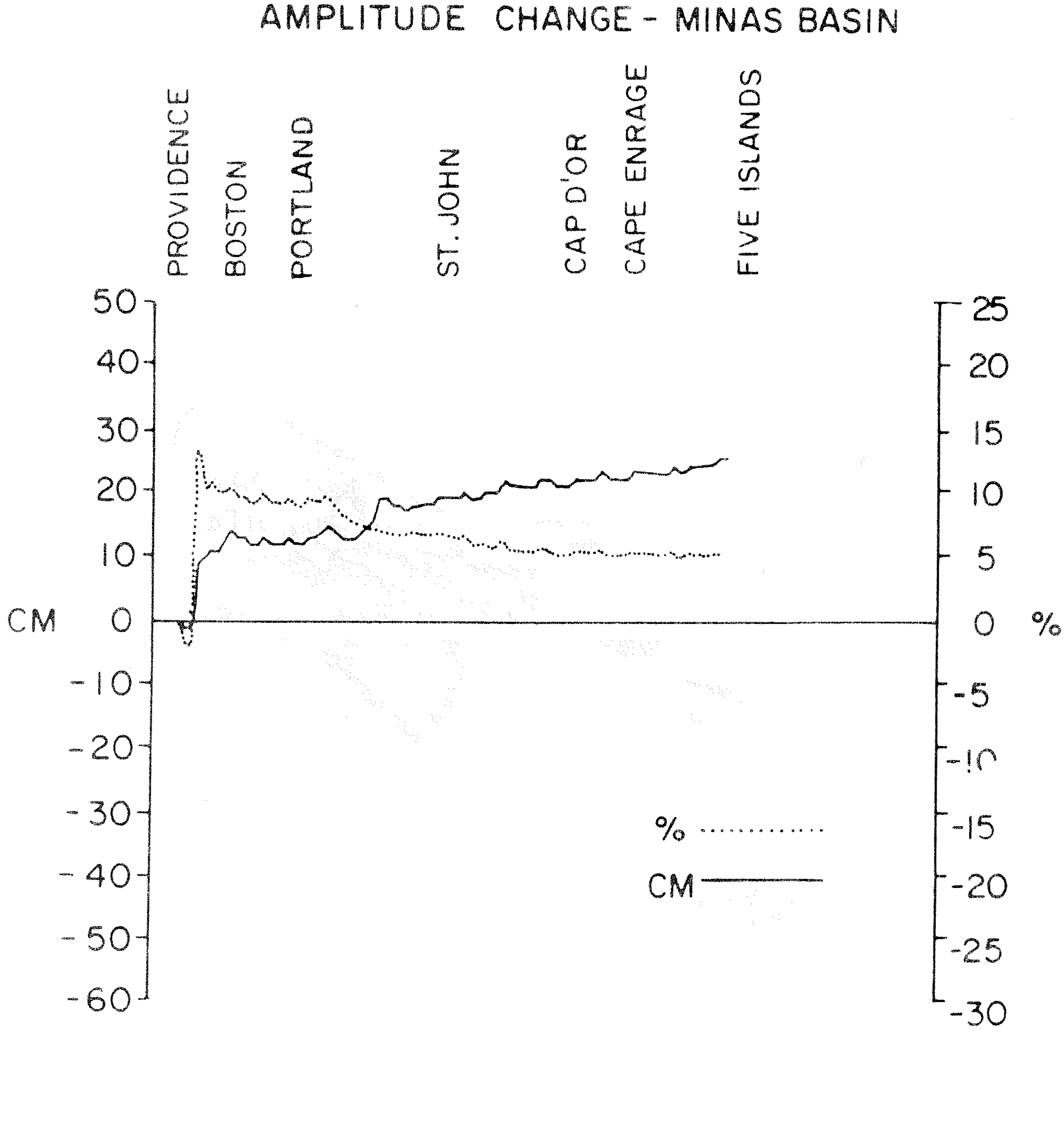


Fig. 2. Predicted absolute and percentage increase in tidal amplitude in the Gulf of Maine associated with the proposed Minas Basin tidal power project (modified from Bay of Fundy Tidal Power Review Board 1977).

tion, describing the basis of the Greenberg model and explaining the intimate relationships between the tides and coastal uses and functions.

In June 1982, the Bigelow Laboratory was awarded a contract from the State of Maine to evaluate the scope of the environmental implications of Fundy tidal power development to the coastal resources of the State. In addition to Bigelow personnel, individuals were involved from the Provincetown Center for Coastal Studies, the University of New Hampshire, the University of Rhode Island and consulting companies.

The objectives of our project were threefold:

1. Determine all the environmental consequences, both positive and negative, that are deemed even remotely possible by members of the scientific community;

2. Prioritize these consequences based on their probability and relative magnitude of impact on the coastal resources of Maine;

   and

3. Outline research needed to increase our predictive capacity. A final report is expected to be available by spring 1984.

At this preliminary stage of our investigation no attempt will be made to offer a comprehensive analysis and summary of our efforts. In this paper it is our intent to examine why we believe environmental concern is warranted and comment on the diversity and scales of potential issues.

RESULTS AND DISCUSSION

We would like to preface this section by saying that, in our opinion, the environmental concern voiced in the United States is not anti-tidal power. The northeast region is heavily dependent on imported oil and would welcome the development of an alternative source of electricity. Furthermore, many people realize that there is an environmental cost to pay for any type of energy. Awareness of preceived and real environmental health risks associated with nuclear and coal- fired generation of electricity, two leading alternatives to tidal power, is high in New England. We believe that after some insight is developed concerning the degree of environmental modification caused by the altered tidal regime, tidal power may be viewed as acceptable relative to other methods of generating electricity.

Thorough investigation of the far-field effects is also directly in the best interest of Fundy tidal power development. It will be difficult to raise investment capital if environmental questions remain unanswered. Costly delays in construction could also result if environmental intervention develops later due to a lack of information.

One might ask "Why is there environmental concern in the United States?" Concern about the far-field effects has largely been played down in Canada by such arguments as: the change in tides is small on an already large tidal range; the change is only equivalent to a small wave on top of the existing high tide level; minor surges due to atmospheric pressure changes are larger than the projected tidal range increases; and, such little change will be lost in the noise.

We consider that the predicted changes in tidal regime are not the equivalent to most random changes, as those induced by discrete meteorological events. There will be a permanent change in the tidal base upon which all other influences will fall. Although the change may be "lost in the noise" of a short-term record, there will be a shift in tidal base observable over longer time periods. The percentage change in tidal regime will be larger in the more developed, western Gulf of Maine than in the Fundy region (Fig. 2). When one considers the length of coastline affected, it is easy to visualize that even a small effect accumulated over such a large area would be grounds for concern.

The problems associated with small-scale, long-term sea level rise in many parts of the world demonstrate that even small changes in tidal amplitude can be of environmental significance. While these changes, roughly 3 mm per year in New England, are small compared to annual variations in sea level [perhaps 18 cm (Redfield 1981)] and meteorologically induced level changes, they are unidirectional and have historically resulted in the loss of coastal land and structures through erosion and flooding. Whereas the Fundy proposal will not change mean sea level, it will elevate the high tide line (e.g. high mean water) which, in terms of coastal planning and management, is the effective sea-land boundary. If one can accept that there are environmental problems associated with long-term rise in sea level, it must be clear that the predicted rise in high tide level will also have environmental consequences associated with it.

One of the principle differences between the phenomena of sea level rise and enhanced tidal regimes resulting from Fundy tidal power development is the rate of change. The natural rise in mean sea level is essentially imperceptible on a scale of day-to-day or year-to-year human activity. Geological and biological systems are able to adapt gradually. By comparison, the proposed tidal range increase will be relatively rapid and therefore be potentially more disruptive. The effective rise in the land-sea interface associated with Fundy tidal power development is equivalent to 50 or more years of natural sea level rise. In addition, there are phenomena related to the predicted tidal regime change which would not necessarily result from sea level rise alone. These include, but are not limited to, a lower low tide level, a larger intertidal zone, stronger tidal currents, and increased estuarine flushing. It is clear that unanswered questions as to the direction, magnitude and socio-economic significance of the possible environmental alterations warrant a major evaluation of the far-field effects of Fundy tidal power development.

We will now briefly consider some examples of the types of environmental consequences that may be expected if the tidal range was increased by 30 cm as predicted (Greenberg 1979). Our purpose is to demonstrate the range of coastal habitats, uses and functions that might be influenced by a small increase in tidal range. For convenience, the discussion has been organized into three parts to include some consequence of (1) higher high tides, (2) lower low tides and (3) changes in the absolute tidal range.

One of the most obvious consequences of a higher high tide is the loss of terrestrial habitat. The loss can be due to submergence or to erosion. Dr. Graham Giese has developed a hypsometric curve for the State of Maine and was able to estimate that a 15 cm increase in high tide level would result in the inundation of 1680 hectares in Maine which are not normally flooded. This is equivalent to approximately a 2.5 m wide strip along Maine's 6,705 km coastline (Topinka and Korjeff 1981). At any given point, of course, the width of the strip lost to submergence would depend on local topography.

Using Old Orchard Beach, Maine as an example, Dr. Giese was able to estimate the profile retreat which would result from a 15 cm increase in high tide level. Methodology and assumptions used will be presented in detail in Larsen et al. (1984). The calculation indicates that a landward retreat of the beach face of 20 m could eventually be expected.

Loss of terrestrial habitat and retreat of beach faces, together with increased storm damage should a storm surge coincide with the modified high tide, are fairly spectacular impacts which will directly affect the value of coastal property. There are other less dramatic consequences, however, which will still have a significant economic or aesthetic impact. For instance, the storm sewer system of parts of Portland, Maine has a very low head. It has been predicted that this head will not be adequate at the modified high tide level and "several million dollars" will have to be spent to retrofit the system. Erosion is considered to be the worst current threat to the archaeological sites of coastal Maine. Because of man's tendency to settle on coasts, and the naturally rising sea level over half of Maine's identified archaelogical sites are on the coast and will ultimately be flooded. In the short-term, Dr. Arthur Spiess of the Maine Historic Preservation Commission believes "...a 6 inch tidal amplitude increase would be a disaster". He estimates as many as 700 shell heaps and other coastal sites, over 30% of those known exist in Maine, would be lost due to the predicted tidal regime changes. It would cost about 5.5 million dollars to excavate the sites before barrage construction (Larsen et al. 1984).

An example of an easily overlooked consequence of unknown magnitude concerns the use of bridges. Will the new tidal regime mean some fixed bridges will be impassible by small craft at high tide? Likewise, will the new tidal regime require more frequent openings of draw bridges? While these questions may appear inconsequential relative to major concerns, they could be of significant, local impact.

Although most attention is given to the consequences of higher high water, lower low water will also have effects on coastal uses and functions. Many small New England harbours and boat basins are presently marginally useful at low tide. A 15 cm reduction in the low tide level will further impede boat traffic at times of low tide and could require increased dredging of harbours or scheduling of activities by fishermen and pleasure boaters. We have observed many piers which will have to be extended to remain useful at low tide. A lower low tide should also result in a short-term increase in the harvest of clams and marine worms as previously unexploited stocks are exposed.

There are many diverse consequences associated with the absolute change expected in tidal range. One of the most obvious is that the intertidal zone will be larger. This could lead to an extension of shellfish beds and increase macroalgal productivity, but also raises questions of property boundaries. The location and thickness of the interface between saltwater and overlying freshwater in coastal groundwater systems is influenced by the tidal cycle. Put most simply, the depth of freshwater under a given point of land thickens and thins with the tides. Dr. A.L. Tolman of the Marine Geological Survey believes that an increase in tidal range coupled with increasing year-round development along the coast will result in more severe and perhaps more widespread saltwater intrustion problems. He states "The localized economic impact could be very large. Small towns, already with limited resources, would find either near-shore properties would have very limited value because of inadequate water supply, or that large sums of money would have to be expended to provide residents with public water" (Larsen et al. 1984).

One result of the projected absolute change in tidal range is an increase in the tidal prism of embayments and estuaries. Larger tidal prisms produce more rapid flushing, temperature dampening and greater pollutant assimilation capacity, all of which might be perceived as beneficial. On the negative side, greater flushing could result in reduced larval retention and altered estuarine zonation. It should be noted that our preliminary calculations indicate that the increase in flushing rate will not be great, perhaps 10%. This is less than the change now experienced over a spring-neap tidal cycle. We believe, however, that there may be an integrated effect over time and that even these relatively small physical changes could cause major biological modifications in certain unique situations. For example, Merrymeeting Bay, one of the largest tidal freshwater wetlands in the United States, is presently protected from large salt water intrustions by a sill at its entrance. Is a 10% increase in tidal prism enough to allow the salt wedge to spill over the sill and change the bay into an oligohaline system? Such a change would certainly have major socio-economic reprecussions. More detailed studies are needed before we can realistically evaluate the significance of tidal prism changes.

The above examples of possible far-field environmental effects of Fundy tidal power development are taken from a report to the Maine State Planning Office by Larsen et al. (1984). They are limited to effects directly associated with changing tidal levels. Another suite of concerns is related to changes in tidal currents. Although a consideration of these concerns is beyond the scope of this paper, they are contained in the aforementioned report.

SUMMARY

In the preceding pages we have discussed how the predicted changes in the Gulf of Maine tidal regime associated with Fundy tidal power development have lead to legitimate environmental concerns in northern New England. These concerns are not limited to the consequences of a higher mean high tide level, but also include potential effects of a lower mean low tide, absolute changes in the tidal range and tidal current changes. Many of the effects of the predicted tidal range changes cannot adequately be addressed and quantified, pointing to a need for expanded knowledge of often complex systems. Further collaborative studies within many disciplines of marine and social sciences are clearly needed to evaluate the significance of many potential environmental consequences.

ACKNOWLEDGMENTS

The background and ideas prerequisite to writing this paper were accumulated over several years, and involved the cooperation and input of many persons. The authors are pleased to acknowledge these contributions. G.S. Giese, F.E. Anderson, B.S. Timson and R.W. Rudolph contributed significantly to the integration of perceptions from several scientific and socio-economic disciplines. The Canadian scientific community was especially helpful and supportive of our efforts. Of particular note are D.A. Greenberg, G.R. Daborn, D.C. Gordon, C.L. Amos and M.J. Dadswell. Special thanks go to G.C. Baker of the Nova Scotia Tidal Power Corporation.

REFERENCES

Bay of Fundy Tidal Power Review Board, 1977. Reassessment of Fundy Tidal Power. Reports of the Bay of Fundy Tidal Power Review Board and Management Committee, 516 p.

Greenberg, D.A. 1979. A numerical model investigation of tidal phenomena in the Bay of Fundy and Gulf of Maine. Mar. Geodesy 2: 161-187.

Greenberg, D.A. 1984. The effects of tidal power development on the physical oceanography of the Bay of Fundy and Gulf of Maine. In this report.

Larsen, P.F., J.A. Topinka, A.L. Lerman, G.S. Giese, F.E. Anderson, R.W. Rudolph and B.S. Timson. 1984. Preliminary evaluation of the environmental consequences of Fundy tidal power development to the resources of the State of Maine. Maine State Planning Office, Augusta, Maine. (In press).

Redfield, A.C. 1981. Introduction to tides: the tides of the waters of New England and New York. Marine Science International, Woods Hole, 108 p.

Topinka, J.A. and W. Korjeff. 1981. Benthic macrophyte programs. Bigelow Laboratory for Ocean Sciences Annual Report 1980-81, pp. 32-33.

The Impact of a Tidal Power Project on Climate in the Bay of Fundy Region

William G. Richards

Atmospheric Environment Service
1496 Bedford Highway
Bedford, N.S. B4A 1E5

ABSTRACT

The ocean and climate are intimately related. Thus a change of one will impact the other. Predicted physical changes to the Bay of Fundy - Gulf of Maine system as a result of a tidal power project will affect certain elements of climate both inside and outside the barrage. The pertinent oceanographic changes are an increase in the extent of winter ice cover, increased summer water temperatures (as a result of stratification) and higher tidal currents in the Gulf of Maine. Inside the barrage these physical changes will result in changes such as: colder winter temperatures, warmer summer temperatures, lower incidence of early fall frost, decreased strength of seabreezes, lower fog frequency and reduced snowflurry activity. Outside the barrage higher tidal current velocities will extend the area of well mixed ocean between Georges Bank and Nantucket Shoals, lowering surface temperature (in summer) and increasing the probability of sea fog occurrence. Secondary effects are a change of wave climate in the headpond and an improvement in regional air quality.

Key words: Fundy tidal power, climate, climatic impact

RÉSUMÉ

L'océan et le climat sont intimement liés. Ainsi, toute variation de l'un a un retentissement sur l'autre. Les variations physiques prédites pour le système baie de Fundy - golfe du Maine, après la construction d'une usine marémotrice, influeront sur certains éléments climatiques, à la fois à l'intérieur et à l'extérieur de l'endiguement. Les variations océanographiques qui nous intéressent sont l'augmentation d'étendue de la couverture de lgace hivernale, l'accroissement des températures estivales des eaux marines (du fait de la stratification), et l'augmentation des courants de marée dans le golfe du Maine. A l'intérieur de l'endiguement, ces variations physiques provoqueront: l'abaissement des températures hivernales, l'élévation des températures estivales, la réduction de la fréquence des gelées au début de l'automne, la diminution de la force des brises de mer, la diminution de la fréquence des brouillards et des averses de neige. A l'extérieur de l'endiguement, les plus forts courants de marée agrandiront la superfice des eaux océaniques fortement brassées entre le banc Georges et les hauts-fonds de Nantucket, et feront par conséquent diminuer les températures de surface (en été), et sans doute augmenter la fréquence des brouillards en mer. Parmi les effets secondaires, il y aura changement du

régime des vagues dans les eaux de retenue, et amélioration régionale de la qualité de l'air.

INTRODUCTION

The presence of a large body of water influences just about every element of the climate in coastal areas. Thus it stands to reason that any changes made to the water body will have an impact on the climate.

Construction of a barrage in the Bay of Fundy is not expected to have a large scale climatic impact (Gates and O'Neill 1977). However, such a project may have limited local effects such as changes in ice cover, water temperature and sea regimes. Tidal power development also has significant implications for regional air quality.

ICE COVER

The construction of a barrage across the Cumberland Basin or Cobequid Bay would likely increase ice cover in the basins and delay the clearing of ice in spring (Gordon 1984). This increased ice cover would tend to lower winter temperatures in the area surrounding the headpond and perhaps delay the start of the growing season. Both effects have potential impacts on agriculture in the area.

In addition, increased ice cover would tend to reduce snowflurry activity which occurs on lee coasts during winter outbreaks of arctic air. Consequent reduction of the snowfall accumulation in these coastal areas would have a direct, though limited, impact on local hydrology.

WATER TEMPERATURE

According to Garrett et al. (1978) single effect mode of operation of a tidal power scheme would decrease mixing inside the headpond. This along with the accumulation of warm fresh runoff water discharged from local rivers and streams would cause the water inside the headpond to become stratified. Surface waters in the headpond would thus become warmer in summer. This will affect the sensible head transfer and evaporation rates over the headpond causing an increase in growing degree day totals and possibly a lower incidence of early fall frost near the headpond.

The occurrence of seabreezes and coastal fog along the Fundy shores is affected by tidal behaviour. Both sea fog and sea breezes are caused by cool water temperatures. They tend to move inland and to seaward in parallel with the advance and retreat of the tides. This secondary effect on local coastline climate will be influenced by any man-made changes to tidal regimes.

The increase in tidal amplitude and currents resulting from the construction of a barrage at sites A8 or B9 (Greenberg 1979) will change oceanographic conditions outside the barrier as well as inside. Garrett et al. (1978) have shown that higher tidal currents will increase the extent of the well-mixed area between George Bank and the Nantucket Shoals. This means that the sea surface temperature in these areas would become cooler resulting in a higher incidence of fog especially during the summer months. No significant changes to the vertical temperature structure and hence climate of the remainder of the Bay of Fundy - Gulf of Maine System outside of the barriers is anticipated.

WAVE CLIMATE

The construction of a barrage across either of the basins will block the propagation of sea waves and swell into the upper reaches of the Bay of Fundy. This will change the wave climate inside the headpond and make it resemble that of an inland lake of similar size. The removal of larger waves from the spectrum will result in less shoreline erosion by wave action and will also contribute to the stratification effects discussed earlier.

AIR QUALITY

Construction of a tidal power system in the Bay of Fundy area will eliminate the need to build equivalent capacity fossil or nuclear power plants. Thus tidal power development has beneficial aspects from an air quality viewpoint by reducing the rate of growth of air pollution sources in eastern North America. This factor is especially significant in view of increasing concerns about the effects of long range air pollution transport and acidification of precipitation on soils, lakes, agriculture, and forestry in the Atlantic provinces.

REFERENCES

Garrett, C.J.R., J.R. Kelly and D.A. Greenberg, 1978. Tidal mixing versus thermal stratification in the Bay of Fundy and Gulf of Maine. Atmosphere-Ocean 16: 403-423.

Gates, A.D. and A.D.J. O'Neill, 1977. The climate of the Bay of Fundy, In: Daborn, G.R. ed. Fundy tidal power and the environment. Acadia University Institute Publication No. 28, pp. 116-124.

Gordon, D.C. Jr. 1984. Predictions of the impacts of tidal power development on ice conditions in the upper reaches of the Bay of Fundy, In this report.

Greenberg, D.A. 1979. A numerical model investigation of tidal phenomena in the Bay of Fundy and Gulf of Maine. Mar. Geodesy 2: 162-187.

QUESTIONS AND COMMENTS

D. Gordon: There has been some concern expressed over the potential effect of climate change on agriculture. This has not been looked into in detail and should be. After hearing what the data base is like is there a possibility of AES setting an additional station to receive long term information at a place like Economy Point or Truro? This is a data base we would find useful in the future.

W. Richards: There are already several in existence on the shores of the Bay of Fundy at the present time. Truro is one. There is one at the Agricultural College. There are at least 2 and possibly 3 in the area providing a significant number of long-term climate data bases containing records of temperature and precipitation. I do not think the climate data base would be a problem. What is, is the input on the magnitude of the changes in the basin, such as changes in water temperature and how much more ice coverage there would be in the area. That is obviously going to be the driving force of any change. I think this is the greatest area of concern rather than what the climate is like now. The latter is well defined in agriclimate analysis.

D. Gordon: We have had many problems from taking data from land sites and applying it to marine areas. We have seen a real difference between the climate of Moncton and that of Cumberland Basin. When conditions are calm at Moncton the wind can be blowing 20 knots in Cumberland Basin. Even extrapolating a short distance such as that is a problem. It might be beneficial to have a station at Economy Point, which is a potential barrage site, and where the climate may be somewhat different.

W. Richards: Well that's probably true. I agree with you. But I remind you it costs money to maintain a climate station. We would like to have them all over but there have to be compromises in everything.

The Sedimentation Effect of Tidal Power Development
in the Minas Basin, Bay of Fundy

Carl L. Amos

Atlantic Geoscience Centre
Geological Survey of Canada
Department of Energy, Mines & Resources
Bedford Institute of Oceanography
P.O.Box 1006
Dartmouth, N.S. B2Y 4A2

ABSTRACT

Predictions on the sedimentologic changes resulting from the Cobequid Bay (B9) option of the Fundy Tidal Power scheme are presented. The cohesive, suspended material is modelled using the Greenberg (1979) 2-dimensional numeric model. The non-cohesive bedload is expressed 1-dimensionally using empirical derivations. Results indicate a summertime, net accumulation of mud in the presently existing intertidal regions of the headpond (0.01 - 0.03 m mo^{-1}) with concomitant intermittant deposition (2000 g m^{-2}) in the subtidal regions either side of the barrage. The extent of deposition is low when compared to predictions for the Bristol Channel Tidal Power Scheme and (or) compared to earlier predictions made using solid fill causeways as analogies. Bedload transport occurs only along the shorelines adjacent and seaward of the barrage. For a 20% reduction in local current velocity there will be an associated reduction in bedload transport by two orders of magnitude to 10,000 m^3 a^{-1}. This transport mass is considered to be a reasonable post-barrage approximation albeit for summer conditions only. Along the south shore of the Bay, bedload transport may occur in an eastwards direction from Walton Bar towards the barrage site. Neither the effect of headpond siltation nor that of bedload transport is thought to present insurmountable engineering problems, though some physical changes to the intertidal zone will result.

Key words: sedimentation modelling, tidal power environmental impacts

RÉSUMÉ

Dans cet article, on présente les prédictions concernant les variations sédimentologiques qu'entraînerait l'option B9 sur l'aménagement d'une usine marémotrice dans la baie de Fundy.

On a établi un modèle de matériaux cohérents en suspension, en faisant appel au modèle numérique bidimensionnel de Greenberg (1979). On a exprimé de façon unidimensionnelle le charriage de fond non cohérent, au moyen de dérivations empiriques. Les résultats indiquent qu'en été, se produit une accumulation nette de boue, dans les régions intertidales actuellement existantes de la partie amont (0,01 - 0,03 m mo^{-1}), en même

temps qu'une sédimentation intermittente (2 000 g m^{-2}) dans les régions subtidales, de part et d'autre de l'endiguement. L'importance de la sédimentation est faible, comparativement aux prévisions concernant l'usine marémotrice du chenal de Bristol, et aux prévisions plus anciennes basées sur l'analogie avec l'installation de chaussées en remblai solide.

Le charriage de fond a lieu le long du littoral seulement à proximité du barrage et du côté orienté vers la mer. Pour une réduction de 20% de la vitesse locale du courant, on observe une réduction corrélative du charriage, de deux ordres de grandeur, jusqu'à 10 000 m^3 a^{-1}. On considère que ce transport en masse constitue une approximation raisonnable de la situation après la construction du barrage, mais seulement dans les conditions estivales. Le long de la rive sud de la baie, le charriage de fond pourrait avoir lieu dans une direction est-ouest, de la flèche Walton vers le site du barrage.

On juge que ni l'envasement de la portion de retenue, ni le charriage de fond ne posent de problèmes techniques insurmontables, même si certains changements apparaissent dans la zone intertidale.

INTRODUCTION

Two-thirds of the larger cities of the world lie on or near tidal estuaries (National Academy of Sciences, 1977). General observations of such tidal estuaries show them to be regions of active sediment transport playing a dominant role in the physical, biological and chemical characteristics of these regions. Dense populations can affect sedimentation by changing the original hydrodynamic regime and (or) the physical properties of the estuarine water mass. Given a turbid environment, it is this change in hydraulic properties which directly controls the distribution of sediment both in suspension and at the estuary bed. An overview of a number of such turbid estuaries is given in the proceedings of the Symposium on the Dynamics of Turbid Coastal Environments (Gordon and Hourston 1983).

In turbid estuaries, such as the upper part of the Bay of Fundy, the extent of sedimentation which can result from marine construction is wide spread. This was demonstrated by the results of a solid-fill dyke built across the Eider River Estuary in 1935 (Caspers, H., unpublished data). Siltation on its seaward side was so severe that attempts to dredge navigation channels 25 kilometres from the dyke failed. The dyke was eventually replaced with a permeable structure which returned the estuary to its former state. Similar, though less catastrophic responses have been measured in the Bay of Fundy seaward of the Petitcodiac River Causeway (Bray et al. 1982), and seawards of the Windsor Causeway (Job Corps Program 1980).

Construction and operation of the B9 option of the tidal power scheme in Cobequid Bay will result in a reduction of tidal energy and an alteration in the distribution of fluid stresses both spatially and through time (Greenberg 1979). This will no doubt have a net effect on the distribution of sediments. Interpolation or interpretations of sediment a-tion by analogy are not usually valid due to non-linear responses of the sediment to flow. Furthermore, results show that physical models cannot provide quantitative results on sedimentation and are often qualitatively in error (Basco et al. 1974, p. 160). The only feasible method of impact prediction is through numeric simulation. Only in recent years, with the development of numerically predictive hydraulic models such as that of Greenberg (1979), has this been possible.

BACKGROUND

Previous Work

Sedimentation studies in relation to nearshore marine construction is an integral part of any environmental impact statement. It is entirely contingent on good hydraulic modelling, while being a prerequisite to biological and chemical impact evaluations (Fig. 1).

A major problem in the past has been the development of a framework or strategy for sedimentation predictions. Kendrick (1972) in part detailed the necessary data sets and interface criteria needed for the evaluation of the Thames Estuary storm surge barrier (Fig. 2).

Post-barrier flow patterns are determined by reference to tidal data and local geometry, thereafter by applying the equations of motion and continuity. The post-barrier sedimentation patterns (cohesive sediments in this case) are determined by quantifying four sedimentation phases. They are:

1. the critical shear stress for erosion;
2. the erosion rate;
3. the limiting shear stress for deposition; and
4. the settling rate of suspended particles.

The above, 1-dimensional strategy was expanded upon by the Hydraulics Research Station (1980) to include tractive load and the transport of non-cohesive sediment. This more complex logic structure is shown in Fig. 3 and was developed to predict the possible siltation due to a rising gate, storm surge barrier proposed for the Western Schelde Estuary, Belgium. The study is of particular significance because of the detailed flume work carried out on the erosive characteristics of cohesive sediments. The work successfully combined laboratory and field results to make the appropriate predictions on sedimentation.

Using an approach similar to that of the Hydraulics Research Station the cohesive sediment characteristics of the Minas Basin were evaluated and interfaced to a 2-dimensional tidal model originally developed by Greenberg (1979). This numerical, barotropic tidal model produced a good simulation of the tides and currents of the Bay of Fundy with a spatial resolution of 1661 m. The equations of sediment advection were solved in an explicit, finite differencing scheme, and a time series of siltation predicted. Details of the model set-up and run criteria can be found in

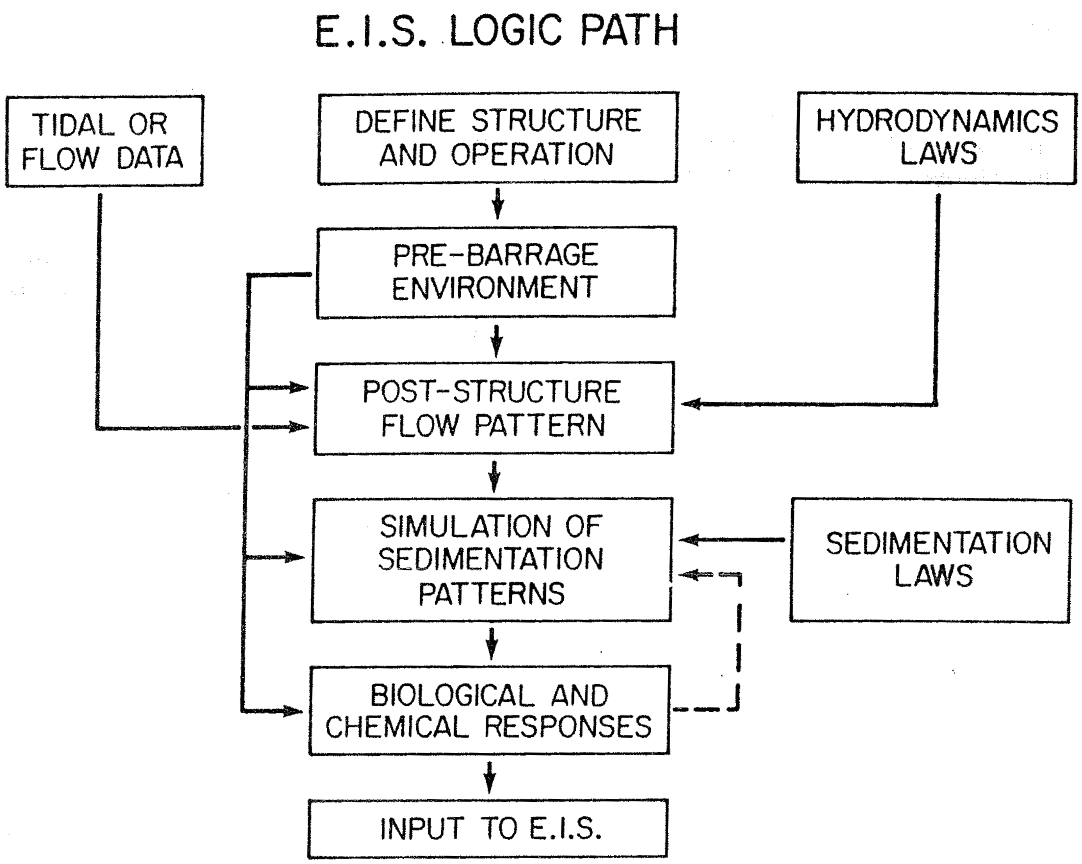


Fig. 1. A proposed logic path for the acquisition of data sets leading to an environmental impact statement.

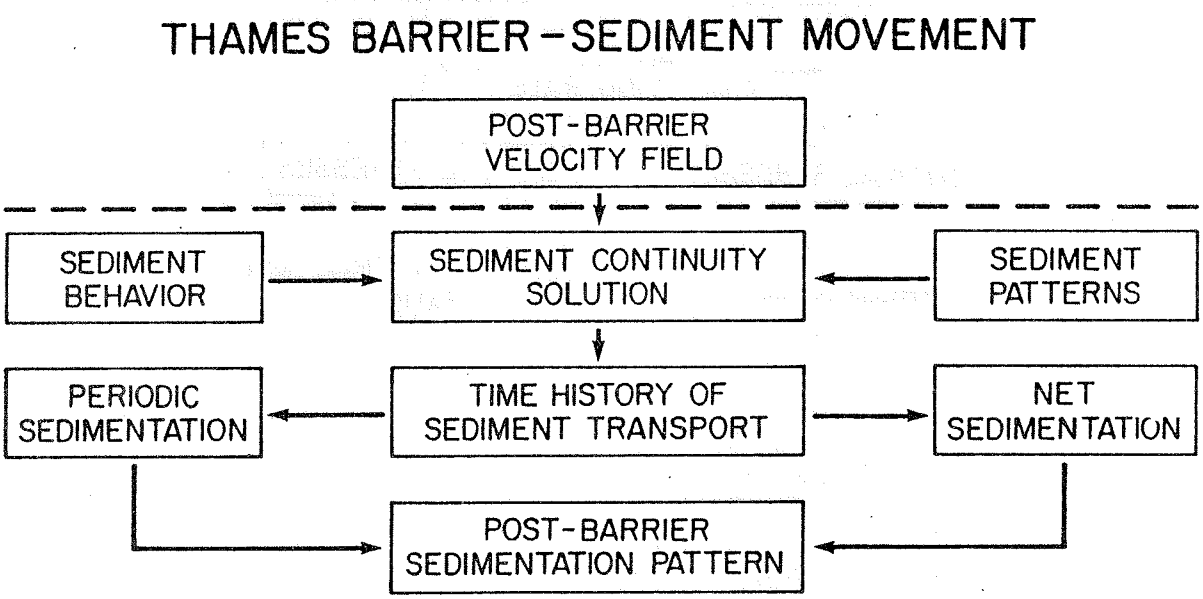


Fig. 2. The strategy adopted by Kendrick (1972) in the prediction of the siltation effects of a Thames River storm surge barrier, U.K.

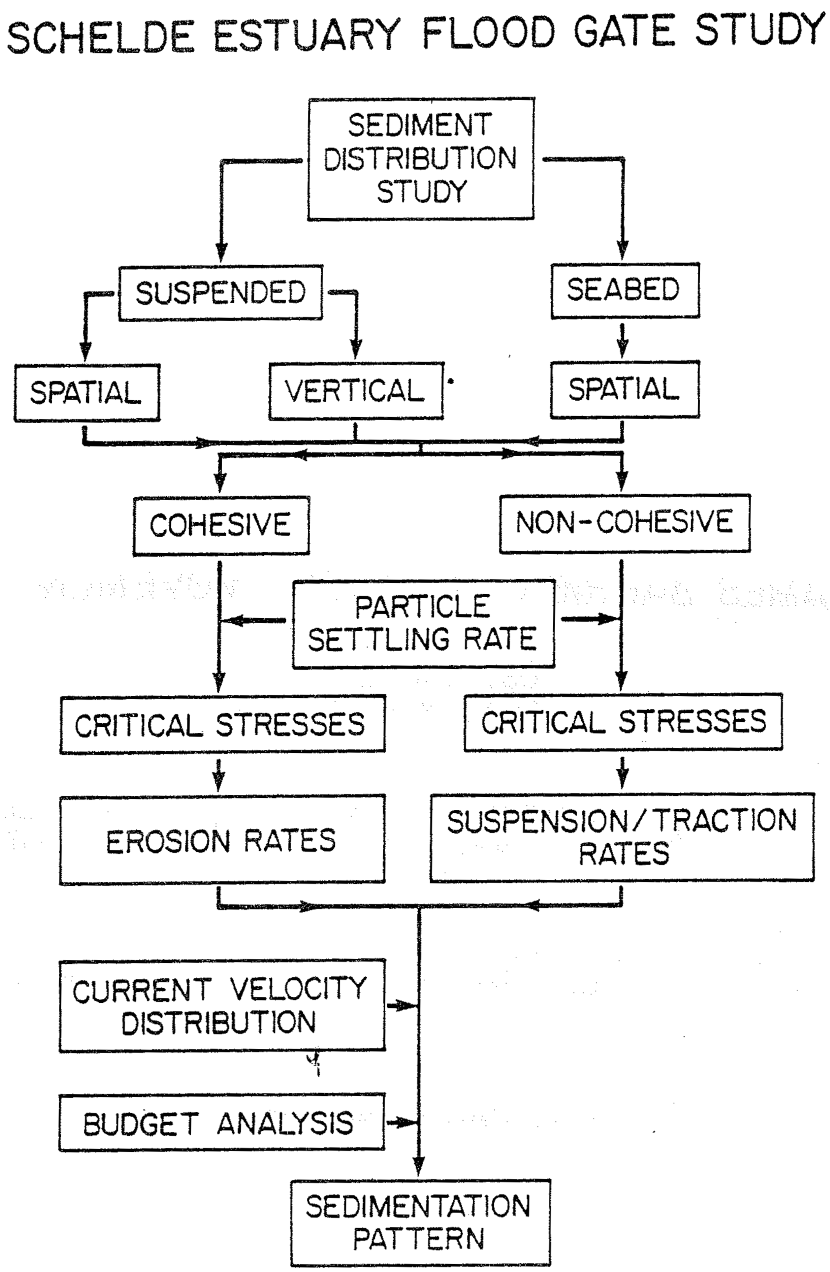


Fig. 3. The strategy adopted by the Hydraulics Research Station (1980) in the analysis of the movement and accumulation of bed material and suspended load resulting from the proposed construction of a storm surge barrier on the western Schelde estuary, Belgium.

Amos and Greenberg (1980) and Greenberg and Amos (1983).

The bedload transport of sand size material has been determined for the B9 site in a general fashion only. Present day bedload movement in the site vicinity occurs only within the northernmost intertidal zone of the Minas Basin. Radio-isotope tracer studies of this material shows a net eastward transport of 0.85 X 10^6 m^3 a^{-1} (Amos and Long, 1980). Peak flows of about 100 cm s^{-1} occur in this region.

The first order mass transport (gs) of traction load is a power function of peak velocity (u)

$$gs = K u^y .$$

The exponent y is between 5 and 6 (Vanoni 1975) and the proportionality term (K) is complex, but was evaluated by the tracer experiment mentioned earlier. This rudimentary relationship, modified from the Einstein-Brown method, can give a first order indication of post-barrage bedload transport provided that a reasonable estimate of the expected current velocity distribution can be made. For present purposes a velocity reduction of 20% was assumed to be in keeping with the tidal current model of Greenberg (1979), though detailed information was not available.

RESULTS

Cohesive Sediments

The results of the numerical simulation of the suspended, cohesive material are shown in Figs. 4, 5 and 6. The model uses high critical stress values and low erosion rates in order to represent the most severe conditions of sedimentation. The use of these values to simulate existing conditions produced results which were close to the observed distribution of sediment, both in suspension and on the seabed. That is, net accumulations occurred in Windsor Bay, Scots Bay, Five Islands and Noel Bay. The rate of accumulation was equivalent to 0.01 m every 3 years approximately corresponding to observed accumulation rates. The model, however, simulates summertime conditions only and does not consider waves, ice or biological effects.

The results of a single phase, single effect tidal power scheme show that sediment deposition will be intermittant over the tidal cycle. Approximately 0.01 m (corresponding to 2000 gm^{-2}) of sediment would accumulate subtidally every still-stand of the tide. This material will be subsequently eroded during power generation or headpond filling. As a consequence net accumulation of sediment is predicted to take place in the presently existing subtidal region, though a 4 to 40 fold increase in intermittant deposition is thought to result. Barrage simulations were made using critical erosion stresses of 1.28 and 2.56 dynes cm^{-2}. The results were not significantly different in either run suggesting that within the subtidal region the peak flow velocity is the controlling factor on net

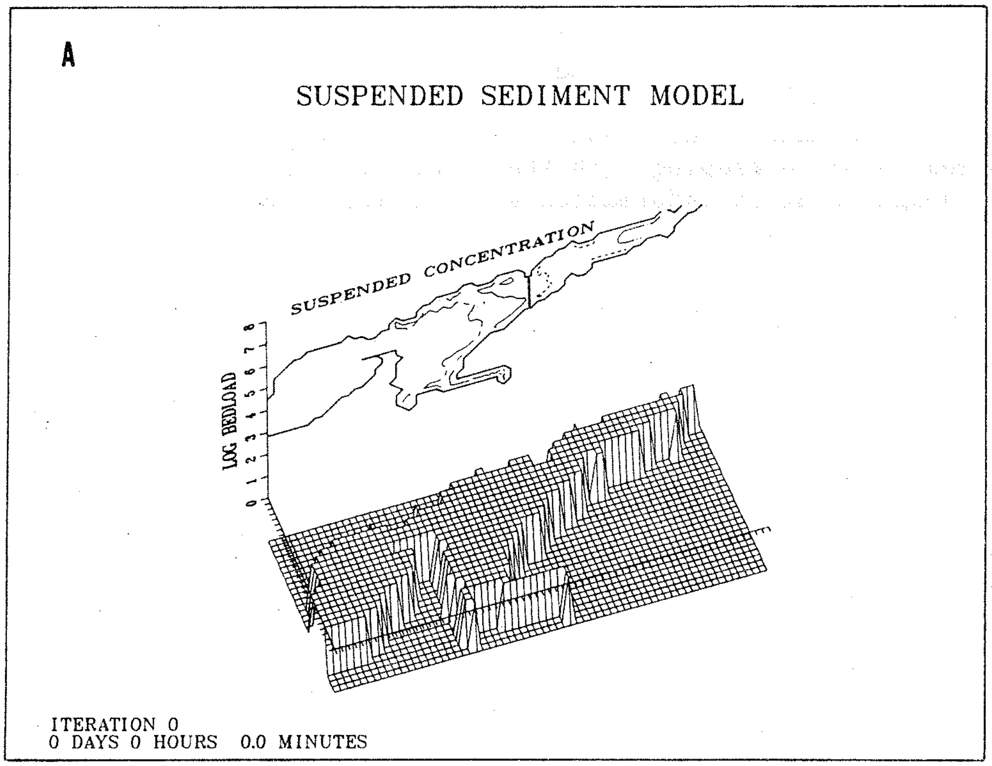


Fig. 4a. The starting condition of the numeric simulation of suspended sediment transport and deposition (after Greenberg and Amos 1983). The mean concentration in suspension is 60 mg L^{-1}. The log bedload term is expressed in units of (1 + mg x 10^{-1} cm^{-2}).

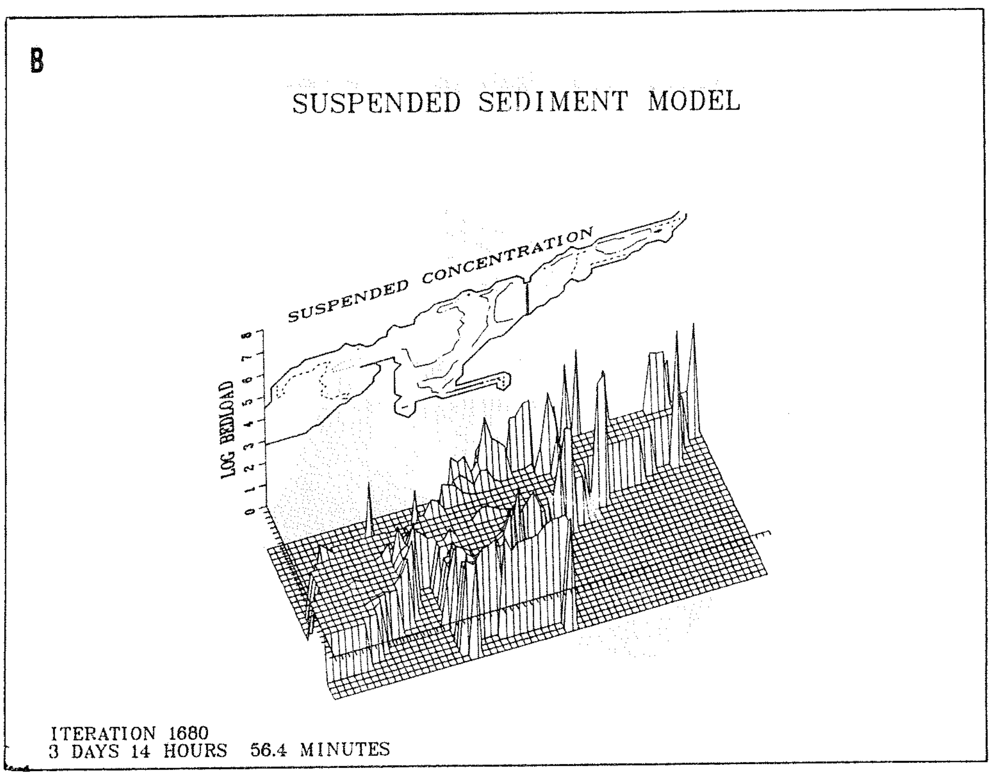


Fig. 4b. The numeric model result of high tide, seven tidal cycles after initialization. Net seabed accumulation (shown on the 3-D plot) is restricted to presently existing intertidal regions.

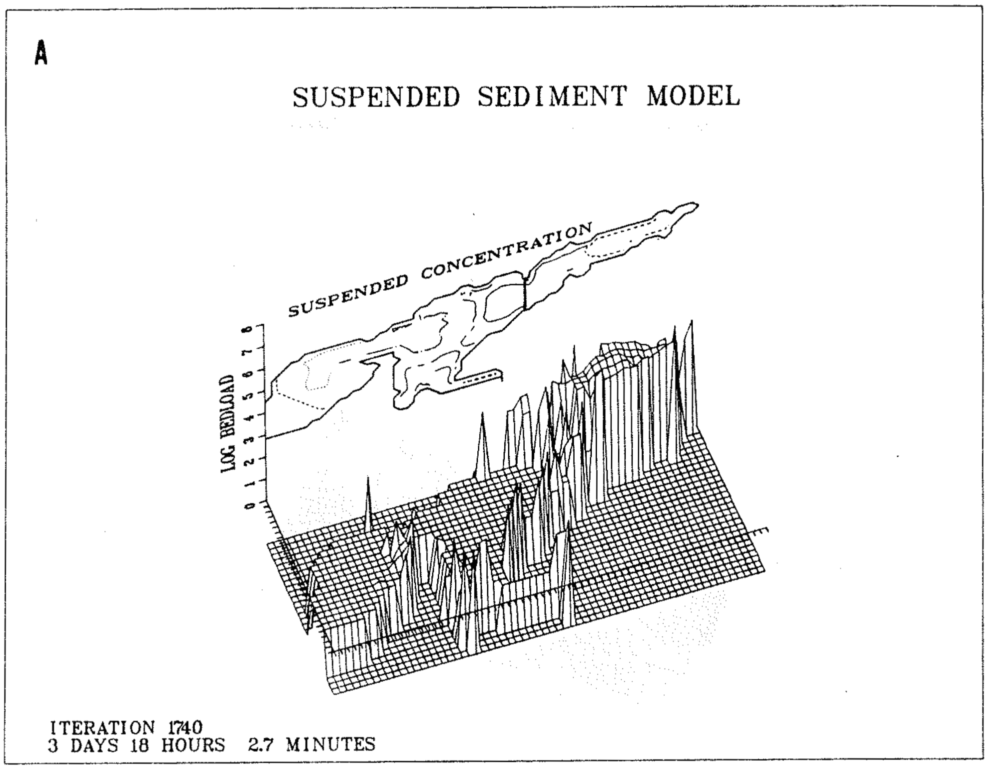


Fig. 5a. The numeric model result of the mid-ebb period of the eighth tidal cycle after model initialization. The still stand period during barrage closure has resulted in a temporary accumulation of material in the headpond.

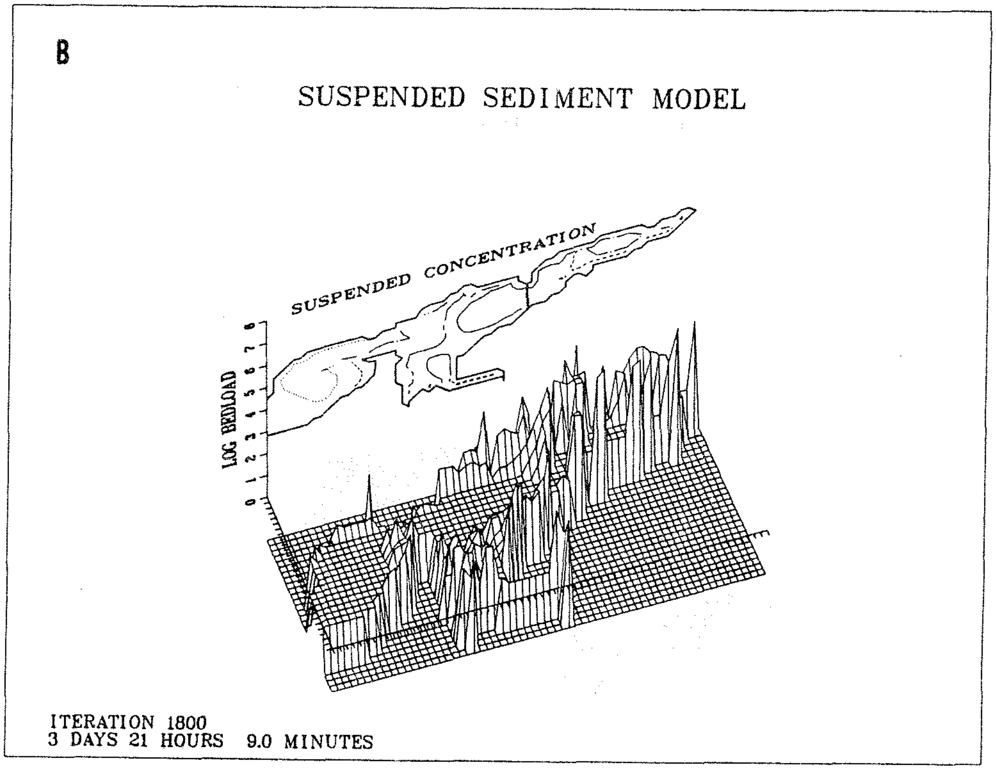


Fig. 5b. The numeric model result of the low tide period of the eighth tidal cycle after model initialization. Resuspension of bottom sediment has taken place as the model simulation enters the power generation phase.

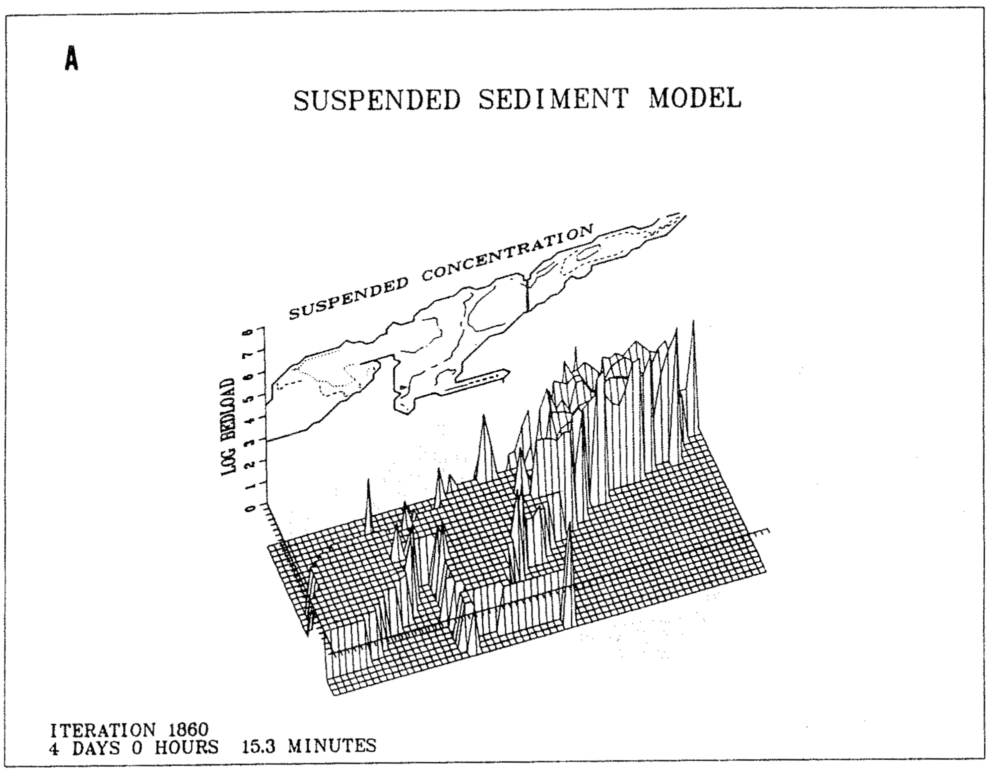


Fig. 6a. The numeric model result during the mid flood stage of the eighth tidal cycle. Accumulations of silt has taken place in the headpond region due to barrage closure shortly after low water.

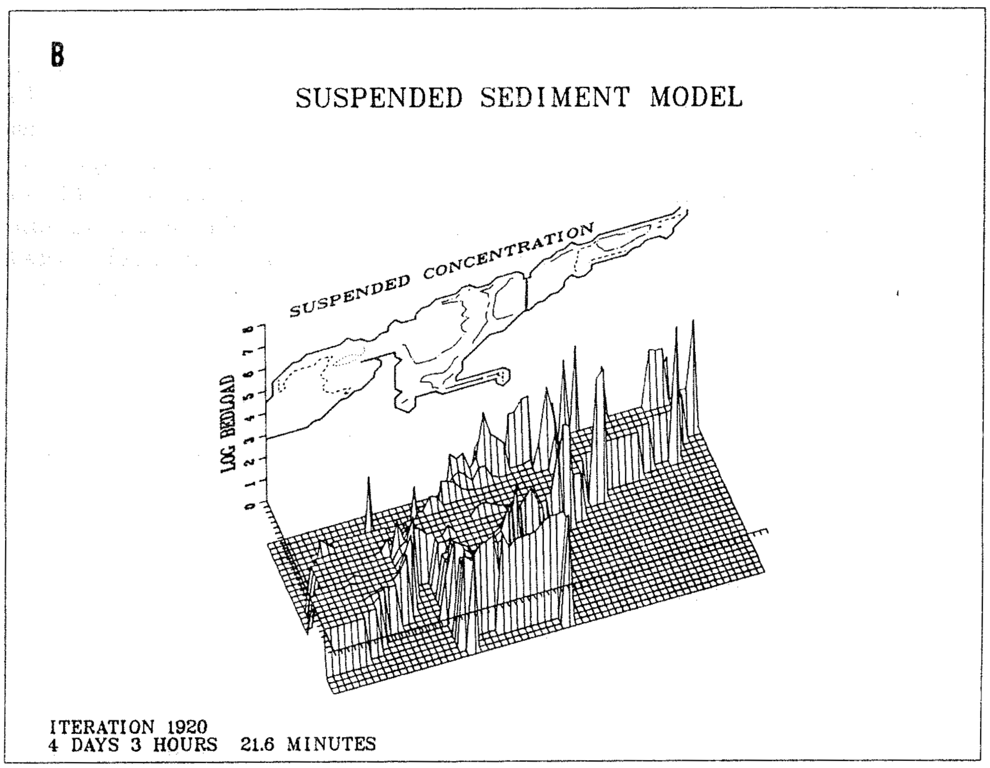


Fig. 6b. The numeric model result for high tide of the eighth tidal cycle. Flooding of the headpond has resulted in the partial erosion of material deposited during the early flood tide.

sedimentation. In the intertidal zone, the relationship is more complex due to solar heating and biological effects.

It is predicted that in Noel Bay and over much of the existing intertidal zone, there will be a net increase in summertime deposition by a factor of 10. Immediately seawards of the barrage there will be a corresponding increase in intertidal deposition of 60%; in Windsor Bay this increase will be 10%; while surprisingly, in the Avon River Estuary, accumulation rates will approximate those of the headpond.

Seawards of the barrage the subtidal region will also be subject to intermittant deposition (50 g m^{-2}) during the extended still-stand periods, though to a lesser degree than in the headpond. The greatest deposition will take place during the high tide and early ebb period. This effect will probably diminish quadratically away from the barrage.

The regions of net accumulation seaward of the barrage will generally reflect those of today, though some subtidal net accumulation will take place in Windsor Bay.

The most significant changes in sedimentation patterns will be located in the headpond region. Short term (3 hour) intermittent mud deposition and the probable development of a nepheloid or pseudo-plastic layer may affect exchange processes between the seabed and water column. This will be paralleled by a decrease in turbidity in the surface water. Over the majority of the intertidal zone the net accumulation rate will be between 0.01 and 0.03 m mo^{-1}. This rate is comparable with accumulation rates measured on the mudflat at Windsor Causeway and will likely result in sediments with high water content and low bearing strength. Assuming that 50% of the intertidal area of Cobequid Bay (186 km^2) is subject to accretion, the volume of material deposited per month (summertime) will be 5.6x $10^6 m^3$. The resident suspended volume in Minas Basin is 30 x $10^6 m^3$ (Amos and Greenberg 1980) replenished annually with 1.6 x $10^6 m^3 a^{-1}$. Within 6 months, the region would be supply limited and would accrete at a much diminished rate, dependent on the supply of silt. The water in Minas Basin would be relatively clear at this time.

Non Cohesive Sediments

The relationship between current speed and bedload transport is non-linear (Stelczer 1981). The effect of this nonlinearity can be demonstrated as follows. If a 20% decrease in peak current velocity were to occur in the intertidal vicinity of the barrage, then a net decrease in bedload transport of 99% would result. Such a velocity decrease is considered reasonable for the Economy Point region. The subsequent post-barrage bedload transport rate would therefore be 10,000 m^3 a^{-1}, which is indeed controllable by conventional methods of groyne emplacement. This transport would continue to take place in the intertidal zone within the complex flood and ebb channelways not resolved by the Greenberg model (1979). Adopting the concept of jet stream return flow (Bruun 1978), the sand marginal to the turbine jet stream will continue to move eastward towards the barrage site and accumulate to form an elongate sand bar extending westward from the barrage. Bedload transport is site dependent and therefore the details of movement depend on the details of the post-barrage flow patterns in that location. Such detailed information is unavailable and predictions are therefore speculative.

Along the south shore of Minas Basin the existing flows have an ebb residual which prevents the eastward migration of sand from Walton Bar. The post-barrage residual transport of sand is likely to be flood dominant with transport and accumulation rates similar to those of the north shore.

The net effect of the B9 site on the extensive sand bars of Cobequid Bay would be to stablize them. The suite of bedforms presently existing over these bars (described by Dalrymple 1977) would likely become moribund and the tidal flood and ebb channels would slowly degrade. Bedload transport in the headpond would probably be reduced to negligible amounts and a fining in grain size of the surface material is anticipated.

CONCLUSIONS

A prediction of the summertime mobility of suspended, fine-grained material has been made which, notwithstanding the model resolution, represents well the observed, existing conditions. However, the prediction of bedload transport made herein is less reliable due to problems of flow prediction in the relatively narrow intertidal areas where this transport takes place. These flows are subject to the influences of mutually evasive flood and ebb dominant channels. Furthermore the long term, seasonal effects on sedimentation in general are poorly known due to the influences of storms, ice and bioturbation.

The headpond is anticipated to suffer the greatest effects of barrage construction. Accumulations of fine-grained material around the margins of the headpond will take place (0.01-0.03 m mo^{-1}), and an intermittant nepheloid layer is likely to develop during still-stands of the tide. Siltation will be limited in less than six months of active accretion due to a limitation in the supply of material (assuming summertime deposition rates).

There will be a continued transport of sand eastwards from Five Islands to the B9 barrage site at Economy Point, but at a much reduced volume from that which presently occurs. The volume of transported material can be adequately stabilized by groyne emplacement. The supply of sand is expected to continue at present day rates due to a maintained cliff-line recession. The reduction in the longshore transport of sand will result in a build-up of material potentially creating a beach along the Minas Basin north shore. This build-up will likely take place in the region between Five Islands and Economy Point. A similar situation is envisioned for the region between Walton Bar and Cape Tenny.

The seabed beneath the turbine jet stream is composed of clay overlain by a thin layer of armouring gravel. Without suitable protection, scouring of this material would likely result, supplying considerable quantities of material to the water column. This material would contribute to the net sedimentation in the headpond. The predictions made are therefore considered conservative.

ACKNOWLEDGMENTS

I would like to thank Mr. B.A. Zaitlin and Dr. D.C. Gordon, Jr. for manuscript review and Dr. K. Kranck for critique on sedimentation phases. The input of the B.I.O. Word Processing Pool is also acknowledged.

REFERENCES

Amos, C.L. and Greenberg, D.A.. 1980. The simulation of suspended particulate matter in the Minas Basin, Bay of Fundy - A region of potential tidal power development. In: Proceedings of Canadian Coastal Conference. Publ. National Research Council. pp. 2-20.

Amos, C.L. and Long, B.F.N. 1980. The sedimentary character of the Minas Basin, Bay of Fundy. In: The Coastline of Canada (McCann, S.B. Ed.) Geological Survey Paper 80-10: 123-152.

Basco, D.R., Bouma, A.H. and Dunlap, W.A. 1974. Assessment of the factors controlling the long-term fate of dredged material deposited in unconfined subaqueous disposal areas. Publ. Depart. Assay, Vicksburg, Va. Under contract No. DACW 39-73-C-0129, 238 p.

Bray, D.I., Demerchant, D.P. and Sullivan, D.L. 1982. Some hydrotechnical problems related to construction of a causeway in the estuary of the Peticodiac River, New Brunswick. Canadian Journal of Civil Engineering. 9(2): 296-307.

Bruun, P. 1978. Stability of tidal inlets. Publ. Elsevier Scientific Publishing Co. 510 p.

Dalrymple, R.W. 1977. Sediment dynamics of macrotidal sand bars, Bay of Fundy. Ph.D. Thesis, McMaster University, Hamilton, 634 p.

Gordon, D.C. Jr. and A.S. Hourston (Ed.). 1983. Proceedings of the Symposium on the Dynamics of Turbid Coastal Environments. Can. J. Fish. Aquat. Sci. 40(Suppl. 1): 365 p.

Greenberg, D.A. 1979. A numeric model investigation of tidal phenomena in the Bay of Fundy and Gulf of Maine. Marine Geodesy 2: 161-187.

Greenberg, D.A. and Amos, C.L. 1983. Suspended sediment transport and deposition modelling in the Bay of Fundy, Nova Scotia - A region of potential tidal power development. Can. J. Fish. Aquat. Sci. 40(Suppl. 1): 20-34.

Hydraulics Research Station. 1980. River Schelde surge barrier. Study of estuary sediments. Hydraulics Research Station Report No. Ex. 928, 38 p.

Job Corps Program. 1980. Activities of the Job Corps Program; Fundy tidal power development. Unpublished B.I.O. Report, 176 p.

Kendrick, M.P. 1972. Siltation problems in relation to the Thames Barrier. Phil. Trans. Royal Soc. London. 272: 223-243.

National Academy of Sciences. 1977. Estuaries, Geophysics, and the Environment. Publ. National Academy of Sciences, 127 p.

Stelczer, K. 1981. Bedload Transport Theory and Practice. Publ. Water Resources Publications, 295 p.

Vanoni, V.A. (ed.) 1975. Sedimentation Engineering. Publ. American Society of Civil Engineers, 745 p.

QUESTIONS AND COMMENTS

B.Silvert: You talked about sedimentary factors at work at very low energy inside the headpond such as biological or geological. Do you think these in anyway could become a limiting factor?

C. Amos: No, I think they are third order factors. It is my own personal feeling that those kind of effects, much like temperature or viscosity effects, are much higher order than the framework of sediment transport theory will allow you to predict. I think at this stage in our knowledge time spent considering that level of effect would be misspent. It would be a much better idea to obtain accurate estimates of the lower order effects.

L. Cammen: If we have a slight increase in tidal energy in Maine will we have a proportional response in bedload transport.

C. Amos: It depends at what point on the energy sediment transport curve you are. It is an exponential curve. If you are on the lower, flatter part of the curve then the change will be small. If you are at currents in the range of 120-140 cm sec^{-1} a small change in flow velocity has large effects. If currents are below threshold, there will be no transport at all. I really think it depends on the absolute magnitude of flow not so much the relative difference.

D. Gordon: You compared the Cobequid Bay sediments to Cumberland Basin sediments. Cobequid Bay sediments are more sandy. As a result of building a barrage and reducing tidal energy is there a chance we would see a decrease in the grain size of sediments in Cobequid Bay such that the intertidal areas would become more like Cumberland Basin or does a supply of fine silt not exist?

C. Amos: I think there is enough of a supply of silt to cover it thinly. I think 30 million m^3 maximum is the resident volume of suspended material which if deposited over the entire intertidal area of the headpond would result in a deposited layer 1/2 m thick. This of course does not account for the long term annual supply. The degree of sedimentation depends entirely on the operating scheme. There are a suite of potential sediment responses. The rate and site of intertidal sedimentation depends on the sequence of events and the exposure time. In general, a fining of intertidal sediment of the B9 headpond is probable.

D. Scarratt: In your sediment analysis have you confined yourself to the upper Bay of Fundy or have you considered sediment transport in the lower, higher fisheries productivity area at the mouth?

C. Amos: The outer Bay is an entirely different problem because you are dealing with significant wave effects at the bed during storms. As a result, when you evaluate combined wave and current motion at the bed, analysis becomes extremely difficult and errors increase proportionally. We have some models that look at this aspect which we are presently working on. They describe considerable movement of sand size sediment during storms.

D. Scarratt: Then there is a likelihood that sediment movement at the mouth of the Bay of Fundy will increase with a new tidal spectrum induced by barrage construction?

C. Amos: Yes. On Georges Bank you are already dealing with currents of 1.5 m/sec which are actively moving sand.

D. Gordon: In this case, however, you are dealing with coarser sediment. Any suspension should stay near the bottom rather than move to the surface and disrupt light penetration, would it not?

C. Amos: That depends on the degree turbulence. I think that during a storm it would be transported to the surface.

D. Scarratt: But there are fisheries, notably scallops, which live on or near the bottom and could be effected by an increase in the bottom transported sediments.

C. Amos: Current speeds on Georges Bank are close to suspension levels now. If you look at the bed forms on eastern Georges Bank they are high energy types (sand waves and tidal ridges). If the current is increased by even 20 cm sec^{-1} I would suspect considerable material would be thrown into suspension.

C. Desplanque: From your last slide you indicate the tidal outflow period is considerably longer than the inflow. Do you believe this will have an effect on the movement direction of silt contrary to what the model describes.

C. Amos: No, the model is a stepped times series and takes this into account.

Predictions of the Impacts of Tidal Power Development on Ice Conditions in the Upper Reaches of the Bay of Fundy

Donald C. Gordon, Jr.

Marine Ecology Laboratory
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, N.S. B2Y 4A2

ABSTRACT

A tidal power project in the upper reaches of the Bay of Fundy would markedly change ice conditions by reducing tidal energy, high water levels and intertidal areas. Sheet ice coverage is expected to increase while the extent and elevation of shore fast ice should decrease, especially along tidal rivers. Sediment scour by drift ice should also decrease. Interactions between drift ice and a tidal barrage (including turbines and sluices) must be closely examined before a final design is adopted.

Key words: ice, Bay of Fundy, Cumberland Basin, Cobequid Bay, tidal power, environmental impacts

RÉSUMÉ

L'aménagement d'une usine marémotrice dans la partie amont de la baie de Fundy modifierait fortement les conditions glaciologiques, en réduisant l'énergie des marées, le niveau de la haute mer, et l'étendue des zones intertidales. On prévoit que la couverture de glace uniforme augmentera, et qu'en même temps, la superficie et la hauteur de la glace côtière diminueront surtout dans les parties des cours d'eau exposées aux marées. L'affouillement des sédiments par la glace de dérive diminuera aussi probablement. On doit examiner en détail les interactions possibles entre la glace de dérive et la digue de l'usine marémotrice (y compris les turbines et les vannes), avant d'adopter le modèle de construction final.

INTRODUCTION

At the Acadia conference in 1976 several speakers addressed the topic of ice (Hodd 1979, Greenberg 1977, and Garrett 1977). There seemed to a consensus that ice cover would increase in the headpond but few detailed predictions were offered because of a lack of knowledge about processes controlling ice formation in the upper reaches of the Bay of Fundy. Since then two further ice studies have been conducted: Knight and Dalrymple (1976) in Cobequid Bay and Gordon and Desplanque (1983) in Cumberland Basin. The following are some predictions based largely on the work in Cumberland Basin. These predictions should be considered very tentative until reviewed and confirmed by others.

There are basically four types of ice occurring in the upper reaches of Fundy:

1. Sheet ice forms a continuous layer that more or less stays in place except for vertical movement which can produce fracturing, especially along the shoreline. It forms where tidal energy is low.

2. Drift ice forms on the seawater surface where tidal energy is high and remains as rounded discrete pieces because of almost continual movement in tidal currents. It can strand on intertidal flats.

3. Shore fast ice forms when drift ice strands along the shoreline between neap and spring high water levels and can develop thick accumulations which remain in place until the spring thaw. It is most pronounced along tidal rivers and contributes to flooding by restricting cross-sectional areas.

4. Frozen crust forms on the surface of intertidal sediments by the downward freezing of pore water and the upward accretion of precipitation.

Ice conditions are profoundly influenced by tidal properties and marked changes are expected in the headpond region of a tidal power project as a result of reduced high water levels, tidal energy, and intertidal area.

Earlier predictions that the areal extent of sheet ice coverage will increase because of reduced tidal energy seem justified (Greenberg 1977). At the present, sheet ice is generally restricted to the upper parts of tidal rivers but how much farther it would extend seaward is difficult to predict. The stratification predicted by Garrett et al. (1978) will also promote the development of sheet ice by producing fresher surface water and a faster cooling rate in the fall. The expanded sheet ice zone would probably be heavily fractured from vertical tidal movement, especially along tidal rivers, and should remain in place until spring breakup. The formation of sheet ice would be encouraged by intentionally holding the headpond water level constant (at a high elevation) for several days in early winter under the proper weather conditions. Before this practice was considered, however, other environmental effects such as sediment compaction must be examined.

The Annapolis River causeway, constructed in 1960, provides a useful analogy. Before construction, the estuary was subject to considerable tidal energy (mean tidal range was 7 m) and contained moving drift ice during the winter months. The causeway removed most of the tidal influence and the water became fresher and stratified. As a result, a continuous layer of sheet ice is now formed each winter, up to 60 cm thick (Sweet, 1967), which extends right down to the causeway. It will be interesting to see what changes occur once the pilot tidal power project is in operation and tidal energy in the basin increases.

The predicted increase in sheet ice coverage in the tidal basin will reduce the open water area where drift ice can form. Expanded sheet-ice coverage should also retard drift ice from reaching the shoreline and forming shore fast ice, especially in the lower parts of tidal rivers. These changes, coupled with the lower high water levels (0.3, 0.7, and 1.0 m for neap, mean, and spring tides, respectively), should reduce both the extent and elevations of shore fast ice in tidal rivers, which in turn should decrease the likelihood and severity of winter flooding produced by drift-ice jams in rivers. If this prediction is accurate, it constitutes a positive impact for the Cobequid Bay site (B9) because of current serious flooding in the Salmon River at Truro, N.S. Shore fast ice will still develop more seaward in the headpond where drift ice now dominates but its elevation and vertical extent will be reduced.

The intertidal area of the headpond will be reduced by about 65% on a mean tide. Therefore, much less intertidal sediment will be exposed to scour by drift ice as the tide rises and falls. The scouring promotes both the resuspension of sediment and the mortality of benthic organisms, especially Corophium, and any reduction in its magnitude may promote biological productivity.

A substantial amount of drift ice can form seaward of both potential barrage sites (Cumberland Basin and Cobequid Bay). The presence of drift ice on both sides of a barrage presents several interesting questions that engineers should consider when preparing final designs. For example, will ice pass through the sluices and turbines? If so, is there a possibility of damage to equipment or clogging? What will happen to the ice that will accumulate on either side of the barrage and could it build up to the degree that water flow would be seriously impeded?

In summary, this brief review identifies a number of possible negative and positive impacts on ice development that could result from tidal power development. It also raises some questions that should be considered by engineers in final project design.

REFERENCES

Garrett, C.J.R. 1977. Tidal influences on the physical oceanography of the Bay of Fundy and Gulf of Maine. In: Daborn, G.R., ed. Fundy tidal power and the environment. Acadia University Institute Publication No. 28, pp. 101-115.

Garrett, C.J.R., J.R. Keely and D.A. Greenberg. 1978. Tidal mixing versus thermal stratification in the Bay of Fundy and Gulf of Maine. Atmosphere-Ocean 16: 403-423.

Gordon, D.C., Jr., and C. Desplanque. 1983. Dynamics and environmental effects of ice in the Cumberland Basin of the Bay of Fundy. Can. J. Fish. Aquat. Sci. 40: 1331-1342.

Greenberg, D.A. 1977. Effects of tidal power development on the physical oceanography of the Bay of Fundy and Gulf of Maine. In: Daborn, G.R., ed. Fundy tidal power and the environment. Acadia University Institute Publication No. 28, pp. 200-232.

Hodd, S.L. 1977. Environmental considerations of a Fundy tidal power project. In: Daborn, G.R., ed. Fundy tidal power and the environment. Acadia University Institute Publication No. 28, pp. 71-81.

Knight, R.J. and R.W. Dalrymple. 1976. Winter conditions in a macrotidal environment, Cobequid Bay, Nova Scotia. Revue de Geographie de Montreal 30: 65-85.

Sweet, C.E. 1967. Preliminary report on ice conditions in Minas Basin, Chignecto Bay and the Annapolis Basin area of the Bay of Fundy. Unpublished report submitted to the Atlantic Tidal Power programming Board, 22 pp.

QUESTIONS AND COMMENTS

K. Mann: With a barrage in place do you think fast ice coverage will extend over the entire Basin and what will variable water levels do to this ice?

D. Gordon: I think the fast ice coverage will be confined to the inner parts of the Basin and it should more or less stay in place and just drop when the tide recedes. I doubt if fast ice coverage would extend seaward to the barrage. There probably would still be a large zone of drift ice. This ice would move with the water and build up on the inside. There might be much more of a problem with build up of drift ice on the seaward face of the barrage.

K. Mann: Do you know whether ice forms on the salt marshes and where?

D. Gordon: There are two types of salt marsh, the low marsh which is dominated by Spartina alterniflora and the high marsh composed primarily of S. patens found at a higher elevation. Under present conditions shore fast ice builds up at or just above the low marsh zone and extends out over the low marsh. Considerable ice builds up and a large area of the zone can be ice-covered for a large portion of the winter. Ice formation in the high marsh is largely fresh water ice in the tide pools. The only time sea ice occurs on the high marsh is in those winters when extreme spring tides occur that push the drift ice up onto the marsh surface. The year before last when we made our observations we had a winter of small spring tides and no sea ice reached the high marsh. The high marshes were covered with snow and locally-formed ice on top of pools. When sea ice reaches the high marsh it appears to remain until it melts in place.

A. Smith: Do you not think the additional sheet ice formed behind a barrage will break pieces off its edge and cause problems such as flooding.

D. Gordon: It is a question of how far seaward the zone of fast ice will extend. Certainly there will be breaking off of it particularly at the outer edge but there will probably still be ice walls forming in all tidal rivers. A more important fact is that a barrage would probably lower the spring high water level by about a meter and even if there is no change in fast ice coverage ice walls will only build to a maximum elevation of 1 m below present elevations and that alone would help alleviate ice problems. We think the additional fast ice coverage across the basin surface will block drift ice from moving inland. At present this stranded drift ice causes many of the flooding problems.

Some Hydrologic Aspects of Fundy Tidal Power Development

Frank B. Cruickshanks

Terry W. Hennigar

and John E. Gibb

Water Planning & Management Branch
Inland Waters Directorate
5th Floor, Queen Square
45 Alderney Drive
Dartmouth, N.S.
B2Y 2N6

ABSTRACT

High fuel costs, predicted energy shortages and Atlantic Canada's heavy reliance on imported oil for energy production contribute to an increasing interest in Fundy tidal power development. Two economically viable sites - the Cumberland Basin and Cobequid Bay - have the potential of producing up to 6,000 megawatts of electricity. Seaward of the barrage no significant effects on freshwater resources are envisioned. However, landward of the barrage, water supplies, flooding, drainage and tidal estuary water quality could be affected. Many coastal water supplies come from private and municipal wells in sand and gravel aquifers of drowned river valleys and in bedrock aquifers of coastal lowland areas. Seasonal climatic changes, precipitation, and groundwater withdrawal cause groundwater level fluctuations in these aquifers. Tidal loading and off-loading elicit diurnal fluctuations that are dominant in the near shore sections of the aquifers. A long term rise in mean sea level will increase the potential for sea water intrusion into both sand and gravel aquifers along river valleys and coastal bedrock aquifers. Flooding of rivers hydraulically influenced by the Bay of Fundy occurs from high tides, winds, storms, ice jamming, and sediment deposition in river channels, and especially when two or more of these coincide. Construction of the barrage will reduce the effects of high tides, while it may increase ice jamming potential and sediment build-up. Raised groundwater levels and reduced drainage from aboiteaux may increase drainage problems in dyked lands. The new tidal regime with a higher mean headpond level could decrease dyke stability. Reduced tidal mixing in estuaries behind the barrage may accelerate water quality deterioration. An environmental assessment addressing these issues is required to better define effects of barrage construction on freshwater resources in the area.

Key words: Bay of Fundy, tidal power, tides, freshwater, groundwater, hydrographs, water supplies, seawater intrusion, flooding, drainage, tidal estuary.

RÉSUMÉ

Le coût élevé du carburant, les prévisions d'une pénurie énergétique et le fait que les provinces de l'Atlantique dépendent fortement du pétrole importé pour leur production d'énergie sont tous des facteurs qui contribuent à accroître l'intérêt d'aménager la centrale marémotrice de Fundy. Deux sites exploitables, soit le bassin de Cumberland et l'embouchure de la baie Cobequid, possèdent le potentiel voulu pour produire jusqu'à 6 000 mégawatts d'électricité. Du côté mer du barrage, on ne prévoit aucun effet appréciable sur les ressources en eaux douces. Toutefois, du côté terre du barrage, les réserves en eau, les crues, le drainage et la qualité de l'eau dans l'estuaire à flot, pourraient être affectés. Bon nombre des réserves en eau le long des côtes proviennent de puits privés et municipaux, creusés dans des aquifères de sable et gravier formés dans des vallées fluviales ennoyées et dans des aquifères logés dans le roc des zones de basses-terres côtières. Les variations climatiques saisonnières, les précipitations et le retrait de la nappe phréatique entraînent des fluctuations du niveau des eaux souterraines dans ces aquifères. Les chargements et déchargements rélevant de la maréé expliquent les fluctuations diurnes qui règnent dans les sections littorales des aquifères. Une élévation à long terme du niveau moyen de la mer fera augmenter les possibilitiés que l'eau de mer envahisse à la fois les aquifères de sable et gravier le long des vallées fluviales et les aquifères côtiers qui se sont logés dans le roc place. L'inondation des rivières qui subissent l'influence hydraulique de la baie de Fundy se produit à la suite de fortes marées, de vents soutenus, de tempêtes violentes, d'embâcles et du dépôt des sédiments dans le lit des rivière, et plus particulièrement lorsque deux ou plusieurs de ces agents se manifestent simultanément. L'érection du barrage réduira bien sûr les effets des fortes marées, mais elle pourra aussi accroître le potentiel d'embâcles et l'accumulation de sédiments. Le niveau élevé de la nappe phréatique et la diminution du drainage des aboiteaux pourrait augmenter les problèmes de drainage des terres à l'intérieur des digues. Le nouveau régime des marées, accompagné d'une tête d'eau moyenne plus élevée, pourrait réduire la stabilité des digues. La réduction du mélange dû aux marées dans les estuaires situés derrière le barrage pourrait accélérer la détérioration de la quanlité de l'eau. Une évaluation environnementale, abordant ces points coutroversés, est nécessaire pour mieux déterminer les effets de la construction du barrage sur les ressources en eaux douces dans cette région.

HISTORY AND INTRODUCTION

Escalating world oil prices and high energy demands have created a need to develop indigeneous energy sources. Atlantic Canada's Bay of Fundy offers a unique opportunity to harness tidal movements for energy production. Bay of Fundy tides have the potential to supply hundreds of billions of kilowatt hours of electricity per year. With foresight and thorough planning, Fundy tidal development could represent a long-term, secure and non-polluting energy source for Atlantic Canada and its neighbors.

Tidal power was utilized in North America as early as 1617 at Lequille near Annapolis Royal, Nova Scotia. In 1919 a Canadian engineer first outlined plans for harnessing the tides of the Bay of Fundy, but no major studies were undertaken in the upper part of the Bay until 1944. Subsequent studies continued until 1966 when the Government of Canada and the provinces of New Brunswick and Nova Scotia initiated a joint investigation to determine the feasibility of large scale tidal power development in the Bay of Fundy. The Atlantic Tidal Power Programming Board 1969 report identified 23 potential sites and led to the undertaking of comprehensive feasibility studies at three of the most promising ones, the mouths of Shepody Bay (A6), Cumberland Basin (A8) and Cobequid Bay (B9)(Fig. 1).

Interest in the energy potential of Fundy tides increased with the completion of a small but uniquely designed 340 kilowatt tidal power plant at Kislaya Guba near Murmansk in the U.S.S.R. (Bernshtein, 1974). The experimental project at Kislaya Guba was the first tidal dam to be constructed from prefabricated float-in powerhouses, virtually eliminating the need for large and expensive coffer dams. Moreover, the extrapolation, by French engineers, of low power "bulb generator" technology for use in high power generation equipment enabled the French to successfully construct and operate a large scale 240 megawatt tidal power plant in the Rance Estuary in France (Anon, 1967).

Reassessments of the three proposed Fundy sites, triggered in part by oil price increases, were conducted over the period of 1972 to 1977. Tidal power development was found to be economically feasible at all three sites (Bay of Fundy Tidal Review Board 1977).

In 1984 the Nova Scotia Tidal Power Corporation will commission a pilot tidal power project at Annapolis Royal, N.S. consisting of a single large 20 megawatt straflo turbine. The development of this version of the straflo turbine was jointly funded by the Governments of Canada and Nova Scotia. The pilot project will yield environmental and other technical information which will hopefully lead to full scale tidal power development in the Bay of Fundy.

In the meantime, a task force of senior Nova Scotia Power Corporation and Tidal Power Corporation officials have released an updated study of tidal power development. It concludes that tidal power is most viable at Cumberland Basin (A8) and Cobequid Bay (B9) (Fig. 1) (Nova Scotia Tidal Power Corporation 1982).

The purpose of this paper is to briefly summarize a number of hydrologic concepts that must be taken into account while planning possible tidal power developments. More detailed discussion of the hydrologic aspects of Fundy tidal developments is reserved for a later forum. For explanatory purposes, Hodd (1977) outlined several hydrologic and other environmental considerations of importance to the successful operation of an environmentally acceptable tidal power plant. Our discussion of the hydrologic effects of Fundy tidal power development will attempt to briefly clarify some of the concerns raised by Hodd (1977).

CONCEPTUAL FRAMEWORK

A basin-to-sea generating scheme will cause the mean tide level in the headpond to rise by nearly 3 m. This situation raises concerns over the environmental impact to surface water and groundwater resources in areas surrounding the headpond. Furthermore, potential expansion of the industrial and population base could also place undue pressure on valuable freshwater resources in coastal areas immediately seaward of the barrage.

PROJECT OUTLINE

Major elements of a tidal power development would include a tidal barrage, a controlled tidal basin and a transmission line to an electrical grid system. Intermittent power generation would then occur by manipulation of the tidal basin water levels in relation to the natural tidal level. Engineering details of the currently favored projects are given by Baker (1984) elsewhere in this report. The Cumberland Basin site (A8) (Fig. 1) lies on the border between New Brunswick and Nova Scotia. The nearest population centers are Moncton, Amherst and Sackville. The Cobequid Bay site (B9) is located in the upper reaches of Nova Scotia's Minas Basin. Two population centers Truro and Wolfville are in close proximity to the proposed site. When completed B9 could displace the equivalent electrical generating capacity of about than seven 630 megawatt nuclear power plants.

HYDROLOGIC EFFECTS

With respect to the seaward side of the barrage and assuming a small increase in tidal amplitude but no increase in mean sea level, we do not envisage a significant effect on freshwater resources. For example, should the Cobequid Bay site (B9) be selected, a water level increase of 0.19 meters is expected in Saint John Harbour above the Reversing Falls and a negligible increase at Fredericton. However, major alterations to the hydraulic regime on the headpond side of the tidal barrage could affect the fresh water resources of coastal areas. Table 1 outlines some aspects of hydrological interactions that may be expected behind a tidal barrier.

There are three major areas of concern with respect to freshwater resources:

(1) Water supplies (domestic, commercial and industrial)
(2) Seawater intrusion (tidal rivers)
(3) Flooding and drainage

Water Supplies

With the exception of the City of Moncton, its surrounding area and the towns of Shubenacadie and Stewiake along the tidal reaches of the Shubenacadie and Stewiake Rivers, the majority of freshwater is supplied by private and municipal wells developed in either shallow sand and gravel de-

Table 1. Hydrological interactions behind barrier (single effect scheme) operating phase.

	1 SURFACE WATER	2 GROUND WATER	3 TERRESTRIAL ENVIRONMENT
1 PROJECT	1.1 - INCREASED POTENTIAL FOR FLOODING OF TRIBUTARY STREAMS - REDUCED DRAINAGE THROUGH ABOITEAUX - BANK STABILITY MODIFIED - WATER QUALITY AFFECTED BY REDUCED TIDAL FLUSHING	1.2 - RISE IN WATER TABLE - RISE IN SALT DIFFUSION ZONE - REDUCTION IN TIDAL TRANSIENT	1.3 - NET LOSS OF MARSHLAND - CHANGE IN VEGETATION TYPE AND DISTRIBUTION - BORROW SITES AND TRANSMISSION CORRIDORS - BEACH FORMATION - POPULATION CHANGES
2 SEDIMENT	2.1 - EFFECT OF TURBIDITY REGIME IN TIDAL RIVERS	2.2 - NEW DEPOSITION COULD CHANGE GROUNDWATER GRADIENT OR RATE OF INTRUSION	2.3 - REDUCED ACCRETION OF MARSHLANDS - LOSS IN BEACH MATERIAL
3 CLIMATE	3.1 - CHANGE IN HYDROGRAPH COULD INCREASE FLOODING POTENTIAL	3.2 - CLIMATE CHANGES COULD INCREASE OR REDUCE INFILTRATION	3.3 - GROWING SEASON REDUCED - SNOW COVER COULD EFFECT TERRESTRIAL ANIMALS
4 ICE	4.1 - ICE JAMS COULD INCREASE FLOODING ON RIVERS - DELAY DRAINAGE OF MARSHLANDS	4.2	4.3
5 SURFACE HYDROLOGY	5.1	5.2 - RATE OF RECHARGE COULD BE AFFECTED	5.3 - POORER DRAINAGE - WETLANDS INCREASED - WORKABILITY OF FARMLAND REDUCED
6 GROUNDWATER HYDROLOGY	6.1 - RAISED WATER TABLE COULD INCREASE SURFACE RUNOFF AND SHEET EROSION	6.2	6.3 - REDUCED LAND CAPABILITY - STRUCTURAL INTEGRITY - GROUND DISPOSAL AND WATER SUPPLY
7 TERRESTRIAL ENVIRONMENT	7.1 - CHANGES IN SURFACE	7.2 - EVAPOTRANSPIRATION EFFECTS	7.3

MODIFIED AFTER HODD, 1976

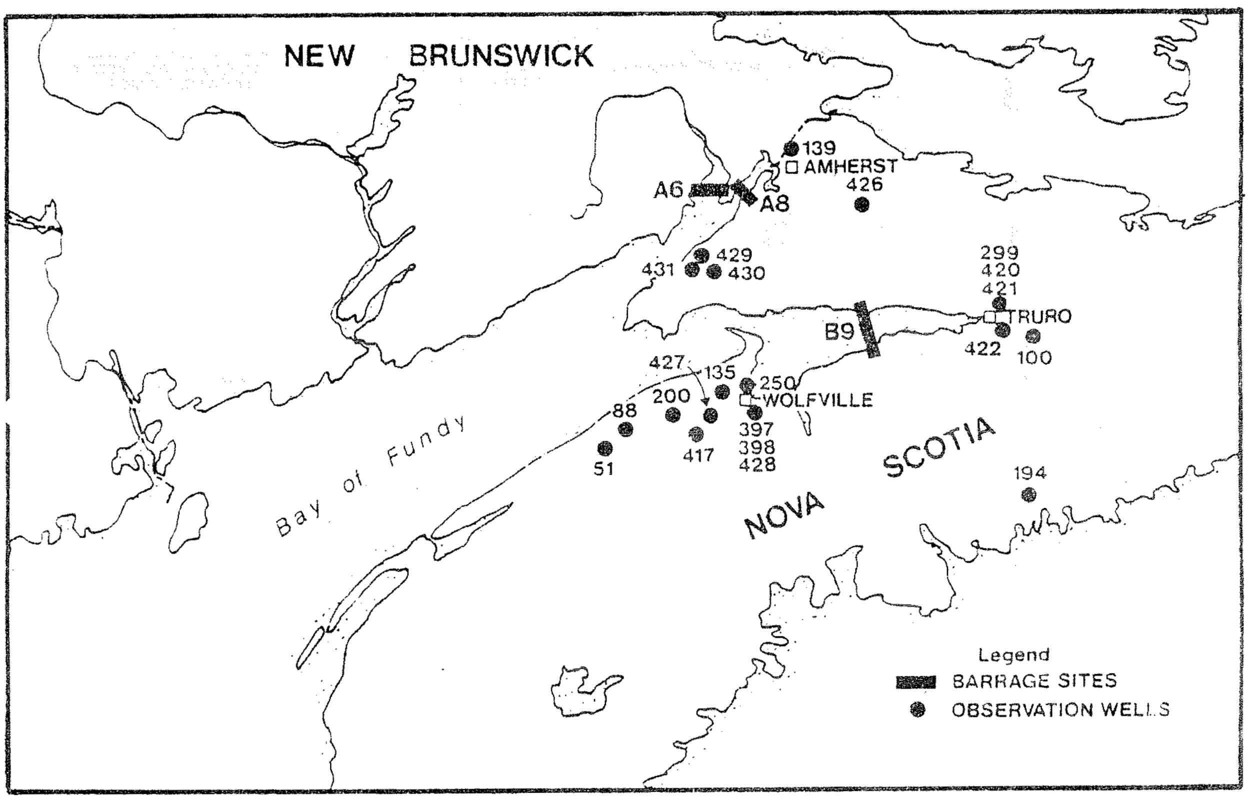


Fig. 1. Tidal barrage sites and observation wells along the Fundy coast.

posits found along river valleys or in bedrock formations along the Fundy coast. For example, the town of Wolfville has developed a high yield surficial aquifer for their water supply (Fig. 2). Two sections of specially designed stainless steel screen, measuring 9 m in length and 3 m in length respectively, allow for the passage of water from the sand and gravel water bearing unit into the well bore. Both units lie at an appreciable depth below mean sea level. However, the water table level at Wolfville is above mean sea level. The difference in hydraulic head from the top of the water table to mean sea level is sufficient to overcome the onslaught of sea water intrusion. This aquifer is often cited as being one of the most productive, both quantitatively and qualitatively, in Nova Scotia.

The phenomenon commonly known as sea water intrusion is characterized in Fig. 3. The curvature of the saltwater-freshwater interface and its depth below ground surface is controlled by two main factors: the density difference between freshwater and seawater and the height of freshwater above sea level (otherwise referred to as hydraulic head).

Freshwater is less dense than seawater and therefore tends to 'override' or 'float' on top of the denser seawater wedge. A rise of one metre of freshwater head above sea level will cause the saltwater-freshwater interface to lower by a factor of 40. This situation also works in reverse. Therefore, the saltwater interface will rise by 40 metres if the water table elevation is lowered by 1 m. More information on the phenomenon of seawater intrusion is available from Todd (1959) and Freeze and Cherry (1979).

The migration pattern of the seawater interface through a confined coastal aquifer is shown in Fig. 4a. Higher than normal mean sea levels will push the seawater front in a landward direction (Fig. 4b) thereby increasing the risk of contamination to freshwater resources.

The physical properties of water and earth materials place measurable controls on aquifers as they respond to external forces. In Fig. 5, a groundwater hydrograph from observation well No.1 at Wolfville clearly shows how external factors such as precipitation (or the lack of it) can affect the shape of the hydrograph. Figure 5 also shows major water level changes due to groundwater withdrawal and recovery. Moreover, one can also observe sinusoidal water table fluctuations resulting from tidal influences.

The groundwater hydrograph of Wolfville observation well No. 3 shows pronounced water level oscillations due to tidal influence (Fig. 6). Although this observation well is located within 100 m of Wolfville Harbour, other wells as far away as 10 km inland from the coast show tidal effects from Fundy's surges.

A third groundwater hydrograph (Fig.7), recorded in the Amherst area of Cumberland County, shows how a bedrock aquifer can respond to precipitation events and tidal forces. Aquifer response to groundwater withdrawal for usage by the town of Amherst does occur but is not readily identifiable from this hydrograph. Often, the other water level influences

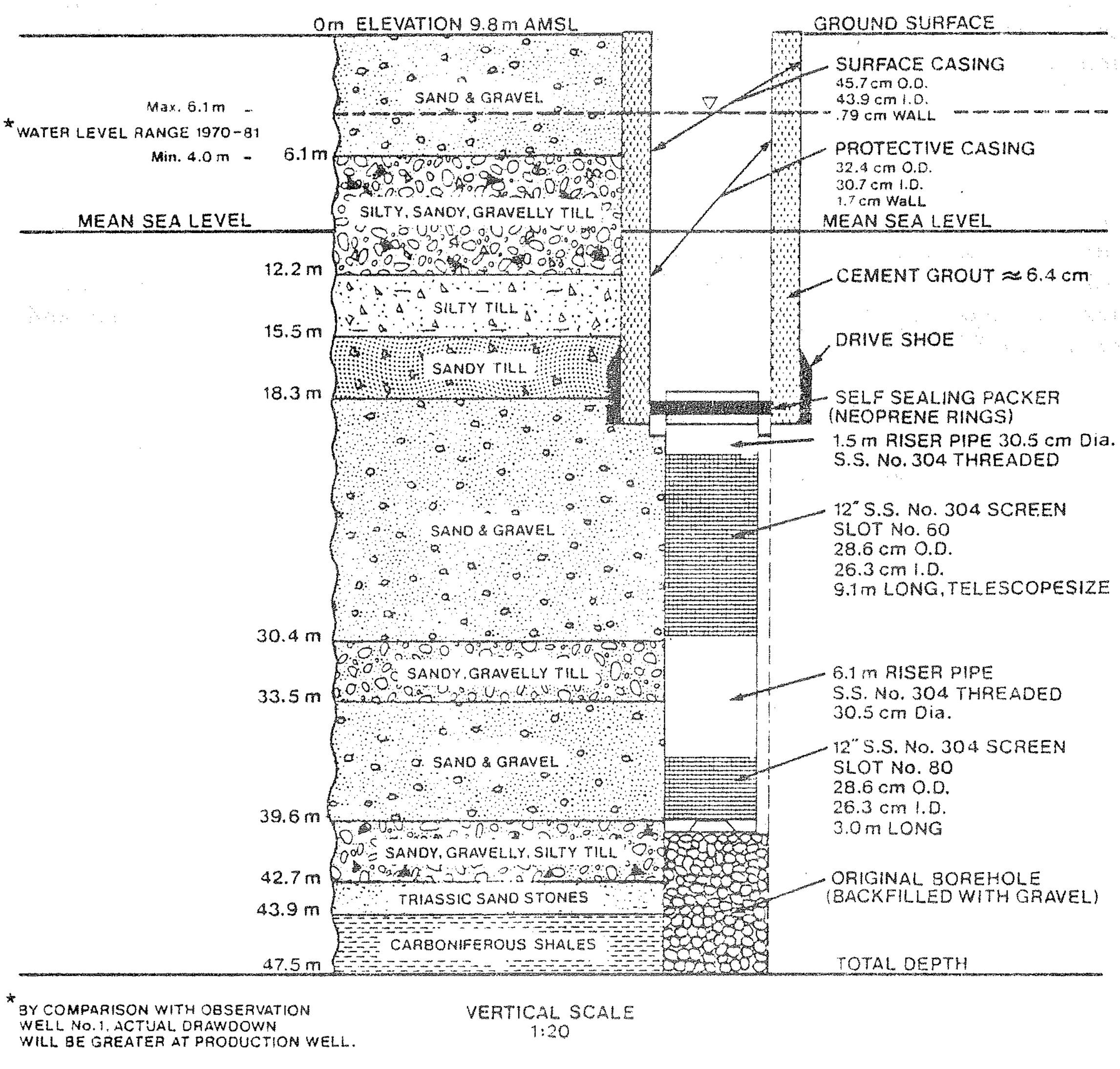


Fig. 2. Town of Wolfville, Production Well #1.

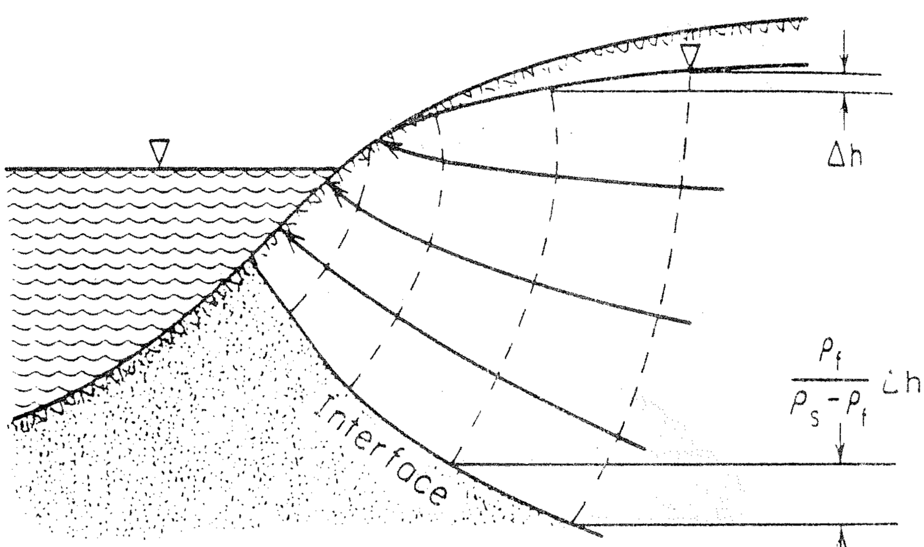


Fig. 3. Saltwater-freshwater interface in an unconfined coastal aquifer (after Hubbert 1940).

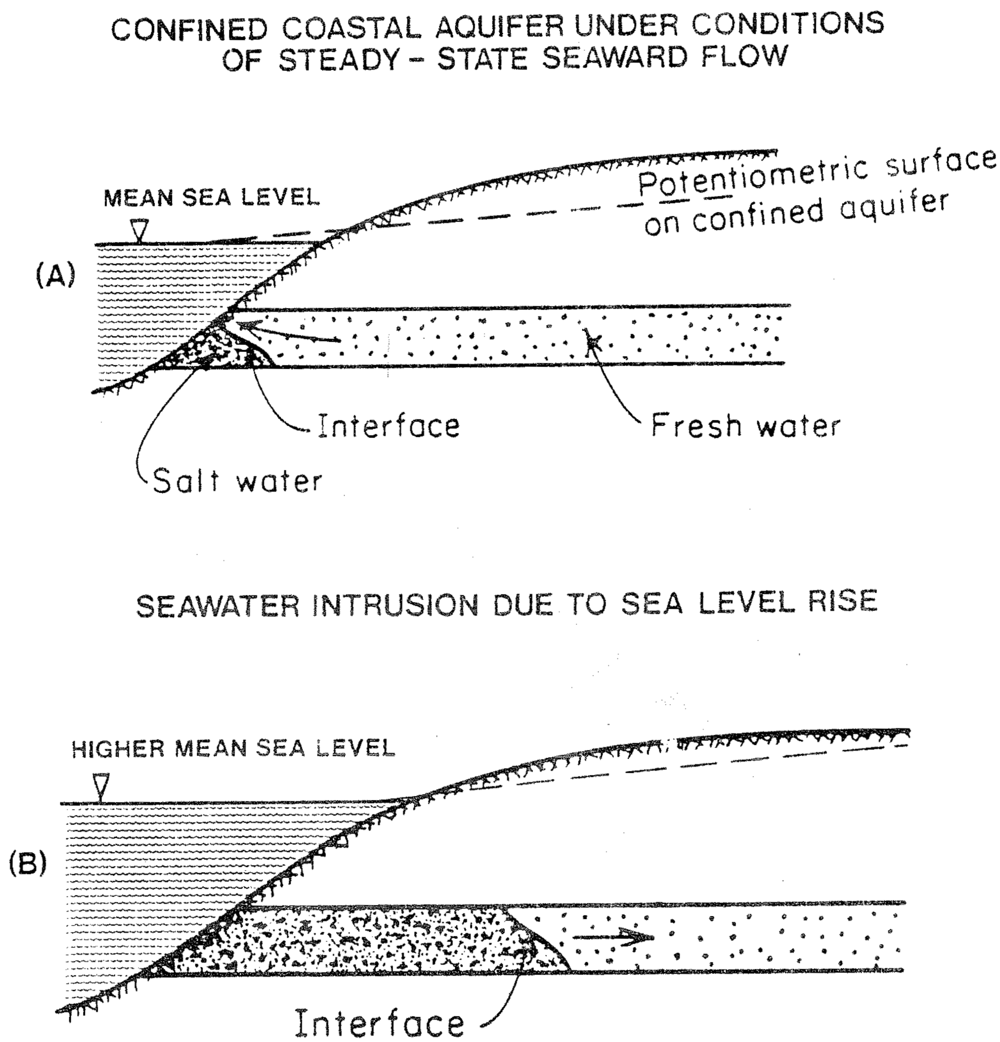
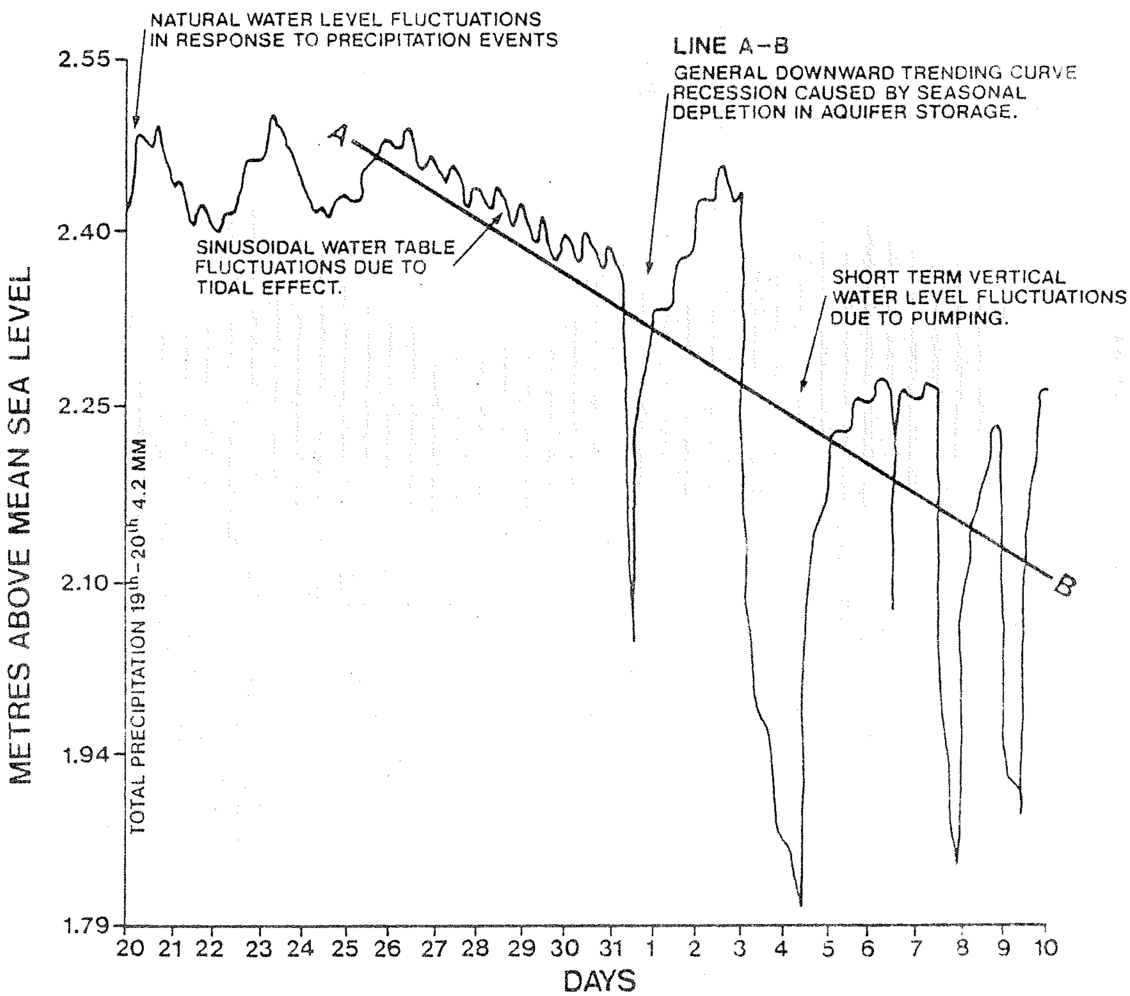


Fig. 4. Idealized saltwater-freshwater interface (modified after Freeze and Cherry 1979). (a) Confined coastal aquifer under conditions of steady-state seaward flow. (b) Seawater intrusion due to sea level rise.



SOURCE: N.S. DOE

Fig. 5. Groundwater hydrograph, Wolfville #1 May-June 1980.

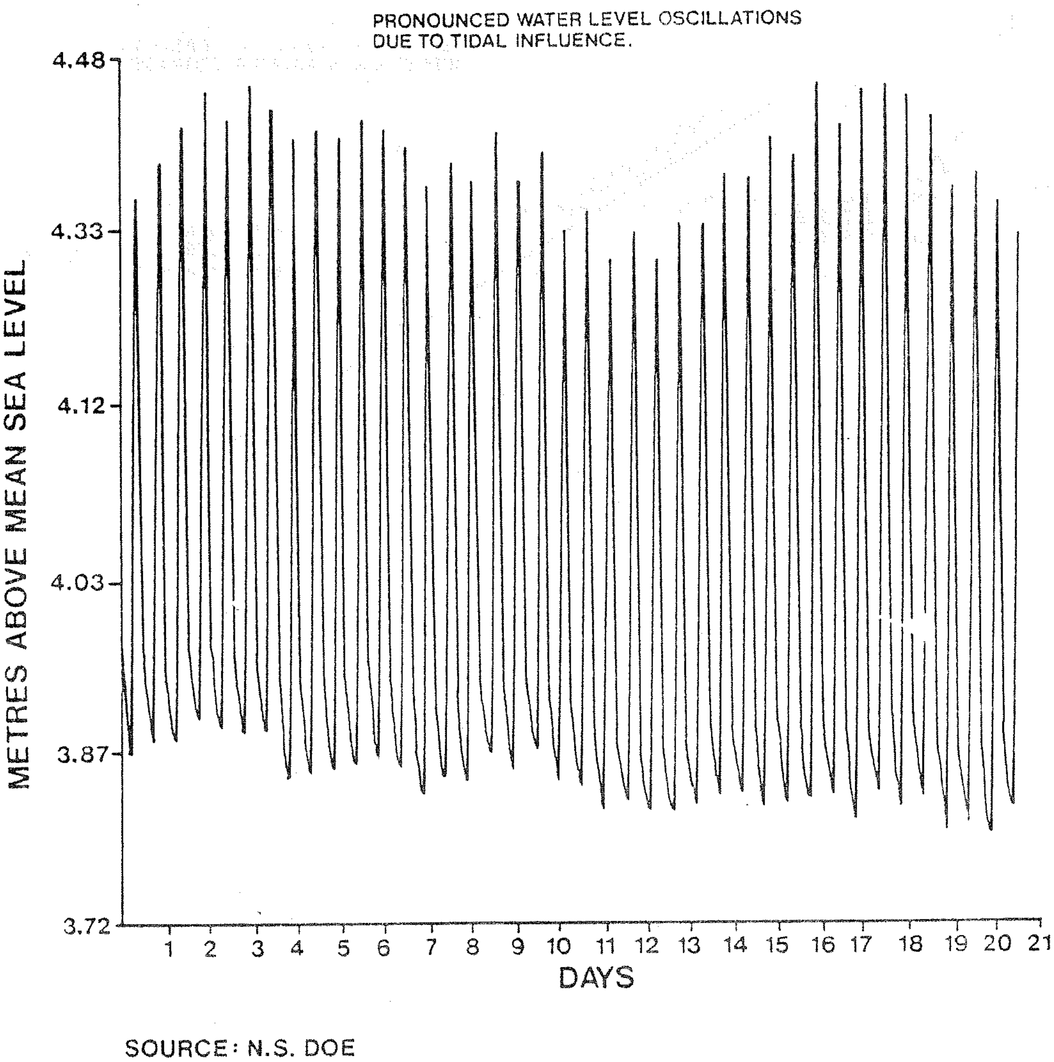
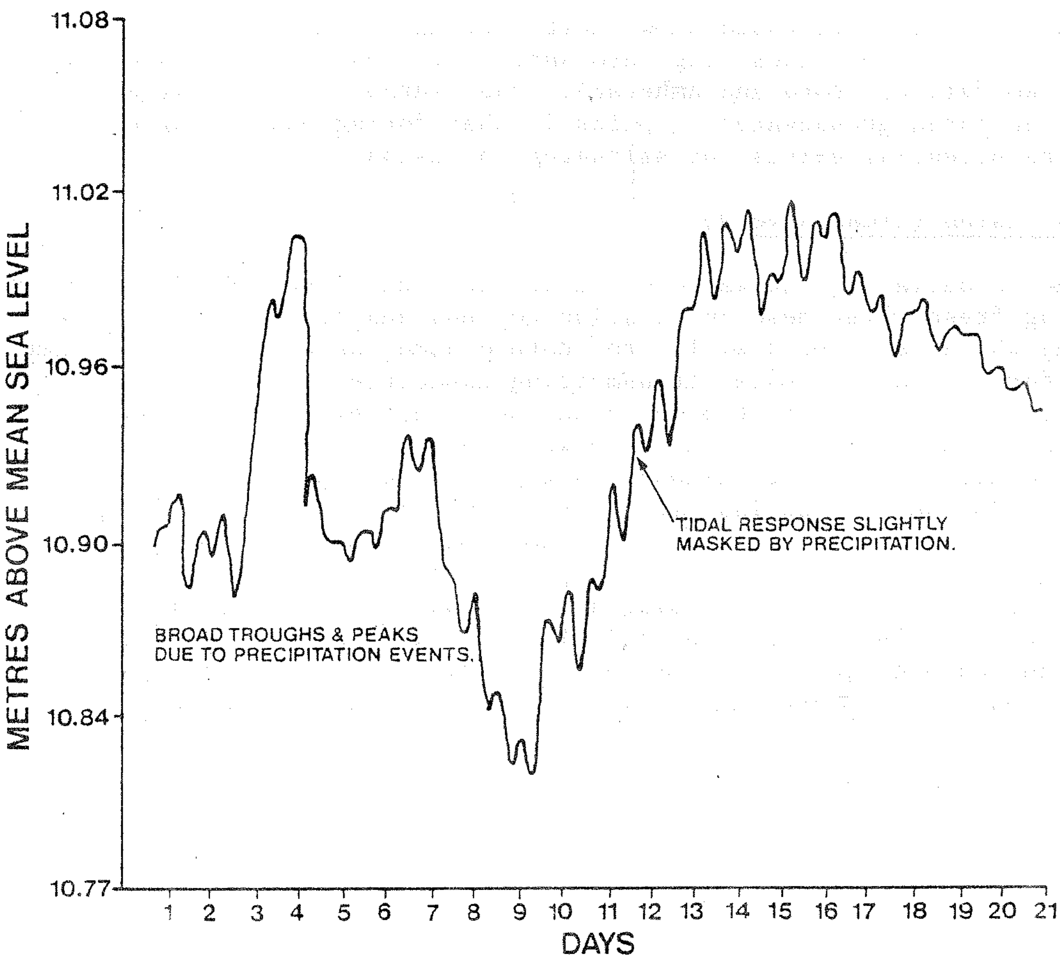


Fig. 6. Groundwater hydrograph, Wolfville #3 Sept. 1982.



SOURCE: N.S. DOE

Fig. 7. Groundwater hydrograph, Amherst July 1980.

dominate changes shown in a hydrograph, especially when the observation well is near the radius of influence of the core of depression created by the pumping well(s). This well penetrates a sandstone conglomerate aquifer in the Pennsylvanian sediments of the Pictou Group. These sediments, overlain by a complex of glacial surficial deposits, dip northward under the head of the Cumberland Basin.

Groundwater in the Truro area is strongly affected by rain events and tidal movements. A rapid water level rise and gradual decline over time is shown in Fig 8. It clearly demonstrates a tidal influence on Truro's groundwater resources. There are two well-defined major aquifers in the Truro area. The hydrograph shown in Fig. 8, from observation well No. 422, is a record of piezometric pressure (head) changes in the Triassic bedrock aquifer. This unit consists mainly of sandstones and conglomerates, referred to as the Wolfville Formation (of the Fundy Group), and dip northward under the head of Cobequid Bay.

The data just discussed show short term water table variations. In comparison, Fig. 9 summarizes long term water level data at the same three locations (Wolfville, Truro and Amherst). One hydraulic characteristic common to the three groundwater supplies is that during major pumping stresses the potential exists for saltwater intrusion.

Sewater Intrusion (Tidal Rivers)

The potential for seawater intrusion in tidal rivers increases with a decreasing fresh water head in relation to mean sea level. The coastal areas along which sea levels will rise feature numerous confined and unconfined aquifers of varying water transmitting capacities (transmissivities). The idealized potential effect of a raised mean sea level on sand and gravel aquifers in the Truro area is shown in Fig. 10. The saltwater wedge will tend to migrate further inland than what is now normally expected. The Fundy Group, which supplies part of Truro's water needs, is an important bedrock aquifer consisting of conglomerates, sandstones and shales of Triassic Age (Fig. 11). The low topographic setting of the Fundy group makes it more susceptible to flooding and salt water intrusion than other upland bedrock aquifers. Hydrogeologically and topographically similar low Triassic Age bedrock aquifers underlie the Cornwallis Valley while sandstones and shales of Pennsylvanian Age supply the town of Amherst.

Flooding and Drainage

Serious flooding in rivers hydraulically influenced by the Bay of Fundy can result from a number of factors and usually happens when two or more factors coincide. These factors are:

(1) High tides
(2) Winds and storms
(3) Ice jamming (either rafting sea ice and /or freshwater ice)
(4) High runoff resulting from heavy precipitation and/or snow melt

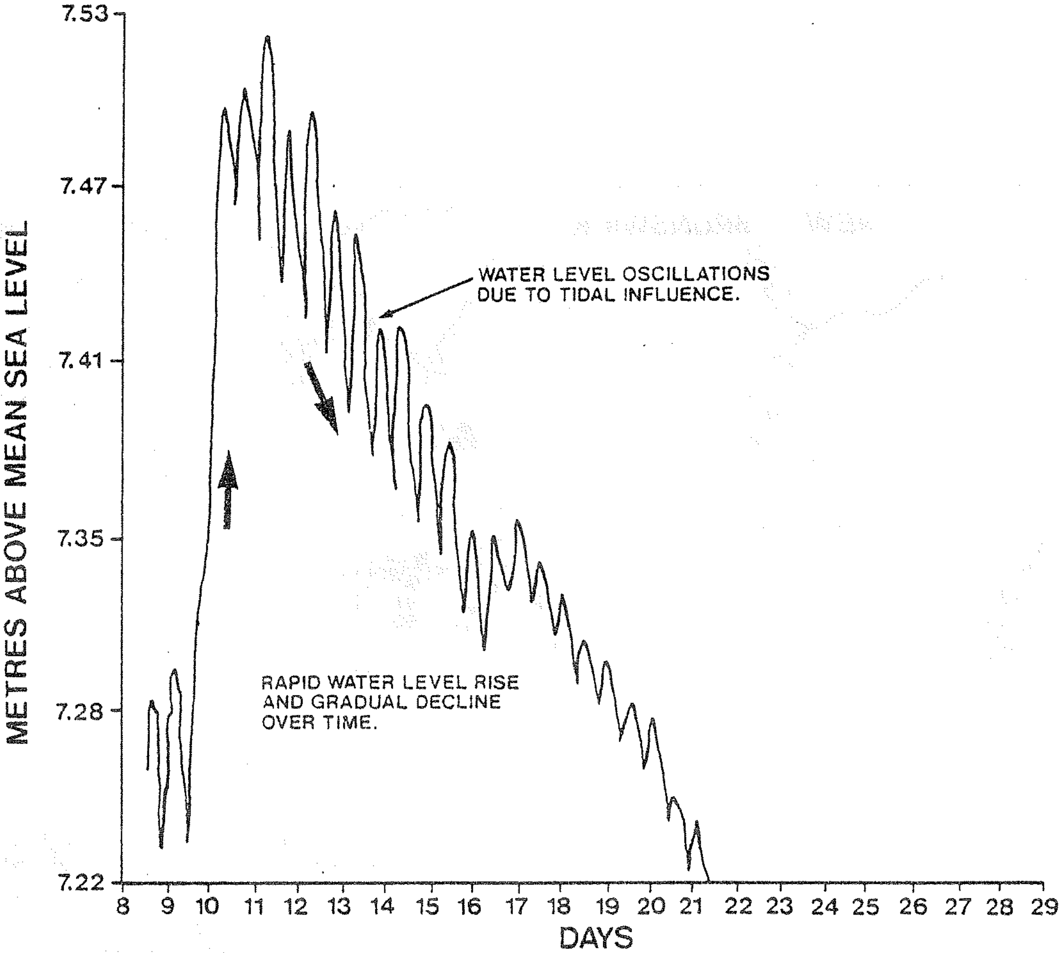
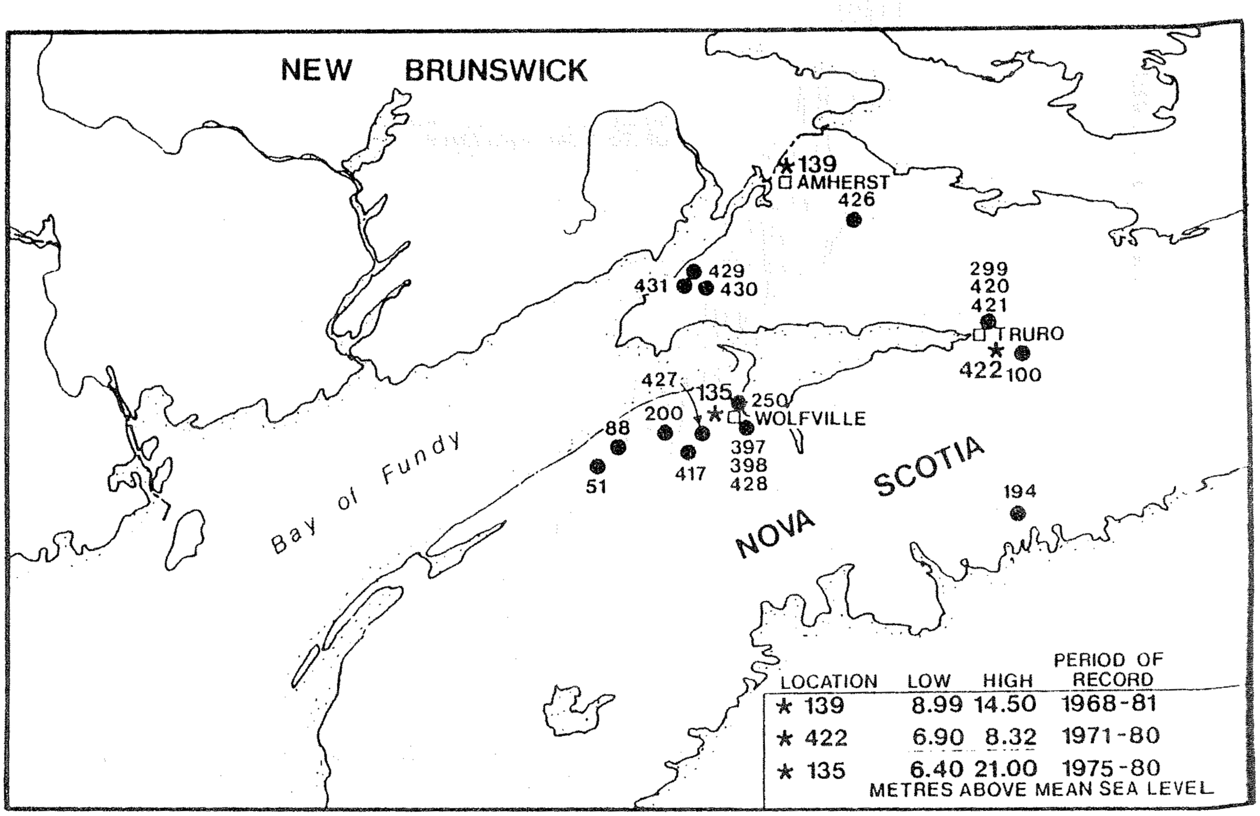


Fig. 8. Groundwater hydrograph, Truro, #422 June 1972.



SOURCE: N.S. DOE

Fig. 9. Longterm water level changes (Water Resources Data Base).

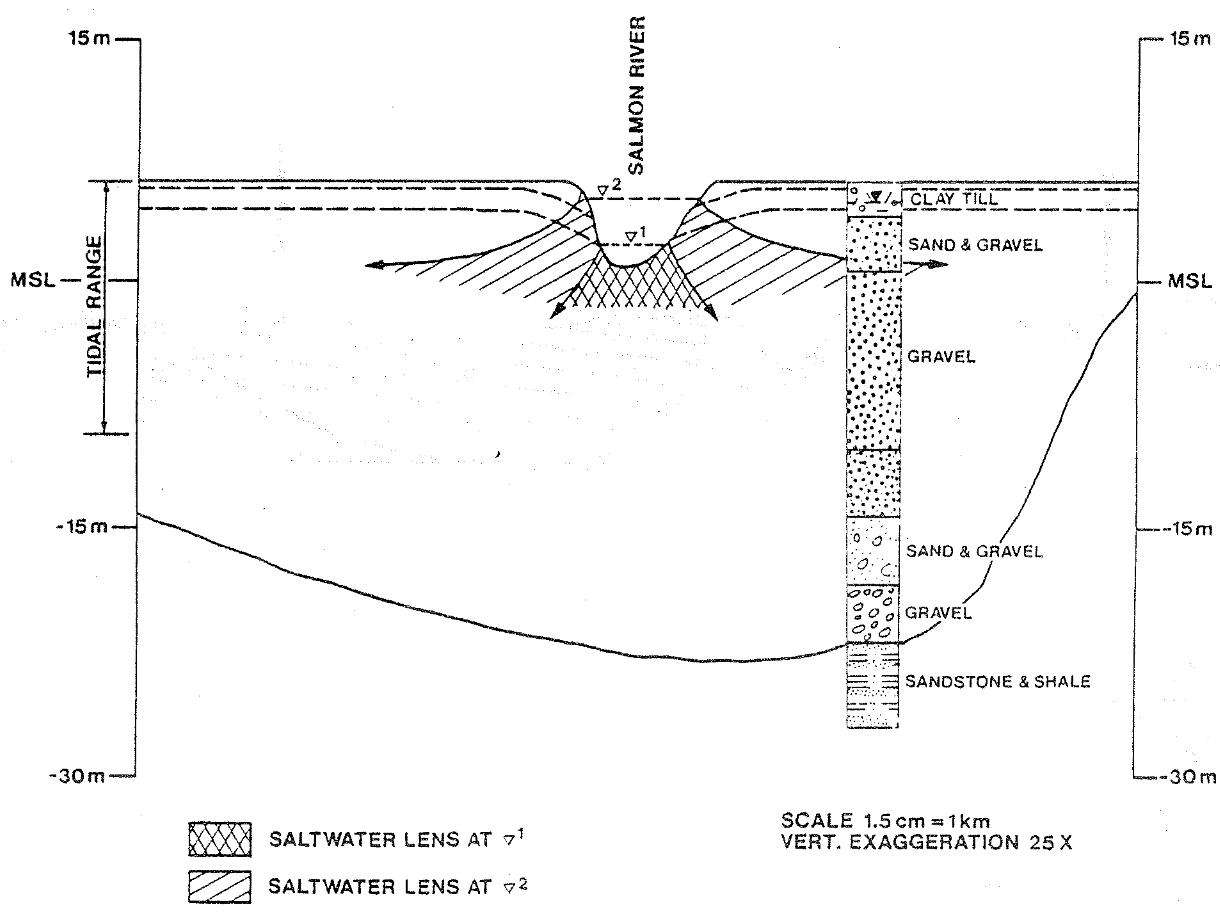


Fig. 10. Cross-section AA' showing strata(N.S. Dept. Mines TH 152) and schematic of saltwater wedge at current and raised level.

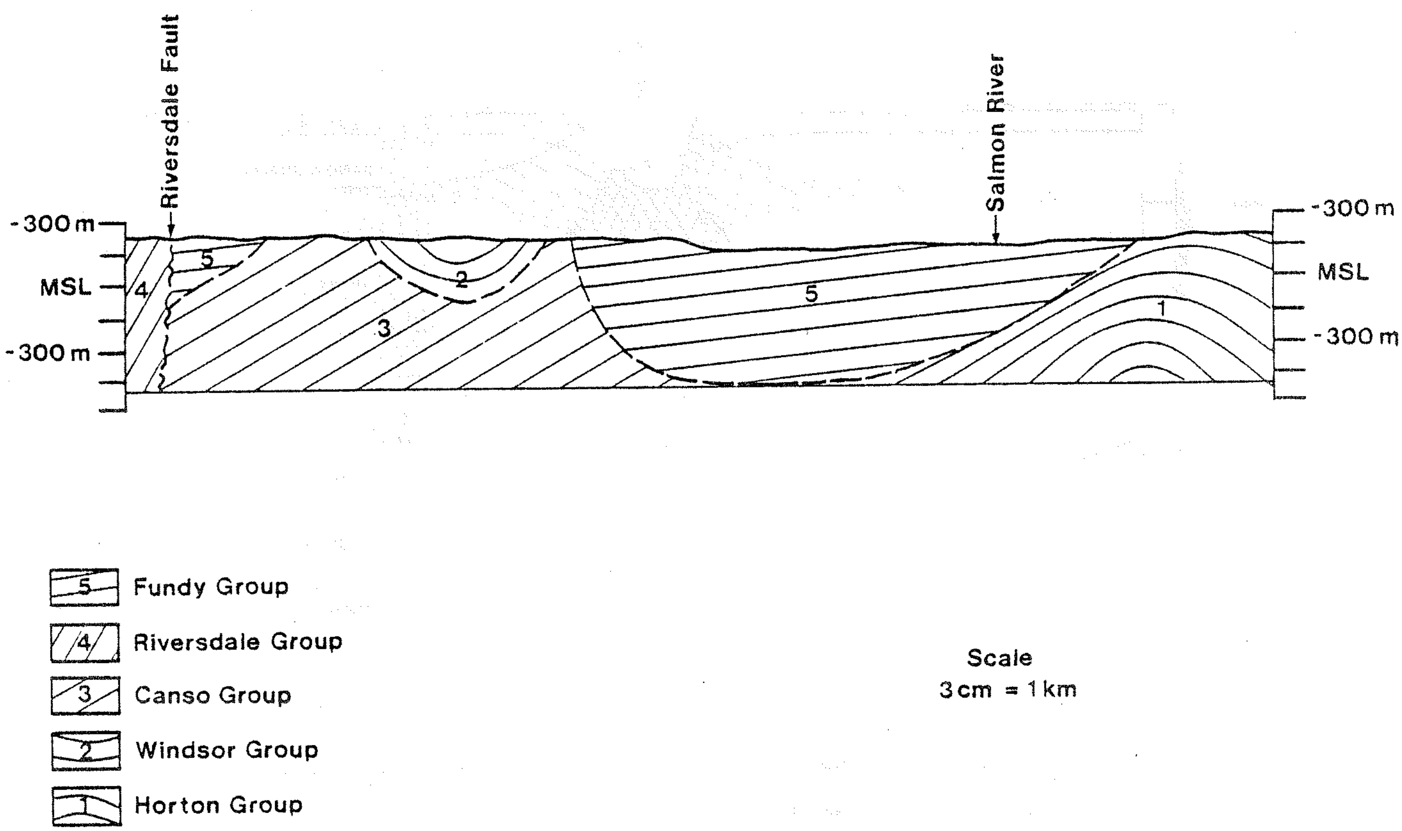


Fig. 11. Cross section at Truro (view east)

(5) Deposition of sediment within river channels, which acts to reduce a river's hydraulic capacity (channel sedimentation sometimes triggers ice jamming)

It seems apparent that under the proposed one-way generation scheme, spring tides would be reduced by 1-1.2 metres behind the barrage, depending on final site selection. Therefore, from a flooding perspective, a reduction in the upper range of the tidal cycle would represent a significant benefit.

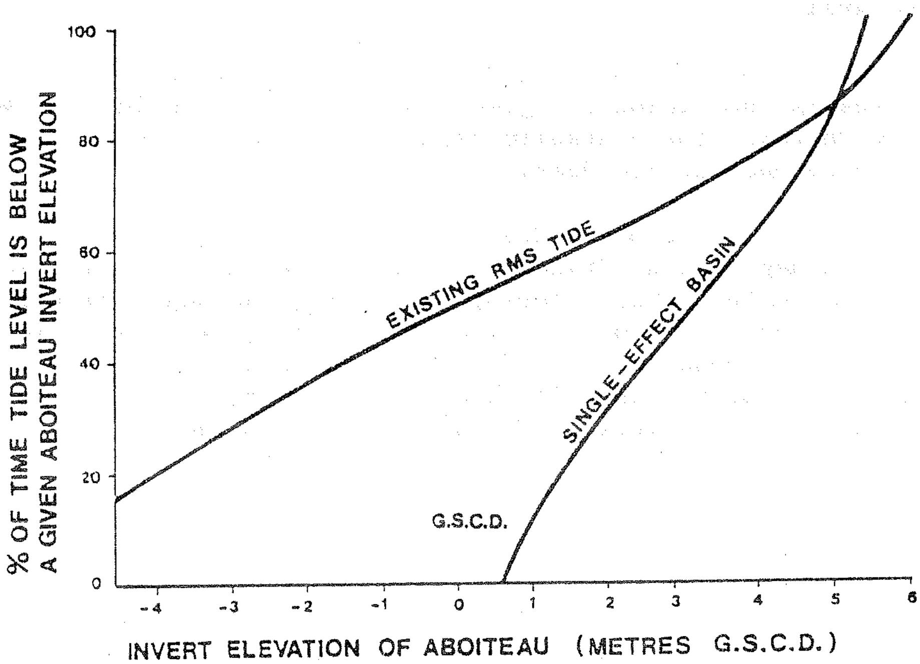
There are, however, other factors which could significantly add to flooding problems. With a decrease in tidal action, mixing energy, a decrease in salinity and the impounding influence of the physical structure itself, there exists the possibility that a stronger more consolidated ice pack may form (Gordon 1984). This situation could increase the ice jamming potential in the estuaries of many rivers, notably the Salmon-North River system at Truro. On the other hand, ice rafting will be minimized by a reduction in tidal action as will the degree to which sea ice is carried inland. This latter phenomena has been a contributing factor to flooding in the Truro area.

Perhaps one of the most significant factors affecting flooding in tidal estuaries is the sediment regime (Amos 1984). A buildup of sediment will not only decrease the hydraulic capacity of the rivers but may also increase the occurence of ice jams.

An increase of the mean water levels behind the barrage in the order of 3-3.5 m may present drainage problems for dyked lands. Water tables will tend to be higher, thereby decreasing the head available for drainage. The percent of time that tide level is below a given aboiteaux invert elevation is shown in Fig. 12. A single-effect scheme is considered in this example. Based on this information it may be necessary to relocate aboiteaux should their outlets be below the range of the new tidal regime.

The structural stability of dykes may also be affected by the new tidal regime. Existing dykes may either become saturated and thereby lose their shear strength or they may be subjected to a more substantial erosion forces.

Reduced tidal action may result in a deterioration of water quality in estuaries behind the barrage. Municipal sewage and industrial wastes normally have high chemical and biochemical oxygen demands and are often discharged into receiving waters after varying degrees of treatment. Agricultural practices and other non-point sources of pollution can also add to the chemical loads of rivers and estuaries. These wastes are constantly flushed by tidal action in concert with freshwater flow. The potential for contaminant levels to increase in sediments may also result.



SOURCE: HODD, 1976

Fig. 12. Indication of the effect of basin elevation on drainage through aboiteaux (Hodd 1977).

CONCLUSIONS

In conclusion, it is envisaged that studies will be required to assess the change in sediment and ice regime in the tidal estuaries and to assess the impact of the project on the groundwater regime behind the barrage. These latter studies would involve:

(1) Hydrogeologic mapping which can be carried out using existing geologic and hydrogeologic data (well logs, geologic maps, prior reports such as those for the Truro and Amherst areas, aerial photography, etc.).

(2) Test drilling to confirm and/or establish a data bank where insufficient information on hydrogeology currently exists.

(3) A review of existing groundwater level records.

(4) The installation of observation wells for conducting pumping tests to establish the hydraulic properties of aquifers which could be affected.

(5) Monitoring water level fluctuations in aquifers that are more sensitive to changes and prone to saltwater intrusion.

(6) Chemical analysis of groundwater samples to establish background water quality and the present location of the saltwater - freshwater interface.

This paper is only a brief review of the most obvious concerns associated with tidal power developments groundwater supplies and surface water drainage. Its purpose is to bring into focus the less obvious problems associated with the "out of sight and possibly out of mind" resource of groundwater. It is hoped that this presentation will foster a greater appreciation for the possible environmental effects from tidal power development to freshwater systems surrounding the Bay of Fundy.

ACKNOWLEDGMENTS

The authors wish to acknowledge the support of the Nova Scotia Department of Environment in providing the groundwater hydrographs. We particularly acknowledge the drafting done by Ron Howatt, Water Planning & Management Branch, Environment Canada.

REFERENCES

Amos, C.L. 1984. The sedimentation effect of tidal power development in the Minas Basin, Bay of Fundy. In this report.

Anon. 1964. The Rance tidal power scheme. Water Power 19: 7-16.

Atlantic Tidal Power Programming Board. 1969. Feasibility of tidal power development in the Bay of Fundy. Halifax, N.S., 5 vols.

Baker, G.C. 1984. Engineering description and physical impacts of the most probable tidal power projects under consideration for the upper reaches of the Bay of Fundy. In this report.

Bay of Fundy Tidal Power Review Board. 1979. Reassessment of Fundy tidal power. Ottawa, 516 p.

Bernshtein L.B. 1974. Kislogubsk: a small station generating great expectations. Water Power 26: 172-177.

Clark, R.H. 1981. Tidal power in Atlantic Canada. Proc. Can. Soc. Civil Eng. 5th Can. Hydrotech Conf. 1: 1-24.

Freeze, R.A. and J.A. Cherry 1979. Groundwater. Prentice-Hall Inc., Englewood Cliffs N.J.

Hennigar, T.W. 1972. Hydrogeology of the Truro area, Nova Scotia. N.S. Dept. Mines Rept. No. 72-1.

Gordon, D.C. Jr. 1984. Predictions of the impacts of tidal power development on ice conditions in the upper reaches of the Bay of Fundy. In this report.

Hodd, S.L. 1979. Environmental considerations of Fundy tidal power development. In: Daborn G.R. ed. Fundy tidal power and the environment. Acadia University Institute Publication No. 28, pp 71-81.

Hubert, M.K. 1940. The theory of groundwater motion. J. Geol. 48:785-944.

Nova Scotia Tidal Power Corporation. 1982. Fundy tidal power; Update '82. Halifax, 41 p.

Todd, D.K. 1959. Ground water hydrology. Wiley, N.Y. 336 p.

Waller, D.H. 1972. Environmental effects of tidal power development. In: Gray,T.J. and O.K. Gashus, eds. Tidal power: proceedings of an international conference on the utilization of tidal power. Plenum Press N.Y., pp. 611-625.

Water Resources Data Base. On file with Nova Scotia Department of Environment.

Potential Effects of Tidal Power Development on the Chemical Environment of the Bay of Fundy

Paul D. Keizer[1]

Atlantic Oceanics Company Limited
46 Fielding Avenue
Dartmouth, N.S. B3B 1E4

and

E.R. Hayes

Department of Chemistry
Acadia University
Wolfville, N.S. B0P 1X0

ABSTRACT

The building of a tidal power barrage in the upper reaches of the Bay of Fundy will have a major effect on the chemistry of the water column and surface sediments upstream from the barrage. Effects seaward of the barrage will be slight although significant changes may occur in the immediate vicinity of the barrage. Changes in the chemistry of the water column and surface sediments will be a direct result of the decreased current speed and turbulent energy behind the barrage. The changes will be affected over a period of several years as a balance is re-established in the biological community in response to the physical perturbation.

Key words: tidal power development, environmental impact, Bay of Fundy, chemical oceanography.

RÉSUMÉ

La construction d'un barrage pour centrale marémotrice dans les appendices nord du fond de la baie de Fundy affectera considérablement la chimie de la colonne d'eau et les sédiments superficiels (au fond de l'eau), en amont du barrage. Les effets côté mer du barrage seront minimes bien que des changements appréciables puissent se produire aux abords du barrage. Les changements intervenus dans la chimie de la colonne d'eau et des sédiments superficiels résulteront directement de la vitesse actuelle réduite et de la moins forte énergie turbulente derrière le barrage. Les modifications s'étaleront sur une période de plusieurs années, à mesure qu'un certain équilibre se rétablira dans la communauté biologique en réaction à la perturbation physique.

[1]Present address: Marine Ecology Laboratory, Bedford Institute of Oceanography, Dartmouth, N.S. B2Y 4A2

INTRODUCTION

The building of a tidal power barrage in the upper reaches of the Bay of Fundy will have a major effect on the chemistry of the water column and surface sediments near the barrage. Seaward of the barrage, effects will be noticeable only in the immediate vicinity of the barrage; more distant effects will be mitigated by dilution with the large volumes of water exchanged with each tide. In the headpond behind the barrage there will be major changes in the chemistry of the water column and the surface sediments.

Weaker currents, decreased turbulence and tidal range behind the barrage, and the resultant decreased rate of exchange of water through the barrage will cause changes in the chemistry of the water and sediments. The waters in the headpond will become clearer and less saline and may become stratified vertically with respect to both temperature and salinity. Some of the chemical changes will be direct results of these physical changes. For example, lower salinity will affect dissolved oxygen saturation concentrations and vertical stratification of the water column may result in the entrapment of more saline waters below the pycnocline. Some of the coarser suspended particulate material will settle out thus affecting the grain size distribution of both surface sediments and suspended particulate material. Concentrations of chemicals, such as nutrients and trace metals, which are strongly correlated with grain size of sediments will thereby be affected (Keizer et al. 1984).

The major chemical changes will result from complex adjustments in the biological community structure as it reacts to changes in the physical and chemical regime. For example, while nutrient-rich water from the rivers emptying into the headpond will have a longer residence time in the area, there will also be greater demand on this nutrient supply from the increased primary production in the water column resulting from the greater light penetration and longer residence times for phytoplankton in the euphotic zone (Hargrave 1984). Input of nutrients from surface and intertidal sediments may decrease due to the decrease in resuspension of these sediments and possible increased levels of primary production by benthic microalgae in the intertidal zone. The resultant nutrient concentration regime will be a complex function of these and other factors.

Changes in the concentration of dissolved oxygen are equally difficult to predict but stratification of the water column could result in some significant changes in the distribution of this variable in the headpond. The oxygen-rich, more saline water may be trapped below the pycnocline. Surface waters may remain saturated with oxygen due to atmospheric exchange and phytoplankton production. However the rain of detrital material from increased biological activity in the surface waters may create a sufficent increase in oxygen demand to cause a layer of oxygen-depleted water to form below the pycnocline.

These changes are speculations based on our current understanding of expected physical environmental changes and the functions which are important in controlling the chemistry of the existing environment in these areas. Much of the chemical data collected over the past few years still remain to be analyzed. More complete analysis of this data may cause some changes in our predictions of the results of building a tidal power barrage in the upper reaches in the Bay of Fundy.

REFERENCES

Hargrave, B.T. 1984. Barrage effects on phytoplankton production and chemosynthesis in Cumberland Basin. In this report.

Keizer, P.D., D.C. Gordon, Jr. and E.R. Hayes. 1984. A brief overview of recent chemical research in the Bay of Fundy. In this report.

QUESTIONS AND COMMENTS

G. Daborn: Your studies have shown we can continue to expect large quantities of nutrients to leach into the water column. Were your extractions made with organic solvents?

E. Hayes: No.

G. Daborn: With seawater?

E. Hayes: Yes, artificial seawater.

G. Daborn: Slow release into salt water brine of nutrients to be ready for uptake as ions?

E. Hayes: As far as we know unless there is a build up of something.

D. Greenberg: What mediums were used for analysis and what effects will reduced salinity have?

E. Hayes: We tried artificial seawater, a potassium chloride solution and distilled water. I do not understand what you mean by reduced salinity. We probably should try that one and investigate the result.

D. Gordon: Do you think there might be a problem of oxygen depletion in the headpond because of summer stratification? Stratification could cause sediments to settle out but considerable nutrients would be left in the water column to nourish phytoplankton. If the phytoplankton settles before it is grazed by zooplankton it could increase the biological oxygen demand at deeper levels and cause oxygen depletion.

E. Hayes: Possibly.

Possible Effects of Tidal Power Development on Phytoplankton Distribution in Bay of Fundy

J.S.S. Lakshminarayana

Department of Biology
Faculty of Sciences and Engineering
Universite de Moncton
Moncton, N.B.
E1A 3E9

ABSTRACT

The use of phytoplankton as indicators gives an idea of differences between regions in respect to productivity and movements of water. Climatic and latitudinal changes are an integral part of the phytoplankton distribution. The vernal flowering of the phytoplankton in the Bay of Fundy region reflects its particular hydrographical and biological conditions. An increase in the tidal range due to possible construction of a tidal power barrage is not expected to bring any significant changes in the phytoplankton populations of the outer regions of the Bay of Fundy.

Key words: phytoplankton, hydrography, tidal power.

RÉSUMÉ

L'utilisation des populations de phytoplancton comme indicateurs pourrait donner un aperçu des différences extrêmes qui existent entre les régions du point de vue de la productivité et des mouvements de l'eau. Les variations climatiques et latitudinales sont intimement liées à la répartition du phytoplancton. La croissance printanière du phytoplancton de la région de la baie de Fundy reflète ses conditions hydrographiques et biologiques particulières. Les liens possibles entre les organismes planctoniques, les conditions hydrobiologiques et la p°eche font l'objet de réflexions. On ne s'attend pas à ce qu'une élévation du marnage par suite de la construction du barrage marémoteur de Fundy apporte de quelconques modifications aux populations de phytoplancton dans les régions périphériques de la baie de Fundy.

INTRODUCTION

Bigelow (1926) considered the relation of plankton to different water masses. The circulation of waters of Passamaquoddy Bay and the Bay of Fundy were considered in relation to the movements and decline of herring (Huntsman 1953). Changes in the phytoplankton due to periodic recruitment of certain floral elements may serve as indicator species and provide a clue to the origin and distribution of waters (Subba Rao 1976).

Semina et al. (1977) discussed the distribution of the indicator species of planktonic algae in the world oceans. Russell (1935), Haffner (1952) and David (1955) indicated that plankton can give clues as to the origin of water masses even in the absence of marked salinity differences. In the English Channel and the Southern Irish Sea Sagitta elegans and S. setosa serve as indicator species (Russell 1935). The major paths of movement of California coastal waters and their currents were identified by the presence of dominant diatom species (Allen 1945). The distribution of phytoplankton is a function of temperature as manifested in their division into arctic, boreal, temperate or tropical types (Smayda 1958). The longitudinal distribution of phytoplankton is also regulated by temperature (Braarud 1945, Smayda 1958). Robinson (1961) and Raymond (1963) observed that dinoflagellates develop in regions with low nutrient levels. Salinity and temperature controls abundance and distribution of dominant phytoplankters in inshore waters like Malpeque Bay, Prince Edward Island and the Welsh Dee Estuary, U.K. (Sita Devi 1980). There seem to be definite direct relationships between the tidal heights of the Dee Estuary and salinity and chlorophyll a (Sita Devi 1980) indicating thereby the influx of phytoplankton by the tidal waters.

The oceanographic conditions of the Bay of Fundy are closely coupled with the phytoplankton populations and their seasonal and spatial distribution. Selected species of phytoplankton could serve as indicators of water masses, changes in zooplankton and fish ecology. There is significant interplay between the pelagic and neritic water masses.

The physical oceanography of the Bay of Fundy has been reviewed by Garrett (1977) and Greenberg (1984a). Recent data on the taxonomy of Fundy phytoplankton are summarized by Prouse et al. (1984).

IMPACTS

With the possible creation of a tidal power barrage in the Bay of Fundy, it is expected that the tidal range behind the barrage will be reduced. This will bring corresponding decreases in the tidal mudflat area and changes in the stratification and production of the waters and their ice cover. A decrease in the tidal range at the barrage will increase the tides in the outer Bay of Fundy and throughout the Gulf of Maine (Greenberg 1984b). This should not bring in any significant changes in the phytoplankton diversity of the outer Bay of Fundy and the input of phytoplankton from Atlantic waters should not change. Quantitative estimates of barrage impacts on phytoplankton and benthic microalgal production are made by Hargrave (1984) and Gordon (1984).

REFERENCES

Allen, W.E. 1945. Vernal distribution of marine plankton diatoms offshore in Southern California in 1940. Bull. Scripps. Inst. Oceanogr. 5: 335-370.

Bigelow, H.B. 1926. Plankton of the offshore waters of the Gulf of Maine. Bull. U.S. Bur. Fish. 40: 1-509.

Braarud, T. 1945. Experimental studies on marine plankton diatoms. Norske Vidensk Akad., Oslo, I. mat. Naturv. Klasse. 1944: 1-16.

David, P.M. 1955. The distribution of Sagitta gazelle Ritter-Zahony. Discovery Repts. 27: 235-278.

Garrett, C.J.R. 1977. Tidal influences on the physical oceanography of the Bay of Fundy and Gulf of Maine. In: Daborn, G.R., ed. Fundy tidal power and the environment. Acadia University Inst. Publ. No. 28, pp. 101-115.

Gordon, D.C. Jr. 1984. Predictions of the impacts of tidal power development on intertidal primary production in the headpond region. In this report.

Greenberg, D.A. 1984a. A review of the physical oceanography of the Bay of Fundy. In this report.

Greenberg, D.A. 1984b. The effects of tidal power development on the physical oceanography of the Bay of Fundy and Gulf of Maine. In this report.

Haffner, R.E. 1952. Zoogeography of the bathypelagic fish, Chauliodus sp. Sys. Zool. 1: 113-133.

Hargrave, B.T. 1984. Barrage effects on phytoplankton production and chemosynthesis in Cumberland Basin. In this report.

Huntsman, A.G. 1953. Movements and decline of large quoddy herring. J. Fish. Res. Bd. Can. 10: 1-50.

Prouse, N.J., D.C. Gordon, Jr., B.T. Hargrave, C.J. Bird, J. McLachlan, J.S.S. Lakshminarayana, J. Sita Devi and M.L.H. Thomas. 1984. Primary production: organic matter supply to ecosystems in the Bay of Fundy. In this report.

Raymont, J.E.G. 1963. Plankton productivity in the Oceans. Pergamon Press, Oxford, 660 p.

Robinson, G.A. 1961. Contribution towards a Plankton Atlas of the North Eastern Atlantic and the North Sea. Pt. I. Phytoplankton. Bull. Mar. Ecol., 5: 81-89.

Russell, F.S. 1935. On the value of certain plankton animals as indicators of water movements in the English Channel and North Sea. Jour. Mar. Biol. Assoc. U.K. 20: 309-322.

Semina, H.J., T.V. Belyaeva, V.V. Zernova, O.A. Movcham, L.V. Saninap, I.N. Sukhanova and I.A. Tarkhova. 1927. Distribution of the indicator species of planktonic algae in the world ocean. Okealogia 17: 867-877.

Sita Devi, J. 1980. Studies on the phytoplankton of Malpeque Bay, Prince Edward Island, Canada and the Welsh Dee Estuary, U.K. Ph.D. Thesis, University of Salford, 572 p.

Smayda, T.J. 1958. Biogeographical studies of marine phytoplankton. Oikos 9: 158-191.

Subba Rao, D.V. 1976. Marine plankton diatoms as indictors of ocean circulation in the Bay of Bengal. Botanica Marina 19: 183-187.

QUESTIONS AND COMMENTS

D. Gordon: If there is a suspended sediment reduction behind the barrage do you think there will be a change in the species composition of the phytoplankton and/or an increase in production and do you think blue-green algae may dominate?

J. Lakshminarayana: Species dominance of phytoplankton will likely change if suspended sediments decrease. I am not sure if primary productivity will increase greatly. At present, however, species composition is poorly known and I am not sure if blue-green algae occurrence will change.

Barrage Effects on Phytoplankton Production and Chemosynthesis in Cumberland Basin

Barry T. Hargrave

Marine Ecology Laboratory
Bedford Institue of Oceanography
Dartmouth, Nova Scotia
B2Y 4A2

ABSTRACT

Holding water behind a tidal barrage would increase phytoplankton production within the enclosed basin simply by increasing the area of water behind the barrier. The average increase in area would be 30% in Cumberland Basin. Reduced turbidity would result through stratification (by the combined effects of solar heating and freshwater discharge) and through reduced turbulence (because of lower levels of tidal energy dissipation). Increased light penetration arising from lower turbidity would result in higher levels of phytoplankton production assuming no nutrient limitations. If light availability is doubled, regression analyses with data collected from seasonal measurements show that phytoplankton production would approximately double. Chemosynthetic production (microbial dark uptake of carbon dioxide) is positively correlated with suspended particulate matter concentration. If turbidity is reduced to half of present day levels, regression analysis shows that chemosynthetic production would be reduced by approximately 30%. There is a close linkage between production and respiration of organic matter in the water column. This implies that whatever changes in photosynthetic or chemosynthetic production occur, the organic matter produced will probably be consumed by macro-and micrograzers and microbial respiration either in the water column or sediments.

Key words: phytoplankton production, chemosynthesis, turbidity, temperature, tidal barrage effects, Cumberland Basin.

RÉSUMÉ

La rétention d'eau au moyen d'un barrage marémoteur aurait pour effet de faire augmenter la production de phytoplancton à l'intérieur d'un bassin fermé simplement en augmentant la superficie du plan d'eau derrière le barrage. Cette superficie augmenterait de 30% dans le bassin Cumberland. Une turbidité réduite s'ensuivrait par suite de la stratification (effets combinés du chauffage solaire et des apports d'eau douce) et par une turbulence réduite (en raison des bas niveaux de dissipation de l'énergie tidale). Une pénétration accrue de la lumière par suite de la plus faible turbidité donnerait lieu à une production phytoplanctonique plus élevée en supposant une quantité suffisante d'éléments nutritifs. Lorsque la lumière disponible est doublée, les analyses de régression faites avec des données collectées à partir de mesures saisonnières

montrent que la production de phytoplancton pourrait doubler. La production chimiosynthétique (assimilation microbienne non photosynthétique de dixoyde de carbone) est corrélée positivement avec la concentration des particles en suspension. Lorsque la turbidité est réduite à la moitié des niveaux quoitidiens actuels, l'analyse de régression montre que la production chimiosynthétique pourrait être réduite d'environ 30%. Il existe donc un lien étroit entre les phénomènes de production et de respiration de la matière organique dans la masse d'eau. Ceci implique que peu importe les changements qui se produisent dans la production photosynthétique ou chimiosynthétique, la matière organique produite sera probablement consommée par des macro- ou des microbrouteurs et par la respiration microbienne, soit dans la masse d'eau ou dans les sédiments.

EFFECTS OF INCREASED BASIN AREA AND VOLUME

A single basin tidal power scheme would increase the average area covered by water behind a barrage by impounding water. Areal increase would amount to a minimum of +10% to a maximum of +50% of present areas at mid tide conditions (dependent on spring, neap and seasonal tidal effects). On the basis of increased area alone, phytoplankton production in the head pond would increase by an average of 30%.

Chemosynthetic production (dark fixation of dissolved carbon dioxide by micro-organisms) is directly related to the presence of suspended particulate matter in the water column. Since this pathway of organic production is independent of light, it occurs throughout the water column. An increase in average water volume held in the headpond by 30% would lead to a corresponding increase in chemosynthetic production if turbidity levels remained the same. Since this is not likely to occur (discussed below), reduced levels of suspended particulate matter will lead to reduced chemosynthesis per unit area. However, increased areal coverage of water behind a barrage will also lead to higher chemosynthetic production in the same proportion as that experienced by phytoplankton.

There will probably be a net increase in organic matter produced behind a barrage through microalgal photosynthesis and bacterial chemosynthesis on the order of 30 to 50% of present-day levels based simply on the increased area and water volume impounded.

CHANGES IN SUSPENDED MATTER CONCENTRATION

Stratification will be enhanced behind a barrage due to restricted water exchange and combined effects of solar heating and freshwater discharge (Greenberg 1984). Reduced tidal flow will also lower rates of resuspension and tidal scouring in intertidal and subtidal regions (Amos 1984). An exception may occur under a permanent ice cover in winter since pumping action of ice where it touches the bottom can resuspend sediment. This, however, is likely to be less than arises from the scouring which occurs from moving ice floes (Gordon 1984). Stratification behind a barrage may also cause higher rates of sedimentation due to reduced turbulence and mixing in the water column.

The net result of all of these processes will be to reduce the level of suspended material in water behind a barrage. This will enhance light penetration. Since light limitation is a critical factor in causing low levels of phytoplankton production in turbid waters of the inner Bay of Fundy (Hargrave et al. 1983 and Prouse et al. 1984), increased light availability because of a deeper photic zone will result in increased phytoplankton production.

CHANGES IN TEMPERATURE AND ICE COVER

Stratification behind a barrage will also result in an increase in temperature of the surface layer, particularly during summer when solar heating is maximum. Photosynthesis, chemosynthesis and respiration are temperature dependent, and thus positive changes in temperature will directly increase rates of these processes. Stratification and reduced salinity of surface water behind the barrage will permit a more complete ice cover than presently exists during winter (Gordon 1984). A more continuous ice cover would reduce light penetration and thereby reduce photosynthesis.

REGRESSION ANALYSES TO ASSESS IMPACT OF CHANGES ASSOCIATED WITH BARRAGE CONSTRUCTION

Simple linear correlations in a multiple regression analysis were determined using published data (Hargrave et al. 1983) for measurements of phytoplankton production and unpublished observations of chemosynthetic production (Prouse, pers. comm.) measured during high tide at Pecks Cove in the Cumberland Basin.

Phytoplankton production and chemosynthetic (dark) carbon assimilation, measured as the fraction of total dark uptake susceptible to poisioning with a 1% $HgCl_2$ solution (Taguchi and Platt 1977), were both measured in situ throughout three seasons over an annual period (with no measurements during winter when ice cover prevented sampling). Integral photosynthetic production was calculated for the surface 1 m water layer which represented the limit of light penetration. Production was positively related to incident radiation, temperature and concentration of suspended chlorophyll and inversely correlated with suspended matter concentration. The equation,

$$(1) \quad \text{mg C m}^{-3}\text{h}^{-1} = -4.0 + 0.11\ (\text{cal m}^{-2}\text{h}^{-1}) + 0.5\ {}^{0}\text{C} + 0.2\ (\text{Chl a mg m}^{-3}) - 3.4\ (\text{g L}^{-1}\ \text{SPM})$$

described the data set with $MR^2 = 0.75$, $n = 22$. No attempt was made to consider non-linear correlations between variables because of a high degree of covariance between independent variables. Light and temperature were positively correlated ($r = +0.4$) as were chlorophyll a and particulate matter suspended in the water ($r = +0.35$).

Chemosynthetic production was not related to light or chlorophyll a concentration, but positive correlations existed with temperature and suspended particulate concentrations. The equation,

(2) $$\text{mg C m}^{-3}\text{h}^{-1} = 11.0 + 12.2\ (\text{g L}^{-1}\ \text{SPM}) + 0.7\ (^{0}\text{C})$$

described the data set with $MR^2 = 0.64$, $n = 12$.

These two equations were used to calculate the effect that changes in light, temperature, chlorophyll and suspended matter concentration expected from barrage construction would have on rates of phytoplankton photosynthesis and microbial chemosynthesis. It is assumed that correlations between variables would be similar before and after barrage construction. The Before columns in Tables 1 and 2 list the independent variables with observed average values typical of existing summer conditions in Cumberland Basin. The After columns list an assumed corresponding value of each variable which might exist after barrage construction. Values of phytoplankton production and microbial chemosynthesis are calculated from the two equations given above.

Since light penetration into the surface waters of Cumberland Basin is limited by high turbidity to the upper 1 m layer (Hargrave et al. 1983), total photosynthetic production by phytoplankton in the Basin is simply a multiple of water surface area. A mean mid-tide value of 79.6×10^6 m^2 (Prouse et al. 1984) was used to convert average hourly values derived from Equation 1 to Basin-wide total values. Substitution of average summer values for incident radiation, temperature, suspended chlorophyll and particulate matter yielded a estimate of 708×10^6 g C h^{-1} for phytoplankton production (Table 1). Recalculation of this estimate on the basis of reduced turbidity levels (by 50%) and resultant increased light availability (doubled) with slight increase in temperature (due to stratification and solar heating) and reduced concentration of suspended chlorophyll, yielded a value 55% higher than the first estimate. The increase is due primarily to increased incident radiation which was the single most important variable in the multiple regression ($R^2 = 0.49$).

Similar calculations for expected changes in rates of chemosynthetic production showed that a decrease (approximately 37%) would occur arising from reduced concentrations of suspended particulate matter (Table 2). Total production for Cumberland Basin by this process must be based on volume rather than area because chemosynthesis occurs throughout the water column and is independent of incident radiation. Water volume estimated at HHW and LLW was used to derive an average value to calculate an estimate of chemosynthetic production for the entire Basin. This value exceeds photosynthetic production five-fold when total production values are compared (Table 2). While assumed values for independent variables after barrage construction increase photosynthetic production, this is offset by a larger calculated decrease in chemosynthetic production. The net result by these calculations would be a 21% decrease in organic matter synthesis by the combined processes of photosynthesis and chemosynthesis (Table 3).

TABLE 1. Calculation of estimates of phytoplankton photosynthetic production during summer at Pecks Cove, Cumberland Basin, using two sets of input values for independent variables. See text for description of equation used to calculate production rates. Production for the entire Basin is estimated using the present mid-tide water area of 79.6 km^2.

Variable	Before	After
Light (cal m^{-2} h^{-1})	44	88
Temperature (^0C)	14	16
Chlorophyll a (mg m^{-3})	17	9
SPM (g L^{-1})	0.4	0.2
Phytoplankton production (mg C m^{-3} h^{-1})	8.9	13.8
Phytoplankton production (entire Basin) (g C x 10^6 h^{-1})	708	1098
	(55% increase)	

TABLE 2. Calculation of estimates of chemosynthetic production (biological dark uptake of dissolved carbon dioxide) in the water column during summer at Pecks Cove, Cumberland Basin, using two sets of input values for independent variables. See text for description of equation used to calculate production rates. Production for the entire Basin is estimated using the present mid tide water volume of $0.81 \times 10^9 m^3$.

Variable	Before	After
SPM ($g\ L^{-1}$)	0.4	0.2
Temperature	14	16
Chemosynthetic production ($mg\ C\ m^{-3}\ h^{-1}$)	3.8	2.4
Chemosynthetic production (entire Basin) $gC \times 10^6\ h^{-1}$	3078	1944
	(37% decrease)	

TABLE 3. Summary of photosynthetic and chemosynthetic production for the average mid tide water area and volume of Cumberland Basin calculated as described in Tables 1 and 2. All values as gC x 10^6 h^{-1}.

Source of Production	Before		After
Photosynthetic	708		1098
Chemosynthetic	3078		1944
Total	3786	(20% decrease)	3042

CONCLUSIONS

Comparison of estimates calculated by substitution of values for independent variables into regression equations cannot be used too rigorously to test for impact effects. Limited data were used to derive the relationships, with no observations made during periods of ice cover. While production by photosynthesis is low because of reduced solar radiation in winter, suspended particulate matter concentrations are likely to be high due to ice scouring and resuspension. Considerable detrital input from eroded Spartina vegetation could also enhance the organic quality of suspended particulate debris.

It is also not likely that relations between variables derived during pre-barrage observations will remain unchanged after closure of the basin. Shifts in species composition of phytoplankton, changes in detrital input from intertidal areas, and altered conditions of stratification and turbulence are all either possible or likely to occur with barrage construction. These changes could or would alter relations between photosynthesis and light and between chemosynthesis and suspended particulate matter concentrations.

Despite these limitations, the calculations do show that light and suspended matter concentrations are critical variables in determining levels of microalgal photosynthesis and microbial chemosynthesis in turbid regions of the inner Bay of Fundy. Post-barrage observations could be carried out to quantify these relationships at locations inside and outside a barrage site. The calculations also demonstrate that chemosynthesis contributes more to the synthesis of organic matter in these waters than does photosynthesis (Table 3). This observation has not been recognized in earlier studies which were designed primarily to determine photosynthetic production (Hargrave et al. 1983 and Prouse et al. 1984).

The estimated decrease in organic matter produced by chemosynthesis if barrage construction results in decreased turbidity in Cumberland Basin (Tables 2 and 3) refers only to production in the water column. It is likely that deposited material settled from the water column would continue to serve as a substrate for microbial chemosynthesis in the sediments of the headpond. Although rates may not be similar because of diffusion-limited transport of carbon dioxide in sediment pore water, assessment of the impacts of barrage construction on the production by photosynthesis and chemosynthesis would have to include measurements in both the water column and sediments. It is characteristic of turbid environments that resuspension blurs the distinction between pelagic and benthic phases. Measurements in both environmental compartments are necessary to fully describe changes in rates of organic matter synthesis and consumption.

REFERENCES

Amos, C.L. 1984. The sedimentation effect of tidal power development in the Minas Basin, Bay of Fundy. In this report.

Hargrave, B.T., N.J. Prouse, G.A. Phillips and P.A. Neame. 1983. Primary production and respiration in pelagic and benthic communities at two intertidal sites in the upper Bay of Fundy. Can. J. Fish. Aquat. Sci. 40 (Suppl. 1): 229-243.

Gordon, D.C. Jr. 1984. Predictions of the impacts of tidal power development on ice conditions in the upper reaches of the Bay of Fundy. In this report.

Greenberg, D.A. 1984. The effects of tidal power development on the physical oceanography of the Bay of Fundy and Gulf of Maine. In this report.

Prouse, J.J., D.C. Gordon Jr., B.T. Hargrave, C.J. Bird, J. McLachlan, J.S.S. Lakshminarayana, J. Sita Devi and M.L.H. Thomas. 1984. Primary production: organic matter supply to ecosystems in the Bay of Fundy. In this report.

Taguchi, S., and T. Platt. 1977. Assimilation of $^{14}CO_2$ in the dark compared to phytoplankton production in a small coastal inlet. Coastal Mar. Sci. 5: 679-684.

QUESTIONS AND COMMENTS

D. Greenberg: How will you be able to obtain observations in the winter?

B. Hargrave: I do not know. We cannot reach the site now nor leave instruments in place because of ice.

M. Dadswell: What is your winter period?

B. Hargrave: January and February.

M. Dadswell: Do you have December measurements?

B. Hargrave: No. We attempted to collect data by inclosing water in light saturation boxes but we cannot use them because the water cleared during the experiment. The data were not comparable to that collected *in situ*.

M. Dadswell: If you were able to catch an ice free period it would be possible in late December?

B. Hargrave: Yes, but we would like to sample each week during the winter. This is the difficulty.

Unknown: Do you think stratification will increase the likelihood of oxygen depletion in the lower part of the water column after the barrage is build especially if primary productivity increases?

B. Hargrave: I do not think stratification would be enough. Nor do I think primary production would be inhanced enough for that to occur. The flushing, remember, is in the lower part of the water column so that on every tidal exchange the lower water mass is going to move in and out and it will be highly oxygenated from passing through the barrage. I do not believe the enhancement of phytoplankton primary production would be sufficient to lower the oxygen nearly as much as has been described in the Annapolis River for example.

D. Greenberg: Did you make your calculations on the basis of whether there would be ice cover in the winter and whether SPM levels increased or decreased?

B. Hargrave: I made the calculation on the basis that the SPM would increase during winter. The idea was that you would have trapped the sediment-laiden water under the ice and the material would move back and forth keeping suspended concentrations high or higher than at present. However if shorebound ice and permanent ice cover behind the barrage reduces scour and resuspension then one would have to assume SPM would be lower.

D. Greenberg: I think SPM would be lower.

B. Hargrave: Well then, if you assume SPM would be lower in the winter the chemosynthetic production would be less than now. That production is proportional to SPM levels.

C. Desplanque: Don't you think that even if ice cover is permanent its movement in the intertidal zone would create suspended sediments? It would act like a bellows.

B. Hargrave: It is very possible.

L. Cammen: What did you consider the euphotic zone to be? Did you just look at the euphotic zone?

B. Hargrave: The euphotic zone in our data is the upper meter. In doubling the light I would infer that is per square meter instant radiation.

N. Prouse: Will dark fixation be influenced by SPM levels?

B. Hargrave: Yes, it would be proportional to whatever the change in concentration is. The idea is that dark fixation occurs throughout the entire water column. I believe levels of fixation are higher in Cumberland Basin than in Cobequid Bay.

Possible Impacts of Tidal Power Development on Microbial Populations of the Bay of Fundy - Gulf of Maine Region[1]

Leon M. Cammen

Bigelow Laboratory for Ocean Sciences
West Boothbay Harbor, Maine 04575

ABSTRACT

Prediction of the impact of tidal power development on microbial populations is difficult due to our lack of baseline information. Inside the barrage, it seems likely that there would be a shift of bacterial abundance and activity from surface to deeper waters. Bacterial populations in the sediments should tend to increase in areas of sediment deposition and decrease in areas of erosion. Outside the barrage, changes in microbial populations and activity will reflect the increased tidal range that has been predicted for the New England coast. However, it is not possible at this time to assess the significance of these changes.

Key words: microbes, bacteria, heterotrophic activity, tidal power, Bay of Fundy, Gulf of Maine.

RÉSUMÉ

Il est difficile de prévoir l'incidence de l'aménagement d'une usine marémotrice sur les populations microbiennes, en raison du manque d'information de base. Il semble qu'à l'intérieur de l'endiguement, il y aurait probablement un changement de l'abondance et de l'activité des bactéries, entre la surface et les eaux profondes. Dans les sédiments, les populations bactériennes tendraient à augmenter dans les zones de sédimentation, et à diminuer dans les zones d'érosion. A l'extérieur de l'endiguement, les changements des populations et de l'activité microbiennes reflèteront l'augmentation de l'amplitude des marées prédite pour la côte de la Nouvelle-Angleterre. Cependant, pour l'instant, il est impossible d'évaluer l'importance de ces changements.

INTRODUCTION

Assessment of the effects of tidal power development on microbes is necessarily less precise than that for many other areas of concern since our baseline information is quite limited. In preparing this brief survey of possible impacts I have drawn mainly on one year's survey of both planktonic bacteria in the Bay and bacteria in a Cumberland Basin mudflat system

---

[1] Bigelow Laboratory for Ocean Sciences Contribution No. 82039

(Cammen 1984). In particular, speculation on the effects outside the barrage must be viewed with caution; nevertheless, it is instructive to consider possible areas of concern.

INSIDE THE BARRAGE

Bacterial populations in the water column of the upper reaches of the Bay of Fundy appear to be controlled to a large extent by the amount of suspended particulate matter (SPM) in the water. This relationship involves not only the abundance of bacteria but also their overall activity. Since one of the predicted effects of the barrage is that the surface waters will tend to be cleared of sediment (Amos 1984) heterotrophic activity will probably decrease near the surface. To some extent, this decrease may be offset by an increase in available nutrients due to increased phytoplankton production (Hargrave 1984), but based on data for the Bay as a whole it appears that the reduction in SPM will be the dominating factor. At the same time SPM is being reduced in the surface waters of the headpond, it will be increasing in the deeper layers of water with a consequent increase in both bacterial abundance and heterotrophic activity. The net result may be that there will be a transfer of heterotrophic activity from surface water to deeper water, but that integrated over the entire water column there will be little measurable change in bacterial populations or heterotrophic activity. The redistribution of bacteria in the water column might be significant, however, to organisms feeding on SPM and the accompanying microbes and limited to either surface or deeper water.

Intertidal bacterial abundance will decrease with the decrease in intertidal area, but it is difficult to predict whether activity per unit area will change. Subtidal bacteria might be expected to reflect the redistribution of sediment in the headpond with populations increasing in areas of deposition and decreasing in areas of erosion.

OUTSIDE THE BARRAGE

Impacts outside the barrage may be less apparent and certainly less predictable than those inside the barrage but, due to the potentially large area affected, they need to be considered. Most of these impacts result from the predicted increase in tidal range of up to 30 cm along the northern New England coast (Greenberg 1979). This increase in tidal range will have two effects: 1) an increase in the area of the intertidal zone and 2) an increase in the amount of water moving with each tidal exchange resulting in greater flushing of coastal estuaries and greater tidal current velocity. What is not at all certain is the magnitude and relative importance of these changes. We can, however, deal with their effect on microbial activity qualitatively.

An increase in intertidal area will have the obvious impact of increasing microbial production in estuarine areas and this increased production will be available to estuarine consumer organisms. The change will be maximal in shallow estuaries already bordered by mudflats, but may be minimal in many of the relatively steep-walled Maine estuaries. In addition, increased intertidal production of macro-and microalgae will provide more organic material to the heterotrophic microbes.

Increased tidal flushing of estuaries may result in both higher estuarine production and an increase in export of this production to offshore areas. Production may increase both due to the increased supply of nutrients resulting from greater tidal exchange and due to a decrease in the turbidity of the water. The decrease in turbidity might also decrease the amount of suspended bacteria. Taken together, the effect of increased production within the estuaries and decreased microbial activity in the water column would have the result of increasing the amount of organic material available for export and the increased flushing rate would tend to increase the percentage of available material that actually was exported. If more organic material were exported to the Gulf of Maine shelf and available to benthic microbes, benthic production might be expected to increase as well as nutrient regeneration which might even have a positive effect on pelagic production.

What is missing from these comments is a quantitative assessment of the relative impact of these changes. One possible way to examine this question is to compare estuarine production with production in the Gulf of Maine proper. Using a value of 290 g C m^{-2} for annual phytoplankton production in the Gulf of Maine (O'Reilly and Busch 1983) and an area of 6 x $10^4 km^2$, total Gulf of Maine production is about 1.7 x 10^{10} kg C y^{-1}. Esturine production is Maine has been estimated as 1.5 x 10^8 kg C y^{-1} (U.S. Fish and Wildlife Service, 1980), but the estimate does not include benthic microalgae or subtidal macrophytes which together may raise the values by an order of magnitude (J. Topinka, personal communication). Even allowing for the fact that the Maine coast may account for only about half the coastline bordering the Gulf of Maine, the estimated estuarine production will be on the order of 1.5 x 10^8 - 3 x 10^9 kg C y^{-1} or about an order of magnitude less than Gulf of Maine phytoplanton production. However, if we consider only nearshore regions, estuarine production may be more important and potential changes in the degree of export of this production more significant to the microbial community of the shelf as well as, by implication, the shelf ecosystem.

REFERENCES

Amos, C.L. 1984. The sedimentation effect of tidal power development in the Minas Basin, Bay of Fundy. In this report.

Cammen, L.M. 1984. Microbial ecology of the Bay of Fundy. In this report.

Greenberg, D.A. 1979. A numerical model investigation of tidal phenomena in the Bay of Fundy and Gulf of Maine. Mar. Geodsey 2: 161-187.

Hargrave, B.T. 1984. Barrage effects on phytoplankton production and chemosynthesis in Cumberland Basin. In this report.

O'Reilly, J.E. and D.A. Busch. 1983. Phytoplankton primary production on the northwestern Atlantic shelf. Rapp Proces-Verbaux Reunions.

U.S. Fish and Wildlife Service. 1980. An ecological characterization of coastal Maine, Vol. 2. Fish and Wildlife Service, U.S. Dept of the Interior.

QUESTIONS AND COMMENTS

D. Gordon: Odum's detrital work indicates there is a point when flushing increases tidal salt marsh production. Could increased flushing along the coast outside the barrage increase detrital production mechanisms there?

L. Cammen: There are two effects. One is increased production and the other is transfer of the production seaward. Both effects work together in the same direction and would increase detrital supply to the coastal shelf waters.

D. Gordon: If tidal range increases too far will it have negative effects?

L. Cammen: I don't think there would be limiting effects in either direction. Some estuaries along the Maine coast are stratified or close to it. They would become more productive if mixing increased with increasing tidal amplitude. With increased tidal range macroalgal production should increase because it is a function of intertidal zone. Both this source and salt marshes would supply the detritus food chain.

B. Hargrave: Everything we know about the Gulf of Maine indicates it is an open system dominated by flow through the Northeast Channel. Forgetting production on Georges Bank, do you have any information that justifies the assumption that estuarine input to the system is substantial in comparison to *in situ* production?

L. Cammen: I do not have supporting data. But other researchers are finding that as you move northward up the Maine coast, macroalgal production becomes substantial in comparison to production in the upper 100 m of the open water column. Anecdotal evidence indicates there is macroalgal contribution to the detritus supply in this region, but we do not have hard and fast information about how much organic production from the intertidal zone moves out to the shelf.

Predictions of the Impacts of Tidal Power Development on Intertidal Primary Production in the Headpond Region

Donald C. Gordon, Jr.

Marine Ecology Laboratory
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, N.S. B2Y 4A2

ABSTRACT

Benthic primary production will decrease in the headpond of a single effect tidal power project because of reduced intertidal area and exposure time. The decreases are currently estimated to be 65% and 30%, respectively, for benthic microflora and salt marshes. These losses could be made up if phytoplankton production increased by 168% in Cumberland Basin and by 46% in Cobequid Bay. Even though the affected area is three times as large, the impacts of the Cobequid Bay (B9) project are less because of the much lower intertidal primary production in this region.

Key words: benthic primary production, microalgae, salt marshes, phytoplankton, Bay of Fundy, Cumberland Basin, Cobequid Bay, tidal power, environmental impacts

RÉSUMÉ

La production benthique primaire diminuera dans les eaux d'amont d'une usine marémotrice à effet simple, en raison de la réduction d'étendue de la zone intertidale et de la diminution de la durée d'exposition. On estime qu'actuellement, ces diminutions seront de 65% à 30% respectivement pour la microflore benthique et les marais salants. Ces pertes pourraient être compensées, si la production de phytoplancton augmentait de 168% dans le bassin Cumberland et de 46% dans la baie Cobequid. Bien que la région touchée soit trois fois plus vaste, les conséquences du projet d'aménagement de la baie Cobequid (B9) seront moins prononcées, la production primaire intertidale étant beaucoup plus modeste dans cette région.

INTRODUCTION

This paper is based upon the projected operational water elevations for the Cobequid Bay (B9) site provided by the Nova Scotia Tidal Power Corporation (Baker 1984) and production estimates developed by Prouse et al. (1984). It focuses on expected changes in the headpond region of a single effect project once it is operational. Possible changes during construction and seaward of a barrage are not considered. The predictions offered are preliminary and require peer review and further refinement before being accepted as highly probable.

BENTHIC MICROALGAE

All that could be said in 1976 was that benthic microalgal production would probably decrease behind a tidal barrage because of reduced intertidal area. Data on productivity rates were not available so nothing could be said about the magnitude of the decrease.

Benthic microalgae, principally diatoms, are ubiquitous in intertidal sediments, which constitute over half the total area of Cumberland Basin and Cobequid Bay (Table 1). Intertidal area in Cobequid Bay is about three times that of Cumberland Basin and the sediments contain a greater proportion of sand.

The gross annual primary production of benthic diatoms has been measured over a two-year period by Hargrave et al. (1983) at two sites: Anthony Park in Cobequid Bay and Pecks Cove in Cumberland Basin. There is a strong seasonal cycle with maximum daily productivity rates generally occurring during the summer months. Because of the very turbid nature of the water, no production occurs when the flats are flooded. There is also evidence that production is greater at higher elevations where exposure is longer. Using the relationship between annual average chlorophyll concentration in surface sediment and annual production observed at these two sites, Prouse et al. (1984) estimate the annual benthic microalgal production in various parts of the Bay of Fundy from sediment chlorophyll data gathered as part of regional surveys conducted by helicopter. The mean estimates for Cumberland Basin (A8) and Cobequid Bay (B9) are 38 and 14 g C m^{-2} y^{-1}, respectively (Table 2).

As discussed by Prouse et al. (1984), light availability appears to be the most important environmental factor limiting primary production by benthic microalgae in the upper reaches of the Bay of Fundy. Other secondary factors include temperature, grazing, nutrient availability, and perhaps physical stress. It is assumed, however, that the major factor affecting benthic microalgal production will be changes in the average intertidal area and duration of exposure.

Changes in exposure are estimated by integrating areas above the water surface before and after project construction using the tidal curves provided by the Nova Scotia Tidal Power Corporation (Baker 1984). Assuming an upper mud/sandflat limit of 5 m above mean sea level (MSL)(based on observations in Cumberland Basin) and a constant slope in the intertidal zone, these measurements indicate that the exposed mud/sandflat area will be reduced by 54, 65, and 90% for neap, mean, and spring tides, respectively.

Despite the much greater mud/sandflat area in Cobequid Bay at present (Table 1), estimates of total annual production are very similar for the two regions because of greater production per square metre in Cumberland Basin (Table 2). Reducing these figures by 65%, the loss of exposed mud/sandflat area for a mean tide yields estimates of annual benthic diatom production after a project is built. The absolute loss is about the same for both projects but on a square metre basis is less for Cobequid Bay (Table 2). Therefore the Cobequid Bay project (B9) may cause less impact.

TABLE 1. Mud/sandflat and salt-marsh areas in Cumberland Basin and Cobequid Bay (Prouse et al. 1984).

Site	Total Area (ha)	Mud/Sandflat Area (ha)	% of Total	Marsh Area (ha)			% of Total Area
				Total	High	Low	
Cumberland Basin (A8)	11810	6246	53	1714	948 (55%)	766 (45%)	15
Cobequid Bay (B9)	29840	17187	58	373	226 (61%)	147 (39%)	1

TABLE 2. Estimates of production losses in the headponds of possible tidal power projects at Cumberland Basin (A8) and Cobequid Bay (B9) assuming decreases of 65% and 30% for benthic microalgae and salt marshes, respectively. Estimated production losses are expressed as absolute amounts (tonnes C y^{-1} for the entire headpond) and normalized for area (g C m^{-2} y^{-1}).

Source	Site	Annual Production (g C m^{-2} y^{-1})	Total Annual Production (tonnes C y^{-1}) Before	After	Loss	Loss (g C m^{-2} y^{-1})
Benthic Microalgae	Cumberland Basin (A8)	38 (23-116)	2259	791	1468	12.4
	Cobequid Bay (B9)	14 (11-30)	2406	892	1564	5.2
Low Salt Marsh	Cumberland Basin (A8)	215 (175-273)	1647	1153	494	4.2
	Cobequid Bay (B9)	215 (175-273)	316	221	95	0.3

It is generally agreed that phytoplankton production in the headpond will increase due to increased light penetration (because of reduced suspended sediment load) and water area (Hargrave 1984). Using the total annual phytoplankton production estimates derived by Prouse et al. (1984), the projected losses of benthic microalgal production could be made up if phytoplankton production increased by 125% in the Cumberland Basin and 44% in Cobequid Bay (Table 3).

The above calculations only consider changes in intertidal mud/sandflat exposure. Other factors could reduce diatom production further, such as a prolonged ice season which should truncate the present growing season at both ends and climatic changes reducing light availability (increased cloud cover or fog, etc.). On the other hand, production losses could be less if diatoms grow faster under less physical stress and warmer temperatures and if enough suspended sediment settles out of the water to allow photosynthesis on submerged areas.

SALT MARSHES

Concern was expressed about impacts on salt marshes in 1976 but again no quantitative data were available. It was recognized that lower high water levels would reduce the flooding of high marsh areas and allow a seaward movement of terrestrial vegetation. There was also speculation that the lower marsh limit might move in a seaward direction, producing no net change or perhaps even an increase in saltmarsh area.

As discussed by Prouse et al. (1984), Fundy saltmarshes are sharply divided into two categories: high marsh, dominated by *Spartina patens* and low marsh, composed almost exclusively *Spartina alterniflora*. Saltmarsh area is much less in Cobequid Bay while the relative amount of high marsh is about the same in both regions (55 to 61%) (Table 1).

Three recent productivity studies of Fundy marshes (Morantz 1976, Smith et al. 1980, and Gordon et al. in preparation), reviewed by Prouse et al. (1984), yield very similar figures for the net annual above-ground production averaging about 215 g C m^{-2} y^{-1} (Table 2). It is clear that elevation plays a key role in controlling productivity. High marsh production is generally less than low marsh, presumably because of nutrient limitation caused in part by infrequent flooding. Low marsh production is greatest near its upper limit and drops linearly with decreasing elevation, presumably because of increasing physical stress from daily flooding. Factors preventing low marsh from extending farther out onto the mudflats are not clearly known but physical stress from flooding and winter ice are suspected to be important.

Changes in high water levels, predicted to drop by 0.3, 0.7, and 1.0 m for neap, mean, and spring tides, respectively, will have a major impact on salt marshes in the headpond region of a tidal power project. The most pronounced changes will occur on the high marsh areas. Tidal flooding will become very rare, resulting in a major shift in species composition toward upland plants as predicted by Pearce and Smith (1973) and observed

TABLE 3. Factors by which phytoplankton production would have to increase to make up estimated production losses by benthic microalgae and salt marshes in the headond of hypothetical tidal power projects.

Site	Estimated Annual Phytoplankton Production (tonne C y^{-1})	Source	Estimated Loss (tonne C y^{-1})	Factor (%)
Cumberland Basin (A8)	1170	Benthic microalgae	1468	125
		Salt Marsh	494	42
		Combined	1962	168
Cobequid Bay (B9)	3587	Benthic microalgae	1564	44
		Salt Marsh	95	3
		Combined	1659	46

by Beeftink (1979) in the delta area of the Netherlands. It is postulated that the landward edge of the saltmarsh zone will move seaward to near the present outer limit of high marsh. Since high marsh is thought to export little of its production, this major change may not have a significant impact on the production of the headpond estuary. The upper limit of low marsh will presumably move down about 0.7 m. It is postulated that sediment deposition will occur just above MHW and develop a limited area of new high marsh.

In 1976, others speculated that the lower limit of low marsh may move seaward but this now seems unlikely. Due to holding back water for power production, the exposure time of the low marsh zone at any elevation will be substantially reduced, averaging about 30%. This means less light and more physical stress for low marsh vegetation. Therefore it is postulated that low marsh production will drop by about 30% and that there may even be a landward displacement of the lower limit of low marsh, reducing its area and production still further.

Because of the much smaller saltmarsh area in Cobequid Bay (Table 1), the estimated total annual production is much less as well (Table 2). Reducing these estimates by 30%, the estimated loss of low marsh exposure time, yields estimates of annual low marsh production after the project is built (Table 2). Despite its much greater size, the loss is much less in Cobequid Bay (B9) and amounts to only 0.3 g C m^{-2} y^{-1}. The B9 site, therefore, is much more suitable because of its lesser impact on saltmarsh production. The projected saltmarsh production losses can be made up if phytoplankton production increases by 42% in Cumberland Basin and by 3% in Cobequid Bay (Table 3).

SUMMARY

It is predicted with a high degree of certainty that primary production of benthic microalgae and saltmarshes will decrease in the headpond region of a single effect tidal power project. This preliminary analysis suggests that the decreases are on the order of 65% and 30%, respectively. Summing these losses, it appears that they could be made up if phytoplankton production increased by 168% in the Cumberland Basin and by 46% in Cobequid Bay (Table 3). Even considering its larger size, the impacts of the proposed Cobequid Bay (B9) project appear to be less. Although total primary production in the headpond may not decrease because of the expected surge in phytoplankton production, there will be major shifts in the relative abundance of consumer organisms as a greater percentage of the production is supplied by phytoplankton.

REFERENCES

Baker, G.C. 1984. Engineering description and physical impacts of the most probable tidal power project(s) under consideration for the upper reaches of the Bay of Fundy. In this report.

Beeftink, W.G. 1979. The structure of saltmarsh communities in relation to environmental disturbances. In: R.L. Jefferies and A.J. Davy, eds. Ecological Processes in Coastal Environments. Blackwell Sci. Publ., pp. 77-94.

Hargrave, B.T. 1984. Barrage effects on phytoplankton production and chemosynthesis in Cumberland Basin. In this report.

Hargrave, B.T., N.J. Prouse, G.A. Phillips and P.A. Neame. 1983. Primary production and respiration in pelagic and benthic communities at two intertidal sites in the upper Bay of Fundy. Can. J. Fish. Aquat. Sci. 40(Suppl. 1): 229-243.

Morantz, D.L. 1976. Productivity and export from a marsh with a 15 m tidal range and the effect of impoundment of selected areas. M.Sc. thesis, Dalhousie University, 77 pp.

Pearce, P.A. and A.D. Smith. 1973. The potential influence on waterfowl of port and tidal power development in the Bay of Fundy. Can. Wildl. Serv. Rep. Ser. No. 29, pp. 91-100.

Prouse, N.J., D.C. Gordon Jr., B.T. Hargrave, J. McLachlan, C.J. Bird, M.L. Thomas and J.S.S. Lakshminarayana. 1984. Primary production: organic matter supply to ecosystems in the Bay of Fundy. In this report.

Smith, D.L., C.J. Bird, K.D. Lynch and J. McLachlan. 1980. Angiosperm productivity in two saltmarshes of Minas Basin. Proc. N.S. Inst. Sci. 30: 109-118.

QUESTIONS AND COMMENTS

M. Dadswell: If construction of a barrage causes increased water temperatures and decreased tidal energy inside the barrage is it possible that saltmarsh production will increase?

D. Gordon: Our calculations indicate this is not likely because of the overall decreased areal cover of the saltmarsh community.

D. Greenberg: Building the B9 site in Cobequid Bay will increase the tidal amplitude in Cumberland Basin. Will this cause any decrease in the saltmarsh production in Cumberland Basin?

D. Gordon: The high marsh would be flooded more frequently which might lead to a slight increase in its production due to greater availability of nutrients. Assuming there is no limitation of sediment the increase in high water level will be followed by sediment deposition. A situation of increased production of the high marsh could occur at first because of increased nutrient supply then production would probably decline after sediment build-up occurs over a period of several years.

K. Mann: What factors now decide the lower limit of the Spartina alterniflora low marsh?

D. Gordon: The limit of the low marsh varies depending on where you go in Cumberland Basin. A large number of our transects ended where they had been truncated by erosion, which seemed to be the major limiting factor on the seaward extent of the salt marsh. In Peck's Cove it was interesting that the erosion activity was further seaward and there was no change in the intertidal slope, but there was a natural lower limit of Spartina. Although we found the rhizomes under the mud further seaward the plants never occurred above ground. It appears that in Cumberland Basin ice or turbidity restricts the lower limit. In other areas of North America Spartina does extend down the intertidal zone to below mean sealevel.

Unknown: How do you compare the effect on saltmarshes of barrage construction in either Cumberland Basin or Cobequid Bay?

D. Gordon: I think the main value of the calculations we did is that the negative impacts on saltmarshes appear to be much greater in Cumberland Basin then they are in Cobequid Bay.

The Impact of a Tidal Power Project on the Intertidal Benthos of Cobequid Bay

Donald L. Peer

Marine Ecology Laboratory
Bedford Institute of Oceanography
Dartmouth, N.S. B2Y 4A2

ABSTRACT

The new tidal regime imposed on the upper part of Cobequid Bay by the proposed power development (B9) would cause over 95% of the productive Macoma baltica area to be permanently lost to the subtidal zone. A new subtidal benthic community will no doubt replace Macoma and this new community may establish over the much larger area of the present lower intertidal and subtidal in which benthic macrofauna are presently absent. An even greater proportion of the Corophium-producing mudflat would be lost under the new tidal regime but this might be compensated to some extent by production on areas of suitable substrate that are be deposited as a result of the new water levels.

Key words - Corophium volutator, Macoma baltica, secondary production, Cobequid Bay, tidal power

RÉSUMÉ

Le nouveau régime de marées qu'imposerait à la partie supérieure de la baie Cobequid l'aménagement proposé d'une centrale marémotrice (B9), provoquerait à plus de 95% la perte définitive de la zone productrice contenant Macoma baltica, qui deviendrait une zone subtidale. Une nouvelle communauté benthique subtidale remplacerait sans aucun doute Macoma, et cette nouvelle communauté pourrait s'établir dans la zone beaucoup plus vaste que constituent les zones intertidale inférieure et subtidale actuelles, dont la macrofaune benthique est actuellement absente.

Le nouveau régime de marées ferait perdre une proportion encore plus grande de la slikke (23) où vit Corophium, mais dans une certaine mesure, cette perte serait compensée par l'apparition de ce dernier dans tout secteur où se formerait un substrat favorable, par suite de l'établissement des nouveaux niveaux d'eau.

INTRODUCTION

The production of Corophium volutator in Cobequid Bay was estimated by applying a P/B (production/biomass) ratio of 1.6 (Peer 1984) to the July biomass data of five intertidal transects from Yeo (1978). Production of Macoma baltica was estimated by applying a variable P/B ratio (Peer 1984), based on mean animal size, to data on mean annual biomass from the same source. Along each of the transect profiles, Macoma and Corophium biomass was sampled from 8-12 equally spaced points. Surveyed profiles of each of the transects were made. From this information it was possible to estimate how the production of Corophium and Macoma was distributed along each transect and how it was related to water level.

Changes in water elevations resulting from a barrage were obtained from Baker (1984). The amount of intertidal production that would be lost to the subtidal due to permanent submergence was estimated and is shown on Table 1.

Under the predicted tidal regime the most productive part of the intertidal area would be permanently submerged and become subtidal and a different benthic community would establish. Any such new community so formed would not necessarily be any less productive than the existing intertidal community.

The present high production of Macoma probably represents a concentration of nutrients in small areas within the coves at the lower end of Cobequid Bay. This can be contrasted to the large areas of shifting sand in the central and upper parts of Cobequid Bay where large organisms are absent. Under the proposed tidal power regime the current-stressed intertidal area in the middle to upper regions of Cobequid Bay would probably attain a similar benthic community to the other submerged formerly productive intertidal areas.

The amphipod Corophium volutator is found throughout the upper Bay of Fundy wherever suitable substrate is encountered. As well as serving as a good food source for fish, it is the chief prey of the shore birds that visit the area late in the summer (Hicklin and Smith 1984).

The average unit production of Corophium is related to the average total unit production of the whole water body (Peer 1984). At present the average unit primary production of Cobequid Bay is quite low, being about half that of Cumberland Basin (Prouse et al. 1984). On that basis, if the assumption is made that under the new tidal regime the average unit primary production will increase, then the unit production of Corophium can be expected to increase. The area of producing mudflat will, however, be substantially less although not to the extent suggested by Table 1 as new areas of suitable mudflat will form in response to a new tidal elevations.

REFERENCES

Baker, G.C. 1984. Engineering description and physical impacts of the most probable tidal power project(s) under consideration for the upper reaches of the Bay of Fundy. In this report.

Hicklin, P.W. and P.C. Smith. 1984. Studies of birds in the Bay of Fundy: a review. In this report.

TABLE 1. Present estimated intertidal production of Corophium and Macoma and that portion which occurs above the proposed low water elevation of a tidal power development. Data from Yeo (1977).

Organism	Transect	Total present intertidal production	Present production above proposed low water
Corophium			
	Sterling Brook	0.64	0.05
	Salter Head	0.53	0.01
	Kings Creek	1.28	0.03
	Anthony Park	0.50	0
	East Noel	1.18	0
Macoma	East Noel	1.74	.05
	Kings Creek	3.55	.18
	Mungo Brook	4.35	.22
	Anthony Park	8.14	.16
	Sterling Brook	9.16	.18

Peer, D.L. 1984. A review of benthic macrofaunal production of the upper Bay of Fundy intertidal area. In this report.

Prouse, N.J., D.C. Gordon Jr., B.T. Hargrave, C.J. Bird, J. MacLachlan, J.S.S. Lakshminarayana, J. Sita Devi and M.L.H. Thomas. 1984. Primary production: organic matter supply to ecosystems in the Bay of Fundy. In this report.

Yeo, R.K. 1977. Animal sediment relationships and the ecology of the intertidal mudflat environment, Minas Basin, Bay of Fundy, Nova Scotia. M.Sc. Thesis, Dept. of Geology, McMaster University, Hamilton, Canada, 396 pp.

QUESTIONS AND COMMENTS

Unknown: Is there a particular region of the mudflats in terms of elevation where *Corophium* production is greatest.

D. Peer: No, it appears to be spotty with no particular trend. It often depends on how the birds are feeding. If they have fed heavily on an area the remaining population of *Corophium* can often have very high rates of production afterwards.

Unknown: How was your calculation of the production loss of *Corophium* to a tidal barrage made.

D. Peer: The calculation was made completely on the basis of existing biomass that would be lost to the subtidal applying a constant P/B ratio. This is the best we can do unless one can predict the population dynamics afterwards.

D. Wildish: What proportion of the entire *Corophium* production area behind the B9 site will be lost to the birds? Is it significant?

D. Peer: One could if one wished take the transect profiles and do the calculations. We did not do it. The loss may be significant but it is difficult to calculate because of the variance of *Corophium* populations in Cobequid Bay is so extreme. Also to do the calculation properly one needs to know whether new mudflats will form and what their area and *Corophium* production will be like.

M. Dadswell: Do you think that subtidal benthic production will increase behind a barrage?

D. Peer: Yes, undoubtedly. There is little or nothing there now.

Unknown: What determines the present lower limit of the intertidal community in Cobequid Bay? Will it change with flooding?

D. Peer: The lower end of the intertidal distribution of animals in Cobequid Bay is determined by substrate type and the fact that the sandflat areas present are so unstable. I am sure the submerged area will become a different type of subtidal community. We do not know what it will be. Tidal energies will be greatly decreased so substrate will change. The area is now sand or hard packed gravel and there is very little macrofauna there at all. Once you flood it a veneer of fine sediment should form and a subtidal community would develop.

L. Cammen: Have you calculated the post-barrage intertidal total production to compare to the present?

D. Peer: No, I haven't. I took it as it is. I do not think it would be worth doing because you would have to contour the new shoreline to do it properly.

Apsects of Lobster Biology and Fishery in the Upper Reaches of the Bay of Fundy

Alan. A. Campbell

Invertebrates and Marine Plants Division
Department of Fisheries and Oceans
Biological Station
St. Andrews, New Brunswick E0G 2X0

ABSTRACT

The lobster fishery in the upper reaches of the Bay of Fundy is low in productivity and consists of less then 10% of the total lobster landings and fishermen of the whole Bay of Fundy. The majority of commercial size lobsters caught are large (95 mm carapace length) and mature. Evidence from size frequency distributions and tag release-recapture experiments indicated that immature lobsters (60-94 mm carapace length) had a 1:1 sex ratio and the majority did not generally move greater than 18.5 km. In contrast, sex ratios changed seasonally for mature lobsters. There was a preponderance of males in traps during the winter, while more females, especially ovigerous ones, were caught during summer (August). The tagging data indicated that mature females moved a greater mean distance (87.9 km) than males (43.2 km) and suggested a seasonal inshore shallow and offshore deep water movement. Chignecto Bay is occupied by many large mature female lobsters during summer months that molt, extrude new eggs, or hatch their old eggs as pelagic larvae. The proposed tidal dam, if placed in either Cobequid Bay or Cumberland Basin, would probably have an insignificant effect on the local lobster fishery and biology.

Key words: lobster, <u>Homarus americanus</u>, tagging, movements, fishery, landings, tidal barrage effects.

RÉSUMÉ

Dans la partie amont de la baie de Fundy, la pêche du homard est caractérisée par une faible productivité, avec moins de 10% du total des captures; d'autre part, les pêcheurs représentent moins de 10% du contingent de l'ensemble de la baie de Fundy. La majorité des homards de taille convenant à la vente sont grands (longeur de la carapace $\geq$ 95 mm) et parvenus à maturité. La distribution de fréquence des tailles, et les expériences consistant à libérer et recatturer des animaux marqués, ont indiqué que les populations de homards juvéniles (longueur de la carapace 60-94 mm) comportaient un nombre égal de mâles et de femelles, et ne se déplaçaient généralement pas de plus de 18,5 km. Par contre, dans le cas des homards adultes, le rapport mâles/Femelles varie de façon saisonnière. On a observé une prépondérance des mâles dans les pièges pendant l'hiver, et de femelles, en majorité gravides, pendant l'été (août). Les données fournies par le marquage ont indiqué que les femelles "matures" se déplaçaient sur

une distance moyenne plus grande (87,9 km) que les mâles (43,2 km), et suggèrent qu'ont lieu des mouvements saisonniers de l'eau à faible profondeur près du rivage, et à grande profondeur au large. La baie Chignecto contient de vastes populations de femelles matures de grande taille pendant l'été, époque à laquelle ont lieu la mue, la production de nouvelles pontes, ou l'éclosion des oeufs avec apparition de larves pélagiques.

Si l'on construit l'usine marémotrice proposée dans la baie Cobequid ou le bassin Cumberland, on n'observera probablement que des effets minimes sur la pêche et la biologie des populations locales de homards.

INTRODUCTION

Apart from some general fisheries statistics (Campbell 1979, Scarratt 1977, Wilder et al. 1974), little published information is available on the fishery and biology of the lobster Homarus americanus H. Milne-Edwards (Decapoda:Nephropidae) in the upper reaches of the Bay of Fundy. The purpose of this paper is to present and discuss data on the lobster fishery for part of Lobster District 3 (from Statistical Districts 24, 40-79) (Fig. 1) and on lobster population size and sex structures and movements of tagged lobsters obtained from a study area off Alma in Chignecto Bay (Fig. 2). Although this study was not specifically designed to determine the impact of tidal power structures on lobsters, the results are used to consider the possible effects on the lobster fishery should a tidal dam be placed in either Cobequid Bay or Cumberland Basin (Daborn 1977).

The study is limited to lobsters of a size range vulnerable to commercial fishing gear, which includes subadult and adult lobsters. Little information is available on the ecology of juvenile benthic and larval pelagic stages of H. americanus in this area.

MATERIALS AND METHODS

Statistical information on annual lobster landings and the number of licenced lobster fishing boats were obtained from Statistics Canada, Halifax, and from local fisheries officers. About 60 lobster traps were randomly chosen from Alma during September 1980 and measured for size (length, width, and height), lath spacing and entrance ring diameter (hoop size).

At-sea sampling of lobsters caught in commercial lobster fishing boats was conducted from representative ports (Alma, Halls Harbour and Canada Creek) in Lobster District 3 during May 1979-November 1980 (Fig. 2). A lobster fishing boat from Alma was also chartered to tag lobsters August-September 1979 and 1980. At-sea sampling included recording the number of trap hauls, carapace length in millimeters, and sex of sublegal ("shorts") ovigerous females and commercial size lobsters. The carapace length (CL) was measured from the inner base of the eye socket to the dorsal posterior margin of the carapace along the mid-line with vernier calipers. The

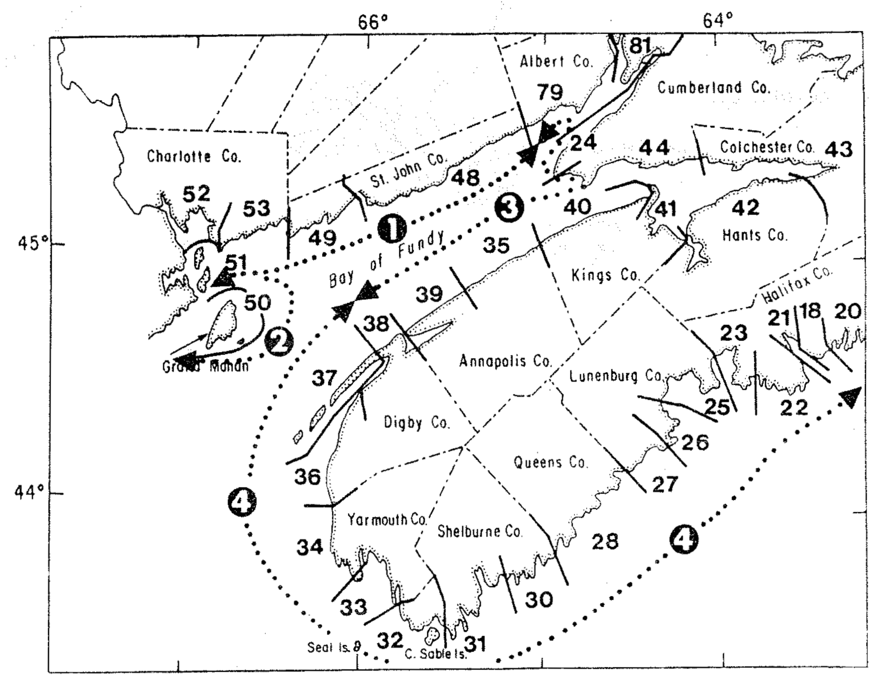


Fig. 1. Counties, statistical districts and lobster districts (dotted lines) for southern New Brunswaick and Nova Scotia.

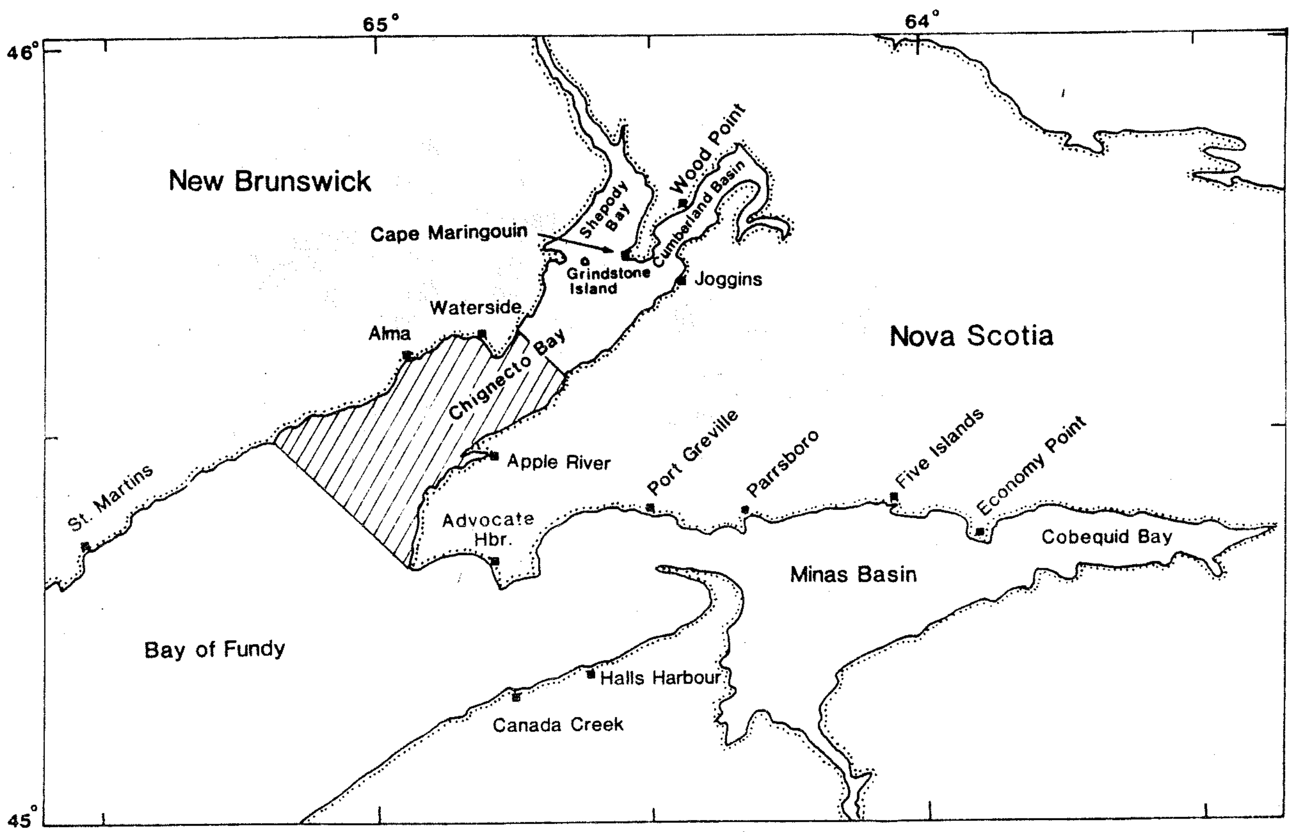


Fig. 2. Upper reaches of the Bay of Fundy. Shaded area shows the Alma study area.

developmental stage of lobster eggs, classed as new eggs (no embryo visible) and old eggs (well developed embryo visible), were recorded for each ovigerous ("berried") female.

During August-September 1979 and 1980, 2831 and 1970, respectively, lobsters were tagged with sphyrion spaghetti tags (Scarratt and Elson 1965) in the Alma area to determine growth and movement. A reward of $3.00 was offered for tags returned with accurate recapture location and depth information. An additional $2.00 was offered to fishermen for allowing each tagged lobster to be measured. Data on tag returns collected up to September 30, 1982 are used in this study. An analysis of variance program (Kim and Kohout 1975) was used to compare the distance travelled by immature, mature male, and female tagged lobsters after $\log_{10}(x + 1)$ transformation to normalize the data. Water temperatures at 10-20 m depth were obtained with continuous recording submersible thermographs (Model J180, Peabody Ryan, Kirkland, WA, U.S.A.).

RESULTS AND DISCUSSION

LOBSTER FISHERY

Regulations

Lobster fishing in Lobster District 3 is regulated in a number of ways. The fishing season is split into two periods, October 15-December 31 of one year and March 1- July 31 of the next year. Fishing seasons were designed, in part, to protect lobsters while mating, extruding eggs and molting, to assist in marketing, and to reduce exploitation rates. The number of licences issued are restricted and the number of traps (300 traps per class A fishermen and 90 traps per class B fishermen) are limited. Egg bearing ('berried') females are protected and a minimum size limit of 3 3/16 in. (81 mm) CL is in effect.

Fishing methods and gear

The fishing vessels now used are generally Cape Island style boats of 10-14 m length constructed of wood or fiberglass. Some class B fishermen use skiffs or dories 4.6-6.1 m long. Hydraulic trap haulers, depth sounders, radar, and improved boat design have allowed fishermen to travel faster, further and fish more efficiently than fishermen prior to ten years ago. Practically all commercial traps are made of oak and laminated plywood or spruce. Some fishermen are experimenting with vinyl-coated wire traps. Traps from Alma are usually half-cylindrical in shape with three bows, 92-216 cm long, about 71 cm wide, and 38 cm high, each with an entrance ring (wire or wood) 15-22 cm in diameter (about 10-15% have entrances made only of knitted twine) and laths spaced about 3.3 cm apart. Lobster traps are set singly, each with a buoy. Trap ballast is made of cement or flat rocks. Bait depends on whatever is locally available at low cost, but usually consists of salted fresh or frozen herring or mackerel. The boats dock in high-water harbours and usually have 1.5 h before and after each high tide to go in and out of ports. The extreme tidal amplitude in this area allows the traps to be hauled only during slack water periods; the strong tidal currents usually submerge the buoys from sight of the fishermen. Recently caught lobsters are usually kept alive in floating wooden crates up to a week by the fishermen prior to selling the lobsters to travelling commercial dealer-buyers. About a third of the lobster catch is sold privately to tourists and local residents.

Catch and effort

The upper reaches of the Bay of Fundy constituted less than 10% of the total lobster vessel licences and lobster landings in the Bay of Fundy. The value of the catch at \$5.50 kg^{-1} was ca. \$0.24 million compared to ca.\$3.75 million for the whole of the Bay of Fundy. The area has traditionally been a low production lobster fishery compared to the rest of the Bay of Fundy (Fig. 3).

The number of licenced lobster fishermen residing in or near towns close to the proposed tidal power dams are six for Alma, two for Waterside, three for Woodpoint, four for Joggins, three for Apple River, seven for Advocate Harbour, one for Port Greville, four for Parrsboro, and four for Five Islands (Fig. 2). Three licenced lobster fishermen at Wood Point would be affected above the proposed tidal barrages in either Cobequid Bay or Cumberland Basin. As few lobsters are caught, lobster fishermen do not consider it economical to set traps beyond Economy Point into Cobequid Bay, beyond Grindstone Island into Shepody Bay and Cape Maringouin (Ward Point) into Cumberland Basin. Most of these fishermen set lobster traps in Minas Basin (and Greville Bay) and Chignicto Bay.

Size Composition

Typically there is a high proportion of large lobsters caught (60% over 100 mm CL for Alma area) in the upper reaches of the Bay of Fundy (Fig. 4, 5). In the more productive areas of the Bay of Fundy (e.g. in Lobster District 2 at Seal cove, Grand Manan) 95% of the commercial sized lobsters caught are within the 80-100 mm CL range (A. Campbell, unpubl. data, Wilder 1960).

LOBSTER BIOLOGY

Most of the following discussion on lobster biology is based on a study of lobsters in the Alma area of Chignecto Bay conducted during 1979-80. Similar phenomena concerning lobsters probably occur in the Advocate Harbour to Parrsboro area. This paper does not discuss every aspect of lobster biology; detailed reviews of lobster biology can be found in Cobb and Phillips (1980).

Seasonal Changes

During July-October of 1979-80 water temperatures at 10-20m depth were in the 13-15 C range, whereas during the winter months (January-April) temperatures were in the 0.5-4.5 C range.

TABLE 1. Lobster landings and total lobster licences in the upper and lower reaches of the Bay of Fundy during 1980. N.B. = New Brunswick and N.S. = Nova Scotia.

Bay of Fundy		Landings		Lobster vessel licences	
		kg x 1000	% of Total	Number	% of Total
Upper reaches					
Stat. District	40	8.7	1.3	10	2.0
	41	2.4	0.3	3	0.6
	42	0.0	0.0	0	0.0
	43	6.2	0.9	4	0.8
	44	6.6	1.0	11	2.2
	24	7.5	1.1	8	1.6
	79	13.0	1.9	11	2.2
	81	0.0	0.0	0	0.0
Total		44.4	6.5	47	9.4
Lower reaches					
N.B. side[1]		392.7	57.6	334	66.7
N.S. side[2]		245.0	35.9	120	23.9
Total Bay of Fundy		682.1	100.1	501	100.0

[1] Statistical Districts 48, 49, 50, 51, 52, 53.
[2] Statistical Districts 35, 37, 38, 39.

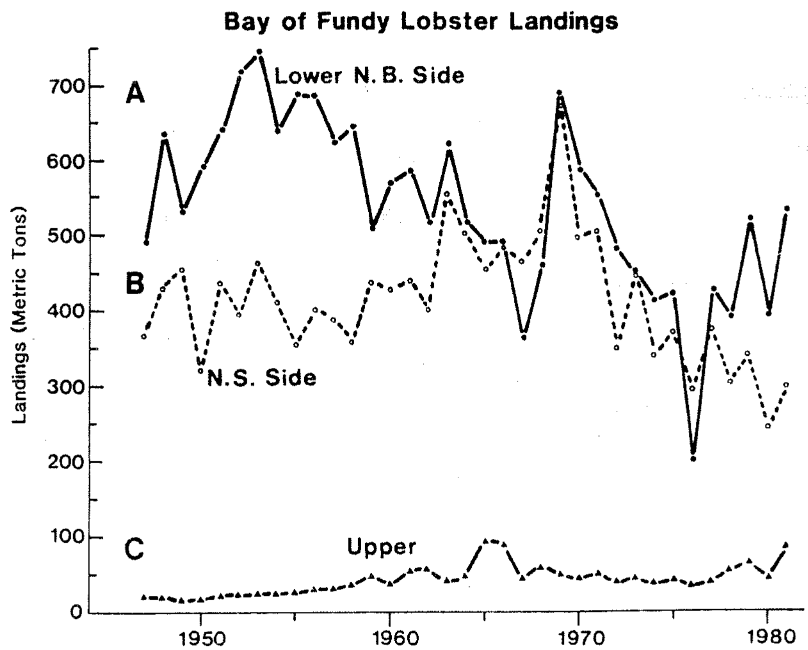


Fig. 3. Annual lobster landings for the Bay of Fundy, 1947-81. A = lower reaches, New Brunswick side (Statistical Districts 48, 49, 50, 51, 52, 53); B=lower reaches, Nova Scotia side (Statistical Districts 35, 37, 38, 39); C=upper reaches (Statistical Districts 40, 41, 43, 44, 24, 79).

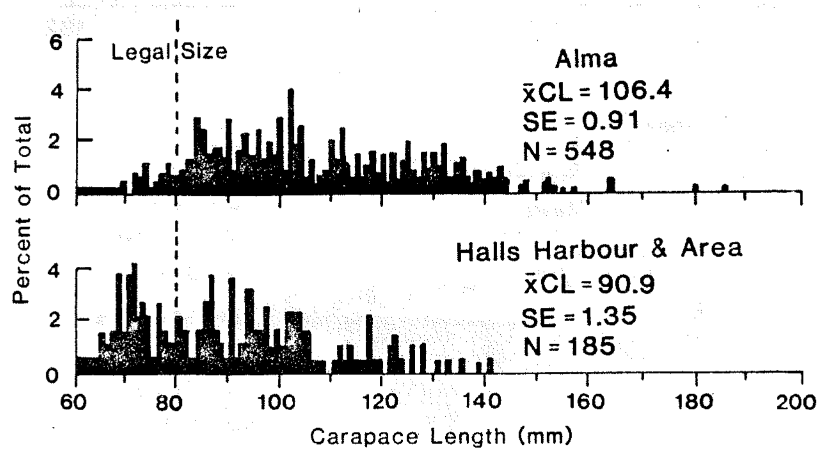


Fig. 4. Size frequency distributions expressed as percentage of total numbers of at-sea trap-caught lobsters at beginning of fishing season October 1979 for Alma area and Halls Harbour area. $\overline{X}_{CL}$ = mean carapace length: SE = standard error of mean; N = total number of lobsters measured.

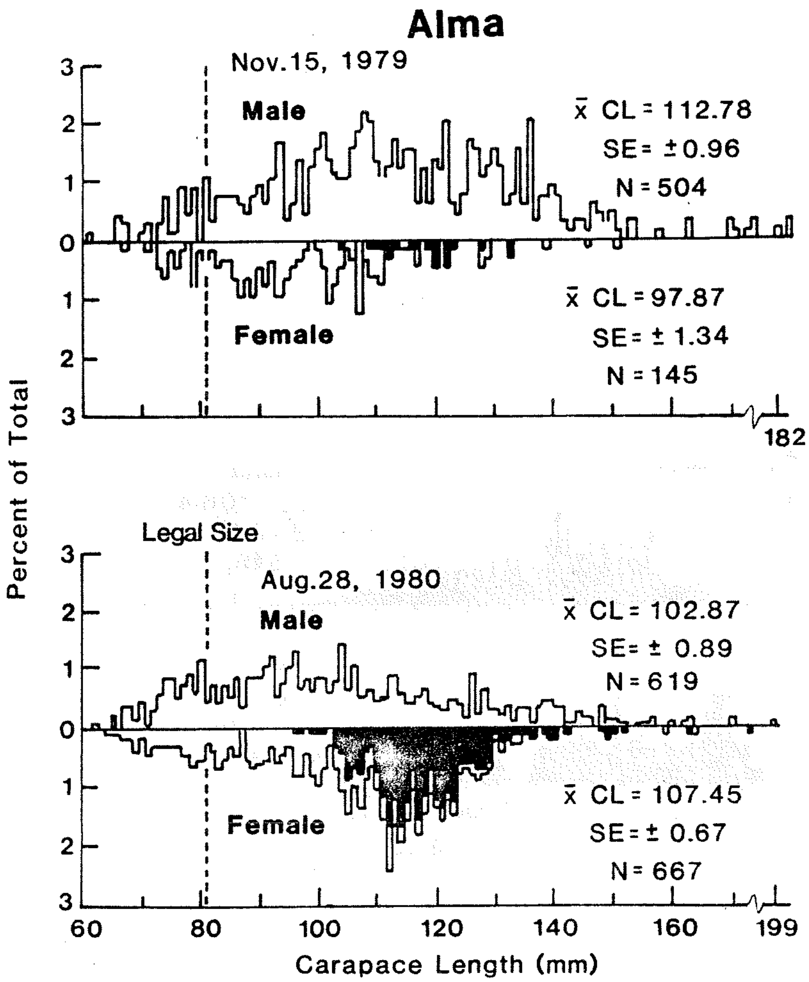


Fig. 5. Size frequency distribution expressed as percentage of total numbers of trap-caught male and female lobsters in Alma study area during November 1979 and August 1980. Black histograms are berried females. $\overline{X}_{CL}$ mean carapace length; SE = standard error of mean; N = total number of each sex of lobsters.

Sex ratio of immature lobsters (60-94 mm CL) caught in traps was generally 1:1, fluctuating between 40-60%. Physiological maturity (50%) for male and female lobsters was estimated at ca. 95 mm CL using the gonad examination technique of Aiken and Waddy (1980). When examining the incidence of mature lobsters (95 mm CL) there was a preponderance of male lobsters during the November-December and May-July fishing periods (Fig.5 , 6). In contrast, during August 1989-80, more females, especially berried females, were found in traps than males (Fig. 5,6).

The mean CL mature males fluctuated between 105 and 118 mm throughout 1979-80, whereas the mean CL of mature females showed definite trends from a low of 95 mm during winter to early summer increasing steadily to over 110 mm in August-September before declining again (Fig. 6).

Increases in male and female lobsters per trap haul during the summer months (Fig. 6) were probably caused by a number of factors, such as increased density of mature male lobsters which due to movement into the area and increased water temperature which increased the catchability of lobsters (McLeese and Wilder 1958) during the summer. Also, there was an apparent increase in berried females because of the overlap of females carrying old and new eggs (Fig. 6D). Lobster females incubate eggs on their pleopods for about 9-12 mo (Perkins 1971). During July and August pelagic larvae hatch from the eggs while different females with mature ovaries will have extruded new eggs by late August (Fig. 6D). Mature females normally undergo a 2 yr maturation cycle, i.e. a female can extrude eggs in alternate years (Aiken and Waddy 1980).

Movement

Between 75 and 80% of immature tagged lobsters were recaptured within 18.5 km of release, wheras 17.7% of mature males and 44.7% of mature females were recaptured greater than 92.6 km from the release site (Table 2). Immature male and female tagged lobsters (60-94 mm CL) moved a mean of 19.3 km and 13.5km respectively (no difference between means, $p>0.05$) (Table 2). In contrast, there were significant ($p<0.001$) differences in mean distance moved between mature and immature tagged lobsters, with mature females moving further (87.9 km) than mature males (43.2 km) (Table 2).

Tagged lobsters that moved <50 km were recaptured in the direction of St. Martins, Advocate Harbour, and up Chignecto Bay as far as Joggins (Fig. 7). No lobsters were recaptured in Cumberland Basin.

Tagged lobsters moving > 50 km were recaptured along the coastlines of Nova Scotia, New Brunswick, Maine, and as far as Cape Cod (Fig.8). The direction of travel was generally west and south for those lobsters moving long distances. The furthest distance moved was 590 km for a 131 mm CL male (at release) and 578 km for a 113 mm CL female (at release) both of which were recaptured in the Cape Cod area about 2 yr after release.

Evidence for lobsters moving long distances (>100 km) and seasonally inshore-offshore (shallow and deep waters) in the Gulf of Maine and on Georges Bank has been shown (cf. reviews by Krouse 1980, Stasko 1980).

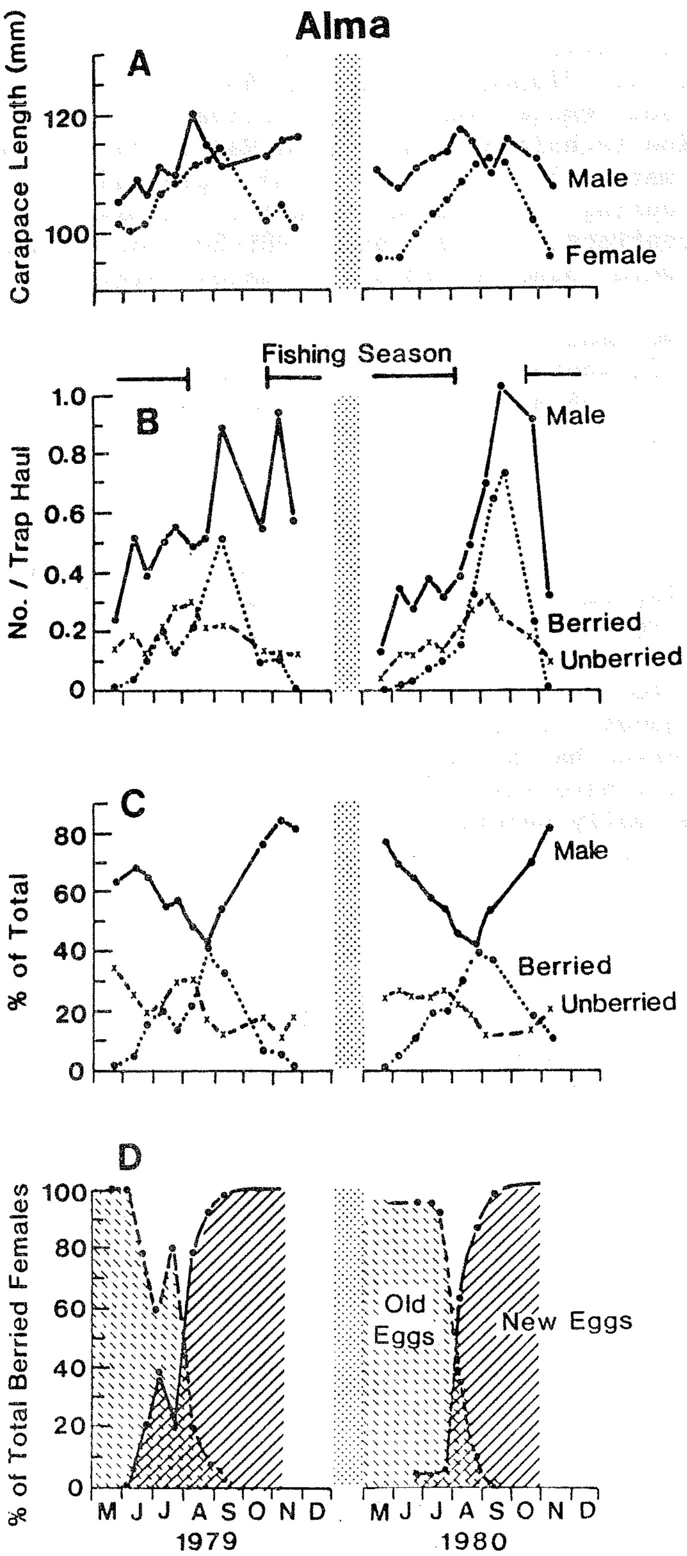


Fig. 6. Two-week means for mature (95 mm CL) lobsters (A) carapace length means, (B) number per trap haul, (C) sex ratio or percentage of total mature lobsters, (D) percentage egg stage of total berried females sampled from the Alma area, 1979-80.

TABLE 2. Summary of movements of tagged lobsters released off Alma. New Brunswick, during August-September 1979-80, including recaptures up to September 30, 1981. Lobsters grouped into physiologically immature (60-94 mm CL) and mature (>95 mm CL) at release.

Details	Percent of total lobster recaptures			
	Male		Female	
	Immature	Mature	Immature	Mature
Distance moved from (km)				
18.5	75.0	56.7	81.2	35.1
18.5-36.9	13.1	22.1	14.5	12.3
37.0-92.6	6.0	3.5	2.9	7.9
92.6	5.9	17.7	1.4	44.7
Total % Recaptured	14.6	14.6	16.9	11.0
Total Number released	577	1737	409	2078
Mean distance(km) travelled	19.3[1]	43.2	13.5[1]	87.9
Max. distance (km) travelled	168.8	590.1	171.1	577.6

[1] Means followd by the same letter in row are similar (p >0.05) other means nor followed by same letter in same row are significantly different from each other (p <0.001).

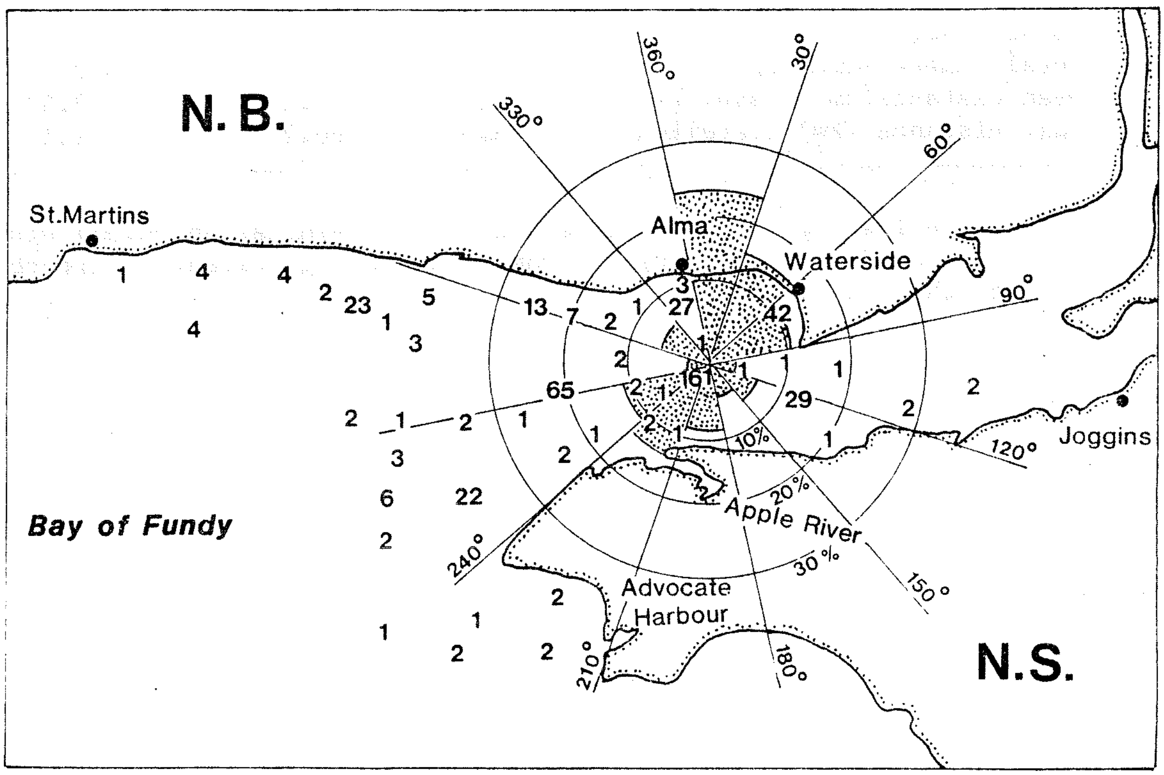


Fig. 7. Map showing number of recaptured tagged lobsters moving <50 km from release. Circles and shading indicate direction moved in 30 degree units (of true north) expressed as percentages of total recaptures.

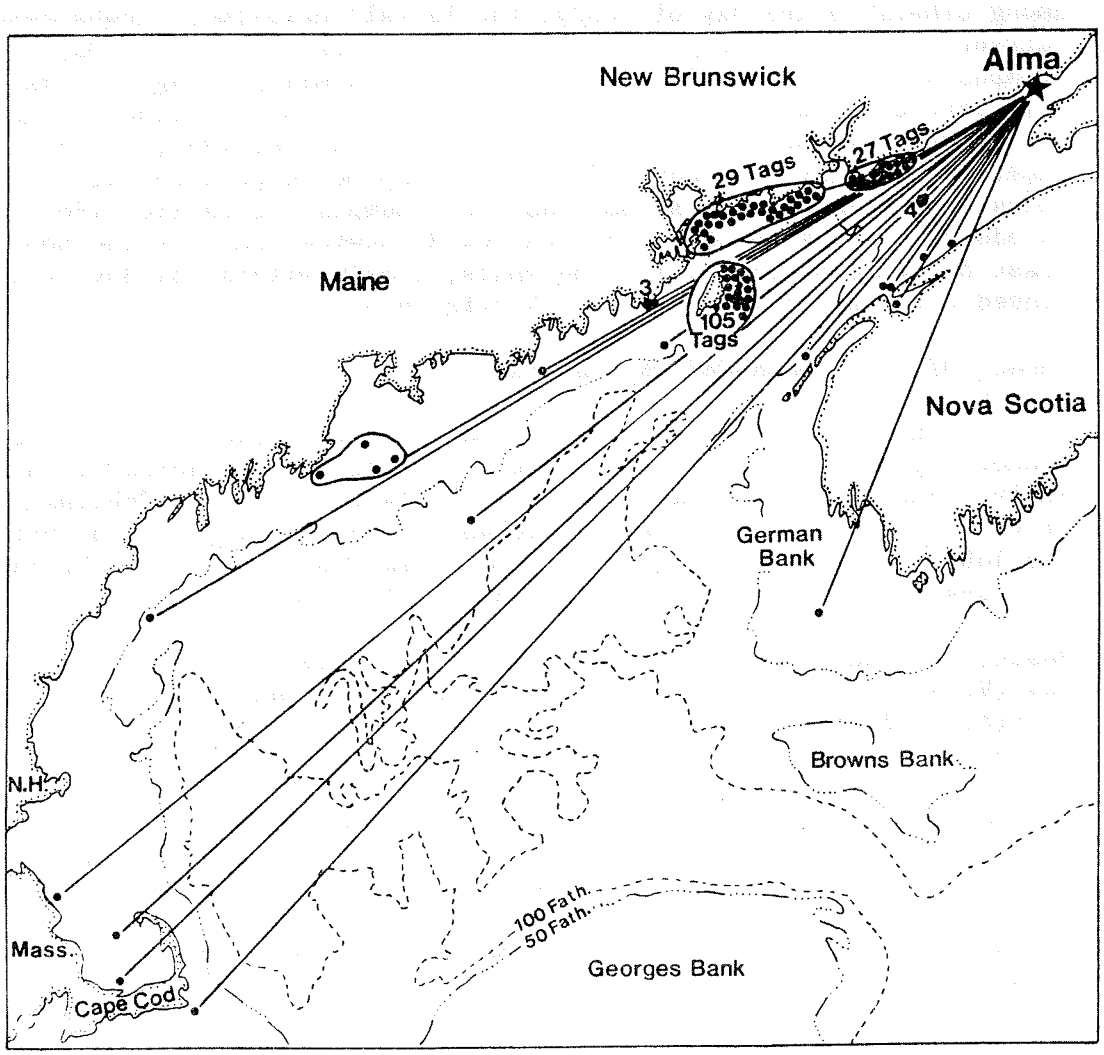


Fig. 8. Map of release and recapture points with straight-line distances travelled for all tagged lobsters recaptured >50 km from the Alma study area, 1979-81.

Additional evidence of tagged lobsters moving up the Bay of Fundy is shown from a similar tagging study conducted at Chance Harbour and St. Martins during 1979-80 (Fig. 9) (A. Campbell, unpubl. data).

Mature lobsters in the Bay of Fundy probably move from deep waters (<60 m) to shallow water during summer months to take advantage of the warm shallow water (up to 15 C) for molting and reproduction. Indeed the Alma area seems to be an important area amongst other shallow waters in the Bay of Fundy (A. Campbell, unpubl data) for large, mature females to come to during the summer months to hatch well developed eggs, molt (Wilder 1953), mate, and extrude new eggs. Thus Chignecto Bay may be an important area, among others in the Bay of Fundy, for larval recruitment downstream. Water currents on the New Brunswick side tend to flush out of the Bay of Fundy (Bumpus and Lauzier 1965). Where the free-swimming pelagic larvae eventually settle as benthic juveniles is a matter of speculation at present as few larvae have been found in plankton tows (Wilder 1960, Stasko, pers. comm.) in the Bay of Fundy. The larvae may be swept with the surface currents along the Gulf of Maine coastline (Bumpus and Lauzier 1965) or caught in eddies in bays on the Maine and New Brunswick coast or the southern coast of Grand Manan or, in some years, remain within the Bay of Fundy in a closed circulating water system (Dickie 1955).

IMPACT OF TIDAL BARRAGES ON LOBSTERS

From results of this paper the following deductions can be made concerning tidal barrages and lobsters in the upper reaches of the Bay of Fundy. The proposed tidal barrages, if placed in either Cobequid Bay (B9) or Cumberland Basin (A8), would probably have an insignificant effect on the lobster fishery in the local area. Few lobsters are caught in these two bays; only three lobster fishermen (only recently licenced) are stationed at Wood Point above the proposed barrage location in Cumberland Basin, and there are no lobster fishermen stationed in towns in Cobequid Bay (V. Nuttall, pers. comm.). There were no fishermen in Statistical Districts 42 and 81 during 1980 (Table 1, Fig. 1). The majority of lobsters caught in Statistical District 43 are from the Minas Basin to Advocate Harbour with the four licenced fishermen from Five Islands fishing well outside Cobequid Bay. Details of lobster landings by towns with these lobster districts are not available. The probable reason for the low number of lobsters is the low salinity and the extreme siltation and muddy substrate in Cobequid Bay and Cumberland Basin (Daborn 1977) which the lobsters may avoid (Cobb 1968, Cooper and Uzmann 1980, Pottle and Elner 1982). Ice scouring during winter in these areas (Gordon and Desplanque 1983) may also be a factor causing severe lobster mortality reducing lobster densities. Whether the tidal barrage would affect water temperatures, siltation, and salinity sufficiently below the barrage in the open Bay of Fundy to affect lobsters is at present unknown.

Although the upper reaches of the Bay of Fundy are lower lobster productivity areas compared to the rest of the Bay of Fundy, the Chignecto Bay area, as are other areas in the Bay of Fundy, may be important biologically as a source of larval recruitment for other areas downstream.

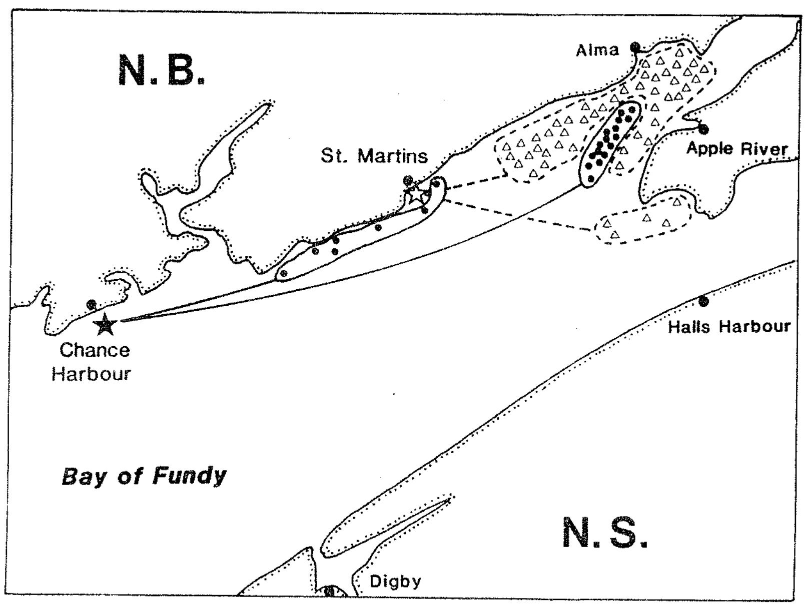


Fig. 9. Map of release and recapture points with straight-line distances travelled for tagged lobsters moving up the Bay of Fundy from Chance Harbour and St. Martins, 1979-81 (after A. Campbell, unpubl. data).

A tidal barrage would probably not have a major effect on the local lobster fisheries in the upper reaches of the Bay of Fundy. One can only speculate on the effect of a tidal barrage on lobsters further downstream on a large scale. Analysis of lobster landing trends and lobster movements indicate that there is probably one lobster stock in the Bay of Fundy including the Gulf of Maine (Campbell and Mohn 1982). If water temperatures and velocities or tidal amplitudes do change as a result of a tidal barrage, as suggested by Greenberg (1984), then lobster populations could be affected. Changes in current velocity or patterns may change larval recruitment patterns which are at present poorly known. Water temperature change would affect lobster development at all stages (Aiken 1980), catchability (McLeese and Wilder 1958), and landings (Dow 1978, Flowers and Saila 1972). The degree to which the tidal barrage induced perturbations would have over seasonal and long term temperature trends affecting lobsters is unknown.

ACKNOWLEDGMENTS

I thank Dr. R. Collins, D.R. Duggan, D.E. Graham, S.L. Hamet, H.J. MacNichol, D.J. Meisner, and A.M. Williamson for technical assistance; D. D. Fraser, V. Nutall, R. Stewart, and L. Tidd for fisheries statistics; F. Cunningham for illustrations; B. Fawks for typing the manuscript; and M.J. Dadswell, P.A. Koeller, and J.D. Pringle for reviewing earlier drafts of this report.

REFERENCES

Aiken D.E. 1980. Molting and growth. In: J.S. Cobb and B.F. Phillips, eds, Biology and management of lobsters, Vol 1. Academic Press, N.Y., pp. 91-163.

Aiken, D.E. and S.L. Waddy. 1980. Reproductive biology of lobsters. In: J.S. Cobb and B.F. Phillips, eds, Biology and Management of Lobsters, Vol 1. Academic Press N.Y., pp. 215-276.

Bumpus, D.F. and L.M. Lauzier. 1965. Surface circulation on the continental shelf off eastern North America between Newfoundland and Florida. Ser. Atlas Mar. Environ. Amer. Soc. Folio 7.

Campbell, A. 1979. Invertebrates and marine plants commercial landings in the Passamaquoddy Region and Bay of Fundy, 1973-78. In: D.J. Scarratt, ed., Evaluation of recent data relative to potential oil spills in the Passamaquoddy area. Fish. Mar. Serv. Tech. Rep. No. 901, pp. 19-26.

Campbell, A. and R.K. Mohn. 1982. The quest for lobster stock boundaries in the Canadian Maritimes. Northwest Atlantic Fisheries Organization (NAFO) Res. Doc. 82/IX/107, N615, p 45.

Cobb, J.S. 1968. Delay of moult by the larvae of Homarus americanus. J. Fish. Res. Board. Can. 25: 2251-2253.

Cobb, J.S. and B.F. Phillips, eds. 1980. Biology and management of lobsters, Vol I and II. Academic Press, N.Y.

Cooper, R.A., and J.R. Uzmann. 1980. Ecology of juvenile and adult Homarus. In: J.S. Cobb and B.F. Phillips, eds., Biology and management of lobsters, Vol II. Academic Press, N.Y., pp. 97-142.

Daborn, G.R., ed. 1977. Fundy tidal power and the environment. Acadia University Inst. Publ. No. 28, 304 p.

Dickie, L.M. 1955. Fluctuations in abundance of the giant scallop, Placopecten magellanicus (Gemlin), in the Digby area of the Bay of Fundy. J. Fish Res. Board Can. 12: 797-865.

Dow, R.L. 1978. Effects of sea surface temperature cycles on landings of American, European, and Norway lobsters. J. Cons. int. Explor. Mer 37: 186-190.

Flowers, J.M. , and S.B. Saila. 1972. An analysis of temperature effects on inshore lobster fishery. J. Fish. Res. Board Can. 29: 1221-1225.

Gordon, D.C. Jr. and C. Desplanque 1983. Dynamics and environmental effects of ice in the Cumberland Basin of the Bay of Fundy, Can. J. Fish. Aquat. Sci. 40: 1331-1342.

Greenberg, D.A. 1984. The effects of tidal power development on the physical oceanography of the Bay of Fundy and Gulf of Maine. In this report.

Kim, J.O. and F.J. Kohout 1975. Analysis of variance and covariance: subprograms ANOVA and ONEWAY In: N.H. Nie, C.H. Hull, J.G. Jenkins, K. Steinbrenner, and D.H. Bert, eds. Statistical package for the social sciences, 2nd edition, McGraw Hill, N.Y., pp.398-433.

Krouse, J.S. 1980. Summary of lobster, Homarus americanus, tagging studies in American water (1898-1978), In: V.C. Anthony and J.F. Caddy, eds. Proceedings of the Canada-U.S. Workshop on status of assessment science for N.W. Atlantic lobsters (Homarus americanus) stocks, St. Andrews, N.B., Oct 24-26 1978. Can. Tech. Rept. Fish. Aquat. Sci. No. 932, pp. 135-140.

McLeese, D.W. and D.G. Wilder. 1958. The activity and catchability of the lobster (Homarus americanus) in relation to temperature. J. Fish. Res. Board Can. 15: 1345-1354.

Perkins, H.C. 1971. Egg loss during incubation from offshore northern lobsters (Decapoda Homaridae). Fish. Bull. 69: 451-453.

Pottle, R.A. and R.W. Elner. 1982. Sustrate preference behavior of juvenile American lobsters, Homarus americanus, in gravel and silt-clay sediments. Can. J. Fish. Aquat. Sci. 39: 928-932.

Scarratt, D.J. 1977. Biological resources of the Bay of Fundy-Gulf of Maine system. In: G.R. Daborn ed. Fundy tidal power and the environment, Acadia Univ. Inst. Publ. No. 28, pp. 131-147.

Scarratt, D.J. and P.F. Elson. 1965. Preliminary trials of a tag for salmon and lobsters. J. Fish. Res. Board Can. 22: 421-423.

Stasko, A.B. 1980. Tagging and lobster movements in Canada In: V.C. Anthony and J.F. Caddy, eds. Proceedings of the Canada U.S. Workshop on status of assessment science for N.W. Atlantic lobster (Homarus americanus) stocks. St. Andrews, N.B., Oct, 24-26, 1978. Can. Tech. Rept. Fish. Aquat, Sci. No. 932: pp. 141-151.

Wilder, D.G. 1953. The growth rate of the American lobster (Homarus americanus) J. Fish. Res. Board Can. 10: 371-412.

Wilder, D.G. 1960. Possible effects of Passamaquoddy tidal power structures on the Canadian lobster industry. J. Fish. Res. Board Can. 17: 553-563.

Wilder, D.G., P.F. Elson, D.E. Gaskin, A.C. Kohler, W.T. Stobo, and S.N. Tibbo. 1974. Section 3 Renewable Marine Resources. In: Summary of physical, biological, socio-economic and other factors relevant to potential oil spills in the Passamaquoddy region of the Bay of Fundy. Fish. Res. Board Can. Tech. Rept. No. 428, pp. 103-138.

QUESTIONS AND COMMENTS

K. Mann: Looking at the slide with respects to temperature and onshore-offshore movements I wonder how the Halifax lobster fishermen catch anything at all if the lobsters move to deeper water during their winter lobster season or does this not apply to other areas?

A. Campbell: Lobster movements along the eastern shore of Nova Scotia are poorly studied. Work by Wilder in this region during the 1960's showed no large scale movements. However it depends on where you are. To reach deep water in the Alma area of the Bay of Fundy a lobster would have to move a large distance but along the east coast of Nova Scotia only a few km of movement would allow the lobster to change the environment.

K. Mann: What about downstream effects of the tidal barrages. Since there is good evidence the Canso Causeway caused recruitment failure do you think a tidal dam at the head of the Bay of Fundy could cause a similar effect.

A. Campbell: I do not think the situation is analogous. The eastern Nova Scotia system is quite different. In terms of Cumberland Basin not that many lobsters seem to go in there or into Cobequid Bay. The majority of the large lobsters only need to go into shallow water in the Alma area to obtain warm temperatures for development of their eggs or to moult. There do not seem to be any similar problems with the tidal barrages unless they change the environment or the ecology in areas outside of them.

The Softshell Clam (Mya arenaria) Resource along the North Shore of the Minas Basin and Potential Impacts of the Proposed Tidal Power Project on its Long-term Productivity

Nancy Witherspoon[1]

Estuarine and Inland Fisheries Division
Nova Scotia Department of Fisheries
P.O. Box 2223
Halifax, N.S. B3J 3C4

ABSTRACT

A soft-shell clam survey was conducted along the north shore of the Minas Basin during the summer of 1982. Areas, densities, frequency distribution of all size classes and abundances of market size clams ($\geq$ 42 mm) were calculated. Shell samples were collected for aging purposes. Information on the past history and present status of the fishery was gathered. Of the estimated 446 ha available for commercial clam digging, 142 were surveyed. Densities of pre-recruits (36-41 mm) were high, with relatively small numbers of 0-16 mm and $\geq$ 49 mm size classes. Growth rates and asymptotic length were low compared to other areas in the Maritimes and along the Atlantic seaboard. Occurrences of stunting were common. Abundances of commercial size clams were considered moderate and exploitation rates were not extremely high. At the time of the survey, an estimated 67,114 bushels of market size clams, worth 1.3 million dollars, were available for harvest. Seventeen percent of this resource was to the east of Economy Point. Impacts of the proposed tidal power barrage on the clam population are considered in light of the potential effects on: the availability of the resource to the fishery, quality and quantity of food supply, establishment of juveniles, mortalities of adults and potential increase in contamination. The value of the resource to the province and locally, as well as its fragility, are documented. Wise management for long term viability is recommended.

Key words: environmental ecology, fishery, invertebrates, Minas Basin, shellfish, shoft-shell clam, tidal power.

RÉSUMÉ

Un inventaire des myes a été mené le long de la côte nord du bassin des Mines au cours de l'été 1982. On a slors calculé les superficies, les densités, la répartition des fréquences de toutes les classes de tailles ainsi que l'abondance des myes assez grosses pour la mise en marché ($\geq$ 42 mm). Des échantillons de coquilles ont été prélevés pour fins de déter-

---

[1] Present address: Department of Biology, Dalhousie University, Halifax, N.S. B3H 4J1

mination d'âge. Des renseignements one été réunis concernant les antécédents et l'état actuel de la pêche. Des 1 446 ha qui se prêtent à la cueillette des myes commerciales, 142 ont fait l'objet de relevés. La densité des pré-recrues de 36-41 mm était élevée, le nombre de myes étant relativement petit dans les classes de taille 0-16 mm et ≥ 49 mm. Les vitesses de croissance et les longueurs asymptotiques étaient faibles comparativement aux autres secteurs des Maritimes et du littoral atlantique. Les cas de croissance interrompue étaient fréquents. L'abondance des myes de taille commerciale a été considérée comme modérée, les taux d'exploitation n'étaient d'ailleurs pas tellement élevés. Au moment de l'inventaire, les quantités prêtes à récolter étaient estimées à 67 114 boisseaux de myes de taille suffisante pour les marchés, d'une valeur de 1,3 million de dollars. De cette quantité, 17% se trouvait à l'est de la pointe Economy. Les répercussions du barrage marémoteur envisagé, sur la population de myes, sont considérées en fonction des effets potentiels sur: l'accessibilité aux ressources pour les pêcheurs, la qualité et la quantité des réserves alimentaires, l'établissement des juvéniles, la mortalité des adultes et l'accroissement potentiel de la contamination. La valeur de cette ressource pour la province et la région immédiate, de même que sa vulnérabilité, font l'objet de commentaires et de données. L'auteur recommande finalement d'adopter des principes de saine gestion, celle-ci pouvant assurer la viabilité lointaine.

INTRODUCTION

The Nova Scotia Tidal Power Corporation has chosen Economy Point to Cape Tenny at the mouth of Cobequid Bay (B9) as the most preferred site for construction of a tidal power barrage (Fig.1). In response to concerns for long term viability of the commercial clam fishery along the north shore of the Minas Basin, the Nova Scotia Department of Fisheries conducted a survey of the resource during the summer of 1982. This paper presents a summary of the results and the possible environmental impacts of the proposed barrage on the commercial clam resource in the area.

METHODS

Transect line-quadrat survey techniques, similar to those used by the author in the summer of 1981 (Witherspoon 1982), were incorporated. Quadrats were 0.09 m^2 and 20 cm deep. Transect lines were 30 m apart parallel to, and 50 m apart perpendicular to, the shore. Clams were sorted from the samples by hand.

Areas, densities (bushels ha^{-1}), and size frequency distributions of juvenile (≥ 35 mm), prerecruit (36-41 mm), and market (≥ 42 mm) size clams were calculated for those areas surveyed. Methods were identical to those employed in the 1981 survey (Witherspoon 1982). Areas of commercial clam flats not surveyed were estimated by pacing. Representative densities were applied to these flats so that total standing stocks (bushels) for the whole resource could be computed.

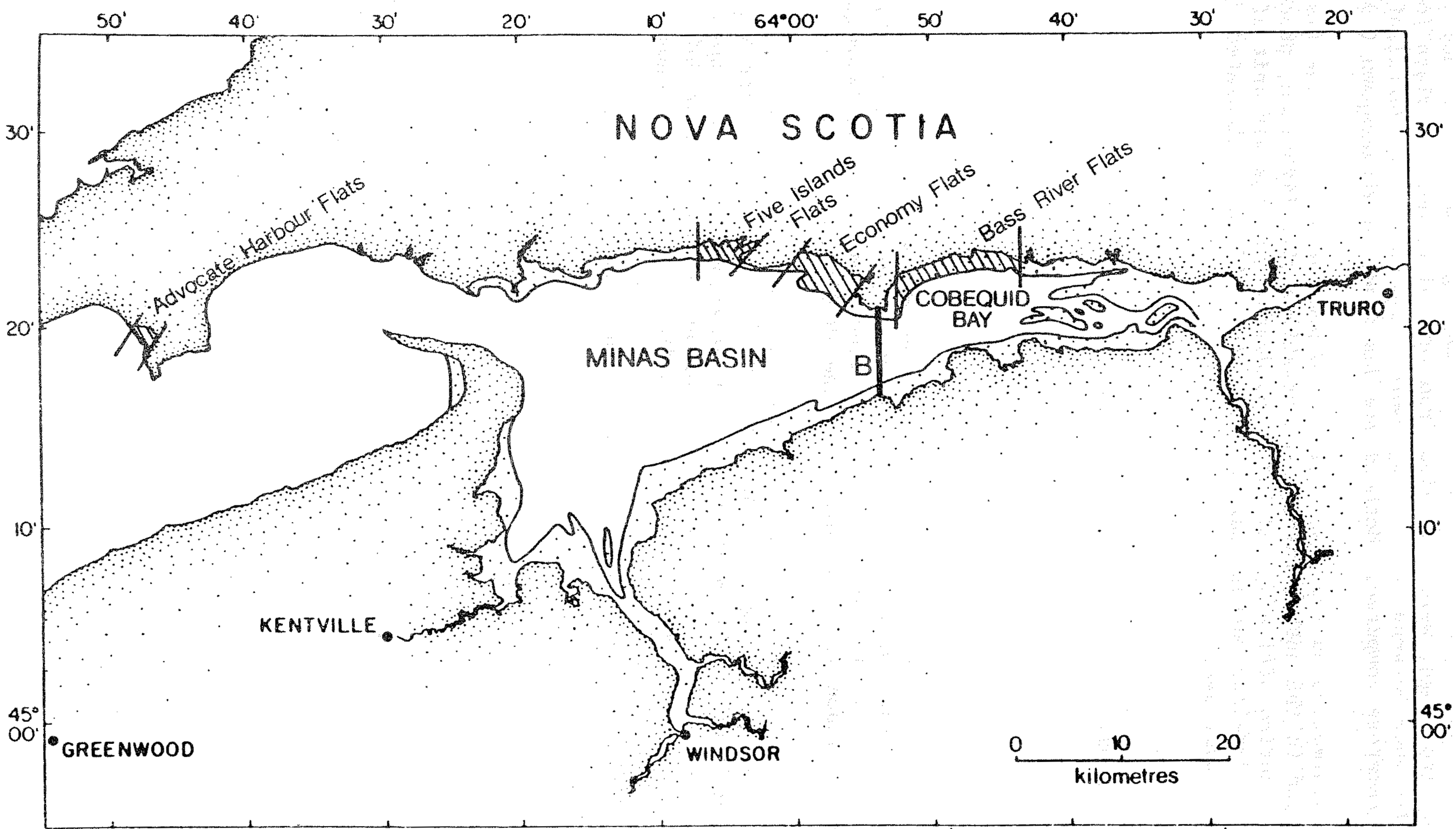


Fig. 1. Location of soft-shell clam flats on the north shore of the Minas Basin (modified from: Geomorphology and sedimentology of the Bay of Fundy, Trip 23 of the Geological Association of Canada and the Mineralogical Association of Canada, May 1980, C.L. Amos et al.). The proposed position of the tidal barrage is denoted by the letter "B".

Fourteen samples of clams, each numbering from 100-200 individuals of a wide size range, were collected from several commercial flats for aging. Distance between annual rings were measured and Von Bertalanffy growth parameters computed. Methods are described in Witherspoon (1982).

Information on the past history and present status of the fishery were related to the author through conversations with fishermen, processor-buyers, fisheries officers, and local residents. Catches per unit effort (numbers of 2-gallon buckets dug per hour) for 1982 were calculated from fishermen interviews.

Literature reviews and discussions were carried out which related to impacts of similar perturbances on commercial clam fisheries in other areas of the Maritimes.

RESULTS

The Industry

The Minas Basin clam fishery began in the early 1940's. In 1946, according to Fisheries and Oceans statistics, a peak of 916 MT of clams was harvested (Fig.2). As the bulk of virgin stocks was removed, landings declined and remained at lower levels for the 1950's and 1960's.

Greater demand and higher prices resulted in a proportional increase in clams being dug throughout the 1970's. Relative to the Nova Scotia clam fishery, the landings from the Minas Basin have increased since the beginning of the 1970's (Fig. 3). They now represent about 30% of the entire Nova Scotian resource. In 1982, landings of 680 MT of clams worth 0.5 million dollars were recorded for District 43 up to the end of November. This is the highest landing figure since 1946 (Fig. 2.).

In 1981, the clam fishery topped in dollar value such higher profile fisheries as squid, gaspereau, and salmon for the Province of Nova Scotia. Locally, 67% of the total value of all fish species reported for the same year was soft-shell clams. One hundred and ten full time licenced fishermen plus numerous part timers and students were digging in 1982. There were three processors in the area who employed 27 people to shuck and ship clams live to New Brunswick and U.S. markets. The industry is largely unmechanized and therefore requires low capital investment. Fishermen use hacks, buckets, and wheeled gigs to dig and haul in their catch.

The Survey

One hundred and forty-two hectares were surveyed (Table 1), approximately one-third of the total commercial clam flats (Table 2). Standing stocks of market size clams ($\geq$ 42 mm) were estimated to be 67,114 bushels (1,812 MT) having a market value of 1.3 million dollars in 1982. To date only 38% of this potential resource is harvested.

Seventeen percent of the estimated standing stocks was located in

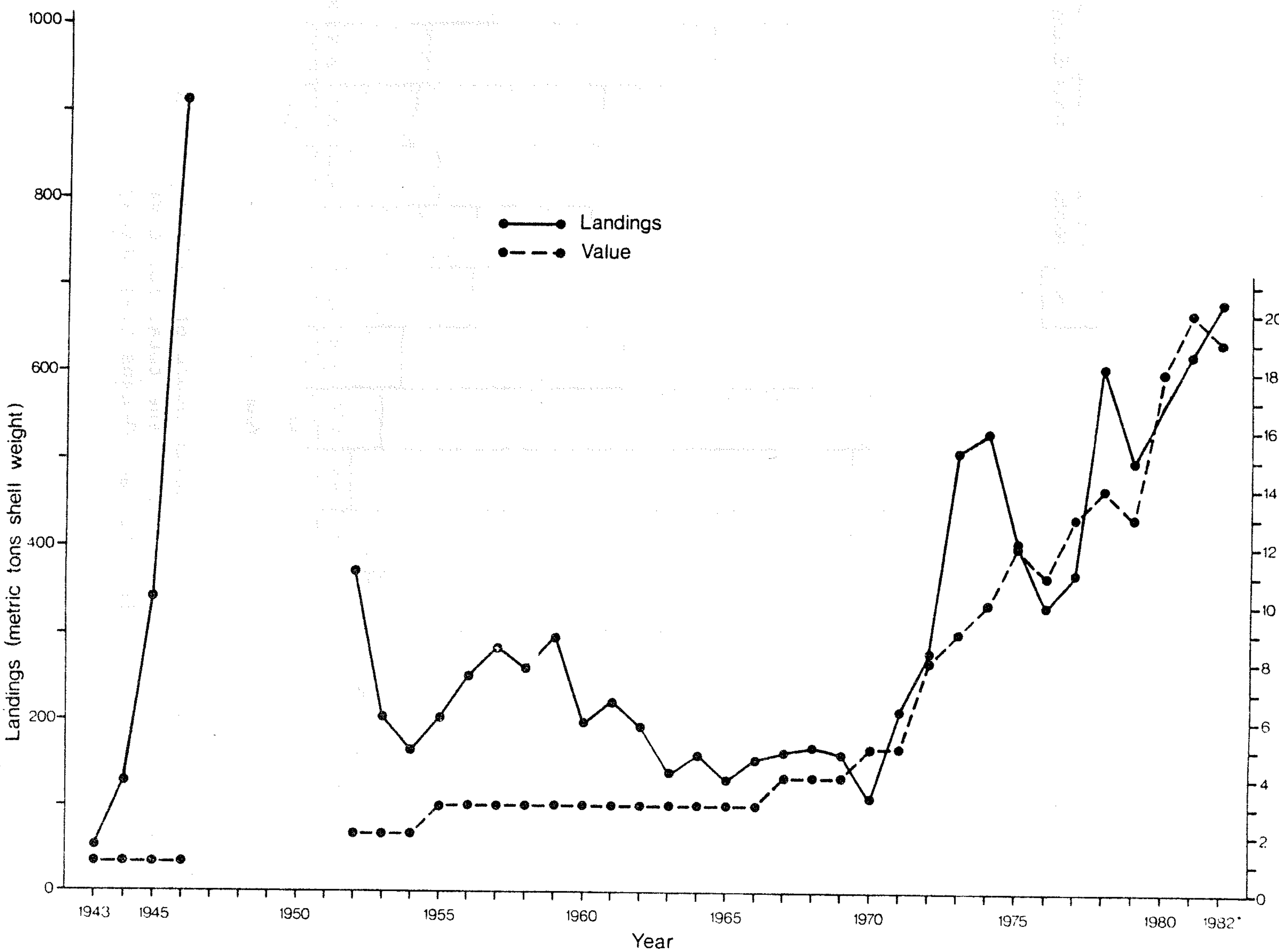


Fig. 2. Landings and bushel values of the soft-shell clam from 1943 -1982 for the north shore of the Minas Basin (from Fisheries and Oceans Statistics).

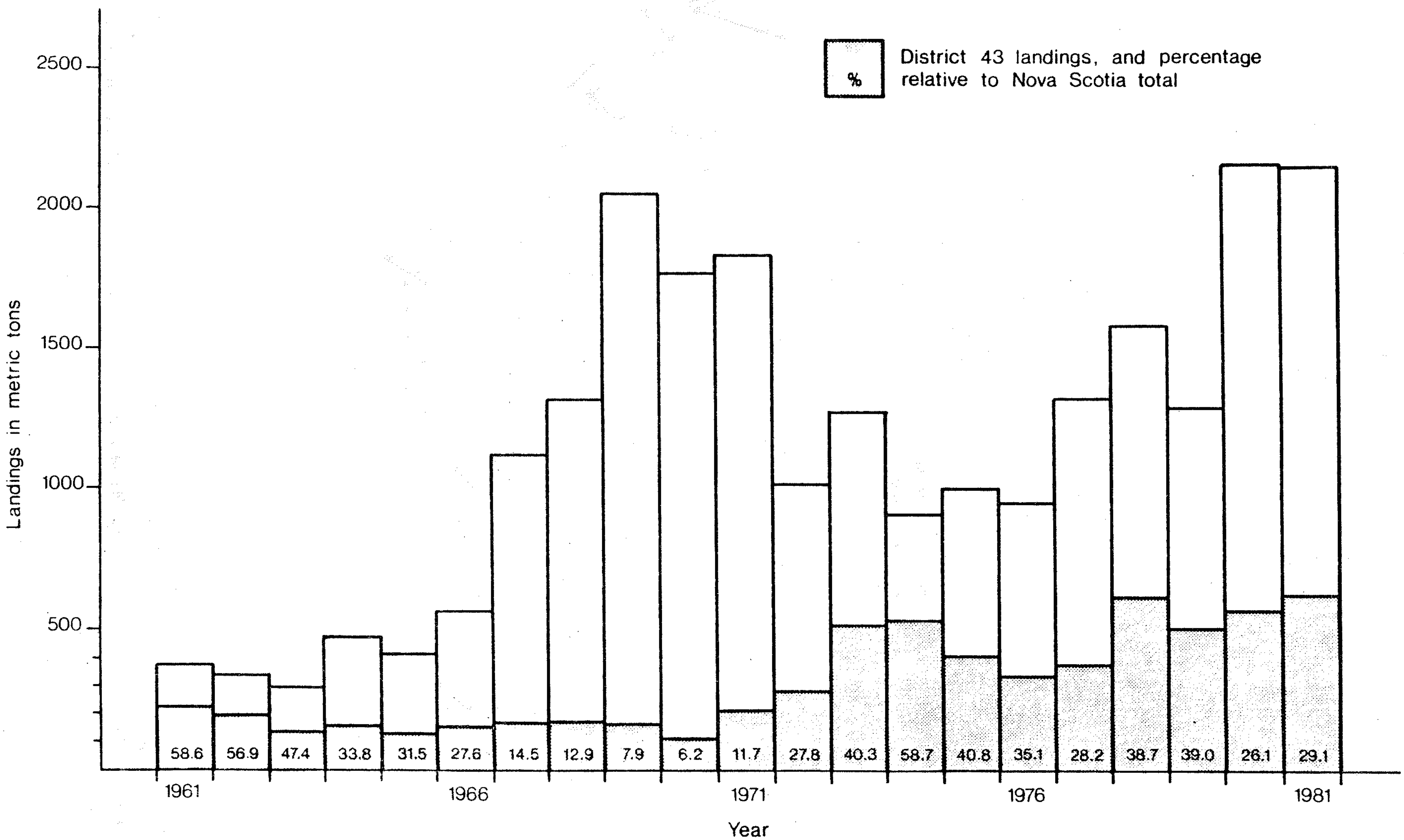


Fig. 3. Landings of soft-shell clams on the north shore of the Minas Basin (District 43) and percentage relative to the total for Nova Scotia, 1961 to 1981 (from Fisheries and Oceans Statistics).

TABLE 1. Areas surveyed, number of areas, number of stations, and number of clams measured for the three locations along the north shore of the Minas Basin.

Location	Area (ha)	Number of areas	Number of stations	Number of clams
Bass River Flats	80	5	598	4,871
Economy Flats	47	5	315	2,067
Five Islands Flats	15	1	120	2,727
Total	142	11	1033	9,665

TABLE 2. Estimated total acreage and potential bushel production (≥42 mm) of soft-shell clams of both surveyed and non-surveyed areas along the north shore of the Minas Basin, Bay of Fundy, 1982. The area of clam flats at Advocate Harbour was estimated by pacing.

Location	Area (ha)	Percentage (%) of location surveyed	Bushels
East of Economy Pt.			
Bass River Flats	85	94	11,571.6
West of Economy Pt.			
Economy Flats	130	36	18,345.3
Five Islands Flats	138	11	17,575.9
Advocate Harbour	93	0	19,621.1
Total	361	17	55,542.3
Overall Total	446	32	67,113.9

Cobequid Bay (east of Economy Point). Approximately one quarter of the 1982 harvest was taken on this side of the point. Presently, the largest and most productive flat of the 17 commercial flats utilized by the fishery is found in Cobequid Bay.

Abundances of market size clams (Table 3) are considered moderate in relation to other commercially fished areas in the Maritimes (Robert 1981; Witherspoon 1982). The prerecruit size class (36-41 mm) had the highest numbers of clams, with 44% of the population concentrated between 36 and 48 mm (Fig. 4). There were relatively low densities in size classes 0-16 mm and $\geq$ 49mm.

The great range in values of the von Bertalanffy growth parameters, k and L_∞, are illustrated in Fig. 5. Length at infinity (L_∞) varied from a minimum 56 mm to a maximum of 99 mm. Half of the aging samples had L_∞ less that 70 mm, indicating stunting of clams. Usually, stunted clams grow little past 45-50 mm in length. Growth rates (k) were slow compared to other areas in the Maritimes (Robert 1979; Robert 1981; Witherspoon 1982) and along the Atlantic seaboard (Brousseau 1979). This was likely a function of the short growing season from May to September (Newcombe 1935), substrate type, food availability, and crowding (Witherspoon, in preparation).

Reproduction in the soft-shell clam is size rather than age dependent, and usually commences around 40 mm (Brousseau, 1978). This length is reached somewhere between the ages of 5 and 8 years on the north shore of the Minas Basin.

DISCUSSION

Status of the Fishery

The fishery appears to be relatively healthy at present, based on the densities and proportions of clams in the prerecruit and market size classes. However, abundances (from catch per unit effort data) are lower now than they were in the past, and numbers of diggers higher (Witherspoon, in preparation). Market demand and subsequently harvest of steamer clams (40-50 mm) has increased in the last three years and is likely to continue. Overfishing of clams in this size range can be detrimental to the future viability of this industry. Slow growth rates and stunting cause clams to accumulate between 40 and 50 mm. If a large proportion of these animals is removed, it may take seven years before clams would again be available for digging. Successful production of juveniles would likely be affected if the numbers of breeding adults (above 40 mm) were decreased significantly. Juvenile densities, presently low, are known to be highly variable from one year to the next (Brousseau 1978; Witherspoon 1982). Yeo (1978) postulates that winter storms and ice cover can cause sudden changes in distribution of sediments, thereby removing or smothering young clams which are positioned close to the sediment surface.

TABLE 3. Estimated bushels ha^{-1} of prerecruits and markets surveyed for individual locations and all locations combined on the north shore of the Minas Basin.

Group	Bass River Flats (bu ha^{-1})	Economy Flats (bu ha^{-1})	Five Island Flats (bu ha^{-1})	All locations (bu ha^{-1})
Prerecruits 36-48 mm	27	20	9	23
Markets $\geq$49 mm	10	19	7	12
Prerecruits 36-41 mm	15	9	4	12
Markets $\geq$42 mm	22	30	12	23

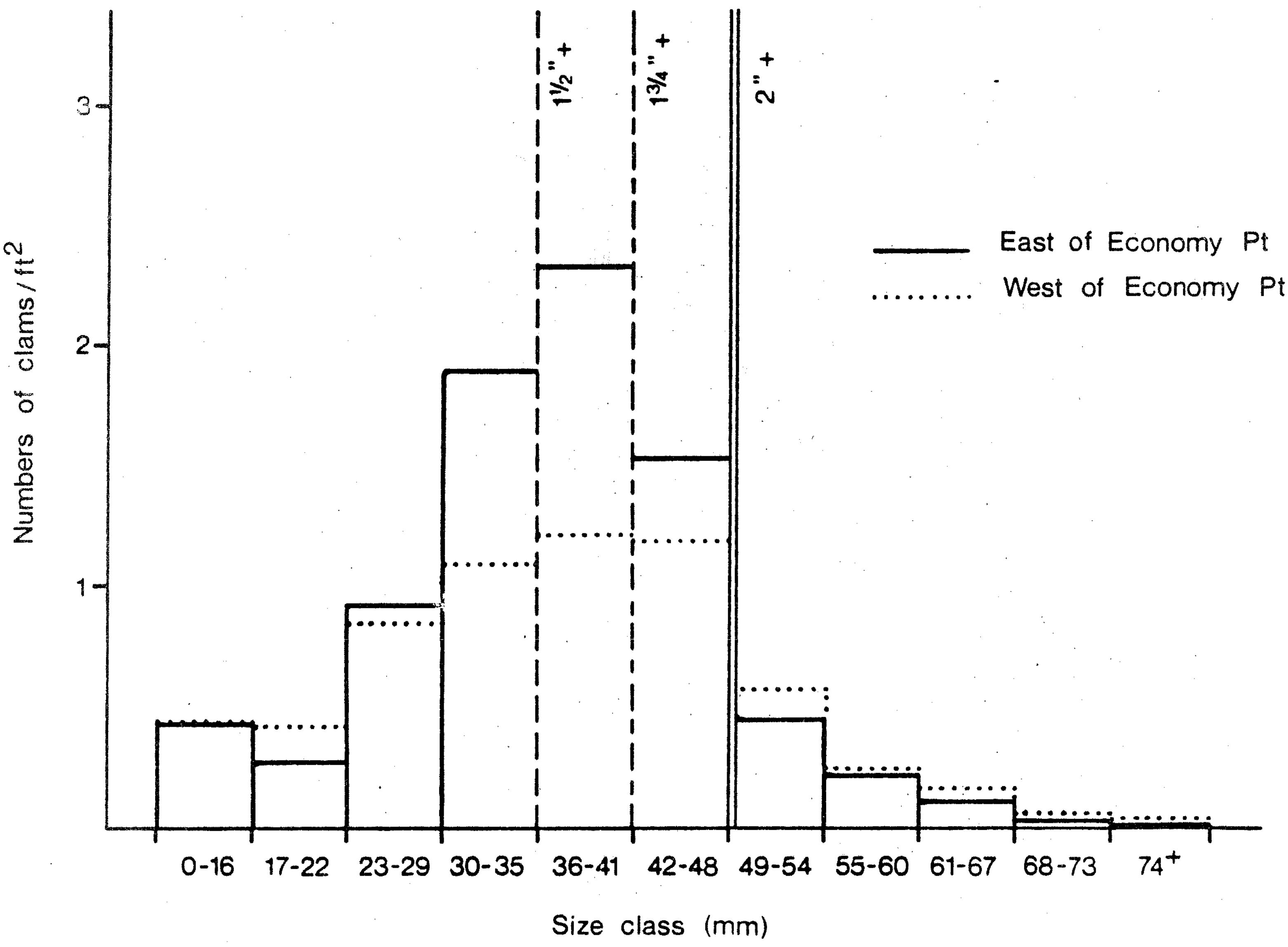


Fig. 4. Size frequency distribution of the surveyed soft-chell clam population along the north shore of the Minas Basis, 1982.

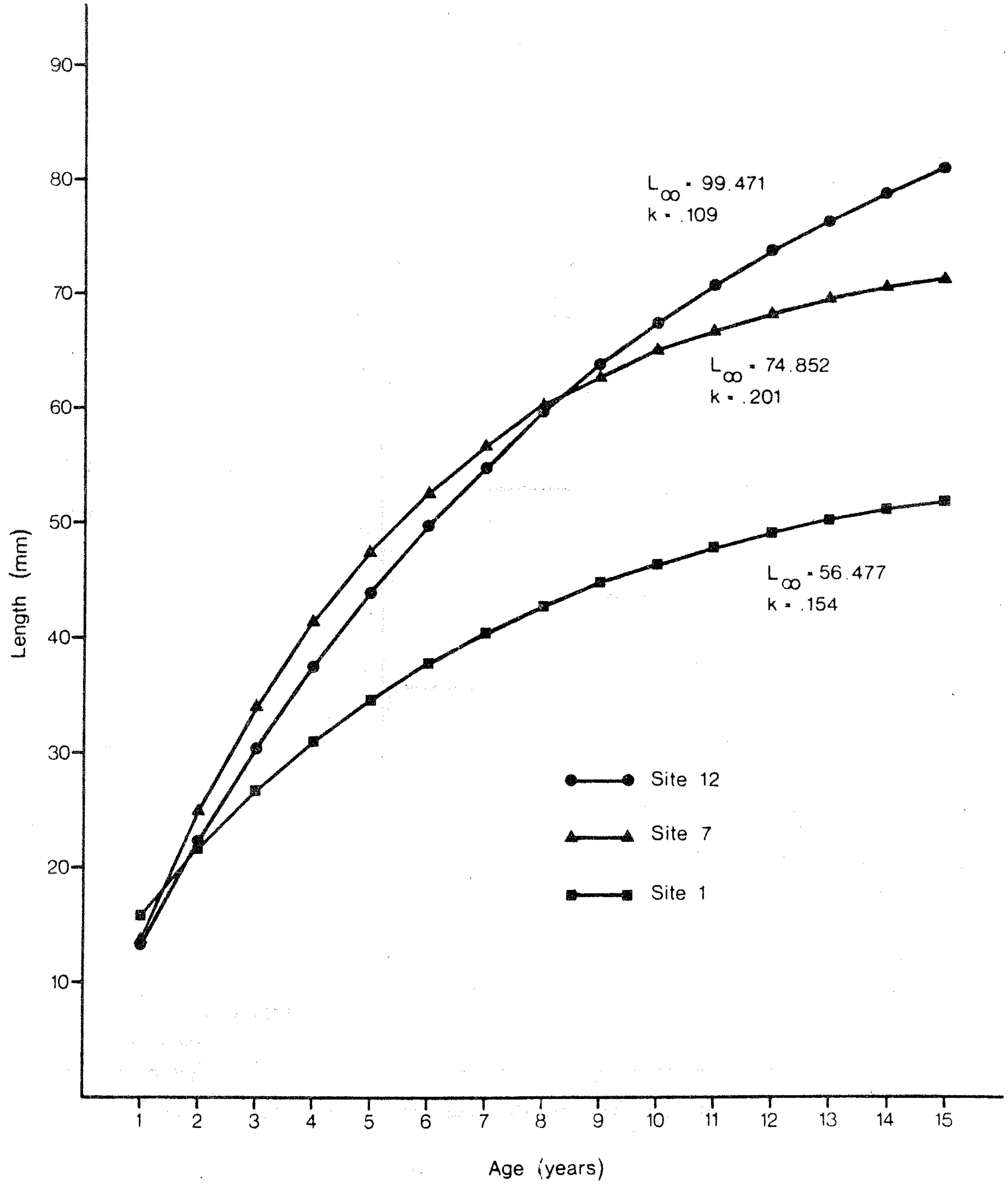


Fig. 5. Length-at-age curves for slow (Site 12), medium stunted (Site 1), and fast (Site 7) growing soft-shell clams on the north shore of the Minas Basin, 1982.

Without establishment of a size limit, the long term success of the fishery cannot be assured, particularly if harvesting effort continues to increase and larger proportions of steamer clams are taken.

Impacts of Tidal Power

Imposed on the present situation is the concern for the impact of the proposed tidal barrage on the resource. The operational mode chosen will have different effects on the clam population. Since it is most likely that single effect ebb generation will be employed, only the potential consequences of this mode of operation on the resource will be considered.

Cobequid Bay (17% of market size standing stocks)

Commercially dug clams are concentrated from the middle to the upper part of the intertidal zone. With barrage construction, there is a projected 65% reduction in the size of the intertidal zone for a mean tide (Baker 1984). Clams in the lower to middle part of the original intertidal zone will be permanently flooded, and will no longer be available to the commercial fishery. Some clams found in the upper most part of the intertidal zone will not be covered by the tide and therefore will die. Their contribution to the breeding population will be lost.

Under normal project operation, Amos (1984) considers there will be intermittent deposition of sediments and subsequent erosion. Should deposits persist longer than 10 h because of altered project function, consolidation will occur. Accumulations greater than 6 cm of fine to mediumgrain sediments can result in high mortalities of clams, due to loss of ability to burrow upwards (Turk and Risk 1981). Fine grain substrates are also known to cause deaths through clogging of filter feeding processes (Newcombe 1935). As well, the fluid-like nature of silty bottoms makes them unsuitable for juvenile establishment (Yeo 1978).

Specific examples of decreased productivity and size of clam flats, as a result of barriers and/or increased sedimentation rates, have been reported in the literature. A survey at Eel River Cove, New Brunswick, in 1978 (Robert 1979) revealed that only 1 ha of commercial flats remained of the 16 ha present prior to construction of a dam. This change was attributed to lowered juvenile survival and conversion of clam flats to salt marsh, both a result of increased siltation. A similar occurence has been reported by Scott (1980) and Witherspoon (1982) in Chezzetcook Harbour along the Eastern Shore of Nova Scotia. Nearby Cole Harbor had a thriving clam fishery in the early 1950's. Excavation of sand and gravel around 1952, for construction of the Angus L. MacDonald bridge in Halifax, brought about a partial blockage at the entrance to Cole Harbour. Subsequent reduction in flushing rates caused the flats to be flooded and deposition of sediment to occur. Local residents reported the flats were "white with dead shells" (Eaton, personal communication). There were attempts to bulldoze a new entrance to the harbour. However, the clam fishery has never recovered, and there is only recreational digging today.

Incidents of clam mortalities caused by accumulation of fine grain sediments have been reported by Medcof (1953) at Sissiboo River (1951-52) and Yeo (1978) at Walton in the Minas Basin (1975-76).

The preferred food type of the soft-shell clam in the Bay of Fundy is benthic diatoms (Newcombe 1935). These grow at low tide in the intertidal zone of the Minas Basin (Yeo 1978 and Hargrave et. al. 1983). Lowered diatom production is hypothesized, with reduction in the extent of the intertidal zone (Gordon 1984). Increased clarity of the waters in Cobequid Bay should cause greater phytoplankton productivity (Hargrave 1984). It is difficult to speculate whether this food type can replace lost diatom biomass in quality and quantity. There may be additional indirect effects on primary productivity. Greater fog and cloud cover would reduce light intensity. Less prolific saltmarsh and endemic bacterial populations could bring about lowered nutrient availability. Both light and nutrients limit algal growth (Hargrave et al. 1983).

More abundant and persistant ice cover will likely bring about increased erosion of the projected smaller intertidal zone where the clam population will be concentrated. Juveniles burrowed near the surface and adults found in shallow substrates will be more susceptible to erosion than more deeply burrowed clams.

Faecal bacteria concentrations may increase due to diminished tidal currents in Cobequid Bay. In 1982, high concentrations of these organisms brought about the closure of some clam flats during the months of July and August.

Reid (1980) has suggested that, if environmental conditions were favorable, paralytic shellfish poisoning, presently a problem at the entrance to the Bay of Fundy could spread into Cobequid Bay.

Flooding, mortalities, and contamination problems will remove clams from the commercial fishery. Altered tidal cycle timing and changes in sediment type and distribution may further reduce the economic viability of the industry in Cobequid Bay. Slow growth rates coupled with potentially lower reproductive success could lessen the ability of clam stocks to maintain densities and total abundances of clams comparable to pre-barrage conditions.

Seaward of Cobequid Bay (83% of market size standing stocks)

Greater tidal amplitudes predicted seaward of the barrage will increase the size of the present intertidal zone. There may be some expansion of clam populations both higher and lower in this zone, which could in turn cause some improvement in overall productivity. However, this improvement may be offset by less favorable conditions for establishment of juveniles. Greater tidal velocities and increased erosion-deposition caused by higher tides will discourage larval settlement and survival.

If loss of the Cobequid Bay resource is substantial, the remainder of clam stocks on the seaward side of the barrage will likely be subject to heavier fishing pressure. This, in combination with lack of management and the present economic conditions, puts the future survival of the industry in question.

SUMMARY

The soft-shell clam industry on the north shore of the Minas Basin comprises a substantial portion of the total Nova Scotia clam fishery and contributes significantly to the local economy. Although covering extensive areas of intertidal flats, it is a species highly susceptible to natural, fishing and man-induced environmental mortalities, and therefore to dramatic population changes. The long term prospertity of this valuable and fragile resource is dependent on our commitment to the wise management and protection of the soft-shell clam industry in the Minas Basin.

ACKNOWLEDGMENTS

I would like to thank Valerie Billard, Clayton Eagles, Jim Graham, Michelle Higgins, and Shauna Prest for their help in the field. Numerous clam diggers, processors and federal fisheries officers provided much information about the industry. Mayilyn Connor drew the figures and edited the manuscript. The Nova Scotia Department of Fisheries funded the project. Typing was completed by Nina Pepper.

REFERENCES

Amos, C.L. 1984. The sedimentation effect of tidal power development in the Minas Basin, Bay of Fundy. In this report.

Baker, G.C. 1984. Engineering description and physical impacts of the most probable tidal power project(s) under consideration for the upper reaches of the Bay of Fundy. In this report.

Brousseau, D.J. 1978. Spawning cycle, fecundity and recruitment in a population of Mya arenaria (soft-shell clam) from Cape Ann, Massachusetts. Fish. Bull. U.S. 76: 155-166.

Brousseau, D.J. 1979. Analysis of growth rate in Mya arenaria using the von Bertalanffy equation. Mar. Biol. 51: 221-227.

Gordon, D.C.Jr. 1984. Predictions of the impacts of tidal power development in intertidal primary production in the headpond region. In this report.

Hargrave, B.T. 1984. Barrage effects on phytoplankton production and chemosynthesis in Cumberland Basin. In this report.

Hargrave, B.T., N.J. Prouse, G.A. Phillips and P.H. Neame. 1983. Primary production and respiration in pelagic and benthic communities at two intertidal sites in the upper Bay of Fundy. Can. J. Fish. Aquat. Sci. 40(Suppl 1): 229-243.

Medcof, J.C. 1953. Soft shell clam investigations. In: Annual Rept. Biol. Sta. St. Andrews. New Brunswick.

Newcombe, C.L. 1935. Growth of *Mya arenaria* L. in the Bay of Fundy Region. Can. J. Res. 13D: 97-137.

Reid, C.R. 1980. Toxic dinoflagellates and tidal power generation in the Bay of Fundy, Canada. Mar. Poll. Bull. 11: 47-51.

Robert, G. 1979. Fourth survey of Eel River Cove, N.B., soft-shell clam *Mya arenaria* population. Fish. Mar. Serv. MS Rept. No. 1941, 41 pp.

Robert, G. 1981. Stock assessement of soft shell clams in open shellfish growing areas of Prince Edward Island. Can. MS Rept., Fish. Aquat. Sci. No. 1606, 47 p.

Scott, D.B. 1980. Morphological changes in an estuary; a historical and stratigraphical comparison. In: McCann, S.B., ed., The coastline of Canada. Geological Survey of Canada, Paper 80-10, pp. 199-205.

Turk, T.R. and M.J. Risk. 1981. Effect of sedimentation on infaunal invertebrate populations of Cobequid Bay, Bay of Fundy. Can. J. Fish. Aquat. Sci. 38: 642-648.

Witherspoon, N.B. 1982. Population surveys of the soft-shell clam *Mya arenaria* in selected estuaries on the Eastern Shore of Nova Scotia, 1981. N.S. Dept. Fish., Man. & Tech. Rept. Ser. 82-03, 48 p.

Yeo, R.K. 1978. Animal - sediment interaction and the ecology of the intertidal mudflat environment, Minas Basin, Bay of Fundy, Nova Scotia. M.Sc. thesis, McMaster University, 396 p.

QUESTIONS AND COMMENTS

M. Dadswell: Do you have data on subtidal occurrence of soft-shell clams in Minas Basin?

N. Witherspoon: Very few occur below low tide. Densities at the low tide limit drop off completely to almost none.

M. Dadswell: What causes this?

N. Witherspoon: I think it is controlled by the tolerances of *Mya* and the high dynamics of the lower intertidal there. In some places *Mya* occurs below low tide but it is generally inside protected estuaries along eastern Nova Scotia and in the Gulf of St. Lawrence.

M. Dadswell: If a barrage was built do you think there could be acommercially viable subtidal population of Mya like in Chesapeake Bay?

N. Witherspoon: Perhaps, but extremely unlikely. Subtidal conditions there are very different from what it would be like behind a barrage in Cobequid Bay.

D. Wildish: Are there presently in Minas Basin any populations that are affected by PSP? It seems the problem is not bad there.

N. Witherspoon: The closest the PSP problem comes to Minas Basin is in clams along the Digby shore. But the PSP problem has moved up the Atlantic coast during the last 100 years. A change in the hydrographic regime could create proper conditions for it to develop.

Unknown: What is the health of the Mya fishery in Minas Basin like at present?

N. Witherspoon: Relatively healthy at this time.

Unknown: Your slides showed a lack of younger year classes and you implied recruitment has been poor of late?

N. Witherspoon: Perhaps I should have said variable recruitment. Depending on the year, particular environmental conditions and where spot settlement occurs recruitment can be variable from one year to the next. Work on the eastern shore of Nova Scotia has demonstrated there are quite obvious fluctuations in year class strengths of clams.

Unknown: Because of the variable growth rates of soft-shell clams don't you think loss of year classes in Minas Basin will be compensated for?

N. Witherspoon: Possibly, but I do think recruitment is a real problem in the Minas Basin area.

Unknown: When are soft shell clams in Minas Basin mature?

N. Witherspoon: Growth rates are variable and that effects maturity. Maturity usually occurs between 6 and 9 years of age.

D. Scarratt: Do you have any idea how much of the soft shell clam resource would be lost if the B9 barrage was built?

N. Witherspoon: It would be possible to calculate but I have not done it. Our data were gathered on a height related basis and we could look at what would be lost due to flooding and calculate the loss to the fishery. I feel we would lose a substantial part of the resource on the Truro side of the B9 barrage anyway. An estimate could be made but any final answer will depend on the type of power generating system used and the amount of sedimentation.

Unknown: You say substantial loses, how large?

N. Witherspoon: I can't really say. I think serious. The Bass River flat has been fished heavily for the last 2 or 3 years and it has been a big producer for that area. I think the local fishermen would really feel the loss of that flat.

Unknown: Are there any factors you can see which lead to the variable growth rates of clams in Minas Basin? What causes the stunting?

N. Witherspoon: It seems the clams that grow the largest are located at the mouths of estuaries. I do not know whether this is a food or sediment related phenomena. I think sediment type plays a large role because most of the stunted clams were found in heavy gravel sediments. Clams that continue to increase in size were in sandy, softer substrates, also these were in less dense concentrations. I am sure density also controls growth rates.

R. Ruliffson: What effect will the barrage have on clam flats on the ocean side of the barrage and do you see these effects reaching as far as the New England coast?

N. Witherspoon: I have thought quite a bit about what may happen on the ocean side of the barrage. The only thing I can really see is the possibility of a greater erosional effect. In terms of the New England coast I would not really want to make any predictions.

Unknown: Can clams adjust to sedimentation or are they always smothered?

N. Witherspoon: Risk and his co-workers found that the effects of sedimentation depend largely on the sediment type in which the clam is living. First of all as clams become older their ability to burrow is reduced because the volume of the body in relation to the foot increases. Secondly it was found in coarser sediments there was a certain amount of ability to burrow upwards and adjust to the rate of sedimentation but in finer sediments the upward burrowing ability seems to decline due to the increased water content of this type of sediment. Also sedimentation itself can cause a decline in the animals' ability to filter food and lead to debilatation.

A. Campbell: When was the large storm that people mentioned earlier? Did it have any observable effects on the clams? What effects the clams most do you think, long term or point events.

N. Witherspoon: I believe the Ground Hog Day storm was in 1976. I have no real data on that storm but clam fishermen reported numerous times how heavy storms would wipe out complete clam beds. They also relate how in certain years clams would be in certain areas and not others, and then vice versa, and how sediment type on the flat would change between years and even between seasons. The entire sediment situation in Minas Basin is very dynamic and always changing. Clams appear to be opportunists in a sense. If they are successful in being on the right sediment when they settle then that is where they stay. They are wholly dependent on where they drift and what the sediment is like. So their life cycle is very risky.

Unknown: Clams are a highly saleable item. In your experience what proportion of the catch is not reported? Do the landing statistics report the whole story?

N. Witherspoon: It is difficult to tell. The local fishery officers say about 10% of the clams are sold without reporting. I think it is probably higher. Also the recreational fishery does not have to report its landings and we have had reports of up to 100 recreational fishermen on a clam flat in one day.

Potential Impacts of Tidal Power Developments on Bird Populations in the Bay of Fundy

Peter C. Smith

Biology Department
Acadia University
Wolfville, N.S. B0P 1X0

and

Peter W. Hicklin

Canadian Wildlife Service
P.O. Box 1590
Sackville, N.B. E0A 3C0

ABSTRACT

Migratory waterfowl, shorebirds, seabirds, and wintering bald eagles constitute the bird populations most likely to be affected by tidal power developments in the Bay of Fundy. The loss of salt marshes following changes in tidal range on either side of a tidal barrage may result in movements of waterfowl away from traditional feeding areas to other sites. Sandpipers (Scolopacidae) and plovers (Charadriidae) may be more severely affected in a number of ways. Those birds which would normally feed in the proposed headpond area (Cobequid Bay) would be displaced to other sites owing to the loss of the lower half of the existing intertidal zone which would remain permanently subtidal following barrage construction. Displaced birds would most likely be forced into the Southern Bight of Minas Basin where much larger numbers already forage during the autumn migration. The resulting increase in densities there may reduce the birds' ingestion and fat deposition rates as a result of increased competition. Furthermore, increased siltation in Minas Basin if a barrage were constructed might reduce prey abundance in the Southern Bight thus reducing birds' ability to deposit sufficient energy reserves for continuous migration to South America.

Shearwaters (Procellariidae), phalaropes (sub-family Phalaropodinae) and gulls and terns (Laridae) in Passamaquoddy Bay and off Brier Island near the mouth of the Bay of Fundy depend on tidal upwellings to concentrate prey near the water surface. Reductions in the velocity of tidal currents may affect these upwellings and thus the birds' ability to obtain food. Wintering bald eagles in the Shubenacadie River may suffer losses or displacement if construction of a tidal power barrage results in the river being frozen during January and February, thus eliminating access to the winter run of tomcod, *Microgadus tomcid,* the major winter food of eagles along the river.

Key words: waterfowl, shorebirds, seabirds, bald eagles, Minas Basin, Cobequid Bay, Shubenacadie River.

RÉSUMÉ

Les oiseaux aquatiques migrateurs, oiseaux du littoral, oiseaux marins et populations hivernantes de l'aigle à tête blanche Haliaeetus leucocephalus sont les populations d'oiseaux que touchera probablement le plus la mise en place d'une usine marémotrice dans la baie de Fundy. La disparition des marais salants résultant des modifications de l'amplitude des marées de part et d'autre de la digue de l'usine marémotrice, pourrait chasser les oiseaux aquatiques de leurs aires traditionnelles d'alimentation. Les bécasseaux (Scolopacidae) et les pluviers (Charadriidae) pourraient être plus sérieusement touchés, et de plusieurs façons. Ces oiseaux, qui normalement trouvent leur nourriture dans la partie amont de l'endiguement proposé (baie Cobequid), rechercheraient d'autres sites, en raison de la perte de la moitié inférieure de la zone intertidale actuelle, qui deviendrait définitivement subtidale après la construction du barrage. Les oiseaux ainsi chassés devront sans doute s'installer dans la baie sud du bassin des Mines, déjà fréquentée par des populations beaucoup plus nombreuses pendant la migration d'automne. L'augmentation résultante de la densité de peuplement pourrait réduire la quantité de nourriture ingérée par ces oiseaux, et provoquer une diminution de leur poids (une moindre accumulation de graisses), étant donné qu'ils devront en plus grand nombre aller en quête de nourriture. De plus, si l'on construit un barrage, l'envasement accru du bassin des Mines risque, dans la baie sud, de réduire l'abondance des proies que peuvent capturer ces oiseaux, donc d'empêcher ceux-ci d'accumuler suffisamment de réserves énergétiques pour effectuer leur migration continue vers l'Amérique du Sud.

Les puffins (Procellariidae), les phalaropes (sous-famille Phalaropodinae), ainsi que les goélands et sternes (Laridae) qui vivent dans la baie Passamaquoddy et au large de l'île Brier, près de l'embouchure de la baie de Fundy, trouvent au moment de la remontée des eaux froides avec le flux (upwellings) une grande concentration de nourriture, près de la surface de l'eau. La réduction de la vitesse des courants de marée pourrait diminuer l'"upwelling", et par conséquent la capacité des oiseaux à trouver leur nourriture.

Les populations de l'aigle à tête blanche hivernant dans le secteur de la rivière Shubenacadie risquent de diminuer ou d'être chassées, si la construction d'une centrale provoque l'englacement du cours d'eau en janvier et février, et par suite empêcher l'arrivée printanière de la petite morue Microgadus tomcod, qui est le principal aliment de l'aigle pendant l'hiver.

INTRODUCTION

In search for independence from fossil fuels governments in recent years have turned a favourable eye towards tidal power developments as a potential source of power generation. Especially in the past decade, serious attention has been given to the possibility of such developments in the Bay of Fundy (Fig. 1; Daborn, 1977), the Severn estuary and other areas in Britain (see Prater 1981 for summaries of various engineering schemes proposed in the U.K.).

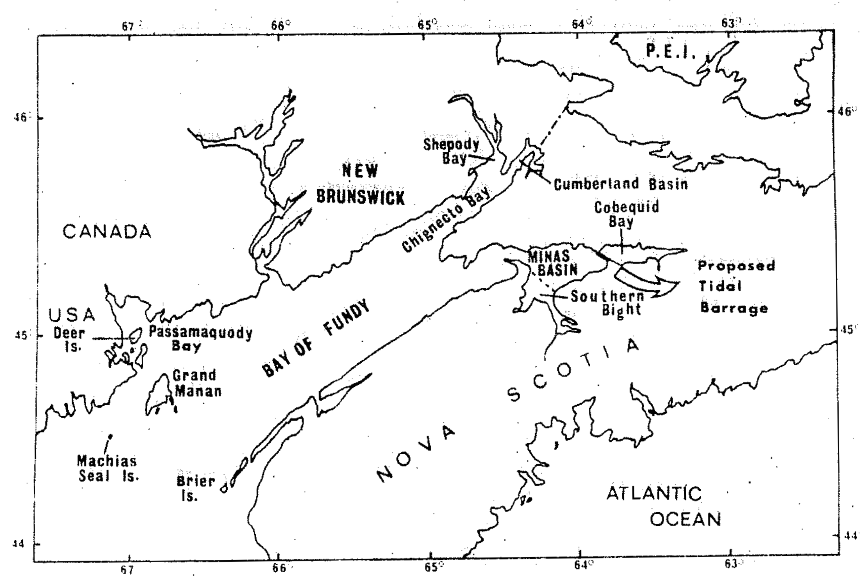


Fig. 1 The Bay of Fundy and location of proposed tidal barrage.

Birds make up part of the conspicuous fauna of coastal bays and estuaries. These include waterfowl (Anseriformes), gulls and shorebirds (Charadriiformes), alcids (Charadriiformes) and other seabirds (Procellariiformes). In order to judge the impacts of man-made developments on the populations, detailed studies are required to understand the relationships between various avian species and their habitats within marine and estuarine environments. Information is needed on 1) population levels of breeding, migrating and wintering species, 2) temporal and spatial distribution of each species, 3) food supply and the ecological requirements of major prey species, 4) feeding characteristics of birds and their inter- and intraspecific relationships, 5) effects of environmental variables and 6) mortality factors affecting populations. In Britain, many such studies have been undertaken independently of tidal power developments over a period of years and more recently as an integral part of environmental studies to measure the possible impacts of development on the estuarine avifauna (see Prater 1978, 1981). At the first workshop on the potential environmental implications of tidal developments in the Bay of Fundy in 1976 (Daborn 1977) the participants quickly became aware of the paucity of information on the ecology and dynamics of the Fundy system. This was especially true for the ornithologists who were keenly aware of the scarcity of information on avian populations in the Bay of Fundy and on the species' ecological requirements (Hughson 1977). Since 1976, research efforts have concentrated on studies of the feeding ecology of migrant shorebirds and seabirds. Much of the information gathered is as yet unpublished and many of the required studies either have not been undertaken or are not yet completed. Hence, to provide some basis for impact assessment we have to rely in large part on the findings of long-term studies in the U.K. and Europe.

In this paper, we examine the possible impacts of tidal power developments on birds, but emphasis is given to species which occur in the upper Bay of Fundy. There, shorebirds, numerically most important, are the focal group, but seabirds, colonial breeding birds, waterfowl and bald eagles are also considered.

SHOREBIRDS

Fundy is an internationally important staging area for migratory shorebirds where individuals of 22 species occur during late summer and fall. There, the birds deposit fat for migratory flight to Central and South American wintering grounds. For those species which concentrate their foraging activities on intertidal mudflats, the food utilized for the formation of fat consists largely of polychaetes and the burrowing amphipod *Corophium volutator* (Hicklin and Smith 1979). From mid-July to October sandpipers and plovers, which altogether probably number several millions, feed on marshes and mudflats when these are exposed and gather along open beaches to roost during high tides. By far the most numerous species is the semipalmated sandpiper, *Calidris pusilla*, which forms large flocks in Chignecto Bay and Minas Basin/Cobequid Bay in the latter part of July and early August (Fig. 2).

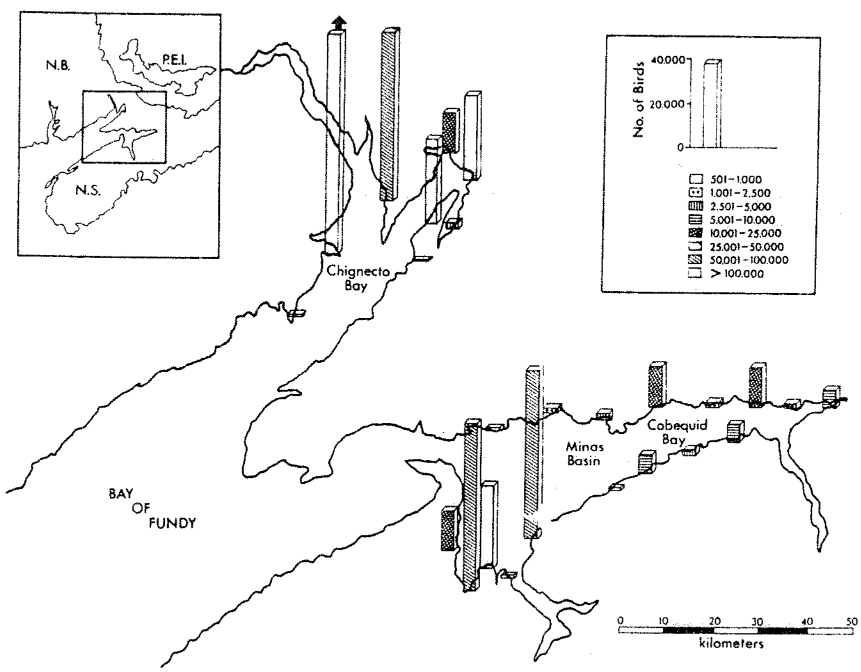


Fig. 2. Numbers of shorebirds in the Bay of Fundy based on aerial survey, 29 July, 1976.

One immediately apparent effect of barrage construction would be the reduction of shorebird numbers in the headpond (Cobequid Bay) owing to the loss of foraging area. One half or more (depending on slope) of the flats in the headpond area would be lost; the lower portion of the existing intertidal zone would remain subtidal following barrage construction under most operating regimes. Two other effects also seem probable, although the magnitude of these is much less clear:

1. Changes in tidal and current patterns in the Bay of Fundy following construction would cause concomitant changes in the sedimentation regime (Amos 1983). The nature of the sediments is crucial with respect to the distribution and abundance of invertebrate prey for birds. Availability of the invertebrates, in turn, affects the foraging distributions, densities, feeding success, rates of fat deposition, and length of stay (in Fundy) of the birds.

2. Birds displaced from the headpond area would move to and increase the densities of birds in other adjacent areas, thus increasing competition through both direct and indirect interactions.

As Cobequid Bay is receiving primary consideration for tidal power development, we will center our discussion of these points with respect to this site. Parallel effects would be expected at other potential sites in Fundy such as Cumberland Basin.

At the peak of migration on 29 July 1976, shorebirds in Cobequid Bay totalled about 65,000 birds and over the course of migration probably attain total numbers of 100,000 or more. With the loss of one half the present foraging area, an appreciable porportion would be displaced. The foraging sites nearest Cobequid Bay, on the seaward side of the barrage, are in the Southern Bight of Minas Basin. The Southern Bight is already the most important area for shorebirds in the Minas Basin-Cobequid Bay complex. Moreover, per unit area, the Starrs Point bar is among the most productive areas in Minas Basin yet studied (Boates 1980).

Our concern focuses upon changes in sediment regime on the Minas Basin side of a barrage built across Cobequid Bay (Amos 1984). We feel that some change would result although the magnitude of this cannot as yet be determined very precisely. The key relationships which exist here are those among the nature of the sediments, the invertebrates species inhabiting these and the birds which in turn prey upon the invertebrates. Certainly the close relationships which exist between substrate type (grain size) and invertebrates species composition and abundance have been well documented from studies conducted in North America and Europe (e.g. Meadows 1964, Longbottom 1970, Wolff 1973, Fenchel et al. 1975 and Scott and Crooker 1976). It is reasonable to assume, therefore, that changes in the sediment regime would lead to changes in the composition and abundances of prey species. Such changes in species composition would in turn affect the birds' ability to obtain food.

Irrespective of such changes, further effects can be predicted with regard to the displacement of birds to sites outside of Cobequid Bay. These effects are based on the premise that shorebird foraging dispersion is related to prey density and availability. This premise is based on our own studies in the Bay of Fundy (Boates 1980, Hicklin 1981, Hicklin and Smith 1984) and those of Zwartz (1980) in Holland and of Goss-Custard (1970, 1977a) in Britain. Furthermore, Zwartz (1980) has shown that, above critical densities of prey, foraging success is dependent on bird density. Hence, a number of interrelationships result. Displaced birds from one area would produce concomitant increases in bird density in other sites, thus depressing foraging efficency in response to decreased prey abundance and greater competition and interaction. For instance, in the Wash, the feeding rate of red knots, Caladris canutus, decreased by 20% owing to a rise in frequency of aggressive encounters over food with increasing bird densities (Goss-Custard 1977b). Lowered foraging efficency of the birds in Fundy would presumably reduce daily rates of fat deposition and thus require birds to remain longer in the area to achieve the level of fat reserves needed for the migration over the Atlantic Ocean to South America. All these effects are complicated by the arrival of additional birds (immatures and later migrants) and by loss of potential prey taken by fish (Gilmurray 1980). These interrelated effects could lead to decreased fat levels. Although mortality by starvation would not be expected in the Bay of Fundy, some mortality could occur during the long transoceanic flight to the wintering sites.

In such a situation, the question arises whether birds would stay in Fundy or move to other foraging areas outside the Bay. In British wintering studies, many birds did not move in hard weather and perished (see Prater 1978). Along the Atlantic seaboard of North America, many areas in the northeast (the Gulf of St. Lawrence, the Maritime Provinces and coastal New England) are used extensively by migrant shorebirds although total numbers are much less than those found in the Bay of Fundy. Work by McNeil and Cadieux (1972) and McNeil and Burton (1973) in the Magdalen Islands, Gulf of St. Lawrence, has shown that many migrant shorebirds which forage there during migration accumulate enough fat to reach the West Indies and the northern coast of South America, a distance of 3200 km. However, they also indicated that on average, the fat reserves of semipalmated sandpipers and other species could only provide sufficient energy for migration of about 2400 km. Hence, although many birds could undertake a non-stop flight from Magdalen Islands to the wintering grounds, "others would need to get fatter somewhere farther south in Nova Scotia or the New England states before undertaking an over-sea flight" (McNeil and Cadieux 1972). Reports of banded and marked birds dispersing from the Magdalens showed that of those subsequently seen in North America 62% occurred in the Bay of Fundy (McNeil and Burton 1973; computed from Table VI). Moreover, some semipalmated sandpipers recently banded and colour marked in Lubec, Maine, were seen in the upper Bay of Fundy during the same summer they were captured (T.A. May, pers. comm. and P.W. Hicklin, unpublished data). Those results suggest that these areas outside the Bay of Fundy cannot support large numbers of birds for the times required to put on necessary fat levels, and this further emphasizes the international importance of Fundy as a major staging area for North American shorebirds during the southward migration.

If the foraging grounds were indeed affected by tidal power developments as we have described and birds had to disperse to other areas, an important question remains. Where can the displaced birds move to in order to ensure successful migration further south? One obvious answer is that birds might adopt a coastal route along the United States to Florida and the West Indies. It remains uncertain whether sufficient habitat is available to support this large a population for few areas south of Massachusetts presently sustain notable concentrations of shorebirds in autumn.

Many small nearshore islands in the Maritime Provinces support small numbers of shorebirds in the fall. There are about 1400 such islands in Nova Scotia and perhaps these could absorb greater numbers of birds, thus helping to maintain the overseas migratory route. Unfortunately, little is known regarding the amounts of suitable and productive habitats available to shorebirds on these islands or on the numbers and species of migrants which might utilize them.

Some key questions have to be examined. How "traditional" are staging areas and migration patterns? How flexible are the responses of migrant shorebirds toward loss of habitat and changes in abundances of prey?

Taking into consideration the points outlined, we present two scenarios which we feel might result following the construction of a tidal barrage across the Minas Basin-Cobequid Bay system.

<u>Increased use of areas near the headpond by migrant shorebirds following barrage construction</u>

If substantial numbers of shorebirds were displaced from Cobequid Bay there is the possibility that the nearest foraging site, the Southern Bight of Minas Basin, could support more birds. However, the information presently available on the foraging distributions of birds in the Southern Bight suggests that the better foraging flats are presently saturated with the maximum number of birds they can support, at least during peak migration. The Starrs Point Flat which is the most productive area for shorebirds in the Minas Basin presently supports more birds and higher densities than surrounding mudflats (Boates 1980, Hicklin 1981). Nearby flats which in area are equal to or larger than the Starrs Point Flat, but which contain low densities of <u>Corophium volutator</u>, support densities of birds which are about 5% of the densities of foraging birds found at Starrs Point (Hicklin and Smith 1979, Hicklin 1981). Birds feeding on the less productive mudflats may have been displaced from the better foraging areas or indeed by high bird densities at Starrs Point. In these cases, the possibility that the Southern Bight can support substantially more birds is remote.

<u>Increased use of the Southern Bight by shorebirds in relation to changing sedimentary patterns on the seaward side of a barrage</u>

If large expanses of mudflat were lost in Cobequid Bay (as predicted) following tidal power development and serious disruptions of the existing flats in Minas Basin developed, we believe that substantial reductions in the numbers of shorebirds would occur. In the Teesmouth estuary in Britain, the numbers of five species of wintering shorebirds declined substantially following reclamation developments (Prater 1978). If tidal power developments in the Bay of Fundy were to reduce invertebrate production significantly, such effects would be especially pronounced for later migrants and particularly immature birds because of lower prey abundance resulting from predation by earlier immigrants, especially adults, and perhaps by fish. The extent of mortality or displacement outside of Fundy cannot be predicted until some idea of the degree of possible change to the foraging areas is known. Presumably, some new equilibrium between bird numbers and the carrying capacity of the intertidal areas would be attained in the long term at a lower population size. However, here there is a problem. Because of the size of the Bay of Fundy and the scarcity of professional and volunteer observers to monitor regularly the numbers of birds at roosting and feeding areas, assessment of the possible change in numbers, if any, will be difficult. Because of the large numbers of some species, such as the semipalmated sandpiper, only broad estimates of numbers can be obtained and these can vary greatly between observers. Hence, unless reductions are substantial, the degree or occurrences of change will be difficult to ascertain.

Although attention is most often focused upon the most abundant species, the least numerous may be more affected. For example, recent work on the ubiquitous but less abundant least sandpiper, _Calidris minutilla_, suggests that it may be competitively excluded from the better foraging and roosting areas by the slightly larger semipalmated sandpiper (P. MacDonald, pers. comm.). Therefore, under periods of environmental change and stress, the least sandpiper may experience the greater loss.

WATERFOWL

Pearce and Smith (1974) briefly examined the potential influences on waterfowl of port and tidal power developments in the Bay of Fundy. Their discussion was based on ground and aerial surveys conducted in 1966-1973. Except for breeding colonies of common eiders, _Somateria mollissima_, in southwestern New Brunswick and a few pairs of black ducks, _Anas rubripes_, breeding in the higher marshes, most of the ducks and geese which utilize the Bay of Fundy are migrants. Dabbling ducks and Canada geese occupy the saltmarshes of the upper Bay of Fundy and the possible loss of these habitats was the chief concern of Pearce and Smith (1974). Since its publication, no systematic research has been conducted on waterfowl populations in the Bay of Fundy and little can be added other than that some distributional change might be predicted. No major deleterious changes at the population level are expected.

COLONIAL BREEDING BIRDS

Colonies of great blue herons, _Ardea herodias_, and double crested cormorants, _Phalacrocorax auritus_, in the Bay of Fundy are small compared to the number and sizes of colonies elsewhere in the Maritimes. One notable exception is a colony of double crested cormorants on Manawagonish Island (2000 pairs). Any effects of tidal power developments are most likely to operate through changes in fish prey. Herring gulls, Larus argentatus, and great black backed gulls, Larus marinus, breed on numerous offshore islands in Fundy. It is doubtful that these would be affected by tidal power developments at all. The puffins, Fratercula arctica, razorbills, Alca torda, and arctic terns, Sterna paradisaea, which nest on Machias Seal Island should not suffer any loss of breeding habitats. Since they probably feed outside the Bay of Fundy, presumably in the Gulf of Maine, it is difficult to envision any detrimental effects.

SHEARWATERS AND PHALAROPES

Large numbers of greater shearwaters, Puffinus gravis, and red phalaropes, Phalaropus fulicarius, congregate off Brier Island in the late summer and fall. Each species may occur there in numbers exceeding 20,000. red-necked phalaropes, Phalaropus lobatus, are even more abundant in fall near Deer Island in Passamaquoddy Bay. These birds forage on copeods and euphausiids in areas of upwelling tidal currents. It remains to be seen if these currents and food availability will be affected by barrage construction in the upper Bay of Fundy. If indeed current velocities are changed so that amphipods and copepods are no longer "pumped" up into the surficial layers, the loss of the food resource might force these migrants elsewhere.

BALD EAGLES

The Subenacadie River, which lies inside the proposed headpond in Cobequid Bay, is the most important known natural wintering area in Nova Scotia for bald eagles (Reid 1982). Maximum numbers recorded in the winters 1977-1982 ranged between 45 and 75 birds. Most are presumed to be of Nova Scotia origin but some may originate from Newfoundland and Labrador.

In winter, about 13-58% of the eagles known to be in Nova Scotia are observed along the river. The main attraction for these birds is the winter spawning run of tomcod, Microgadus tomcod, which also serves as an important food for 500-600 common mergansers, Mergus merganser.

The tides affect the Shubenaciaie River up to 40 km above the mouth. The stretch of river most frequented by wintering eagles is 15-20 km from the mouth. Under the existing tidal regime this portion of the river presently remains relatively open in most winters. Since the river lies in the headpond area of the proposed tidal dam, it would very likely freeze completely in winter, thus eliminating this important wintering area for bald eagles and common mergansers. In addition, the tomcod run is likely to be affected by tidal changes. Can the eagles, displaced from this wintering area after barrage construction be supported elsewhere in coastal and inland Nova Scotia? Probably not all would survive, as some mortality may be expected there or upon movement down the seaboard.

Wintering sites which currently share smaller numbers of eagles may be able to support additional birds, but little is known of the carrying capacity of any of these areas.

GENERAL CONCLUSIONS

Although we know much more about the ecology and behaviour of some birds utilizing Fundy than we did in 1976, especially about shorebirds, seabirds and to some extent eagles, we are not much farther ahead with respect to assessing impacts. Many "ifs" and "buts" remain. We require more detailed information on the abundance, distribution and habitat use of many of the species we have discussed. Of the migrant sandpipers and plovers, much study has been devoted to the semipalmated sandpiper with less emphasis on other less abundant species. Fortunately, such studies are presently underway. Until more is known of engineering design and related changes in physical environment, a statement concerning impacts of Fundy tidal power on birds cannot be more precise than that made at present.

ACKNOWLEDGMENTS

We thank A.J. Erskine for reviewing the manuscript. Peter MacDonald and Andree Dubois provided many helpful comments. Peter Austin-Smith kindly provided information on eagles.

REFERENCES

Amos, C.L. 1984. The sedimentation effect of tidal power development in the Minas Basin, Bay of Fundy. In this report.

Boates, J.S. 1980. Foraging semipalmated sandpipers *Calidris pusilla* L. and their major prey *Corophium volutator* (Pallus) on the Starrs Point Mudflat, Minas Basin. M. Sc. thesis, Acadia University, 199 p.

Daborn, G.R. 1977. Fundy tidal power and the environment. Acadia University Institute Publ. No. 28, 304 p.

Fenchel, T., L.H. Kofold and A. Lappalainea. 1975. Particle size-selection of two deposit feeders: the amphipod *Corophium volutator* and the prosobranch, *Hydrobia ulvae*. Mar. Biol. 30: 119-128.

Gilmurray, M.C. 1980. Occurrence and feeding habits of some juvenile fish in the Southern Bight of Minas Basin, Nova Scotia, 1979. M.Sc. thesis, Acadia University, 107 p.

Goss-Custard, J.D. 1977a. The energetics of prey selection by redshank *Tringa totanus* (L.), in relation to prey density. J. Anim. Ecol. 46: 1-19.

Goss-Custard, J.D. 1977b. The ecology of the Wash/III. Density-related behavior and the possible effects of a loss of feeding grounds on wading birds (Charadrii). J. appl. Ecol. 14: 721-739.

Hicklin, P.W. and P.C Smith. 1979. The diets of five species of migrant shorebirds in the Bay of Fundy. Proc. N.S. Inst. Sci. 29: 583-488.

Hicklin, P.W. 1981. Use of invertebrate fauna and associated substrates by migrant shorebirds in the Southern Bight, Minas Basin. M.Sc. thesis, Acadia University, 212 p.

Hicklin, P.W. and P.C. Smith, 1984. Studies of birds in the Bay of Fundy: a review. In this volume.

Hughson, W.B. 1977. Fundy avifauna: an overview. In: Daborn, G.R., ed. Fundy tidal power and the environment. Acadia University Institute Publ. No. 28, pp. 180-186.

Longbottom, M.R. 1970. The distribution of Arenicola marina. (L.) with particular reference to the effects of particulate size and organic matter of the sediments. J. exp. mar. Biol. Ecol. 5: 138-157.

McNeil, R. and F. Cadieux. 1972. Fat content and flight range capabilities of some adult spring and fall migrant North American shorebirds in relation to migration routes on the Atlantic coast. Nat. Can. 99: 589-606.

McNeil, R. and J. Burton. 1973. Dispersal of some southbound migrating North American shorebirds away from the Magdalen Islands, Gulf of St. Lawrence, and Sable Island, Nova Scotia. Caribb. J. Sci. 13: 257-278.

Meadows, P.S. 1964. Substrate selection by Corophium species: particulate size of substrates. J. Anim. Ecol. 33. 387-394.

Pearce, P.A. and A.D. Smith 1974. The potential influence on waterfowl of port and tidal power development in the Bay of Fundy. Can. Wild. Serv. Rept. Ser. No. 29: 91-100.

Prater, A.J. 1978. The effect of estuarine engineering schemes on birds. Hydrobiol. Bull. 112: 322-332.

Prater, A.J. 1981. Estuary birds of Britain and Ireland. T & AD Poyser, 440 p.

Reid, P.R. 1982. Aspects of the winter ecology and behavior of bald eagle (Haliaeetus leucocephalus alascanus Townsend) on the Shubenacadie River, Nova Scotia. M.Sc. thesis, Acadia University, 131 pp.

Scott, K.J. and R.A. Croker. 1976. Microinfauna of northern New England marine sand. III. The ecology of Psammonyx nobilis (Stimpson), 1853 (Crustacea: Amphipoda). Can. J. Zool. 54: 1519-1529.

Wolff, W.J. 1973. The estuary as a habitat: an analysis of data on the soft-bottom macrofauna of the estuarine area of the rivers Rhine, Meuse and Scheldt. Communication No. 106 of the Delta Institute for Hydrobiological Research, Leiden, E.J. Brill, 242 p.

Zwartz, L. 1980. Habitat selection and competition in wading birds. In: Smit, C.J. and W.J. Wolff, eds, Birds of the Wadden Sea, A.A. Balkema, Rotterdam, 308 p.

QUESTIONS AND COMMENTS

D. Gordon: Your projection of the decline in bird populations and tide flat area agrees closely with our findings on changes in primary and secondary production. But do you think there will be a decline in bird populations if the barrage is built or will they just move to new areas?

P. Hicklin: My point is the length of time it takes the flats to readjust to the new tidal regime and resume maximum *Corophium* production levels. Throughout that period the birds will have difficulties and populations might decline or crash.

D. Gordon: Yes, but after a crash for 5 years or so, when the tide flats recover, will not the birds?

P. Hicklin: Perhaps but I think there is an element of risk.

Unknown: I assume in the past few years there has been some annual variation in the production and availability of *Corophium*. Has this ever manifested itself in the birds?

P. Hicklin: I never felt that this was really noticeable except one time after there had been a severe storm at Mary's Point the birds became very aggressive and this may have been in response to unavailability of food. In terms of your original question abundances of birds and benthos seems to have been uniformly high.

Mysids; Possible Consequences of a Barrage

N.J. Prouse

Marine Ecology Laboratory,
Bedford Institute of Oceanography
Dartmouth, N.S. B2Y 4A2

ABSTRACT

Neomysis americana and Mysis stenolepis exist in large numbers in the Cumberland Basin and are an important food source for fish such as shad. A tidal barrage might have the consequence of reducing the available food for mysids in the form of Spartina detritus while increasing predation by resident fish populations as a result of lowered turbidity.

Key words: Neomysis americana, Mysis stenolopis, detritus, Cumberland Basin, turbidity, predation.

RÉSUMÉ

Neomysis americana et Mysis stenolepis sont très nombreuses dans le bassin Cumberland, et constituent une importante source alimentaire pour les poissons tels que l'alose. L'aménagement d'une usine marémotrice aurait peut-être pour conséquence de réduire la quantité de nourriture que trouvent les Mysidés sous forme de restes de Spartina, et en même temps d'augmenter leur taux de prédation par les populations de poissons locales, en raison de la moins grande turbidité des eaux.

INTRODUCTION

For the past two years, the distribution and abundance of mysid shrimp, an important food source for fish, have been studied in the Cumberland Basin. Two species were present, Neomysis americana and Mysis stenolepis, and large numbers were found, especially in July and August when juveniles appeared. Concentrations of up to 1000 juveniles m^{-3} (N. americana) existed in some localities during this time. Their distribution appeared associated with the large amount of Spartina-derived detritus which is exported from the extensive Cumberland Basin marshes and moved back and forth in the Cumberland Basin by oscillating tidal currents. It is possible that mysids are feeding on this material. There was some indication that adult mysids avoid surface water during daylight even in the turbid water.

A possible consequence of a tidal barrage might be a reduction in the food source for mysids if saltmarsh production does decrease as predicted (Gordon 1984). Increased phytoplankton production might compensate for this (Hargrave 1984). Of greater significance would be decreased turbidity resulting in increased predation especially for the juveniles which tend to be more light tolerent and occur higher in the water column. Although fewer predators such as shad might enter the Basin because of the barrage, local resident fish populations might increase behind the barrage at the expense of mysids. The barrage might also interfere with any import or export of mysids from the Basin. It is felt that any temperature and salinity changes would only affect the local distribution of mysids.

REFERENCES

Gordon, D.C. Jr. 1984. Predictions of the impacts of tidal power development on intertidal primary production in the headpond region. In this volume.

Hargrave, B.T. 1984. Barrage effects on phytoplankton production and chemosynthesis in Cumberland Basin. In this volume.

QUESTIONS AND COMMENTS

G. Daborn: Are there many fish which may feed on mysids, other than shad, and do you think they will be affected?

N. Prouse: Virtually every fish feeds on them both on the bottom and in the water column. No, they will probably just go where the mysids are.

D. Scarratt: I am uncertain why you said if there might be as much as a 30% reduction in the availability of detritus why this would not affect the mysid populations?

N. Prouse: These estimates are largely guesswork. It seems there is so much detritus now that the existing populations are not food-limited. We are not sure the mysids are actually feeding on this detritus and it should be looked at. Even with a reduction in detritus there should still be a large population of mysids in these areas.

Impact of a Tidal Power Station on Zooplankton-Fish Interactions in Minas Basin

Graham R. Daborn

Gail S. Brown

and

Brian Scully

Department of Biology
Acadia University
Wolfville, N.S. B0P 1X0

ABSTRACT

Study of zooplankton populations in inner reaches of the Bay of Fundy, particularly in Minas and Cumberland Basins, has indicated that the zooplankton association is of limited diversity and highly contagious distribution. All species are common estuarine ones that are either omnivorous or carnivorous and are utilized primarily by larval and early juvenile stages of fish. With increasing size some fish switch to feeding on benthic prey which is seen as a reflection of the relatively greater abundance and/or productivity of the benthos in completely mixed waters. Construction at the B9 site will reduce vertical mixing in some portions of the headpond and consequently decrease SPM levels and increase light penetration. Increased phytoplankton production will compensate in part for decreased production of benthic algae and provide a more varied food supply for zooplankton. Some increase in diversity, but not necessarily in abundance or production of zooplankton, is indicated as the detritus-based estuarine forms are augmented by algivorous species. Visual predation by zooplankton and fish is presently restricted by high turbidity. With decreased SPM levels some new predators should extend into Cobequid Bay for feeding. Decreased tidal scour in many areas will allow development of a mixed deposit- and suspension-feeding benthos with indirect effects on the zooplankton. Competition for suspended food will probably limit increases in abundance of zooplankton within the headpond. A definite potential for aquaculture development is indicated.

Key words: zooplankton, juvenile fish, turbulence, stratification, diversity, productivity, suspended sediments.

RÉSUMÉ

L'étude de populations de zooplancton dans les appendices rentrantes de la baie de Fundy, particulièrement dans les bassins des Mines et de Cumberland, a révélé que l'association du zooplancton a une diversité limitée et une répartition fortement contagieuse. Toutes les espèces sont

courantes dans les estuaires et elles sont soit omnivores ou carnivores; elles servent surtout au poisson à l'état larvaire ou nouvellement juvénile. A mesure que leur taille augmente, certains poissons commencent à se nourrir de proies benthiques, ce qui est considéré comme un reflet de l'abondance ou de la productivité relativement supérieures du benthos en eaux entièrement mélangées. Les travaux de construction au site B9 réduiront le mélange vertical dans certaines portions du bassin de chute, ce qui abaissera les niveaux du SPM tout en accroissant la pénétration de la lumière. La production accrue de phytoplancton compensera en partie la baisse de production des algues benthiques, tout en fournissant une alimentation plus variée au zooplancton. On a constaté une certaine hausse de la diversité, mais pas nécessairement de l'abondance ou de la production du zooplancton, puisque les formes estuariennes reposant sur les détritus sont augmentées par des espèces algivores. La prédation par le zooplancton et le poisson est actuellement empêchée par une forte turbidité qui rend la visibilité mauvaise. Avec la baisse des niveaux du SPM, certains nouveaux prédateurs devraient s'avancer dans la baie Cobequid pour s'alimenter. La diminution de l'affouillement tidal dans de nombreux secteurs favorisera la formation d'un benthos à alimentation mixte dépôt-suspension, avec effets indirects sur le zooplancton. La compétition pour les aliments en suspension limitera probablement l'augmentation quantitative du zooplancton à l'intérieur du bassin de chute. Un potentiel assuré de développement de l'aquaculture a été constaté.

INTRODUCTION

At the present time, information on species compositions and biological interactions in the water column of Cobequid Bay, east of the Economy Point-Cape Tenny line, is extremely sparse. Jermolajev (1958) reported on a few zooplankton collections in this area and others were obtained at an anchor station in August 1979 as part of the series of cruises of C.S.S. Dawson (Daborn 1984). Much more information is available for other areas, however, notably for Cumberland Basin, Shepody Bay and the Southern Bight of Minas Basin. To the extent that dynamic processes are similar in Cobequid Bay to those in physically comparable regions elsewhere, some tentative predictions can be made regarding the impact of the proposed B9 barrage at the mouth of Cobequid Bay.

Studies of zooplankton populations in the inner reaches of the Bay of Fundy system have indicated that zooplankton associations are of limited diversity and highly contagious distribution. Most of the species are common estuarine ones that are omnivorous and capable of subsisting upon nonliving particulate matter and its associated microflora. A few common species are carnivorous, depending upon physical contact with prey for successful capture. In the most turbid localities such as Cumberland Basin and the Cornwallis Estuary, visual predators are uncommon or completely absent.

Similarly, knowledge of the ichthyofauna of the more turbid areas is fragmentary. Although less than 50 species of fish have previously been recorded from the Minas Basin (Bromley 1979) more recent work suggests that there may be more and it is equally apparent that utilization of Cobequid Bay and other portions of the system by juvenile alosids and other migratory species is very extensive (Dadswell et al. 1984). The zooplankton association is utilized by larval and early juvenile stages of fish (Imrie and Daborn 1981, Gilmurray and Daborn 1981). With increasing size however, fish often switch to feeding mainly on benthic organisms, particularly vagile species, an apparent reflection of the much greater production of the benthos than the plankton in these turbid macrotidal estuaries. In Minas Basin and Cumberland Basin at least, benthic animals represent a far greater and perhaps more acceptable food supply. Although the benthos of Cobequid Bay appears to be somewhat less productive than either Cumberland Basin or the Southern Bight of Minas Basin, existing data do indicate extensive utilization of the benthos in that area by migrant and resident juvenile fish.

IMPACT OF THE PROPOSED BARRAGE

The major conclusion of our studies in recent years is that the turbid inner regions of the Bay of Fundy system are examples of extreme physical stress. High suspended particulate matter (SMP) levels are a result of turbulent mixing associated with large tidal range and strong currents. Consequently, any modification of physical conditions is expected to produce extensive changes in biological processes.

Construction of the B9 barrage from Economy Point to Cape Tenny, and subsequent operation of the power station in an ebb-generation regime, will moderate considerably the extensive vertical turbulence now prevailing in Cobequid Bay. Much of the present-day energy of the flooding tide will be dissipated against the barrage itself and in raising the reservoir level. Consequently, it is expected that SPM levels in the upper portion of the headpond water column will be considerably lower and the euphotic zone much greater than the present. There may be some stratification at the surface as presently occurs in the Annapolis headpond (Daborn et al. 1982). However, the annual freshwater input to Cobequid Bay is very small relative to the tidal prism and hence the surface low salinity layer may be shallow and stratification readily broken down by wind action. On the seaward side of the barrage the tidal range is expected to be slightly reduced and hence the euphotic zone marginally increased.

Within the headpond, increased light penetration, coupled with an adequate (if not abundant) nutrient supply (Keizer 1984) should allow much greater phytoplankton production, particularly in the presently more turbid peripheral portions of Cobequid Bay (Hargrave 1984). Increased pelagic primary production, based on small flagellates and dinoflagellates, should allow an increase in zooplankton diversity as algivorous species common in the outer Bay of Fundy (cf. Fish and Johnson 1937, Roff 1983) will also be able to survive. Since the dominant zooplankton species present in Cobequid Bay are common omnivorous estuarine ones (Daborn 1984), none should be eliminated from the headpond by the changed conditions although the relative abundance of some (e.g. *Eurytemora herdmani* and *Acartia tonsa*) may well change. Similarly, some predatory zooplankters, such as *Tortanus discaudatus* and *Oithona similis*, will become more prevalent and abundant.

In all likelihood, the increased diversity of the zooplankton association will be accompanied by a decrease in annual secondary productivity, despite the rise in primary production. Although nutrients are presently abundant, increased utilization will eventually lead to a nutrient-limited regime, exacerbated by a decrease in remineralization rates as the intertidal zone and tidal resuspension will be much reduced. Furthermore, the zooplankton presently exhibits an inverse relationship between light penetration and biomass. Minimum biomass and (presumably) production of zooplankton is found in Minas Basin and Chignecto Bay where SPM levels are less than 50 mg L^{-1} (Daborn 1984). In contrast, maximum biomass values are found in the most turbid waters such as Cumberland Basin and the Cornwallis Estuary where SPM levels often exceed 1 g L^{-1}. Biomass values, however, are not in themselves measures of production and only in the Cornwallis Estuary is the relationship between biomass and production close to being established. In most regions the highly contagious distributions of zooplankton species make even estimates of mean abundance impossible.

In Minas Basin, on the seaward side of the barrage, the increased euphotic zone will have little direct effect on zooplankton production and diversity. Secondary effects, however, may well be observed, particularly during the first few years following commencement of construction. Changed patterns of water movement and current velocity will undoubtedly result in new patterns of sediment deposition. Some present intertidal areas will be subject to greater current scour, whereas others will experience new deposition. Consequently there will be extensive changes in the relative abundance of benthic organisms, many of which have planktonic larvae. At certain times of the year, and particularly over productive mudflats, the holoplankton is overwhelmed by very large numbers of meroplanktonic forms such as trochophore and veliger larvae. It is probable that during and for some years after the constructive phase notable variations will occur from year to year in release of plankton larvae. This will make generalizations about the abundance, biomass and production of zooplankton virtually impossible. At present many of these meroplanktonic forms are cropped by predatory zooplankters such as *Labidocera aesrtiva* and *Neomysis americana*; in the latter instance, predation on such forms may compensate for the expected decrease in non-living particulate food derived from intertidal and supratidal areas.

Effects on the zooplankton-fish interaction are predictable in very general terms. Present research indicates that most fish species utilizing the Minas Basin-Cobequid Bay system as larvae subsist upon the zooplankton, particularly *Eurytemora hermani*, but subsequently switch to benthic forms. Within the headpond, we would expect that planktivorous forms such as *Menidia menidia*, *Gasterosteus aculeatus*, *Clupea harengus*, *Alosa aestivalis* and *A. psuedoharengus* will persist as planktivores as long as planktonic food is available. Benthic feeders such as *Liopsetta putnami*, *Pseudopleuronectes americana* and *Microgadus tomcod* will presumably continue to utilize the benthos, although the size of the intertidal resource will be reduced by the reduction of the intertidal zone. Post-construction conditions should favor more planktonic feeding both because of increased light levels (allowing visual feeding) and because a greater proportion of available primary production in the headpond will be intercepted within the upper portion of the water column.

For some species, at least, the probable decline of larger zooplankters, such as the mysids, associated with increased light penetration and decreased detritus food may well be a significant change. In particular, the American shad, Alosa sapidissima, feeds largely by straining large zooplankters such as Neomysis from the extremely turbid areas such as Cumberland Basin (Dadswell et al. 1984) and may not find such suitable conditions behind the barrage.

CODA

As indicated above, some general statements regarding the effects of the B9 proposal on zooplankton, young fish and zooplankton-fish interactions can be made. It seems certain that direct effects of the barrage will be of a small scale and may well be positive in many respects. Increased primary production in the headpond will probably be accompanied by greater planktonic diversity and utilization by young fish. The general trend will be toward the light-based estuarine pelagic community that is more commonly encountered elsewhere and away from the strongly stressed regime of the present. Although not an accurate or adequate paradigm, studies of the Annapolis Estuary have proved instructive (Redden et al. 1984).

It should also be noted that increases in phytoplankton production might well offer opportunities for aquaculture within the headpond that would compensate in part for some of the losses of intertidal production that are anticipated. At present Cobequid Bay appears to be free of paralytic shellfish poisoning that affects soft-shelled clam and mussel beds in the outer Bay of Fundy. Although the winter conditions may prove difficult, a raft-type culture of mussels (for example) might be feasible in the headpond.

ACKNOWLEDGMENTS

This account has been derived from the accumulated studies of many people that we wish to acknowledge with thanks. They include: L. Arsenault, D. Calquhoun, P. Crawford, A. Evans, M. Frame, G. Gibson, R. Gregory, D. Irmie, H. Leslie, A. McDonald, G. McQuarrie, C. Pennachetti, A. Redden, P. Reid, F. Rogers, N. Rogers, J. Slater, K. Strong, and J. Williams. Financial support has been provided through grant A9679 from the Natural Sciences and Engineering Reasearch Council, through grants 2-R41 and 4-R71 from the Canadian National Sportsmen's Fund, and through funds from the Nova Scotia Tidal Power Corporation. To all of these we are most grateful.

REFERENCES

Bromley, J.E.C. 1979. A preliminary checklist of marine fauna of Minas Basin and Minas Channel. Proc. N.S. Inst. Sci. 29: 517-541.

Daborn, G.R. 1984. Zooplankton studies in the upper Bay of Fundy since 1976. In this report.

Daborn, G.R., A.M. Redden and R.S. Gregory. 1982. Ecological studies of the Annapolis Estuary 1981-1982. Acadia Univ. Insitute Publ. No. 29, 80p.

Dadswell, M.J., J. Williams and G. Brown. 1984. Possible impact of large scale tidal power developments in the upper reaches of the Bay of Fundy on certain migratory fish stocks of the western North Atlantic. In this report.

Fish, C.J. and M.W. Johnson. 1937. The biology of the zooplankton population in the Bay of Fundy and Gulf of Maine with special reference to production and distribution. J. Biol. Bd. Can. 3: 189-321.

Gilmurray, M.C. and G.R. Daborn. 1981. Feeding relations of the Atlantic silverside, Menidia menidia, in the Minas Basin, Bay of Fundy. Mar. Biol. Progr. Ser. 6: 231-235.

Hargrave, B.T. 1984. Barrage effects on phytoplankton production and chemosynthesis in Cumberland Basin. In this report.

Irmie, D.M.G. and G.R. Daborn. 1981. Food of some immature fish of Minas Basin, Bay of Fundy. Proc. N.S. Inst. Sci. 31: 149-154.

Jermolajev, E.G. 1958. Zooplankton of the inner Bay of Fundy. J. Fish. Res. Bd. Can. 15: 1219-1228.

Keizer, P.D. 1984. Potential effect of tidal power development on the chemical oceanography of the Bay of Fundy. In this report.

Redden, A.M., G.R. Daborn and R.S. Gragory. 1984. Ecological aspects of the Annapolis Estuary with specific reference to operational effects of the Annapolis Tidal Power Station. In this report.

Roff, J.C. 1982. The microzooplankton of the Quoddy Region. Unpubl. manuscript, 37pp.

QUESTIONS AND COMMENTS

Unknown: What do you think causes the great abundance of Corophium in fish stomachs?

G. Daborn: It is probably due to the abundance of Corophium on tidal flats and turbulence caused by wave action and the rising tide.

M. Dadswell: Most amphipods become pelagic or semi-pelagic when they are adult. If stomach contents were examined closely for the quality of Corophium it may be that most are adults that had been swimming actively in the water column.

G. Daborn: We have examined the sex ratio of the *Corophium* in guts but we didn't see any predominance of males or females.

Unknown: Do you think if food became a limiting factor under new conditions that the benthos could compete with zooplankton for it?

G. Daborn: The reality I see is that in shallow water the capacity for benthos to strain water is infinitely greater than zooplankton. If there is a limitation on food and its utilization from time to time, I see no reason why the benthos would not be very effective in competing with zooplankton.

D. Gordon: Do you have any feeling concerning whether Cobequid Bay will turn out to be low as far as zooplankton production is concerned when compared to other parts of the upper Bay of Fundy.

G. Daborn: I believe it depends on the availability of primary production. Zooplankton can use either primary production or detritus particles from primary production for feeding. In the Cornwallis River system where SPM concentrations are up to 5 g L^{-1}, a small animal can filter a large amount of particles but I do not think they can depend on non-living particles to survive and grow. I find it difficult to say that Cobequid Bay will be any less productive than other parts of the upper Bay of Fundy. I think in Minas Basin and the Southern Bight abundances appear to be lower than other areas, perhaps Cobequid Bay is similar.

J. Lakshminarayana: Do you think inside the Annapolis Basin headpond you will have greater diversity in the stratified regions?

G. Daborn: In general, the relationship between diversity and distance inside the headpond is straightforward and dominated by salinity. However this relationship is complicated by the fact that if you have a stony or gravelly substrate diversity of benthos tends to be higher. So wherever that is situated in relation to the causeway it will change the pattern.

J. Lakshminarayana: What about diversity or faunal differences on the inside and outside of the Annapolis Causeway?

G. Daborn: You are comparing the upstream side of the Causeway to the downstream side? Well, of course, the degree of scouring downstream is much greater than on the upstream side of the Causeway. The downstream side empties out fairly completely at low tide and current velocities are high. This adds a physical stress there which is considerably greater than above the Causeway. The causeway doesn't act as a barrier to fauna and there is considerable vertical mixing there. Stratification is mostly broken down within 1/2 km of the Causeway. There is enough turbulence to keep it mixed.

Ecological Aspects of the Annapolis Estuary With Specific Reference to Operational Effects of the Annapolis Tidal Power Station

Anna M. Redden

Graham R. Daborn

and

Robert S. Gregory[1]

Department of Biology
Acadia University
Wolfville, N.S. B0P 1X0

ABSTRACT

Results of physico-chemical and biological studies in the Annapolis Estuary are reviewed with reference to possible environmental effects of the Annapolis Tidal Power Station. Tidal barrage construction in 1960 transformed a vertically homogenous type of estuary into a highly stratified salt wedge estuary with a reduced tidal range. Stratification is highly stable in the lower river and variable in the headpond where stability of stratification depends on a number of interacting factors, notably wind strength and river discharge. Annapolis Basin seaward of the barrage remains a partially mixed body. Above the barrage biological production is moderate to high in the summer due to reduced mixing, warm surface waters, low levels of SPM and adequate light and food requirements. Zooplankton densities are highest in the surface layers in the lower river and lowest in the mixed waters of the Basin. Above the barrage predation by larval and juvenile fish results in patchy zooplankton distribution. A strong meroplanktonic component is present in Basin waters as a result of vertical mixing and suggests a decrease in the relative importance of the zooplankton and a corresponding increase in the role of the benthos. Diversity and abundance of benthic invertebrates is greatest in the coarse sediments found on both sides of the barrage and along the shore. An obvious consequence of turbine operation will be the destabilization of stratification in the headpond. The possible biophysical consequences of modifying the pattern and degree of mixing are discussed.

Key words: phytoplankton, zooplankton, benthos, stratified estuary, juvenile and larval fish, Annapolis Basin.

[1] Present Address: Department of Biology, Trent University, Peterborough, Ontario

RÉSUMÉ

L'auteusr examinent les résultats d'études physico-chimiques et biologiques menées dans l'estuaire de l'Annapolis du point de vue des répercussions possibles sur l'environnement dues à la station marémotrice d'Annapolis. La construction en 1960 d'un barrage marémoteur a transformé un type d'estuaire verticalement homogène en un estuaire à coins de sel fortement stratifiés et à marnage réduit. La stratification a une stabilité élevée dans le cours inférieur de la rivière tandis qu'elle est variable dans le bassin de chute où la stabilité de la stratification dépend de nombreux facteurs interreliés, notamment de la force du vent et du débit du cours d'eau. Le bassin demeure une masse d'eau partiellement mélangée. Au-dessus du barrage, la production biologique va de modérée à élevée en été par suite du mélange réduit des eaux chaudes de surface, des bas niveaux du SPM ainsi que des quantités suffisantes de lumière et de nourriture. Les densités de zooplancton sont les plus fortes dans les couches de surface en aval de la rivière et les plus faibles dans les eaux mélangées du bassin. En amont du barrage, la prédation des poissons larvaires et juvéniles entraîne une répartition dispersée du zooplancton. Une forte composante méroplanctonique est présente dans les eaux du bassin par suite d'un mélange vertical et elle permet de croire à l'existence d'une diminution de l'importance relative du zooplancton et de l'accroissement correspondant du rôle du benthos. La diversité et l'abondance des invertébrés benthiques est la plus forte dans les sédiments grossiers que l'on trouve des deux côtés du barrage marémoteur ainsi que le long de la rive. Comme conséquences évidentes du fonctionnement des turbines, on assitera à la déstabilisation de la stratification dans le bassin de chute. Les conséquences biophysiques possibles d'une configuration modifiée et du degré de mélange font l'objet de considérations élaborées.

INTRODUCTION

The Annapolis Estuary is presently the site for construction of North America's first tidal power station. Annapolis Royal was chosen for intial prototype testing of a large (7.6 m diam.) straight flow turbine in part because of the existing Annapolis barrage which was constructed in 1960. Installation of the turbine will test its operational capabilities and reliability as well as develop 17.8 MW of power from an operating head of 5.5 m. The project is expected to become operational in 1984. Although the principles of turbine operation would be similar to the larger tidal power schemes projected for the upper Bay of Fundy, the pre-and post- operating conditions differ greatly. The two projects, therefore, cannot be considered entirely comparable.

The barrage built across the Annapolis Estuary in 1960 served to protect about 1740 ha of rich marshland from tidal flooding. Prior to construction, the river was tidal as far as 30 km upstream. Tidal range below the dam is presently 7-9 m but above is controlled to ± 0.5 m (Jessop 1976). The only exchange of water occurs via a permanently open 3 x 7 m fishway, 2 sluice gates (when open) and leakage through the rockfill barrage. As a result of impoundment, the Annapolis Estuary has been transformed from a vertically homogenous type of estuary into a highly stratified salt wedge estuary with a reduced tidal range.

No environmental impact studies were apparently conducted before the original construction of the barrage. Subsequently, examination of creel census data collected since 1973 suggested that the Annapolis River's striped bass (Morone saxatilis) population was in decline (Jessop 1980). This prompted a series of studies dealing with the recruitment of striped bass (Williamson 1974, Jessop and Vithayasai 1979, Jessop and Doubleday 1976, Williams 1978, Jessop 1980, Parker and Doe 1981) and more generally with physical and biological features of the estuary (Mennon 1974, Jessop 1976, Boates 1977, Daborn et al. 1979 a, b,). Notably omitted were surveys of the benthos and plankton communities.

The present ecological studies (Daborn et al. 1982) were initiated in order to compensate for obvious omissions and to provide a more comprehensive account of pre-operating conditions in the headpond and lower river. Although not a good paradigm, the Annapolis Tidal Power Project does provide an opportunity to investigate some aspects of turbine operation and its environmental impact that are revelant to the much larger development presently under consideration.

RESULTS

Physical and Chemical Features

Sampling was carried out in intervals of two to three weeks between 12 May and 22 September, 1981 and thereafter once per month in October, November, March and April. Eighteen stations, located between Allains Creek and Pré Rond, were selected as sampling sites (Fig. 1).

For most of the year, the headpond and lower river are stratified with more or less steep pynoclines at a depth of 2-4 m. In contrast, the Annapolis Basin seaward of the barrage is partially mixed with only a moderate increase in salinity and decrease in temperature with depth. The stability of stratification is variable and depends on a number of interacting factors, notably river discharge and wind strength. During periods of low river flow, the relative importance of tidal influx is increased and results in a greater degree of mixing in the area immediately above the barrage. Strong westerly winds also cause the breakdown of stratification but these effects are restricted to the headpond region and usually persist only for a couple of days before stratification is reestablished.

As a consequence of stratification in the headpond and lower river, mid-summer heating of surface waters produces higher surface temperatures than found in the Basin. These warmer surface waters with reduced mixing, low levels of SPM (<21 mg L^{-1}), greater than 70% O_2 saturation at all depths and a photic zone of about 5 m provide conditions highly favorable for phytoplankton production. Chlorophyll a data also indicate abundant growth with moderate to high production in the summer.

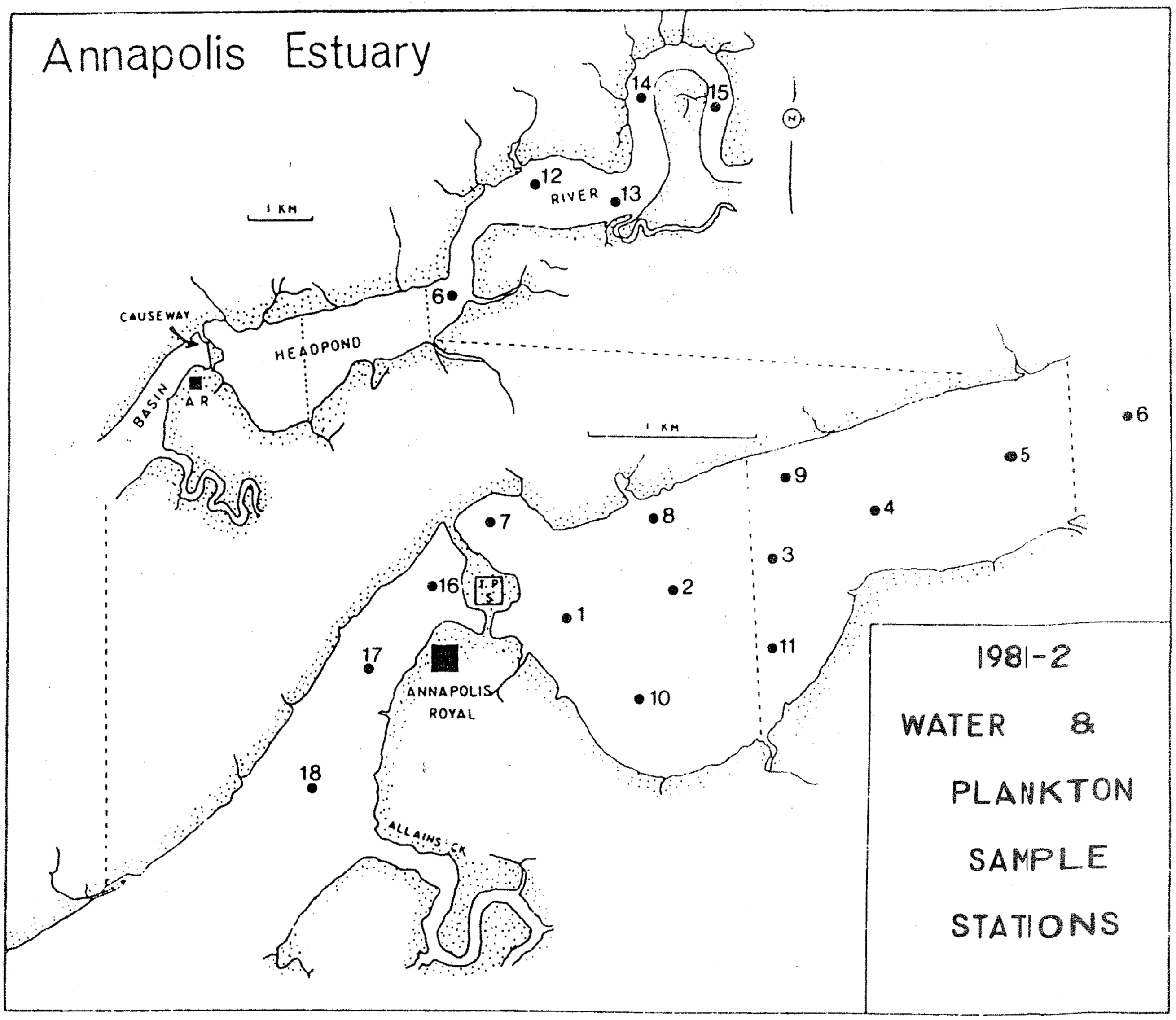


Fig. 1. Water and plankton sampling stations in the Annapolis Estuary, 1982-82.

Phytoplankton and Zooplankton Surveys

Plankton samples were taken concurrently with water samples at the 18 stations indicated in Fig.1. Phytoplankton collections were restricted to the headpond Stations 1-6.

The surface low salinity layer in the headpond receives adequate light and nutrients and consequently harbours a dense phytoplankton association at times. Eighteen taxa have been recorded, all marine and estuarine in distribution and dominated by diatoms.

Zooplankton samples in the estuary reveal a diverse and complex population dominated largely by copepods. Regional variation is evident in the composition, distribution and abundance of zooplankton. For the most part, zooplankton densities on the Basin side are less than those above the barrage. Highest numbers of plankters are found at those stations (14 and 15) located farthest upriver where stratification is highly stable. Basin collections are often dominated by benthic larval forms that are only weakly represented in the headpond and even less so upriver. This pattern appears to be related to the regional variation in the degree of mixing. In the lower river, where stratification is highly stable, the greatest densities of zooplankton are found concentrated in the upper few metres. In contrast, strong vertical mixing in Basin waters results in less stratified water and lower plankton densities. A strong meroplanktonic component below the barrage also indicated a decrease in the relative importance of the zooplankton in the Basin and a corresponding increase in the role of the benthos.

Fish predation by schools of larval and juvenile fish also appears to have a direct effect on the zooplankton population in the headpond and lower river. Here, zooplankton densities are patchy in comparison to much more uniform densities found in Basin waters.

Benthic Survey

Benthic samples were taken at 146 sites located above and below the barrage during the first week of June 1981 (Fig. 2). Sample sites were chosen on a stratified random basis to avoid local bias while emphasizing the headpond region where changes are anticipated as a result of turbine operation.

The benthic fauna of the Annapolis Estuary reveals a highly diverse and complex community. Strong regional differences are indicated in sediment type and species composition, distribution and abundance. Substrate type and distance away from the barrage are believed to be major factors affecting both diversity and abundance of benthic invertebrates. The number of taxa and their densities are markedly higher in the Basin and mixed portion of lower headpond where the bottom has been scoured and consists mostly of coarse sands, gravel and rock. Upstream, the substrate gives way to progressively finer sediments consisting mostly of brown and grey muds which support fewer benthic animals. Numbers are lowest in the very deep areas of the headpond where reduced black mud predominates. The greatest

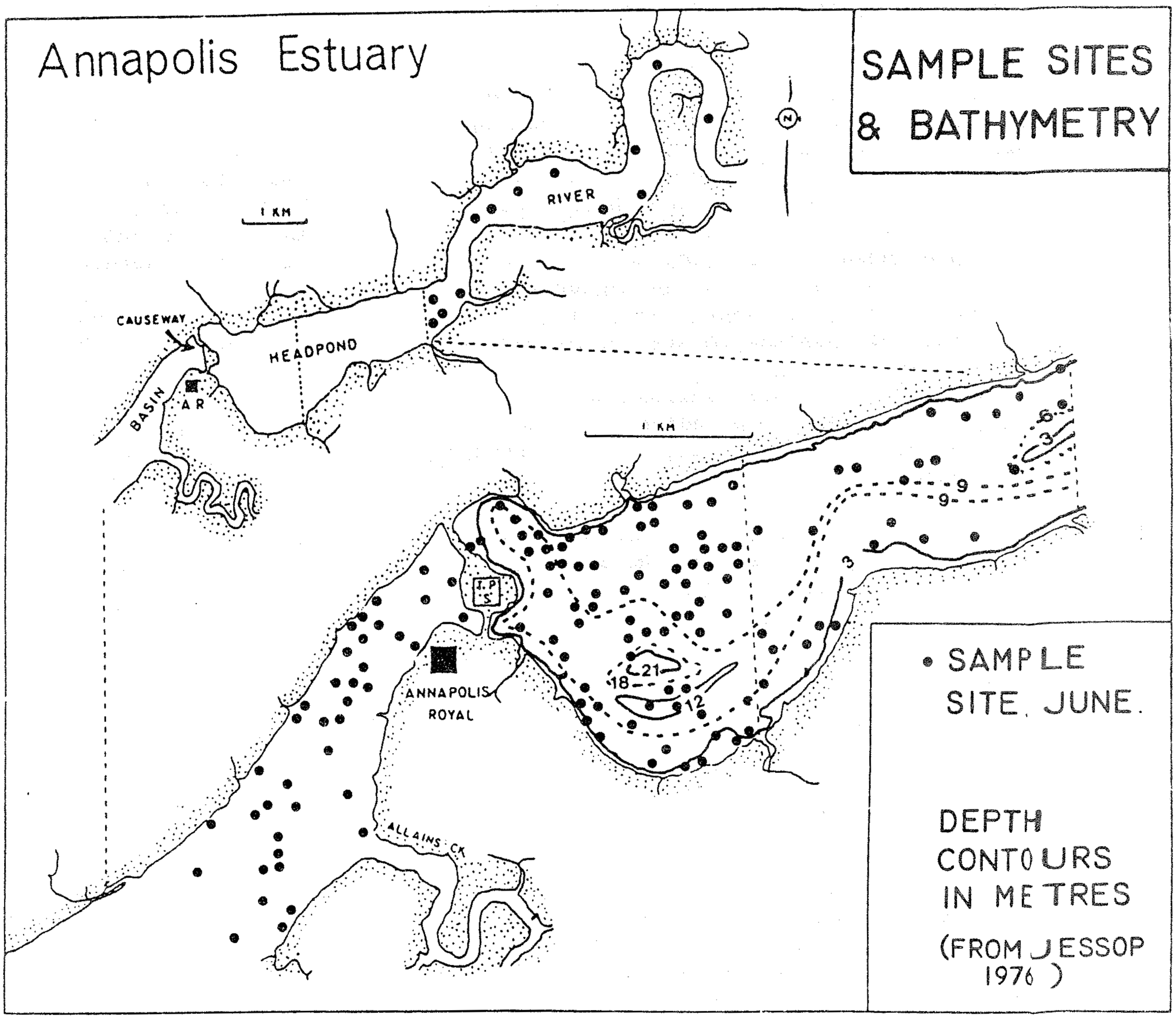


Fig. 2. Benthic sampling stations and bathymetry of the Annapolis Estuary, 1981.

diversity and abundance is consistently found at near shore stations in the lower headpond and Basin.

DISCUSSION

The present studies have demonstrated that the physico-chemical and biological features of the Annapolis Estuary are strongly influenced by the degree of water column mixing and stability of stratification. With an increase in turbulence and subsequent mixing due to turbine operation, one may expect considerable effects.

One of the most obvious consequences of greater mixing will be to destabilize stratification in the headpond so that it is more easily broken down. With a greater influx of saline water from the Annapolis Basin and increased turbulence, surface-to-bottom salinity differences in the lower headpond will be diminished. The effect is expected to extend for about 1 km upstream from the dam. Farther upriver, however, stratification should be more pronounced as bottom water salinities reach slightly higher levels. Greater mixing in the headpond should maintain higher levels of dissolved oxygen. At the same time, an increase in turbulence will be associated with reduced surface temperature.

The biological consequences of greater mixing above the barrage may be diverse. Present data indicate that reduced mixing, as a result of impoundment, provides highly favorable conditions for plankton production. An increase in mixing and subsequent lower summer surface temperatures may reduce phytoplankton production. Benthic suspension feeders may also come into competition with the zooplankters due to an increase in the availability of phytoplankton for grazing. As a result of competition in the mixed headpond waters, levels of both phytoplankton standing crop and zooplankton production may be reduced. At the expense of the zooplankton, one might then expect to see an increase in the diversity and abundance of benthic fauna in the lower headpond, and, as the intertidal zone above the barrage will be increased, one should also expect an increase in the already high densities of near-shore benthic invertebrates.

Ecological studies in the Annapolis Estuary will be continued in order to test the strength of the above prediction. Although the Annapolis project is a very poor paradigm for the proposed tidal power developments in Cobequid Bay or Cumberland Basin, many aspects of turbine operation and its environmental impact may be relevant. It is hoped that the accumulated knowledge and experience of these studies will make possible more refined and reliable predictions of the biophysical consequences in modifying the pattern and degree of vertical mixing in future large scale developments.

REFERENCES

Boates, J.S. 1977. A microdistribution study of stream insects of the Annapolis River, Nova Scotia. B.Sc. Honours thesis, Acadia University, 55 pp.

Daborn, G.R., R.R.G. Williams, J.S. Boates and P.S. Smith. 1979(a). Limnology of the Annapolis River and Estuary; 1. Physical and chemical features. Proc. N.S. Inst. Sci. 29: 153-172.

Daborn, G.R., J.T. O'Neil and R.R.G. Williams. 1979(b). Limnology of the Annapolis River and Estuary: II. Fish distributions in the Estuary, 1976 and 1977. Proc. N.S. Inst. Sci. 29: 173-183.

Daborn, G.R., A.M. Redden and R.S. Gregory. 1982. Ecological studies of the Annapolis Estuary. Acadia Univ. Inst. Publ. No. 29, 80 p.

Jessop, B.M. 1976. Physical and biological survey of the Annapolis River, 1975. Data Record Series No. MAR/D-76-8, Fish. Mar. Serv. Can. Dept. Environ., 29 p.

Jessop, B.M. 1980. Creel survey and biological study of the striped bass fishery of the Annapolis River, 1978. Manu. Rept. Fish. Mar. Serv. Can. Dept. Environ., No. 1566, 20 p.

Jessop, B.M. and W.G. Doubleday. 1976. Creel survey and biological study of the striped bass fishery of the Annapolis River, 1975. Tech. Rept. Fish. Mar. Serv. Can. Dept. Environ. No. MAR/T-76-3, 47 p.

Jessop, B.M. and C. Vithyayasai. 1979. Creel surveys and biological studies of the striped bass fisheries of the Shubenacadie, Gaspereau and Annapolis Rivers, 1976. Man. Rept. Res. Branch Can. Dept. Fish. Oceans, No. 1532, 32 p.

QUESTIONS AND COMMENTS

Unknown: Do you have any idea of the difference between zooplankton production in the Annapolis Basin and the headpond behind the causeway?

A. Redden: Only in terms of abundance of zooplanktors in surface and bottom water in comparison to the density of the benthic fauna. It appears to be quite obvious that there are a large number of barnacle and other benthic larvae in the Basin and a surprisingly low number of obligate zooplankton in relation to the amount of available nutrients. The light penetration in the Basin is much greater than in the headpond. We would expect phytoplankton production to be high there as well.

Possible Impact of Tidal Power Development on the Spawning Population of American shad (Alosa sapidissima) in the Annapolis River, Nova Scotia

by

Gary D. Melvin

Aquatic Industries Ltd.
St. Andrews, New Brunswick
EOG 2XO

and

Michael J. Dadswell

Department of Fisheries and Oceans
Fisheries and Environmental Sciences
Biological Station, St. Andrews,
New Brunswick EOG 2XO

ABSTRACT

A spawning run of approximately 100,000 American shad was present in the Annapolis River during both 1981 and 1982. The population was dominated by old, repeat spawners with a slow growth rate. Potential mutilation rate of 50-cm shad, estimated using the Von Raben relationship, was 9% for a single passage through the designed STRAFLO low-head turbine. Future adjustment of the shad population to turbine mortality should provide a sensitive monitor for the effect of turbine operation on other fish populations in the river.

Key words: population dynamics, natural mortality, turbine mutilation rate, low-head turbine, Bay of Fundy, STAFLO, fish passage.

RÉSUMÉ

Une population de frai d'environ 100 000 aloses savoureuses était présente dans la rivière Annapolis au cours des années 1981 et 1982. Cette population était dominée par des poissons d'âge avancé et à faible taux de croissance, qui n'en étaient pas à leur premier frai.

Le taux de mutilation potentielle des aloses de 50 cm, estimé à l'aide du rapport de Von Raben, a été de 9% pour un seul passage dans la turbine à faible hauteur de chute désignée STRAFLO. Les adjustements futurs de la population d'aloses à la mortalité due aux turbines devraient fournir un mode de contrôle sensible de l'effet du fonctionnement des turbines sur d'autres populations de poissons dans la rivière.

INTRODUCTION

Construction of the powerhouse for a single STRAFLO turbine in the causeway at Annapolis Royal, Nova Scotia, is complete and the turbine on-site. Installation began during the winter of 1982-83 and power generation is scheduled to begin in 1984. During the spring of both 1981 and 1982 we conducted baseline surveys on the spawning run of American shad, *Alosa sapidissima* (Wilson 1811), returning to the Annapolis River. This population should prove a sensitive, natural monitor for estimating the impact of turbine operation on the local fish populations.

The Annapolis spawning population of shad is large (estimated 1981: 100,000-150,000; 1982: 80,000-100,000), dominated by older fish (mean age males = 4.4 y; females = 4.7 y) and has a high portion of repeat spawners (over 75%) (Melvin 1982). The condition factor of adults from the weight-length relationship was poor (males = 2.95; females = 2.53), expressing the multiple spawning nature of the population (up to 7 repeats) and growth rate was slow (K for males = 0.23; for females = 0.21) (Fig. 1). Instantaneous total mortality (Z) of the adult spawners was 0.43. Since the catch from both local sport and commercial fisheries was small (est. 10,000 shad), total mortality probably approximates the instantaneous natural mortality (M) for this population. Fecundity is low but similar to other northern populations (Fig. 2). Distance recaptures of tagged shad from this population indicates it participates in the shad migration around the Bay of Fundy in summer (Dadswell et al. 1983) and then migrates offshore to overwinter from the Nova Scotia shelf to Virginia (Dadswell and Melvin unpubl. data).

The Annapolis River has the only large shad population in eastern North America not commercially fished by selective gear and is unique in this respect. Commercial and sport fisheries are confined to relatively inefficient and non-selective methods such as scoops and hook and line. Shad are moderately large (adult length 40-60 cm) and adults will traverse the turbine only once or twice a year during up or downstream migration, depending on the mode for filling the headpond (sluicing through gates and/or turbine; Anon. 1980). Accordingly, change or similarity in the population structure between pre-operation (1981-82) and for some time period after operation (6-8 years for turbine mortality of adults to effect recruitment) should give a measure of turbine-related impact.

IMPACTS

A scenario of possible population changes that could be caused by various levels of turbine mortality is presented in Table 1. Calculated mutilation rate using the Von Raben (1957) relationship indicates a 50-cm shad would be hit an expected 9% of the time during passage through a turbine with specifications of the STRAFLO being installed at Annapolis Royal (Dadswell 1984, Douma and Stewart 1981). Since mortality rates approximate 50% of expected mutilation rate (Ruggles 1980), mortality is expected to range from 5-10% of each spawning run. If this estimate proves valid, the shad population in the Annapolis River should undergo little

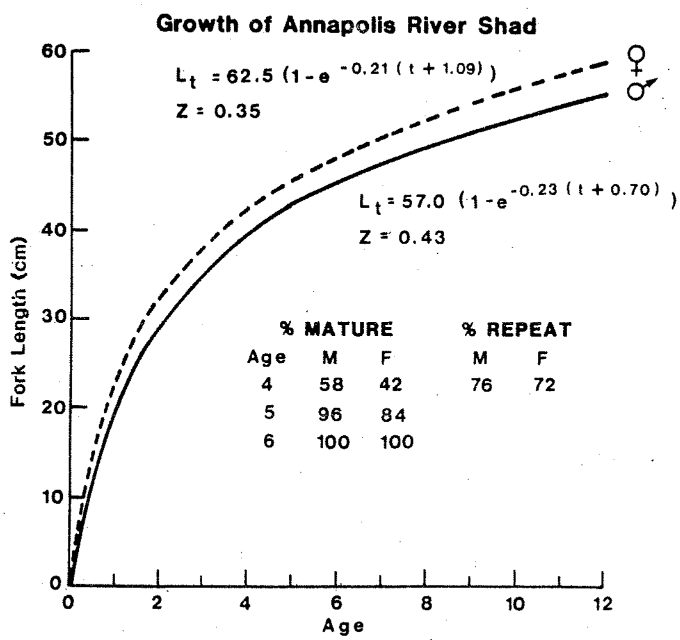


Fig. 1. Growth and population parameters of spawning American shad from the Annapolis River.

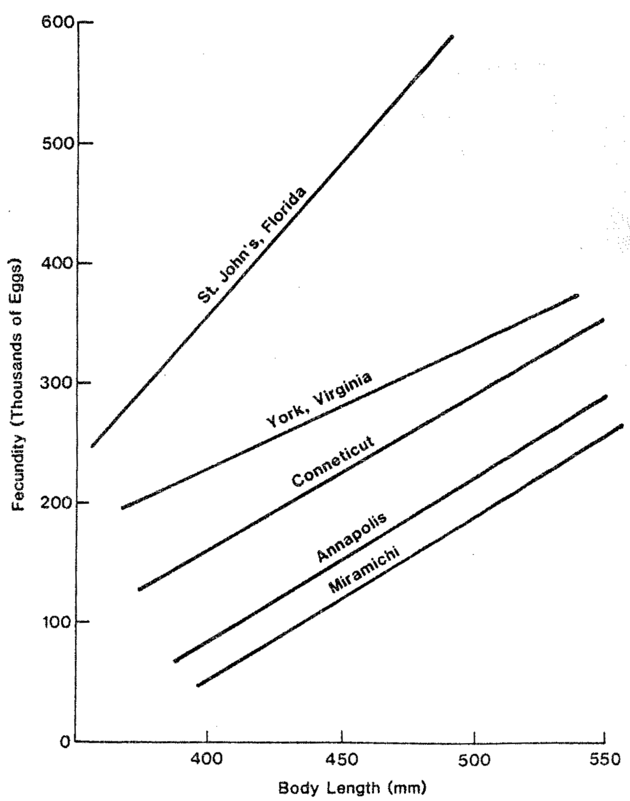


Fig. 2. Fecundity of American shad from the Annapolis River, N.S. as compared to other shad populations of eastern North America.

TABLE 1. Annapolis tidal power scenario for effects of different levels of turbine mortality on the Annapolis River shad spawning population.

Turbine Mortality	Population Size	Growth rate	% Repeat Spawners	Mean Age (y)	Mean Lifetime Fecundity
Low (1-10%)	Stable	No change	Slightly lower	6-8	No increase
Moderate (11-50%)	May increase (fishing up)	Slight increase	Less than 50%	4.5-5.5	Slight increase
High (51-90%)	Decline (overfishing)	Increase	Few or none	4.0-4.5	Increase
Unacceptable (91-100%)	Variable (possible collapse)	Increase	None	4.0-4.2	Decline

change from present conditions as a result of tidal power generation at Annapolis Royal. If a change is expressed, it could be used for modelling turbine mortality of larger fish and/or those that traverse the turbines numerous times in one year (striped bass, Atlantic sturgeon).

ACKNOWLEDGMENTS

We thank Mr. G. Baker and the Nova Scotia Tidal Power Corporation for providing the funds necessary to perform this study. J. Martin, K. Jarvis, M. Kellock and J. Williams assisted in the field. The Department of Fisheries and Oceans provided equipment and logistic support. F. Cunningham prepared the figures and J. Hurley typed the manuscript.

REFERENCES

Anon. 1980. Annapolis tidal power project fish passage investigations. Martec Ltd., Halifax, 82 p.

Dadswell, M.J., G.D. Melvin, and P.J. Williams. 1983. Effect of turbidity on the temporal and spatial utilization of the inner Bay of Fundy by American shad (Alosa sapidissima)(Pisces: Clupeidae) and its relationship to local fisheries. Can. J. Fish. Aquat. Sci. 40 (Suppl.1): 322-330.

Dadswell, M.J., G.D. Melvin, P.J. Williams, and G.S. Brown. 1984. Possible impact of large scale tidal power developments in the upper Bay of Fundy on certain migratory fish stocks on the northwest Atlantic. In this report.

Douma, A., and G.D. Stewart. 1981. Annapolis STRAFLO turbine will demonstrate Bay of Fundy tidal power concept. Hydro Power 1: 1-8.

Melvin, G.D. 1982. Report on the Annapolis River American shad - 1981. A preconstruction study. Aquatic Industries Ltd., Rept. No. 3, 58 p.

Ruggles, C.D. 1980. A review of the downstream migration of Atlantic salmon. Can. Tech. Rept. Fish. Aquat. Sci. No. 952, 39 p.

Von Raben, K. 1957. Zur Frage der Beschadigung von Fischen durch Tubinen. Die Wasserwirtschaft. 4: 97-100.

QUESTIONS AND COMMENTS

D. Greenberg: Will the spawning area of shad in the Annapolis River be affected by the increased upriver penetration of saline water under the new tidal barrage regime?

G. Melvin: No, they spawn above the present or future possible extent of tidal influence, largely above Bridgetown. Spawning occurs all the way to the headwaters at Aylesford.

Unknown: Is the Annapolis the only river in Nova Scotia with a shad population?

G. Melvin: No, the Shubenacadie River has an excellent population of shad as well as striped bass.

G. Brown: Do you believe that the growth rate of the shad population will increase if turbine mortality reduce the population?

G. Melvin: No. Generally if you remove the older, slower growing fish, faster growing younger fish will dominate the population. The result of this will be that population parameters will change since the proportion of younger fish is changed. Because proportionally more young adults would be in the spawning run the general population growth rate K will increase. Individual fish may not grow faster but the general population growth rate will increase. We honestly do not know if there will be turbine mortality of the shad but it is a possibility and this is one parameter that can be easily checked.

G. Brown: Do you think there will be an increase in the fecundity of Annapolis River shad if the population is impacted to a great enough degree?

G. Melvin: It seems reasonable. Biological systems will attempt to reorganize themselves if they are being detrimentally effected. One way fish populations adjust to additional mortality of adults is to increase fecundity. Another way is to spawn at a younger mean age.

Unknown: Can you be sure in which direction population characteristics will change?

G. Melvin: We can't be. All the mentioned changes are just possibilities. Perhaps only small fish will be able to pass the turbine. Turbine mortality of fish is directly related to length.

R. Ruliffson: In the southestern US, the growth rate of shad is greater and age of maturity is less. Did you see much difference between the Annapolis and these populations?

G. Melvin: Yes, in a number of ways. Southern shad populations have very few repeat spawners. The Annapolis has many. In the south all shad are mature at age 5, in the Annapolis they do not all mature until age 6. The mean age of population maturity in the Saint John's River, Florida is 3.8 years and for the Annapolis River it is 4.7 years.

Potential Fish Mortality Associated with Large Hydroelectric Turbines

Norval H. Collins

Washburn and Gillis Associates Ltd.
Suite 527, 1657 Barrington Street
Halifax, N.S. B3J 2A1

ABSTRACT

The general factors influencing fish mortality as a result of passage through a turbine are reviewed. Recent studies have indicated mechanical injury within turbines is highly correlated with fish size and turbine size. Fish passage through large tidal generating units is likely to result in minimal fish mortality during periods of the tidal cycle when turbines are operating near peak efficiency. Significant mortality may be associated with turbine operation at maximum heads because of unfavourable inlet hydraulic conditions. Suggestions for further study are made.

Key words: mortality, STRAFLO turbine, Francis turbine, Kaplan turbine, fish length, tidal power, environmental impact, fish passage

RÉSUMÉ

L'auteur s'est penché sur les facteurs généraux qui influent sur la mortalité du poisson par suite de son passage dans une turbine. Des études récentes ont indiqué que les blessures mécaniques subies à l'intérieur des turbines sont fortement corrélatives de la taille des poissons et des turbines. Le passage du poisson dans une grande centrale motrice est suceptible d'entra°iner une mortalité minimale au cours de certaines périodes du cycle tidal lorsque les turbines sont en service à leur quasi capacité. Une mortalité appréciable pourrait découler du fonctionnement des turbines à des hauteurs de chute maximales en raison de mauvaises conditions hydrauliques d'entrée. Des suggestions sont faites pour l'approfondissement de l'étude.

INTRODUCTION

Fish passing through a turbine are subjected to potentially lethal conditions in the form of pressure differentials, shearing forces (two water masses moving at different velocities), cavitation, and mechanical injury (abrasion, contusion or severing as a result of direct contact with turbine parts). The degree to which these various sources of injury are important is related to fish size, turbine characteristics (e.g. head and runner diameter) and operating conditions. Factors that affect fish mortality resulting from turbine passage have been reviewed by Lucas (1962) and Bell (1981) but accurate prediction of fish mortality using a mathematical synthesis of turbine characteristics, fish species and fish size is not possible because of the complex interaction of these factors. Results of tests investigating fish mortality at turbine installations have been characterized by high variability, which is probably at least partially related to the dynamic hydraulic conditions within a turbine.

The potential for fish mortality at the Annapolis Tidal Power STRAFLO turbine was discussed at an earlier workshop and by Humes et al. (1980). Recently available information (Bell 1981, and Montreal Engineering Company, Ltd. 1982) has provided further insight into the relative importance of fish size and certain turbine characteristics. The various components of fish mortality resulting from turbine passage will be discussed briefly but emphasis will be placed on the importance of fish size in relation to turbine size. The characteristics of the STRAFLO turbine will be discussed in relation to other turbines at which actual fish mortality tests have been conducted.

SOURCES OF FISH MORTALITY

Pressure related injury resulting from passage through a turbine is not a major component of fish mortality in turbines of up to moderately high head (approximately 200 m). The average pressure differentials encountered in a turbine are experienced for a short period of time (0.5 sec) and providing fish entering the turbine have been acclimated to atmospheric pressure, the pressure drop encountered in the turbine runner area is not sufficient to cause rupture of the air bladder or air embolisms in the blood. Harvey (1963) demonstrated that sockeye salmon smolts (Oncorhynchus nerka) could withstand sudden reductions in hydrostatic pressure from 2.1 MPa (equivalent to a head of about 206 m) to atmospheric and below.

While overall pressure differentials within a turbine are unlikely to result in significant fish mortality, localized hydraulic conditions within a turbine can differ substantially from average conditions. Turbulent flow patterns can occur between the runner blade and housing and at the entrance and exit of gate and blade structures. Minute pockets of low pressure can occur which implode when they are carried into the main water flow (i.e. cavitation). Tests have indicated stresses in the order of 350 MPa (50,000 psi) along with high temperatures can result from cavitation. Cavitation is potentially harmful to a turbine and is controlled by maintenance of positive pressure within the turbine. The vertical placement of the turbine in relation to tailwater level is used to prevent excessive cavitation, deeper settings providing higher positive pressures within the turbine. While cavitation is potentially lethal to fish, tests conducted under varying tailwater levels, which would be expected to result in variations in the magnitude of cavitation, have not shown significant correlations between tailwater levels and fish mortality (Bell 1982, Montreal Montreal Engineering Company, Ltd. 1982). It appears that the localized effect of cavitation reduces its overall importance as a cause of fish mortality.

Injury as a result of shearing action of different water flow patterns and actual contact with parts of a turbine appear to be the most common form of fish injury within a turbine. Bell (1981) concluded that inlet conditions, particularly the design of the leading edge of the runner blade, could be a major factor determining the magnitude of fish mortality. Montreal Engineering Company Ltd. (1982) found that variation in flow conditions below the turbine runner had little apparent affect on fish mortality. While injury can occur anywhere within a turbine, flow conditions at the inlet to the turbine runner or within the runner area appear to be the most important determinant in fish mortality.

Turbine efficiency is related to the flow pattern within the turbine. Optimum efficiency is obtained when flow is most streamlined and when negligible whirl remains. Fish mortality is closely correlated with turbine efficiency with minimum mortality occurring at the point of maximum turbine efficiency. The relationship between turbine efficiency of some Francis and Kaplan turbines is illustrated in Figs. 1 and 2. While minimum mortality occurs at maximum turbine efficiency, the rate at which mortality increases as efficiency decreases varies considerably between turbines.

TURBINE CHARACTERISTICS

The magnitude of fish mortality varies between types of turbines and the head under which the turbine operates. There appears to be a relationship between size of water passages within a turbine and the magnitude of fish mortality (Bell 1981). Francis turbines, generally used at heads of greater than 50 m, have more blades and therefore smaller water passages than Kaplan or propeller turbines, generally used at lower heads. Within the Francis turbines (Fig.1) fish mortality increased as turbine size decreased: the Shasta turbine was the largest (runner diameter = 4.67 m) and fish mortality was near 12% at optimum while the Lequille turbine was the smallest and fish mortality was near 53% at optimum for similarly sized fish. In comparison, fish mortality in the Kaplan turbines (Fig.2) was less than 10%. The Kaplan turbines had 6 blades compared to the 13 or 15 blades of the Francis turbines and water passages were comparatively larger.

The relationship between fish size and mortality was investigated at the Lequille turbine in Nova Scotia (Montreal Engineering Company Ltd. 1982). The relationship between fish length and the mortality represented by only those fish that were severed is illustrated in Fig. 3. The mortality represented by severed fish is used to illustrate the component of mortality most clearly associated with shearing forces or contact with the runner. At Lequille, minimum clearance between the runner blades was 5 cm and at optimum efficiency minimum clearance between the wicket gates and runner blades was 8.3 cm. A combination of regression equations using injury types that were length correlated predicted that a fish of about 5 cm should escape injury. An estimated "effective water passage width" can be calculated by the following formula initially suggested by Von Raben (1957):

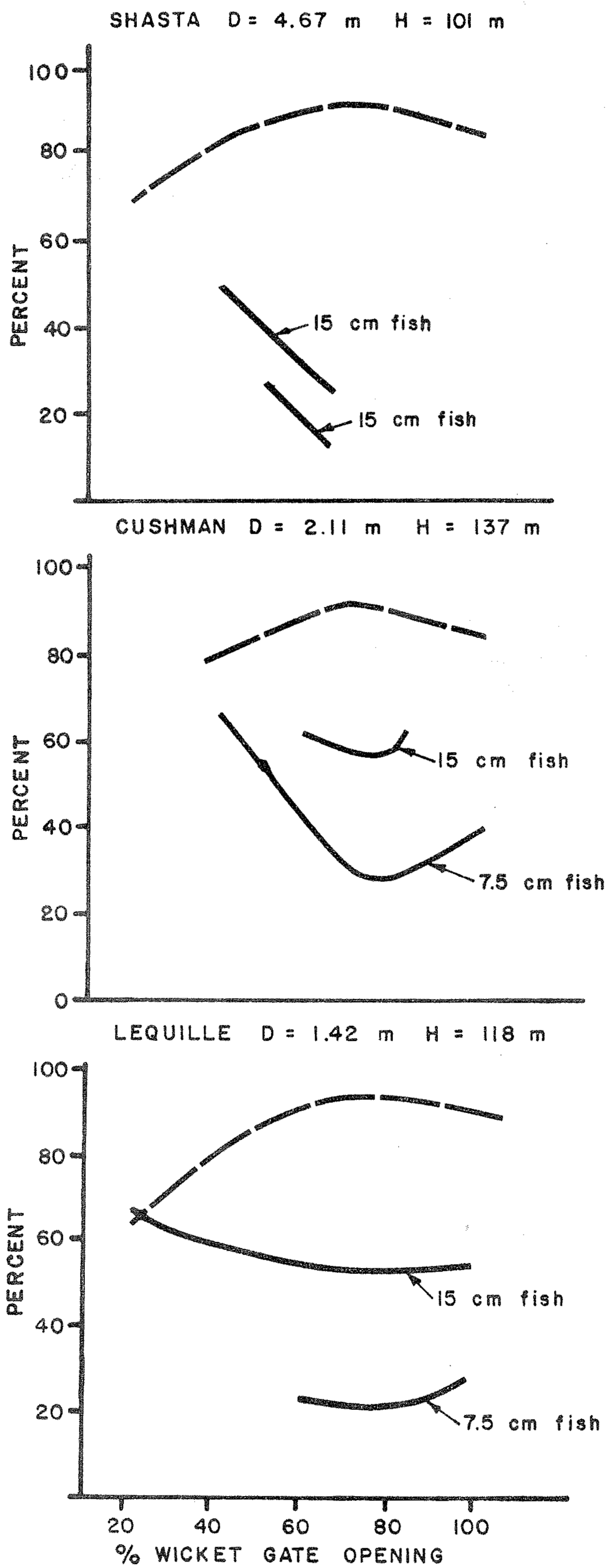


Fig. 1. Fish mortality and turbine efficiency in three Francis turbines; (dash line) represents turbine efficiency, (solid line) represents fish mortality resulting from passage through turbine, (D) represents turbine runner diameter, (H) represents operating head of the turbine. Data from Cramer and Oligher (1964) and Montreal Engineering Co. (1982).

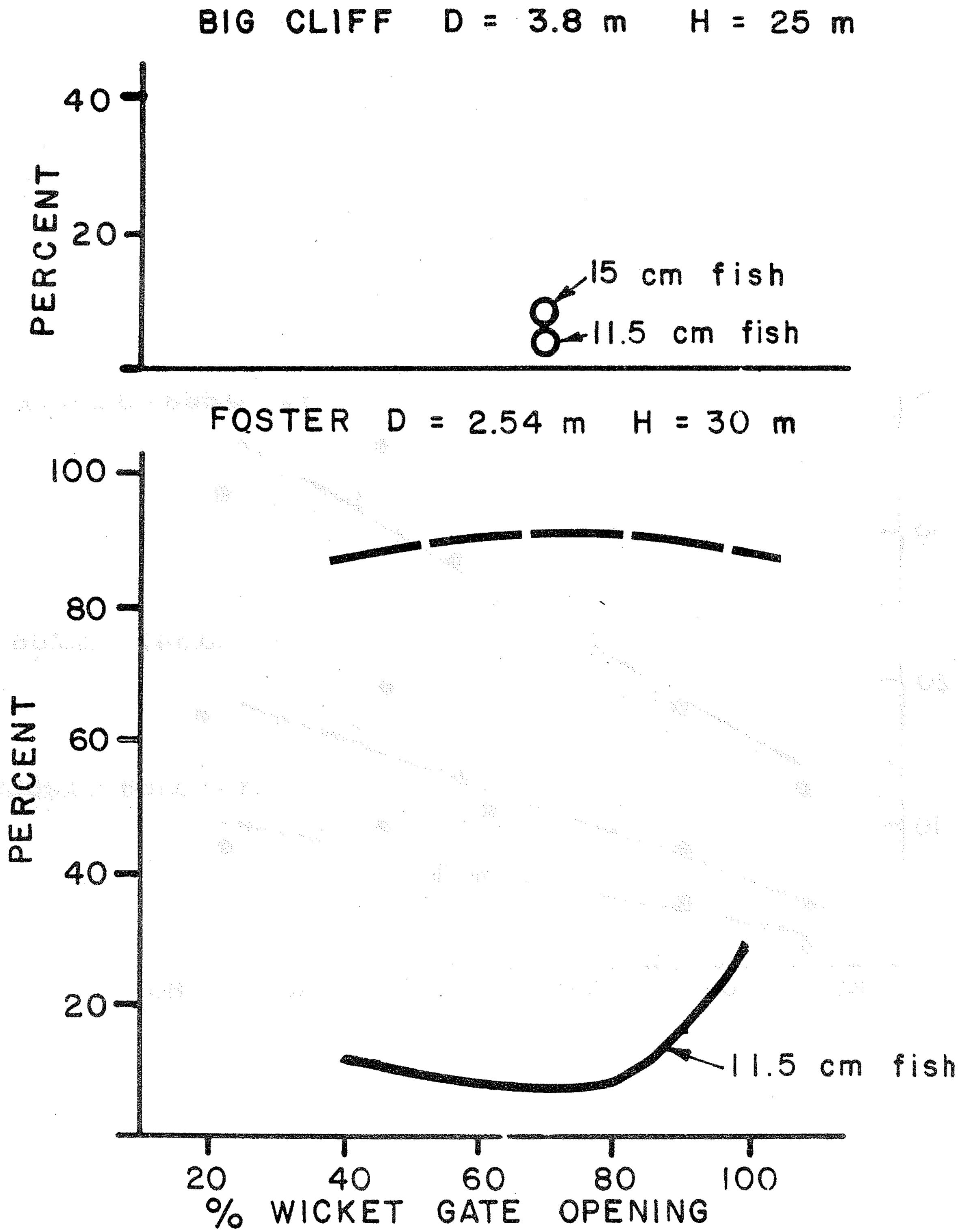


Fig. 2. Fish Mortality and turbine efficiency in two Kaplan turbines; (dash line) represents turbine efficiency, (solid line) represents fish mortality resulting from passage through the turbine, (circle) represents average fish mortalty for two size groups of fish, (D) represents turbine runner diameter, (H) represents operating head of the turbine. Data from Bell (1981).

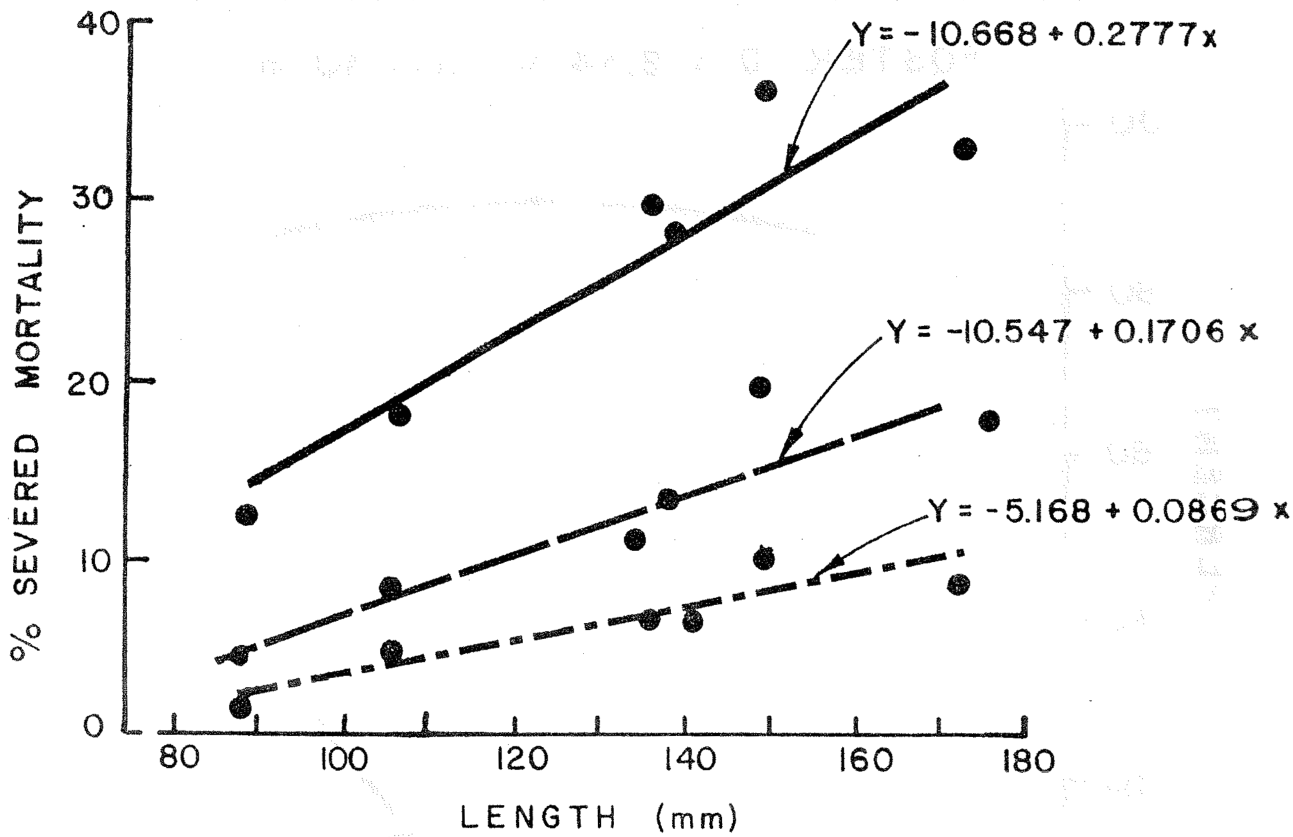


Fig. 3. Relationship between mortality of fish severed during turbine passage to fish length at Lequille; (solid line) represents tests at 100% wicket gate opening, (dash line) represents tests at 75% wicket gate opening, (dash and dot line) represents tests at 50 and 60% wicket gate opening, equations are linear regressions with Y representing mortality and X representing fish length. Data from Montreal Engineering Co. (1982).

$$w = \frac{\text{Flow (60)}}{\text{Cos a (No. blades) (RPM) (inlet area)}}$$

where Cos a = cosine of the angle between inflow water trajectory and the tangent to the runner at the inlet

For the Lequille turbine, w = 7.3 cm, similar to the size of fish predicted by analysis of injury data to escape mechanical injury. While the above formula may have some predictive power for indicating the approximate size of fish that would be subjected to minimal mortality, it does not accurately predict the level of mortality for fish above the minimum size. The overall fish mortality measured at Lequille is illustrated in Fig. 4. Fish mortality appears to be composed of a complex set of factors and only a few are covered by this formula. Mortality is probably not a simple linear function of fish length. In fact, at Lequille the proportion of mortality due to mechanical type injuries (shearing or contact) only accounted for 27.7 to 61% of total mortalities. At Lequille, cavitation and possible localized pressure differentials appeared to be responsible for a significant amount of the observed mortality.

POTENTIAL FISH MORTALITY IN PASSAGE THROUGH LARGE TIDAL TURBINES

While precise prediction of fish mortality at a turbine installation is not possible, sufficient data are available to allow mortalities within a few percentage points to be estimated in some situations. A tidal generating station in the Bay of Fundy would likely be composed of large units similar to that being installed at the Annapolis Tidal Power Project. Characteristics of the Annapolis STRAFLO turbine are provided in Table 1 along with those of the Lequille turbine for comparison. Water passages within the STAFLO are large with a minimum clearance of 88 cm between the wicket gates and blades. Based on the above formula for "effective water passage width", fish of up to 2.98 m length can be expected to suffer minimal mortality from shearing forces or contact with the blades. The calculation of "effective water passage width" used a cos a of 1.0 which therefore provides a minimum estimate of passage width.

Calculation of the "effective water passage width" provides an estimate of fish length under which only minimal mortalities are expected. Mortalities for fish larger than this minimum length would be expected to increase with fish length. The large size of the water passage also reduces the likelihood of a fish passing through a lethal zone of cavitation or large pressure differential. The probability of a fish passing through a localized lethal zone is probably more a function of turbine size than fish size. At Lequille, a large number of injury types did not demonstrate a significant correlation with fish size. There is likely a minimum mortality associated with passage through a large turbine which is dependent on the cavitation potential and the overall efficiency of water passage through the turbine. Maximum pressure drop within the inlet to a horizontal flow turbine such as the STRAFLO is expected to be in the order of 90% of the net head. In the case of a large tidal barrage, fish passing

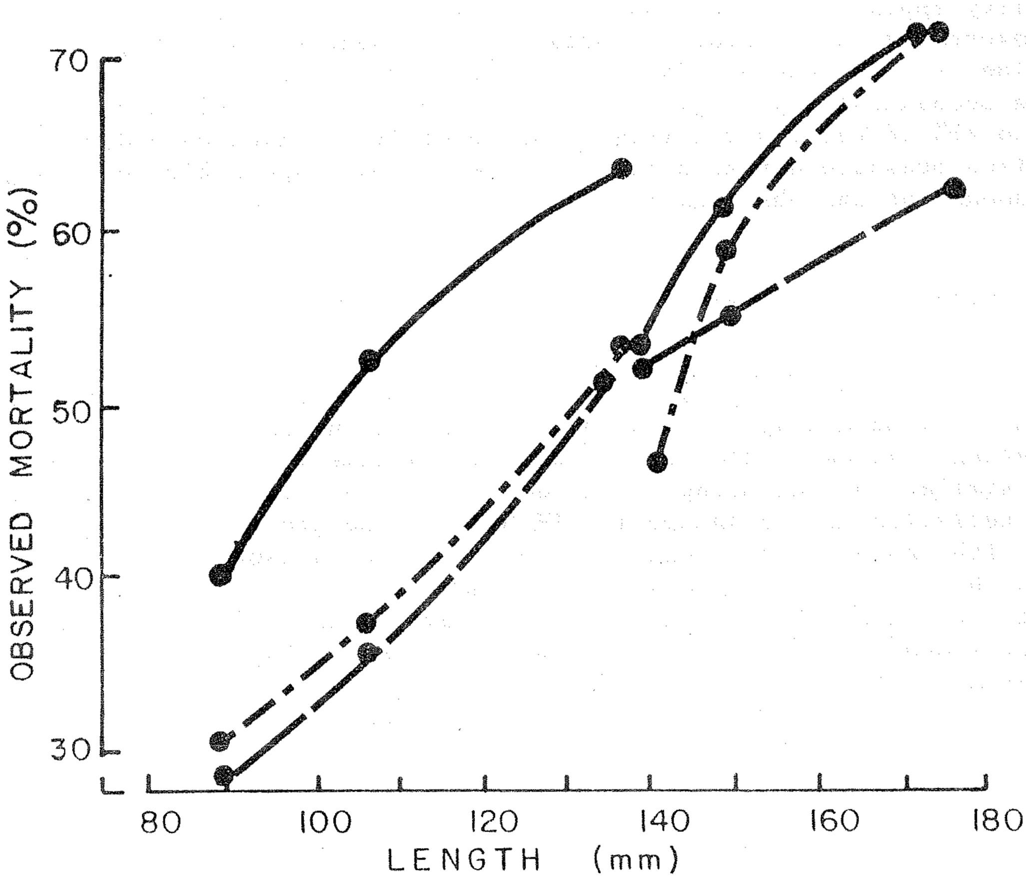


Fig. 4. Relationship between overall mortality of fish resulting from fish passage to fish length at Lequille; (solid line) represents tests at 100% wicket gate opening, (dash line) represents tests at 75% wicket gate opening, (dash and dot line) represents tests at 50 and 60% wicket gate opening. Data from Montreal Engineering Co. (1982).

TABLE 1. Characteristics of turbines installed at Lequille (hydropower) and Annapolis (tidal power)

Characteristic	Lequille	Annapolis
Type	Francis	STRAFLO
Rated head	118 m	5.5 m
Rated horsepower	15,000	23,000
Discharge at rating	11.3 m^3/s	378.0 m^3/s
RPM	514	50
Manufacturer	Dominion Eng.	Escher Wyss
Number of Blades	13	4
Runner diameter	1.38 m (inlet)	7.6 m
Runner hub diameter		3.04 m
Efficiency at rating	92.3%	87.3%
Efficiency at minimum head		78.0%
Efficiency at maximum head		81.8%

through the turbines may be acclimated to relatively deep water but the pressure differentials in a low head turbine are still unlikely to be sufficient to result in significant mortality.

Efficiency in the Annapolis STRAFLO turbine is expected to be within the range of 78 to 89% except for a short interval of operation (25 min under mean tides) when heads are less than 2 m. At maximum head, the wicket gates would partially close reducing the intake area by 21% (a wicket gate opening of 57%). Under maximum generation and maximum head, turbine efficiency would drop to 82%. Inlet hydraulic conditions are likely to be poor in terms of fish passage when the wicket gates are used to restrict flow. A turbine with adjustable blade pitch would improve turbine efficiency and reduce fish mortality under these conditions. It is not possible to accurately predict what level of mortality would occur under maximum generation but a mortality of around 30% as found in the Foster turbine (Fig. 2) under maximum generation is possible. Given the large size of the STRAFLO or other tidal generating turbines, maximum mortalities would likely be less than 30% and over two-thirds of the generating cycle mortalities when turbine efficiency is relatively high would likely be less than 5%.

Turbine operation in a tidal generating station differs from that in a standard hydroelectric development. In a tidal development, variation in head is extreme and it may not be economically feasible to install turbines with adjustable blades which would maintain relatively high efficiency over the entire spectrum of heads. A tidal generating turbine without wicket gates but with variable pitch blades is also a possibility. Since in general clearances between the wicket gates and runner blades do not appear to be crucial in large tidal turbines, relative turbine efficiency is probably a better criterion for selecting a turbine that minimizes fish mortality. If a turbine without wicket gates is lower in operating efficiency, fish mortality is likely to be greater. The potential for substantially reduced fish mortality should be assessed in the economic evaluation of tidal turbines.

It should also be noted that given a particular turbine design, operation and layout of the generating station can significantly affect the overall fish mortality that results from the installation. In particular, elimination of generation at minimal heads, when generating efficiency is low, may be advisable. In this regard, it is extremely important to have information on the timing of fish movement through the turbine in relation to the tidal cycle. Fish may concentrate their movements through a tidal barrage at mean tides when water velocities through turbines or sluices are low. If fish remain near the surface and avoid high velocity areas, simple gated openings through the barrage may pass a high proportion of the fish when headpond and tailwater elevations are near equal.

SUGGESTIONS FOR FURTHER STUDY

Inlet hydraulic conditions may be a major factor influencing the magnitude of fish mortality associated with passage through a turbine.

Investigations of fish mortality at large tidal generating stations is extremely difficult because of the large water flows involved. A small turbine of design similar to the STRAFLO is currently being completed by the Nova Scotia Power Corporation on the Sissiboo River. This turbine could provide a useful test site to evaluate the potential fish mortality associated with larger prototype units.

While accurate estimates of fish mortality at the Annapolis STRAFLO turbine would be difficult to obtain, information on fish movements within the intake and tailrace structures would be helpful in determining the potential impact of a large tidal power development on fisheries. While there is considerable information on fish behaviour in relation to fish passage at hydroelectric facilities, there has been little study of fish behaviour in tidal environments.

REFERENCES

Bell, M.C. 1981. Updated compedium on the success of passage of small fish through turbines. U.S. Army Crops of Engineers, North Pacific Division, Contract No. DACW-68-76-C-0254.

Cramer, F.K. and R.C. Oligher. 1964. Passing fish through hydraulic turbines. Trans. Am. Fish Soc. 93: 243-259.

Harvey, H.H. 1963. Pressure in the early life history of sockeye salmon. PhD thesis, University of British Columbia.

Humes, T.M., M.E. Coolen, and N.H. Collins. 1980. Fish passage at the Annapolis Tidal Power Development. Paper presented at the Northeast Fish and Wildlife conference, Ellenville, N.Y.

Lucas, K.C. 1962. The mortality to fish passing through hydraulic turbines as related to cavitation and performance characteristics, pressure change, negative pressure and other factors. In: Proceedings of the International Association for Hydraulic Research Symposium on Cavitation and Hydraulic Machinery, Sendai, Japan, pp. 307-335.

Montreal Engineering Company, Limited. 1982. Fish mortality in Francis turbines. Prepared for the Canadian Electrical Association, Montreal, P.Q., Contract No. G 261.

Von Raben, K. 1957. Turbines and their destructive effect on fishes. (translated from German by the Fish. Res. Board Can.) Zeitschrift fur Fischerei und deren Hilfswissenschaften, Sonderdruck aus Band VI Heft 1-7, pp. 171-182.

QUESTIONS AND COMMENTS

G. Brown: What happens to the fish that are damaged by the turbines?

N. Collins: Some of them die. It is quite difficult to compare the results from different studies, because you are really not sure what they used for their criteria to divide injuries that would cause death and those that wouldn't. In the main data set which I used for comparison they reported that mechanical injury caused 70% of the mortalities. This could mean the fish were in pieces, or that they had torn opercula, missing fins, or similar injuries. There would have been few dead fish that appeared uninjured. In tests at Lequille, the types of injuries were different. We had a large number of fish with no visible injuries that were dead. They had blotchy skin which may have been caused by cavitation but we were not sure.

G. Brown: Can you explain cavitation?

N. Collins: In general at the inlet of a turbine, the water velocity should be the same over the entire height of the blade. Blades from different turbine designs have a different shape and size at the inlet. This provides a constant velocity over the blade. The flow through turbines should be smooth, because the smoother it is the higher the efficiency is. At the outlet there is lower pressure below the blade and higher pressure above. This is where shearing forces occur. It is the same idea as lift on an airplane wing. The differences in pressure on the blade is what lifts or pushes it. This creates an area below the turbine runner where two zones of different water velocities merge. There is more water pushing the front of the blade than behind it, and this is where shearing or cavitation occurs. If the low pressure areas reach the vapour pressure of water, then vapour pockets form that implode as they move into higher pressure areas.

G. Brown: How do you do these experiments? Are there controls?

N. Collins: Experiments have been conducted in many different ways. I think studies that have credibility used large numbers, say around 10,000 fish. In my studies I used about 7000 fish in groups of 100. Sometimes we would have three size class groups going into the turbine at once and they were considered three separate tests. That type of experimental design is usual. Fish are introduced somewhere upstream of the turbine. What we did was introduce the fish at the top of the penstock, the pipe leading to the turbine, about 400 m from the turbine. Velocities were too high there for the fish to swim against the current so we knew they would go through the turbine. We tried to introduce the fish without causing injury. We used PVC pipe and poured them down. The control fish were treated, identically but were introduced to the tailrace below the turbine. You try to perform the same activities with the control fish so they are recaptured by the same gear but do not go through the turbine.

P. Larsen: Is there reason to believe there are lethal effects from fish passage through turbines that do not manifest themselves immediately?

N. Collins: I think that the relative importance of discriminate and indiscriminate stress has largely been determined for turbines. Our studies suggested that fish are either fine or dead. There can be predation at the outflow of the turbine because the fish can be mildly stunned. We held all our fish for at least a week to check for delayed mortality. There were frequently a small number of fish with minor injuries and it was difficult to estimate the long term effect of these injuries. Normally the main stress appeared to be on the air bladder due to pressure effects and that is unlikely to have any long term sublethal effects. Air bladders are stretchable to certain limits. The exposure appears to be short and is limited to about half a second during turbine passage.

Possible Effects of Tidal Power Development in the Upper Bay of Fundy On Anadromous Fish Passage

J.R. Semple

Department of Fisheries and Oceans
Fisheries Research Branch
P. O. Box 550, Halifax, N.S.
B3J 2S7

ABSTRACT

This report summarizes some of the probable negative effects of a tidal power barrage in the upper Bay of Fundy on the passage and hence maintenance of anadromous fish in freshwater streams embraced by the development. The predicted negative impacts are based mainly on supporting research conducted in freshwater and estuarine situations, since studies of fish passage at marine obstructions are lacking. Probable negative impacts on anadromous fishes include: delayed or failed passage, straying from native rivers, mortality of large adults in turbines (particularly if re-cycling is high), decreased passage time at tidal aboiteaux, and loss of spawning and rearing habitat through inundation if peripheral pumped storage facilities are constructed. It is speculated that the overall success of maintaining passage of anadromous fishes into the tidal headpond and its freshwater tributaries will likely be determined by the ultimate placement and relationship of the sluice (both in plan and elevation) and hydroelectric turbines.

Key words: Atlantic salmon, alosids, striped bass, sturgeon, smelt, STAFLO turbine, mortality, cavitation, sluices, Cobequid Bay, Cumberland Basin.

RÉSUMÉ

Comme il est question d'aménager un barrage de centrale marémotrice au fond de la baie de Fundy (rentrant nord), l'auteur s'interroge au sujet de certains des effets négatifs prévisibles sur le passage et, par conséquent, le renouvellement des poissons anadromes dans les cours d'eau (non salés) affectés par l'aménagement. La prévision de ces effets négatifs s'appuie surtout sur des recherches effectuées dans les milieux d'eau douce et les zones estuariennes, puisqu'il n'y a à peu près pas d'études portant sur le franchissement des obstacles marins par les poissons. Au nombre des effets négatifs probables sur les poissons anadromes, on peut mentionner les suivants: passage retardé ou empêché, abandon forcé des cours d'eau d'origine, mortalité des adultes de grande taille dans les turbines (particulièrement si le recyclage est élevé), diminution du temps de passage aux aboiteaux et, finalement, perte de l'aire de frai et d'accroissement du saumon, de l'alose et du bar rayé par des inondations sur les lieux des

installations possibles de stockage pompé à la périphérie. L'auteur estime que les succès général résultant du maintien du passage des poissons anadromes dans l'échancrure tidale et ses ramifications d'eau douce dépendra vraisemblablement de l'emplacement ultime et de la dispostion relative des vannes registres (tant en plan qu'en altitude) et des turbines hydroélectriques.

INTRODUCTION

There are seven commercially or recreationally important anadromous fish species that could be affected by a tidal power barrage in the upper Bay of Fundy: Atlantic salmon (Salmo salar), alewive (*Alosa pseudoharengus*), blueback herring (*Alosa aestivalis*), American shad (*A. sapidissima*), striped bass (*Morone saxatilis*), Atlantic sturgeon (*Acipenser oxyrhynchus*), and rainbow smelt (*Osmerus mordax*). All of these species spend most of their adult lives in the ocean but migrate to freshwater habitat to spawn.

The fisheries resources of the Bay of Fundy and some of the possible impacts of tidal power development have recently been reviewed by Scarratt (1977). Kerswill (1960) has broadly recorded the possible effects of a tidal power project in the Passamaquoddy Bay area on anadromous fishes and Martin (1960) has done the same for groundfishes. The present report emphasizes some of the possible effects of tidal power development on the passage and migration of anadromous fishes between the tidal barrage and the freshwater streams that it embraces.

Two tidal power sites are presently considered as economically attractive, the mouth of Cobequid Bay (B9) and the mouth of Cumberland Basin (A8). Feasibility designs are for a single effect operation mode whereby power would be generated in only one direction when the head difference between the headpond and the sea is 0.6 m or greater.

FISH PASSAGE AT EXISTING TIDAL STRUCTURES

In the upper Bay of Fundy tidal barrages are present near the mouths of several rivers. In 1968 a causeway was built across the Petitcodiac River at Moncton and a vertical slot fishway was incorporated into the tidal structure to pass anadromous fishes. Despite the provision of a fishway, anadromous fish passage at the causeway was impeded (Dominey 1970a). This finding has been substained by ultrasonic tagging of Atlantic salmon, fishway counts and significant reductions in angling catch and commercial landings of anadromous fishes in statistical reporting areas associated with the Petitcodiac River (Semple 1979).

Tidal barrages are also present near the mouths of the Tantramar, Missaguash and Nappan Rivers at the head of Cumberland Basin and at the Great Village and Chiganois Rivers near the head of Cobequid Bay. All of these barrages were constructed to reclaim marshlands for farming or to prevent flooding. The water control structures at all of these sites, except Tantramar River, are aboiteau flap gates. The flap gates are mounted and hinged on the seaward side of conduits which pass through the barrage. At low tide, the pressure of impounded water automatically forces the gates to open allowing fish passage and conversely closes the gates on the rising tide preventing fish passage.

Salmon passage at the Great Village River aboiteau was investigated by Dominey (1970b). The available information from this study and other unpublished data concerning the Great Village aboiteau indicate that aboiteau structures can provide adequate passage for anadromous fishes. Dominey (1970b) estimated that Great Village River could produce about 400 adult salmon each year. A trap net located upstream from the aboiteau took 207 in 1973; hence, if commercial salmon landings in local and distant fisheries are taken into account, the river appears to be producing salmon near its potential. At electrically operated lift-gates, such as those on the Tantramar River, the problem has been to get the owners to open the gates when water levels on the seaward and landward sides of the gates are near equalization. Observations indicated that under such conditions, anadromous fishes can successfully pass upstream into a tidal impoundment while there is positive flow seaward.

While fish passage at existing tidal barrages in the Maritime Provinces is not quantitatively well defined, the available evidence would suggest that passage is delayed (Riley 1970, Dominey 1970a) and for this reason there may be more straying of homing species like salmon, shad, alewives and striped bass away from their natal rivers.

In rivers where dams have been created above tidal influence and where fishways have been installed to pass shad and striped bass, passage success for these species has in many cases been disappointing (Talbot 1966, Jessop 1975). On the other hand, fishways for salmon (Clay 1961) and some of the more recent fishways for shad (Dalley 1980) have been more successful, provided that the entrance is properly located.

In the Bay of Fundy and Maritime Provinces, shad and striped bass were abundant in the Saint Croix (Walburg and Nicholas 1967), the Saint John (Ruggles and Watt 1975), and the Petitcodiac and Tusket rivers (local accounts). Hydroelectric dams in these rivers, or the causeway in the case of the Petitcodiac River, have nearly eliminated these species from areas above the dams despite the fact that fishways were provided. Not all of the blame for the demise of shad and striped bass in the river reaches affected by these dams is due to fish passage problems. Water quality and spawning and rearing habitats for these species have also been impaired. This is amply demonstrated in the case of the Saint John River (Ruggles and Watt 1975, Jessop 1975).

FISH PASSAGE AT A TIDAL POWER BARRAGE

Emmigration Through Sluice Gates

In order to maintain the production of anadromous fish stocks from the freshwater rivers embraced by proposed tidal power barrages, passage of fish beyond the barrages will be necessary.

The seaward migration of anadromous species that have spawned, and of juvenile fish originating from the spawning, will probably be less difficult than for adult fish trying to reach their home rivers inside the barrage.

Not much is known about the movements of juvenile and adult anadromous species after they enter the ocean (Scott and Crossman 1973). Atlantic salmon originating from Maritime waters are intercepted as far away as West Greenland and Newfoundland (Stasko et al. 1973). Shad, striped bass and alewives that have spawned in Maritime rivers have been recaptured as far south as Virginia and South Carolina (Jessop, pers. comm.). In any event, at some time within the year it is likely that underyearling alewives, shad, striped bass and 1 to 3-year old salmon smolts will be emmigrating out of the areas that would be embraced by the proposed tidal power barrages.

Moreover, it is probable that most emmigrant anadromous species will move out of the tidal headpond(s) during the massive export of water in the power generation phase of tidal power operation. At times, when the tidal inflow through the filling gates creates velocities up to 10 m s^{-1} (Swales 1977), egress through the filling sluice gates will be barred since such a velocity exceeds the maximum swimming speed of most fishes. After extensive review of the literature, Blaxter (1969) concluded that salmonids are capable of burst speeds of 10 b.l.s. (body lengths per second) while weaker swimmers such as alewives probably can only reach speeds of 8 b.l.s.

The orientation of emmigrating anadromous fishes to currents created by emptying (power generation) and filling the tidal headpond(s) will also have a bearing on whether these species leave the tidal headpond(s) through the turbines or through the sluices. Although little is known about the orientation of spent adult shad, alewives, smelt and striped bass (and their juvenile stages) to water currents, the subject has been dealt with extensively for juvenile salmonids (Arnold 1974, Stasko et al. 1973, Ruggles 1980). These reviews suggest that salmon smolts, while in freshwater, orient and swim with the current in low velocity water, but in accelerating currents they orient themselves upstream against the current and are carried passively downstream.

Emmigration Through Turbines

Anadromous fish passing through turbines will be subjected to rapidly changing pressures and the possibility of contact with the rotating turbine blades (Collins 1984). In hydraulic turbines, the velocity is relatively slow and the pressure strongly positive in water passages leading to the turbine (Cramer and Oligher 1964). After passage through the turbine, negative pressures may develop depending on the relative elevation of the turbine runner to the tailwater elevation. This condition can be minimized by setting the turbine runner below the minimum low tide level. The significance of negative pressures in the turbine draft tube is that it can cause cavitation or the violent collapse of vapor masses severe enough to remove small particles of metal from turbine blades; hence, it is potentially harmful to fish using this route.

In connection with smolt passage through hydroelectric turbines, Montén (1955), reported in Mills (1971), considered that because of the short exposure time of fish to high pressure and cavitation, it is unlikely that fish will be injured by them at least up to water heads of 32.3 m. Caulderwood (1945) concluded that Atlantic salmon smolts would not be injured by them at least up to water heads of 32.3 m. From their extensive review of the literature concerning the passage of small fishes through turbines, Bell et al. (1967) indicated that Canadian and American research on the subject of cavitation and damage to fish showed this to be a significant factor. Installation specifications for the tidal power projects proposed for the upper Bay of Fundy would appear to present few problems relative to fish survival and pressure and cavitation in the turbines.

Passage of fish through the turbines will subject fish to the possibility of contact with the turbine blades. While I am not aware of any information relative to fish mortality in the type of turbine (Straflo or bulb type) being considered for potential tidal power developments in the upper Bay of Fundy, they are propeller turbines similar to Kaplan units. Bell et al. (1967) concluded that for Kaplan and Frances turbines the highest survival of fish occurs when the turbine is operated at highest efficiency. For Kaplan turbines, this is achieved by adjusting the blade angle for a given head and load. Bell et al. (1967) provided maximum and minimum fish survival estimates for Kaplan turbines at nine dams and for thirteen tests. The average maximum survival was 95.1% and the lowest maximum survival was 77.1%. The average minimum survival was 73.2% and the lowest survival rate was 0.0%. Since mortality rate in turbines increases as fish size increased (Bell et al. 1967) the mortality of smaller juvenile stages of anadromous fish passing tidal power barrages in the upper Bay of Fundy will be less than that of spent adults.

Because of the large dimensions of the turbines for the proposed developments in Cobequid Bay and Cumberland Basin and because of the relatively slow runner speeds (67.92 to 75 rpm), it is unlikely that turbine mortality of fish will be high, particularly for juvenile anadromous fishes. However, if the feeding behaviour of larger adult anadromous fishes leads to recycling through the turbines, which is quite possible, mortality could be significant.

Immigration to a Tidal Headpond and its Freshwater Tributaries

There is considerable evidence that spawning runs of Atlantic salmon (Stasko et al. 1973), American shad (Mansueti 1955), alewives (Hildebrand 1963) and striped bass (Raney 1952) return or "home" to the stream where their parents spawned. The mechanism whereby these homing species are able to navigate to their native stream is a subject which has received much research and considerable review (Arnold 1974, Liley 1982, Nordeng 1971, Hasler 1966, Stasko et al. 1973).

A widely accepted hypothesis for salmon homing is that salmonids imprint on distinctive odors of the home stream (olfactory hypothesis) during their freshwater residence. Later the adults use this information to locate their natal stream, at least during the later portion of their homeward journey. Hasler et al. (1978) reviewed much of the direct and circumstantial evidence in support of this hypothesis. The pheromone hypothesis (Nordeng 1977) proposed that homeward navigation is an inherited response to population-specific chemicals released by the fish themselves and to which the fish respond. Migrating adults are attracted to streams containing conspecifics (Liley 1982).

If homing is as dependent on olfaction as the evidence suggests, then migration of homing anadromous fish at the tidal barrage could be adversely affected since the turbines will draw the deeper saline water which is likely to lack those odors which would guide the fish to their home streams. Only for a short period of time after power generation until water level equalization would there be any seaward flow of surface waters (assuming the device gates are near water surface) containing native stream odors or pheromones. Hence, it is possible that considerable straying of homing anadromous fishes could result, and much of the fishery and production potential of freshwater tributary streams could be lost for anadromous species. Water currents also influence the route choice of fish (Arnold 1974, Banks 1968) but may be secondary to stream odor. A loss of positive rheotaxis has been observed in chinook salmon displaced upstream from home water (DeLacey et al. 1969). Banks (1968) has reviewed the importance of "attraction water" relative to passing fish at dams and the correct siting for a fishway entrance. In this connection it has been possible for instance with sockeye and chinook salmon to manipulate the spill-pattern at a hydroelectric dam to guide migrant salmon upstream (Leman and Paulik 1966). Collins (1952) found that the choice of migrating route for alewives could be influenced by the velocity of flowing water. The fish took the water with the faster flow. This is also true for salmonids (Banks 1968).

The above findings lead to the conclusion that if olfactory cues do not emminate from the turbine outflow in a tidal power barrage, homing anadromous species may not collect there. If the positive outflow through the filling sluice gates (between turbine shutdown and water level equalization) is only maintained for a short duration of time then anadromous fish migration into the tidal headpond could be severely limited, particularly if the sluice gates are mounted deep below the water surface where pheromones and stream odors may not be present.

If stream odors and pheromones are present during seaward flow through the turbines, then when the rising tide forces water into the tidal headpond fish may move through the sluices voluntarily or be sucked through in the high velocity water.

With regards to the orientation of anadromous fish species in tidal currents, some of the existing research is contradictory and difficult to interpret. Atlantic salmon wander in estuaries (Huntsman 1952). Stasko (1975) found that salmon bearing ultra-sonic tags spent more tidal periods progressing upstream with the current than against it. He concluded that Atlantic salmon moved upstream with flood tides but also found random movements both with and against all phases of the tide. Stewart (1971), in his studies of salmon movement in the Lune Estuary, concluded that more salmon move upstream on the ebb rather than flood tide. With American shad, Dodson and Leggett (1973) found that this species moved upstream against ebb tides while also moving upstream with flood tides. Later research by Dodson and Leggett (1974) showed that on flood tides the orientation of shad ranged from concurrent to countercurrent. Ripe striped bass drift with the tidal flow and then hold position when the tide reverses (Koo and Wilson 1972). Spent striped bass showed unpredictable movements patterns with and against tidal currents. Dudley et al. (1977) found that striped bass ascended the Savannah River to spawn on ebb rather than flood tides.

If and when a tidal power barrage is constructed in Cobequid Bay or Cumberland Basin, the mean tidal elevations and amplitude in the headpond will be changed significantly (Baker 1984). Mean high water in Cobequid Bay will be about 0.6 m lower, mean tide about 2.7 m higher and low tide about 6.0 m higher than before the barrage. Tidal amplitude will be about 5.8 m less.

The implications of the altered tidal regime within the tidal impoundment may be significant relative to anadromous fish passage at aboiteau flap gates located at the mouths of tributary streams embraced by the tidal power barrage. Depending on the sill elevations of the flap gates, the new tidal regime could decrease the available time for anadromous fish passage and result in more straying to unencumbered tributaries.

Increased erosion and sedimentation together with changes in tidal currents within the impoundment may alter the route selection of anadromous fishes and hence the traditional fishing locations and fish landings from these areas.

Since tidal power production will not always be in harmony with the power demand cycle, it is possible that additional storage sites might be created in freshwater tributaries anywhere in the Maritime Provinces and that low demand, low cost power might be used to pump water into these reservoirs to produce power at conventional hydroelectric installations when it is most needed. This could result in lost spawning and rearing habitat (inundation) for salmon, shad and striped bass and new spawning habitat for alewives. Pumped storage could also lead to fish passage problems at the storage sites if fish passage is not provided.

SUMMARY

Passage of shad and striped bass at existing tidal and non-tidal obstructions in the Maritime Provinces where fishpasses have been provided has been disappointing. Passes for Atlantic Salmon and alewives have been more successful.

Emmigration of anadromous species from the proposed tidal impoundments will likely be predominantly through the turbines and the negative impact will probably be negligible for juvenile anadromous species. Adults on the other hand could suffer significant mortality if their movement patterns leads to much recycling through the turbines.

Immigration into tidal headponds, in contrast to emmigration, may present more of a problem for homing anadromous species that are bound for natal streams embraced by the barrage. Negative impacts such as stock reduction may occur if the sluice gates are deeply submerged. The compressed time available to pass fish due to the operation mode of the power plants could also lead to a considerable amount of straying to freshwater tributaries outside the barrage or to lack of spawning.

The altered tidal regime within the headpond may also result in compressed passage time at existing tidal aboiteaux (flap gates) on freshwater streams embraced by the tidal power barrage. Moreover, changed tidal currents could effect fishing success in traditional fishing areas. Furthermore, attempts to tune power production to demand, through pumped storage at freshwater sites anywhere in the Maritime Provinces, could destroy spawning habitat for some species (salmon, shad and striped bass) and create new habitat for others (alewives). Fish passage problems could also be created at pumped storage sites if fish passage is not provided.

The overall success or failure of maintaining the passage of anadromous fishes into the tidal power impoundment and its' freshwater tributaries may well hinge on the ultimate placement, both in plan and evaluation, of the sluices and turbines.

REFERENCES

Arnold, G.P. 1974. Rheotropism in fishes. Biol. Rev. 49: 515-576.

Baker, G.C. 1984. Engineering description and physical impacts of the most probable tidal power project(s) under consideration for the upper reaches of the Bay of Fundy. In this report.

Banks, J.W. 1968. A review of the literature on the upstream migration of adult salmon. J. Fish. Biol. 1: 85-136.

Bell, M.C., A.C. DeLacey, and G.J. Paulik. 1967. A compendium on the success of passage of small fish through turbines. U.S. Army Corps. of Engineers, Portland, Ore., 54 p. plus appendix.

Blaxter, J.H.S. 1969. Swimming speeds of fish. FAO Fish. Rept. No. 62: 73-100.

Calderwood, W.L. 1945. Passage of smolts through turbines: effect of high pressures. Salm. Trout Mag. 115: 214-221.

Clay, C.H. 1961. Design of fishways and other fish facilities. Queens Printer, Ottawa, 301 p.

Collins, G.B. 1952. Factors influencing the orientation of migrating andromous fishes. U.S. Fish and Wildl. Serv., Fish. Bull. 52: 375-396.

Collins, N.H. 1984. Potential fish mortality associated with large generating units. In this report.

Cramer, F.K., and R.C. Oligher. 1964. Passing fish through hydraulic turbines. Trans. Amer. Fish. Soc. 93: 243-259.

Dalley, P.J. 1980. A review of fish passage facilities for American shad. A paper presented at the Northeast Fish and Wildlife Conference, Ellenville, N.Y., 32 p.

DeLacey, A.C., L.R. Donaldson, and E.L. Brannon. 1969. Homing behaviour of Chinook salmon. Res. Fish., Fish Res. Inst., Univ. Wash. 300: 59-60.

Dodson, J.J., and W.C. Leggett. 1973. Behaviour of adult American shad (Alosa sapidissima) homing to the Connecticut River from Long Island Sound. J. Fish. Res. Bd. Can. 30: 1847-1860.

Dodson, J.J. and W. C. Leggett. 1974. Role of olfaction and vision in the behaviour of American shad (Alosa sapidissima) homing to the Connecticut River from Long Island Sound. J. Fish. Res. Bd. Can. 31: 1607-1619.

Dominey, C.L. 1970a. Petitcodiac River Causeway - Fishway evaluation studies. Can. Dept. Fish. and Forest., MS Rept. 70-3, 16 p.

Dominey, C.L. 1970b. Great Village River Aboiteau - progress report, 1969. Can. Dept. Fish. and Forest., MS Rept. 70-4, 6 p.

Dudley, R.G., A.W. Mullins, and J.W. Terrell. 1977. Movements of adult striped bass (Morone saxatilis) in the Savannah River, Georgia. Trans. Amer. Fish. Soc. 106: 314-322.

Hasler, A.D. 1966. Underwater guide posts - homing of salmon. Univ. of Wisconsin Press, Madison, 155 p.

Hasler, A.D., A.T. Scholz, and R.M. Horall. 1978. Olfactory imprinting and homing in salmon. Am. Sci. 66: 347-355.

Hilebrand, S.F. 1963. Family Clupeidae. Fishes of the western North Atlantic. Mem. Sears Found. Mar. Res. 1: 257-442.

Huntsman, A.G. 1952. Wandering vs homing in salmon. Salmon and Trout Mag. 136: 185-191.

Jessop, B.M. 1975. A review of the American shad (Alosa sapidissima) stocks of the Saint John River, New Brunswick, with particular reference to the adverse effects of hydroelectric development. Fish. Mar. Serv. Tech. Rept. Ser. No. MAR/T-75-6, 23 p.

Kerswill, C.J. 1960. Effects of proposed Passamaquoddy Power Project on anadromous fishes in Canadian waters. J. Fish. Res. Bd. Can. 17: 713-720.

Koo, T.S.Y., and J.S. Wilson. 1972. Sonic tracking striped bass in the Chesapeake and Delaware Canal. Trans. Amer. Fish. Soc. 101: 453-462.

Leman, B., and G.J. Paulik. 1966. Spill-pattern manipulation to guide migrant salmon upstream. Trans. Amer. Fish Soc. 95: 397-407.

Liley, N.R. 1982. Chemical communication in fish. Can. J. Fish. Aquat. Sci. 39: 22-35.

Mansueti, R.S. 1955. Natural history of the American shad in Maryland waters. Md. Tidewater News 11 (11 Supp. 4).

Martin, N.R. 1960. Predicted effects of proposed tidal power structures on groundfish catches in Charlotte County, N.B. J. Fish. Res. Bd. Can. 17: 169-173.

Mills, D. 1971. Salmon and trout: A resource, its ecology, conservation and management. Oliver and Boyd, Edinburgh, 351 p.

Montén, E. 1955. On utravandrande langungars moj-lighteter alt oskadda passera genour kfaftverksturbiner. Vandringfiskutredningen, Meddelande sr. 13. Stockholm.

Nordeng, H. 1971. Is the local orientation of anadromous fish determined by pheromones? Nature 233:155-159.

Nordeng, H. 1977. A pheromone hypothesis for homeward migration in anadromous salmonids. Oikos 28: 155-159.

Raney, E.C. 1952. The life history of striped bass (Roccus saxatilis) (Walbaum) Bull. Bingham Oceanog. Coll. 14: 5-97.

Riley, D.C. 1970. Anadromous fish passage problems associated with tidal structures. Can. Dept. Env., MS Rept. 70-4, 13 p.

Ruggles, C.P. 1980. A review of the downstream migration of Atlantic salmon. Can. Tech. Rep. Fish. Aquat. Sci. No. 952, 39 p.

Ruggles, C.P., and W.D. Watt. 1975. Ecological change due to hydroelectric development on the Saint John River. J. Fish. Res. Bd. Can. 32: 161-170.

Scarratt, D.J. 1977. Biological resources of the Bay of Fundy-Gulf of Main system. In: Daborn, G.R., ed. Fundy tidal power and the environment. Acadia Univ. Inst. Publ. No. 28, pp. 131-147.

Scott, W.B., and E.J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Bd. Can. Bull. 184, 96 p.

Semple, J.R. 1979. Anadromous fish stocks in the Petitcodiac River system and the Moncton Causeway: a status report. Can. Dept. of Fisheries and Oceans, MS Rept., 28 p.

Stasko, A.B. 1975. Progress of migrating Atlantic salmon (Salmo salar) along an estuary observed by ultrasonic tracking. J. Fish. Biol. 7: 329-338.

Stasko, A.B., A.M. Sutterlin, S.A. Rommel, Jr., and P.F. Elson. 1973. Migration-orientation of Atlantic salmon (Salmo salar L). Intern. Atl. Salmon Symp., Intern. Atl. Salmon Found., Spec. Publ. Ser. 4: 119-137.

Stewart, L. 1971. Water resources in the North: Report of migration of salmon in the Lune Estuary in England and the Faughan Estuary in Northern Ireland with special reference to a tidal barrier on the River Lune. Lancashire River Authority, Mill Lane, Holton, Nr. Lancaster. 67 p.

Swales, M.C. 1977. Tidal power plant design and operation. In: Daborn, G.R.., ed. Fundy tidal power and the environment. Acadia Univ. Inst. Publ. No. 28, pp. 35-44.

Talbot, G.B. 1966. Estuarine enviornmental requirements and limiting factors for striped bass. In: Smith, R.F., A.H. Schwartz, and W.H. Massman, eds. A symposium on estuarine fisheries. Amer. Fish. Soc. Spec. Publ. No. 3., pp. 37-49.

Walburg, C.H., and P.R. Nichols, 1967. Biology and management of the American shad and status of the Fisheries, Atlantic coast of the United States, 1960. U.S. Fish and Wildl. Serv., Spec. Sci. Rep. Fish. No. 550, 105 p.

Possible Impact of Large-Scale Tidal Power Developments in the Upper Bay of Fundy on Certain Migratory Fish Stocks of the Northwest Atlantic

Michael J. Dadswell

Department of Fisheries and Oceans
Fisheries and Environmental Sciences
Biological Station, St. Andrews, N.B.
E0G 2X0

Gary D. Melvin

Department of Biology
University of New Brunswick
Fredericton, N.B. E3B 5A3

P. James Williams and Gail S. Brown

Department of Biology
Acadia University
Wolfville, N.S.
B0P 1X0

ABSTRACT

Megatidal embayments of the upper Bay of Fundy are occupied in summer by large numbers of feeding fish, particularly alosids. The American shad present contribute to a local fishery. Tagging experiments indicate these shad are derived from populations native to all rivers on the North American Atlantic Coast from Florida to Quebec. A large portion of the total western Atlantic adult shad stock, estimated at 3.5×10^7 individuals in 1981, may frequent the upper Bay of Fundy each summer. Construction of large-scale tidal power structures in these embayments will alter the habitat by changing turbidity and temperature regimes and may alter migratory routes of the species concerned. Additionally, repeated passage through the turbines may cause significant mortality.

Key words: megatidal, alosids, American shad, migration, populations, low-head turbines, turbine mutilation rates, impact velocities, Cobequid Bay, Cumberland Basin.

RÉSUMÉ

Les rentrants mégatidaux du fond de la baie de Fundy (rentrant nord) servent en été d'aires d'alimentation à de vastes populations de poissons, et plus particulièrement à ceux de genre des aloses. L'alose savoureuse qu'on y trouve fait partie des pêches locales. Des expériences d'étiquetage indiquent que ces aloses proviennent de populations indigènes dans tous les cours d'eau de la côte atlantique nord-américaine, de la

Floride au Québec. Une grande partie de l'ensemble du stock d'aloses adultes de l'Atlantique ouest, estimé à 3,5 x 10^7 individus en 1981, se rend parfois au fond de la baie de Fundy (rentrant nord) tous les étés. La construction d'énormes ouvrages à des fins marémotrices sur ces rentrants affectera l'habitat en modifiant la turbidité et le régime thermique; elle pourrait aussi perturber les routes migratoires des espèces visées. De plus, le passage répété dans les turbines peut donner lieu à une mortalité appréciable.

INTRODUCTION

Recent research conducted in the megatidal embayments of the inner Bay of Fundy (Cobequid Bay, Cumberland Basin and Shepody Bay) indicates these regions are occupied in summer by an assemblage of migratory fishes numerically dominated by alosids (Dadswell et al. 1983a). The assemblage consists of alewife (*Alosa pseudoharengus*), blueback herring (*A. aestivalis*), American shad (*A. sapidissima*), Atlantic salmon (*Salmo salar*), striped bass (*Morone saxatilis*), Atlantic sturgeon (*Acipenser oxyrhynchus*) and dogfish (*Squalus acanthias*). Of these, shad were selected for concentrated study because of their apparent abundance in the region, moderately large size, ease of capture in large numbers and a thriving commercial and sports fishery here and along the Atlantic Coast. We believe, however, our remarks apply equally to other species of fish which occur in and/or utilize the embayments in a manner similar to shad.

SHAD FISHERY

The American shad, *Alosa sapidissima* (Wilson 1811), is a large, anadromous clupeid, 40-50 cm in length and 1-2 kg in weight at maturity, which ranges from Florida to Labrador. Shad are migratory, moving north to south and back again annually, following an ocean isotherm envelope of 7-17°C (Leggett and Whitney 1972) and homing to their natal rivers for reproduction (Dobson and Leggett 1973). Commercial fisheries are usually concentrated in or near estuaries of rivers and exploit mature shad returning to spawn during a short spring season (Walburg and Nichols 1967). Sport fisheries occur in the upper reaches of rivers and the largest, by both number caught and anglers participating, are on the Delaware and Connecticut Rivers (annual sport catch is 20,000-100,000 shad) (Miller et al. 1982, Leggett 1976). The commercial fishery of the inner Bay of Fundy is concentrated in Minas Basin and Chignecto Bay and is unique since it exploits non-spawning, ocean-feeding shad during an extended 4-mo season from June to September (Dadswell et al. 1983b).

Between 1870 and 1900, annual shad landings for the inner Bay of Fundy averaged 2-4 x 10^5kg y^{-1} (Fig. 1) and constituted two-thirds of total Canadian shad landings. It was the most valuable fishery in the Bay of Fundy at the time (Dadswell et al. 1983b). North American landings during this period peaked at 3.0 x 10^7 kg with about one-third coming from the Delaware River Basin (Fig. 2). After 1900, landings declined dramatically as a result of markedly decreased shad abundance (Leim 1924). Possible

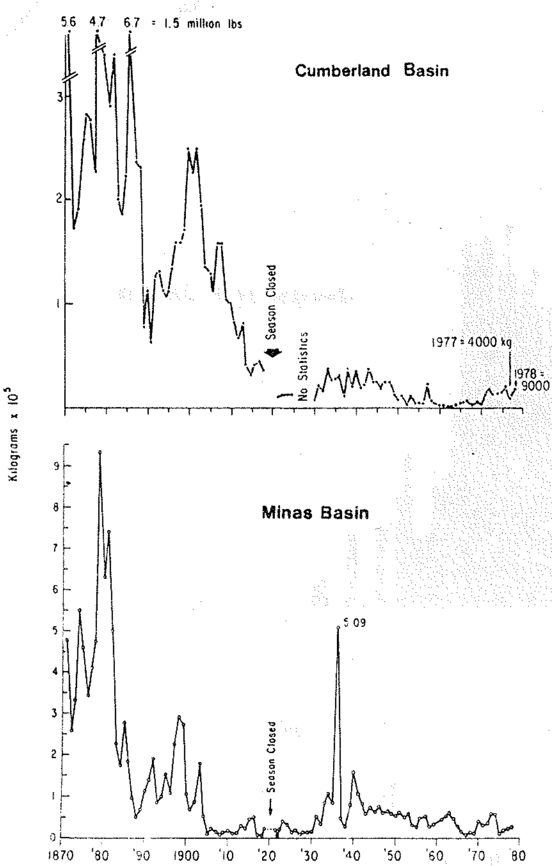


Fig. 1. Annual commercial landings for Cumberland and Minas Basins from 1870-1978.

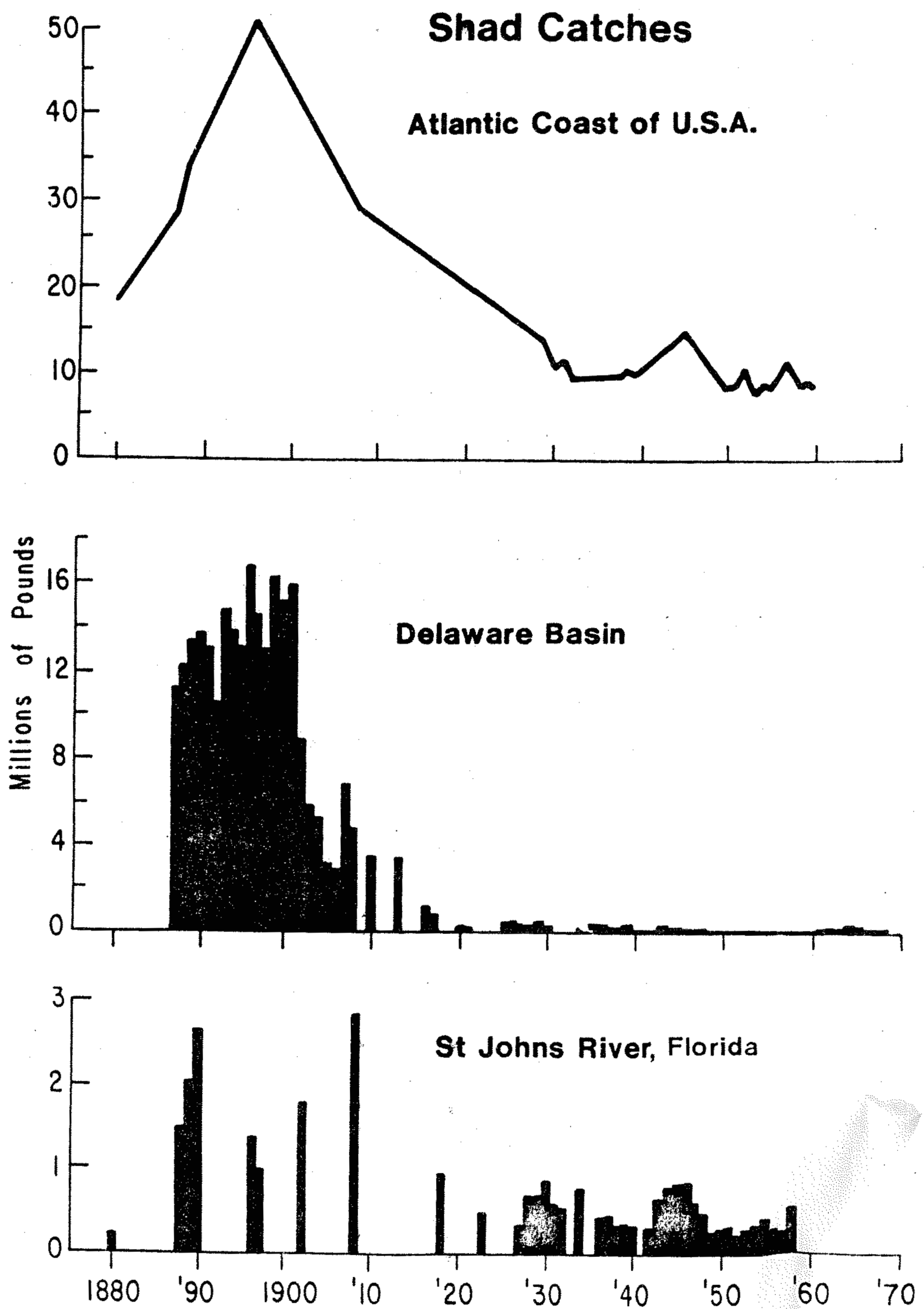


Fig. 2. Annual commercial landings for the eastern United States and various river systems during 1880-1970.

reasons for the decline were damming of natal rivers (dams blocked two-thirds of formerly available spawning habitat by 1930, Walburg and Nichols 1967), pollution (0 ppm O_2 levels on Delaware River in May to October, Miller et al. 1982), climatic variation and overexploitation. Since the 1950's, large-scale anadromous fish restoration programs, in many cases specifically for shad, have been in progress in the United States and shad abundance is increasing (Miller et al. 1982). Although Bay of Fundy fishermen agree that shad abundance has increased during the last decade and catch rate has increased fivefold during this period (Fig. 3), total shad landings from the upper Bay of Fundy do not reflect this fact because of poor local markets and therefore minimal fishing effort. The 1980 commercial landings and value for shad in Canada and the United States were 2×10^5 kg and US$ 171,000 and 1×10^6 kg and US$ 2 million, respectively. Female shad landed between Florida and Virginia during January through March are worth up to US$ 3.85 kg^{-1} to the fishermen. The value of the sport fishery on the Delaware and Connecticut Rivers is estimated at US$ 10 million yr^{-1} (Miller et al. 1982, Leggett 1976).

Our research indicates shad arrive in the Bay of Fundy from the south during late May and migrate around the Bay in a counterclockwise direction following the residual current system (Fig. 4; Dadswell et al. 1983b). The runs peak in the inner embayments during late June through July, lasting around 12 wk or until mid-August in Minas Basin (Fig. 5) and about 20 wk or until mid-October in Chignecto Bay (Fig. 6). Shad are abundant within the embayments because the run effectively doubles back on itself. The increased turbidity levels in these regions apparently cause the shad to swim high in the water column and reduces gear avoidance, resulting in a high catch per unit effort for the local commercial fishery (Dadswell et al. 1983b).

During 1979 to 1982, 14,500 shad were tagged and released in Minas and Cumberland Basins and in the Annapolis River. Tag returns (466) for ocean-tagged shad (Minas, Cumberland) were 34 (7%) from Canadian marine locations, 130 (28%) from coastal U.S. waters, 32 (7%) from Canadian rivers, and 269 (58%) from U.S. rivers (Fig. 7). Tag returns of Annapolis shad were 42 from the Annapolis River in the next year after tagging, 30 from Canadian marine locations and 11 from coastal U.S. waters. No Annapolis tagged shad were taken in U.S. or other Canadian rivers. Recaptures within the Bay of Fundy indicated the average migration rate of shad while in the Bay was 3.7 ± 0.94 km d^{-1} relative to the shoreline (Table 1). Realizing that shad return to their natal rivers to spawn (Walburg and Nichols 1967), as the Annapolis River shad demonstrated, the distant recapture from many rivers of those tagged in the upper Bay of Fundy during summer reflects their intermixed population structure (Dadswell et al. 1983b).

Within the megatidal embayments mean time-at-large for shad recaptured by gillnet was 5.4 and 5.1 d in Cumberland Basin and Cobequid Bay, respectively (Table 1). Mean time-at-large for those recaptures in weirs at the outlet of Cobequid Bay was 18.9 d (Table 2). During 1982, shad were batch tagged over a 3-d period each week and analysis of gillnet recaptures (commercial and experimental) showed 78% of recaptures were

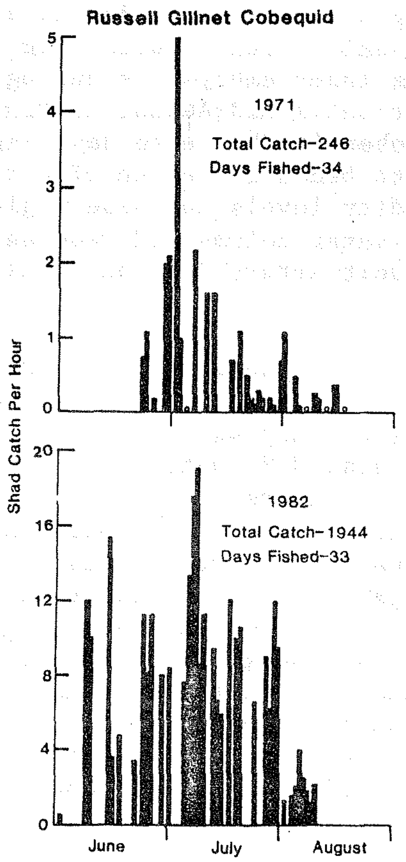


Fig. 3. Daily shad catch/hour of one commercial driftnet fisherman in Cobequid Bay in 1971 and 1982. Circles indicate fishing days when no shad were captured.

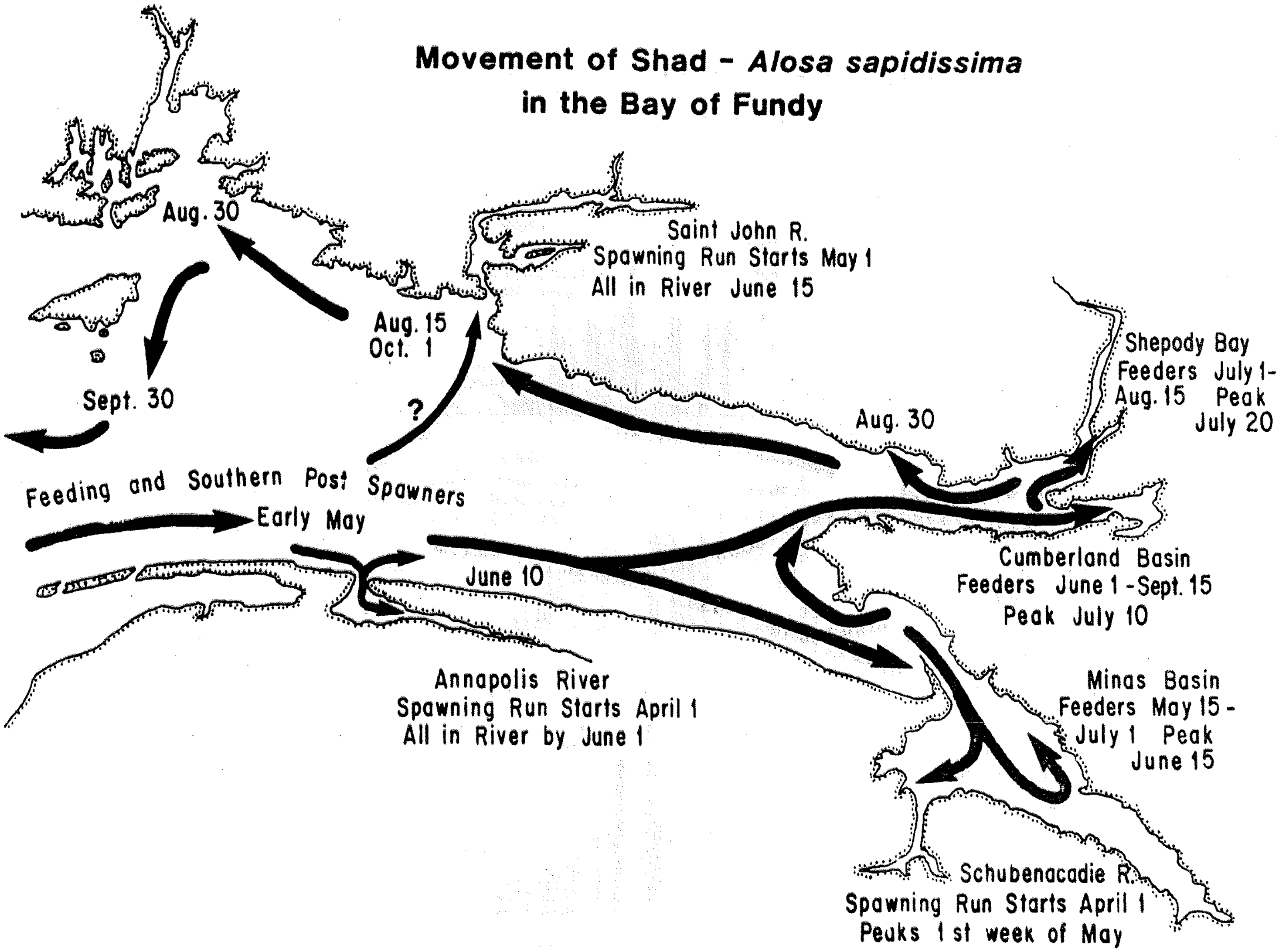


Fig. 4. Hypothetical migration pattern for American shad around the Bay of Fundy during a summer seseason.

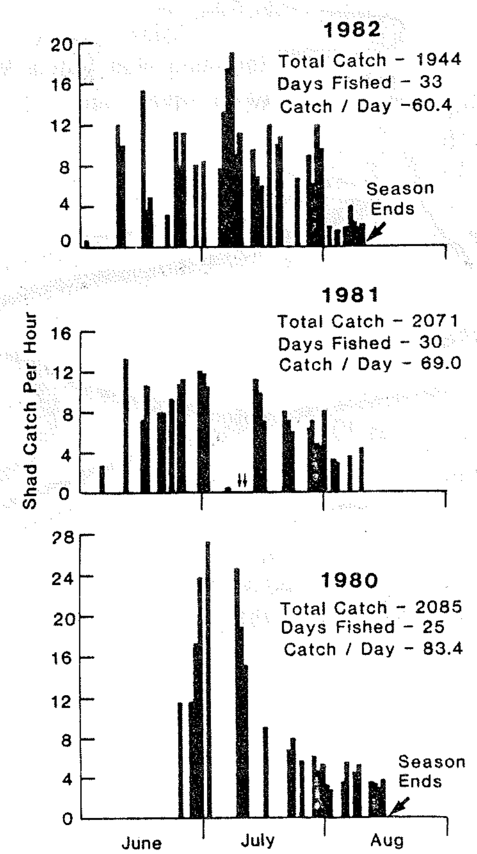


Fig. 5. Daily shad catch/hour of one commercial driftnet fisherman in Cobequid Bay during 1980, 1981, and 1982. Arrows indicate fishing days when no shad were captured.

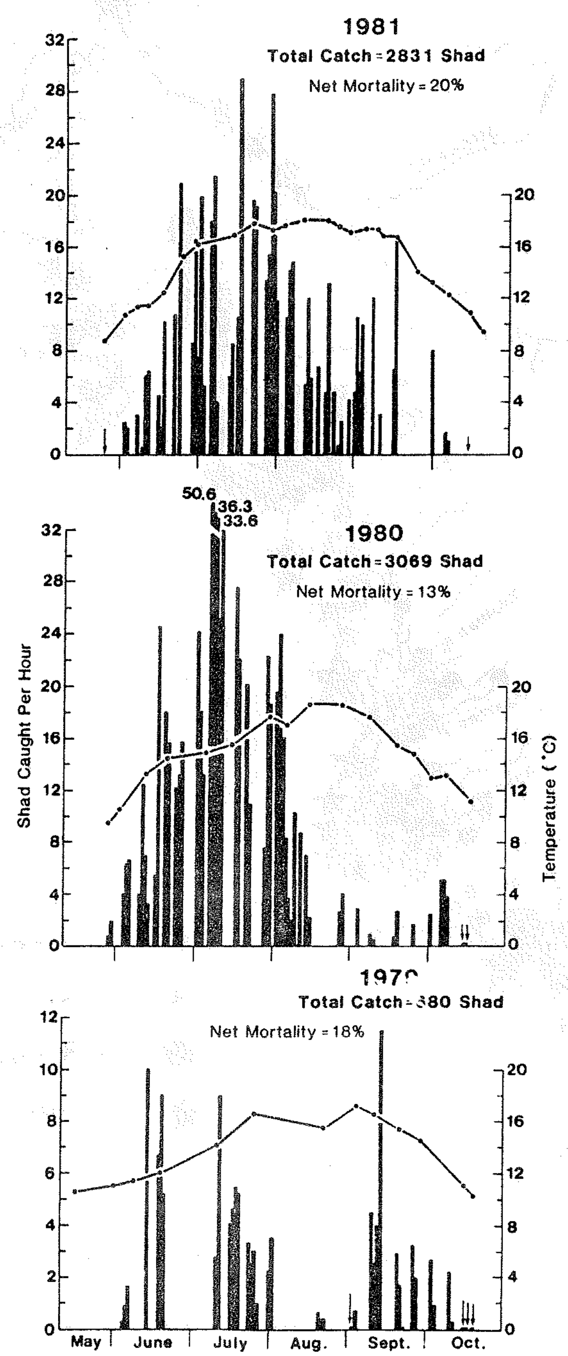


Fig. 6. Capture rate of American shad with experimental gillnets in Cumberland Basin during May to October 1979, 1980, and 1981. Arrows indicate fishing days when few or no shad were captured.

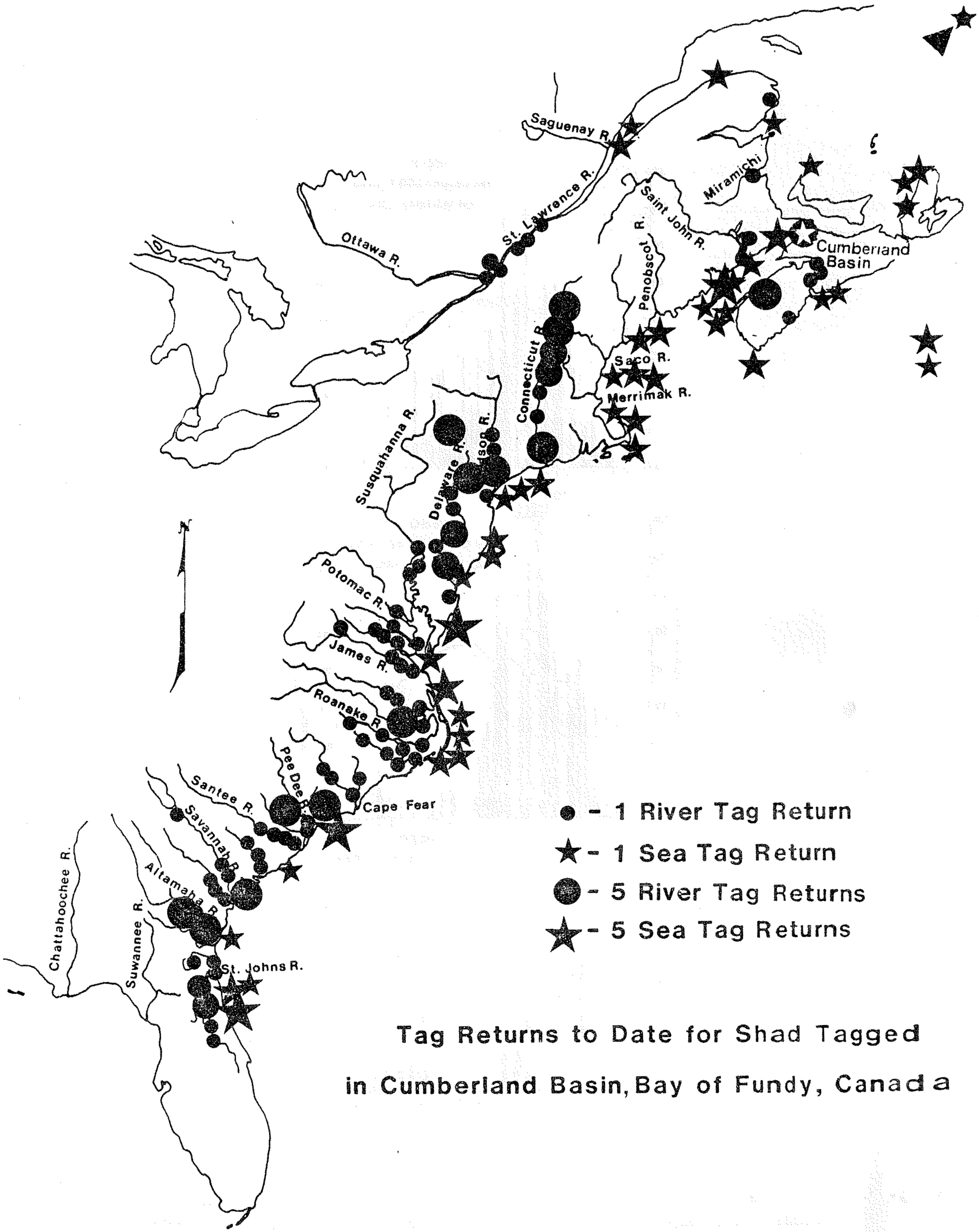


Fig. 7. Locality map for recaptures of shad tagged in Cumberland Basin.

TABLE 1. Recaptures during same year in the Bay of Fundy/Gulf of Maine for shad tagged in Annapolis River, Cumberland Basin and Minas Basin.

Place Tagged	Place Recaptured	n	Mean time at large (Days)	Minimum Migration Distance (km)	Migration Rate (km/day)
Annapolis	Cobequid	6	57.0	220	3.9
Annapolis	Cumberland	5	64.1	160	2.5
Annapolis	Shepody	3	49.6	210	4.2
Annapolis	Saint John	1	71.0	360	5.1
Annapolis	Head Harbour	5	102.3	440	4.3
Annapolis	Grand Manan	3	132.0	470	3.6
Cobequid	Cobequid (gillnet)	9	5.1	15	2.9
Cobequid	Cobequid (weir)	16	18.7	40	2.1
Cobequid	Head Harbour	1	99.0	250	2.5
Cobequid	Gulf of Maine	4	118.0	625	5.3
Cumberland	Cumberland	33	5.4	30	5.5
Cumberland	Shepody	12	13.9	50	3.6
Cumberland	Gulf of Maine	1	131.0	310	2.4
					X = 3.7 km/day

TABLE 2. Recaptures of tagged adult shad by weir and gillnet in Cobequid Bay, Nova Scotia, during 1982.

Weir			Gillnet		
Date Tagged	Date Recaptured	Days at Large	Tagged	Recaptured	Days at Large
June 10	June 16	6	June 15	June 16	1
June 16	July 10	24	June 23	June 24	1
June 21	July 13	22	June 16	July 7	21
June 24	July 15	21	June 23	June 23	1
June 25	July 11	16 EW[1]	June 25	June 28	3
June 16	July 11	25 EW	July 5	July 8	3
June 16	July 11	25	July 1	July 14	13
June 16	July 15	29	July 7	July 8	1
June 16	July 11	25	July 21	July 23	2
June 22	July 16	24	Mean Days at Large		5.1
June 23	June 30	7	One Salmon		
June 29	June 30	1	Tagged - July 14		
June 28	July 22	24 EW	Recap. - Aug. 10		
June 29	July 22	23 EW	27 Days		
June 29	July 11	12 EW			
July 2	July 17	15			
Mean Day at Large		18.7			

[1] Captured at East Walton outside Cobequid Bay

made within 1-3 d or a 2- or 3-wk period occurred (12-29 d) before there was a second set of recaptures (Fig. 8). The difference was significant ($F_{7,30}$ = 7.97; P = 99.9). Time-at-large before recapture in weirs represented a similar ratio in reverse (75% at large more than two wk, Fig. 8) but the period of recapture of a batch of tags extended for a longer time [e.g. 8 d for shad tagged on June 16 (Table 2), possibly because the weirs were greater in length than gillnet sets (1500 m vs. 500 m) and there were two, 3000 m apart].

These data suggest we tagged spatially discrete groups of shad dependent upon the actual area of water which was fished. During 1982, 80% of our fishing took place in the water mass occupying the head of Cobequid Bay at high tide (Fig. 9). Tag returns indicated shad followed an orderly progression through this region (Table 2), possibly in a pattern similar to that shown in Fig. 9, and each shad or discrete group of shad occupied it at high water during a single 1-3 d period. Since it then took 20-30 d for a shad to progress from the head of Cobequid Bay to Economy Point while leaving the Bay (Table 2), it is reasonable to assume that it takes one a similar period to reach the head while entering. Therefore the total residence time for an individual shad or group of shad in Cobequid Bay might be 40-60 d and, by the same reasoning, residence time in Cumberland Basin appears to be 10-15 d.

We used a modified Peterson model to estimate the number of adult shad occurring in the water mass at the head of Cobequid Bay during high tide for any 3-d period between June 15 and 30, 1982. Shad were captured for tagging with gillnets and recaptures were taken from weirs inside Economy Point (Fig. 9). Estimates were adjusted for tags applied in other parts of Cobequid Bay during this period and recaptures indicated that only fish present at the head of the Bay between June 15-30 were in the vicinity of the weirs when high catch rate conditions prevailed in mid-July (Table 2, Fig. 10).

Based on these assumptions, the mean 3-d estimate was 6.9×10^4 shad (Table 3). Since our tagging data indicate the summer shad population of Cobequid Bay is transient with some arriving inside Economy Point for the first time, some reaching the head, and some leaving the Bay on each tide cycle, we believe the 3-d estimate represents the mean size of a discrete group of shad occupying the head of the Bay for about 2.2 d or four tide cycles. It leaves the area after this period and is replaced by a new group and so on. Thus, on any one day in summer the total adult shad population of Cobequid Bay would be the sum of all these groups or:

$$\frac{\text{Mean 3-d estimate x total tides during residence } (\bar{x} = 50 \text{ d})}{\text{Number of tides at head of Bay}} =$$

$$6.9 \times 10^4 \times \frac{100}{4} = 1.7 \times 10^6 \text{ adult shad}$$

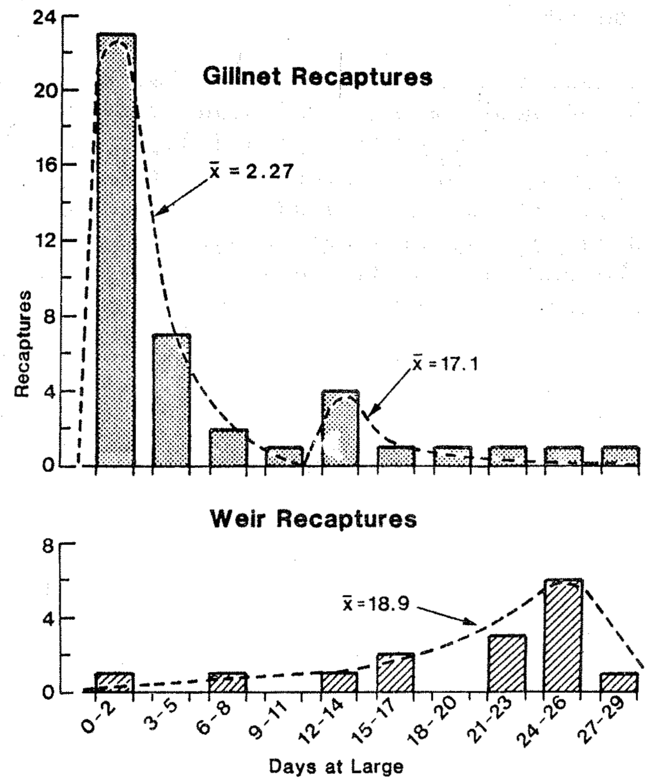


Fig. 8. Time-at-large of shad recaptured by drift gillnets and weirs in Cobequid Bay and Cumberland Basin.

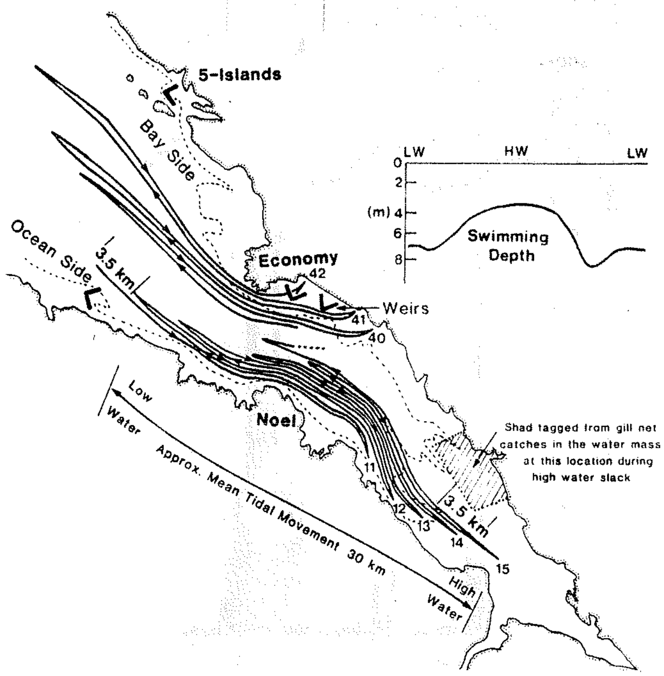


Fig. 9. Hypothetical mode of movement for a single shad or shad group through Cobequid Bay during a summer season. Swimming depth with respect to tidal phase is from experimental data (Dadswell et al. 1983b). Dotted line is mean low-tide mark.

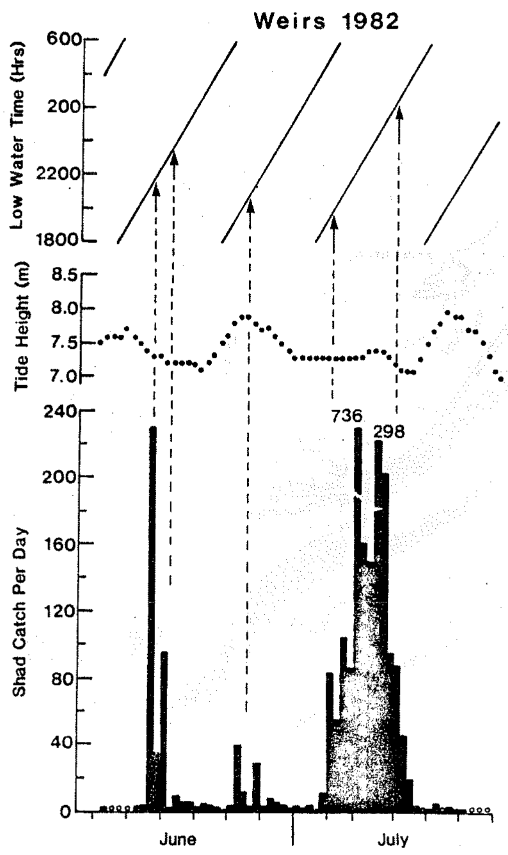


Fig. 10. Shad catch/day for weirs at Ecomony Point, Cobequid Bay in relation to daily tide height and time of low water.

TABLE 3. Modified Peterson population estimates for adult shad occurring in the head of Cobequid Bay, Nova Scotia, during June 15-30, 1982. Number tagged adjusted for tags applied in other parts of Cobequid Bay which were unavailable to the weirs during the period (20%).

Shad Group Period	Number Tagged	Weir Recapture Period	Recaptures	Total Weir Catch	Population Estimate (x 10^4)	3-Day Population
June 15-18	168	July 5-16	4	2982	10.1[1]	10.1 x 10^4
June 21-24	164	July 10-21	3	1804	7.4[1]	7.4 x 10^4
June 16-23	268	July 6-23	6	3042	11.7[2]	5.8 x 10^4
June 15-30	687	June 22 - July 30	9	3187	22.0[2]	4.4 x 10^4
				Mean 3-Day Population		6.9 x 10^4

[1] Estimate not valid $MC < 4\hat{N}$

[2] Estimate valid $MC > 4\hat{N}$

Similarly, the total number of adult shad migrating through Cobequid Bay in 1982 can be estimated where

$$\frac{\text{Mean 3-d estimate x total tides during run (12 wk)}}{4} =$$

$$6.9 \times 10^4 \times \frac{168}{4} = 2.9 \times 10^6 \text{ adult shad}$$

Tag returns to date indicate each large embayment (Minas Basin and Chignecto Bay) has a separate group of shad during a given summer and embayment selection by any group may be random (Fig. 4; Dadswell, unpublished data). If Chignecto Bay contains a number of shad similar to Minas Basin each summer, and gillnet catch/effort data suggest this is true (Dadswell et al. 1983b), then the upper Bay of Fundy would contain about 6 million adult shad each year. This represents about one-fifth of the estimated 1981 Western Atlantic adult shad stock (Table 4).

IMPACTS

Again, as our tagging data suggest, if shad follow a set migration route in and out of Cobequid Bay with each tidal excursion (Fig. 9) advancing at a rate of 3.5 km. d^{-1}, remaining in the region for about 50 d and taking a week to pass a given site, an individual might pass Economy Point up to 30 times while entering and leaving Cobequid Bay. This may mean, even under a reduced tidal range after barrage installation, that individual shad could pass through the barrage and hence the turbines, 10 to 20 times or more depending on the mode of operation. Similarly, shad follow the tidal excursion while advancing through Cumberland Basin and there a shad might pass the Peck's Point site five or more times under reduced tidal regimes.

By using the mathematical relationships developed by Von Raben (1957), the water lengths (i.e., distance between each pass of the runner blades), impact velocities (velocity of fish striking blade) and mutilation rates (% by fish length) were calculated for the specifications of the proposed STRAFLO turbines at Economy Point (B9) and the Annapolis River (Table 5). Although the RPMs of a STRAFLO turbine are low compared to other hydroelectric turbines, its large diameter means the blades are actually turning at high speed (up to 27.5 m sec^{-1} tip velocity) and impact velocities are similar to or greater than Kaplan or Francis turbines. On the other hand, calculated mutilation rates are low when compared to the latter turbine types, especially for smaller fish (<30 cm). At Annapolis the STRAFLO turbine will probably pose little hazard for small and medium-sized fish (Table 5) since most will pass the turbine only once a year during downstream migration. Large fish, like striped bass and Atlantic sturgeon, however, which remain in or near the estuary for longer periods are so large the probability of a runner strike on each pass is high (over 30%). In Cobequid Bay and Cumberland Basin, where the fish are moving in and out

TABLE 4. Population estimates of the Atlantic Ocean stock of adult American shad by simple Peterson Method. All estimates are valid.

Tagged	Recaptured	M	C	R	$\hat{N}$	95% Confidence Limits	$MC>4\hat{N}$
Cumberland 1980	Holyoke Connecticut R. 1981	2416	380,000	10	9.1×10^7	$5.0 \times 10^7 - 19.5 \times 10^7$	>1
Cumberland 1981	Holyoke Connecticut R. 1982	3200	295,000	26	3.6×10^7	$2.6 \times 10^7 - 5.8 \times 10^7$	>1
Saint John Harbour 1981	Holyoke Connecticut 1982	280	295,000	4	2.06×10^7	$0.8 \times 10^7 - 8.2 \times 10^7$	>1
Cumberland 1981	Delaware R. 1982 Est. Population	3200	509,000	30	5.4×10^7	$4.3 \times 10^7 - 9.0$ 1x 10^7	>1
Cumberland 1981	Delaware R. 1982 Sport Catch	3200	53,960	28	0.6×10^7	$0.5 \times 10^7 - 1.0 \times 10^7$	>1
Cumberland 1980	Delaware R. 1981 Est. Population	2416	546,000	10	13.2×10^7	$7.2 \times 10^7 - 28.0 \times 10^7$	>1
Cumberland 1980	Delaware R. 1981 Spot Catch	2416	40,420	7	1.4×10^7	$0.6 \times 10^7 - 3.5 \times 10^7$	>1
Cumberland 1981	Annapolis R. 1982	3200	100,000	5	6.4×10^7	$2.7 \times 10^7 - 20.0 \times 10^7$	>1

TABLE 5. Water length and impact velocities of STRAFLO turbines from specifications given by the Nova Scotia Tidal Power Corporation and related estimated potential fish mutiliation rates.

Site and Specifications	Rev/Min	Water length (m)	Impact Velocity (m/sec)	Mutilation Rate (% by length)
Minas (B9)	70	2.26[1]	23.99[2,3]	30 cm - 5.7%[4] (alewife)
Discharge = 378 m^3/sec) For Both turbines				50 cm - 9.5% (shad)
Blades = 4)				80 cm - 15.2 (salmon)
Diameter = 7.6 m)				100 cm - 19.0% (bass, dogfish)
Hub - 2 m (est.))				100 cm - 38.0% (sturgeon)
α = 32°)				
Annapolis	50	3.17	16.87	50 cm - 6.8% (shad)

[1] Water Length = $\frac{240 \text{ x Discharge } m^3/sec}{\text{COS . \# Blades. Rev/Min [Runner diameter}^2\text{(m)-Hub diameter}^2\text{(m)]}}$;

[2] Impact velocity calculated from Von Raben (1957);

[3] Critical borderline mutilation velocity between 11-14 m/sec (Von Raben 1957);

[4] Mutilation rate = $\frac{\text{Fish length (cm) x mutilation ratio (theoretical/observed)}}{\text{Water length (m)}}$ (Von Raben 1957).

with the tide making repeated passes through the turbine, mutilation rates will be higher and can be calculated using the exponential survival relationship (i.e, fish not multilated) where:

$$N_0(1 - \text{mutilation rate})^{\text{passes}} = \text{survivals}$$

A population of 100,000, 50-cm shad after 5 passes would have 100,000 $(1-0.095)^5$ = 60,700 survivors or 39,300 mutilated. After 10 and 20 passes, 63,200 and 86,500 will have been hit. In other words, 40, 70, or almost 90% will have been struck. Since most experimental work with turbines indicates the Von Raben relationship overestimates mutilation rates by a factor two (Ruggles 1980), the calculated rates can be adjusted downward to a range of 20-45%. If most of these mutilations result in mortality, and this relationship is unknown, then large-scale structures with an array of turbines may impose an unacceptably high mortality rate on the presently recovering western North Atlantic shad stock.

There remains a number of questions to answer before the limits of this problem are resolved. Data on actual mutilation rates experienced at the Annapolis STRAFLO turbine will allow more accurate modelling of the Cobequid Bay (B9) project. Sonic tagging and tracking of fish will help clarify their behavior around the Annapolis turbine and determine the validity of our hypothesis concerning fish movement in Cobequid Bay and Cumberland Basin. The resource inventory of these embayments is incomplete, as is our knowledge of their contribution in the life history of the Atlantic Coast migratory stocks of alewife, blueback herring, Atlantic sturgeon, striped bass and dogfish. Finally, we should determine how returning adult Atlantic salmon behave during their residency in these embayments before they enter the local rivers to spawn. Our few tag returns for this species indicate an individual salmon may remain at sea in this area for up to a month (Table 2). If they follow the tidal excursion similar to the shad, there exists the possiblity of high turbine mortality, which might place the salmon runs in the Shubenacadie, Stewiacke, Salmon, Portapique, Economy, Maccan, Hebert, Petitodiac and Shepody rivers in jepardy.

ACKNOWLEDGMENTS

We wish to thank Jim Martin, Carl Jarvis, Mike Kellock, Stephen Bubine, Daphne Themelis, Judy Dawson, Roger Rulifson and his students from Unity College, Leslie Linkletter, Brenda Blanchard and Peggy Crawford for their assistance in the field and in assembling this report. Shad fishermen, Marvin Snowden and Russel Cooke helped in many technical matters related to gillnet drift fishing. Art Lupin of New Jersey Fish and Game, Peter Minta of the Connecticut Department of Environmental Protection, and Bob Krska of the University of Massachusetts kindly provided unpublished data on the estimated and observed populations in the Delaware and Connecticut Rivers. M. Irwin and B. Garnett typed the manuscript and Frank Cunningham prepared the figures.

REFERENCES

Dadswell, M.J., R. Bradford, A.H. Leim, G.D. Melvin, R.G. Appy and D.J. Scarratt. 1984. A review of fish and fisheries research in the Bay of Fundy betweeen 1976 and 1982. In this report.

Dadswell, M.J., G.D. Melvin, and P.J. Williams. 1983b. Effect of turbidity on the temporal and spatial utilization of the inner Bay of Fundy by American shad (Alosa sapidissima) (Pisces: Clupeidae) and its relationship to local fisheries. Can. J. Fish. Aquat. Sci. 40 (Suppl. 1): 322-330.

Dodson, J.J., and W.C. Leggett. 1973. Behaviour of adult American shad (Alosa sapidissima) homing to the Connecticut River from Long Island Sound. J. Fish. Res. Bd. Can. 30: 1847-1860.

Leggett, W.C. 1976. The American shad (Alosa sapidissima), with special reference to its migration and population dynamics in the Connecticut River. In: Merriman, D. and L.M. Thorne, eds. The Connecticut River ecological study. The impact of a nuclear power plant. Amer. Fish. Soc. Mono. 1: pp 169-225.

Leggett, W.C., and R.R. Whitney. 1972. Water temperature and the migrations of shad. Fish. Bull. 70: 659-670.

Leim, A.H. 1924. The life history of the shad (Alosa sapidissima) (Wilson) with special reference to the factors limiting its abundance. Contrib. Can. Biol. 2: 163-284.

Miller, J.P., F.R. Griffiths, and P.A. Thurston-Roberts. 1982. The American shad (Alosa sapidissima) in the Delaware River basin. Delaware Basin Fish Wildl. Coop., 132 p.

Ruggles, C.P. 1980. A review of the downstream migration of Atlantic salmon. Can. Tech. Rep. Fish. Aquat. Sci. No. 952, 39 p.

Von Raben, K. 1957. Zur Fraye der Beshadigung von Fischen durch turbinen. Die Wasserwirtschaft 4: 97-100. (Fish. Res. Board Can. Transl. Ser. 448).

Walburg, C.H. and P.R. Nichols. 1967. Biology and management of the American shad and status of the fisheries, Atlantic Coast and the United States, 1960. U.S. Fish. Wildl. Serv., Spec. Sci. Rep. 550, 105 p.

QUESTIONS AND COMMENTS

Unknown: We have heard that after barrage construction we can expect the summer temperatures to rise at bit. Do you think this will be enough to keep shad from entering the headponds?

M. Dadswell: I would expect that the mean temperature in the region where it should be fairly highly mixed might go up by a degree or two. We find that adult shad seem to be limited by water temperatures of about 18°C. This is what most of Cobequid Bay is now during peak summer temperatures. The juveniles (2 and 3 year olds) seem to be more temperature tolerant. We find them in water up to 20°C. However, you must remember that in Cobequid Bay the main shad run arrives in mid-June when water temperatures are still low anyway.

Unknown: Is there a chance that a change in conditions would have less effect on Canadian fish?

M. Dadswell: I don't think so. The northern shad populations arrive during the earliest part of the run. The first fish arrive in the middle of May. In Cumberland Basin most of the early fish arrive when water temperatures are between 10-13°C. These temperatures occur in Cobequid Bay during the last two weeks of May.

C. Desplanque: Since the turbines are large, do you really think fish will actually be contacted by the blades? The water flow is parallel to the blades and should carry a fish past.

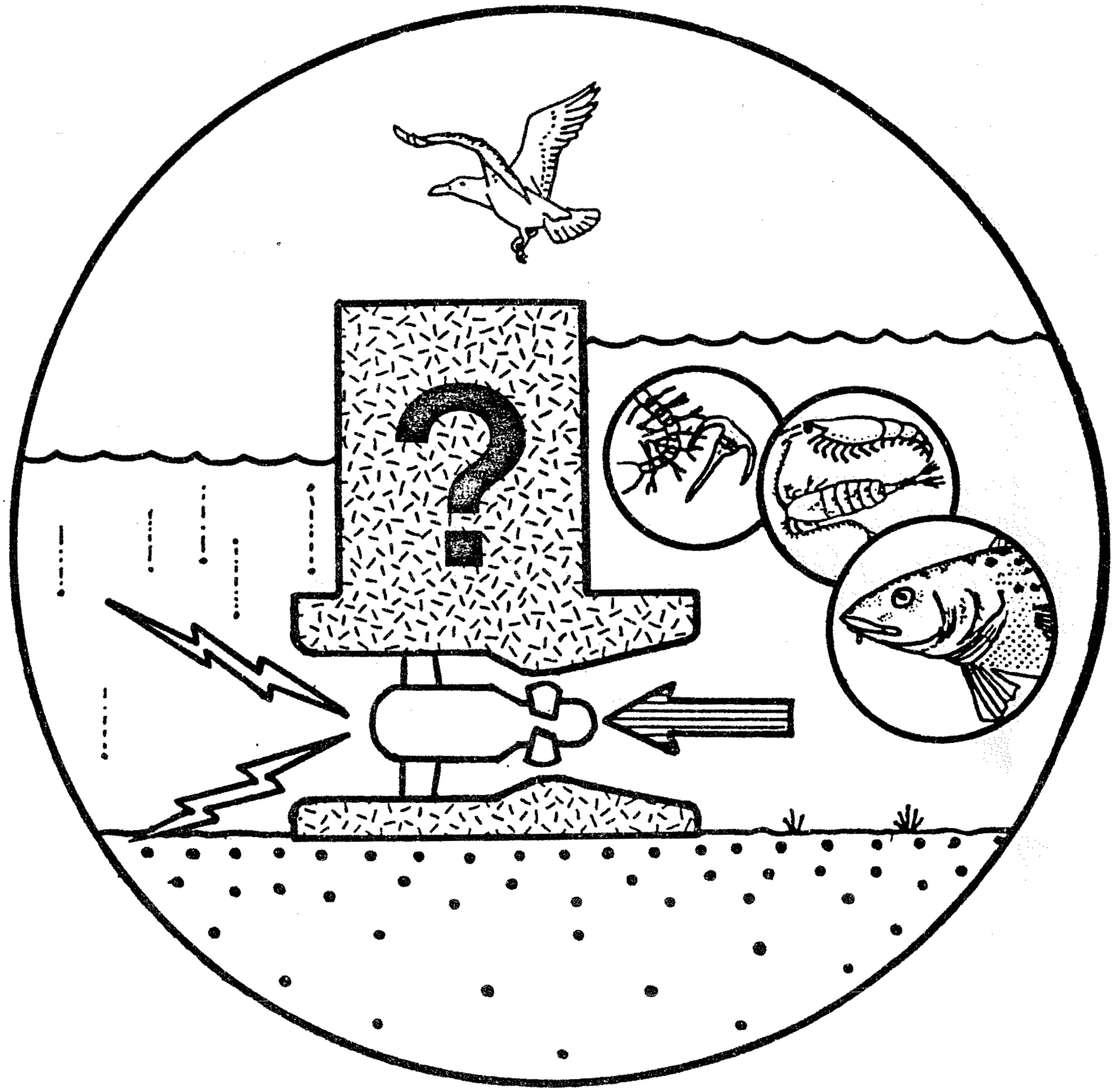
M. Dadswell: The impact velocity is not only an actual contrant with a fish but also the product of the shearing force of the different velocities of water on either side of the blade. Also fish passing this structure will be up to six or eight feet in length and actual strikes are certain. I am not saying the rate of contact will be great for most fish. What I am saying is some fish will pass the turbines repeatedly and this will lead to a large accumulated mortality.

G. Baker: Is there anyway to use the Annapolis turbine to test the mortality effects on large fish?

M. Dadswell: We can do what is normally done in turbine mortality tests with small fish but use large fish. What we have to do is capture large, adult fish and pass them through the turbine to test its effects on them, otherwise we will never know the true effects.

SESSION IV

Panel discussion of the adequancy of environmental studies conducted to date and requirements for further research.



Instead of concluding the workshop with a session solely summarizing its scientific content, the Steering Committee decided to organize a panel discussion which would review the science presented in terms of the requirements for a proper environmental impact assessment. Panelists came from a variety of backgrounds and were asked to express their views on the adequacy of the environmental studies conducted to date plus the requirements and responsibilities for future work. The environmental impacts of tidal power development relative to other power producing schemes were also addressed. The membership of the Panel was as follows:

1. Dr. Fred J. Simpson - Chairman
   Chairman, Atlantic Provinces Council on the Sciences
   Director, Atlantic Regional Laboratory
   1411 Oxford Street
   Halifax, N.S. B3H 3Z1

2. Mr. George C. Baker, P. Eng.
   Executive Vice-President, Tidal Power Corporation
   Suite 1109
   5251 Duke Street
   Halifax, N.S. B3J 1P3

3. Mr. Walter Kozak
   Manager, Fundy Weir Fishermen Association Inc.
   St. Andrews, N.B., E0G 2X0

4. Mr. Hal Mills
   Marine Policy Consultant
   1691 Edward Street
   Halifax, N.S. B3H 3J2

5. Dr. Gordon Beanlands
   Institute for Resource and Environmental Studies
   Dalhousie University
   Halifax, N.S. B3H 1W7

6. Mr. Ronald Edwards
   Office of Environmental Affairs
   Energy Mines and Resources
   20th Floor
   580 Booth Street
   Ottawa, Ontario K1A 0E4

7. Dr. Donald C. Gordon Jr
   Chairman, Fundy Environmental Studies Committee
   Marine Ecology Laboratory
   Bedford Institute of Oceanography
   Box 1006, Dartmouth, N.S. B2Y 4A2

PRESENTATIONS

G.C. Baker:

The Tidal Power Corporation has a sort of a program to bring large Fundy development toward fruition. I guess we could call it a game plan and like any other game plan it is not immutable. These things have a way of being changed by circumstances and you can't always follow them the way you intend at the outset but I thought perhaps as a sort of a background for this afternoon's session it might be interesting to know what the Corporation does have on its mind.

The plan has three elements and the first one is to satisfy certain preconditions. The preconditions are to establish a feasible and acceptable financial plan for a large-scale development to line up potential customers for the energy output and to establish some degree of assurance that long term export permits would be available.

Now if those conditions were satisfied we would at once launch what we call a precommitment program. That would consist of many things but I think that I can catagorize them again under three labels. The first would be environmental assessment and definitive design. I purposely put those under the one blanket because I feel that they are inextricably mixed. The second would be negotiation of conditional agreements with respect to financing, sales, transmission rights-of-way, other land requirements and that sort of thing. The third one would be risk analysis. The precommittment program would probably last about three years, it might last longer. If it were completed, a decision would be made to commit to the construction of the development or otherwise. Commitment would lock in all the parties; the customers, the guarantors, the underwriters, the lenders, the providers of equity capital and so on. The formal and final decision to commit would no doubt be made by governments, probably the governments of Canada, Nova Scotia and New Brunswick, and it would be made also no doubt on the basis of public opinion and the benefits, disbenefits and risks apparently involved in the scheme.

However, the decision process would not just be as abrupt as that would seem to indicate. All the way through the precommitment program the decision could be made not to go ahead and that sort of a decision could be triggered by any affected party. For example, if the State of Maine thought that the potential environmental disbenefits and the other risks outweighed the advantages to the State of Maine, the state could simply say 'sorry, but we don't want to give you transmission rights of way'. If customers, on the way through the precommitment program, decided that the design results were not bearing out the predictions of the feasibility study, that the benefits were losing their 'shine', they could say 'well look, really we don't want to carry this thing any further'. If it should turn out on environmental assessment that some of the disbenefits, some of the environmental impacts, were unconscionable again one would walk away from the scheme. So that the final commitment decision would really be the last in a long line of decisions by many different entities affected.

Now that may make it sound as if the chances of a positive commitment decision are fairly remote. They could be but, in order to bias the probabilities a little more toward the favorable side, the proponents of such a scheme would be well advised to make sure that the entities, all of them, were going to get some benefits out of the scheme and then it becomes a question of simply balancing those benefits against the disbenefits. We think on the basis of our present knowledge that there is at least a fair probability that the benefits are sufficient so that all parties can have a piece and they will be sufficient to outweigh the disbenefits.

In order to see that that happens of course we are very keen to make sure that impacts are mitigated by design to the greatest extent possible and that brings one down to the environmental aspects. The Tidal Power Corporation does think that the assembly of a data base, the basic understanding of natural processes that would be necessary in order to make an environmental assesment, is the responsibility of public agencies. We see ourselves as totally responsible on the other hand for making an assesment as to the impacts to be expected from a definitely proposed tidal power scheme. So that is a pretty clearcut split. The basic knowledge, the data, is a responsibility of public agencies; using that data base to predict the actual impacts of the scheme is our responsibility. Now that may not be everybody's view but that is the Corporation's view for starters.

The other thing about environmental matters I would like to say involves the questions of whether all the gaps that are now percieved in the data base would have to be closed up before we could make an assesment and I think perhaps the answer is no, they wouldn't all have to be. Supposing for instance that some gap exists so that a prediction can't be made on some matter that has some material potential for disbenefit. In that case the disbenefit would add to the risks in the scheme. If it can be assessed it is added to the cost of the scheme. If it can't be assessed it's a risk. One assumes the worst and that is the potential risk involved in that particular item. Now of course it would be nice to have no risks, to have everything taped down. But if for some reason, through lack of understanding, through lack of time, through any circumstance whatsoever, some environmental matter can't be resolved then it remains as a risk and has to be taken into the same account as all sorts of technical, economic and other risks.

So I guess that outlines our present position on the matter of environmental assessment and I would like to say that we would be in a far worse position at this stage had it not been for the work of the APICS Fundy Environmental Studies Committee and member institutions and I feel more comfortable about the chances of being able to complete an adequate environmental assesment today than I did a week ago. Thank you very much Mr. Chairman.

W. Kozak:

I represent a group of fishermen and our interest is a very very narrow one. What we are looking at and what we are concerned about is what is going to happen if a tidal power project is built. What will be the effects upon the fishery, in particular the parts of the commercial fishery that affect us? First of all, in terms of the stocks, will it affect the populations and, equally important because of changes in tidal regime, will we be able to fish them the same ways? In other words will the fish, if they are there, be catachable by the methods we are using today? I feel these two questions are very important.

If somebody could come along and say 'we are not going to effect any of the fisheries', I'd feel great about it but I think that one of the things we have found out over the years is we want to make sure we are on top of things. We want to be informed about what the possible happenings may be so that we as a group can then start to do something about it. Our experience has been in many cases that we are the last ones to be informed. In many cases our interests have not been considered an important factor in some of the decisions that have been made which affect our industry. Realistically, the governments of today have two things which really turn them on. One of them is energy and the other one is jobs. Decisions are sometimes made not in terms of the ultimate effects, but basically whether a project will provide energy or whether it will provide jobs.

Rather than ramble on, I will just state in summation that our objective is to find out, or to try and find out, what effects a tidal project would have upon our fishery and indeed our livelihood. Once having obtained this information we would want to be able to take some course of action to protect our interests.

H. Mills:

I am here specifically to talk about socio-economic aspects of tidal power. As a number of people have identified, the Fundy Environmental Studies Committee is primarily concerned with environmental things and although some people have in the past dealt with socio-economic impacts it is perhaps one of the major considerations which does require additional attention. I would like to pass comments on really two different aspects. One is the socio-economic considerations that might be involved in trying to reach a decision as to whether or not we should build a major tidal barrage, and the second would be looking at the socio-economic considerations related to an actual project.

I want to start off by talking about the opportunity costs. By the way, I think that the costs of this project are quite interesting for they went up 16 billion dollars in about a six hour period yesterday and I find that a little bit frightening. Late yesterday morning George Baker, in response to a question, said that the B9 project would cost about 6 billion dollars. I left yesterday afternoon's session a little early and was listening to the 6 o'clock news on the drive back to the hotel. I heard Dick Delorey being interviewed on the radio and he was waxing eloquently about the billions of tons of cement and other things in the project and said that the project would take 12 years to construct at a cost of 22 billion dollars. So there is quite a large variation there and if that happened just yesterday it leaves one a bit worried about next week.

The point I want to make is that even if the funds are available for a large project, the large number of dollars, whatever it might be by the time they actually build it, even if the funds are available from some Baron or Sheik or New England, it's still going to be a loan even if the money comes easy upfront, it's still going to be a debt, it's something that will have to be paid back and it's going to limit the ability of Nova Scotia to do other things over a long period of time. This is the sort of opportunity cost that has to be discussed. I'm not just looking at how you might spend 22 billion dollars if you happened to have it, but I think we really have to take a look at what are the goals of Nova Scotia over the next fairly long period of time, what other types of projects might we be going to foreign money markets for, because our ability to borrow money for those projects is going to be very limited if we go ahead with this one.

Related to that, I want to talk about risk. We have had risk analysis mentioned a number of times here and of course that has been primarily in terms of environmental connotations. I think there is a very high economic risk associated with this project as well. If we are looking 10 and more years down the road, in terms of economic future, about the only thing we can predict with certainty is that we are going to be wrong. It is very difficult to tell what economic conditions are going to be surrounding the project ten years from now, so that the point I am making is that even if the economic planning for the project itself is done really well, and I assume it will be, the surrounding economic conditions still place a very high risk factor on that project and the rest of our economy. For instance, if we have an economic recovery and if all costs stay high or go higher, Fundy tidal power (the B9 project) is going to look just fantastic. It will be the best deal we can think of. On the other hand if we have continued depression and if world oil prices go even lower, then the B9 project could be a major albatross that could really hurt us in a lot of ways. Thinking in terms of what Carl Amos was doing yesterday with his little arrows going in different directions with his whole range of possibilities, I think we have to do that sort of a risk analysis and take a look at the overall economic aspects of the project and try to judge whether or not we can afford to take that sort of a gamble.

As part of that I think we have to look at who is going to make that decision as well and what sort of a role the public is going to play. Certainly on environmental aspects the Fundy Environmental Studies Committee has been quite effective in terms of getting different people together, having open discussions and getting a pretty good handle on what is happening. But what about the socio-economic side of things and the public policy aspects? I realize that those people aren't barred from this group but still I don't see that sort of discussion taking place and it worries me a bit. Now if we look at a B9 project, and I think one can use a bit of a pun on that, it appears from the discussions that we have been having that although there are a lot of environmental concerns related to B9 there is nothing really scary in the way of environmental impacts. There are some worrisome things but it looks like in the overall scheme of things that quite likely environmental considerations are not going to rule out this project.

But perhaps we should still be looking at alternatives. We are talking about building a project for which we really don't need the energy at the moment, at least one could put forward that argument. We are planning to export 90% of the power over probably the first 25 or 30 years that it is in production. So we don't actually need it. What are the alternatives to it then? Conservation is one possibility. What about the water wheel idea? If we want to get into tidal power we could very well be putting structures out there that we could experiment with but would not be as expensive in terms of upfront money and which we could eventually put a large number of them out there and be generating tidal power; undoubtedly in a scheme that would be easier to finance, easier for us to live with as economic conditions change and presumably even less damaging to the environment.

Now if we do decide, or if somebody decides to go ahead and start building a project, then we get into another range of socio-economic considerations, and here again we can break them down into two phases: the major construction phase and the longer term aspects of it. From the construction phase there are a lot of regional benefits. There are going to be a lot of people employed, a lot of things happening and so undoubtedly a major stimulus to the economy, not to mention the types of industrial spin-off benefits which will come from both building and having the project. There are some negative aspects of the construction phase as well. You are undoubtedly going to have some sort of a boom-bust economy, you are going to have a lot of workers moving into an area that is not heavily populated at the moment, you are going to have questions to answer related to whether or not you have a permanent type of community for them, whether they are going to live in Truro, the sort of services that they will require, or whether you can find ways to perhaps do a fair bit of construction in fact in Halifax or other locations and be floating caissons around to the site. I think there are quite a few problem areas associated with the heavy amount of industrial activity that is going to be taking place during the construction phase that, although they are good in the sense that things are happening, could have quite a negative impact on small communities in the local area, and certainly ways to mimimize them are going to be one of the considerations once you actually get into the construction.

As far as the long term economics go, once again there are many positive factors. It will be cheap, clean power. If you need the power and if you start to look at the alternative ways of generating it, tidal power looks pretty good, certainly a lot better than burning coal and so on. You do have the industrial spin-off benefits that you can get from attracting industries that require a lot of power if you have a rate structure or a price structure that they can actually take advantage of it. You can go through a range of things all the way down to the tourism aspects of the fact that undoubtedly quite a few people will be interested in looking at a major tidal barrage. On the negative side you have certain diseconomies related to the headpond; concern with climate, agriculture, erosion, groundwater, and flooding. Quite a few of the things that you have been discussing here at this particular workshop of course have economic aspects to them and most of them look like they are a little bit on the negative side, but in the overall scheme of things there probably aren't large dollars associated with them. Also as we heard from Peter Larsen yesterday there are the external diseconomies related to the fact that you are going to have higher tidal amplitudes and the effects of this will be felt farther down the coast as well as in Nova Scotia and New Brunswick. That is perhaps a point that the type of study that Maine is undertaking, to look at the cost associated with having the higher high water levels after the project is in place, really has to be gotten underway in Nova Scotia and New Brunswick as well.

I think that perhaps I will wrap up with just a brief comment. I will put on my Canadian Nature Federation hat for a moment and talk about the need that I see to open up the discussion to a much larger range of interest groups. Aside from academics and scientists, there are going to be quite a few people out there who will take an interest in the decision as to whether or not there should be a project built, and in the actual impacts from it. I think that the Tidal Power Corporation would probably be well off if it were to start initiating more on this, and perhaps set up more formal mechanisms to deal with groups such as the National Farmers Union, the Womens Institute of Nova Scotia, the herring weir fishermen, and groups like the Canadian Nature Federation because if you let things go too long you'll find that these groups, largely through lack of understanding of just what is happening, will be concerned. I think it would be much better and that you would get a much better quality of participation from these groups if you get them onboard early and start having those discussions. Thank you.

G. Beanlands:

I have a rather unique interest in what has happened over the last three days of this workshop. The Institute of Resource and Environmental Studies of Dalhousie University was awarded a contract by the federal government about two and one half years ago to investigate ways of improving the scientific integrity of environmental impact assessment in this country. I was asked to head up the project. In some ways what hashappened in Fundy over the last six years represents to me a microcosm in time of what the applied research community across this country has been telling us should happen to improve the scientific basis for impact assesment. Now I do not think that this is solely an academic interest because I am aware that the federal government is already instituting some of the recommendations from our project.

I would like to take you on a tour through the preliminary results of the project and compare what you people said you would do to what you actually did. I would like to look at it in an overview perspective for a moment. I kept asking myself during the workshop why has this exercise over the past six years been so successful, particularly in terms of a joint venture between research establishments that heretofore have not focussed research activity on a common problem before. Somebody said that maybe it is a backyard syndrome. We have a number of scientific institutions sitting around the edge of the Bay of Fundy and the Bay is the common denominator. I think however that it is perhaps a bit more than that. I think that because it is a unique system it probably represents a rather stimulating intellectual challenge as opposed to a separate study devoid from any holistic system approach or one which is re-inventing the wheel. I also think that it is perhaps successful because of the foundation provided by Dave Greenberg's numerical tidal model which serves as a common denominator where everybody can start. It may also have been successful because the proponent is government through a crown corporation and in that respect it has probably been easier to get government funds funneled into applied research in support of a mega-project than it would be if this had been a project funded by say Mobil Oil or Petro-Can (although we are making progress with joint ventures with industry).

At the beginning of the workshop, Don Gordon estimated that several million dollars of federal funds have been spent on the environmental studies conducted during the past six years. Experience on an international level for mega projects like this indicate that environmental studies cost between one and three percent of the total project budget. Even after increasing that estimate to account for support facilities and salaries it comes out to be no more than 0.1% of 6 billion, so we've got a long way to go yet before we reach international standards in terms of level of effort.

Next I'd like to briefly go over with you some of the preliminary results of the project I mentioned and see how they compare with what has happened over the past six years with Fundy. In some cases I have been quite gratified while in other cases I have been quite disappointed. In effect I think there are individual examples in all the results that have been reported over the past three days which reflect the recommendations that came from the applied research community in Canada. I might say that we involved just under 200 people in research laboratories from St. Johns to Vancouver.

To begin with we have been told by everyone that we have to stop the shotgun approach and focus on those aspects that really matter. We do not have time to study everything. One of our recommendations is that we should make social scoping exercises a manditory requirement of all impact assesments. The only evidence I have seen of that occurring at the workshop was given by Peter Larsen from Maine who attempted to look at the public perspective of what might happen in the event of a tidal barrage. From a scientist's point of view, that approach may be irrelevent but from a politician's point of view it is public opinion that fuels his political engine. We have been warned by the scientific community that social scoping can be dangerous for you can not rely on the public to know everything that's important. I think there is also a wrinkle in that for sometimes even the scientists don't know everything that is important. I draw to your attention that Mike Dadswell noted that up until the recent studies in Fundy started nobody was aware of the importance of the upper reaches for shad. Also I believe Peter Hicklin indicated that the importance of the Shubenacadie River for bald eagles was only recently realized. I think you would agree that both of these environmental components will be quite important to a decision-making process.

The research community involved in our project said that the first thing you do after scoping is set your boundaries. Anybody involved with predictive modelling does that initially in any case. They also said that there was no such thing as a common study boundary for the impact assesment. They range all over the map so to speak but they must be clearly defined. I draw to your attention the study boundaries for the shad which range all the way down to Florida and those for the shorebirds which range to South America. I'm not talking about a study boundary from the point of view of drawing a line on a map. I'm talking about a study boundary from which data are acquired. I think you remember that both Mike Dadswell and Peter Hicklin indicated that they received data from all areas within the study boundaries.

Also it is important to set the time boundaries. One thing that has really bothered me during the workshop is that the proposed project I believe is to take about eleven or twelve years to construct and may not start for another three or four years. We are talking about a completion date of possibly twenty years in the future. If there was one consensus from the people involved in our project it was that biological predictions beyond five years are a 'fairy tale'. I really wonder if we have taken into account the extremely long time span over which we are attempting to predict the changes.

Another time boundary is response time. In some people's minds it may be more important to study the potential biological response capability of the system impacted than to get totally infatuated with the level of impact. Another example mentioned during the workshop is that we don't know the time required for Corophium to recolonize areas that may be changed as a result of a tidal barrage. I think that everybody agrees that that is rather important, particularly from the impact on the migratory bird population.

Another boundary which I think we hardly ever see recognized in environmental impact statements are the technical boundaries. I know that is pushing the term a bit but again I wonder how we are going to predict the impacts on migratory shore birds when Peter Hicklin said that he can't even count them accurately because they are present in such large numbers. If we get a small shift in the population we probably couldn't detect it.

People over the last couple of years have said we should be focusing impact assessment studies on systems which are relatively non-mobile because we can get a better handle on them statistically. Yet when Nancy Witherspoon gave her presentation on clams somebody said that 'I doubt very much whether you will be able to pick up the effect of a tidal barrage because of the noise in the population system'.

Another opinion emphasized during our study was that one should start with a concept and then move through hypotheses to experimentation. I only saw one conceptual framework presented during the workshop and that was Dave Wildish's showing the interactions governing secondary productivity in the benthos. I am sure there must be others.

Everybody involved in the project told us that there should be a study strategy. From a military point of view, tactics only make sense within an overall strategy. To continue with the analogy, one could say that in the last ten years impact statements in this country have been long on tactics and short on strategy. The only overall impact assesment strategy that I saw was the one put up by Carl Amos which was in effect an environmental impact assessment logic flow chart. I found that extremely helpful in determining where he was coming from and where he is attempting to go. For example, it demonstrated the sequential nature of the activities as he saw them and he couldn't proceed very far without results from the previous links in the flow chart. He mentioned the accumulation of errors. I spoke to Dave Greenburg just before dinner and asked him if there were confidence limits on his tidal amplitude change predictions and he said no. Also it clearly demonstrated that we can have fairly high predictability in physical systems which drops off to almost nothing in the higher trophic level system.

To finish up, I'd like to talk about prediction. That is what presumably we are all here for. To be simplistic about it, I think that there are four basic ways of predicting something: 1) using your gut feeling or professional judgement, 2) looking at the results from similar projects and seeing if they are relevent to what we are planning to do, 3) conducting experiments or 4) undertaking a modelling exercise. We have heard lots of professional judgement the last three days and about the only thing that is going to give us is a feeling for the direction of impact and order of magnitude. Maybe in some cases, in response to George Baker's words, that is enough. I think there has been evidence that we are attempting to look at the results of similar projects. The Annapolis River tidal project is a good example and it will be interesting to see the effects of the Straflo turbine on fish mortality. Perhaps it will answer some questions. Concerning the third way, experimental results, I was really quite disappointed to see the lack of experimentation in the more formal sense that has been attempted. Some people said that they recognized it was important but didn't feel it was necessary. We have been repeatedly told during our project that the best investment for one's money is a pilot scale perturbation exercise. I am reminded of the pipeline loops that were constructed for northern oil and gas pipelines which were a major investment of money, time and expertise to see what would happen in a microcosism. The information gained could then be applied to the full system. I think that if you talk to anybody in the federal government or industry about northern developments you will hear a very good response on the returns from the Baffin Island Oil Spill program (BIOS), a controlled experimental release of oil under true Arctic conditions. I suggest that we will learn more from BIOS than from all impact assesments done over the last ten years. Is it possible to select some small site in the upper reaches of the Bay, put a barrage up on a very small scale, regulate it according to Dave Greenberg's model and let it go? I don't know if its practical but this is an approach that should be considered.

Finally I think that we have to realize that predictions are easy. Do you want me to predict the weather tomorrow? I'm quite prepared to do that. The accuracy of my prediction is something else and that implies that it has to be tested. If we don't go back and test the prediction, why bother with it in the first place? One of the several conclusions of our project is that our ability to predict the impacts of mega projects is so limited once you move away from the physical systems that we really have to treat the whole endeavor as an experiment. We simply have to go back and see what happens afterwards. Unfortunately the extent at which we can interpret monitoring data is determined by what we measure and how we measure it before the project goes ahead.

I don't know whether my feeling is right but I suspect that perhaps the intellectual interest in the Bay of Fundy system, regardless of the potential tidal power project, may have peaked. There seems to be a general feeling that we know basically how the system operates and maybe people will now be drifting onto different things. It raises in my mind the question of what happens then. We have had very few testable predictions presented here in the last couple of days. The University of Aberdeen in Scotland has just finished looking at all the predictions made about North Sea developments over the last ten years. They identified over 500 predictions but less than 5% could be tested in any way. The rest simply were not testable and so one wonders why they were made in the first place. A major factor however was that the engineering designs were changed after the impact assessment was written which altered all the assumptions upon which the predictions were based. If plans are changed all the assumptions that underpin your predictions are out the window and you can't trust the predictions. I hope that this doesn't happen with Fundy and I'd like to hear some discussion about who will have the responsibility if and when this project ever gets off the ground to find out how right or wrong we were with our environmental impact predictions.

R. Edwards:

I've been asked today to say a few words about the environmental impact of alternatives to the Fundy tidal power development project. It has been mentioned earlier in the proceedings that in the Maritimes the conventional alternatives to tidal power are coal-fired and nuclear generating stations. Looking for a moment at other less likely alternatives, I would say that future conventional hydro will be very small-scale and non-conventional alternatives such as solar and wind appear less attractive for a number of reasons including costs, intermittent supply and storage problems. Wood is abundant but perhaps it is more suitable for domestic heating where it can be utilized at 70% efficiency as compared to perhaps one half of that for electrical generation. In better economic times there could also arise competition for supply from lumber and pulp operations. Perhaps to give you an idea of the order of scale we are discussing for the smallest tidal proposal of about 1100 MW the wood consumption required to give the same output would be about 300 cords of hardwood per hour (dried to 20% moisture).

Two additional potential sources of energy mention merit here. Both oil-shale and peat are found in substantial quantities in the Maritime region. There has been a lot of interest in oil shale in recent years so perhaps a few words are in order. Although exploitation of peat deposits as an energy source is a subject that just will not quite go away, I would prefer not to discuss it here. I am sure that electricity can be generated better and more easily than by exploiting a fuel source that requires first lowering the water table in order to obtain a fuel that has a moisture content greater than 95%. Going back to oil shale for a moment, it is a resource found in every province in Canada except Prince Edward Island. Of the known Canadian deposits those most attractive occur in the Moncton area which is perhaps why I introduce it into the talk now. Yield of oil from shale in this region is about 100 liters per ton which compares generally to the yield from Colorado's Piceance Basin shales. The estimated reserves in the prime deposit of New Brunswick are about 270 million barrels of oil indicating some potential for development depending on the economics. Recovery of the shale involves heating to about 400°C to bring about pyrolysis of the kerogen to produce shale oil. The process can be a surface operation where the shale is mined and processed in surface retorts or it can be an underground or in situ operation where essentially a fireflood technique is used to release the liquid or gas products.

It is apparent that conventional surface treatment raises the problems that are normally associated with open-pit mining and subsequent land rehabilitation. Experience derived from past synthetic liquid fuel operations would indicate a likelihood of worker exposure to a variety of health and safety concerns. For example, fugative gaseous emissions within the plant probably include trace metals, light hydrocarbons, sulphur, nitrogen compounds and polycyclic organic matter. Liquid effluent from such plants frequently contain hydrocarbons, phenols, trace metals, sulphides, ammonia, polycyclic organic matter and a whole host of others. I think that the list of trace elements that are associated with coal liquifation or gasification is quite lengthy. The high proportion of waste to product in the material being mined would indicate handling problems that are normally associated with the large volumes of spent shale and waste rock. Again, on the positive side, synthetic gas and synthetic oil production facilities are normally constructed with sulphur removal which enables production and combustion of a clean fuel. In situ development involves underground treatment of the shale by partial combustion in order to release the shale oil or the gas. This alleviates many of the environmental problems associated with conventional processes but raises the concern of ground water contamination. This is foreseen as a major problem in the Piceance Basin which until recently has been in the early stages of development and is likely to be a problem elsewhere.

As I mentioned, the conventional alternatives to tidal power development in the Maritimes are coal and nuclear power. I would say that from an environmental perspective the nuclear option is preferable to coal in almost every respect. Starting at the front end of the fuel cycle, I would say that underground coal mining is more hazardous than most occupations that Canadians turn their hand to and certainly more so than uranium mining where the ore is found in rock safer to mine. Experience in the Elliot Lake area has in the past shown a high incidence of silicosis in mine workers due to the presence of radon gas and from working quartz rich ores. This is perhaps analagous to pneumatacosis or black lung disease suffered by coal miners. In each of these cases, the problems can be overcome with better mine ventillation, better dust control and such measures.

In comparing uranium ore treatment with coal washing it is interesting to note that one environmental problem is common to both, namely the contamination of ground and surface water by acid runoff. Both uranium mill waste and coal washery rejects contain pyrite which is leached out as sulfuric acid. Contamination of surface water by radioactive elements has not been a significant source of the aquatic problems that have been experienced in the Serpent River system downstream of Elliot Lake. However, there has been significant environmental damage done by the discharge of acid mine water, by acid-leaching from coal waste piles and also from mill tailings at the Elliot Lake area. The difference perhaps is that a uranium tailings rehabilitation program is operating successfully in the Elliot Lake area and is unmatched in either the base metal industry, which in Canada is largely dependent on sulphide ores, or at coal preparation plants.

At the power production stage, airborne emissions and cooling water discharge streams are closely monitored and regulated in the nuclear industry, a circumstance that is not generally applicable to coal fired stations. The same comparison can be made in respect of the regulation of spent nuclear fuel and coal ash. The philosophy of the nuclear industry for example is to totally isolate radioactive material from the biosphere until physical decay has rendered them non-problematic. Where radioactive waste is currently stored on site, with a view to ultimate deep geological disposal, surface disposal of coal ash will inevitably see leaching of trace metals into ground and surface waters. I say this in defence of the nuclear industry which perhaps is subject to a fair amount of criticism from those who are under the environmentalist banner. I would say that the entire fuel cycle (mining through reactor operation, reactor safety, waste handling and disposal) is the subject of a fairly well-based and a well-controlled regulatory system.

Considering for a moment the broader range of environmental problems faced by our society, I would say that the most significant that we are currently engaged with is that posed by acid rain. There is also concern, perhaps a more distant concern, that atmospheric carbon dioxide and climate change may become a serious issue. If so I think that they would be very difficult to deal with. It's interesting to note that coal contributes to both of these problems while nuclear and tidal contribute to neither. It's clear that the choices among options for generating electricity are decided essentially on economic grounds. It's worth noting that the environmental costs of nuclear power are almost completely internalized whereas the environmental costs of others, including tidal power, are not. In the past the emissions from coal utilities and the impact of coal mining have been left entirely for society at large to bear. Public concern some years ago with particulate emissions, and more recently with acid gas emissions, and concern with early strip mining practices is leading to control of these environmental problems with associated cost increase to the utilities. Strip-mined land is now generally rehabilitated to agricultural use and emission standards (under the Environment Canada guidelines) almost demand control features such as flue gas scrubbers unless very low sulphur coal is used. Perhaps the extent to which pollution is controlled is a reflection of the seriousness with which environmental impacts are viewed by the public and regulators.

In this context, and perhaps I should be cautious here with respect to some of the problems that have been identified such as salt incursion into ground water and perhaps fish mortality in turbines, I'm not sure that the discussions of the last few days have identified any environmental impacts associated with tidal power that are likely to cause great alarm to the public or a response from regulatory agencies that would be unduely burdensome to the operation. With apolgoies to the coal people, Mr. Chairman, I think that is all I have to say.

D. Gordon:

I am going to address four questions: (1) what have we learned about the environmental characteristics of the Bay of Fundy and how does this basic knowledge relate to requirements for environmental impact assessment of a potential tidal power development; (2) what has been learned about possible environmental impacts to date; (3) how does the general environmental assessment situation in the Bay of Fundy compare to other regions around the world; and (4) what steps are necessary in the future if a precommittment program is undertaken?

Much has been learned in recent years about the environmental characteristics of the Bay of Fundy. This is illustrated by plotting the scientific publication rate over the past 70 years (Fig. 1) which emphasizes the spurt of knowledge which occurred during the 1970's. The peak in 1977 reflects the publication of the 1976 Acadia workshop proceedings while the dip in the early 1980's is exaggerated somewhat by work in progress yet to be published.

I wish to emphasize the distinction between what I see as being two different, yet interrelated, types of investigation that are involved in environmental assessment (Fig. 2). The first, and I think the most important, is basic scientific research which is aimed at understanding the natural environment and serves as the foundation for subsequent applied work. By its very nature, it is long-term and most investigations require at least several years to complete adequately because of seasonal and year-to-year variability. It is usually conducted by government research laboratories and universities and consists of a combination of field programs, laboratory experiments and theoretical studies. A point I wish to emphasize is that this information can not be gathered on a crash basis in a short time-frame. This is the kind of research that was summarized in the series of papers given in Session I and is where the bulk of scientific attention has focused to date.

In contrast, only limited attention has been given to impact assessment studies (Fig. 2). These studies are critically dependent on the basic scientific research and address specific environmental questions which arise when the engineering details of a project are known (which were covered in Session II). The presentations in Session III addressed the

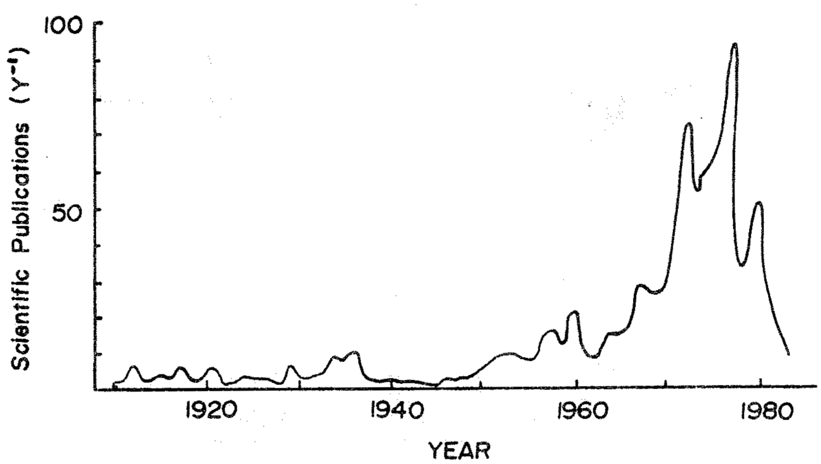


Fig. 1. Annual publication rate of scientific papers and reports covering environmental studies in the Bay of Fundy. Based upon Moyse (1978) and later supplements.

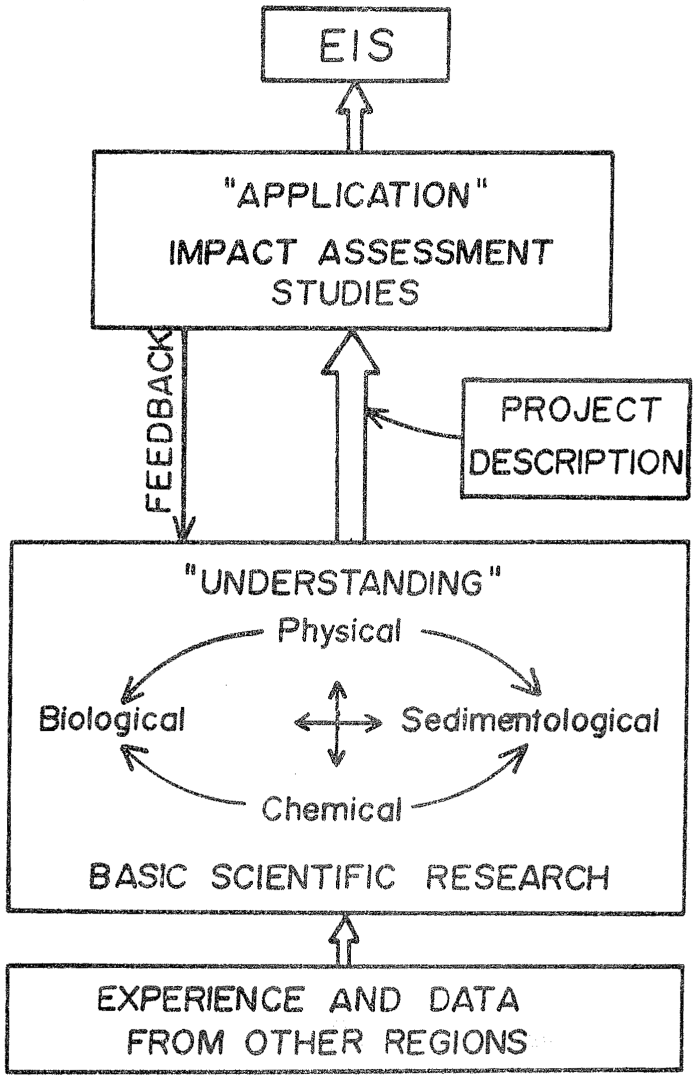


Fig. 2. Schematic diagram illustrating the relationship between basic scientific research and impact assessment studies.

kind of questions that would be considered in impact assessment studies and the key word is application. In most instances, these studies can be done in a relatively short time-frame. They are largely analytical and consist of reviewing data that already exist although at time they do require a certain amount of experimentation and additional field work. In my opinion, which seems to be shared by George Baker, this type of investigation is the responsibility of the project proponent, both to fund and direct. They form an important part of the formal environmental assessment procedure. The actual work is usually done by environmental consulting firms. Sometimes universities are involved and occasionally government laboratories depending upon their mandates and policies. Feedback to basic scientific research is highly desirable, such as has occurred at this workshop, to insure it is going in the right direction. It is beneficial to look at the application stage fairly early during your basic research to be sure that you are focusing on the right aspects, organisms and processes. One does not have to study every environmental component to prepare a reasonable and useful impact assessment document.

I am not concerned about the limited amount of impact assessment work done so far because it can be done when required in a short time-frame. The basic research must be done first. There are cases however where a fair amount of impact assessment work has already been done and I am thinking of the tidal and sedimentation numerical modelling studies of Dave Greenberg and Carl Amos. They have been working across the interface between basic and applied research and their excellent progress demonstrates the value of having the same people participate in both kinds of study.

To summarize our knowledge of the environmental characteristics of the Bay of Fundy, it is clear from the papers presented at this workshop that much has been learned since the initial workshop at Acadia in 1976. Our knowledge is especially strong now for the benthic aspects of the Bay of Fundy ecosystem. Despite the significant progress made however important information gaps still exist. For example, further studies on zooplankton and certain microbial processes are warranted. Also, as was so well illustrated at the end of Session III, there is still much about the fisheries we do not understand especially near the mouth of the Bay.

Another point I wish to emphasize is that it is not essential that all the data used in a possible environmental assessment come specifically from the Bay of Fundy. Experience, and even sometimes data, developed by scientists working in comparable environments can be used. There is no doubt that we have learned much from recent contact with scientists from the USA, Great Britain, the Netherlands and other countries.

The second question I promised to address is what have we learned so far about possible environmental impacts of a tidal power project? What did we learn from Session III of this Workshop? Firstly, I would like to praise the Session III speakers for their willingness to stick out their necks and make predictions. When we first met at Acadia in 1976 some predictions were offered but as a rule I think we were much more reserved because of the more-limited data base that existed then. At this workshop nobody hid behind the excuse of not having enough data. Everyone made an honest attempt to give reasonable predictions as speculative as they might be. It is interesting to note, as observed by others before me on the panel, that an air of gloom and doom did not surround Session III. Quite a number of positive impacts were identified. There also are many negative ones which require more study before they can be quantified with acceptable accuracy.

As discussed in Session II, a choice can be made between building parallel tidal power projects in Cumberland Basin and Cobequid Bay or a single over-sized project in Cobequid Bay. This workshop has clearly demonstrated that the Cumberland Basin is a more productive estuary. On that basis it would appear to be reasonable to follow the second option and leave the Cumberland Basin undisturbed. Despite its larger size, the environmental impacts of the Cobequid Bay project in the headpond area seem to be less.

It should be emphasized that this workshop has only covered marine aspects. Terrestial impacts have not been considered in any detail although reference to them was made in the talks on ice, climate and hydrology. The workshop has also focused upon the upper reaches of the Bay of Fundy where our knowledge is currently most complete and predictions are easiest to make. Limited attention to date has been given to predicting environmental impacts in the lower Bay of Fundy and along the New England Coast and our confidence levels for such predictions would be much lower than for the upper Bay. Although site-specific impacts may be less in distant regions, the net effect could become a major determining factor because of the much larger area affected. Therefore, one should not necessarily expect the same generally positive feeling to prevail when <u>all</u> potential environmental impacts are assessed. The aspects not covered in this workshop should be addressed the next time a similar gathering is convened.

The third question I want to address is how does our current knowledge of the environmental impacts of a possible tidal power project compare with other mega projects in Canada and around the world. As is shown in Fig. 3, there is a relationship between our ability to offer accurate predictions and the level of effort expended in research. In 1976 I would judge that we were near the lower end of the curve because of our limited knowledge of the upper reaches of the Bay of Fundy. Most environmental impact assessments in Canada and abroad probably fall into this region as well since they are usually done in a year or less and adequate background data rarely exist. Fortunately in the case of Fundy political and financial factors have slowed the pace of tidal power development and this extra time has been well used to expand our environmental data base and understanding. As a result we have moved up the curve considerably (Fig. 3). Simply speaking, spending more money on scientific research has improved our ability to predict environmental impacts of tidal power development. Time still appears to be with us and it is possible to move still further along the curve with a modest continued investment of research funding before a formal environmental assessment might begin. Because of the asymptotic nature of the curve, a point will eventually be reached where

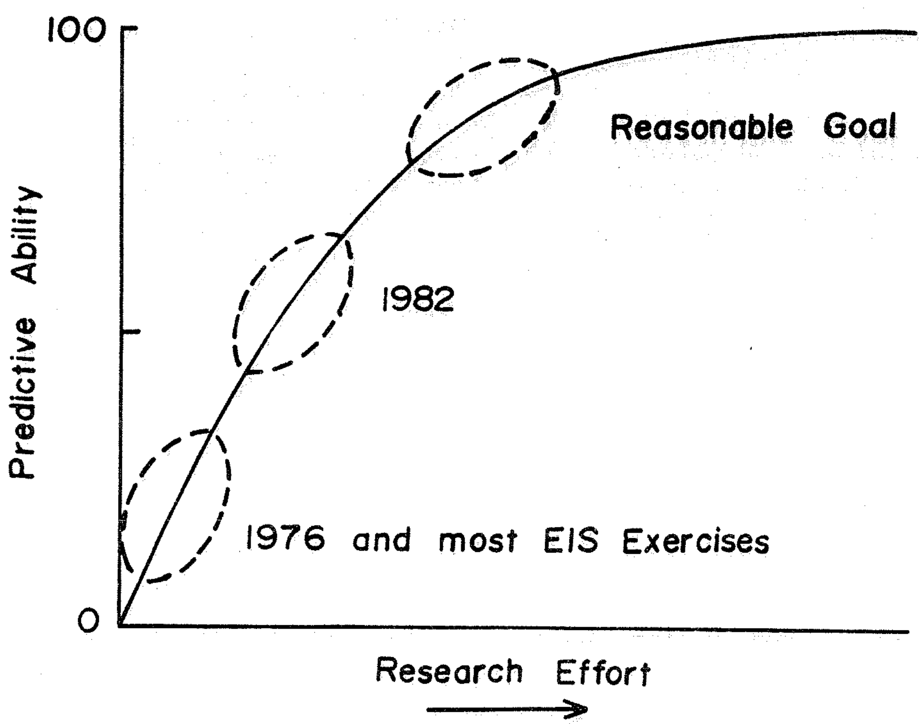


Fig. 3. Diagram showing the relationship between research effort and predictive ability. Dashed lines indicate the approximate location of Bay of Fundy environmental research at different stages.

continuing scientific research will not substantially add to our predictive ability, but I feel that it is at least five years away.

On an international standard, I think our environmental work in Fundy ranks quite high compared to other possible tidal power developments (or similar large engineering projects). I think it is safe to say that the upper reaches of the Bay of Fundy are becoming one of the best understood coastal regions in Canada. However, there still is more that should be done before the present momentum is lost.

Finally I will say a few words about what I would like to see happen in the future. For reasons given above I would like to see the basic scientific research continue at the highest possible level under the present funding constraints. New data definately need to be gathered to help fill the important information gaps identified at this workshop, for examples certain aspects of microbiology, zooplankton ecology and fisheries. There also is a large amount of data already collected that needs to be completely analyzed and interpreted. Steps should also be taken to synthesize the results from all the individual research programs that have been conducted. Strategies for doing this were discussed at yesterday's meeting of the Fundy Environmental Studies Committee and the favoured approach is to attempt an ecosystem modelling exercise. A number of us wish to start such a project early in 1983 building upon the experience gained by a group of Dutch scientists who have been modelling the Ems-Dollard estuary in Europe. This research can be justified even if tidal power development goes no farther than it is today. The information gained can be used for other practical applications and it also possesses intrinsic scientific value. If the research comes to a halt and we lose our present momentum it would be difficult to get moving again when and if tidal power development plans were announced in the future. Gordon Beanlands said he thought the science had peaked. I hope he is not right for I would like to see our knowledge spurt ahead even more before our research effort drops substantially.

If a precommittment program is undertaken one of the first steps will be to revise the draft environmental assessment guidelines that were prepared back in 1977. Firstly they should be rewritten after scientific review to incorporate all of the environmental knowledge that has been gained in the last five years. Secondly, and just as important, they should be reviewed by the public, as also recommended by Hal Mills. Such a public review was planned to happen when the guidelines were written but is unnecessary until a precommittment program is announced. Public input is very important before the final guidelines are adopted and conveyed to the proponent.

When the final guidelines are received, the proponent must plan his impact assessment studies (Fig. 2). This exercise will hopefully include input from the scientific community and a workshop similar to this one would be extremely valuable. The proponent will then have to fund the impact assessment studies and prepare his environmental impact statement, hopefully promoting effective dialogue with the scientific community at all stages. The environmental impact statement would then be reviewed and acted upon accordingly to federal and provincial regulations.

Finally, I wish to emphasize that environmental research should not necessarily stop the day that the environmental impact statement is submitted. If the decision is made to construct a tidal power project I think the proponent should fund the establishment of a multidisciplinary research group consisting of several dozen permanent staff which has the mandate of conducting environmental research to follow the actual changes that occur. The information generated can be used to assess the accuracy of environmental impact predictions and to help manage the operation of the project. Certain questions are likely to arise such as sealing off the barrage for a few tidal cycles to promote sheet ice formation or to keep out storm tides and knowledgeable environmental input is essential in answering them. The best advice would come from a group specifically hired for the purpose. Although funded by the proponent, I think such a group should be housed in one of the established scientific research establishments in the region where they can interact daily with other research scientists and make full advantage of existing support facilities. A good example of such a group can be found in the Netherlands. In the 1950's the Dutch undertook their massive Delta project which has involved the construction of numerous dams, sluices and dykes to protect the southwest Netherlands from flooding. They established the Delta Institute in Yerseke to follow the numerous resultant environmental changes and the data obtained have played an important role in the planning and operation of the project. Thank you.

DISCUSSION

F.J. Simpson:

Perhaps George Baker would like to make some comments about some of the financial options as you see them, particularly with regard to the use of money.

G.C. Baker:

I guess the only comment I am really anxious to make about financing is that the cost didn't go up from 6 billion to 22 billion in six hours as Hal Mills might have known if he had seen the Update'82 Report. We quoted the costs of the project in two ways. The first way was in 1981 constant dollars and that was the 6 billion. The other way was the amount on the books at completion if inflation went on at 10% per year from 1981 to the completion date. That was the 22 billion. So that explains the difference of 16 billion. I'd hate to say how far our governments have taken us along the way from the 6 to the 22 billion since that report was written but not all that distance anyway.

L. Cammen:

I have a few observations to offer which have occurred to me during the course of this workshop. To begin with, we have heard on the order of fifty papers. Only a very few of these have really been considering environmental effects outside the barrage and I think that is not an unrealistic reflection of the research effort in the past few years. I think the reasoning for this has been that it is more obvious what the impacts will be inside the barrage in the headpond. It is more difficult to assess impacts outside the barrage. The trouble with this is that a perception has resulted, despite disclaimers now and then, that the headpond impact is the project impact. I think this is a mistake. If you consider the area impacted within the barrage and compare that with the area outside or if you consider the population impacted inside the barrage compared with the population along the New England coast or if you consider the possible economic implications I think you can see that we need to change our perceptions a little bit. So the questions I want to pose, not necessarily to the Panel but just in general, are about these outside impacts. How important will they be? For example, what if Dave Greenberg's model has underestimated the actual tidal amplitude change? I asked Dave what are the confidence limits on his model and he answered there are none.However, he is confident in the model, and I also have confidence in Dave, but if there is a chance that the effects have been under-estimated what kind of chance are we willing to take? One in one hundred or one in one thousand? If changes in tidal range were to cause trouble along the New England coast very significant environmental impacts would result. Therefore, I think we need to consider both the probability and the magnitude of the possible impacts over the total affected area and I don't think that this has really been done yet. For example, the graph which Carl Amos showed yesterday and Don Gordon showed again today (Fig. 3) poses the question of essentially how far up this curve are we willing to go or do we even think we need to go? Well, I would offer the illustration that if we were talking about a nuclear power plant we certainly wouldn't be stopping half or three quarters of the way up; we would demand that we have a complete assessment of the environmental impacts.

W. Kozac:

I agree whole heartedly with what you are saying and from my perspective I see that a lot of work is being done but it doesn't answer any of the questions that I have. I agree with you that everything is looked at in terms of either very close to the barrage or behind it. I think that a lot of people further down the Bay could be affected by a project. I think some of the things that were mentioned previously might exert an influence as far away as Georges Bank because of a possible increase in tidal currents. What effect for instance might this have on the deposition of scallop spat? Does that mean that there may not be a scallop fishery there? What does it mean in terms of the herring larvae which now come up from Trinity? Nobody has even mentioned that there is, or was (and I hope it is still there), a large spawning population of herring in Scots Bay. The larvae move with the currents. If the currents increase, where are they going to go, what will their survival rates be, and will we be dealing with the same populations of animals that we have been? I think that these questions haven't been answered and I think that they must be addressed.

Mary Majka:

I would like to represent the general public plus the naturalists of this province and this country. I also am an inhabitant of the area that will be affected so in a way I am here in a double capacity. I have been listening to three days of discussion. I came here to listen and to learn and perhaps also to answer some of my questions and the questions that will be asked of me by the general public, by people who belong to organizations or by people who live around me and I must say that I am quite confused. I am torn between being optimistic and very pessimistic. I am sometimes very relieved and sometimes very frightened or at least concerned. I was very glad that Hal Mills and Don Gordon have mentioned the public and the concerns of the public. There are some people around the area where I live who would like to know more about the proposed tidal power project but only for economic gains. Those people couldn't care less what is going to happen ten years from now but I would say that the majority of people are not informed at all. This is where I think that the mandate of this group lies because it is very wonderful when scientists talk to scientists but I think that sometimes scientists have to go out of the world of science and I am glad to hear that some of them did at this meeting especially. I thank all those who have, as somebody phrased it, 'stuck out their necks'.

F.J. Simpson:

I fully appreciate why you would be quite confused because at times I was too and I'm sure some of those in the audience got confused about the pluses and minuses of various papers that were given. Certainly your remarks are pertinent to some of the questions and some of the recommendations that have come from the panel, and I'm sure there will be more opportunity for public interaction as the project moves forward.

D. Scarratt:

I would like to thank Don Gordon for trying to put into perspective the work that different scientists and researchers have tried to do over the past six or seven years and perhaps try to clarify what I percieve as a misconception that Gordon Beanlands appears to have. While I think that privately as individuals and scientists we clearly have responsibilities there has never been a clear mandate ever set for any of us to do any of this type of work with the exception of one or two people who clearly have been funded by the Tidal Power Corporation. The work for most part has been done by scientists who have felt they had an interest either in the dynamics of the system as a whole or in particular components. Their interest perhaps was triggered by the potential for tidal development but possibly also by the potential for a deep-water port somewhere, or an oil well somewhere else or any other of the numerous environmental assaults that we can percieve for the Bay of Fundy. In most cases, these scientists and researchers have persuaded their superiors that this represented not only a valuable avenue for research but one that was also socially appropriate at the present time. Despite the lack of a collective mandate considerable progress has been made. We are like the play 'Six Characters in Search of an Author'. We have always felt that there was an important role for cooperative Fundy research and the old Department of Environment Fundy Working Group went specifically looking for somewhere where we could hang its hat in order that we could continue to meet and exchange ideas and information. Our association with APICS has been ideal.

When we first started to plan this workshop a year ago we decided the time had come to do more than review our research and that we should really begin to challenge ourselves and make some predictions. Several of our members have made some predictions, others have made calculated guesses and some have come up with what you might call reasonable hunches, and I think this represents an important step along the road. I am a little disappointed that Gordon was critical of us. We have come a long, long way on relatively modest and insecure funding. I realize that there is a long way yet to go. We are not at the moment in a formal EIS process and I think we have to remember that.

With respect to Mary Majka's comment, yes I think it is confusing that some people are relatively positive and some people are still relatively unsure. We are in a very early stage and we are simply doing our best not only to prepare ourselves intellectually in case tidal power should come along but also in case there should be any other assault that somebody may dream up for the Bay of Fundy, be it salt water brine discharges from potash mines, new industrialization in Saint John, the old Eastport refinery question which stimulated our work of 12 years ago or any number of things. We have to be prepared for any one or all of these and any one of them may be announced tomorrow.

G.C. Baker:

After Dave Scarratt's most appropriate statements, I don't think I need to say anything except to point out that Don Gordon's chart (Fig. 2) provides a very useful picture of where we are now, down in the understanding stage, and it is at the application stage that we would attempt to answer the specific questions posed by Wally Kozac, Mary Majka and other people who wonder how confident we can be in our predictions, how confident we should be, and what those predictions are. We're just not there yet and we haven't any mandate to make predictions for public consumption. We haven't got all the background information yet and we have years of very serious and costly work to do before we can make any predictions like that. As Dave Scarratt said the scientists are now testing the state of their own knowledge to see if they can. I'm going to be in real trouble if we start an impact assessment and they can't so I'm hoping they will keep this process going until they can make adequate predictions. Until their understanding has reached that point, I think it would be a disservice to the public if we represented our present ideas to be predictions of what really will happen. All we would do is encourage the taking of sides and a debate on rhetorical grounds rather than on the basis of fact.

G. Beanlands:

I'm not sure what my misconception is that Dave Scarratt was referring to because I quite agree with what he is saying and I certainly don't want to leave this group with the impression that I was negative. In fact I started by asking why has this venture been so successful? The reason I think that it is important to know that is because there are two concepts of what environmental assesment is all about. One is that top block on Don Gordon's chart (Fig. 2) and the other is the entire chart. I ask you the question what happens to the top block without the bottom block? If we are going to improve the science of environmental assesment we need good scientists and how do we get them involved? I start out by asking that question because I really don't know what the magic formula was that prompted all of these people here to come together and focus their efforts in a well-organized way. I think that it is extremely important to understand why it happened with Fundy because we are moving into an era of offshore research in which we are going to be funded by the Environmental Studies Revolving Fund to the tune of millions of dollars. There is one fund established for the east coast and another one for the Canadian Arctic, and the fund managers I'm sure will want to envolve the people who undertake the studies in that bottom block. They are not really interested in pursing the way we have done things in the past which has been a very much different exercise and largely a waste of time. So I don't think I disagree with you Dave at all. The point I was trying to make, which has evolved out of the project that I have been involved with over the past two years, is let's make sure that everybody involved in environmental assesment understands the opportunities and the scientific constraints involved and that we don't go off half-cocked about what we think we can do and what we can predict because in many cases we have to go by best professional judgement. There is nothing wrong with that. What we have had up to now is professional judgement pawned off in environmental impact statements as the state of the art in scientific research and the decision makers and politicians unfortunately believe it. I think that an order of reality has to creep into impact asessment and I don't think we can get very far with impact assesments per se in that top block of Fig. 2 unless we can somehow manage to capture the kind of activity that has gone on for Fundy in the other mega-projects down the pipe. I throw up the Beaufort Sea as an example. It's in nobody's back yard so to speak and little basic research had been conducted. A lot of money was spent however on impact assessment studies which would dwarf the budgets of most institutions around the world. It's a shame the money couldn't have been used to conduct environment studies like those done in Fundy.

F.J. Simpson:

My own comments are that a group like this is quite frequently successful because of a few people who put a lot of energy into it. Don Gordon has been one of them, also Dave Scarratt and several other people in the scientific community, including some who unfortunately couldn't be here.

Bob Cummings:

I cover environmental topics for a publication and it seems obvious from having sat here for three days that there will be both benefits and damages associated with a tidal power project. Is there going to be any mechanism for compensating those people who may be damaged and, secondly, how do you really figure out who those people are if in fact you are going to compensate them when you are dealing with essentially the whole north eastern coast of North America? I have raised this question with several people here and one of the first questions I asked Dave Scarratt when I arrived was about the impact of the tidal changes on the coast of Maine, especially on the beaches. His comment was that he didn't think a 1% increase in tidal amplitude would have any impact. That is Bay of Fundy thinking. It is a 1% change in the Bay of Fundy but it is about a 12% increase at the mouth of the Kennebec River where I live. For that person who has invested all his savings in a house on a sand dune it may have been unwise for him to have built there in the first place, but certainly it is more unwise to consciously make the situation worse. Is there any mechanism for compensating that person? It seems very likely from all the discussion that over a period of years the clam flat production in Maine will increase because of the greater tidal range, but it also seems likely from the discussion that for four or five years, as the sediments shift back and forth to reach a new equilibrium, production may go down. For the person who makes his living digging clams, his concern is not what is going to happen five years in the future but with feeding his family for this week. It seems to me that at some point in the environmental assessment process these considerations have to be looked at. I really don't see any evidence that they have been yet.

G.C. Baker:

I would think that the subject of compensation would come up at that time when the interaction of the environmental perception of impacts and the design of the project was being debated. We only have one experience and one swallow doesn't make a summer. But in the case of the Annapolis project, the agency for representing the environmental concerns of all the various parties that do have such concerns is the Intergovernmental Environmental Advisory Committee (EAC). The EAC frequently says: 'Well, what are you going to do about this?' 'Can you fix it up?' 'Are you going to compensate?' 'What is your approach?' This is the sort of forum in which questions such as the one just raised has, in our limited experience to date, been settled.

G. Beanlands:

I would just like to make one comment after Mr. Baker's words. From my experience in dealing with industrial proponents across the country compensation is the one reason why they need good firm predictions from scientists because in many cases compensations are initially costed in the project based on predictions of what the losses are going to be. They have just as much need for a reasonably tight estimate of these changes for compensation calculation purposes as the scientist does for scientific reasons. I suggest that this is one area where we can get somewhere with industrial proponents because in many other cases they are not really interested in refining predictions because there is a certain comfort in flexibility of interpretation from their point of view.

R.P. Delory:

I would like to make a comment in response to Gordon Beanlands and put in a little plug for the engineering community. I gather from his talk that he was almost blaming the engineers for not having the common sense to stick with their plan and making it very hard for the environmental people to come up with the proper assesements. I say thank God the engineers have enough sense to change the plan if it looks like it is not going to work!

C. Desplanque:

I'd like to make a couple of comments. I'd like to thank Don Gordon for all the nice remarks about the Dutch. Being a Dutchman, one of the two here in the audience, I should point out to keep things in balance that the Dutch can make awfully grave errors. One example is found in that particular project being mentioned, the Delta Works. They are at the moment busy closing off the last tidal inlet which is about the same magnitude as Cobequid Bay. They had to change plans in mid-stream because of public outcry over environmental implications. Consequently they change plans from a closed dam to an open dam. Parliament shifted very suddenly and they are more or less at the moment in a technical fix. It cost so much to change plans in mid-stream that the Dutch budget is awfully strained at the moment and the maintenance of other dykes is more or less hampered by the drainage of funds toward the project.

I agree with you that we have to look over the horizon and see what other people do. If the Dutch had looked to Canada to see that you can grow oysters in Whycocomagh Bay (Bras D'Or Lakes) with a tidal range of just a few cm then they would have realized that their conclusion that a 2.3 m tidal range was required for oyster growing was a rather exaggerated demand.

The second point I want to bring out concerns increasing in the tidal amplitude by 15 cm in the Gulf of Maine. We all know that the eastern seaboard is settling at the rapid pace of about 30-40 cm per century and that affects the mean water level as well as low and high water levels. Tidal amplitude is also increasing naturally. If Dave Greenburg's prediction is right, and I think there is a good chance he is right, then the resulting situation is exactly the same that will occur naturally about 30 years from now. If we are going to pay damages to the New Englanders then we should only have to do it for about 30 years. After 30 years they will be in the same situation that would have happened anyway.

W. Silvert:

During the past couple of days we have heard about 50 papers concerned with different segments of a problem. Normally at a conference there would then be a session where everything would be summed up. That hasn't really happened here because the intent of this Panel is somewhat different. This is not a panel designed to sum up the scientific work that has been discussed but one designed to take off in a somewhat different and very important direction. I think that this is somewhat unfortunate in a way because it leaves us with a feeling that we don't know what we have accomplished in the last couple of days and it looks like we may have to wait until next fall's workshop to have some attempt to summarize and integrate the knowledge we have gained.

I would like to point out something which I don't feel has really been said during the workshop although it has been said in the restaurants and in the hotel rooms. There is a curious imbalance here in the viewpoint of assessments because we have heard just one physical oceanographer, one sedimentologist, and several engineers but a vast number of biologists discuss potential environmental impacts. Yet it appears that in terms of impact assessment the really critical factors to look at are going to be the physical oceanography and the sedimentology. For me one of the most interesting observations during the entire workshop was how virtually all the biologists used the same model in the predictive papers of Session III. It wasn't perhaps exactly obvious and people implemented it differently but it was clear that virtually all the models the biologists were using to make their predictions were either identical or compatable. They were based on certain fairly simple physical predictions about changes in size of the intertidal zone, the turbidity of the water in and outside of the barrage and a couple of other factors. In fact, people seem to assign the same priorities to them. Therefore, I have come to the conclusion that our biological predictability is not, as several speakers have said, orders of magnitude worse than anything else in the system, but in fact is likely to prove in fairly good shape. Furthermore, biological systems have a degree of robustness and homeostasis which I think is likely to be evidenced in the future development of Fundy. What I think is unfortunate is that we haven't yet determined the impact of uncertainty in the physical and sedimentological predictions and it is important to understand this in any kind of impact assessment exercise. For that reason I wanted to present this brief summary of my own.

J. Lakshminarayana:

We have heard mention made of the recently established Environmental Studies Revolving Fund which will provide millions of dollars to study the environmental impacts of offshore oil and gas development. I think a similar fund should be established for the coastal zone which must be protected from a large number of environmental insults. I also think that we should begin to pay more attention to the synergistic effects of developments. We already have one mega-project nearing completion in the Bay of Fundy, that is the Point Lepreau nuclear generating station. How will this project interact with tidal power development? How will a mishap with one project affect the other? These questions must be considered.

R. Edwards:

I think that the question of synergistic effects would be addressed in an environmental impact statement which would review the existing body of knowledge and attempt to make an assessment of what the likely impacts of the project under discussion are going to be on the coastal zone ecological system and on society at large. New research into these problems may be generated.

D. Gordon:

If you look at the draft EIS guidelines for Fundy I believe you will find statements about considering the interaction of a tidal power project with other large scale developments that are already in existence or may be constructed within the lifetime of the project. Also, as you very well know, that the activities of the Fundy Environmental Studies Committee have not been focused solely on tidal power issues. We have been looking at diverse aspects of the Fundy environment and the BIO scientists responsible for the radiation monitoring of the Point Lepreau project are usual attendees at our workshops. I think that it is fair to say that within the Committee attention and interest is given to various issues that could very well arise and that we are developing basic information that can be used to solve any number of problems once they become known.

G. Beanlands:

I think that Dr. Lakshminarayana has identified a very real problem that we as a society face, namely being into the environmental impact statement age but only looking at individual projects. This applies to both government agencies and to the public at large. We do not have good institutional mechanisms for looking at the synergistic effects of different projects and the overall quality of the environment. It seems to be the coastal zone or enclosed areas like the Bay of Fundy where the impacts of different projects impinge upon each other. A much different type of approach is necessary for regions like this.

SÉANCE IV

RÉUNION-DÉBAT

Plutôt que de conclure l'atelier par une séance qui n'en résumerait que le contenu scientifique, le comité directeur décide d'organiser une réunion-débat sur les exigences d'une bonne évaluation des incidences environnementales. Les participants, qui viennent de divers milieux, sont invités à exprimer leur opinion sur la valeur des études environnementales faites à ce jour et sur les exigences et les responsabilités entraînées par les travaux futurs. Les incidences environnementales de l'exploitation de l'énergie marémotrice par rapport à d'autres sources d'énergie sont également discutées. Voici la liste des participants :

1. Dr Fred J. Simpson - Président
   Président du Conseil des sciences des provinces de l'Atlantique
   Directeur du Laboratoire régional de l'Atlantique
   1411 Oxford Street
   Halifax, N.S. B3H 3Z1

2. M. George C. Baker, Ing.
   Vice-président exécutif, Société de l'énergie marémotrice
   Suite 1109
   5251 Duke Street
   Halifax, N.S. B3J 1P3

3. M. Walter Kozak
   Président de la Fundy Weir Fisherman Association Inc.
   St. Andrews, N.B., E0G 2X0

et il n'est pas toujours possible de le suivre de la façon voulue au départ. Mais j'ai pensé que peut-être, en guise d'introduction à la séance de cet après-midi, il serait intéressant de connaître les intentions de la Société.

Le plan comprend trois volets. Le premier est de satisfaire certains préalables : établir un plan financier faisable et acceptable de l'aménagement à grande échelle pour déterminer les clients potentiels de l'énergie produite et s'assurer jusqu'à un certain degré que des permis d'exportation à long terme seront disponibles.

Donc, si ces conditions étaient remplies, nous nous lancerions tout de suite dans ce que nous appelons un programme de pré-engagement. Celui-ci comporterait divers aspects, mais je pourrais les classer en trois groupes. Le premier serait l'évaluation environnementale et la conception définitive. J'ai fait exprès de réunir ces deux aspects parce que je les trouve imbriqués. Le deuxième groupe serait la négociation d'accords conditionnels en ce qui a trait aux finances, aux ventes, aux emprises et à d'autres exigences foncières. Le troisième serait l'analyse des risques. Le programme de pré-engagement durerait probablement environ trois ans, peut-être davantage. S'il était achevé, il serait décidé de s'engager ou non à réaliser l'aménagement. Cet engagement lierait toutes les parties, c'est-à-dire les clients, les garants, les souscripteurs, les prêteurs, les fournisseurs de capitaux propres, etc. La décision d'engagement finale et officielle serait sans doute prise par les gouvernements, probablement ceux du Canada, de la Nouvelle-Écosse et du Nouveau-Brunswick. Cet engagement dépendrait sans doute de l'opinion publique ainsi que des avantages, des inconvénients et des risques apparemment rattachés au projet.

Cependant, le processus décisionnel ne serait pas aussi rude qu'il n'en a l'air. En effet, à tout moment du programme de pré-engagement, il pourrait être décidé de mettre fin au projet, et ce, par n'importe laquelle des parties intéressées. Par exemple, si l'État du Maine estimait les inconvénients environnementaux éventuels et les autres risques supérieurs aux avantages qu'il en retirerait, il pourrait dire : "Nous nous excusons, mais nous ne vous accordons pas d'emprise." Ou encore, si des clients, à un stade quelconque du programme de pré-engagement, décidaient que les résultats de conception ne correspondaient pas aux prévisions de l'étude de faisabilité et que les avantages n'étaient pas aussi "alléchants" qu'avant, ils pourraient dire : "Eh bien, nous n'avons pas envie de poursuivre." S'il devait s'avérer, lors d'une évaluation environnementale, que certains des désavantages, certaines des incidences environnementales seraient déraisonnables, le projet pourrait très bien s'arrêter là. La décision finale de s'engager serait donc la dernière d'une longue série de décisions prises par les divers intéressés.

Il peut donc sembler, d'après ce que je viens de dire, que les chances qu'une décision positive soit prise sont très minces. Elles pourraient l'être, mais, afin de rendre le projet plus probable, les promoteurs auraient avantage à ce que tous les intéressés bénéficient du projet d'une manière ou d'une autre; il ne s'agirait ensuite que d'équilibrer avantages et inconvénients. D'après nos connaissances actuelles, nous croyons qu'il y a au moins une bonne probabilité que les avantages soient suffisants pour que toutes les parties puissent en bénéficier et pour compenser les inconvénients.

À cet effet, nous veillons donc particulièrement à ce que les incidences soient atténuées, dans la mesure du possible, par la conception. Cela m'amène à parler des aspects environnementaux. La Société de l'énergie marémotrice croit fermement que la mise sur pied d'une base de données, nécessaire à la compréhension des processus naturels à connaître pour faire des évaluations environnementales, incombe aux organismes publics. D'autre part, nous nous sentons totalement responsables de l'évaluation des incidences prévues par un projet arrêté d'exploitation d'énergie marémotrice. Chacun aurait donc une tâche bien définie. Les données de base sont la responsabilité des organismes publics, l'utilisation de ces données pour prévoir les incidences réelles du projet est la nôtre. Ce n'est peut-être pas là l'opinion de tous, mais c'est celle de la Société au départ.

J'aimerais traiter d'une autre question environnementale : toutes les lacunes actuellement perçues dans la base de données devraient-elles être comblées avant que nous puissions faire une évaluation? Je crois que la réponse est non. Par exemple, supposons qu'il existe une lacune et qu'aucune prévision ne puisse être faite sur un aspect qui pourrait être matériellement désavantageux. Dans ce cas, l'inconvénient accroîtrait les risques du projet. S'il pouvait être évalué, il serait ajouté au coût du projet, et, s'il ne pouvait l'être, il constituerait un risque. Le pire est envisagé, et il s'agit là du risque potentiel particulier à cet aspect. Bien sûr, ce serait une bonne chose qu'il n'y ait aucun risque et que tout soit mis noir sur blanc. Mais si, pour une raison ou pour une autre, par manque de compréhension ou de temps, un aspect de l'environnement ne peut être étudié à fond, il reste un risque qui doit être considéré au même titre que tous les risques techniques, économiques ou autres.

Je crois donc vous avoir fait voir notre situation actuelle en matière d'évaluation environnementale, et j'aimerais ajouter que notre situation à ce stade-ci serait pire, n'eût été le travail du Comité des études environnementales Fundy du Conseil des sciences des provinces de l'Atlantique (CSPA) et des institutions membres; je me sens plus sûr aujourd'hui qu'il y a une semaine de pouvoir faire une évaluation environnementale adéquate. Merci beaucoup, Monsieur le Président.

W. Kozak :

Je représente un groupe de pêcheurs, et nous avons des préoccupations très, très précises. Ce qui nous intéresse et nous préoccupe, c'est de savoir ce qui va se produire si un projet de captage de l'énergie marémotrice est réalisé. Quels en seront les effets sur les pêches, en particulier sur la pêche commerciale? D'abord, ce projet affectera-t-il les stocks? Et, autre question tout aussi importante à cause des variations du régime des marées, serons-nous capables de pêcher de la même façon? En d'autres mots, pourrons-nous, s'il y a toujours des poissons, pêcher par les mêmes méthodes qu'actuellement? Je crois que ces deux questions sont très importantes.

Si quelqu'un venait nous dire : "Nous ne toucherons à aucune des pêcheries", j'en serais réjoui, mais l'expérience nous a appris, il me semble, que nous devons nous assurer de maîtriser la situation. Nous voulons être informés des éventualités afin de pouvoir, en tant que groupe, commencer à y faire quelque chose. Dans bien des cas, nous nous sommes rendus compte que nous étions les derniers informés. Dans beaucoup de décisions qui ont touché notre industrie, nos intérêts n'ont pas été considérés comme des facteurs importants. Il est vrai que les gouvernements d'aujourd'hui n'ont d'yeux que pour deux choses : l'énergie et les emplois. Les décisions sont parfois prises non pas en fonction de leurs effets ultimes, mais simplement en considérant si un projet fournira de l'énergie ou des emplois.

Plutôt que de continuer à discourir, je conclurai en disant que nous voulons trouver ou tenter de trouver quels effets un projet d'exploitation de l'énergie marémotrice aura sur nos pêches, c'est-à-dire sur notre gagne-pain. Une fois ces informations obtenues, nous voulons être en mesure de protéger nos intérêts.

H. Mills :

Je suis ici, je crois, pour traiter en particulier des aspects socio-économiques de l'énergie marémotrice. Comme un certain nombre de personnes l'ont constaté, le Comité des études environnementales Fundy s'occupe surtout d'aspects environnementaux, et, bien que certaines personnes aient déjà étudié les incidences socio-économiques, ce sont là peut-être les préoccupations principales, qui appellent un surcroît d'attention. J'aimerais en fait parler de deux aspects différents. Le premier touche aux considérations socio-économiques que pourrait impliquer la décision de construire un gros barrage pour capter l'énergie marémotrice, et le deuxième, aux considérations socio-économiques liées à un projet concret.

Je veux d'abord parler des coûts d'option. En fait, je crois que les coûts de ce projet sont très intéressants puisqu'ils ont grimpé de 16 milliards de dollars en six heures hier, et je trouve cela un peu effarant. En fin de matinée hier, en réponse à une question, George Baker a dit que le projet B9 coûterait environ 6 milliards de dollars. J'ai quitté la séance d'hier après-midi un peu tôt, et j'écoutais les nouvelles de six heures en me rendant à mon hôtel. Dick Delorey était interviewé à la radio et décrivait avec éloquence les milliards de tonnes de ciment et d'autres matériaux requis par le projet. Il a déclaré qu'il faudrait 12 ans pour le réaliser, au coût de 22 milliards de dollars. Il y a donc une très grande différence entre les deux coûts, et si cela s'est passé hier, je me demande ce qui se produira la semaine prochaine.

Ce que je veux faire remarquer, c'est que même si les fonds sont disponibles pour un projet d'envergure, peu importe le coût véritable une fois le projet terminé, même si les fonds viennent d'un baron, d'un cheik ou de la Nouvelle-Angleterre, la grosse somme nécessaire sera sous forme de prêt; même si l'argent est facile à emprunter, ce sera toujours une dette à rembourser, ce qui limitera les autres activités de la Nouvelle-Écosse pendant longtemps. C'est le genre de coût d'option qui doit être discuté. Je ne tente pas seulement de savoir comment dépenser 22 milliards de dollars, si jamais nous les avons. Je crois cependant que nous devons vraiment tenir compte des objectifs à assez long terme de la Nouvelle-Écosse. Nous devons, de même, nous interroger sur le type de projet pour lequel nous pourrons peut-être faire appel à des marchés monétaires étrangers, car notre capacité d'emprunt pour d'autres projets sera très limitée si nous réalisons celui-ci?

À cela se rattachent les risques. Il a été question de l'analyse des risques à plusieurs reprises ici, mais plutôt en fonction des problèmes environnementaux. Je crois que ce projet comporte également un très grand risque économique. Si nous considérons les 10 prochaines années ou plus en termes d'avenir économique, à peu près la seule chose que nous soyons capables de prévoir avec certitude, c'est que nous allons nous tromper. Il est très difficile de dire quelles conditions économiques entoureront le projet dans dix ans. Ce que je veux souligner, donc, c'est que même si la planification économique du projet est faite avec beaucoup de soin, et je suppose qu'il en sera ainsi, les conditions économiques imposent un facteur de risque très élevé au projet et aux autres secteurs de notre économie. Par exemple, s'il y a reprise économique et que tous les coûts demeurent élevés ou montent, le projet B9 paraîtra fantastique. Ce sera une affaire en or. D'autre part, si nous nous trouvons toujours aux prises avec la crise économique et que les prix mondiaux de pétrole diminuent encore davantage, alors le projet B9 pourrait donner beaucoup de tracas et nous toucher de diverses façons. Si je reprends un peu l'idée de Carl Amos, qui représentait hier par diverses petites flèches orientées dans des directions différentes toute la gamme des possibilités, à mon avis, nous devons faire ce genre d'analyse de risques et évaluer globalement les aspects économiques du projet ainsi que tenter de juger si nous pouvons faire ce pari.

Dans ce contexte, je crois que nous devons considérer ceux qui prendront la décision et le rôle que le public jouera. Certainement, en ce qui a trait aux aspects environnementaux, le Comité d'études environnementales Fundy a été très efficace pour réunir les diverses personnes, organiser des discussions franches et suivre les choses d'assez près. Mais qu'en est-il de l'aspect socio-économique et de la politique publique?

Je me rends compte que ces personnes ne sont pas tenues à l'écart du groupe, mais je ne vois toujours pas ce genre de débat se tenir, et cela m'inquiète un peu. Si on considère le projet B9, il ressort des discussions que nous avons eues que, même si de nombreuses préoccupations environnementales y sont liées, aucune des incidences n'apparaît très alarmante. Il y a certains aspects inquiétants, mais il ne semble pas, dans l'ensemble, que des considérations environnementales réussiront à contrecarrer ce projet.

Mais peut-être devrions-nous nous pencher encore sur les autres choix. Nous parlons de réaliser un aménagement qui produirait de l'énergie dont nous n'avons pas vraiment besoin en ce moment. On pourrait tout au moins avancer cet argument. Nous prévoyons exporter 90 % de l'énergie, probablement pendant les 25 ou 30 premières années d'exploitation. Nous n'en avons donc pas vraiment besoin. Quels sont les autres choix? Les économies d'énergie sont une des possibilités. Que pensez-vous de la roue hydraulique? Si nous voulons nous lancer dans l'énergie marémotrice, nous pourrions très bien construire des ouvrages qui exigeraient moins d'emprunts et qui pourraient servir à faire des expériences, et nous pourrions en ériger plusieurs à la longue pour produire de l'énergie marémotrice; sans doute s'agirait-il d'un projet plus facile à financer, plus facile à supporter à mesure que les conditions économiques changeraient, et probablement encore moins dommageable pour l'environnement.

Si nous décidons ou si quelqu'un décide d'entreprendre un projet, nous devons nous attarder à d'autres considérations socio-économiques, que je classerai de nouveau en deux groupes : la phase de construction proprement dite, et ses aspects à plus long terme. La phase de construction amène une foule de bénéfices régionaux. Il y aura création de nombreux emplois, beaucoup d'activités, donc stimulation importante de l'économie, sans parler des retombées industrielles de la construction et de lasimple existence du projet. La phase de construction comportera toutefois des aspects négatifs. Il faudra sans doute vivre une prospérité sans lendemain; de nombreux travailleurs émigreront dans une région actuellement peu peuplée, et il faudra préciser si une communauté permanente sera établie pour eux, s'ils pourront habiter Truro, de quels services ils auront besoin, s'il sera possible d'assembler un certain nombre de pièces à Halifax ou ailleurs et de transporter des caissons au chantier par voie d'eau. À mon avis, pas mal de problèmes accompagneront la grande quantité d'activités industrielles liées à la phase de construction, qui, tout en permettant une foule de choses, pourrait avoir un impact négatif sur les petites municipalités de la région. Les façons de minimiser certains de ces impacts seront certainement des préoccupations au stade de la construction.

Au niveau des aspects économiques à long terme, il y a encore une fois de nombreux facteurs positifs. En effet, il s'agira d'énergie propre et peu coûteuse. Si l'on a besoin d'énergie et qu'on cherche différents moyens d'en produire, la houille bleue semble assez intéressante, certainement plus que la combustion du charbon ou d'autres méthodes. On a des retombées industrielles en attirant des industries "énergivores" par une structure tarifaire avantageuse. On peut encore envisager toute une gamme d'avantages, jusqu'aux aspects touristiques - en effet, de nombreuses personnes voudront aller voir un vaste barrage à marées. Mais, du côté négatif, il y a les déséconomies liées au réservoir et les craintes pour le climat, l'agriculture, l'érosion, les eaux souterraines et les inondations. Bien des aspects dont vous avez traité ici lors de cet atelier revêtent, bien sûr, des aspects économiques, et la plupart d'entre eux semblent un peu négatifs. Mais, compte tenu de l'envergure du projet, ils ne sont pas associés à de grandes sommes d'argent. Nous avons également entendu Peter Larsen nous parler hier des déséconomies externes liées aux amplitudes maréales plus fortes et aux effets qui se répercuteront plus loin sur la côte de même qu'en Nouvelle-Écosse et au Nouveau-Brunswick. Il s'agit peut-être d'une question à laquelle tentent de répondre les études entreprises par le Maine pour évaluer le coût afférent à l'élévation des niveaux des hautes mers une fois le projet achevé. Ces études doivent être mises en branle en Nouvelle-Écosse et au Nouveau-Brunswick.

Pour terminer, un commentaire. Je vais prendre la parole en tant que membre de la Fédération canadienne de la nature pour un moment et traiter de la nécessité d'élargir le débat à un éventail beaucoup plus large de groupes d'intérêts. En plus des universitaires et des scientifiques, un bon nombre de personnes auront un intérêt dans la décision de réaliser ou de ne pas réaliser un projet et dans les incidences qui en découleront. Je crois que la Société de l'énergie marémotrice ferait bien de s'y mettre, de commencer, par exemple, à établir des mécanismes plus officiels pour sonder les diverses parties, notamment l'Union nationale des fermiers, l'Institut des femmes de la Nouvelle-Écosse, les pêcheurs de harengs aux fascines et la Fédération canadienne de la nature. Si nous laissons aller les choses trop longtemps, ces groupes, en grande partie parce qu'ils comprennent mal ce qui se passe, se poseront des questions. Je crois que cela vaudrait beaucoup mieux et que la qualité de la participation de ces groupes serait meilleure si nous les mettions dans le coup et les faisions participer à ces discussions dès le début. Merci.

G. Beanlands :

J'ai été particulièrement intéressé par ce qui s'est passé dans cet atelier au cours des trois derniers jours. L'Institute of Resource and Environmental Studies de l'Université Dalhousie a reçu du gouvernement fédéral, il y a environ deux ans et demi, le mandat de trouver des façons d'améliorer la valeur scientifique des études d'impact dans notre pays. On m'a demandé de diriger ce projet. À certains égards, ce qui se produit à Fundy depuis six ans représente en accéléré ce qui, selon le milieu de la recherche appliquée au Canada, devrait arriver pour améliorer notre base scientifique de l'évaluation des incidences. Je ne crois pas qu'il s'agisse d'une question purement académique, car je sais que le gouvernement fédéral applique déjà certaines des recommandations.

J'aimerais vous présenter les résultats préliminaires du projet et comparer ce que vous avez dit que vous feriez et ce que vous avez réellement fait. Pour l'instant, intéressons-nous au problème dans une perspective globale. Pendant l'atelier, je n'arrêtais pas de me demander pourquoi cet exercice des six dernières années a été si fructueux, en particulier grâce à une collaboration entre des établissements de recherche qui, jusqu'alors, ne s'étaient jamais tournées vers un problème commun. Quelqu'un a dit que c'était peut-être là le signe d'un intérêt pour ce qui se passe chez soi. Il y a un certain nombre d'institutions scientifiques autour de la baie de Fundy; celle-ci est donc le dénominateur commun. Mais je crois que ce n'est pas tout. À mon sens, parce qu'il s'agit d'un système unique, il représente probablement un certain défi intellectuel par rapport à une approche qui ne ferait pas partie d'un tout ou qui réinventerait la roue. Je crois également que son succès repose en partie sur le modèle numérique des marées élaboré par Dave Greenberg et qui sert de point de départ à toutes les études. Le projet pourrait également avoir été un succès parce que le promoteur est le gouvernement par l'entremise d'une société de la Couronne et qu'il a sans doute été plus facile de canaliser les fonds gouvernementaux vers la recherche appliquée d'un mégaprojet que s'il s'était agi d'un projet subventionné, par exemple, par Mobil Oil ou Petro-Can (bien que nous concluions de plus en plus d'accords de coentreprise avec l'industrie).

D'après ce que Don Gordon a dit au début de l'atelier, il semblerait que plusieurs millions de dollars de fonds fédéraux ont été versés aux études environnementales des six dernières années. Selon des expériences au niveau international dans les mégaprojets comme celui-ci, les études environnementales prennent entre un à trois pour cent du budget total du projet. Même après avoir ajouté à l'évaluation de Don Gordon les équipements et les salaires indirectement liés à l'étude environnementale, le coût n'est toujours que de 0.1 % de 6 milliards de dollars; le chemin qui reste à faire est donc long avant d'atteindre les normes internationales.

J'aimerais ensuite parler brièvement de certains des résultats préliminaires du projet en question et les comparer à la situation des six dernières années à Fundy. Dans certains cas, j'ai été fort agréablement surpris, alors que, dans d'autres, j'ai été très déçu. En fait, je crois que plusieurs exemples particuliers parmi les résultats qui nous ont été présentés ces trois derniers jours reflètent les recommandations du milieu de la recherche appliquée au Canada. Je voudrais ajouter qu'un peu moins de 200 personnes y ont travaillé dans des laboratoires de recherches, de Saint-Jean à Vancouver.

Tout le monde nous a dit que nous devons cesser de nous éparpiller et nous attarder aux aspects qui comptent vraiment. Nous n'avons pas le temps de tout étudier. L'une de nos recommandations vise à rendre obligatoire, pour toutes les études d'impact, les exercices de mise en perspective sociale. La seule fois où j'ai vu cela se produire au cours de l'atelier a été lorsque Peter Larsen, du Maine, a tenté de cerner l'opinion publique à propos d'un barrage à marées. Pour un scientifique, cette approche peut sembler inappropriée, mais, pour un homme politique, elle permet d'apporter de l'eau à son moulin. Le milieu scientifique nous a prévenus du danger de la mise en perspective sociale parce qu'on ne peut assumer que le public est au courant de tout ce qui est important. Je crois qu'il y a également un hic car, parfois, même les scientifiques ne connaissent pas tout ce qui est important. Mike Dadswell a fait remarquer que, jusqu'au moment où ont commencé les études récentes dans la baie de Fundy, personne ne comprenait l'importance des sections supérieures des cours d'eau pour l'alose. En outre, je crois que Peter Hicklin a fait remarquer que l'importance de la rivière Shubénacadie pour les aigles à tête blanche vient tout juste d'être réalisée. Je crois que nous sommes tous d'accord pour dire que ces deux composantes environnementales auront un poids dans le processus décisionnel.

Selon les chercheurs participant à notre projet, la première chose à faire après la mise en perspective est d'établir des limites, et tous ceux qui s'occupent de modélisation prévisionnelle ne manquent pas de le faire. Toujours selon nos chercheurs, il n'existerait pas de limites d'étude communes pour les évaluations des incidences. En un sens, ces limites peuvent se situer partout sur la carte, mais elles doivent être bien définies. J'attire votre attention sur les limites de l'étude de l'alose, qui s'étendent jusqu'en Floride, et celles de l'étude des oiseaux de rivage, qui vont jusqu'en Amérique du Sud. Il n'est pas question d'une limite d'étude au sens d'un trait sur une carte, mais plutôt d'une limite à partir de laquelle les données sont recueillies. Je crois que vous vous rappellerez que Mike Dadswell et Peter Hicklin ont dit qu'ils avaient reçu des données de toutes les régions à l'intérieur des limites de l'étude.

Il est également important d'établir les limites temporelles. Cela m'a vraiment embêté, pendant l'atelier, de voir qu'il faudrait environ onze ou douze ans pour réaliser le projet proposé et que la construction pourrait ne débuter que trois ou quatre ans plus tard. Le projet ne serait peut-être donc achevé que dans vingt ans. Si les participants sont arrivés à un seul consensus, c'était que les prévisions biologiques pour plus de cinq ans sont à peu près impossibles. Je me demande si nous avons vraiment considéré la période extrêmement longue pour laquelle nous tentons de prévoir des changements.

Une autre limite temporelle est le temps de réponse. Selon certains, il pourrait être plus important d'étudier la capacité potentielle de réponse biologique du système touché que de s'en tenir au seul niveau de l'impact. Prenons un autre exemple dont il a été question lors de l'atelier : nous ne connaissons pas la période nécessaire au Corophium pour recoloniser des régions susceptibles d'être modifiées par un barrage à marées. Je crois que tout le monde est d'accord pour dire que cela est très important, en particulier pour l'impact sur la population d'oiseaux migrateurs.

Un autre aspect qui, je trouve, n'est pas souvent reconnue dans des études d'impact est celui des limites techniques. Nous forçonspeut-être un peu le sens du terme, mais je me demande vraiment comment nous pourrons prévoir les impacts sur les oiseaux de rivage migrateurs; Peter Hicklin nous a dit qu'il ne pouvait même pas les compter de façon précise à cause de leur trop grand nombre. Si la population se modifiait un peu, nous ne pourrions probablement pas le déceler.

Ces dernières années, on prône les études d'impact sur des systèmes relativement fixes parce qu'il est plus facile de les définir statistiquement. Par contre, lorsque Nancy Witherspoon a fait son exposé sur les clams, quelqu'un a répliqué : "Je n'ai pas l'impression que vous serez capables d'évaluer l'effet d'un barrage à marées à cause des incertitudes dans le système de la population."

On a émis l'opinion, durant notre étude, qu'il faut partir d'un concept, ensuite élaborer des hypothèses, puis les soumettre à des expériences. Je n'ai cependant eu connaissance que d'une seule structure conceptuelle présentée au cours de l'atelier, celle de David Wildish, qui a montré les interactions régissant la productivité secondaire du benthos. Il y en a sûrement d'autres.

Tous ceux qui ont participé au projet étaient d'accord pour dire qu'il faut une stratégie. Au point de vue militaire, les tactiques ne sont valables que si elles font partie d'une stratégie globale. Pour continuer l'analogie, on pourrait dire que, ces dix dernières années, les études d'impact au Canada ont abondé en tactiques, mais manqué de stratégie. La seule stratégie globale d'étude d'impact dont j'aie eu connaissance a été celle élaborée par Carl Amos et qui était en fait un graphique de cheminement logique pour l'évaluation des impacts environnementaux. Cela semblait efficace pour montrer d'où l'auteur venait et ce qu'il tentait de faire. Ainsi, ce graphique montrait la nature séquentielle des activités telles qu'elles lui apparaissaient et ne pouvait aller bien loin sans les résultats des liens précédents du graphique de cheminement. Il a cependant noté l'accumulation d'erreurs. J'ai parlé à Dave Greenburg juste avant le dîner, et je lui ai demandé s'il y avait des limites de confiance dans ses prévisions de changement des amplitudes maréales; il m'a répondu non. Le graphique a également montré clairement qu'il est possible de faire des prévisions relativement fiables dans le cas de systèmes physiques, mais que ces prévisions ne le sont à peu près plus dans le cas de systèmes situés à un niveau trophique plus élevé.

En conclusion, j'aimerais parler de la prévision. Je suppose que c'est ce pourquoi nous sommes tous ici. Nous pouvons dire simplement qu'il y a quatre manières fondamentales de prévoir quelque chose : 1) se fier à ses intuitions ou à son jugement professionnel, 2) s'attarder aux résultats de projets semblables pour voir s'ils peuvent s'appliquer à ce que l'on cherche à faire, 3) réaliser des expériences, ou 4) tenter un exercice de modélisation. Nous avons beaucoup entendu parlé de jugement professionnel ces trois derniers jours, et je crois que la seule chose que cela nous apportera est une idée générale de l'impact et de son ordre de grandeur. Peut-être que, dans certains cas, en réponse à la question de George Baker, cela est suffisant. Il semble y avoir des preuves que nous tentons d'observer les résultats de projets semblables. Le projet de captage de l'énergie marémotrice dans la rivière Annapolis est un bon exemple, et il sera intéressant de voir les effets de la turbine Straflo sur la mortalité des poissons. Cela répondra peut-être à quelques questions. À *propos de* la troisième manière de prévoir - les résultats des expériences - j'ai été très déçu de voir le manque d'expériences réalisées dans les formes. Certaines personnes ont reconnu que cela est important, mais elles n'en ont pas senti la nécessité. On nous a répété, tout au long de notre projet, que le meilleur investissement est un exercice pilote de perturbation à petite échelle. Cela me fait penser aux doublements construits parallèlement au pipeline du Nord et qui ont représenté un investissement important en argent, en temps et en compétences pour étudier ce qui se passerait dans un microcosme. L'information obtenue a ensuite pu être appliquée au système tout entier. Je crois que quiconque,du gouvernement fédéral ou de l'industrie, participe à la mise en valeur du Nord vous parlera en bien des retombées du Projet de déversements de pétrole à l'île Baffin (BIOS), rejets expérimentaux contrôlés de pétrole dans des conditions arctiques. Je crois que le projet BIOS nous en apprendra beaucoup plus que toutes les autres études d'impact effectuées ces dix dernières années. Ne serait-il pas possible de choisir un petit emplacement dans les sections supérieures de la baie, d'y construire un barrage à très petite échelle, de le régulariser selon le modèle de Dave Greenberg et de voir ce qui se passera? Je ne sais pas si cela est pratique, mais c'est une approche qui devrait être au moins envisagée.

Somme toute, je crois que nous devons réaliser qu'il est facile de faire des prévisions. Voulez-vous que je prévoie la température de demain? Je suis tout à fait prêt à le faire. Mais cela ne veut pas dire que ma prévision sera exacte; elle doit donc faire l'objet d'expériences. Si nous ne vérifions pas la prévision, alors pourquoi en faire? L'une des nombreuses conclusions de notre projet est que notre capacité de prévoir les impacts des mégaprojets est si limitée en dehors des systèmes physiques que tout le processus prévisionnel doit être traité comme une expérience. Il faut absolument retourner voir ce qui se passe par la suite. Malheureusement, le degré auquel nous pouvons interpréter des données de contrôle est déterminé par ce qui est mesuré et par la façon dont ces données sont mesurées avant que le projet ne commence.

Je ne sais pas si j'ai raison, mais je crois que l'intérêt intellectuel pour le système de la baie de Fundy, quel que soit le projet d'exploitation de l'énergie marémotrice, n'est peut-être plus ce qu'il était. Il semble généralement acquis que nous savons comment fonctionne le système; peut-être les recherches s'orienteront-elles vers autre chose. On peut donc se demander ce qui se passera ensuite. Durant ces derniers jours, très peu de prévisions vérifiables nous ont été présentées ici. L'Université d'Aberdeen, en Écosse, vient de terminer une étude des prévisions faites au cours des dix dernières années sur les aménagements dans la mer du Nord. L'étude a recensé plus de 500 prévisions, mais moins de 5 % d'entre elles ont pu être vérifiées d'une façon ou d'une autre. Les autres n'étaient tout simplement pas vérifiables, et l'on peut donc se demander pourquoi elles ont été formulées. Facteur important toutefois, les conceptions techniques ont été modifiées après la rédaction de l'étude d'impact, ce qui a changé toutes les suppositions sur lesquelles se fondaient les prévisions. Si les plans sont modifiés, toutes les suppositions à la base des prévisions sont au rancart, et il n'est plus possible de s'y fier. J'espère que cela ne se produira pas avec le projet de Fundy, et j'aimerais que soit décidé qui aura la responsabilité, si jamais ce projet voit le jour, d'évaluer nos prévisions des incidences environnementales.

R. Edwards :

On m'a demandé aujourd'hui de dire quelques mots sur l'impact environnemental des alternatives à l'exploitation de l'énergie marémotrice dans la baie de Fundy. Il a été dit, au cours des débats, que, dans les Maritimes, les alternatives classiques à l'énergie marémotrice sont les centrales au charbon et nucléaires. Attardons-nous aux autres formes d'énergie possibles, mais moins probables; je dirais que les futurs aménagements hydroélectriques classiques seront à très petite échelle et que les énergies non classiques, notamment solaire et éolienne, apparaîtront moins séduisantes pour un certain nombre de raisons, notamment les coûts, l'approvisionnement intermittent et les problèmes de stockage. Le bois est abondant, mais il est peut-être préférable de le conserver pour le chauffage domestique, où il peut être utilisé avec une efficacité de 70 %, alors que, pour la production d'électricité, son efficacité est probablement d'environ 35 %. Dans un contexte économique plus favorable, une concurrence pour l'approvisionnement pourrait également venir des entreprises de pâte et de bois. Voici un exemple pour vous donner une idée de l'échelle : pour le plus petit projet proposé, celui d'environ 1,100 MW, la consommation nécessaire pour permettre le même rendement serait d'environ 300 cordes de bois dur par heure (séché jusqu'à ne contenir que 20 % d'humidité).

Deux autres sources potentielles d'énergie méritent d'être mentionnées : le schiste bitumineux et la tourbe, présents en grande quantité dans les Maritimes. Le schiste bitumineux a suscité beaucoup d'intérêt ces dernières années et il vaut peut-être la peine qu'on en parle. Bien qu'une augmentation de l'exploitation de la tourbe comme source d'énergie soit toujours possible, je préférerais ne pas en parler ici. Il y a certainement une façon meilleure et plus facile de produire de l'électricité que d'exploiter une source de combustible pour laquelle il est nécessaire tout d'abord d'abaisser le niveau de la nappe phréatique afin d'obtenir un combustible dont le contenu en humidité dépasse 95 %. Le schiste bitumineux, lui, est une ressource disponible dans toutes les provinces du Canada sauf dans l'Île-du-Prince-Édouard. De tous les gisements canadiens connus, les plus intéressants sont situés dans la région de Moncton, ce qui explique peut-être pourquoi j'en parle ici. La production d'huile de schiste dans cette région est d'environ 100 litres par tonne, ce qui est comparable en général à la production du bassin de schiste Piceance du Colorado. Dans le gisement principal du Nouveau-Brunswick, les réserves sont évaluées à environ 270 millions de barils d'huile, ce qui indiquerait une mise en valeur potentielle selon la situation économique. Pour récupérer le schiste, il faut chauffer à environ 400 °C, température nécessaire pour entraîner la pyrolyse du kérogène et ainsi produire l'huile de schiste. Il peut s'agir d'une exploitation en surface pour laquelle le schiste est extrait puis traité dans des cornues en surface, ou bien d'une exploitation souterraine ou sur place où, en gros, une technique de combustion *in situ* est utilisée pour libérer les produits liquides ou gazeux.

Il semble que le traitement classique de surface entraîne les problèmes normalement associés à l'exploitation à ciel ouvert et la remise en valeur des terres qui s'ensuit. D'après des expériences antérieures avec du combustible de synthèse liquide, il y a divers risques pour la santé et la sécurité des travailleurs. Par exemple, les émissions de gaz fugaces dans l'usine peuvent renfermer des métaux-traces, des hydrocarbures légers, du soufre, des composés d'azote et des matières organiques polycycliques. Les effluents qui proviennent de ces usines contiennent fréquemment des hydrocarbures, des phénols, des métaux-traces, des sulfures, de l'ammoniac, des matières organiques polycycliques et un grand nombre d'autres composés. Je crois que le nombre d'éléments-traces associés à la liquéfaction ou la gazéification du charbon est considérable. La quantité élevée dans les matériaux extraits de déchet par rapport au produit semble indiquer des problèmes de manutention normalement associés au volume plus important de schiste utilisé et de stériles. Cependant, les installations de production de gaz et de pétrole synthétiques sont normalement construites de façon à prévoir l'élimination du soufre et permettent donc la production et la combustion d'un carburant propre. Pour la production in situ, il faut un traitement en souterrain du schiste par la combustion partielle afin de libérer le gaz ou l'huile de schiste. Cela atténue bon nombre des problèmes environnementaux associés au processus classique, mais entraîne le risque de contamination des eaux souterraines. Il s'agit d'un important problème probable qui a commencé à se manifester récemment dans le bassin Piceance et qui apparaîtra probablement ailleurs.

Comme je l'ai déjà dit, le charbon et l'énergie nucléaire sont, dans les Maritimes, les alternatives classiques à l'énergie marémotrice. Je dirais que, pour l'environnement, l'option nucléaire est préférable à l'option charbon sur presque tous les plans. Commençons au début du cycle du combustible : je crois que l'exploitation en souterrain du charbon est plus dangereuse que la plupart des autres métiers des Canadiens et certainement beaucoup plus que l'extraction de l'uranium, ce minerai étant situé dans des roches moins dangereuses à exploiter.
L'exploitation des mines dans la région du lac Elliot a, par le passé, entraîné une grande fréquence de la silicose chez les travailleurs à cause de la présence de radon et de mineraisriches en quartz. Cette situation rappelle la pneumoconiose ou l'anthracose dont souffrent les mineurs de charbon. Dans chacun de ces cas, les problèmes peuvent être résolus grâce à une

meilleure ventilation de la mine, à une élimination améliorée des poussières et à d'autres mesures.

Lorsque l'on compare le traitement du minerai d'uranium et le lavage du charbon, il est intéressant de remarquer qu'il existe un problème environnemental commun - la contamination des eaux superficielles et souterraines par le ruissellement acide. Les déchets du traitement de l'uranium et les rejets du lavage du charbon contiennent tous deux de la pyrite, qui est lessivée sous forme d'acide sulfurique. La contamination des eaux superficielles par des éléments radioactifs n'a pas été une source importante de problèmes aquatiques dans le système de la rivière Serpent en aval du lac Elliot. Cependant, un grave dommage environnemental a été causé par le déversement d'eau de mine acide et par le lessivage acide des terrils de charbon et des résidus d'usine dans la région du lac Elliot. La seule différence est peut-être que le programme de revalorisation des résidus d'uranium fonctionne avec succès dans la région du lac Elliot et qu'il n'a pas d'équivalent dans l'industrie des métaux de base, qui dépend en grande partie, au Canada, des minerais de sulfure, ou dans les usines de préparation du charbon.

Au stade de la production d'énergie, les émissions aériennes et les circuits de déversement d'eau de refroidissement sont étroitement surveillés et réglementés dans l'industrie nucléaire, ce qui n'est généralement pas le cas dans les centrales au charbon. La même comparaison peut être faite en ce qui a trait à la réglementation du combustible nucléaire et des cendres de charbon épuisés. Par exemple, la philosophie de l'industrie nucléaire est d'isoler totalement les matériaux radioactifs de la biosphère jusqu'à ce que, par la décomposition physique, ils ne posent plus de problèmes. Là où les déchets radioactifs sont actuellement entassés sur place, et où on pense les enfouir pour de bon à de très grandes profondeurs, l'élimination en surface des cendres de charbon entraînera inévitablement le lessivage des métaux-traces dans les eaux superficielles et souterraines. Je dis cela pour défendre l'industrie nucléaire, qui semble très critiquée par ceux qui se rangent sous la bannière écologique. Je dirais que le cycle complet du combustible (de la mine à l'exploitation du réacteur, la sécurité dans le réacteur, la manutention et l'élimination des déchets) est assujetti à une réglementation assez bien contrôlée et bien fondée.

Si l'on considère un instant la gamme plus large des problèmes environnementaux auxquels notre société doit faire face, je dirais que le problème le plus important que nous vivions maintenant est celui des pluies acides. Un autre problème, peut-être un peu plus lointain, est celui du dioxyde de carbone atmosphérique et des variations du climat qui pourraient devenir très graves. S'il en était ainsi, je crois qu'il serait très difficile d'y remédier. Fait intéressant à noter, le charbon aggrave ces deux problèmes, et les énergies nucléaire et marémotrice, non. Il est clair que les choix parmi les options pour produire de l'électricité sont faits essentiellement selon des critères économiques. Il est remarquable que les coûts environnementaux de l'énergie nucléaire sont presque totalement intériorisés, alors que les coûts environnementaux des autres énergies, notamment l'énergie marémotrice, ne le sont pas. Par le passé, les inconvénients des émissions des installations de charbon et l'impact de l'exploitation du charbon ont dû être supportés par toute la société. Il y a quelques années, les préoccupations à l'égard des émissions de particules, des émissions de gaz acide, plus récemment, ainsi que despremières pratiques d'exploitation à ciel ouvert conduisent à la lutte contre ces problèmes environnementaux et à l'accroissement des coûts pour les services publics. Actuellement, les emplacements de mines à ciel ouvert sont en général remises en valeur et utilisées pour l'agriculture, alors que les normes d'émission (selon les directives d'Environnement Canada) exigent presque des caractéristiques de lutte anti-pollution, notamment des laveurs de gaz de carneau, à moins que du charbon à très faible teneur en soufre ne soit utilisé. Peut-être que la mesure dans laquelle la pollution est éliminée reflète la façon dont les impacts environnementaux sont perçus par le public et les agents de réglementation.

Dans ce contexte, mais peut-être devrais-je ici mettre à part certains des problèmes qui ont été identifiés, notamment les intrusions de sel dans les eaux souterraines et peut-être la mortalité des poissons dans les turbines, je ne suis pas certain que les discours de ces derniers jours aient identifié les impacts environnementaux associés à l'énergie marémotrice et propres à alarmer le public ou à susciter chez les organismes de réglementation une réaction qui gêne indûment les activités. Mes excuses à l'industrie du charbon, Monsieur le Président; je crois que je n'ai plus rien à ajouter.

D. Gordon :

Je traiterai de quatre questions : 1) qu'avons-nous appris des caractéristiques environnementales de la baie de Fundy et comment ces connaissances de base sont-elles liées aux exigences d'une évaluation des impacts environnementaux d'un projet d'exploitation de l'énergie marémotrice? 2) qu'avons-nous appris des impacts environnementaux possibles à ce jour,

3) comment la situation générale des évaluations environnementales dans la baie de Fundy se compare-t-elle à celle d'autres régions du monde, et 4) quelles étapes seront nécessaires si un programme de pré-engagement est entrepris?

Beaucoup d'informations ont été acquises ces dernières années sur les caractéristiques environnementales de la baie de Fundy. C'est ce qui ressort de la quantité des publications scientifiques parues ces 70 dernières années (figure 1), qui montre bien l'explosion des connaissances pendant les années 1970. La quantité la plus élevée, en 1977, reflète la parution du compte rendu de l'atelier tenu à Acadia en 1976, alors que le plus bas niveau, au début des années 1980, correspond à des travaux en cours dont les résultats n'ont pas encore été publiés.

J'aimerais souligner la différence entre ce que je crois être deux types d'études, distincts bien que reliés, nécessaires à l'évaluation environnementale (figure 2). Le premier type, le plus important selon moi, est la recherche scientifique de base qui vise à comprendre l'environnement naturel et sert par la suite de fondement à des travaux appliqués. De par sa nature,les études de ce genre se font à long terme, et la plupart ne sont achevées qu'au bout de quelques années à cause de la variabilité saisonnière et interannuelle. Elles sont généralement effectuées par les laboratoires de recherche gouvernementaux et par les universités et se composent de programmes sur le terrain, d'expériences en laboratoire et d'études théoriques. Ces informations, et j'insiste sur ce point, ne peuvent être amassées "en catastrophe", en très peu de temps. Il s'agit du type de recherche dont le résumé apparaît dans les séries d'articles donnés à la première séance; et c'est vers ce type de recherche que le gros de l'attention scientifique s'est tourné jusqu'à présent.

Au contraire, peu d'attention a été donnée aux études d'impact (figure 2). Celles-ci sont tout à fait dépendantes de la recherche scientifique de base et s'intéressent à des questions environnementales précises qui se posent au moment où les détails techniques d'un projet sont connus (sujet abordé au cours de la séance II). Les exposés de la séance III portaient sur la plupart des aspects qui feraient parties des études d'impact; le mot-clé est mise en oeuvre. Dans la plupart des cas, ces études peuvent être effectuées en un temps relativement court. Elles sont en grande partie analytiques et consistent en l'examen des données existantes, mais elles nécessitent parfois une certaine quantité d'expériences et d'autres travaux sur le terrain. Je crois, et George Baker semble partager mon opinion, que c'est la responsabilité du promoteur du projet de financer et de diriger ce genre d'étude, qui forme en fait une partie importante du processus officiel d'évaluation environnementale. Le travail concret est généralement effectué par des firmes de consultants en environnement, mais des universités et des laboratoires du gouvernement, selon les mandats et les politiques, y participent parfois. Une réaction à la recherche scientifique de base, comme cela s'est produit pendant cet atelier, est extrêmement souhaitable afin d'assurer qu'elle est orientée dans la bonne direction. Il est avantageux d'étudier le stade de la mise en oeuvre dès les débuts, lors de la recherche de base, afin de s'assurer que l'accent porte sur les aspects, les organismes et les processus en cause. Il n'est pas nécessaire d'étudier toutes les composantes environnementales pour préparer un document d'évaluation environnementale sensé et utile.

La quantité limitée de travaux d'évaluation des impacts réalisés jusqu'à présent ne me préoccupe pas parce que ces travaux peuvent être effectués assez rapidement au moment voulu. La recherche de base doit cependant venir en premier. Dans certains cas, cependant, une bonne quantité de travaux d'évaluation des impacts ont déjà été accomplis, notamment les études de modélisation numérique de la marée et de la sédimentation faites par Dave Greenberg et Carl Amos. Leurs études étaient à cheval sur la recherche de base et la recherche appliquée, et l'excellence de leur travail montre bien qu'il était bon que les mêmes personnes participent aux deux types d'études.

Pour résumer, il semble clair, d'après les exposés faits lors de cet atelier, que nos connaissances des caractéristiques environnementales de la baie de Fundy sont beaucoup plus étendues qu'elles ne l'étaient au premier atelier tenu à Acadia, en 1976. Nos connaissances sont particulièrement bonnes en ce qui a trait aux aspects benthiques de l'écosystème de la baie de Fundy. Mais, malgré les progrès importants, il reste toujours des points obscurs. Par exemple, d'autres études sur le zooplancton et sur certains processus microbiaux sont absolument nécessaires. De même, comme cela a été indiqué à la fin de la séance III, le domaine des pêches reste encore bien mal compris, en particulier près de l'entrée de la baie.

J'aimerais souligner également qu'il n'est pas essentiel que toutes les données utilisées dans une éventuelle évaluation environnementale proviennent précisément de la baie de Fundy.

L'expérience et même parfois les données de certains scientifiques travaillant dans des environnements comparables peuvent être mises à profit. Il ne fait cependant aucun doute que les contacts récents avec des scientifiques des États-Unis, de la Grande-Bretagne, des Pays-Bas et d'autres pays nous ont été bénéfiques.

J'ai promis aussi de déterminer ce que nous avons appris jusqu'à présent sur les impacts environnementaux possibles d'un projet d'exploitation de l'énergie marémotrice? Qu'est-ce que la séance III de cet atelier nous a appris? Premièrement, je tiens à féliciter les conférenciers de la séance III, parce qu'ils n'ont pas hésité à se mouiller et à faire des prévisions. Lorsque nous nous sommes rencontrés à Acadia, en 1976, certaines prévisions ont été émises, mais, en règle générale, je crois que nous étions beaucoup plus réservés à cause de la base de données plus limitée à l'époque. En revanche, au présent atelier, personne n'a allégué qu'il n'avait pas assez de données. Tout le monde a fait un effort honnête pour donner des prévisions raisonnables,même si elles étaient très spéculatives. Il est intéressant de noter, comme d'autres membres de la réunion l'ont fait avant moi, que la séance III n'était pas empreinte de morosité. Un bon nombre d'impacts positifs ont été identifiés, et beaucoup d'impacts négatifs doivent être étudiés plus à fond avant qu'il soit possible de les quantifier de façon acceptable.

Comme cela est apparu à la séance II, un choix peut être fait entre la réalisation de projets parallèles de captage de l'énergie marémotrice dans le bassin Cumberland et la baie Cobequid ou la réalisation d'un seul aménagement monstre dans la baie Cobequid. Il a été clairement montré, lors de cet atelier, que le bassin Cumberland est un estuaire plus productif. C'est pourquoi il semblerait raisonnable de choisir la deuxième option et de ne pas perturber le bassin Cumberland. Malgré sa plus grande ampleur, le projet de la baie Cobequid semble avoir des effets moindres sur la retenue.

Il est à noter que, lors de cet atelier, seuls les aspects marins ont été traités. Les impacts terrestres n'ont pas été discutés en détail, bien qu'il en ait été question lors des exposés sur la glace, le climat et l'hydrologie. Au cours de l'atelier, l'accent a également porté sur les sections supérieures de la baie de Fundy, pour lesquelles nos connaissances sont actuellement complètes et les prévisions, les plus faciles à faire. Peu d'attention a été portée jusqu'à présent à la prévision des impacts environnementaux dans la partie sud de la baie de Fundy et le long de la côte de la Nouvelle-Angleterre; le niveau de confiance de ces prévisions serait de beaucoup inférieur à celui pour la partie nord de la baie. Certes, les impacts ponctuels pourraient être moins nombreux dans les régions plus éloignées, mais l'effet net pourrait devenir un facteur déterminant à cause de l'étendue de la région touchée. On ne doit donc pas s'attendre nécessairement au même sentiment généralement positif lorsque toutes les incidences environnementales possibles sont évaluées. Les aspects qui n'auront pas été touchés lors du présent atelier devraient être abordés la prochaine fois qu'une réunion semblable sera organisée.

Voici la troisième question dont j'aimerais traiter : comment nos connaissances actuelles des impacts environnementaux d'un projet d'exploitation de l'énergie marémotrice se comparent-elles aux connaissances relatives à d'autres mégaprojets au Canada ou ailleurs dans le monde. Comme l'indique la figure 3, il existe un lien entre notre capacité de fournir des prévisions exactes et l'effort investi dans la recherche. En 1976, je dirais que nous nous trouvions près du bas de la courbe à cause de notre connaissance limitée des sections supérieures de la baie de Fundy. La plupart des évaluations des incidences environnementales au Canada ou à l'étranger font probablement aussi partie de cette catégorie, parce qu'elles sont généralement effectuées en un an ou moins et que des données de base adéquates existent rarement. Heureusement, dans le cas de Fundy, des facteurs politiques et financiers ont ralenti le développement de l'énergie marémotrice, et ce sursis a été bien utilisé pour augmenter nos connaissances et la base des données environnementales. Nous nous trouvons donc présentement plus haut sur la courbe (figure 3). C'est donc dire que le fait d'avoir affecté plus d'argent à la recherche scientifique a amélioré notre capacité de prévoir les impacts environnementaux de l'exploitation de l'énergie marémotrice. Il semble que nous ayons encore un peu de temps devant nous, et il est possible que nous nous retrouvions encore plus haut sur la courbe en investissant modestement dans la recherche avant qu'une évaluation environnementale officielle puisse commencer. Vu la nature asymptotique de la courbe, nous atteindrons peut-être un point où une quantité supérieure de recherche scientifique n'ajoutera rien ou presque à notre capacité de prévision; selon moi, cela ne se produira que dans cinq ans au moins.

Selon les normes internationales, je crois que nos travaux environnementaux à Fundy ont une bonne cote par rapport à d'autres projets de captage de l'énergie marémotrice (ou à d'importantes réalisations semblables). Je crois que l'on peut dire sans crainte de se tromper que les sections supérieures de la baie de Fundy deviennent l'une des régions côtières les mieux connues au Canada. Il faut cependant en faire plus avant que le feu sacré ne s'éteigne.

Finalement, je dirai quelques mots sur ce que j'aimerais voir se produire. Pour les raisons données ci-dessus, j'aimerais que la recherche scientifique de base se poursuive au niveau le plus élevé possible, compte tenu des contraintes financières actuelles. De nouvelles données sont absolument nécessaires pour combler les trous importants identifiés lors de cet atelier, notamment certains aspects de la microbiologie, de l'écologie du zooplancton et des pêches. Une grande quantité de données déjà amassée doivent être complètement analysées et interprétées. Il faudrait également déployer un effort pour synthétiser les résultats de tous les programmes individuels de recherche qui ont été effectués. Pour ces synthèses, des stratégies ont été proposées à la réunion d'hier du Comité des études environnementales Fundy, et l'approche favorisée est un exercice de modélisation de l'écosystème. Un certain nombre d'entre nous aimeraient mettre sur pied un tel projet au début de 1983 en se fondant sur l'expérience acquise par un groupe de scientifiques hollandais qui ont modélisé l'estuaire Ems-Dollard en Europe. Cette recherche serait peut-être justifiée, même si le développement de l'énergie marémotrice s'arrêtait demain. Les informations obtenues peuvent être utilisées pour d'autres applications pratiques, mais elles possèdent également une valeur scientifique intrinsèque. Si les recherches s'arrêtaient et que nous perdions notre entrain actuel, il serait difficile de recommencer au moment où des projets de captage de l'énergie marémotrice seraient annoncés. Selon Gordon Beanlands, les recherches auraient atteint un sommet. J'espère qu'il a tort, parce que j'aimerais que nos connaissances s'accroissent encore avant que nos efforts ne diminuent fortement.

Si un programme de pré-engagement est entrepris, l'une des premières étapes sera de revoir les directives officieuses d'évaluation environnementale qui ont été préparées en 1977. Elles devraient d'abord être remaniées après une étude scientifique afin d'inclure toutes les connaissances environnementales acquises ces cinq dernières années. Deuxièmement, et cela est tout aussi important, ces directives devraient être critiquées par le public, comme l'a également recommandé Hal Mills. Une telle critique a en effet été planifiée au moment où les directives ont été rédigées, mais elle ne s'imposera pas tant qu'un programme de pré-engagement ne sera pas annoncé. L'apport du public est très important avant que les directives finales ne soient adoptées et transmises au promoteur.

Lorsqu'il aura reçu les directives finales, le promoteur devra planifier ces études d'impact (fig. 2). Cet exercice comprendra, je l'espère, un apport des scientifiques, et un atelier semblable à celui-ci serait très utile. Le promoteur devra alors financer les études d'impact et préparer un énoncé des incidences environnementales tout en stimulant les rapports avec le milieu scientifique à toutes les étapes. L'énoncé des incidences environnementales devrait alors être étudié et modifié de façon à se conformer aux règlements fédéraux et provinciaux.

Finalement, je tiens à dire que la recherche environnementale ne devrait pas s'arrêter nécessairement le jour où l'énoncé des incidences environnementales sera présenté. S'il est décidé de réaliser un projet d'exploitation de l'énergie marémotrice, je pense que le promoteur devrait financer la création d'un groupe de recherche multidisciplinaire comprenant quelques dizaines de membres permanents et dont le mandat serait d'effectuer des recherches environnementales pour suivre les variations. Les informations obtenues pourraient être utilisées pour évaluer la précision des prévisions des impacts environnementaux et aider à la bonne marche du projet. Certaines questions se poseront certainement, par exemple, la fermeture du barrage pendant quelques cycles de marée pour favoriser la formation d'une couche de glace ou contenir les marées de tempête; des informations environnementales sont essentielles pour répondre à ces questions. Sans doute les meilleurs conseils proviendraient-ils d'un groupe dont c'est précisément la tâche. Bien que financé par le promoteur, je crois qu'un tel groupe devrait travailler dans l'un des établissements de recherche scientifique de la région afin de pouvoir se mêler tous les jours à d'autres scientifiques et profiter pleinement des services de soutien existants. Aux Pays-Bas, il existe un groupe semblable. Dans les années 1950, les Hollandais ont entrepris leur vaste projet Delta, qui comprenait la construction de barrages, d'écluses et de digues en grand nombre pour protéger le sud-ouest de leur pays contre les inondations. Ils ont de plus fondé l'Institut Delta, à Yerseke, afin d'étudier les nombreuses variations environnementales résultantes; les données obtenues ont servi à la planification et l'exploitation du projet. Merci.

F.J. Simpson :

Peut-être que George Baker aimerait commenter certaines des options financières telles qu'elles vous apparaissent, en particulier en égard à l'utilisation de l'argent.

G.C. Baker :

Le seul commentaire que je tiens à faire concernant le financement est que le coût du projet n'est pas passé de 6 milliards à 22 milliards en six heures, comme Hal Mills l'aurait su s'il avait vu le rapport Update '82 (mis à jour). Nous avons donné les coûts du projet de deux façons. La première était en dollars constants de 1981, c'est-à-dire 6 milliards. L'autre était le coût au moment où le projet serait terminé si l'inflation se maintenait à 10 % par année entre 1981 et la date d'achèvement, soit 22 milliards. Cela explique donc la différence de 16 milliards de dollars. Il me déplairait de dire jusqu'où nos gouvernements nous ont menés dans l'augmentation de 6 à 22 milliards depuis que le rapport a été écrit, mais la distance n'est pas si terrible.

L. Cammen :

J'aimerais vous faire part de quelques observations qui me sont passées par la tête au cours de l'atelier. Tout d'abord, nous avons entendu une cinquantaine d'exposés. Seulement quelques-uns ont réellement tenu compte des effets environnementaux extérieurs au barrage, et cela reflétait peut-être justement les efforts de recherche des 6 dernières années. Je crois qu'il en a été ainsi parce que les impacts dans le bassin de retenue sont les plus évidents. Il est plus difficile d'évaluer les impacts à l'extérieur des barrages. Une perception en a malheureusement résulté, malgré les désaveux exprimés parfois, et peut-être même malgré une perception non formulée, que l'impact du bassin de retenue est l'impact du projet. Je crois que c'est là une erreur. Si on considère la région touchée à l'intérieur du barrage et qu'on la compare à la région extérieure, ou si l'on considère la population touchée à l'intérieur du barrage par rapport à celle, par exemple, de la côte de la Nouvelle-Angleterre, ou encore si on considère les implications économiques possibles, il est clair, à mon avis, que nous devons changer nos perceptions un peu. Les questions que je veux donc poser, non pas nécessairement aux intervenants, mais simplement en général, touchent ces impacts extérieurs : Seront-ils importants? Qu'arrivera-t-il, par exemple, si le modèle de Dave Greenberg a sous-estimé les variations réelles de l'amplitude des marées? J'ai demandé à Dave quelles étaient les limites de confiance de son modèle, et il m'a répondu qu'il n'en avait pas. Il fait cependant confiance à son modèle, et j'ai moi aussi confiance en Dave, mais s'il existe ne serait-ce qu'un seul risque, sommes-nous prêts à le prendre? Et dans quelle mesure? Un risque sur cent ou un sur mille? Si des variations de l'amplitude des marées devaient causer des perturbations le long de la côte de la Nouvelle-Angleterre, des impacts environnementaux très importants en résulteraient. Il me semble que nous devons donc considérer la probabilité et l'ampleur des impacts possibles pour toute la région touchée, et je ne crois pas que cela a été réellement fait jusqu'ici. Par exemple, le graphique que Carl Amos nous a montré hier et que Don Gordon nous a représenté aujourd'hui (fig. 3) soulève la question suivante : jusqu'où, sur cette courbe, voulons-nous ou croyons-nous que nous devons nous rendre? Je dirais, s'il s'agissait d'une centrale nucléaire, que nous ne nous arrêterions sûrement pas à la moitié ou aux trois quarts; nous nous assurerions d'avoir une évaluation complète des impacts environnementaux.

W. Kozac :

Je suis tout à fait d'accord avec vous, mais, bien que beaucoup de travaux soient en cours, ils ne répondent pas vraiment aux questions que je me pose. Je suis d'accord lorsque vous dites que les impacts sont pris en compte selon qu'ils sont très près du barrage ou derrière. Je crois que bien des personnes qui habitent plus bas pourraient être touchées par un projet. Je crois même que certains des aspects mentionnés précédemment pourraient influencer une région aussi éloignée que celle du banc Georges à cause d'un accroissement possible des courants de marée. Quel effet, par exemple, cela peut-il avoir sur la fixation du naissain de coquilles Saint-Jacques? Cela veut-il dire qu'il n'y aura plus de pêche possible de coquilles Saint-Jacques? Qu'est-ce que cela veut dire pour les larves de harengs qui arrivent actuellement de Trinity? Personne n'a même parlé de cette importante population de harengs reproducteurs qui est, ou était (j'espère qu'elle y est encore) dans la baie Scotts. Les larves sont transportées par les courants. Si les courants s'accroissent, où ces larves iront-elles, quels seront leur taux de survie; aurons-nous affaire aux mêmes populations d'animaux qu'avant? Je crois que ces questions n'ont pas reçu de réponses, et il faudrait y voir.

Mary Majka :

J'aimerais parler au nom du grand public et des naturalistes de notre province et de notre pays. J'habite une des régions qui sera touchée; donc, d'une certaine manière, je suis ici à deux titres. J'ai assisté à trois jours de discussion. Je suis venue ici pour écouter et apprendre et peut-être trouver des réponses à certaines des questions que je me pose et que le grand public, les gens qui appartiennent à des organisations ou les gens qui habitent près de chez moi me poseront. Malheureusement, je suis un peu perdue. Je ne sais trop si je devrais être optimiste ou très pessimiste. Je suis tantôt soulagée, tantôt très effrayée ou tout au moins préoccupée. J'ai été très contente de voir que Hal Mills et Don Gordon ont parlé du public et de ses préoccupations. Certaines personnes qui habitent près de chez moi aimeraient en connaître davantage sur le projet seulement en termes de gains économiques. Ces gens se fichent éperdument de ce qui se passera dans dix ans, mais je dirais que la majorité des gens ne sont pas informés du tout. Je crois que là réside le mandat de ce groupe, car c'est bien beau quand des scientifiques parlent à d'autres scientifiques, mais je crois que ces scientifiques doivent parfois sortir du monde de la science, et je suis bien contente d'apprendre que certains l'ont fait, en particulier lors de cet atelier. Je remercie tous ceux qui, comme quelqu'un l'a dit, "n'ont pas eu peur de se mouiller".

F.J. Simpson :

Je comprends très bien que vous puissiez être perdue, parce qu'à certains moments, je l'ai été aussi, et je suis certain que les tenants et aboutissants de divers exposés ont été mal compris par certains des auditeurs. Vos remarques sont très pertinentes à certaines des questions et certaines des recommandations des intervenants, et je suis certain qu'il y aura plus d'occasions d'interaction avec le public à mesure que le projet avancera.

D. Scarratt :

Je tiens à remercier Don Gordon d'avoir tenté de mettre en perspective le travail que divers scientifiques et chercheurs ont tenté d'accomplir ces six ou sept dernières années; j'aimerais également peut-être tenter de clarifier une idée fausse que Gordon Beanlands semble avoir.
Même si je pense que, de façon individuelle, les scientifiques et nous, nous avons certainement des responsabilités, personne n'a jamais eu de mandat clair pour effectuer ce genre de travail, à l'exception d'une ou deux personnes qui ont été financées par la Société de l'énergie marémotrice. La majeure partie du travail a été effectuée par des scientifiques qui avaient un intérêt particulier pour la dynamique du système dans son ensemble ou pour certaines de ses composantes. Leur intérêt a peut-être été déclenché par la possibilité de l'exploitation de l'énergie marémotrice, mais peut-être également par la création potentielle d'un port en eau profonde quelque part ou d'un puits de pétrole ailleurs ou de toute autre des nombreuses agressions environnementales qui pourraient atteindre la baie de Fundy.
Dans la plupart des cas, ces scientifiques et ces chercheurs ont persuadé leurs supérieurs, avec plus ou moins de succès, que cela représentait une orientation de recherche non seulement intéressante, mais encore socialement appropriée à l'heure

actuelle. Malgré l'absence de mandat collectif, des progrès considérables ont été faits. Nous ressemblons à l'histoire de la pièce "Six personnages en quête d'auteur". Nous avons toujours pensé que la recherche conjointe avait un rôle important à jouer à Fundy, et l'ancien Groupe de travail Fundy du ministère de l'Environnement est allé à la recherche d'un petit coin intime où nous pourrions continuer à nous rencontrer et à échanger des idées et des informations. Notre association avec le CSPA a été idéale.

Lorsque nous avons commencé à organiser cet atelier il y a un an, nous avons décidé qu'il était temps de faire plus que d'évaluer notre recherche et que nous devions vraiment nous poser des défis et faire des prévisions. Plusieurs d'entre nous ont fait certaines prévisions, d'autres ont émis des hypothèses fondées, et certains ont eu ce qu'on pourrait appeler des intuitions raisonnables; selon moi, c'est un pas important dans la bonne direction. Je suis pourtant un peu déçu que Gordon Beanlands nous ait critiqués. Nous avons franchi bien des étapes avec des fonds relativement modestes et incertains. Je me rends compte qu'il reste un long chemin à parcourir. Nous ne sommes pas encore rendus au stade du processus officiel d'énoncé des évaluations environnementales, et je crois que nous ne devons pas l'oublier.

Pour répondre aux commentaires de Mary Majka, je crois qu'il est en effet troublant de voir que certaines personnes sont très positives et d'autres toujours incertaines. Nous sommes à l'un des tout premiers stades et nous faisons notre possible pour nous préparer intellectuellement non seulement au cas où l'énergie marémotrice serait exploitée, mais également au cas où toute autre agression atteindrait la baie de Fundy, que ce soit des effluents de saumure des mines de potasse, une industrialisation accrue à Saint-Jean, la vieille question des raffineries d'Eastport qui a tant stimulé notre activité il y a 12 ans, ou d'autres choses. Nous devons nous préparer à toutes ces éventualités, dont n'importe laquelle pourrait être annoncée demain.

G.C. Baker :

Après les commentaires très appropriés de Dave Scarratt, je crois que je n'ai rien à ajouter, sauf peut-être pour montrer que le graphique de Don Gordon (fig. 2) nous indique de façon très claire où nous en sommes, c'est-à-dire au stade de la compréhension, et que c'est au stade de la mise en oeuvre que nous pourrons tenter de répondre aux questions précises posées par Wally Kozac, Mary Majka et les autres, qui se demandent s'ils peuvent faire confiance à nos prévisions, dans quelle mesure on peut y faire confiance et quelle en est la nature?
Nous ne sommes pas encore rendus à ce stade, et nous n'avons pas reçu de mandat pour faire des prévisions qui informeraient le public. Nous n'avons pas encore toutes les informations de base requises, et plusieurs années de travaux très sérieux et très coûteux nous séparent du moment où nous pourrons faire des prévisions comme celles-là. Comme Dave Scarratt l'a dit, les scientifiques sont en train d'évaluer l'état de leurs propres connaissances pour voir s'ils le peuvent; j'aurai de sérieux problèmes si nous commençons une étude d'impact et qu'ils en sont incapables. J'espère donc qu'ils poursuivront ce processus jusqu'à ce qu'ils fassent des prévisions adéquates. Mais tant que leur compréhension n'aura pas atteint ce point, je crois que ce ne serait pas un service à rendre au public que de lui

présenter nos idées actuelles comme des prévisions de ce qui se passera vraiment. Cela ne servirait qu'à encourager les divisions et les débats sur des questions de rhétorique plutôt que sur des faits.

G. Beanlands :

Je ne comprends pas très bien à quelle idée fausse Dave Scarratt fait allusion; parce que je suis tout à fait d'accord avec ce qu'il disait et je serais certainement déçu de quitter ce groupe en donnant l'impression que j'ai été négatif. En fait, j'ai commencé par demander pourquoi cette aventure avait si bien réussi? La raison pour laquelle je pense qu'il est important de le savoir, c'est qu'il y a deux concepts des évaluations environnementales. L'une est située dans le bloc supérieur du graphique de Don Gordon (fig. 2), l'autre est le graphique tout entier. Et je vous demande ce qu'il arrive au bloc du haut sans le bloc du bas? Si nous voulons améliorer la science de l'évaluation environnementale, nous avons besoin de bons scientifiques; comment pouvons-nous les faire intervenir? Je pose tout d'abord cette question parce que je ne connais pas vraiment la formule magique utilisée pour amener tous ces gens à se rassembler et à tendre leurs efforts dans un but commun de façon si organisée. Je crois qu'il est extrêmement important de comprendre pourquoi cela s'est produit dans le cas de Fundy, compte tenu du fait que nous entrons dans une ère de recherches off-shore pour laquelle nous serons financés par le Fonds renouvelable pour les études environnementales à coups de millions de dollars. Il y a un fonds pour la côte est et un autre pour l'Arctique canadien, et je suis certain que les gestionnaires du fonds voudront faire participer les gens qui effectuent les études dans le cadre de ce bloc du bas. Ils ne tiennent pas vraiment à poursuivre dans la voie que nous leur avons tracée, ce qui s'est avéré un exercice très différent et en grande partie une perte de temps. Je ne dirais donc pas que je ne suis pas d'accord avec toi, Dave. Ce que j'essaie de dire, et c'est ce qui est ressorti du projet auquel je participe depuis deux ans, c'est qu'il faudrait s'assurer que toutes les personnes qui collaborent aux évaluations environnementales comprennent les possibilités et les contraintes scientifiques et que nous ne partions pas en peur avec nos capacités et nos prévisions parce que, souvent, il faut se fier aux meilleurs jugements professionnels. Et il n'y a rien de mal à cela. Jusqu'à présent, les décideurs et les hommes politiques ont malheureusement cru que les jugements professionnels consignés dans les énoncés des incidences environnementales sont à la fine pointe de la recherche scientifique. Je crois qu'une certaine dose de réalisme doit se glisser dans les études d'impact, et je ne crois pas que celles-ci nous mènent très loin dans le bloc supérieur de la figure 2 à moins que nous parvenions à saisir le type d'activité qu'impliquent le projet de Fundy et d'autres mégaprojets à l'horizon. Je cite l'exemple de la mer de Beaufort. C'est loin de tout et peu de recherches de base y ont été effectuées. On a toutefois affecté aux études d'impact des sommes qui feraient paraître bien petits les budgets de la plupart des organismes du monde. Il est vraiment dommage que l'argent n'ait pu servir à des études environnementales comme celles qui ont été effectuées à Fundy.

F.J. Simpson :

Tout ce que j'ai à dire, c'est qu'un atelier comme celui-ci donne souvent des résultats fructueux à cause de quelques personnes qui y ont mis beaucoup d'énergie. Je veux parler ici de Don Gordon, également de Dave Scarratt et de plusieurs autres personnes du milieu scientifique, y compris certains qui n'ont malheureusement pas pu être des nôtres.

Bob Cumming :

J'assure la couverture des sujets liés à l'environnement, et il m'apparaît évident, après trois jours passés ici, qu'il y aura à la fois des avantages et des dommages associés au projet d'exploitation de l'énergie marémotrice. Y aura-t-il des mécanismes d'indemnisation des personnes lésées, et comment allez-vous décider qui sont ces personnes si tant est que vous leur offriez des indemnités, la zone touchée s'étendant sur à peu près toute la côte est de l'Amérique du Nord? J'ai déjà posé cette question à plusieurs personnes ici. L'une des premières questions que j'ai posée à Dave Scarratt lorsque je suis arrivé touchait l'impact des variations de la marée sur la côte du Maine, en particulier sur les plages. Selon lui, un accroissement de l'amplitude maréale de 1 % n'aurait aucun impact. Cela n'est valable que pour la baie de Fundy. Il s'agit d'une variation de 1 % dans la baie de Fundy, mais cette variation est d'environ 12 % à l'embouchure de la rivière Kennebec, où j'habite. Pour la personne qui a mis toutes ses économies dans une maison bâtie sur une dune, il n'était peut-être pas sage d'y construire sa maison, mais il est certainement encore moins sage d'empirer consciemment la situation. Existe-t-il des mécanismes d'indemnisation dans ce cas? Il semble très probable, d'après les discussions, que, pendant un certain nombre d'années, la production de clams au Maine s'accroîtra à cause d'un marnage accru, mais il semble également probable, d'après les discussions, que, pendant 4 ou 5 ans, période où les sédiments se balanceront avant d'atteindre un nouvel équilibre, la production diminuera. La personne dont c'est le gagne-pain se fout de savoir ce qui se passera dans cinq ans, mais elle tient à pouvoir nourrir sa famille cette semaine. Il me semble qu'à un certain moment pendant le processus d'évaluation environnementale, ces problèmes doivent être examinés. Malheureusement, ces questions ne me semblent pas avoir été abordées encore.

G.C. Baker :

Je pense que la question de l'indemnisation qui surgirait au moment de l'interaction entre la perception environnementale des incidences et la conception du projet serait à l'étude. Nous n'avons encore qu'une seule expérience, et une hirondelle ne fait pas le printemps! Mais, dans le cas du projet d'Annapolis, le Comité consultatif intergouvernemental des affaires environnementales est l'organisme qui représente les préoccupations environnementales des diverses parties. Ce comité dit souvent : "Qu'allez-vous faire à ce sujet?" "Pouvez-vous arranger les choses?" "Allez-vous offrir des indemnités?" "Quelle est votre approche?" Voilà le genre de tribune dans laquelle des questions comme celle qui vient d'être soulevée ont été résolues, d'après notre expérience limitée à ce jour.

G. Beanlands :

J'aimerais faire un seul commentaire après ce que M. Baker a dit. D'après l'expérience que j'ai acquise dans mes rapports avec des promoteurs industriels de tout le pays, le problème des indemnités est l'une des raisons pour lesquelles ils ont besoin de prévisions fiables venant des scientifiques, parce que, dans bien des cas, les indemnités sont prévues au début dans les pertes. Ils ont autant besoin d'une évaluation relativement précise de ces changements pour calculer les indemnités que les scientifiques pour des raisons scientifiques. C'est peut-être là un aspect sur lequel nous pouvons être d'accord avec les promoteurs industriels car, dans beaucoup d'autres cas, ils ne sont pas vraiment intéressés à raffiner leurs prévisions parce que la liberté de les interpréter de leur point de vue est quelque peu rassurante.

R.P. Delory :

J'aimerais répondre à Gordon Beanlands et donner un petit coup de pouce aux ingénieurs. Si je comprends bien, il blâme presque les ingénieurs de ne pas avoir la bonne idée de s'en tenir à leur plan et il rend très difficile la tâche des spécialistes de l'environnement qui veulent y aller de leur propre évaluation. Dieu merci, les ingénieurs ont assez de jugement pour changer leur plan s'il n'a pas l'air de marcher!

C. Desplanque :

Je voudrais faire quelques commentaires. J'aimerais remercier Don Gordon pour toutes ses gentilles remarques sur les

Hollandais. Étant Hollandais moi-même, et l'un des deux qui sont ici aujourd'hui, je me permets de faire remarquer que, malgré tout, les Hollandais peuvent également commettre des erreurs énormes et bêtes. Un des projets qui a été mentionné, celui de Delta, en est un exemple. En ce moment, on s'affaire à fermer le dernier inlet à marées, dans le même ordre de grandeur que la baie Cobequid. Les responsables du projet ont dû modifier leurs plans en cours de route à cause de l'opinion publique à propos des implications environnementales. Un projet de barrage fermé est donc devenu en réalité un barrage ouvert. Les députés ont changé d'idée assez rapidement et se retrouvent donc maintenant dans de beaux draps, sur le plan technique. Cela coûte tellement cher de changer des plans à mi-chemin qu'en ce moment, le budget hollandais est extrêmement serré et l'entretien des autres digues est à peu près inexistant.

Je suis donc d'accord avec vous pour dire qu'on doit regarder chez les voisins pour voir ce qui s'y passe. Si les Hollandais avaient observé le Canada, où l'on cultive des huîtres dans la baie Whycomagh (lacs Bras-d'Or) avec une amplitude de marées de quelques centimètres, ils se seraient rendu compte qu'une amplitude de 2.3 mètres pour la culture des huîtres est plutôt exagérée.

J'aimerais ensuite parler des préoccupations concernant l'augmentation de l'amplitude des marées de 15 cm dans le golfe du Maine. Nous savons tous que le bord de mer est s'enfonce rapidement - d'environ 30 à 40 cm par siècle - et que cela fait varier le niveau moyen de l'eau de même que les niveaux des hautes mers et des basses mers. En outre, l'amplitude des marées s'accroît naturellement. Si la prévision de Dave Greenburg est juste, et je dirais qu'il a de fortes chances d'avoir raison, alors la situation résultante est exactement la même que celle qui existera naturellement dans environ 30 ans. Si nous devons payer les dommages aux habitants de la Nouvelle-Angleterre, nous ne devrions avoir à le faire que pendant environ 30 ans; après 30 ans, ils se retrouveraient dans la même situation de toute façon.

W. Silvert :

Ces derniers jours, nous avons entendu 50 exposés qui touchaient divers aspects d'un problème. Normalement, il devrait y avoir une séance où tout serait résumé. Cela ne s'est pas produit ici parce que l'objectif de cette réunion-débat est un peu différent. Il ne s'agit pas d'une réunion-débat pour résumer les travaux scientifiques qui ont été discutés, mais pour faire les choses d'une manière différente. Je crois que cela est un peu malheureux en un sens, parce que nous avons l'impression que nous ne savons pas ce qui a été accompli ces derniers jours, et il semble que nous devrons attendre l'atelier de l'automne prochain pour tenter de résumer et d'intégrer les connaissances que nous avons acquises.

J'aimerais souligner une chose qui ne me semble pas avoir vraiment été dite pendant l'atelier, bien qu'elle l'ait été dans les restaurants et les chambres d'hôtels. Il y a un déséquilibre bizarre en ce qui concerne les évaluations parce que nous venons d'entendre un seul spécialiste de l'océanographiephysique, un seul sédimentologiste, quelques ingénieurs mais un grand nombre de biologistes discuter des impacts environnementaux possibles. Cependant, il semble qu'en termes d'évaluation des impacts, les facteurs réellement critiques à surveiller seront l'océanographie physique et la sédimentologie. Une des observations les plus intéressantes de tout l'atelier est de voir comment tous les biologistes qui ont fait un exposé à la séance III ont utilisé le même modèle pour faire leurs prévisions. Cela n'était peut-être pas tout à fait évident, et tout le monde a interprété cela différemment, mais il est clair que tous les modèles que les biologistes utilisaient pour leurs prévisions étaient soit identiques soit compatibles. Ces modèles se fondaient sur quelques prévisions physiques relativement simples des variations de la taille de la zone intertidale, de la turbidité des eaux en dedans et en dehors du bassin de retenue et de quelques autres facteurs. En fait, les gens semblent assigner les mêmes priorités à ces facteurs. J'en suis donc venu à la conclusion que notre capacité des prévisions biologiques n'est pas, comme plusieurs intervenants l'ont dit, extrêmement pire que n'importe quoi dans le système, mais qu'elle s'avérera en fait relativement bonne. De plus, les systèmes biologiques présentent une certaine robustesse et une homéostasie qui seront probablement mis en évidence lors de l'aménagement futur de Fundy. Par contre, je trouve malheureux que nous n'ayons pu encore déterminer l'impact de l'incertitude de nos prévisions physiques et sédimentologiques, et il importe de le comprendre pour tout genre d'exercice d'évaluation des incidences. C'est pour cette raison que je voulais présenter mon propre résumé.

J. Lakshminarayana :

Quelqu'un a parlé du nouveau Fonds renouvelable pour des études environnementales, qui fournira des millions de dollars pour étudier les impacts environnementaux de l'exploitation off-shore des hydrocarbures. Je crois qu'un fonds semblable devrait être établi pour la zone côtière, qui doit être protégée d'un grand nombre d'agressions environnementales. Je pense également que nous devrions commencer à faire plus attention aux effets synergiques des aménagements. Il y a déjà un mégaprojet presque terminé dans la baie de Fundy, c'est-à-dire la centrale nucléaire de Pointe-Lepreau. Comment ce projet réagira-t-il à un aménagement d'énergie marémotrice? Comment réagira un projet si l'autre est touché par un problème? Toutes ces questions doivent être considérées.

R. Edwards :

Je crois que la question des effets synergiques serait soulevée dans un énoncé des incidences environnementales qui résumerait le bagage des connaissances actuelles et tenterait d'évaluer les impacts possibles d'un projet potentiel sur le système écologique de la zone côtière et sur la société. Cela pourrait entraîner des études additionnelles de ces problèmes.

D. Gordon :

Dans les directives officieuses des énoncés des incidences environnementales pour Fundy, je crois qu'il est question des interactions d'un projet d'exploitation de l'énergie marémotrice et d'autres aménagements à grande échelle existants ou qui pourraient être construits pendant la durée de vie du projet. Également, comme vous le savez très bien, les activités du Comité des études environnementales Fundy n'ont pas été uniquement axées sur les problèmes liés à l'énergie marémotrice. Nous avons également été préoccupés par divers aspects de l'environnement de Fundy, et les chercheurs du projet BIO responsables du contrôle de la radiation au projet de Pointe-Lepreau participent régulièrement à nos ateliers. Je crois qu'il est juste de dire qu'au sein du comité, l'attention et l'intérêt sont portés à divers problèmes qui pourraient se présenter, et nous mettons sur pied des informations de base qui pourront être utilisées pour résoudre un certain nombre de problèmes à mesure qu'ils se présenteront.

G. Beanlands :

Dr Lakshminarayana a cerné un problème véritable auquel nous, en tant que société, devons faire face, c'est-à-dire que nous sommes à l'ère des énoncés des incidences environnementales, mais que nous nous attardons seulement à des projets individuels. Cela vaut pour les organismes gouvernementaux et pour le grand public. Nous ne possédons pas de bons mécanismes d'observation des effets synergiques des différents projets et de la qualité globale de l'environnement. Il semble que c'est dans des zones côtières ou des régions fermées, comme la baie de Fundy, où les impacts de différents projets réagissent les uns avec les autres. Dans des régions comme celle-ci, une approche très différente est nécessaire.

ATTENDANCE LIST

Amos, C.L.	Bedford Institute of Oceanography
Anderson, F.I.	Bedford Institute of Oceanography
Auffrey, R.	Université de Moncton
Aucoin, A.	Université de Moncton
Baker, G.C.	Nova Scotia Tidal Power Corporation
Beanlands, G.E.	Dalhousie University
Beunders, J.	New Brunswick Department of Environment
Blanchard, B.	Acadia University
Blanchard, J.-A.	New Brunswick Department of Fisheries
Borland, W.	Fredericton, N.B.
Bradford, R.	University of New Brunswick
Bray, D.I.	University of New Brunswick
Brown, G.	Acadia University
Burzynski, M.	Parks Canada
Butler, M.J.A.	Maritime Resource Management Service
Cammen, L.M.	Bigelow Laboratory (USA)
Christie, D.S.	New Brunswick Museum
Cranford, P.J.	Bedford Institute of Oceanography
Crawford, P.	Acadia University
Chiasson, L.	Université de Moncton
Collins, N.H.	Collins Environmental and Fisheries Consultants
Cool, J.	Université de Moncton
Campbell, A.	St. Andrews Biological Station
Cummings, R.	Gannet Publishing Co. (USA)
Daborn, G.R.	Acadia University
Dadswell, M.J.	St. Andrews Biological Station
DeCoste, A.	Saint John, N.B.
Desplanque, C.	Maritime Resource Management Service
Dubois, A.	Acadia University
Edwards, R.	Energy, Mines and Resources Canada
Denn, E.E. le-	Centre oceanologique de Bretagne (FRANCE)
Ferguson, E.	New Brunswick Department of Fisheries
Foy, M.	LGL Limited
Gordon, D.C. Jr.	Bedford Institute of Oceanography
Gordon, K.M.	New Brunswick Department of Environment
Gratto, G.	University of New Brunswick
Greenberg, D.A.	Bedford Institute of Oceanography
Guillaumont, B.	Station Biologique (FRANCE)
Gaudet, J.V.	St. Joseph, N.B.
Godin, G.	Canadian Wildlife Service
Hamilton, I.	University of New Brunswick
Hargrave, B.T.	Bedford Institute of Oceanography
Hattie, D.	Sackville, N.B.
Hawkins, C.M.	Fisheries and Oceans, Halifax
Hayashi, T.	Dalhousie University
Hayes, E.	Acadia University
Hennigar, T.W.	Environment Canada
Hicklin, P.W.	Canadian Wildlife Service
Hill, B.	St. Andrews, N.B.
Hutt, R.	Canadian Broadcasting Corporation

Houweninge, G. van	Rijkswaterstaat (NETHERLANDS)
Joanis, M.	Fisheries and Oceans, Ottawa
Johnson, S.	Acadia University
Reely, D.	State of Maine (USA)
Keizer, P.D.	Atlantic Oceanics
Kellock, M.	Aquatic Industries Ltd.
Kozak, W.	Fundy Weir Fishermens Association, Inc.
Lakshminarayana, J.S.S.	Université de Moncton
Lamson, C.	Dalhousie University
Larsen, P.F.	Bigelow Laboratory (USA)
Leslie, H.	Acadia University
Linkletter, L.E.	St. Andrews Biological Station
Lanteigne, S.	Université de Moncton
Lanteigne, M.	Université de Moncton
MacDonald, P.	Acadia University
Majka, M.	New Brunswick Naturalists Federation
Maltais, P.	Université de Moncton
Mann, K.H.	Bedford Institute of Oceanography
Marcus, H.	Rijkswaterstaat (NETHERLANDS)
Milligan, D.C.	Nova Scotia Department of Agriculture
Mills, H.	Freelance marine policy consultant
Murray, J.	Saint John, N.B.
Parsons, J.	Acadia University
Peer, D.L.	Bedford Institute of Oceanography
Prouse, N.J.	Bedford Institute of Oceanography
Redden, A.	Acadia University
Richards, W.G.	Atmospheric Environment Service
Riley, D.C.	Fisheries and Oceans Canada
Rioux, P.	Université de Moncton
Rioux, R.	Université de Moncton
Roanowicz, J.	University of New Hampshire (USA)
Roberts, D.L.	St. Andrews Biological Station
Rulifson, R.A.	Unity College (USA)
Saulnier, C.	University of New Brunswick, Saint John
Scarratt, D.J.	St. Andrews Biological Station
Scheibling, R.	Dalhousie University
Schwinghamer, P.	Bedford Institute of Oceanography
Silvert, W.L.	Bedford Institute of Oceanography
Simpson, F.J.	Atlantic Regional Laboratory
Spiller, J.	University of New Hampshire (USA)
Stephenson, R.L.	Dalhousie University
Stone, H.	Acadia University
Tay, K.L.	Environmental Protection Service
Thirumurthi, D.	Technical University of Nova Scotia
Thurston, H.	Freelance writer
Trueman, S.	University of New Brunswick, Saint John
Walsum, E. van	Shawinigan Consultants Inc.
Wildish, D.	St. Andrews Biological Station
Williams, J.	Acadia University
Wilson, R.	Environmental Protection Service
Witherspoon, N.	Dalhousie University
Weldon, J.	JMA Armstrong High School