Science Review 1990 & '91

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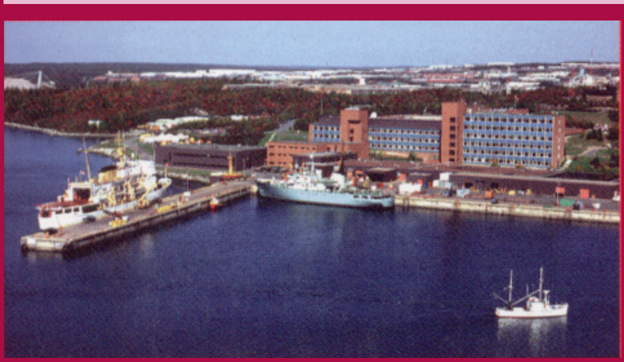

Bedford Institute of Oceanography

Halifax Fisheries Research Laboratory

St. Andrews Biological Station

Canada

The *Science Review of the Bedford Institute of Oceanography, the Halifax Fisheries Research Laboratory, and the St. Andrews Biological Station* describes the research and survey programs being undertaken at these three federal establishments. The broad objectives of the programs are:

- to perform applied research leading to the provision of advice on the management of marine and freshwater environments, including fisheries and offshore hydrocarbon resources;
- to perform targeted basic research in accordance with departmental mandates;
- to perform surveys and cartographic work necessary for ensuring a supply of suitable navigational charts for the region stretching from Georges Bank to the Northwest Passage in the Canadian Arctic;
- to respond with all relevant expertise and assistance to major marine environmental emergencies.

Three departments are involved: the Department of Fisheries and Oceans; the Department of Energy, Mines and Resources; and Environment Canada. The work encompasses the fields of marine geology and geophysics, physical oceanography, marine chemistry, biological oceanography, fisheries research, seabird research, and navigational surveys and cartography.

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continued...

The Science Review of the Bedford Institute of Oceanography, the Halifax Fisheries Research Laboratory, and the St. Andrews Biological Station is published by the Scotia-Fundy Region of the Department of Fisheries and Oceans.

Change-of-address notices and other correspondence regarding this publication should be sent to:
Marine Assessment and Liaison Division
Department of Fisheries and Oceans
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia
Canada B2Y 4A2

Cat. no. Fs75-104/1991E
ISBN 0-662-20245-7

La version française est disponible.

Editors:
To June 1992: Thea E. Smith, TES Technical Services, Halifax, Nova Scotia
From July 1992: Joanne Cook, CEF consultants Ltd., Halifax, Nova Scotia

Production:
Arthur Cosgrove

Photographs:
BIO Photography Unit

Electronic Assembly:
Paragon Services, Lower Sackville, Nova Scotia

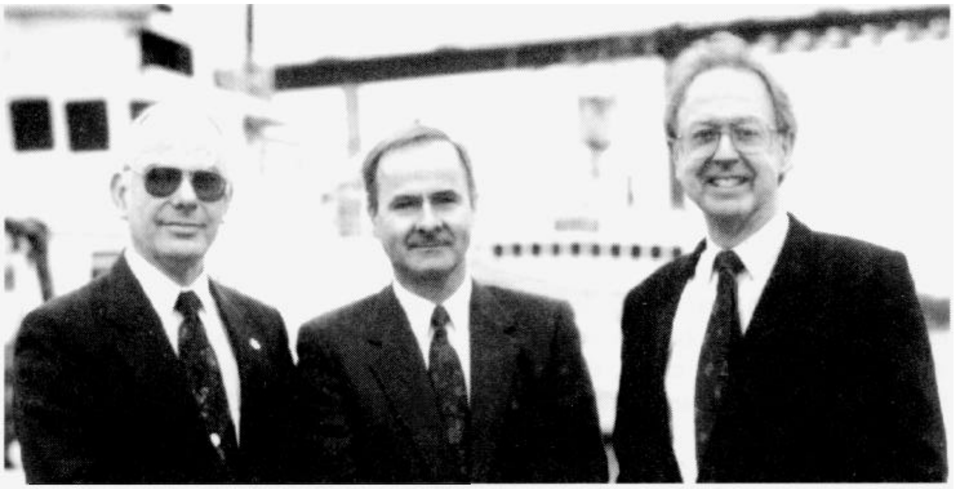
Printer:
McCurdy Printing and Typesetting Limited, Halifax, Nova Scotia

Editor's note:
This edition of the Science Review *was produced using Aldus(R) Freehand™, Aldus(R) PageMaker™, and Microsoft(R) Word™ on an Apple Macintosh IIci computer.*

Research

1990 and '91 in review

S. B. MacPhee, D. I. Ross, and H. B. Nicholls



D. I. Ross, S. B. MacPhee, and H. B Nicholls

Although it was a period of financial restraint, the years 1990 and '91 were interesting and fruitful ones for the research and survey programs carried out at the Bedford Institute of Oceanography (BIO), the Halifax Fisheries Research Laboratory, and the St. Andrews Biological Station. The following paragraphs describe a number of significant events that occurred during those years at the laboratories of the Department of Fisheries and Oceans (DFO), and at those of the Department of Energy, Mines and Resources (DEMR) and Environment Canada.

Staff

Within DFO, the one senior staff change was the appointment of Mr. Neil Bellefontaine as Regional Director-General of the Scotia-Fundy Region.

N. Bellefontaine

Mr. Bellefontaine assumed his new duties in late 1990 and replaced Mr. Jean-Eude Haché, who became Assistant Deputy Minister of Fisheries Operations.

Within the Atlantic Geoscience Centre (AGC) of DEMR, there were a number of key staff changes. Mr. Don McAlpine replaced Dr. Mel Best as Head of Basin Analysis when the latter transferred to the Pacific Geoscience Centre. In addition, Dr. Jacob Verhoef replaced Dr. Matt Salisbury as Head of Regional Reconnaissance, and Mr. George McCormack (on assignment from Statistics Canada) took over the responsibilities of Head of Administration upon the departure from BIO of Ms. Carol Racine.

Within Environment Canada, Dr. Harry Samant, Chief of the Regional Laboratory (Environmental Protection), left the Institute to take up a new appointment with Public Works Canada.

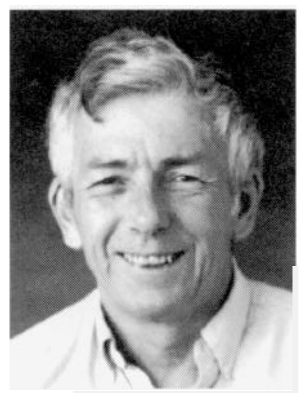
In memorium

Dr. Michael J. Keen, former Director of AGC, died suddenly at home on January 8, 1991. He began his career at Dalhousie University in 1961, with a mandate to establish the first academic program in marine geophysics in Canada. Dr. Keen wrote one of the first textbooks on marine geophysics, and rose to be the Chairman of the Department of Geology and Assistant Dean of Science. He joined AGC in 1977 as its second Director and remained in that post for 11 years. He led major growth of the Centre by securing strong support from a number of government initiatives, including the Frontier Geoscience Program. He was a strong supporter of international science, and spearheaded the initiative for Canada to join the Ocean Drilling Program. In 1988, Dr. Keen "returned to the bench" to pursue studies of the origin and distribution of metamorphic rocks on the seafloor, and the impact of recent geological processes on global climate change.

Awards, appointments, and presentations

The following were among the awards, appointments, and presentations involving staff of the laboratories:

- Dr. Shubha Sathyendranath, Adjunct Research Scientist in the Biological Oceanography Division of DFO, was awarded the EUROSENSE Prize for 1989. This award is presented by the Remote Sensing Society for work published in its International Journal of Remote Sensing.
- Dr. Trevor Platt, Head of the Biological Oceanography Division of DFO, was elected a Fellow of the Royal Society of Canada.



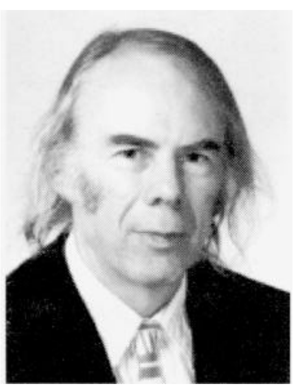
M. J. Keen

- Dr. Peta Mudie, Research Scientist in the Environmental Marine Geology Subdivision of AGC, was elected a Fellow of the Royal Society of Canada.
- Dr. Alan Longhurst, Research Scientist in the Biological Oceanography Division of DFO, was awarded the 1991 Gold Medal by the Professional Institute of the Public Service of Canada for his cumulative influence in the development of Canadian oceanography.
- Dr. Charlotte Keen, Research Scientist in the Regional Reconnaissance Subdivision of AGC, was named the 1991 Rutherford Lecturer for her contribution to understanding the development of continental margins and associated sedimentary basins.
- Dr. Ken Frank, Research Scientist in the Marine Fish Division of DFO, was named the 1992 J. C. Stevenson Lecturer. This prestigious lectureship was instituted in honour of Cam Stevenson, the longtime editor of the Canadian Journal of Fisheries and Aquatic Sciences.

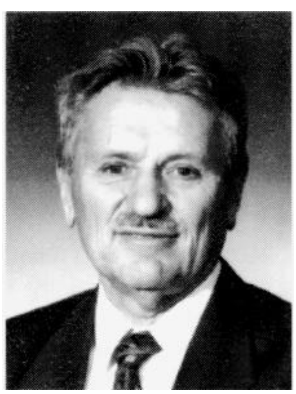
Huntsman Award: The A. G. Huntsman Award for excellence in the marine sciences is administered by a private foundation based at BIO. It was awarded twice during the period covered by this *Review:*

On January 8, 1991, Dr. Nick Shackleton of Cambridge University was presented with the 1990 Huntsman Medal in recognition of his innovative work on paleo-oceanography and the development of oxygen isotopic stratigraphy.

On November 15, 1991, Dr. Gabriel Csandy of Old Dominion University in Norfolk, Virginia, was presented with the 1991 Huntsman Medal in recognition of his fundamental contributions to the understanding of circulation and mixing on the continental shelf and in lakes.



N. Shackleton



G. Csandy

Research and survey highlights

Some of the major events that occurred during the 1990-91 biennium are listed below by broad geographic region.

Gulf of Maine, Georges Bank, Bay of Fundy: In August 1990, AGC and the University of Maine studied the shallow geology of the Gulf of Maine in a project sponsored by the U.S. National Science Foundation (NSF). The purpose of the study, which took place aboard the NSF vessel *Cape Hatteras,* was to determine how the Gulf of Maine developed from a basin filled with glacial ice into the biologically productive body of water that it is today. During the cruise, the deep-towed, high-resolution seismic reflection system developed by Huntec Ltd., a Canadian company, provided high-quality profiles of the seafloor and subsurface. Maps and reports prepared from the joint survey will aid in the geological interpretation of this region.

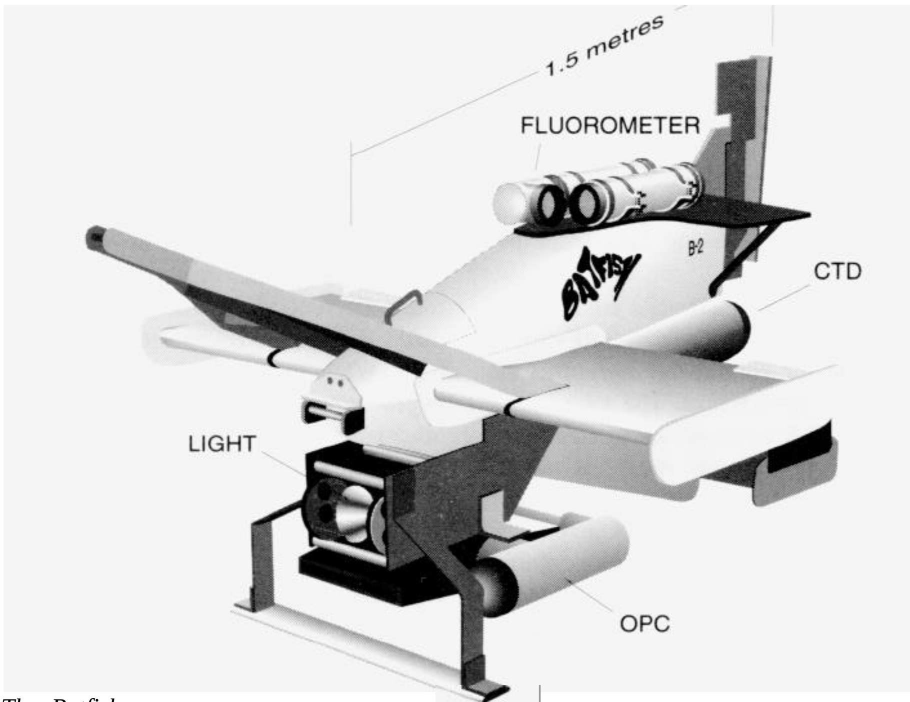
Work continued during 1990 on a project to examine the population structure of the sea scallop on major east coast fishing grounds. The approach adopted was to determine differences in shell morphology and to identify groups showing common morphological traits. The work involved the collection of over 1,000 shells of four- and five-year-old scallops from the Bay of Fundy, Georges Bank, Western Bank, and St. Pierre Bank.

An important emerging issue addressed throughout the review period is the environmental impact of aquaculture on the coastal zone. The main impacts are thought to be due to the release of dissolved and particulate wastes such as inorganic nutrients, feces, and, in the case of finfish aquaculture, ungrazed food. A multidisciplinary program is being undertaken which aims to develop a hierarchy of computer impact assessment models. Underlying the development of the numerical models are associated field studies. One example in 1991 was an experiment, conducted in cooperation with SeaFarms Canada Limited, to determine the flushing rate in the vicinity of salmon cages located in the L'Etang area of New Brunswick, and to determine the rate's correlation with current velocity, cage fouling, and stocking density.

During both 1990 and '91, research on lobster migrations in the Gulf of Maine area continued. Movements over long distances, sometimes as great as 100 km, are unique to the Gulf of Maine and parts of the southern New England shelf. Movements along the Eastern and South Shores of Nova Scotia, the Gulf of St. Lawrence, and Newfoundland are generally less than 10 km. Migration studies in the Gulf of Maine have identified three common elements: the vast majority of tagged animals are recaptured near the area of release; long-distance return migrations occur; and a small percentage of animals move very long distances in what appears to be a one-way dispersal. This research, which is important for stock management purposes, is continuing.

Scotian Shelf: The Scotian Shelf Basin Atlas, the second in an east coast series being produced by the AGC as a synthesis of existing geoscience knowledge of frontier basins, was published in 1991. The atlas covers bathymetry, surficial geology, structural geology, geophysical parameters, biostratigraphy, seismostratigraphy, and paleo-environmental conditions throughout the period of formation of the sedimentary basins.

During a 1990 cruise of C.S.S. *Dawson,* DFO scientists investigated euphausiid abundance on the Scotian Shelf. They utilized a Batfish-mounted optical plankton counter, the BIONESS plankton net sampler, and multifrequency acoustics. The research, which focused on Emerald Basin and the "Gully" (a canyon at the shelf edge adjacent to Banquereau Bank), is of interest to fisheries managers, since euphausiids may provide a winter food source for silver hake in Emerald



The Batfish

components: a mark-recapture experiment to determine the size of the bluefin tuna school in the Hell Hole, and an ultrasonic telemetry experiment to assess mortality rates and follow tuna movements during the fishery. A total of 133 tuna have been tagged in the two years since the experiment began. The movements of telemetry-tagged fish show that tuna remain active after being tagged and released. Additional mark-recapture and telemetry experiments are planned for 1992.

Scientists from DFO joined colleagues from Dalhousie University, Memorial University, the University of Quebec at Rimouski, Lava1 University, McGill University, the University of British Columbia, and Simon Fraser University for an interdisciplinary study of Atlantic cod and sea scallops during the review period. The research is being carried out as part of the Ocean Production Enhancement Network (OPEN), one

Basin. Concentrations were found to be extremely high near the bottom of Emerald Basin, a phenomenon which appears to persist throughout the year. However, sampling in the Gully and in the coastal Nova Scotia current showed these areas to be virtually devoid of euphausiids.

Over the review period, AGC completed the last of a series of cruises in Halifax Harbour as part of a program to study the geological history of the inlet and to map the distribution of sediments and seabed features. The purpose of this 1990 cruise was to fill in remaining gaps in the data and to collect seabed samples. A digital sidescan sonar system provided detailed information about the harbour floor, while a ROV (remote-operated vehicle) with onboard camera systems investigated sites of particular interest. The resulting geological maps will be useful to the engineering community in the design and construction of the new regional sewage system for the Halifax-Dartmouth area.

During 1990 and ‘91, personnel at the St. Andrews Biological Station conducted a bluefin tuna tagging experiment in the “Hell Hole” area of Browns Bank. The research was a cooperative effort between the Biological Station and the Southwest Nova Tuna Association and had two

The BIONESS net Sampler system.

of the Networks of Centres of Excellence (NCE) announced by the government of Canada in 1990. The principal goal of the OPEN program is to investigate the processes which control the survival, growth, and reproduction and distribution of these species. In addition to government and university support, the OPEN program receives funding from the three major fishing companies in Atlantic Canada.

C.S.S. *Hudson's* AGC cruise to Sable Island Bank in March 1990 provided a valuable database on sediment stability and the internal fabric of the sands comprising the bank. Vibracores, box cores, and large grabs of bottom sediment across the postulated position of a "hydraulic fence" demonstrated a dramatic change in sediment type. Above the fence, sediments are well-sorted sands, while below it they are silty or clay-like. The hydraulic fence barrier to sand transport is caused by a major change in the magnitude and direction of the current flow on the bank edges. It appears from this work that Sable Island Bank is analogous to ancient petroleum reservoirs, and that the hydraulic fence is a viable mechanism for the generation of reservoir-scale sand bodies at the edge of continental shelves.

Grand Banks, Labrador Sea: In January 1990, scientists onboard C.S.S. *Hudson* worked in the region of the Southeast Newfoundland Ridge. This was the *Hudson's* first cruise after an extended mid-life refit. The cruise was part of a study of the flow across this ridge, the objective of which was to gain a quantitative understanding of the role of ocean currents in transporting heat from southem latitudes to the northern North Atlantic. A seven-mooring current meter array that had been set from the *Hudson* in April 1988 was recovered during the cruise, and various measurements of temperature, salinity, dissolved oxygen, and nutrients were taken.

A survey of the pack ice off the Newfoundland and Labrador coast was conducted in March 1990 during a cruise of C.S.S. *Baffin*. The work was part of the Labrador Ice Margin Experiment (LIMEX), which has been undertaken annually since 1987. The cruise studied the oceanic conditions and ice movement during the retreating phase. It was led by DFO, in cooperation with the Atmospheric Environment Service, which conducted two flights with synthetic aperture radar (SAR) in order to obtain microwave images of ice distribution. In addition, the Centre for Cold Ocean Resources Engineering, at Memorial University in Newfoundland, deployed a sonic sensor for measuring ice ablation, and collected ice-melt data from the bottom of a floe.

In 1990, AGC scientists collaborated with French colleagues from IFREMER in a study of the continental margin of the southeast Grand Banks. The joint cruise onboard C.S.S. *Hudson* utilized the French high-precision, deep-tow digital sidescan (SAR) and the Canadian Huntec system to image the seafloor across the margin in an investigation of slope stability and debris flows.

During the summer of 1991, C.S.S. *Dawson* completed the first of a series of cruises to investigate the impacts of fishing gear on the benthic habitat of Canadian fishing banks. Surveys were conducted at two sites: an area just north of Hibernia on the Grand Banks, and one on Western Bank on the Scotian Shelf. Side-scan sonar was used to map the distribution of trawl and dredge marks on the seafloor, and sampling gear was equipped with video cameras to supply information about the efficiency of the gear and the composition of benthic communities.

In late 1991, the initial cruise of the second Canadian Atlantic Storms Program (CASP) was conducted from ***C.S.S. Hudson*** on the northern Grand Banks near Hibernia. The major objectives of the cruise were the following: to deploy a mooring array; to conduct a hydrographic survey of the area; to carry out surface drifter studies along the inshore edge of the Labrador Current; and to coordinate Batfish and acoustic Doppler current profiler transects of the Labrador Current with SAR measurements made by aircraft flying along the same track. While several fierce storms resulted in problems with moored instruments and other equipment, the experiment was successful in many respects and useful data were obtained.

Arctic: In January 1990, Soviet geologists from the All Union Ocean Research Institute in Leningrad visited Canada to work on the final stage of the Circum-Arctic Quaternary Mapping Project. The result was the first map to show the genesis, age, and material composition of Quaternary deposits in the region from latitude 65°N to the North Pole. The western part of the map was produced collaboratively by scientists at the Geological Survey of Canada and marine geologists from AGC. The eastern portion was compiled by geologists from the Soviet institute. The map, which was produced using the Canadian CARIS computerized geographic information system and which complements the Circum-Arctic Geology Map that the two

The Polarstern, *a German icebreaker. was one of the first conventionally powered ships to reach the North Pole as part of the Arctic '91 expedition.*

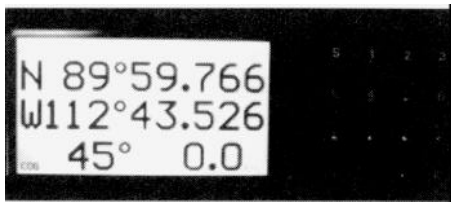
countries published jointly in 1989, was released to the public during the visit of President Gorbachev to Ottawa in June 1990.

That same year, the successful recovery of two sediment traps moored under Canada's Ice Island research station provided the first annual record of particulate matter sedimentation in the upper water column of the Arctic Ocean. The field work, completed in early September, was undertaken as a joint project between scientists from DFO and AGC.

In 1991, the Environmental Marine Geology subdivision at AGC initiated collaborative studies with Hydro-Québec to investigate the environmental impact of hydroelectric projects such as the proposed Grande Baleine development. Under the terms of the collaboration, AGC will provide the regional perspective seaward of the proposed outflows, and Hydro-Québec will undertake the detailed, site-specific studies near the river mouths. The regional work will provide the overview and context for the site-specific work, both aspects being essential for understanding the cumulative impact of the projects. A major cruise of *C.S.S. Hudson* to Hudson Bay and James Bay is planned for 1992.

During August 1991, two BIO scientists, Dr. John Vandermeulen and Dr. Don Gordon, visited Prince William Sound, Alaska, the site of the *1989 Exxon Valdez* spill. When the *Exxon Valdez* grounded on March 24, 1989, it spilled 36,000 t of Prudhoe Bay crude oil into Prince William Sound, contaminating about 20% of the shoreline with oil. Exxon undertook a cleanup program which continues to the present. Visiting teams of scientists, including Vandermeulen and Gordon, witnessed once heavily contaminated shorelines that now bear few traces of oil. Intertidal plant and animal communities appear healthy and productive, and other information indicates that marine mammal and fish populations are at normal levels.

Arctic '91, an international scientific expedition to the Arctic Ocean, took place from August through October of 1991. The expedition initially comprised three ships: the Swedish icebreaker *Oden,* the German icebreaker *Polarstern*, and the U.S. icebreaker *Polar-star*. BIO scientists were onboard both the *Oden* and the *Polarstern*. Unfortunately, *Polarstar* developed problems with a propeller shaft and was forced to retire from the expedition. Scientific programs on *Oden* focused on studying the origin and circulation of water masses within the Arctic Ocean, the radiation properties of sea ice, and processes involved in cloud formation in the Arctic. The *Polarstern* and *Polarstar* science programs were primarily geological and included studying the history of seafloor spreading within the Arctic Ocean basin and the history of the region's climate. On September 7, both *Oden* and *Polarstern* arrived at the North Pole. This marked the first time conventionally powered ships reached the Pole, and the first time ever that two surface ships were at the North Pole together.

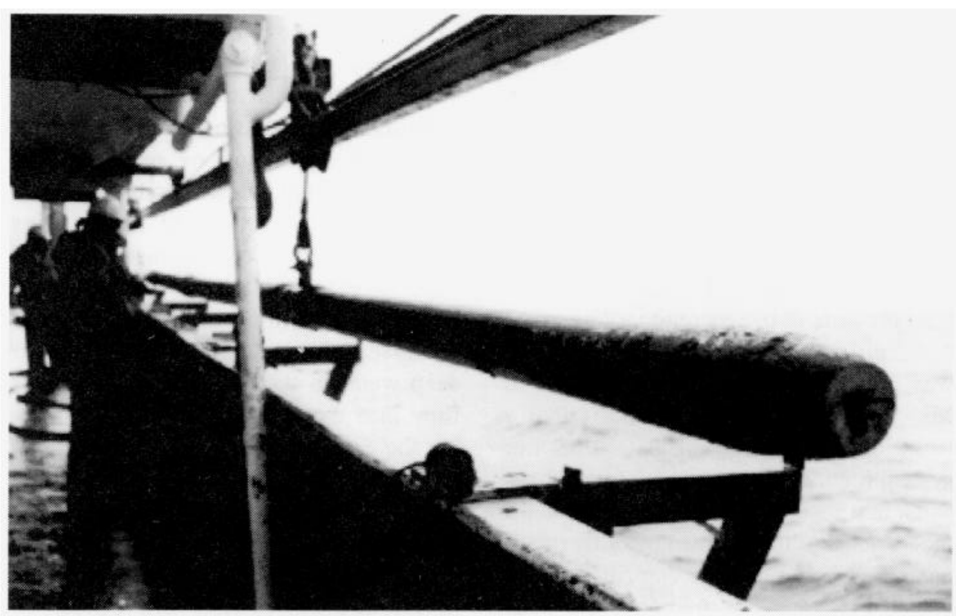


The GPS screen reading at the North

Offshore and international: In 1990, a C.S.S. *Hudson* cruise to the northeast Bermuda Rise provided the opportunity for the first sea trial of AGC's modified "long corer". This part of the Atlantic Ocean is a sediment-drift region with very high sedimentation rates (20 m per 1,000 years). These high rates in a deep-sea environment provided unique conditions for testing the corer, which was initially developed at the University of Rhode Island with participation from AGC. The successful deployment during the 1990 cruise led to interest being expressed by several other countries.

In March and April 1990, DFO chemists participated in the first cruise of a multi-year international investigation of baseline levels of inorganic contaminants in the Atlantic Ocean. This project was developed by the Intergovernmental Oceanographic Commission's Environment Programme Group of Experts on Methods, Standards, and Intercalibration, with considerable input from DFO scientists. The first cruise was conducted on the German research vessel *Meteor* with participation by marine geochemists from several countries. The main objective of this project is to determine the background distributions of trace inorganic contaminants in the major deep-water masses of the Atlantic Ocean.

In April and May 1991, studies were undertaken in the North Atlantic in support of two major global research programs: the Joint Global Ocean Flux Study (JGOFS) and the World Ocean Circulation Experiment (WOCE). During April, as part of the JGOFS program, scientists onboard C.S.S. *Hudson* investigated oceanographic events surrounding the


Atlantic Geoscience Centre's "Long Corer"

spring bloom of phytoplankton, a brief period of intense biological activity in the oceans that accounts for a substantial fraction of the year's total primary production. During May, the *Hudson* was involved in WOCE activities to define water transports into and out of the northwest Atlantic Ocean. Also on this second cruise, measurements in support of the JGOFS work were taken to assess the transport of dissolved inorganic carbon to the ocean interior. Both cruises were undertaken in cooperation with ships from other nations.

In December 1991, Dr. Alex Herman of DFO participated in a cruise on the American vessel *Cape Hatteras* as a co-investigator in the U.S.-sponsored South Atlantic Bight Recruitment Experiment (SABRE). The project is developing techniques for detecting and measuring the concentration of Atlantic menhaden eggs along the east coast of the U.S. and in the Gulf of Mexico. Surveys of menhaden eggs could provide important information required by stock assessment scientists, and the new techniques could eventually be used by DFO's east coast ichthyoplankton programs. The SABRE cruise resulted in successful sea trials of the system for counting menhaden.

AGC's Kate Moran participated in the 1990 Ocean Drilling Program Leg 131 cruise to the Nankai Trough. The accretionary prism of this trough is the product of subduction of the Philippine Sea Plate below the Honshu Arc. The focus of the drilling program was to study the influence of pore fluids on the accretionary wedge, the mechanical state and physical properties of deformed sediments, and the fabric and structural styles of accreted sediments. An *in situ* lateral stress tool developed by AGC in cooperation with university and industry partners was used for the first time to measure stress and pore pressure in the accretionary prism.

Non-site-specific: An experiment was conducted from C.S.S. *Dawson* in May 1990 to test the hypothesis that a light on the Canadian BIONESS net system reduces net avoidance by euphausiids, and results in population estimates much closer to those given by other methods. It is believed that euphausiids use visual cues to avoid predators and nets, and that the bright light prevents the animals from seeing the approaching net. The experiment showed that, with the light, the BIONESS caught orders of magnitude more euphausiids during both day and night than it did without the light. The outcome of the experiment has important implications for krill biomass estimates in the Antarctic and other oceans, suggesting that the biomass should be orders of magnitude higher than previously thought.

In December 1990, Dr. Allister McVicar from the Marine Laboratory in Aberdeen, Scotland, and Dr. Trevor Evelyn from the Pacific Biological Station in Nanaimo, B.C., conducted an in-depth peer review of the DFO Scotia-Fundy Fish Disease Program based at the Halifax Fisheries Research Laboratory. Both scientists have longstanding expertise in fish diseases in the traditional fisheries and aquaculture industries of Scotland and the west coast of Canada. The review included an assessment of the program's scientific content and its relevance to the needs of Atlantic Canada. The review report was favourable; in particular it lauded the close link between the diagnostic and research components of the program, and commended the provision of integrated advice on disease control.

During 1991 and '92, researchers at BIO and McGill University made progress toward developing a relatively simple computer model which can be used to study the very long time-scales of interest to modellers of ocean climate. The model's key innovation is its ability to efficiently represent the circulation of individual ocean basins by using zonally averaged equations of motion. The resulting global ocean model yields a realistic representation at sensitivities found in much more sophisticated and expensive models. In addition, it can reproduce present oceanic conditions and processes - for example, the formation of deep water in the North Atlantic and its flow into the Pacific and Indian oceans via the Southern Ocean, where it slowly upwells and eventually returns to the North Atlantic as near-surface water.

Natural history facilities dedicated to the long-term maintenance of important taxonomic collections are becoming increasingly important in marine research. One such facility, the Atlantic Reference Centre (ARC), marked its seventh year of operation in 1991. Located on the grounds of the St. Andrews Biological Station, the ARC is a joint project of DFO and the Huntsman Marine Science Centre. It houses collections of aquatic biota from the Atlantic region and serves as a centre for taxonomy, life history, functional morphology, the determination of environmental baselines, and the provision of ecological advice. The ARC museum now contains over three million samples of preserved organisms, ranging from protozoans to fishes (freshwater, estuarine, and marine) and including marine algae. Construction of a building to accommodate the collections, which are currently housed in a trailer complex, was begun in late 1991.

The Canadian Ocean Mapping System (COMS), an initiative to implement Canada's Ocean Strategy, progressed favourably during the review period. The goal of this cooperative venture between government, industry, and universities is to enhance ocean-mapping capability in the private sector through technology transfer. To achieve this, the remotely operated semi-submersible DOLPHIN has been transferred to industry, where a new multi-beam sonar system has been installed and a handling system to launch and recover the system has been developed. In addition, DFO staff are working closely with industry and the University of New Brunswick's Ocean Mapping Group to develop software for managing the data that the system will collect.

Task force membership

Staff were appointed to a variety of national and international task forces and other working groups during the review period, including the following:

- Dr. T. Platt, Head of DFO's Biological Oceanography Division, was appointed Chairman of the Joint Global Ocean Flux Study (JGOFS) international program. In this particular position he will lead a group of international scientists in the study of the ocean carbon cycle and its effect on climate.
- Dr. M. Best, Head of AGC's Basin Analysis Subdivision, was appointed to the Canada-Newfoundland Offshore Oil and Gas Committee in 1990.

Conferences and workshops

During the review period, the following conferences and workshops were among several held at, or sponsored in whole or in part by, the three regional facilities:

- GLOBEC Workshop - Sponsored by the U.S. Joint Oceanographic Institutions and involving Canadian and U.S. scientists supplemented by several other experts, this event was held at BIO from June 19-21, 1990. GLOBEC (Global Ocean Ecosystems Dynamics) is designed to evaluate the likely consequences of changes in global climate and physics on the sustainability of animal production in the sea. The focus of the BIO meeting was a proposed GLOBEC study in the Georges Bank/ Gulf of Maine region.
- 1990 Canadian Workshop on Harmful Marine Algae - This workshop (the second in the series) was held at BIO from October 2-4, 1990. It involved 60 participants from government, academia, and industry who discussed recent research in the fields of the ecology, toxicity, monitoring, and chemistry of toxin-producing algae.
- Halifax Inlet Research Workshop - This workshop, held at BIO on February 13, 1991, provided a forum for the presentation and discussion of research results and plans pertaining to the inlet. A workshop on the same topic had been held in 1989. In addition to scientists, the audience comprised persons from a wide variety of backgrounds, including members of the joint federal-provincial environmental review panel that is examining the environmental implications of the proposed regional sewage treatment facility.
- Workshop on the Environmental Aspects of Aquaculture - This national workshop was held at BIO on March 5 and 6, 1991. Participants represented DFO, relevant provincial agencies, and the aquaculture industry.
- American Society of Limnology and Oceanography (ASLO) - BIO hosted ASLO's 1991 annual summer meeting at Saint Mary's University, Halifax, from June 10-13. The meeting drew the largest number of participants in recent memory (650) with 400 papers in four concurrent sessions and over 100 poster presentations.
- ICES Working Group on Environmental Assessment and Monitoring Strategies - This working group held its first meeting outside of continental Europe when it met at the Halifax Fisheries Research Laboratory and BIO from November 4-8, 1991.
- Joint Annual Meeting and Conference of the World Aquaculture Society and the Aquaculture Association of Canada - This major event, held in Halifax in June 1990, involved staff of the Halifax Fisheries Research Laboratory and the St. Andrews Biological Station as officers of the societies, organizers of meetings, and chairs of sessions.
- Fourth Biennial Benthic Workshop - The 1991 workshop in this series, held at the St. Andrews Biological Station, focussed on the impacts of mariculture on coastal systems.

Technology transfer

A major open house was held at BIO from October 18-20, 1990, during which the Institute was host to almost 30,000 members of the general public. The day before the open house, October 17, was designated "client day", which gave BIO's clients from industry, universities, and government the opportunity to tour the open house exhibits, attend sessions on the science activities at BIO, and meet with various scientists in an informal setting in order to discuss common areas of interest and concern. Several of the many items on display were the result of technology transfer involving DFO and DEMR scientists at BIO. Other technology transfer highlights during the review period include the following:

- A Transfer of Technology Agreement was signed between DFO and ORACLE Canada Corporation so that spatial data structuring techniques developed by DFO's Canadian Hydrographic Service

Young visitors to the BIO Fish Laboratory during the 1990 Open House.

Students take a close look at BIO during the 1990 Open House.

could be investigated and implemented as a marketable database product.

- AGC continued to provide geological advice to the oil industry with regard to offshore exploration and production. In particular, during 1990 and 1991 considerable emphasis was placed on the Cohasset-Panuke-Balmoral development offshore Nova Scotia, which began production in 1992.
- Technology transfer in the field of aquaculture continued during the review period. A focus for such transfer was the Atlantic Aquaculture Fair, which is held annually in St. Andrews and involves staff of the St. Andrews Biological Station.
- Technology transfers to industry involving instruments and other items of hardware during 1990 and '91 included the BIO water sampling bottle, the AGC vibracoring system, the BUD (biological upwelling and downwelling) probe, and an underwater magnetic release mechanism.

Visitors

As in previous years, the three regional establishments received many special visitors from Canada and abroad. Of particular interest were the visits to BIO by the following: the Commons Standing Committee on Industry, Science and Technology, Regional and Northern Development; the Select Committee on Energy and Processing of Resources of the Legislative Assembly of Western Australia; the Minister of Fisheries of the former Soviet Union; Dr. R. K. Steedman, Chairman-Designate of the Australian Institute of Marine Sciences; the Engineering Committee on Oceanic Resources (ECOR) on the occasion of its 1990 General Assembly and Council Meeting; M. Pierre Papon, President of IFREMER, France; the Canadian Commission for UNESCO; and members of the Japan Marine Science and Technology Centre (JAMSTEC).

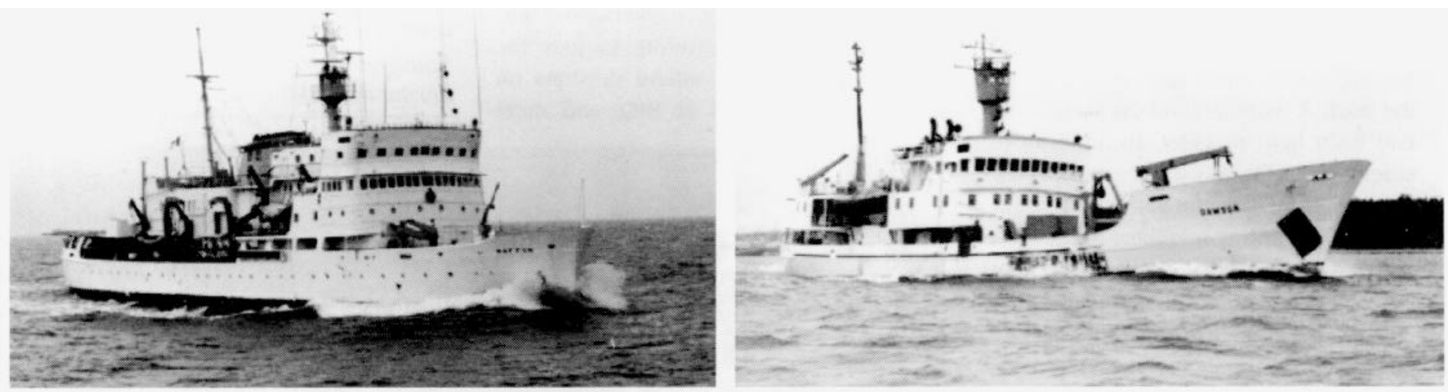
Support services

With regard to support services, items of interest during the 1990-91 biennium include the following:

- C.S.S. *Hudson* returned to service on March 9, 1991, after an extensive refit that included the replacement of two main engines.
- On May 23, 1991, a new conference room at the St. Andrews Biological Station was officially opened and dedicated to Dr. H. B. Hachey (1901-85) in recognition of his significant contribution to marine science in Atlantic Canada.
- During 1990, a "mini-supercomputer", a Stardent 3040, was installed at BIO for physical oceanography modelling applications.
- Two of BIO's major research vessels, C.S.S. *Baffin* and C.S.S. *Dawson*, were retired from active service during 1991. Part of the *Baffin* workload will be taken up by C.S.S. *Matthew*, transferred from DFO's Newfoundland Region, while the *Dawson* will be replaced by C.S.S. *Parizeau*, to be transferred from DFO's Pacific Region in January 1992.

Publications

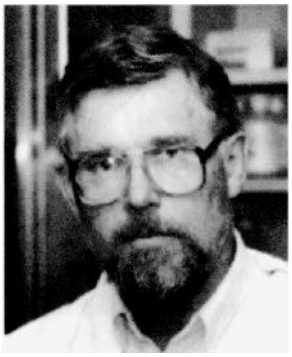
The establishments reach their respective clients and customers through a variety of means, including journal articles, reports, and nautical charts. During 1990 and '91, the published output of the establishments continued high. In particular, several books and atlases were produced. Full details are provided in the section of this ***Review*** entitled "Charts and Publications".



C.S.S. *Baffin and* C.S.S. *Dawson retired from service in 1991.*

Detecting the effects of marine pollution

R. F. Addison



R. F. Addison

Most of us think about pollution in terms of chemistry. We worry about the concentration of mercury in fish, or about the amount of DDT in sea birds. In the long run, however, we are not concerned so much about the absolute levels of these pollutants as about the effects that they produce. Will high mercury concentrations in fish be toxic to anyone who eats them? Or will high DDT concentrations prevent seabirds from breeding? Chemical information is only one step toward answering biological questions; we describe pollution in chemical terms only because we are better able to measure small concentrations of chemicals than the biological effects that they may cause. In other words, analytical chemistry is more advanced than toxicology.

That situation is changing. During the past 20 years or so, we have devised some very sensitive methods to detect subtle biological changes in organisms affected by pollutants; these approaches have become known as "biological effects monitoring". In this article I will outline some of these approaches and describe some results of their application.

In one sense, that of lethality, we have used biological-effects monitoring for a long time. Lethality provides a means to estimate the overall quality of industrial effluents; for example, if an effluent kills fish or some other test organism, then regulations may require that it be diluted to some nonlethal concentration. But the biological effect measured here - death - is not a useful indicator of the quality of lakes or the open sea. We need a measure of environmental quality that records a change long before organisms begin to die, and that is what many of the newer effects-monitoring methods provide.

We can think of biological effects as occurring at different levels of biological complexity. Some are biochemical effects, where an enzyme or a hormone changes in response to pollution. Other effects may occur in whole organisms, in populations or communities, or at other points on a continuum of biological organization. In practice, the most useful and sensitive responses involve biochemical changes, physiological changes within whole organisms, and changes in the structure of benthic communities. I will describe examples of each of these.

Measuring biochemical responses to pollution

One of the best biochemical measures of the effects of some organic contaminants is induction of the mixed-function oxidase (MFO) enzyme system in fish liver. MFOs in mammals were first described about 30 years ago by pharmacologists who were studying how drugs and other foreign compounds acted on animals. They found that some drugs were metabolized by an enzyme system induced by exposure to them. Normally, the enzymes were quite inactive, but if the animal were exposed to drugs or other foreign chemicals, the activity of the system increased dramatically to degrade and excrete the drug. Once it had rid the body of the compound, the system reverted to its usual low level of activity. In other words, this MFO system, as it came to be known, functioned as a sort of latent defence mechanism for the animal.

Many of the chemicals that induced MFO systems were pollutants, like polychlorinated biphenyls (PCBs) and polynuclear aromatic hydrocarbons (PAHs), so it seemed that measuring the activity of the MFO system would show the extent to which the animal had been exposed to these chemicals. During the last 20 years, we have done a lot of work to characterize the MFO systems in fish, and to define what chemicals induce them, how the induction process varies with exposure and dosage, and how induction is influenced by natural factors like the age of the fish and its sex and reproductive condition. As a result, we have "calibrated" the MFO response in a few species of fish and can use MFO measurements to indicate the sublethal effects of some marine contaminants.

A study of Sydney Harbour in Nova Scotia illustrates the kind of information we get from MFO measurements. This area has been contaminated by PAHs discharged during the last 90 years or so from the coking operation associated with the Sydney Steel Corp. (SYSCO). Figure 1 is a contour map of PAH contamination in the sediments of Sydney Harbour: there is a clear gradient of PAH concentrations (over a thousand-fold) from locations close to the Sysco steel plant down to the mouth of the harbour. Although the harbour is polluted, it supports a varied population of fish and other marine organisms.

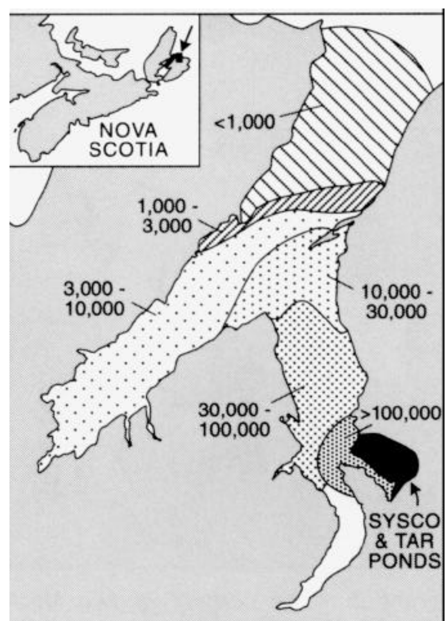


Figure 1. Concentrations (parts per billion) of polynuclear aromatic hydrocarbons (PAHs) in the sediments of Sydney Harbour.

In 1989 and '90, we measured MFO activity in winter flounder from various points around the harbour and from Georges Bay, a reference site chosen because there is no obvious source of contamination there. (We chose winter flounder as our test fish because they do not migrate very far, so they will usually be fairly representative of their environment. As well, they bury themselves in sediment and so maximize their exposure to sediment-bound pollutants.)

Figure 2 shows the activity of two MFO enzymes in these test fish: ethoxyresorufin O-de-ethylase (EROD) and cyanoethoxycoumarin O-de-ethylase (CN-ECOD). EROD and CN-ECOD activities in fish from Georges Bay were low, indicating the absence of any pollution there. As fish from Sydney Harbour were sampled from locations progressively closer to the steel plant, MFO activity increased along with the increasing PAH contamination in the harbour. The correlation between MFO activity and PAH distribution was not perfect for a number of technical reasons, but the general trend in MFO activity reflects PAH trends very well.

It is worth emphasizing that these results show a sensitive, sublethal response to PAH contamination. A cursory glance suggests that Sydney Harbour is not unhealthy, as it supports a varied community of marine organisms. A superficial examination of the fish suggested that they were healthy, and even chemical analysis of the fish did not show any PAH residues (because the MFO system had partially degraded them). But the induced EROD and CN-ECOD activity showed that exposure to PAHs in Sydney Harbour sediments was affecting the normal biochemical functions of the fish.

A biochemical change rather similar to MFO induction occurs in response to exposure to metals. Many organisms detoxify metals such as cadmium by producing a metal-binding protein called metallothionein (MT). Measurement of the concentrations of MT can be used to indicate exposure to metals in much the same way as MFO induction reflects exposure to organic contaminants such as PAHs.

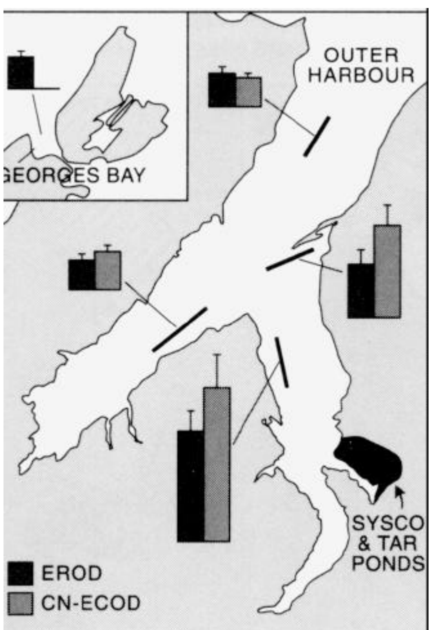


Figure 2. The activity of two MFO enzymes, EROD and CN-ECOD, in winter flounder trawled at various sites in Sydney Harbour. The height of the bars shows the extent of enzyme activity (mean ± s.d.).

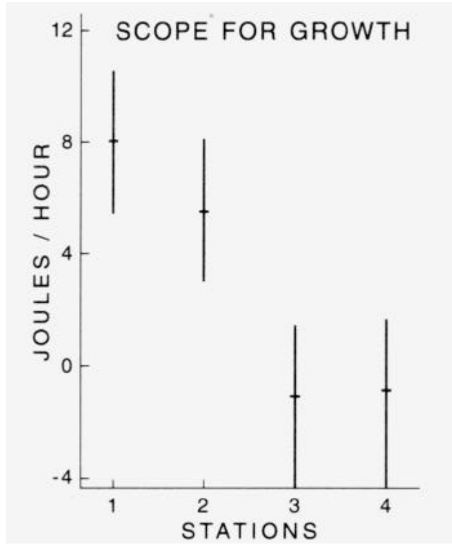


Figure 3. Scope for growth (SFG) in mussels from Stations 14 in Langesundfjord, Norway.

Measuring scope for growth

An effects-monitoring method which has been very useful at a higher level of biological complexity is the measurement of "scope for growth" (SFG) in mussels or other bivalves. SFG is a measurement of how bivalves use their energy, reached by calculating the amount of joules (or calories) they ingest, and how the absorbed energy is used for maintenance and for growth. SFG provides a fairly integrated measure of the quality of the environment in which the bivalves live. It responds to specific pollutants such as oil or metals, but also to general factors like food supply, temperature, and the oxygen content of water, which must be allowed for when interpreting SFG measurements.

Figure 3 shows some SFG measurements made in blue mussels taken from an industrialized fjord in Norway. The fjord had been contaminated by various chemicals, including PAHs, PCBs, and metals, with the highest concentrations of these occurring near the industrial sites at the head of the fjord and the lowest levels at its mouth (fig. 4). At sites 1 and 2, the least contaminated, the mussels were relatively healthy and actually gained energy during the six-hour course of the SFG measurement; this energy would eventually have been used for growth or reproduction. At sites 3 and 4, however, the mussels actually lost energy, as shown by a negative SFG, during the measurement period. The quality of the habitat at sites 3 and 4 was poor enough to cause the mussels to ingest and use energy much less efficiently than those from sites 1 and 2.

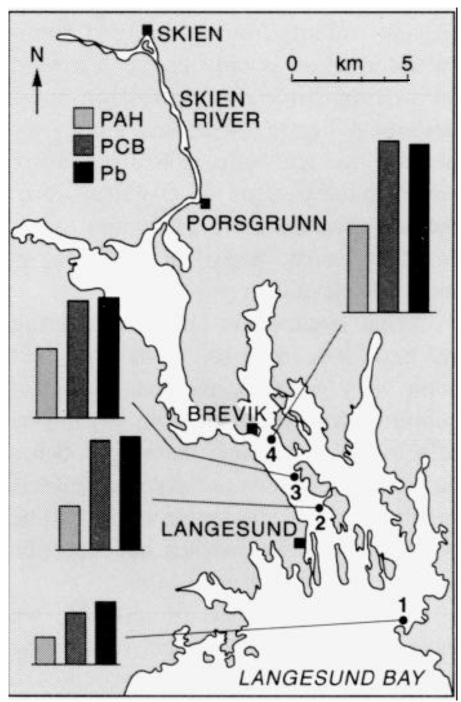


Figure 4. Map of Langesundfjord, Norway, showing relative concentrations (on different scales) of polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and lead (Pb) in mussels sampled from stations 14.

This could affect the long-term survival of mussel populations at sites 3 and 4. (If the mussels lost energy continuously in their natural habitat, they would eventually die. In this experiment, however, the negative SFG probably reflects the slightly artificial but standardized conditions under which SFG was determined.)

It is worth noting that SFG measurements do not identify a possible cause of a deterioration in environmental quality - unlike MFO induction, the response does not identify the cause - and the reduced SFG in mussels from sites 3 and 4 may result from the combined effects of several contaminants, rather from any one specific contaminant. Again, it is worth emphasizing that these SFG measurements showed a sublethal effect: mussels were obviously living at sites 3 and 4, but under more stressful conditions than at sites 1 and 2.

Measuring a community's health

The final general approach to detecting sublethal effects of contaminants is the application of modem statistical methods to data about the abundance and diversity of species. Healthy communities contain not only appreciable numbers of organisms (consistent with conditions such as food supply) but a variety of species. By counting the numbers of species present, and the number of organisms within each species, one can arrive at an index of the health of a community.

In marine research, this approach has been used most often with benthic communities, which are relatively stable. Usually, communities of benthic meiofauna (animals whose size ranges from 0.1 to 10 mm) and macrofauna (animals greater than 10 mm) are examined separately. Although the modern approaches are based on the same principles as the traditional diversity index approaches, they use powerful analytical procedures to extract more information from smaller data sets.

Studies of sediment communities in Hamilton Harbour, Bermuda, illustrate the value of these approaches. This harbour is not industrialized, but it receives some urban runoff from the city of Hamilton and so has slightly elevated levels of lead (probably from gasoline) and PAHs. There are also fairly high levels of tri-butyl tin (TBT), a component of marine antifouling paints, probably contributed by recreational sailing vessels.

Figure 5 shows sampling stations in Hamilton Harbour, whose sites were chosen because they are approximately the same depth and have sediments with approximately similar grain sizes, enabling these "nuisance" variables to be eliminated during comparisons of community structures. Figure 6a shows an analysis of the similarity of the structure of macrofaunal communities at these sites, as identified through an approach called multidimensional scaling. Essentially, the closer are the points on this plot (where each number represents one site and there are four replicate analyses of each site), the more similar are the sites. The structure of the benthic macrofaunal communities at sites 2, 6, and 7 (all of which are in the inner harbour) differs appreciably from that at site 5 (the outermost site) and, to a lesser extent, from sites 3 and 4.

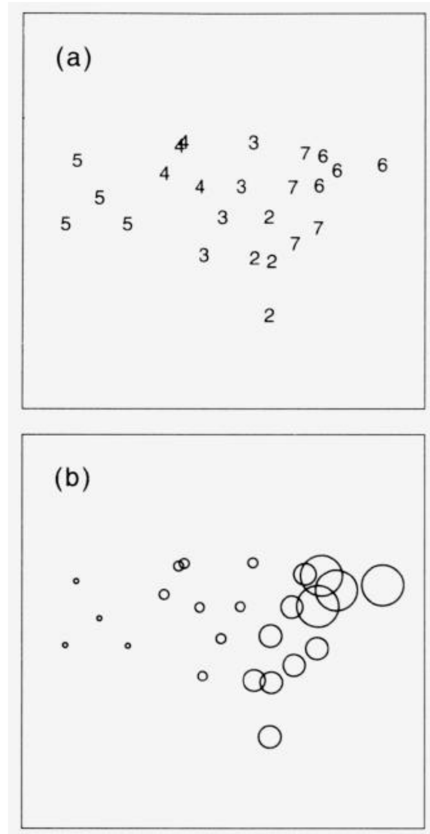


Figure 6. Two-dimensional representations of multidimensional scaling (MDS) plots, which show how closely any one station is related to any other station. (a) Benthic macrofaunal abundance at stations 2-7 in Hamilton Harbour, Bermuda, with four replicate analyses per station. (b) Tributyl tin (TBT) concentrations in the water column above sampling stations 2-7. The diameter of the circles is proportional to the concentrations of TBT.

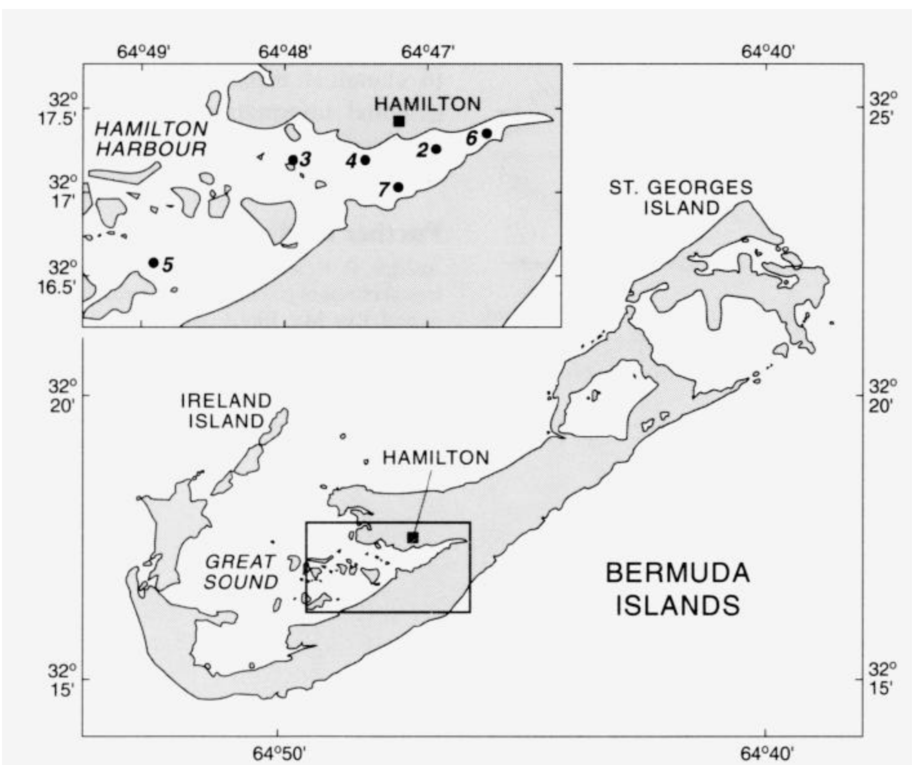


Figure 5. Sampling stations numbers 2 through 7 in Hamilton Harbour, Bermuda.

Figure 6b shows concentrations of TBT in the water at these sites, with the larger circles indicating greater concentrations of TBT. It is clear that sites 2, 6, and 7 are associated with high TBT levels in the overlying water, although this correlation does not establish a cause-effect relationship between TBT concentrations and changes in benthic community structure. Nevertheless, the data show the resolving power of these approaches, even between very similar sample types.

Conclusion

Modern effects-monitoring techniques of the sort described here can provide considerable insight into the subtle and sublethal effects of pollution. Each of the approaches I have described has some strengths and some weaknesses. Biochemical approaches, for example, are specific and sensitive, but difficult to interpret at the population or community level. For example, how does MFO induction affect the population of winter flounder in Sydney Harbour? At the other end of the scale, changes in the benthic macrofaunal community, such as those seen in Hamilton Harbour, show that an effect, albeit a sublethal one, has already been felt, possibly in response to TBT. This is useful information, perhaps for litigation or for subsequent regulation, but it does not allow any control or prevention of the identified problem.

These points are expressed more generally in figure 7, which shows that responses are related to biological complexity in such a way that sensitivity and specificity decrease with increasing complexity, and so does timeliness - the ability of these measurements to provide an early warning for control. On the other hand, the relevance to the real world increases. The choice of an effects-monitoring approach therefore depends very much on the problem being addressed; to monitor the possible effect of a specific contaminant, biochemical responses are probably the best choice, but a retrospective assessment of the impact of a sewage discharge may best be achieved through analysis of benthic community structure.

One final point concerns the mechanisms of these responses. Biochemical measurements are good indicators of the sublethal impact of pollution because we understand quite well the mechanism by which the presence of a chemical in the environment causes a biochemical response. Yet we do not understand these connections as well in the more complex responses; thus, we cannot explain in detail why SFG is lowered in mussels exposed to a mixture of industrial wastes. However, in situations where several effects-monitoring techniques have been used together, there have been good correlations between responses. Thus, in Hamilton Harbour in Bermuda, the sites at which biochemical responses showed the effects of contamination were the same as those at which SFG and community changes also indicated the effects of pollution.

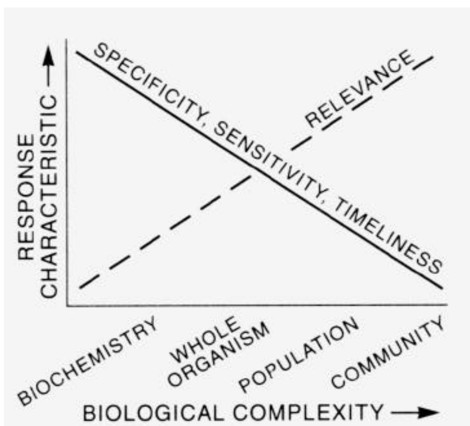


Figure 7. The sensitivity, specificity, and timeliness of biological-effects monitoring techniques in relation to biological complexity.

Although the links between responses at different levels of organization are not understood, the fact that they are correlated may have some predictive value. In other words, if we detect MT induction in fish from waters which are beginning to be contaminated by, say, a new industrial effluent, we can be reasonably sure that higher-order responses will occur in the future.

Where do we go from here with effects monitoring? Some of these techniques, especially those for MFO induction in fish, are already being used for environmental assessments. For example, during the last two years the North Sea Task Force Master Monitoring Plan (an attempt to monitor the overall state of the North Sea environment) has included EROD measurements as a complement to other measurements. The results of such programs will allow us to assess the value of these effects-monitoring approaches.

As a final point, however, I should emphasize that no one yet sees biological effects monitoring as replacing analytical chemistry as a way of assessing contamination. Instead, the measurement of biological effects is seen as a complement to chemical measurements, providing essential information to help interpret the significance of chemical data.

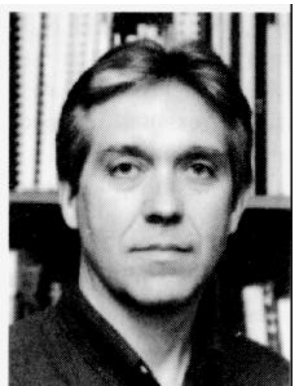
Further reading

Addison, R. F., and K. R. Clarke (eds.). 1990. Biological effects of pollutants in a subtropical environment. J. Exp. Mar. Biol. Ecol. 138: l-2.

Bayne, B. L., K. R. Clarke, and J. S. Gray (eds.). 1988. Biological effects of pollutants. Mar. Ecol. Prog. Ser. 46: 1-3.

Population energetics of seals on the Scotian Shelf

W. D. Bowen



W.D. Bowen

In many parts of the world, the interaction of marine mammal populations and fisheries is thought to be often detrimental to commercial fishing activities (Beddington, Beverton, and Lavigne, 1985). The central question is simple enough: do marine mammals reduce the yield of fish to fishermen? Conversely, is the recovery of an endangered or threatened marine mammal population adversely affected by current fishing practices?

On the Scotian Shelf, grey seals *(Halichoerus grypus)* and harbour seals *(Phoca vitulina)* likely interact with commercial fisheries in four ways: by interfering with the operation of gear or by damaging the fish caught in fishing gear; by transmitting the sealworm parasite *(Pseudoterranova decipiens)* to commercially harvested fish stocks; by directly feeding on commercial species; and by indirectly affecting the productivity of commercial species by feeding on their food.

To evaluate these interactions, the following information is needed: the number of seals in each age class; their distribution in different parts of their range at different times of the year; the species and weight of food they eat; how the types of prey vary at different times of the year; and the yearly energy requirements of individual seals of different ages. Finally, we need information on the seasonal distribution, abundance, and energy content of species eaten by seals, and on how the mortality caused by seals compares to other sources of mortality, such as predatory fish, seabirds, whales, man, and the effects of unfavourable ocean conditions. Given the nature of the above list, it is clear that seals and fisheries will interact in complex ways. In this essay, I present the results of recent studies on the energy requirements of seals, and the foods which are eaten in order to meet these requirements.

The distribution and abundance of grey and harbour seals have been studied by scientists in the Department of Fisheries and Oceans' Marine Fish Division of the Bedford Institute of Oceanography for more than 15 years. The main colonies for both species are located on Sable Island, although several small breeding colonies are located on islands along coastal Nova Scotia. About half of all the grey seal pups in Canada are born on Sable Island (Stobo and Zwanenburg, 1990), and since the early 1960s production of these pups on the island has been increasing at a compound rate of almost 13% per year (Zwanenburg and Bowen, 1990). Slightly more than 10,600 pups were born there in 1990. As a result of efforts to tag all of the harbour seal pups, we know that the harbour seal population on Sable Island has also been increasing, but less rapidly, at a rate of 3 to 5% per year since the mid 1970s (Stobo, unpublished). In 1991, 591 harbour seal pups were born.

Studies to monitor trends in population size are continuing, but since 1988 there have been increased efforts to provide a better understanding of the diets and energy requirements of both species. However, determining what and how much seals eat is difficult for several reasons. First, seals forage at sea and are often widely distributed both in coastal areas and on offshore banks (Stobo, Beck, and Home, 1990). Because it is usually impossible to directly observe seals feeding, information on seal diets is routinely derived from the analysis of the stomach contents of seals collected at sites where the animals haul out on land. Second, the rapid passage of food from the stomachs of grey seals (within about 6 hours) means that most stomachs are empty when collected, and those stomachs which do contain food probably represent feeding which occurred near shore. Thus, offshore feeding by seals is likely not represented in these samples. Third, because it is more difficult to hunt seals at certain times of the year, information is still not available for significant periods in all of the study areas.

Between September 1988 and December 1990, hunters contracted from communities along the Eastern Shore of Nova Scotia and Grand Manan Island collected the stomachs of grey and harbour seals in order to complement samples which scientists from the Marine Fish Division had taken from Sable Island. To estimate the type and weight of food items consumed, hard parts such as fish otoliths were recovered from the stomachs by passing the contents through a series of fine-mesh sieves and water baths. Recovered hard parts were used not only to identify the type of food eaten, but also to determine the size of prey on the basis of, for example, relationships between otolith size and fish length and between fish length and weight.

About 530 grey seal stomachs have been analyzed since the fall of 1988. However, only 143 (27%) of these contained food remains. Based on these limited data, it appears that grey seals feed primarily on juvenile fish, ranging from about 15 to 40 cm in length, depending on the species consumed (fig. 1). Grey seals summering off Anticosti Island also consumed primarily young fish, with the mean lengths of 5 species ranging from 14 to 28 cm (Benoit and Bowen, 1990). Thus, with a few exceptions (for example, spawning herring and silver hake), it appears that the fish eaten by grey seals are prerecruits to commercial fisheries (fig. 1).

Our studies also indicate that relatively few species, usually 3 to 5, account for most of the estimated wet weight of food consumed by grey seals in any one area or season. For example, only 4

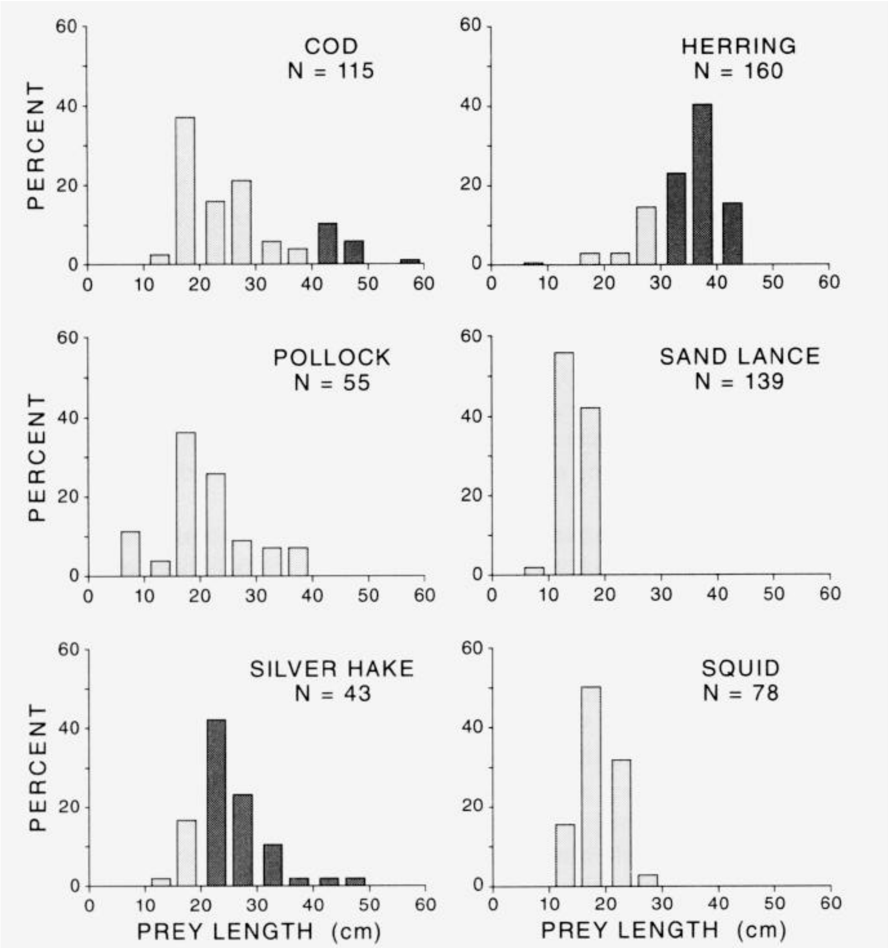


Figure 1. Estimated length of six prey species eaten by grey seals on the Scotian Shelf. Light hatched bars represent lengths which are not normally retained by commercial fishing gear, whereas the heavy hatched bars are commercial-size prey. N is the number of uneroded otoliths measured.

species accounted for about 90% of the mass of this food sampled at Sable Island in 1989. These were young cod, 26.5%; silver hake, 23%; squid, 22%; and sand lance, 19%. Similarly, grey seals collected at inshore sites along the Eastern Shore of Nova Scotia in the fall of 1989 fed mainly on herring (66% by weight) and young cod (18% by weight).

Although only a few species account for most of the weight of food consumed, as data from the Scotian Shelf illustrate, there is considerable seasonal, geographic, and interannual variation in the composition of grey seal diets. Seals taken on Sable Island in 1989, which presumably had been feeding offshore, consumed mainly sand lance (56% by weight) and young cod (36%) in winter, but ate silver hake (41%), squid (25%), and juvenile cod (21%) in summer. Inshore samples taken from the Eastern Shore of Nova Scotia in late summer consisted mostly of herring (66%) and juvenile cod (18%), whereas mackerel (47%), herring (9%), juvenile cod (14%), and squid (13%) were most important in winter.

These results illustrate the considerable variation in the relative importance of species eaten by grey seals. Although we are beginning to document the extent of this variation, we do not have sufficient data to explain its causes and hence to predict how diets will change in the future. However, because young fish are usually taken, variations in year-class strength could have marked effects on the species composition of the diet. In addition to this factor, it is likely that our present understanding of seal diets also suffers from a number of sources of bias (Benoit and Bowen, 1990).

Knowing what seals eat is necessary but not sufficient for evaluating interactions between seals and fisheries. We must also know the quantity of food consumed by seal populations. Population energetics is the study of how populations meet their energy requirements. In theory, energy needs could be determined by estimating the average meal size of an average-size seal from, for example, stomach contents, and multiplying this value by the number of meals per day, the energy content of the meal, and the total number of seals. However, in practice this approach is difficult, as was previously discussed. Another approach has been to estimate the quantity of food required to maintain captive seals at a relatively constant body weight, or to estimate the resting metabolic rate of captive seals. These estimates are then usually multiplied by a factor of two or three to account for the greater energy needs of wild seals.

Because data from captive animals may not be reliable when extrapolated to the wild, we have initiated studies on the feeding behaviour, food intake, and energy requirements of seals in their natural environment. These studies are now possible because of advances in electronics and computer technology which have led to the development of time-depth recorders (TDRs), and to developments in the analysis of low concentrations of stable isotopes of water and oxygen. TDRs are microprocessors capable of measuring and recording information about depth at timed intervals over the course of several weeks or months. These units, deployed on the seals' backs (fig. 2), can deliver detailed information about the proportion of time the animals spend at sea and the frequency and depth of their dives, and thus can measure their overall activity and foraging behaviour.

Stable (that is, nonradioactive) isotopes of water and oxygen have been used to study animal energetics for several decades (Nagy, 1989). However, until recently, their use in seals and other large mammals was limited by the high cost of high-enrichment ^{18}oxygen. The recent development of isotope-ratio mass spectrometers, which are 50 to 100 times more accurate and precise, has enabled the use of low-enrichment ^{18}oxygen and thus has lowered the cost to the point where isotopes can now be used to study grey and

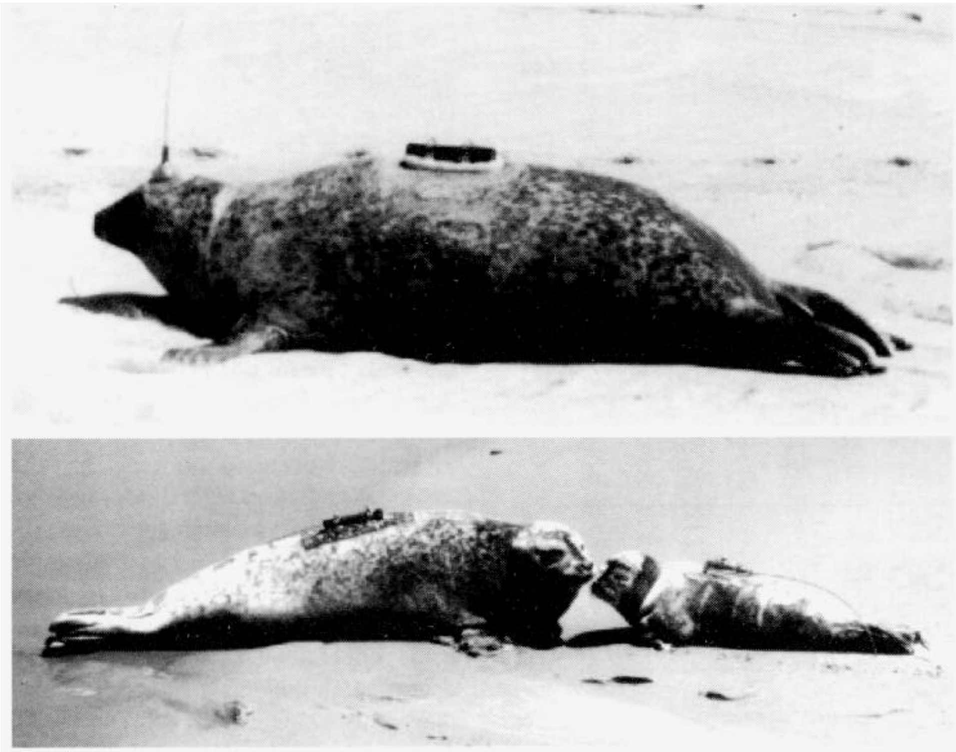


Figure 2. Two adult female harbour seals equipped with microprocessor-based time-depth recorder. The pup in the lower panel has been fitted with a radio transmitter.

harbour seals.

In the past three years, we have been studying the diving (that is, feeding) behaviour, food intake, and metabolic rate of adult female harbour seals during the breeding season on Sable Island. We chose these seals for several reasons. First, harbour seals on Sable Island are easily caught and recaptured at frequent intervals, enabling us to test methods of TDR attachment and to determine the appropriate isotope dosage for different kinds of studies. Second, the cost of conducting isotope studies on harbour seals is substantially reduced because they are smaller than grey seals. Third, we already had eight adult female harbour seals from Sable Island in captivity at Dalhousie University, and these could be used to validate methods we planned to use on wild seals.

In 1989 and 1990, with colleagues from the Smithsonian Institution in Washington, D.C., we deployed TDRs on 24 adult females, starting shortly after the birth of their pups and continuing for periods of up to 60 days. A typical pattern of diving behaviour is illustrated in figure 3. These studies show that the female spends most of the first week postpartum with her pup, either on land or in the sea. Females exhibit little diving during this period, and thus must support their own metabolic requirements and those of their pups from energy stored prior to giving birth. However, about 10 days after the pups are born, females begin to make foraging trips of several hours duration, as evidenced by the bouts of dives to 20 m or more. By late in the nursing period, foraging trips average 13 hours and females often reach depths of 60 m. During these sessions, each dive lasts about 2 minutes on average, with about 60% of this time spent at the sea bottom. Thus, for the first time we are learning how these marine mammals behave under natural conditions at sea. We now have enough experience with this technology that studies on the diving behaviour of grey seals are planned for 1992.

To estimate the amount of food eaten during the diving sessions, a subset of this group of adult harbour seals was administered a known quantity of deuterium oxide (D_2O), a stable isotope of water, when the animals were initially captured. After about 3 hours, the concentration of D_2O in the body water of the seal reaches an equilibrium and can be determined from a blood sample. Provided that certain assumptions are met, a plot of the natural logarithm of the concentration of D_2O over time can be used to estimate the turnover rate of body water (fig. 4) and thus the rate of water intake. Since seals do not normally drink, the isotope concentration will be diluted only by the intake of water in the food and by metabolic water production. If the water, fat, and protein content of the food are known, then it is possible to estimate food intake once the rate of dilution of the isotope is known (fig. 5).

Recently, we conducted feeding experiments using the captive harbour seals at Dalhousie University to test this approach. Each of 7 females was hand fed a known quantity of herring daily for 3 weeks and also given D_2O at the beginning of the experiment. In this way, the

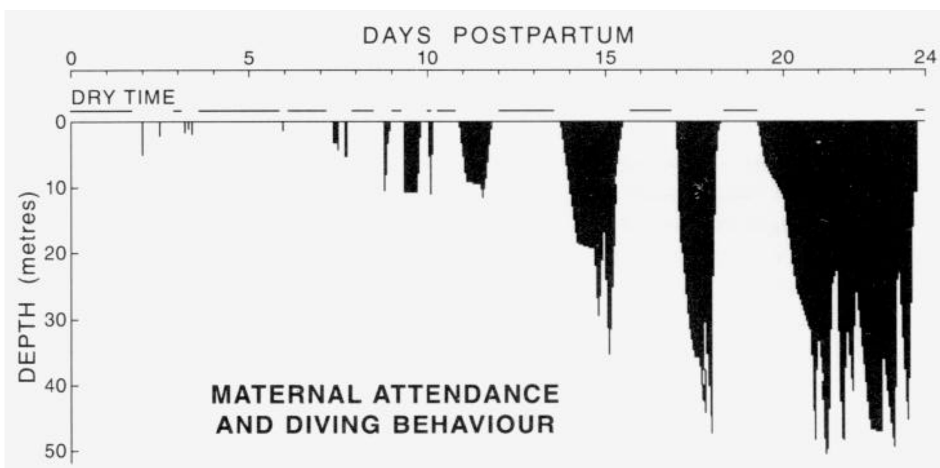


Figure 3. A diagrammatic representation of the type of data collected by the time-depth recorders. Although the instrument samples depth every 7 seconds, the data have been aggregated into I-hour blocks for ease of presentation.

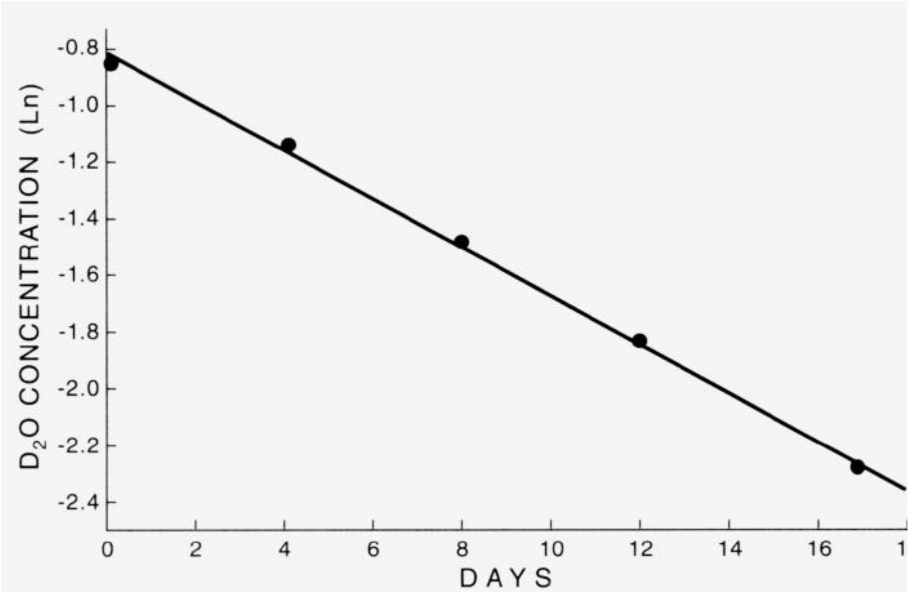


Figure 4. A typical plot of the natural logarithm (Ln) of the concentration of D_2O against time. The slope of the line is an estimate of the rate of water turnover. This rate, along with other information, can be used to determine food intake.

estimated food intake from isotope dilution could be compared to the known amount of food eaten by each female.

Figure 6 illustrates the results from one of these experiments. In all cases, the estimate of food intake derived from measurement of the isotope was greater than the known intake, but the mean overestimation was only about 12%. These results suggest that reasonable estimates of food intake of free-ranging seals are possible using this method. The food intake of wild females can be calculated from the difference between the water-turnover rate during fasting and the rate observed later during the lactation period (fig. 5).

As part of our long-term goal to determine the energy requirements of seals, we have also completed studies on the milk production of grey and harbour seal females. The lactation period is the most energetically demanding time of the year for all female mammals, with the greatest single cost being milk production. Shortly after giving birth, grey seal females on Sable Island weigh an average of 226 kg. Over the 16-day lactation period, during which they fast, about 47% of their body mass is lost in the course of meeting their own metabolic requirements and those of their rapidly growing pups. Using isotope dilution methods, we have determined that, every day, grey seal mothers produce an average of 4 kg of milk containing an average of 60% fat. Thus, grey seal pups consume 22,000 kilocalories a day - the equivalent of more than 9 litres of whipping cream, or 10 to 15 times the food energy that a person typically consumes in a day. Of this, the pups store 15,400 kilocalories, or 2.8 kg.

Although it is widely believed that adult seals have ravenous appetites, critical reviews of previous research suggest that the metabolic requirements of grey and harbour seals are about what one would predict for land mammals of similar body weight (for example, Lavigne *et al.*, 1986). In fact, recent studies by British scientists indicate that, during diving, the heart rate of grey seals falls dramatically (to only a few beats per minute), so that the overall metabolic rate of these diving seals is only marginally greater than an animal at rest. Also, we now know that seals dive for up to 80% of their time at sea, as a result of our studies on the diving behaviour of harbour seals, as well as British studies on grey and harbour seals and studies on several other species. Thus, the overall metabolic requirements of seals may turn out to be considerably lower than previously thought.

Given present uncertainties in our basic understanding of the diets and energy requirements of seals, we can make only rough estimates of how much food is eaten by seal populations on the Scotian Shelf. If metabolic rates are as low as recent work suggests, then current estimates of food needs, which are based on Kleiber's allometric relationship between metabolic rate and body mass, may be too high. Furthermore, food intake will also depend on the quality of food eaten. For example, if seals eat only lean prey, such as cod or squid, which have an

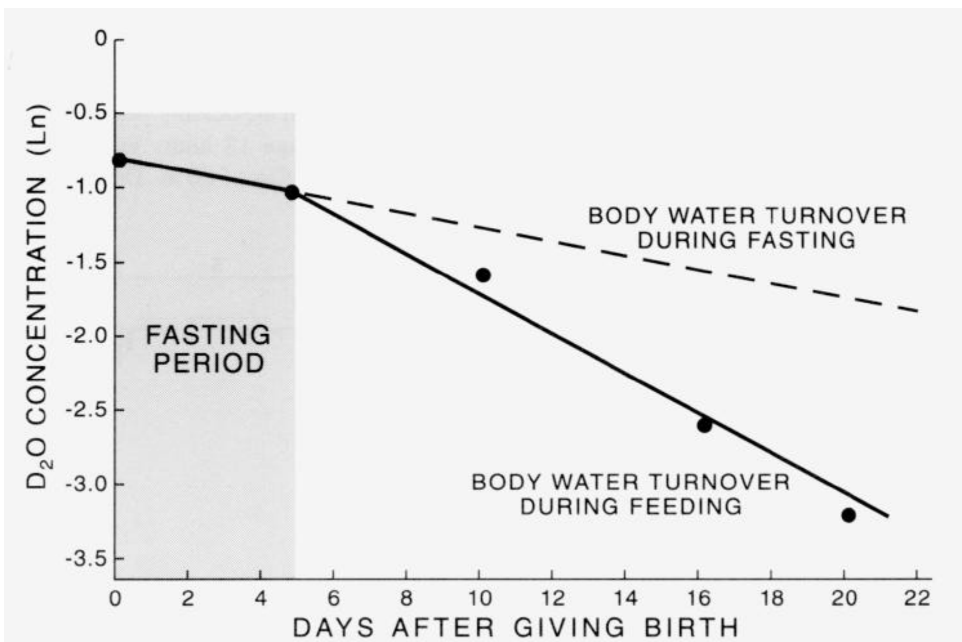


Figure 5. A plot of ln D_2O concentration against time during a period of fasting (shaded area) and during a period of feeding in a free-ranging adult female harbour seal on Sable Island. The difference between these two slopes can be used to estimate food intake.

average energy content of 1 kilocalorie per gram of wet weight, then they would need to consume about 2.5 times more food than that required on a high-fat diet of herring. This comparison illustrates the range of values that can result from different assumptions about even the energy content of the prey consumed, even though neither of these diets is likely to occur because seals consume a varying mixture of both fat and lean prey.

Our studies over the past 2 to 3 years show that seal diets vary according to place and season, and almost certainly over time as the availability of prey changes. This suggests that long-term research programs will be necessary if we are to reliably predict the diet and food consumption of seals and, ultimately, the impact of seal predation on commercial fisheries. We need to continue studying the diets and food requirements of seals in their natural environment. However, we must also determine the location of feeding areas and what fraction of seal populations use these different feeding areas. As part of this research, a study planned for 1992 will attach small (500 g) satellite transmitters to a number of adult grey seals. These transmitters will send positional data and diving information to the Argos satellite for periods of 8 to 12 months. In this way, we hope to significantly increase our understanding of the feeding ecology of seals and how seals interact with commercial fisheries.

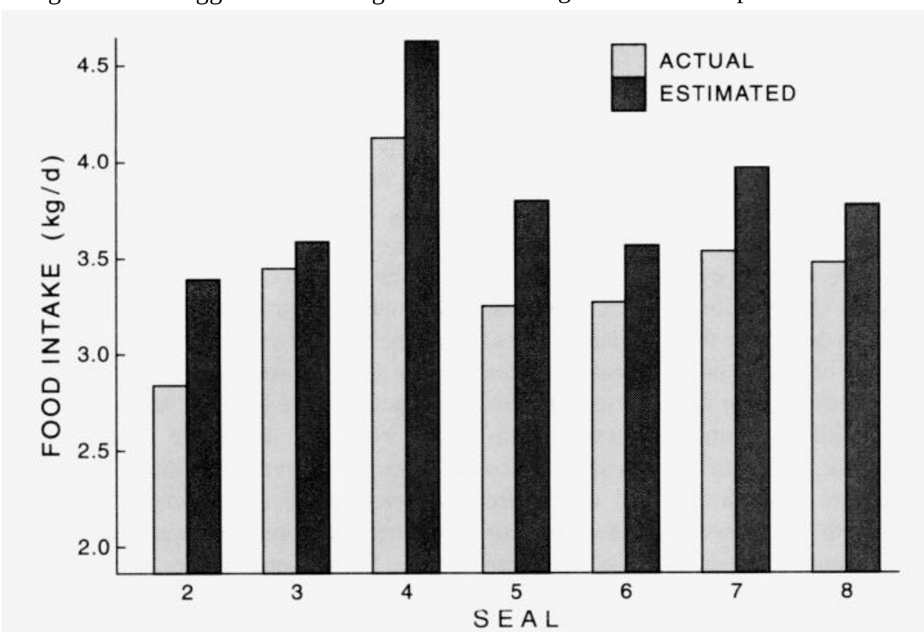


Figure 6. Comparison of actual and isotope-derived estimates of the food intake of seven adult female harbour seals in captivity.

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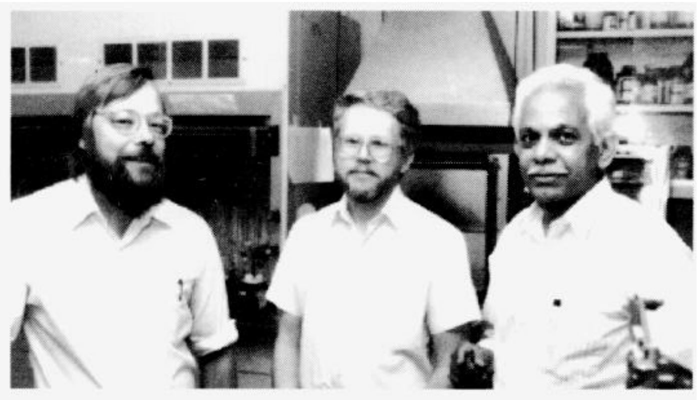
The phytoplankton profiling project

G. L. Bugden, D. V. Subba Rao, and P. A. Yeats



G. L. Bugden, P. A. Yeats, and D. V. Subba Rao

Shellfish poisoning has been a serious problem along the Canadian Atlantic coast, especially in the Bay of Fundy and the St. Lawrence Estuary. These poisonings are caused by eating bivalve molluscs, such as clams and mussels, that have accumulated toxins produced by certain dinoflagellates, a type of phytoplankton on which molluscs feed.

In late 1987 a unique shellfish poisoning occurred in eastern Prince Edward Island. Massive atypical blooms of a ubiquitous diatom *Nitzschia pungens f. multiseries,* another type of phytoplankton, were implicated. These phytoplankton produced domoic acid, a toxin which affects the central nervous system; this effect had not been recognized before. The domoic acid poisoning caused the tragic deaths of several elderly people. As well, it had an adverse effect on the mariculture industry in Atlantic Canada, through loss of consumer confidence.

At the time, detailed studies of the distribution of phytoplankton, including this diatom, did not exist for the Atlantic region. Consequently, the Department of Fisheries and Oceans sponsored a multi-laboratory, coastal phytoplankton monitoring program, with sampling in the St. Lawrence Estuary, Chaleur Bay, and the Gulf of St. Lawrence, and along the Atlantic coast of Nova Scotia and in the Bay of Fundy.

The sampling program along the Atlantic coast of Nova Scotia, undertaken by the Department of Fisheries and Oceans' Biological Sciences Branch at the Bedford Institute of Oceanography, was started in October 1988. The general approach was to establish the phytoplankton composition of selected inlets; that is, to determine the abundance, types, and time of occurrence of various species throughout the year for a period of three years. With this information, it was anticipated that it would be possible: 1) to determine what areas and times are favourable or unfavourable for shell or finfish aquaculture in terms of the presence of toxin-producing species; 2) to indicate times when screening for toxins should be intensified, assuming a consistent species succession could be established; 3) to provide background information for gauging whether observed phytoplankton distributions are normal, or whether changes in biomass and species diversity may be related to exceptional meteorological events, changes in the adjacent ocean, or human activity.

An important part of this project was the identification of the physical and chemical factors that can affect phytoplankton dynamics. Therefore, measurements of variables such as nutrient supply, turbidity, stability of the water column, temperature, salinity, and exchange with offshore waters were an integral part of the program. The knowledge gained about the physical and chemical dynamics of the various estuaries and inlets would also apply to such topics as aquaculture capacity, waste disposal, and recreation.

Five sites along the coast of Nova Scotia were chosen on the basis of their different physical characteristics, as well as their proximity to aquaculture operations. These were Tor Bay, Ship Harbour, St. Margarets Bay, Woods Harbour, and

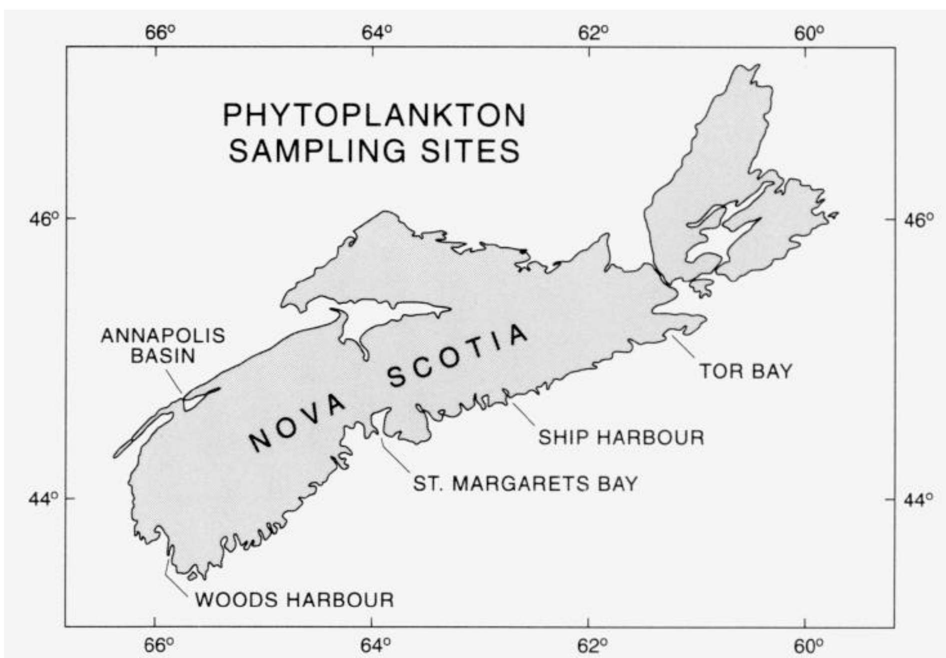


Figure 1. Phytoplankton monitoring sites along the Atlantic Coast of Nova Scotia.

Annapolis Basin (fig. 1). The differences in their physical - chemical environments resulting from their differing geography, tides, and freshwater input (table 1) were expected to be reflected in each site's phytoplankton populations.

The sampling schedule was fortnightly during the periods from October to December and March to May, monthly during January through March, and weekly during June through October. At some sites, ice caused sampling problems during the winter months.

At each location, detailed vertical profiles of light intensity, temperature, salinity, and fluorescence (an indicator of the amount of phytoplankton present) were obtained (fig. 2). In addition, water samples were collected at a depth of 1 m, at mid-depth, and just above the sea bottom, and were analyzed for nutrients (fig. 3), the abundance of phytoplankton species, and extracted chlorophyll. To monitor changes in the inlets over periods shorter than this sampling frequency was able to resolve, instruments which recorded water temperature every hour were moored at two depths at each of the sampling sites.

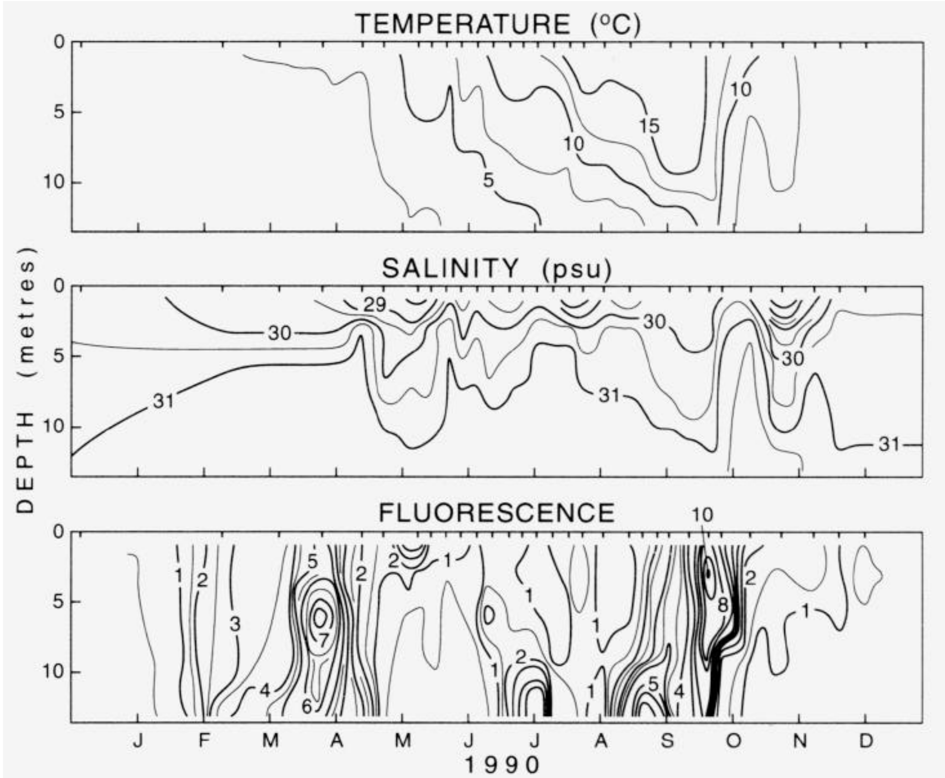


Figure 2. Time-depth contour plots of temperature, salinity, and fluorescence (a measure of phytoplankton biomass) at Ship Harbour in 1990. The upper tick marks indicate the times at which the measurements were taken.

Results

Phytoplankton distribution: In general, the annual phytoplankton cycle had two peaks of biomass: a major one in spring, and a minor one in the fall (fig. 2). There were regional differences in the timing and magnitude of these peaks. For example, in 1989 major peaks occurred between March and April at Tor Bay, between March and June at Ship Harbour and St. Margarets Bay, in March at Woods Harbour, and between April and June at Digby. Minor peaks occurred during October at Tor Bay, Ship Harbour, and St. Margarets Bay, between October and November at Woods Harbour, and in late September at Digby. During the peaks, the bulk of the phytoplankton consisted of diatoms. At all sites, phytoplankton were sparse during the winter.

More than 300 different types of phytoplankton were identified, and the distribution studied of 120 of these which are common to northwestern Atlantic waters. Diatoms, the microscopic algae which specifically require silicon to construct their skeletons, were the dominant

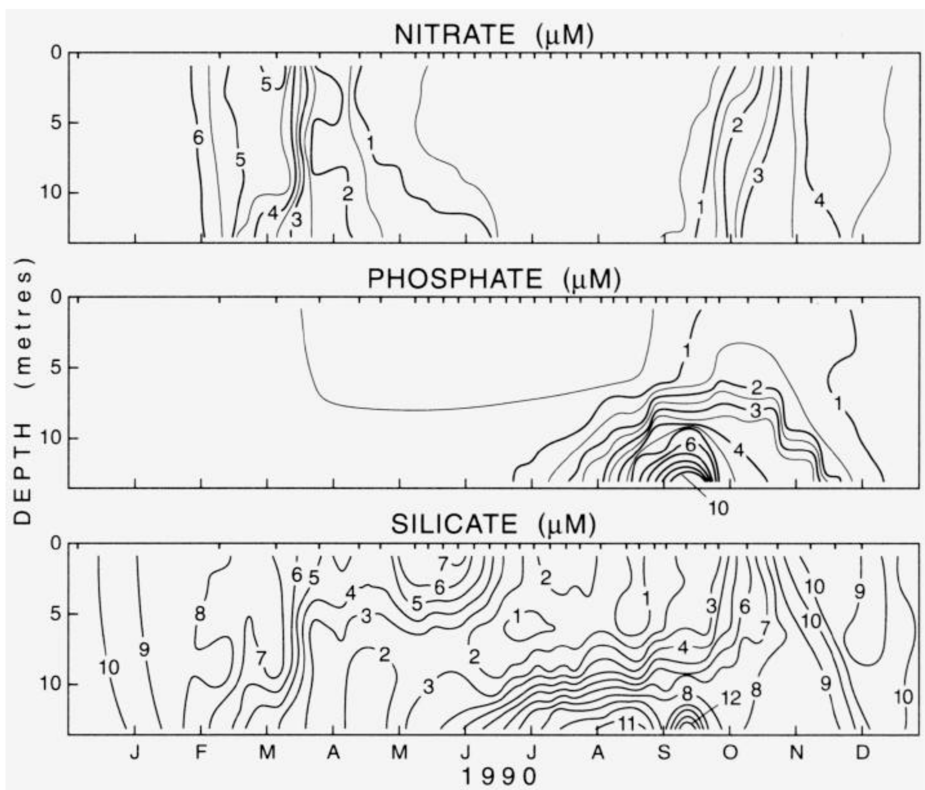


Figure 3. Time-depth contour plots of nitrate, silicate, and phosphate, the inorganic nutriants required for phytoplankton growth, at Ship Harbour in 1990. The upper tick marks indicate the times at which the measurements were taken,

group, represented by 96 types. Dinoflagellates were represented by 23 types. A variety of microflagellates (less than 10 microns) were abundant, but because of their fragility were difficult to identify.

Many phytoplankton known to be toxigenic elsewhere were observed at the sampling sites. However, none of them achieved concentrations high enough to be of concern. *Nitzschia pungens f. multiseries*, the diatom responsible for the poisonings in P.E.I., was present in small quantities at all sampling sites. It attained a maximum of 221 x 10^3 cells/litre at Woods Harbour and 66-125 x 10^3 cells/litre at the other stations. It was present year-round at Woods Harbour and most of the year at Digby, generally increasing from May through September. At the other three stations it appeared intermittently.

Dinophysis norvegica, D. acuta, D. acuminata, and *Prorocentrum micans,* which can be toxigenic species, were also present in small quantities at various times and places. *Alexandrium,* a toxigenic dinoflagellate known for its seasonal recurrence in the Bay of Fundy, was not observed in our samples.

Although there were no monospecific toxic blooms of algae at the five regular monitoring stations, blooms of the benign dinoflagellate *Gonyaulax digitale* and the toxigenic *Dinophysis norvegica* and *Prorocentrum micans* occurred at other locations in Nova Scotia during the study.

Table 1

Physical characteristics of phytoplankton monitoring inlets

	Tor Bay*	Ship Harbour	St. Margarets Bay	Woods Harbour	Annapolis Basin
Geometry					
Surface area at low water (km)	1.81	19.3	130	21.5	65.1
Mean depth at low water (m)	4.3	8.3	34	5.6	9.6
Station depth (m)	9	14	12	8	10
Sill depth (m)	none (some reefs)	6	none	none	none
Mean tides					
Nontidal volume (10^6 m^3)	7.72	161	4420	121	626
Tidal range (m)	1.3	1.4	1.6	2.6	6.8
Ratio of tidal to nontidal volume	0.29	0.17	0.05	0.50	0.84
Mean freshwater runoff					
Monthly maximum (m^3/s)	2.0 (Apr.)	34.0 (Apr.)	67.0 (Apr.)	2.5 (Apr.)	103.0 (Apr.)
Monthly minimum (m^3/s)	0.4 (Sep.)	7.5 (Sep.)	6.0 (Aug.)	0.6 (Aug.)	14.4 (Sep.)
Annual total (10^6 m^3)	33.7	578	836	49.2	1750
Ratio of average runoff over a tidal cycle to nontidal volume (x 10^3)	6.3	5.2	0.27	0.59	3.96
Environmental factors					
Pollutant source				fish plant	town, agriculture
Aquaculture	mussels	mussels	mussels, salmon, trout	mussels	none
Toxic episodes	none	none	none	DSP	PSP
Ice cover	solid	solid	little, variable	little	negligible

*Values for the Northwest Arm of Whitehaven Harbour only.

Physical-chemical environment: The five stations chosen for the project vary widely in their geography, tidal range, freshwater runoff, and aquaculture activity (table 1). For example, Woods Harbour and Annapolis Basin have the largest ratios of tidal to nontidal water volume, suggesting that tidal exchange is important at these sites. Annapolis Basin, Ship Harbour, and Tor Bay have comparable, relatively large ratios of freshwater discharge to nontidal volume, suggesting the potential importance of this driving force.

The annual range of temperature was greater at Tor Bay, Ship Harbour, and St. Margarets Bay, resulting in ice formation in winter (table 1). Summer temperatures at these three inlets were also higher than at Woods Harbour and Annapolis Basin. This suggests that a larger tidal exchange with the ocean moderates the temperature throughout the year at these two inlets.

Observations obtained from Ship Harbour in 1990 are shown in figure 2, as an example of the temperature-salinity cycles observed at the monitoring sites. In winter, Ship Harbour had subsurface water temperatures which were uniformly near 0°C. River discharge was relatively high, resulting in a fresher, lighter surface layer, the top of which froze to form an ice cover. The ice cover broke up and melted in late February and early March as surface heating increased and the inlet began to warm. Warming of the deeper layers lagged behind that of the surface.

River discharge was higher in the spring, and the entire water column gradually became fresher and warmer as heat and freshwater were mixed downward. Warming and freshening continued steadily through to early October, with some irregularities caused by variations in surface heating, river discharge, and exchange with outside waters. A major storm-induced event occurred in early October when the whole inlet was flushed with saltier, cooler water from the continental shelf. Toward the end of October and until early November, the inlet again became fresher as river discharge increased. Through December, the water column became uniformly cool as seasonal cooling and vertical mixing proceeded.

The nutrient distributions at all five sites varied in a manner that is fairly typical of temperate coastal waters. Concentrations of silicate, nitrate, and phosphate were high during the winter months, with substantial and rapid reductions occurring in the spring as the phytoplankton populations increased (fig. 3). This initial spring depletion of nutrients was generally followed by increased concentrations in late spring/early summer, and then by periods of variable duration when very low levels were observed. In the late fall, a return to the elevated wintertime concentrations was seen. The observed pattern was similar for silicate, nitrate, and phosphate, but complete removal essentially occurred only for nitrate. The nutrient concentrations were generally fairly uniform from surface to bottom at these rather shallow sampling sites. The exception was Ship Harbour, where marked vertical gradients were found for all three nutrients in summer and fall.

A comparison of the nutrient distributions at the five sites can be made using two indicators of nutrient dynamics (table 2). The first, nutrient concentrations during the winter months, gives a measure of the nutrient accumulation during the period of minimum biological activity. The second, the timing and extent to which nitrate levels were reduced to less than 0.1 micromolar (µM), indicates the amount of nutrients removed in the course of spring and summer biological activity.

Winter concentrations were substantially higher than those in spring and summer. Nevertheless, they were relatively low compared to winter levels in some other inshore areas, especially those with large industrial or sewage inputs. As a result of phosphate inputs from natural and human sources, nitrate to phosphate and silicate to phosphate ratios were low compared to those in offshore waters.

Winter concentrations at each of the five stations were surprisingly constant, varying little from one year to the next. There were, however, some significant station-to-station differences. The most noticeable were the relatively high concentrations of nutrients and the high nitrate to phosphate ratios seen at Annapolis Basin. This may be due to the predominance of agriculture in the surrounding area, and the resulting contamination of runoff with fertilizers. The major determinant of the nutrient input via freshwater is the ratio of freshwater discharge to estuarine volume; Tor Bay, Ship Harbour, and Annapolis Basin thus have by far the largest input of nutrients via freshwater (table 1).

Nitrate concentrations were reduced to less than 0.1 µM for at least one sampling period at each station each year. The timing of this nitrate reduction, and the duration of the period before levels in excess of 0.1 µM were again observed, varied significantly from station to station. The earliest onset and longest duration for the period with essentially no nitrate concentrations in the water column occurred in Tor Bay and St. Margarets Bay, and the latest and shortest period occurred in the Annapolis Basin, perhaps indicating the effect of larger freshwater discharge and differences in regional land use.

Table 2

Indices of nutrient dynamics

	Tor Bay	Ship Harbour	St. Margarets Bay	Woods Harbour	Annapolis Basin
Concentrations of winter nutrients					
Si (µM)	7.80	8.70	7.60	6.00	9.40
NO_3 (µM)	3.60	5.40	5.30	4.70	8.90
PO_4 (µM)	0.68	0.82	0.79	0.74	0.89
N : P	5.30	6.60	6.70	6.40	10.00
Si : P	11.50	10.60	9.60	8.10	10.60
Nitrate level <0.1 µM					
Onset	June/July	July	June/July	July	July/Aug.
Length (weeks)	13	10	14	3	1

Note: Si = silicon; NO, = nitrate; PO, = phosphate; N = nitrogen; P = phosphorus.

The most fascinating station from the perspective of nutrient chemistry is Ship Harbour, where extremely high concentrations of silicate, phosphate, and ammonia, another nitrogen-containing nutrient, were seen in the bottom waters in late summer and fall. This is probably a result of both the geometry of the inlet and the large freshwater discharge. Ship Harbour has a shallow sill at the entrance which to a certain extent prevents the free exchange of the deeper waters in the inlet with shelf waters. The large freshwater discharge results in a fresher, lighter surface layer, which limits vertical mixing, again isolating the deeper waters.

The silicate, nitrate, and phosphate distributions for 1990 in Ship Harbour are shown in figure 3. Extensive measurements of ammonia were not made in 1990, but the results for 1991 showed that elevated bottom-water concentrations of phosphate were accompanied by elevated ammonia concentrations.

Fluorescence, which is a measure of phytoplankton biomass, is shown in figure 2. The fluorescence was low in winter and increased during the spring bloom in late February, remaining high until late April, when it decreased to levels which are as low as those found in winter. The low values were maintained in the surface waters from early May to early September and in the bottom waters from early May to early July. Nitrate concentrations were high until late March and then decreased through April and May, remaining below 0.1 µM from July 4 to September 25 in the upper water column and from July 10 to August 7 in the bottom waters.

Ammonia, phosphate, silicate, and fluorescence increased in the bottom waters starting in early July. The nutrients were presumably released by the decomposition of biogenic debris on or in the sediments, and the increases in fluorescence resulted from increased biological productivity stimulated by the increased nutrient levels. By late September, fluorescence, phosphate, and silicate were elevated throughout the water column as vertical stratification was reduced and the fall bloom occurred. In mid-October, the high fluorescence throughout the water column and the nutrients in the deeper water were reduced rather abruptly as the whole bay was flushed by denser, cooler shelf waters.

Further work

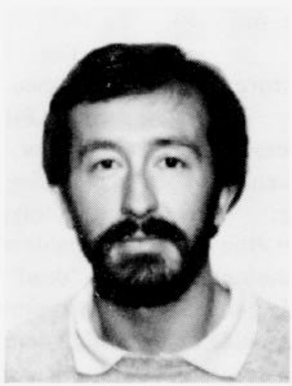
The Phytoplankton Profiling Project has identified the major phytoplankton types in five inlets in Nova Scotia. An extensive suite of complementary biological, physical, and chemical data has been gathered from the five dynamically different sites. A first look at the interaction between the oceanographic environment and phytoplankton dynamics at one site has shown some interesting interrelationships which may be typical of inlets with similar physical characteristics. In the future, we hope to analyze more fully the unique physical-chemical environment in each of the inlets and its effect on the phytoplankton populations. The reasons why toxic blooms occurred at some locations and not at others will also be explored. It is hoped the results will have a wider application to different problems in inlets with characteristics similar to those of the five inlets studied.

Development of a Canadian ocean mapping system

G. Costello, D. Peyton*, and G. Lebans**

(*Geo-Resources Inc. **Brooke Ocean Technology Ltd.)

G. Costello



D. Peyton

G. Lebans

The Canadian Hydrographic Service, in cooperation with the academic and private sectors, has developed a unique ocean mapping system by integrating the SIMRAD EM100 multibeam sounder with the Autonomous Underwater Vehicle (AUV), DOLPHIN.

DOLPHIN is a semi-submersible AUV developed in the mid-1980s for the Canadian Hydrographic Service (CHS) by International Submarine Engineering Research Limited (ISER). DOLPHIN's intended use was to conduct offshore hydrographic surveys in a multi-DOLPHIN and mother-ship configuration. During five years of trials, DOLPHIN has proved to be an excellent operational platform, and several sensors in addition to echosounders have been successfully deployed on the vehicle.

The need for a systematic ocean mapping program in Canada was recognized in the Oceans Policy for Canada announced by the Minister of Fisheries and Oceans in 1987 (DFO, 1987). One component of the new policy called for the development of a contracted-out ocean mapping program to collect hydrographic and geophysical data.

In response to this policy, a proposal

Canadian Ocean Mapping System - COMS

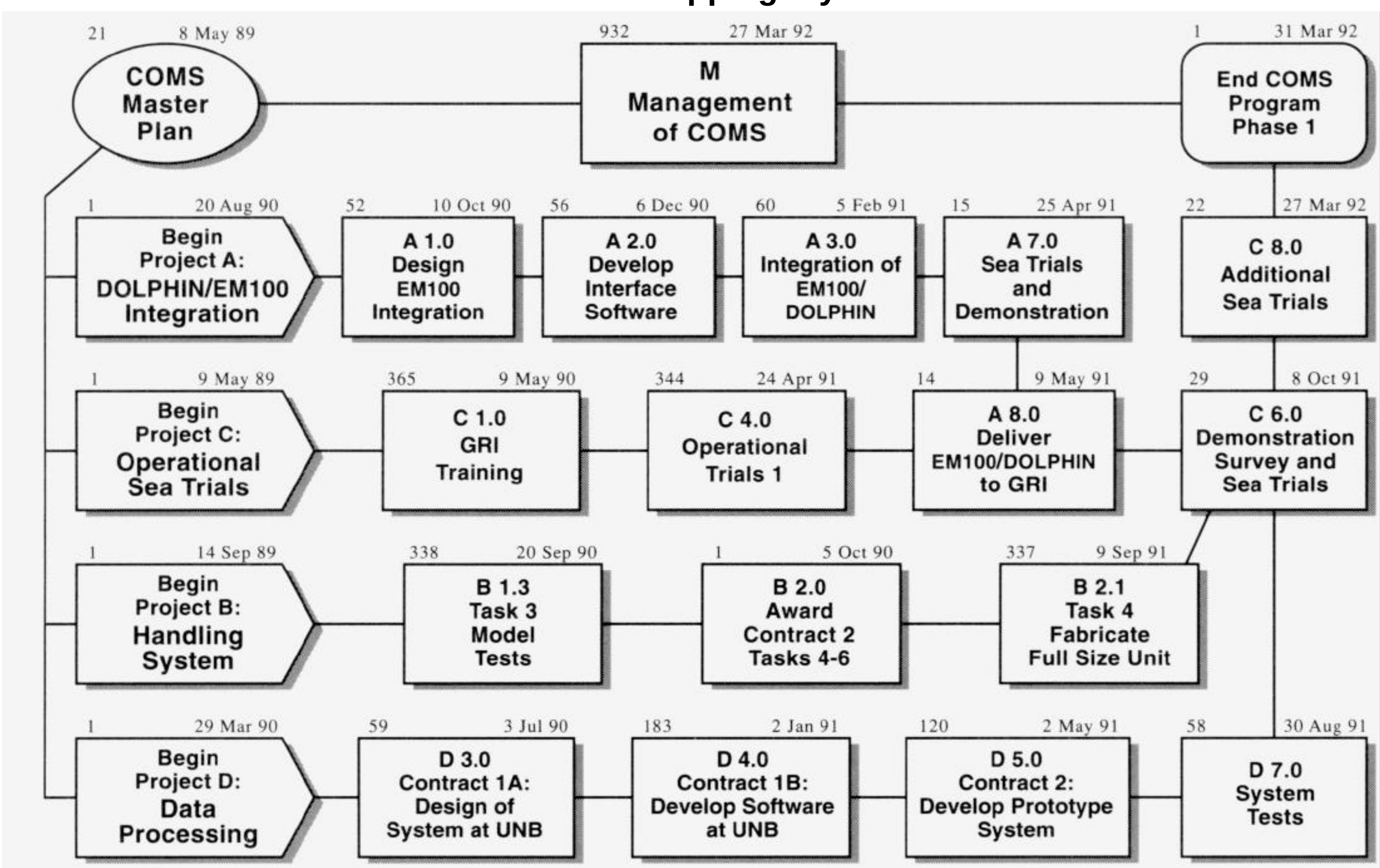


Figure 1. COMS Master Plan. This is a generalized version of a detailed schedule chart prepared for COMS project management.

was submitted to the Department of Fisheries and Oceans (DFO) in 1988 by four private companies, led by Geo-Resources Inc. of Newfoundland. They proposed to integrate existing technology within government and industry and to complete the necessary research and development to produce an operational ocean mapping system. Initially there were three projects; a fourth, Data Processing, was added to have a complete production system. The final DOLPHIN/EM 100 program consisted of four projects involving several companies:

- DOLPHIN/EM100 Integration: ISE Research and Simrad Mesotech, Vancouver, B.C.;
- DOLPHIN Launch and Recovery System (Atlantic Arm): Brooke Ocean Technology, Dartmouth, N.S.;
- Operational Sea Trials: Geo-Resources Inc., St. John's, Nfld.;
- Data Processing System: Ocean Mapping Group at University of New Brunswick, and Universal Systems Ltd., Fredericton, N.B.

These projects were grouped into a single program over three years with a common management team. The program became the Canadian Ocean Mapping System (COMS) and a Master Plan was established for project management. COMS began in May 1989 and was successfully completed in May 1992.

COMS project management

Because the COMS program involved several projects and organizations, a comprehensive Master Plan, which included an organizational structure and a schedule chart, was prepared to ensure coordination and completion of the projects (fig. 1).

The organizational structure consisted of:

- DFO senior management: responsible for overall program management including the allocation of funding;
- steering committee: responsible for reviewing and approving planning and contract documents, and general guidance of the projects, and made up of technical personnel;
- project manager: responsible for planning and coordination of all the projects and contract management;
- four project teams: responsible for detailed project plans and completion of the deliverables according to contract specifications.

The schedule chart outlines the individual projects and their major tasks and shows the relationship between all the projects. This schedule was based on the proposal from the private companies, with modifications to reflect changes before work commenced. This *deliverable-based structure* was well suited for the COMS program, as each project team was responsible for a well-defined deliverable. Although the projects were exclusive in that they had separate teams, they were also interdependent; in particular the success of Project C, Operational Sea Trials, was very dependent on the success of the other three projects.

The objectives for COMS, clearly established at the outset, were as follows:

- a DOLPHIN with an EM100 multibeam sounder operational in survey mode, including navigation and data logging;
- a prototype DOLPHIN handling system, capable of launch and recovery of a live or 'dead' DOLPHIN in sea states up to 6;
- an improved data processing system for high density bathymetric data.

About DOLPHIN

DOLPHIN is an acronym for Deep Ocean Logging Platform with Hydrographic Instrumentation and Navigation. The DOLPHIN concept was conceived in 1982 following renewed efforts to increase productivity in offshore hydrographic surveying, at the same time minimizing the risk to humans under the strenuous working conditions in open seas (Dinn *et al.*, 1987).

The first DOLPHIN was delivered in 1983; its primary purpose was the technical evaluation and proof of its concept. The first sea trials demonstrated that the vehicle could be used as a hydrographic sensor platform having superior stability and hydro-dynamics (Malone *et al.*, 1984).

In 1984 hydrographic instrumentation was also successfully installed and tested. Analog echo sounding and Loran C positioning data were telemetered from DOLPHIN and logged on the mother ship (Malone *et al.*, 1984).

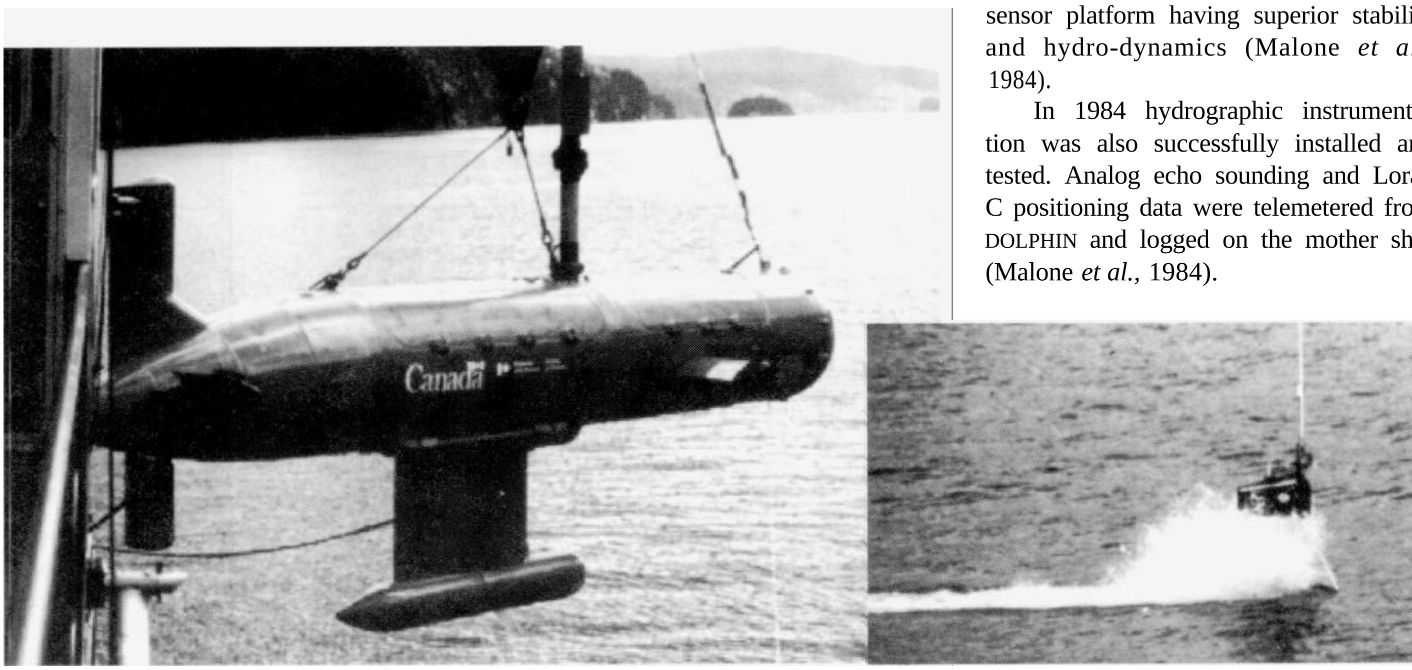


Figure 2. DOLPHIN has a 7 m long aluminum hull with a lead keel for stability. It is powered by a diesel engine and can cruise at 12 knots about 4 m below the surface.

From 1985 to 1987 efforts concentrated on improving the hydrographic operations and developing a launch and recovery system. The hydrographic operations progressed well (Lamplugh, 1986), but the launch and recovery system did not. Following unsuccessful sea trials in 1987, there was a period of retrenchment; in 1989 the DOLPHIN project within CHS was renewed under the broader COMS initiative, emphasizing greater private sector involvement.

The DOLPHIN hull is constructed of marine grade aluminum and is 7 m long by 1 m diameter. A 212 horsepower diesel engine supplies power for propulsion, hydraulics and electronics. DOLPHIN can cruise at 12 knots with a maximum speed of 16 knots (fig. 2). A microprocessor-based active control system controls the vehicle's hydrodynamics and maintains its stability in roll, pitch, heading, and depth. The reader is referred to the many published papers, some of which are listed in the references here, for more details on DOLPHIN design and previous sea trials.

COMS Project A: DOLPHIN/EM100 integration

Project A involved the design, development and integration of the EM100 multibeam sounder in DOLPHIN. A multibeam sounder developed by Simrad Subsea, Norway, the EM100's main components include a transducer, transceiver/preamplifier, operator console and quality assurance unit. Its bottom coverage is up to 2.4 times water depth across track (100° angle), with 32 narrow beams and a 3° beam angle in the along track direction. It operates at 95 kHz and has a range from 10 to 600 m depth.

Two main technical problems were faced in this project: how to physically accommodate the EM100 transducer and the transceiver/preamplifier electronics in DOLPHIN, and how to handle the increased data rate from the EM100 required to be telemetered to the mother ship. Both of these were easily solved following design modifications to DOLPHIN.

The transducer, because of its relatively small size (about 50 cm x 100 cm) and a radius of curvature almost the same as the DOLPHIN hull, fits well in the forward compartment. The transducer is aligned and rigidly mounted with no mechanical pitch correction, and can be easily removed and replaced by another transducer if desired. The nose of DOLPHIN is attached to the hull by a bolted flange and can be removed for servicing (fig. 3).

The transceiver/preamplifier electronics and power supplies are repackaged in splash-proof aluminum boxes, designed to dissipate heat effectively through electric fans, black heat sink fins, and paste on the floor of the compartment.

The existing RMS radios were replaced with Dataradio Asynchronous Packet Radios, which provide the capability to multiplex up to 5 separate serial data streams onto one radio channel; configuration is straightforward, and the level of ongoing software effort is reduced. In addition, the Surface Network Computer on the mother ship, no longer required, was removed from the system (ISER, 1991). In shallow water, at a maximum of 3 pings per second, the EM100 data rate is about 4400 bits per second. With the 9600 baud radio link, about 15% of radio usage is required for vehicle control, leaving a sufficient 85%, or about 8000 bits per second, for the EM100 sounder and positioning data. Good data throughput is estimated to be 98% with the Automatic Repeat Request (ARQ) function enabled (Dinn, 1991).

Some new sensors were also installed in DOLPHIN, including a Robertson gyrocompass, a Watson motion sensor package and a heave meter, required for vehicle dynamics, and to supply accurate heading, heave, roll, and pitch data to the EM100. Later, during final sea trials in Newfoundland, it was determined that the Watson sensor did not meet specifications; it was replaced by a TSS 335 motion sensor.

Following integration and bench testing, sea trials were carried out near Vancouver. A small survey area was successfully completed to demonstrate the functionality of the system. Following this the DOLPHIN/EM100 was shipped to BIO for testing with Brooke Ocean Technology's Handling System, then to the DOLPHIN shore base in Newfoundland for operational sea trials with Geo-Resources.

COMS Project B: DOLPHIN handling system

Project B involved the design, model testing and then the fabrication of a full size unit of a DOLPHIN handling system. Brooke Ocean Technology (BOT) was responsible for installing the handling system on a ship, and then delivering it to Geo-Resources for operational sea trials. The general requirements for the handling system were as follows:

- portable and adaptable to vessels of opportunity;
- must be capable of launching and recovering DOLPHIN in sea states up to 6, corresponding to average wave

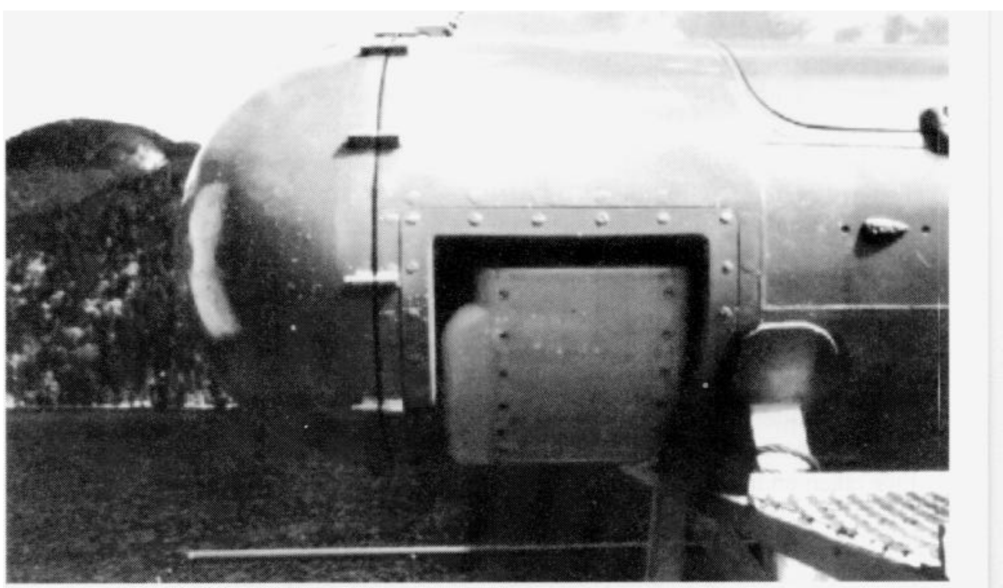


Figure 3. During the EM100 Integration project, the curved transducer fitted well into the DOLPHIN hull and the nose is now removable to permit servicing.

heights of 4 to 6 m and wind of about 35 to 40 knots in open sea;
- capable of being remotely operated, without the need for a person in the water.
- capable of handling multiple DOLPHINS, with a minimum of three vehicles to be operated simultaneously;
- capable of recovering disabled or 'dead' DOLPHINS.

The project was carried out in two phases. Phase I covered the design of concepts and model testing, and Phase II involved the fabrication of a full size system, and its testing during operational trials.

During Phase I, five concepts were evaluated; two were selected for model testing and one, the Centre of Gravity (CG) Lift, was selected as the most suitable to meet the requirements. The CG Lift concept, or "Atlantic Arm" as it became known, was fabricated and sea trialed during Phase II of the project. Details of these concepts can be found in BOT's Phase I contract report (Brooke Ocean Technology, 1991).

The five concepts included:
- Mast Lift: a side recovery system with a single point pick-up at the mast head, using a motion compensated crane and a clamping assembly around the hull of DOLPHIN;
- CG Lift: a side recovery system that evolved as a variation of Mast Lift, with a single point pick-up near the DOLPHIN's centre of gravity using a motion compensated crane and a snubber assembly. A tow cable was attached to stabilize the DOLPHIN during hoisting;
- Ramp System: could either be a side or a stern system, with the DOLPHIN guided onto the ramp and then taken up to the ship's deck. This concept was similar to ISE Research's ramp concept and the UK GLORIA system;
- Scissors: could be a side or stern system, with the DOLPHIN guided into an underwater motion-compensated scissors-shaped mechanism and then taken on board with a crane;
- Docking Garage: could be a side or stern system, with the DOLPHIN manoeuvred into a submerged rectangular frame and hoisted on deck using a motion compensated crane.

Following a detailed analysis of each concept, the Mast Lift and CG Lift were identified as systems that appeared to meet the required criteria, and were further evaluated with model testing. The other three were eliminated.

Model seakeeping tests were conducted at the Ocean Engineering Research Centre at Memorial University in Newfoundland, to observe vessel response at various headings in sea state 6. Towed and moored tests were conducted in sea state 6 in the water tank. The results showed that large, and at times violent, pitch and yaw motions were continually experienced; the rolling motion was not as severe. This re-affirmed the decision to eliminate the ramp, scissors, and docking garage concepts, and to proceed with the two side recovery, single point pickup concepts.

Two radio controlled models of DOLPHIN and an electro-pneumatic model crane were fabricated at approximately 1/6 scale. The crane was installed on an 11 m fishing boat for the model trials. Following a series of model trials in Halifax Harbour the Mast Lift concept was eliminated, primarily because of the potential for damage to DOLPHIN during hoisting and the magnitude of the modifications to DOLPHIN required to permit lifting at the mast head.

Model tests continued with the CG Lift concept; following several design changes the following recovery procedure evolved:
1. Ship underway at 4-5 knots, about 30° off the significant sea or wind to give some lee on the recovery side;
2. DOLPHIN manoeuvred alongside in position about 8 m from the ship's hull (fig. 4a);
3. DOLPHIN's tow cable remotely latched to the towing boom (fig. 4b);
4. DOLPHIN winched forward of the crane;
5. CG Hook latched remotely to the CG lifting frame on DOLPHIN (fig. 4c);
6. Hoisting cable placed in constant tension mode;
7. DOLPHIN hoisted, tilted nose down at about 20° and with the tow cable tensioned to minimize pendulum motion (fig. 4d);
8. DOLPHIN secured within the snubber (fig. 4e);
9. Locking plates engaged, and brakes locked on the swing frame;
10. DOLPHIN swung over the deck and into the cradle.

The launching procedure is more or less the reverse order of recovery.

A disabled or 'dead' DOLPHIN is initially retrieved using the First Line ATTachment System (FLATTS). FLATTS consists of a projectile and a spool containing a tag line and sea anchors, all mounted in the nose of DOLPHIN. When DOLPHIN is disabled, and following a certain sequence of events, the projectile and attached tag line are fired from DOLPHIN's nose using compressed air. The tag line floats on the surface; the DOLPHIN streams downwind with the aid of the sea anchors; and the tag line is retrieved from the mother ship. DOLPHIN is then taken under tow from the towing boom, and a normal recovery is completed, starting at step #3 above.

Once this CG Lift concept had been successfully demonstrated during model trials, a full size system was fabricated in Phase II of the project. The main components of the system include (fig. 4):
- articulated marine crane with self-contained electro-hydraulic power unit. A Seattle marine crane, model MCK-1837, was selected to meet the requirements;
- capture mechanism consisting of a swing frame and snubber. It serves to guide and eventually lock DOLPHIN in place once hoisted;
- constant tension winch for hoisting and lowering DOLPHIN;
- towing boom assembly, with tension-limiting system to minimize line surges when DOLPHIN is under tow;
- deck cradle with tilting mechanism;
- remote latching equipment for initial attachment of the tow cable and the CG hook to DOLPHIN;
- FLATTS, the First Line Attachment System for retrieving 'dead' or disabled DOLPHINS.

Except for the crane and winch, all the components were designed and fabricated in Dartmouth. The complete system was assembled and tested on the wharf at BIO. Once the ship was selected, final modifications were made and the system was installed on board ready for sea trials.

COMS Project D: data processing system

Project D developed a data processing system to handle more efficiently the high density data sets collected by acquisition systems such as the SIMRAD EM100 and Navitronic MCS-1B. Existing processing systems that involved generalization or gridding techniques were not acceptable to nautical charting organizations such as the CHS, which require strict point data integrity for the safety of navigation. Following a study completed by the University of New Brunswick (UNB) Ocean Mapping Group in 1988, the CHS adopted its recommended approach, which called for the development of new algorithms with hydrographic criteria combined with interactive graphics and visualization tools. UNB selected Universal Systems Ltd. (USL) as their industrial partner to commercialize the software package.

The concepts of "cleaning" point data and retaining measured data were fundamental to the software package. Statistical analysis tools and automatic and interactive cleaning tools were developed by the UNB Ocean Mapping Group (Ware *et al.*, 1991) as part of the Hydrographic Data Cleaning System (HDCS) (fig. 5). These tools were combined with USL's CARIS visualization software, and packaged as a commercial product called the Hydrographic Information Processing System (HIPS).

During processing, data from the acquisition system is loaded in HDCS where it is cleaned. This includes correcting the data for tides and various sensor offsets, navigation editing, generating various statistical surfaces, and automatic (algorithmic) and interactive editing of soundings. Once cleaned, the data can be passed on to a source database, or to the visualization software for generating various surfaces such as digital terrain models, 3D perspectives, field sheets, contour maps, profiles and volumes (fig. 6).

HIPS has the following features:

- rigid adherence to software and user interface standards such as X-windows and Motif;
- a generic data structure to accept data from a variety of ocean mapping systems;
- retention of all measured data, without thinning of the data;
- fast, automatic algorithms and statistical surfaces. This "power tools" approach can quickly highlight possible

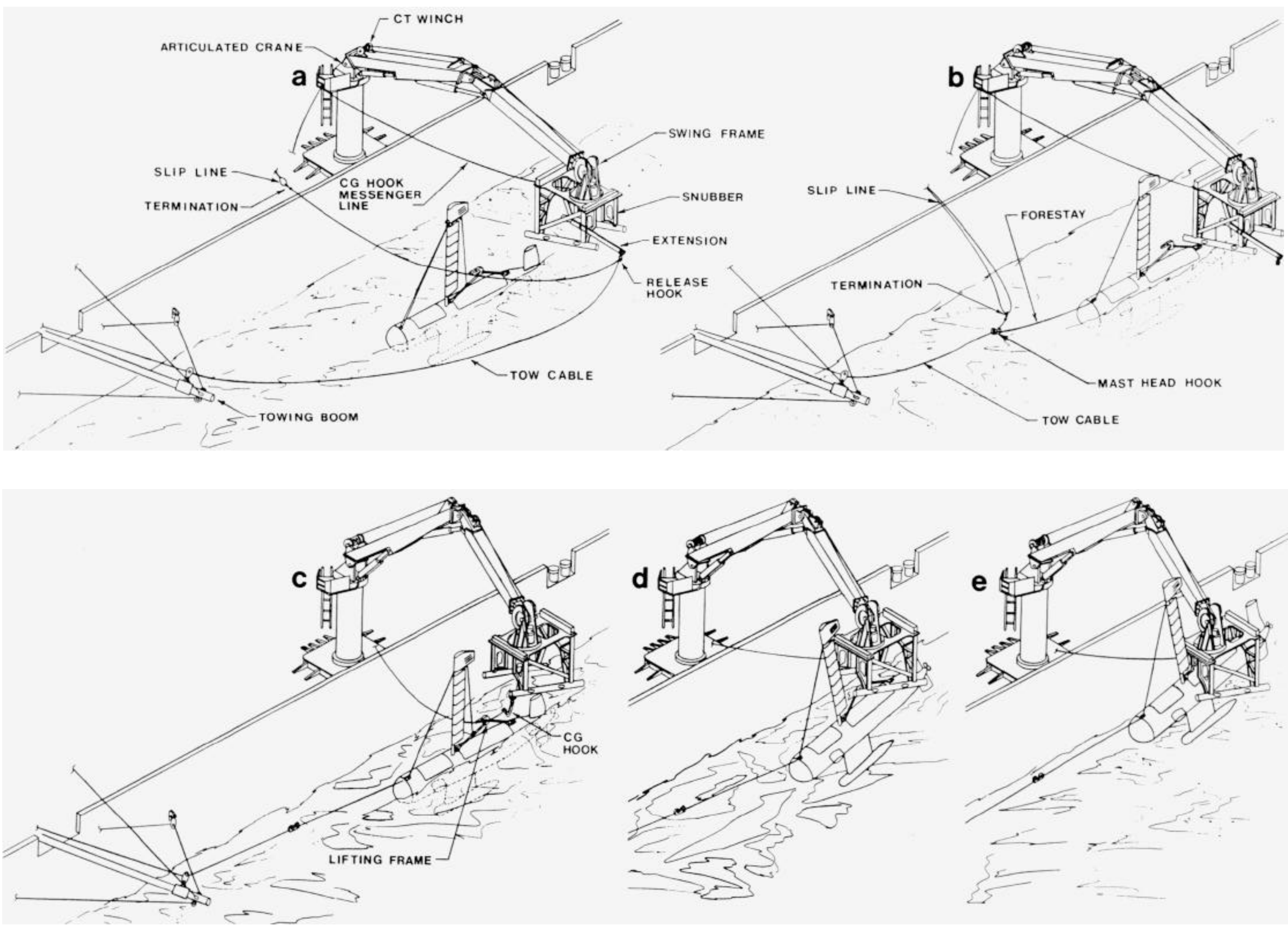


Figure 4. (a) To begin recovery, DOLPHIN is manoeuvred alongside in position about 8 m from the ship's hull. (b) DOLPHIN's tow cable is remotely latched to the towing boom. (c) The CG hook is latched remotely to the CG lifting crane on DOLPHIN. (d) DOLPHIN is hoisted, tilted nose down at about 20° and with the tow cable tensioned to minimize pendulum motion. (e) DOLPHIN is secured within the snubber before it is swung into its deck cradle.

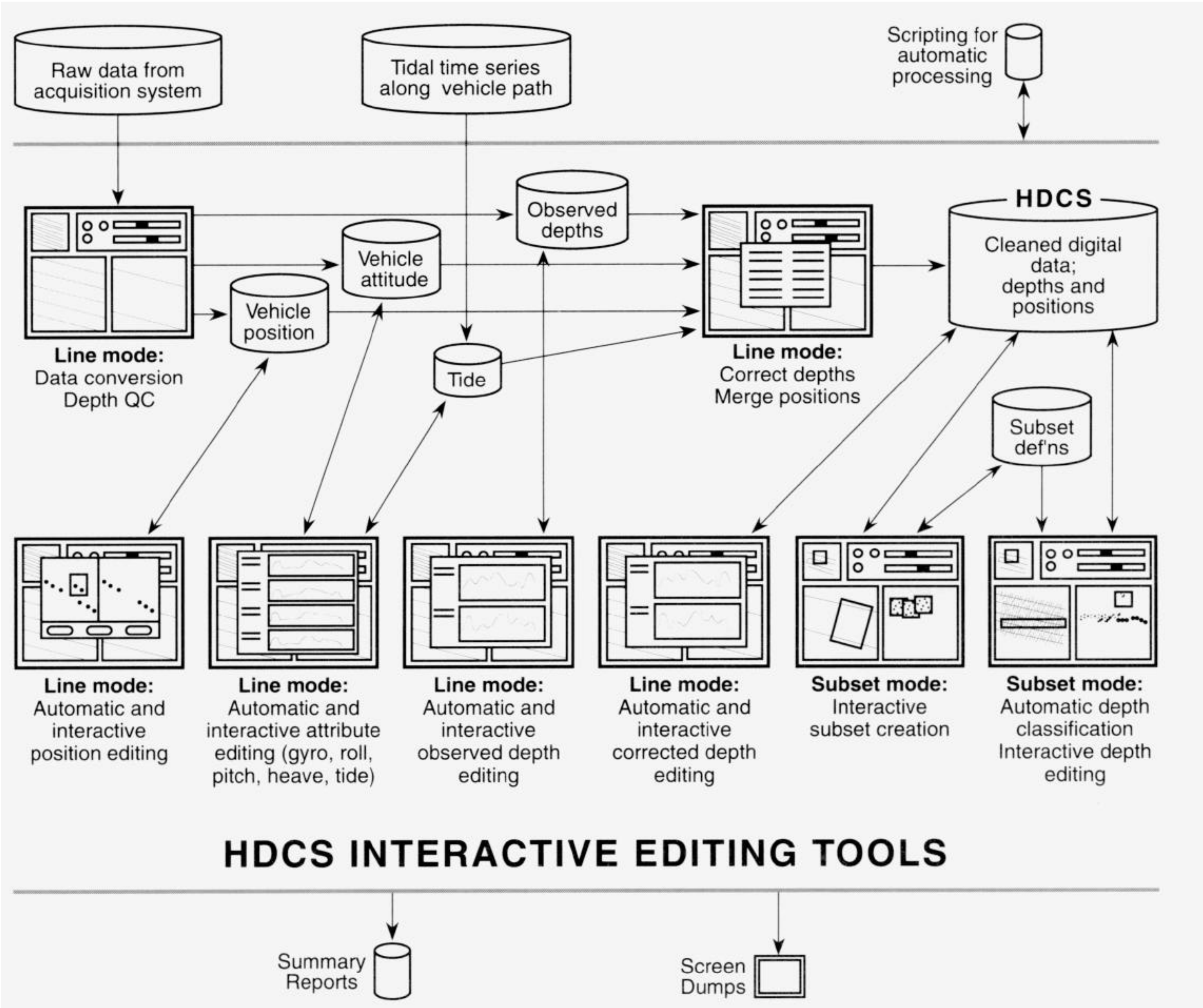


Figure 5. The Hydrographic Data Cleaning System (HDCS). The raw data are loaded into HDCS; automatically and interactively cleaned; and then passed onto a source database or to the CARIS HIPS visualization package (from Wells et al., 1991).

errors in the navigation and depth data;

- interactive editing tools to allow the hydrographer to check and override the results of the automatic tools;
- efficient transfer of cleaned data to a hydrographic source database, retaining all required attributes;
- supply of statistical and reporting functions for quality control purposes and to check for adherence to standards;
- provision of a wide range of output products such as Digital Terrain Models, 3D perspectives, field sheets, contour maps, profiles and volumes (Wells *et al.*, 1991; USL, 1992).

The HIPS package was first sea trialed in November 1991, and following modifications it was implemented in the CHS hydrographic program during 1992.

Project C: operational sea trials

In Project C, Geo-Resources was the COMS system integrator. This involved training, development work, sea trials, and marketing the system as an ocean mapping service. As the other three projects (DOLPHIN/EM100 Integration, DOLPHIN Launch and Recovery System, and Data Processing) were completed, Geo-Resources conducted a series of sea trials and made the necessary refinements to bring the system to a production level. This was an important project in that it forced COMS to be product-oriented rather than development-oriented. This project involved technology transfer between all alliance members, in particular to Geo-Resources, who received the end product.

During 1989 and 1990 the project emphasized training. Geo-Resources were involved in CHS hydrographic surveys, and they became experts with DOLPHIN. In 1990 a shore base was established at Long Pond, Newfoundland,

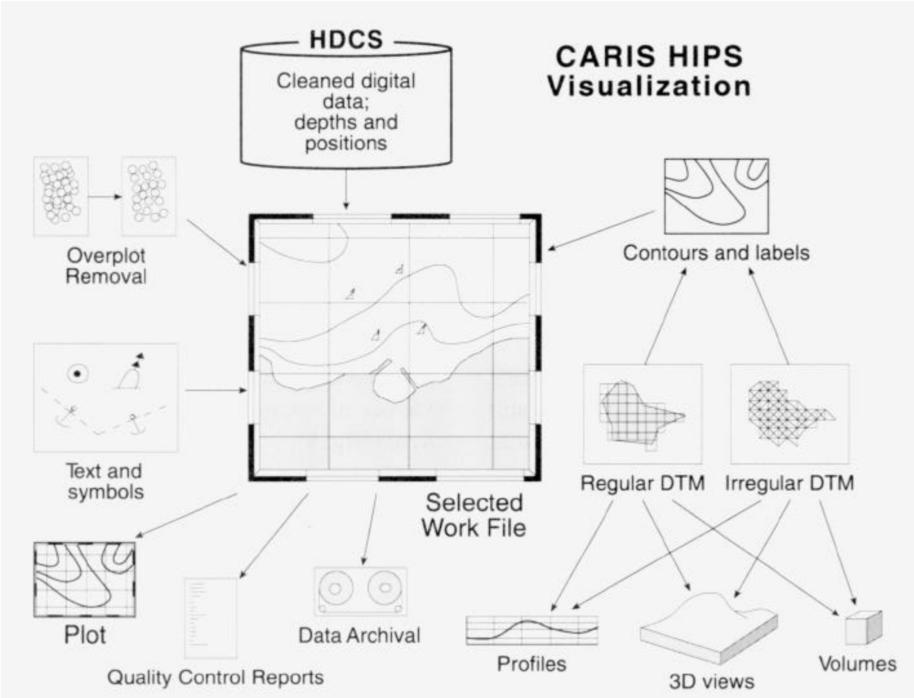


Figure 6. CARIS HIPS Visualization. Here workfile files are created and various tools are available for visualization and plotting of data sets (from USL, 1992).

and the first series of sea trials were conducted from there. These included general testing of all DOLPHIN components following a complete overhaul, navigation software development, installation of GPS positioning in DOLPHIN, and completion of a hydrographic survey of a test site in Conception Bay.

Sea trials, November 1991: These trials, based from Long Pond, involved DOLPHIN/EM100, Differential GPS, and Data Processing; these were conducted in conjunction with the C.S.S. *Matthew.* The Handling System was not used. This was the first real test of the fully integrated system, and the trials were extremely successful. DOLPHIN and the *Matthew,* both equipped with EM100 multibeam sounders and real time Differential GPS (DGPS) positioning, completed the survey of the 8 km by 17 km test site. The bathymetric data sets were processed using the USL/UNB Hydrographic Information Processing System. The data were "cleaned", and then both computer visualizations and hard copies such as 3D perspectives, field sheets, and contour maps were produced on board ship shortly after the data were collected.

In sea state 5 (35 knot gales and 3 to 4 m seas) the DOLPHIN/EM100 functioned much better than the *Matthew* /EM100. In these conditions, the *Matthew* /EM100 experienced significant data loss due to pitching, whereas the DOLPHIN/EM100, travelling below the waves, functioned well. There was no acoustic interference between the two EM100 sounders when DOLPHIN and *Matthew* were staggered along track. With positioning accuracy of about 5 m using DGPS and DOLPHIN under computer control, excellent line keeping was achieved (Clarke *et al.,* 1991).

Previously, this same test site was surveyed using conventional single beam sounders; 200 kHz and 30 kHz. This permitted the comparison of the single beam and EM100 multibeam surveys. The two data sets agreed well. The real advantages of the EM100 multibeam data were in coverage and time; the multibeam survey gave 100% bottom coverage in only a fraction of the time it took to complete the single beam survey, which did not give full coverage. In addition, the amplitude

Figure 7. DOLPHIN IS recovered from the north Atlantic in sea state 4 with the "Atlantic Arm" during the Grenfell *sea trials in February 1992.*

data (pseudo imagery) supplied by the EM100 system permitted some geological interpretation, which was later completed by the UNB Ocean Mapping Group.

One particular day during the trials there was an air of suspense and excitement. About 20 people stood on the *Matthew's* bridge, including U.S. Navy personnel and CHS senior management. The *Matthew* and DOLPHIN were underway in survey configuration at 12 knots; DOLPHIN was under 'hands-off' computer control; both were collecting 100% bottom coverage bathymetry at a rate of 3 megabytes per hour each, and DGPS was providing positioning to about 5 m! It was a first for hydrography.

Sea trials, February 1992. These trials involved the DOLPHIN/EM100 and the Handling System and were conducted off the east coast of Newfoundland. With the cooperation of the Canadian Coast Guard (CCC), BOT's Handling System and the DOLPHIN/EM100 were installed on the C.C.G.S. *Sir Wilfred Grenfell.* The *Grenfell,* formerly an offshore supply vessel now used for search and rescue, had ample deck space on the stern and proved to be a very stable ship. Operating conditions were typical winter North Atlantic, with temperatures as low as minus 20°C without a wind chill factor. Winds were as high as 30 to 40 knots, with freezing spray.

A number of launch and recoveries were completed in sea states up to 4 (3 m wave heights). Although sea state 5 was not experienced, the crew were quite confident that operations could have been safely performed had the conditions been present. The ship's speed during handling operations was approximately 5 knots. The sea trials went quite well. After two weeks of training an inexperienced crew, the launching or recovery of the DOLPHIN could be completed in 10 to 15 minutes for each.

Following these trials, some procedures had not yet been tested including the recovery of a disabled DOLPHIN, recovery in sea state 5, and night time operations; there were also some mechanical problems with the crane. These all required additional sea trials.

Sea trials, May 1992. These were the last series of sea trials for COMS. Following some modifications to the Handling System, two weeks of sea trials, again using the *Grenfell,* were conducted off the east coast of Newfoundland in May 1992.

Several successful launch and recoveries demonstrated that the DOLPHIN could be safely launched and recovered with this Handling System. Night time operations and 24 hour endurance tests were successful. Depths up to 530 m were collected and the data were within specifications.

The recovery of a disabled DOLPHIN using FLATTS was also demonstrated and worked well. Some minor problems were overcome by modifying the procedures. Once the FLATTS projectile and tag line were fired, DOLPHIN did not stream as expected; as well, the tag line could potentially foul on parts of the DOLPHIN hull if it were left unattended for a long period. Retrieving the tag line as quickly as possible avoided this problem. All the objectives of the trials were accomplished.

Following these trials the complete system, including three DOLPHINs and the Handling System, were transferred to Geo-Resources under a Loan Agreement for further exploitation and marketing. Geo-Resources are now equipped to provide ocean mapping services to interested clients (fig. 8).

Other applications and future developments

In addition to hydrography,

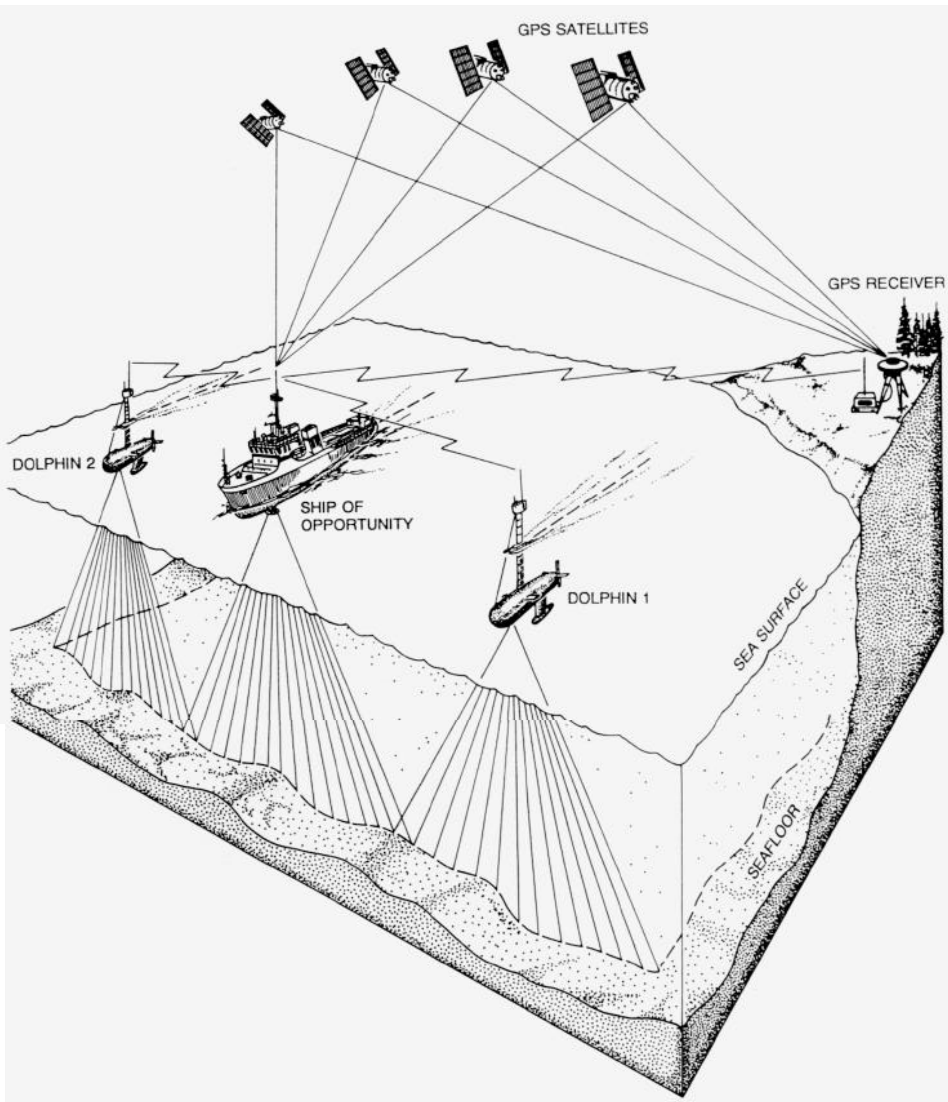


Figure 8. This would he a typical configuration with two DOLPHINs and mother ship equipped with DGPS positioning and providing 100% bottom coverage. Geo-Resources are now equipped with DOLPHIN/EM100 technology to provide ocean mapping services to interested clients.

DOLPHIN has been used and tested in other applications; it is an ocean-going platform with many potential uses.

In 1991, DFO contracted Geo-Resources to conduct a Wave Breaking Study using DOLPHIN. The objective was to investigate the transfer of gases from the ocean to the atmosphere during surfing conditions on the sea surface. To do so, various sensors, including sidescan sonar, upward and downward looking sonar, thermistors, void fraction sensors and video cameras were installed on DOLPHIN (fig. 9). The project was a success. Although ideal surfing conditions were not encountered, sufficient data were collected to demonstrate the feasibility of using DOLPHIN for such research.

Other organizations have shown keen interest in DOLPHIN, in particular the United States and Canadian Departments of Defence. Defense applications focus on mine countermeasures, in particular the mine hunting role. Towed sidescan sonar systems have been installed and tested by these departments and ISER.

Figure 9. During a "Wave Breaking Study", DOLPHIN was equipped with side scan sonar on the keel, thermistors and void fraction sensors along the forestay, upward and downward looking sonar on the bow, and video cameras at the mast head and base. The system worked well and the data were recorded on board.

Several companies are jointly planning a project similar in magnitude to that of COMS, whereby DOLPHIN will be modified to accommodate a sonar for fish stock assessment and then sea trialed as part of a larger research project.

In August 1992 the U.S. Navy contracted Geo-Resources and USL to complete a demonstration of the system in U.S. waters. Two 24-hour surveys were completed in the Norfolk Canyon area. The DOLPHIN/EM100 data were processed on site using HIPS, and compared with data collected by the HYDROCHART multibeam system on the NOAA ship *Whiting*. General impressions were positive, and several people indicated that the DOLPHIN/EM100 system "would add tremendous survey capability to existing and future platforms" (Kalcic, 1992). The project was very successful and has heightened interest in the DOLPHIN/EM100 system among several U.S. organizations.

The next logical development is to install an EM1000 in DOLPHIN. The EM1000 is Simrad's latest shallow system; it has bottom coverage up to 7 times water depth, range of 10 to 800 m, and provides high quality sidescan imagery. The preliminary design for the EM1000 installation in DOLPHIN was completed as part of the ISER Integration project; with a new radio and other minor modifications it appears to be feasible (ISER, 1991).

Conclusion

The Canadian Ocean Mapping System (COMS) consists of a SIMRAD EM100 multibeam echosounder integrated into an autonomous underwater vehicle, DOLPHIN. The system is fully integrated with differential GPS navigation, and provides real time automatic acquisition of seafloor bathymetry and pseudo imagery. A handling system was developed to safely launch and recover DOLPHIN in sea states up to 5. A new processing package, HIPS, was developed to manage the resulting large data sets collected. The complete system has been successfully put through extensive sea trials. The DOLPHIN/EM100 has also been operated from a 10 m survey launch for near shore and coastal applications. This first system is now in production and expansion to a multi-vehicle system for cost effective seafloor mapping world wide is feasible.

Acknowledgements

Several factors contributed to the success of COMS, including: strong support and commitment from DFO senior management (Paul Bellemare, Director of Hydrography, Atlantic Region, and Don Dinn, Manager, Engineering and Technical Services, BIO); interdepartmental cooperation, in particular from the Canadian Coast Guard; a hands on working relationship between government, academia and industry; and most importantly, a "commitment to completion" effort from all the project teams who actually conducted the work.

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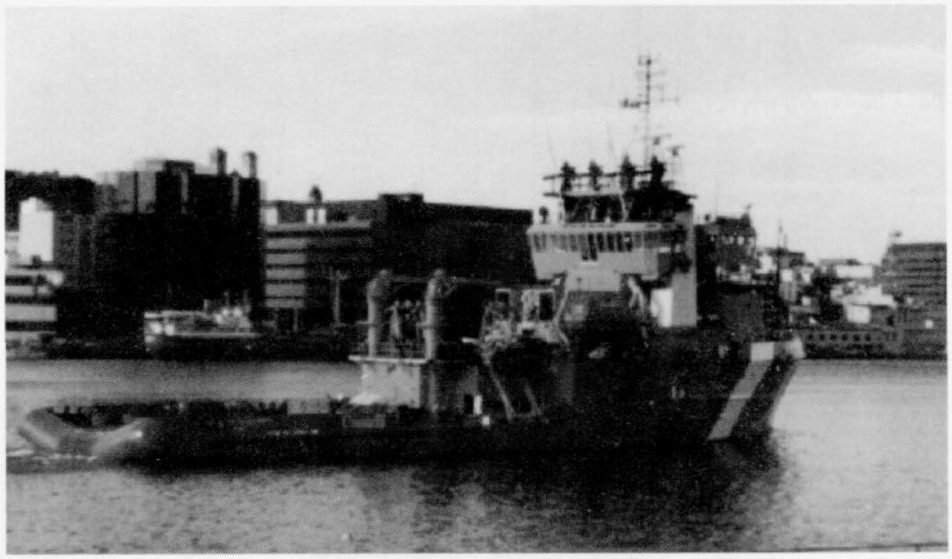
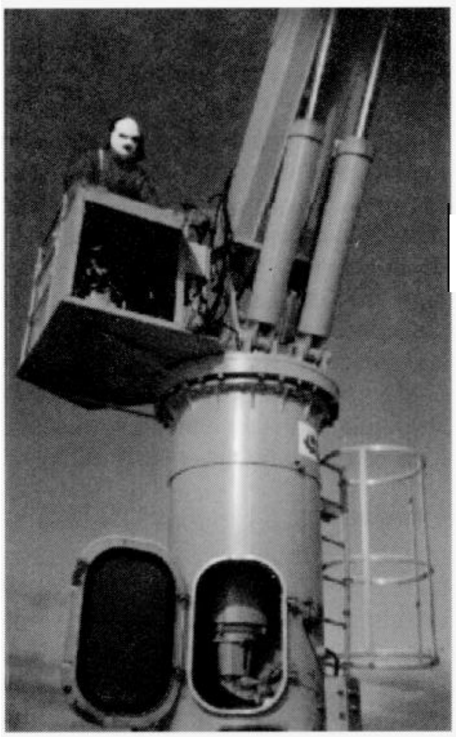


The C.C.G.S. Sir Wilfred Grenfell, *shown here in St. John's Harbour, proved to be an ideal ship from which to conduct the sea trials.*



At -20°C and 35 knot gales, the crane operator had the coldest job.

DOLPHIN/EM100 passing the U.S. Navy 2nd Fleet in Norfolk, Virginia, enroute to the Norfolk Canyon survey in August 1992.

The role of information in a scientific community

A. Fiander

A. Fiander

The Department of Fisheries and Oceans' (DFO) Scotia-Fundy Regional Library System is composed of three libraries: the Bedford Institute of Oceanography Library, the Halifax Fisheries Research Laboratory Library, and the St. Andrews Biological Station Library. These facilities serve 1,333 staff of the Department of Fisheries and Oceans, 132 staff of the Atlantic Geoscience Centre (part of the Department of Energy, Mines and Resources), and 19 staff of Environment Canada. In addition, they are used by consultants from industry, students and professors from universities in the area, staff from provincial government departments, and the general public.

Scientific researchers

Scientists are voracious consumers of information. They need information in order to keep in touch with research being done around the world, to explore new fields and methods of approaching their work, to gain insight into research already accomplished in their area of expertise, to acquire background material for projects they are working on, and to give them ideas for innovative programs in the future.

The library has always been a quiet place to browse through current periodicals, as well as a service centre where scientists get access to the information they need. Scientists and researchers using a special library like ours have traditionally asked, "Do you have this?" If we have it they ask, "Where is it?". And if we don't, "When can you get it?".

The library's changing role

Libraries, however, are undergoing a metamorphosis and they are forcing their users to change as well. They are changing from being warehouses of published materials to being gateways to information. A number of factors are playing a role in this change.

Cost increases have made it virtually impossible to collect comprehensive materials in a particular subject area, such as the marine sciences (table 1 and figure 1) (Hoffer, September 1992). The costs of scientific books and periodicals have suffered inflationary increases in the last two decades which are three times those imposed on social sciences and humanities materials (Hoffer, February 1992). Space limitations for libraries make it difficult to house expanding collections in accessible quarters. And yet, despite increased publishing costs, new periodical and book titles continue to proliferate. Francis Bacon wrote, "I have taken all knowledge to be my province." However, it is no longer possible or practical to think of libraries as being so comprehensive, even in a specialized and limited subject field.

Table 1
Increases in journal prices, 1992

Prices in Britain	18%
Prices in Europe	27%
Prices in the U.S.	14%
Average increase:	19-20%

Traditional and modern roles

Libraries like ours must play a dual role in the 1990s. While offering traditional services such as reference, acquisitions, and interlibrary loans, we must explore the changing face of information and determine how, both technically and philosophically, we can deliver optimum services in a cost-efficient but effective way.

The role of the modem library lies in effective networking. Since we can no longer collect everything we need in order to be self-sufficient, we must establish co-operative ties with other libraries which complement our collection.

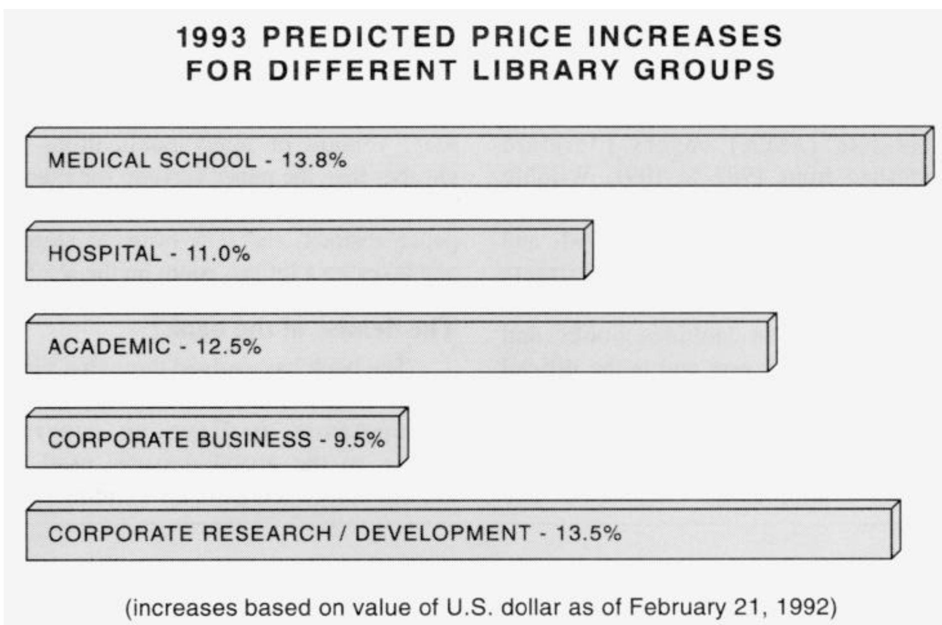


Figure 1. Predicted I993 price increases for various libraries.

Technology and information

Technology and information are now inextricably linked. In addition to the materials collected in our libraries, library staff have access to more than 400 online databases. Our scientists have 4 databases available to them on CD ROM (compact disk read-only memory).

A CD ROM can hold up to 600 megabytes of data, the equivalent of about 1,600 floppy disks or 250,000 single-spaced typewritten pages. CD ROMs are user-friendly, with menus to choose from, a variety of display options, and plain-language search terms. The disk itself is virtually indestructible in a normal environment, so it requires no special handling or treatment. And because CD ROM is a nonmagnetic medium, magnetic fields cannot corrupt the data. Finally, the disk itself is a sandwich of tough polycarbonate and aluminum, which encase a protected reading surface. As a result, fingerprints and spilled coffee will not harm the data.

CD ROM technology is attractive to scientists because it gives them the opportunity to do bibliographic searches of extensive databases without incurring the high costs associated with online database inquiries. CD ROM searches can also be done independently of library staff, so they are available whenever the library is open.

The libraries at BIO, the Halifax Laboratory, and St. Andrews are each equipped with an IBM PC clone with a CD ROM player attached, and each facility subscribes to updated abstracts on CD ROM. Aquatic Sciences and Fisheries Abstracts (ASFA) covers literature published from 1982 to 1991, Wildlife and Fish Worldwide includes material published from 1971 to May 1991, and Pollution and Toxicology Abstracts (Poltok I) covers the years 1982 to 1991. WAVES/VAGUES includes books and reports from all years and is the official information database of the Department of Fisheries and Oceans (DFO).

All of these CD ROM databases contain bibliographic information and abstracts for books, reports, and journal literature published worldwide. In addition, WAVES identifies the locations of material housed in DFO's 13 libraries across Canada. This database represents a very successful step toward networking DFO's libraries and is regarded as an exemplary model of information-sharing.

The future

In the future, the trend among libraries will be toward providing electronic information. The costs of print-on-paper information continue to escalate and scientific journals are pricing themselves beyond the resources of many subscribers. As library budgets remain static and inflation continues, our purchasing power decreases. This in turn necessitates the cancellation of subscriptions, and creates a vicious circle for publishers, since fewer subscribers mean prices must be increased to cover costs. It is not economically feasible to sustain print-on-paper publications unless an extremely large market can be reasonably assured. Because of this, many publishers will begin new journals in electronic form. With more office computers available, scientists will have direct access to full-text data (versus simply bibliographic information) through either online services or CD ROM products. Since many researchers now compose and edit their papers by electronic means, the transmission and even the publishing of journals will be possible without a printing process.

In the 1990s more material will be available on CD ROM. Even now, the CD ROM version of many publications is cheaper than the paper version; for example, ASFA on CD ROM is cheaper than the paper abstract, and it is faster to search and takes up a lot less room on the shelf.

The demise of the book?

The book has evolved through a variety of forms: from the clay tablets of Mesopotamia, to Egyptian papyrus scrolls, to the goatskin pages used in ancient Greek Pergamum. Printing and movable type brought us the book as we now recognize it, with computer typesetting improving the quality and speed of production.

Today, the media are fond of predicting the demise of the book in the so-called paperless society. In the 1970s all paper was to be replaced with microfilm or microfiche. In the 1990s we still have paper books, but the arrival of books in electronic form has offered qualitative and quantitative benefits. For example, extensive word searches of a CD ROM encyclopedia can be performed rapidly through the use of simple logic parameters - something that is just not possible with the 33-volume printed version. Electronic books, periodicals, and indices are also excellent for quick reference, brief reading, and bibliographic searching. They are less costly than the printed version, consume less space, and are portable.

However, before electronic versions replace books as we now know them, significant improvements must be made either to computer screens or to the human eye. So far, nothing has replaced the superb characteristics of paper and ink. Paper does not "flicker", whereas the typical computer screen is displaying 60 to 72 interlaced frames per second. This constant flickering is detected by our eyes as motion and causes constant movement of the fovea portion of the retina, substantially reducing reading speeds. A well-printed book has an ink-to-paper contrast of about 120 to 1, whereas typical computer screens are half that. And print and illustrations in a book represent a resolution of about 600 to 1,000 dots per inch, whereas computer screens offer one-tenth of that and books on CD ROM provide even less. Given these disadvantages of electronic media, it seems that the book will be with us for some time to come!

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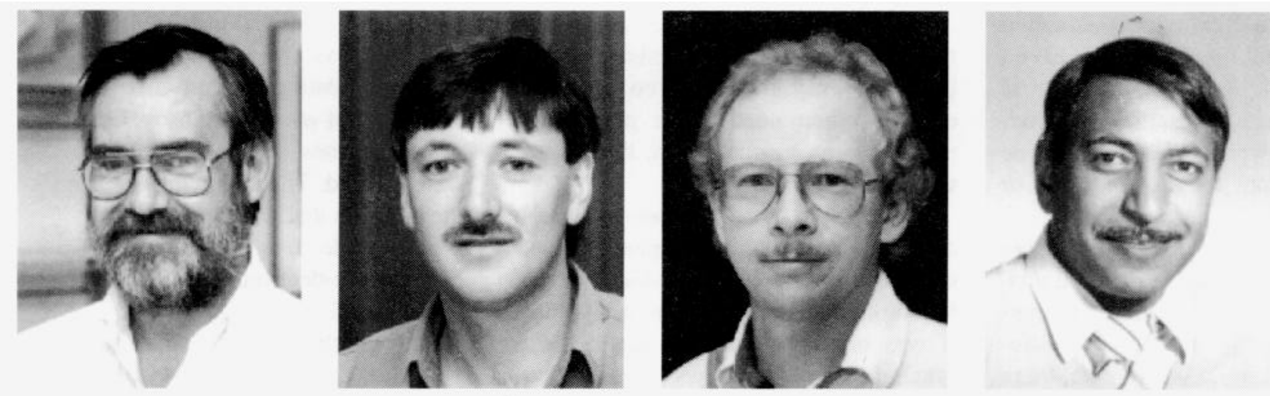
Geographic information systems applied to the production of nautical charts

D. R. Frizzle, D. D. Nicholson, S. A. Smith, and H. P. Varma



D. R. Frizzle *D. D. Nicholson* *S. A. Smith* *H. P. Varma*

For centuries, the sextant and the leadline comprised the backbone of data collection tools for hydrographic surveys. Information was collected and drawn manually on field sheets. These hardcopy data representations were brought to a common scale photomechanically and were compiled on a single base known as a mosaic. Cartographers selected appropriate data from the mosaic and, using traditional drafting techniques, produced a nautical chart.

By the 1970s echosounders and electronic positioning systems revolutionized the acquisition of hydrographic information. Data loggers, able to store information about position and depth in digital form, were introduced. At the same time, the use of computers to produce chart borders and LORAN lattices increased the speed of the chart-making process.

Advances in data processing in the late '70s and early '80s included the ability to store not only information about position and depth but also supporting attributes. Computer-assisted drafting became used in virtually all aspects of cartography. However, the process was still graphically oriented (fig. 1).

In the 1970s the Canadian Hydrographic Service (CHS) realized that the full power of digital information was not being used, and it became increasingly accepted that CHS' mandate was to create a hydrographic database of digital information. Charts would become one of the many byproducts of the database that provide information to clients.

The early to mid '80s saw experimentation with interactive chart compilation using CARIS (the Computer-Aided Resource Information System). At the same time, data acquisition technology was making significant improvements and the advent of acoustic sweep and swath systems increased the volume of data by orders of magnitudes. The difficulty of managing these large data sets necessitated a proper database management system.

In 1988 work began on the design of a bathymetric database system. Relational concepts in database technology were recognized as being most appropriate for this task. However, the relational technology in existence at the time could not handle large sets of spatial data.

The main problems with managing spatial objects were associated with their relationships, representation, analysis, and retrieval. These problems included:

- how to maintain spatial objects in a format that a user could query;
- what query language to use for spatial and nonspatial data;
- how to provide spatial relationships that could be analyzed;
- how to generate an image on the basis of query conditions.

These were the fundamental questions that CHS (Atlantic Region) and Oracle Corp. (Canada) explored during the development of a SIMS (Spatial Information Management Systems) prototype.

SIMS is based on a new concept of hydrographic hyperspatial codes, or HH codes. These codes are generated by subdividing space using a quadtree approach. That is, any shown subpartition is, by

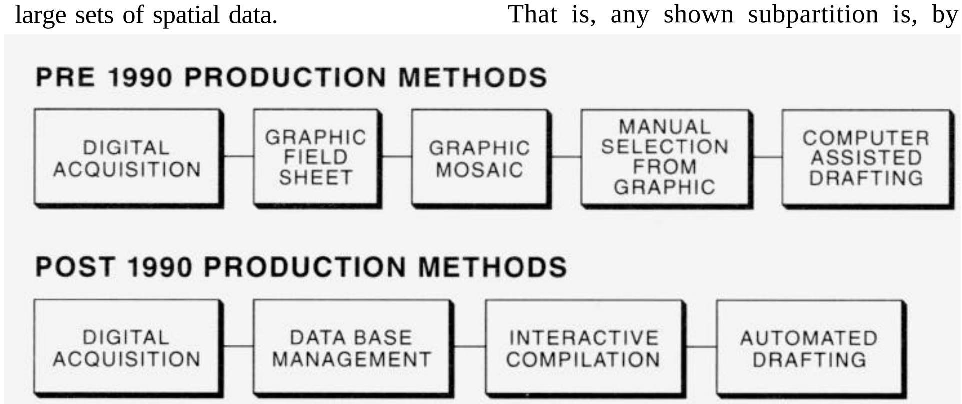


Figure I. The creation of nautical charts: The old and the new.

definition, one-fourth of the parent and is given an identity code containing the characters 0, 1, 2, and 3. Subsequent repartitioning generates new HH codes derived from the existing code, with the size of the squares dictated by the length of the codes: the longer the code, the smaller the square. Relationships are then formed by matching codes to given lengths and signifying whether the areas specifically relate. With this method, relationships between point data can be established without the use of grids or polygons.

HH codes give relational databases the capability to use SQL, a standard relational database query language, to perform efficient queries on sets of spatio-temporal information. For example, these could include the following:

- analyzing the difference between two sets of spatial data;
- computing the volume by summing all areas and multiplying them by the depth attribute;
- compressing data by subdividing information into statistical tiles;
- finding the nearest neighbours to a selected data item;
- defining trends over periods of time;
- making *ad* hoc queries among several distributed databases.

Previous relational database management systems were not capable of performing such tasks.

The SQL query language has been extended to incorporate encoding, decoding, windowing, and the manipulation of HH codes. The user can work with standard coordinate systems; however, the database management system will convert them to HH code representation in order to facilitate the database's internal operations.

Points can also be clustered by sorting and grouping similar HH codes into tables (designated as a common GROUP HHCODE name of a given length), and storing these tables off line on either tape media or disks.

What is most important about this capability is that it provides a means of maintaining a very large database off line, bringing only the required segments on line when needed. At present the prototype can handle points, lines, areas, volumes, and topology.

While progress was being made in data acquisition and management, work continued on the computer-aided compilation of nautical charts from digital data. It was originally planned that a cartographic compilation expert would assemble all necessary digital data files and then window them to fit the chart before beginning the compilation. But without a database management system, this plan was doomed to failure. The data collected over the years within a charted area had created a large number of digital files. In addition, these files had required various degrees of modification as the geography within their limits changed. Unless the source information could be validated and managed, compiling charts from the digital data would be impossible.

Validating the source data on a chart-by-chart basis has begun. This has allowed CHS to begin the interactive compilation process while preparing for the eventual arrival of the database management system. A special group within CHS has been created to supply all the necessary digital information. One electronic file for each chart is provided at the scale and projection of the particular area; figure 2a is an example of the digital data available for a charted area.

The early stages of interactive compilation virtually mimicked the traditional methods of data selection. The person compiling the information was required to review all the data visually to make the selection and derive features such as contours. However, this method falls apart as the density of collected data grows. Figure 2a shows the visually impenetrable volume of data plotted at chart scale. In order to deal with this density, computer-aided methods of selecting digital data were created. The following are some of the methods that were used:

- to exclude data with unwanted attributes, pre-determined sets of attributes were used;
- to automatically select soundings, variable spacing specifications were used in combination with depth biasing;
- to automatically generate depth contours, a triangulation network was used, and the lines smoothed after they were processed.

Figure 2b shows the results of using these data selection tools. The product, although not meeting exact standards, favourably resembles a printed nautical chart and is referred to as a pseudochart. The creation of the pseudochart is virtually automatic. Figure 2c shows the final product after human interaction. Very little difference can be seen between 2b and 2c. However, the processing of data to produce a pseudochart takes a matter of hours, as opposed to the months required for manual equivalents.

With the installation of a relational database management system, data manipulation specialists will have quick access to all of the data for a given area, and can also call upon data analysis and comparison devices as required. This will allow the necessary decision-making

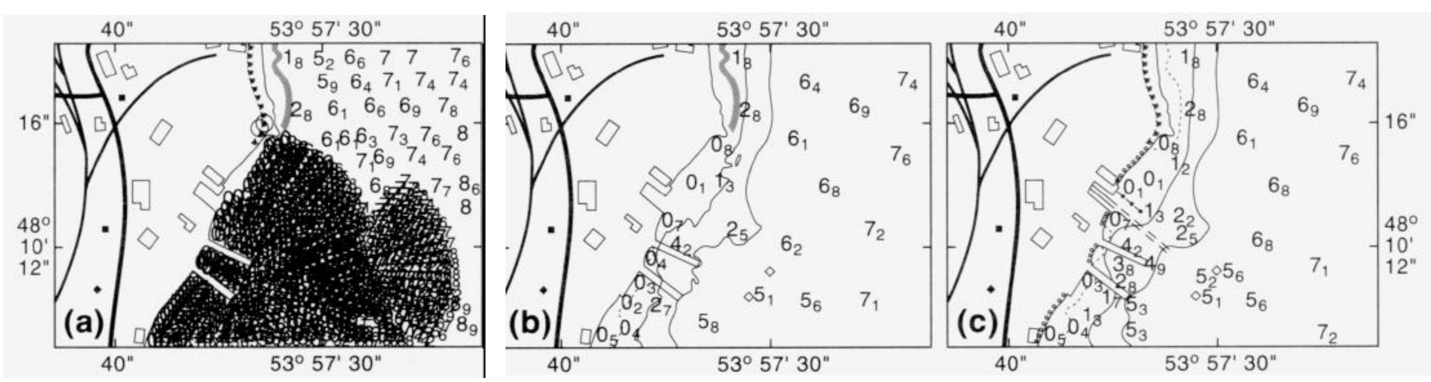


Figure 2. The compilation process.

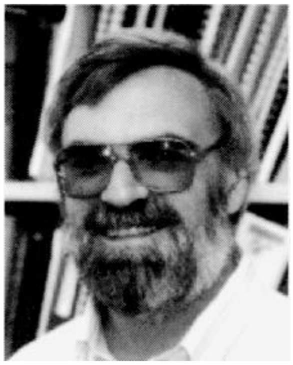
when producing charts to be better informed. Many of the routine tasks of chart-making will also be completed by computers, resulting in a faster process.

CHS collects and maintains a very diverse base of information, and the number of people who use these data is increasing at a rapid pace. The electronic chart is one example of the changing demand for digital information. Since the size of a digital chart typically is about one megabyte, in theory all of the 404 charts of the Atlantic region could be stored on one side of a CD ROM disk. Sailing directions, annual notices to mariners, tidal predictions, and other nautical publications could also be included on this medium.

To serve the needs of mariners and of an increasingly diverse group of clients, the requirement for a complete database with an efficient management system is paramount. The Canadian Hydrographic Service is dedicated to attaining that goal.

From oceanographic research to operational oceanography

D. Gregory



D. Gregory

Through its many research programs, the Physical and Chemical Sciences (PCS) Branch at the Bedford Institute of Oceanography is developing the techniques and, in many cases, collecting the data to answer a broad range of questions in the fields of fisheries, climate, and offshore energy. Providing this information to other organizations and disciplines is one of the challenges faced by a research laboratory. Clients increasingly demand useful products that will help them solve problems such as assessing the abundance of fish stocks, determining suitable sites for aquaculture facilities, and modelling the effect of an oil spill. While the availability of high-speed computer networks allows easier access to data, it also introduces a new level of complexity, as data and software needed for a particular project are frequently spread over a number of different machines.

An immediate concern is improving distribution and accessibility of information, through products that already exist or can be produced relatively easily. These objectives are relatively short term and have well-defined goals. A longer-term objective is to develop the necessary hardware and software infrastructure and the scientific expertise to facilitate the development of new oceanographic products for our clients. It is in the context of these short- and long-term objectives that this article will discuss some of the many developments being introduced by PCS in order to improve access to data, provide oceanographic analyses, and create environmental databases.

Data access

The needs of other organizations and disciplines for oceanographic data divide roughly between those clients who require immediate statistical summaries and those who want to access complete data sets in order to carry out their own analyses. To inform both groups of the availability of data and how these data can be accessed, a series of online directories is being developed which describes all of the physical oceanography holdings at our laboratory. The directories contain detailed monthly statistical summaries (means and variances - see Gregory and Smith, 1988), as well as instructions for retrieving complete data sets in a format suitable to the client's requirements. At the same time, similar directories and statistical summaries, which can be sent to client agencies and updated on an annual basis, are being developed for use on a personal computer.

An obvious advantage of the personal computer is that the directories can be easily integrated into commercially available and relatively inexpensive database and mapping programs, thereby greatly increasing the usefulness of the information. Users do not have to contend with telecommunication charges or poor response times if our own computer facilities are busy. Telecommunications systems must be used when clients want to obtain a complete data set, but in such cases it is simply a matter of submitting a directory-generated request to BIO's computer. Figure 1, which shows the distribution and number of months of ocean current data held in the PCS archive, is an example of the type of product that is readily accessible through the directories and a commercially available PC-based mapping program.

Supplementing the observational data are the simulated observations from numerical models. Many of these models are remarkably reliable in duplicating observational results, and they are

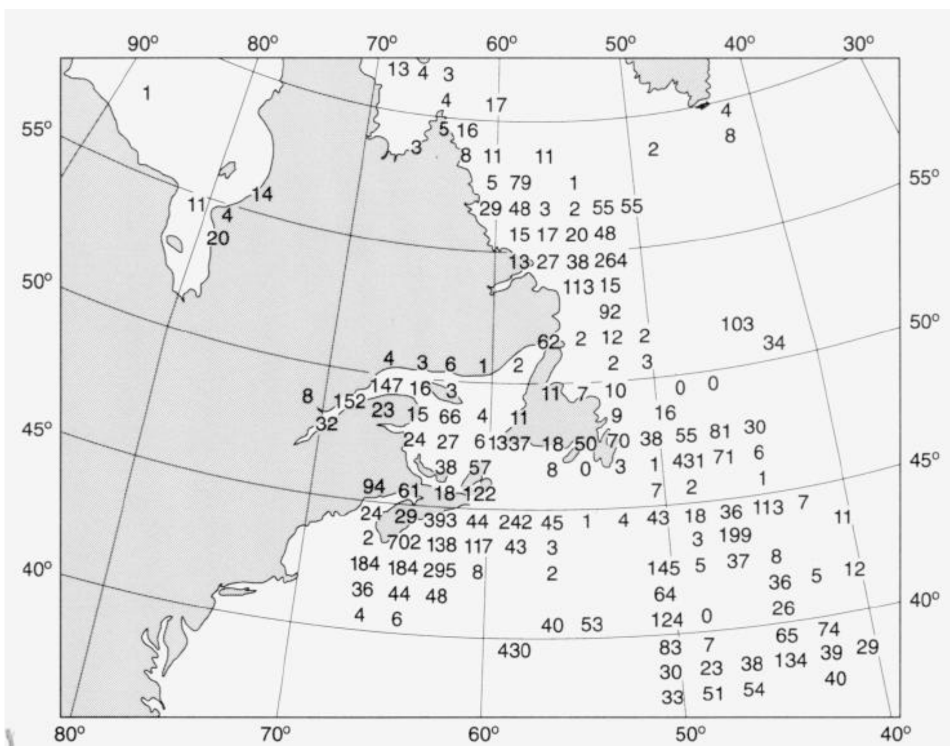


Figure 1. The number of months of ocean current data observed in 1° x 1° squares and archived by PCS for the Atlantic east coast.

becoming accepted as an alternative form of oceanographic information in data-poor regions and seasons. Numerical models, when verified, have a considerable advantage over observational data in that they offer spatial or temporal coverage and a degree of resolution that is simply not available with field data. Frequently, the results from such models are the only source of information about some areas and are therefore a valuable resource. Inclusion of these data in the online directories will become a priority after completing the directories of observational data.

Oceanographic analyses

The state of the ocean: Since 1984, a group of scientists within PCS have been producing a monthly state-of-the-ocean summary which describes the sea-surface temperature, the amount and location of sea ice, and the positions of fronts, all in relation to other environmental variables such as wind and air temperature. The current monthly values of sea temperature and ice cover are compared to long-term averages in order to assess whether or not the conditions are normal for the period. The region of interest extends from the Gulf of Maine to the Grand Banks and offshore to the Gulf Stream. The primary source of data for the analysis is the frontal chart titled “Oceanographic Analysis”, which is produced three times a week by the National Environmental Satellite, Data, and Information Service and the National Weather Service, both American agencies. This chart is, in turn, based primarily on infrared imagery collected by polar orbiting and geostationary satellites and prepared by the National Oceanic and Atmospheric Administration. These satellite data are also supplemented by surface observations. Other data used in the analysis come from various sources, including the Atmospheric Environmental Service Ice Centre, and field measurements by research scientists and the maritime fishing industry. The monthly report is sent to an extensive list of environmental consultants, universities, other government agencies. and clients in the fishing industry.

NAFO ***annual environmental overview:*** Since 1982, PCS scientists have provided annual reviews of environmental conditions in the Northwest Atlantic to the Environmental Subcommittee of the Northwest Atlantic Fisheries Organization (NAFO) (Drinkwater and Trites, 1991). The reviews are based on a variety of oceanographic and meteorological data sets, on information provided in national research reports, and on other research documents prepared for the NAFO Science Council. Data sets include:

- coastal and offshore sea-surface temperatures;
- hydrographic data from standard oceanographic stations (such as Station 27 off St. John’s, and Prince 5 at the mouth of the Bay of Fundy);
- the position of the shelf-slope front, the number and location of warm core rings;
- the first and last appearance of sea ice;
- the number of icebergs;
- the air pressure and geostrophic wind fields over the North Atlantic;
- air temperature over eastern North America.

Environmental conditions are compared with those of the preceding year and with the long-term means.

Analysis tools: Combining data from different sources in order to subject them to a uniform analysis is often made more difficult by the need to deal with a variety of formats and data structures. To facilitate this process, the PCS disciplines have made a major effort over the past two years to develop an analysis and data management system (O’Neill and Bodner, 1991) which is a radical departure from previous systems. Instead of developing large programs that perform specific tasks and require a rigid input and output format, the analysis software, written to strict ANSI standards, consists of a number of modules or functions which operate independently of any data format. The modules can be assembled in various ways to provide the desired analysis.

As new analysis techniques are developed, modules can readily be added to the system without affecting the existing ones. The data management component, which the system sees as simply another module, permits scientists to define the structure of the data being supplied to the analysis routines. Using this approach, data from a variety of sources can be combined and subjected to the same uniform analysis without requiring the development of new software. The system, which to date consists of over 125 oceanographic modules, has been received with enthusiasm within Canada, and interest has been expressed from research laboratories in the United States, Korea, and China.

Data assimilation: Incorporating observational data into statistical or numerical models is another way to maximize the information available from existing data. This process can also help to determine the quantity of data required to achieve a given level of accuracy or the point of diminishing returns for additional data. The technique of blending observational data with models, called “data assimilation”, has been in use for some time in meteorology, but the methodology is still being developed in oceanography. However, the imminent availability of oceanographic satellite measurements that will cover the entire globe with unprecedented spatial and temporal resolution is accelerating the efforts at **BIO** to make use of these techniques.

Various aspects of the research include developing algorithms to produce representations of surface wind and pressure fields from satellite imagery, combining these data with *in situ* observations, and coupling both types of data into models. Optimal estimation techniques are being investigated so that gridded data fields can be generated from observational data, which are generally not uniform in space and time and have different degrees of resolution and accuracy. Sophisticated data-sorting algorithms are being developed in order to allow efficient access to large data sets, a step that is necessary before the large volumes of modelled parameters can be considered as a source of data to be managed and archived.

Oceanic indices

With an understanding of a physical system that comes from the analysis of both observational data and the use of modelling techniques, it becomes possible for oceanographic variability over a large area to be summarized in one or more oceanographic, hydrological, or meteorological indices. These indices may then be applied to a whole range of problems, from long-term climate change to shorter-term fluctuations in the abundance of a particular fish stock. By comparing these oceanographic indices with time series from individual sites, monitoring locations can be established, thereby reducing the need for massive observation programs.

An example

A scientific study currently under way illustrates many of the developments mentioned in this paper (Drinkwater *et al.*, 1990, 1991); it involves the establishment of a database, the application of analysis tools, the process of data assimilation, and the formulation of oceanographic indices. Its purpose is to determine the dominant temporal and spatial scales of oceanic variability in the Scotia-Fundy Region, to identify the forces controlling local climate change, and to determine what large-scale environmental factors contribute to long-term fluctuations in groundfish abundance. The Gulf of Maine area (fig. 2) has been selected for a pilot study because of its relatively great climatic variability and its importance to the fisheries.

In total, the records of some 55,000 stations with over 600,000 observations of temperature and salinity have been obtained from both the Canadian Marine Environmental Data Service (MEDS) and the United States National Oceanographic Data Center. As the database is expanded to include the entire shelf region, there will be approximately half a million stations and five million observations. Furthermore, 25 longtime series of various oceanographic and meteorological parameters have been assembled into the database of climatic indices. Some of the series, such as sea-surface temperature off Halifax Harbour and St. Andrews, New Brunswick, span seven decades.

When the system is fully operational, scientists at BIO will be able to select and review data using a high-speed data link connected directly to the MEDS databases. As with any large database, identifying duplicate or erroneous data is a major problem. Quality-control tests, developed by MEDS in conjunction with the Global Temperature-Salinity Pilot Project, have been adopted by BIO's analysis system to further upgrade the data.

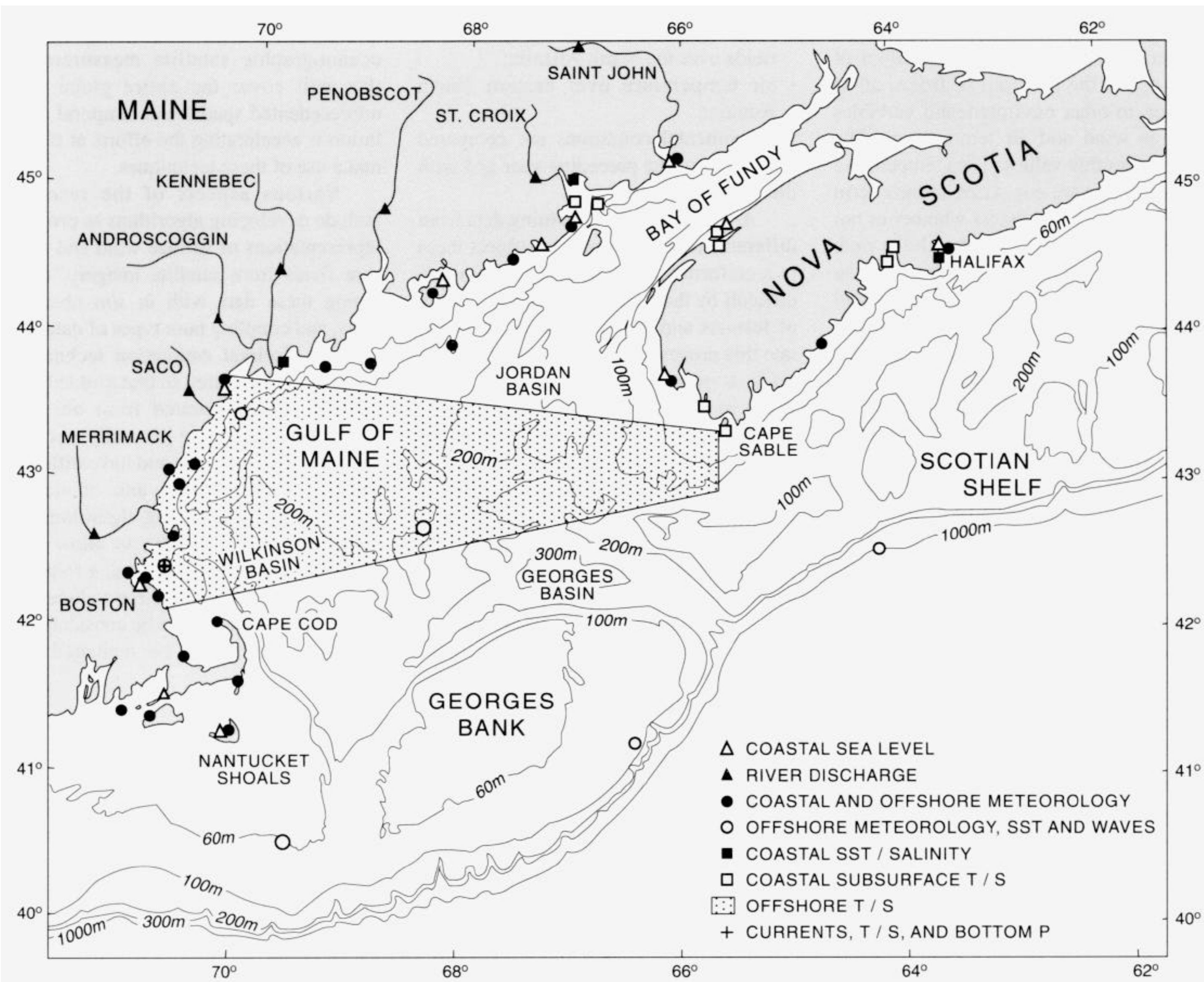


Figure 2. The Gulf of Maine region showing the location of monitoring sites for a number of physical variables.

A simple data storage structure has been defined, consisting of the space and time coordinates (latitude, longitude, depth, and time), the parameter name, and the parameter value. This structure permits the data to be easily transferred between the physical analysis system (for example, for the computation of climate indices) and a relational database (ORACLE) that supports fisheries sciences and stock assessment programs. Selected volumes of data are also transferred over the network to a graphics mini-supercomputer, where grid interpolation is performed using nearest-neighbour and optimal-estimator techniques in support of visualization studies. These studies will result in three-dimensional colour displays of the data and animated movies. When this project is completed in about four years, it will produce a system that integrates data acquisition, quality control, volume selection, statistical analyses, and three-dimensional graphical displays of the ocean.

Conclusion

The current development of data analysis and interpretation techniques represents one of the most exciting areas of oceanographic research at BIO. It brings together scientists from many disciplines and will lead to an understanding of oceanographic processes on a broad range of spatial and temporal scales not previously possible.

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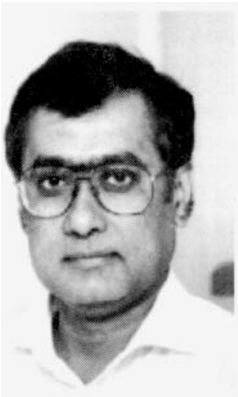
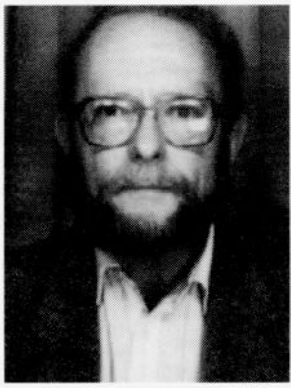
Fish and invertebrate nutrition

S. P. Lall and J. D. Castell





S. P. Lall *J. D. Castell*

Nutrition is defined as the sum of the processes by which a plant or animal takes in and utilizes food substances. Nutrition research integrates principles of biochemistry and physiology into a study of the relationships between organisms and their food supply, including ingestion, digestion, absorption, and utilization of the various chemicals which constitute the food, or which the organism needs. The nutrients animals need include proteins, carbohydrates, lipids, vitamins, and minerals. Knowledge of how each functions, and of the relationships between them, is necessary before one can make practical decisions about the formulation of feeds used both in the scientific study of fish and shellfish and in aquaculture.

Early researchers into fish biology and fish culture relied on natural or readily available foods such as fresh beef liver, shrimp, chopped fish, and fish scraps. A similar story can be told about lobsters. Most lobsters harvested in Canada are sold alive, which requires that they be stored alive. Traditionally, stored lobsters were fed scrap fish, other low-grade food, or nothing at all for periods lasting up to 5 months. Losses due to disease or cannibalism were often quite high, and it was reasonable to suppose that providing these lobsters with suitable food might improve their survival and quality. Studies of the nutritional requirements of lobsters, however, were not initiated until the early 1970s when high prices and apparently decreasing stocks stimulated interest in the potential of lobster culture in North America and Europe.

Biologists first approached the problem of fish nutrition by investigating the chemical composition of natural foods and the effect they had on growth and development. In 1924, Embody and Gordon studied the chemical composition of insects, the natural food of wild trout, and found that they were approximately 49% protein, 15% lipids, 8% fibre, and 10% ash. Fish feed formulations based on this information resulted in relatively good growth, but when liver and fresh fish were replaced by protein supplements derived from plants, the fish exhibited vitamin deficiencies. However, the lack of feed ingredients that were free of vitamins prevented these deficiencies from being characterized.

This situation changed in 1957, when Halver developed a semipurified diet. Purified diets are composed of individual feed ingredients of known composition mixed in predetermined proportions. In experimental conditions, they allow absolute control over all aspects of the animal's nutrition. They are, however, very expensive and may not be acceptable to the fish. In contrast, semipurified diets contain a combination of natural and pure ingredients. They can be designed to allow control over one aspect of the animal's nutrition - a study of a single vitamin, perhaps - while allowing the researcher to formulate a diet that is natural in all other aspects and still acceptable to the fish. Halver's semipurified diet led to the quantitative determination of the requirements of Pacific salmon for fat-soluble and water-soluble vitamins and amino acids. Since then, nutritionists have tried to formulate balanced diets by selecting food materials from both plant and animal sources and supplementing them with vitamins and trace elements. It is from this foundation that our knowledge of the nutritional requirements of fishes has evolved.

Early concern for improving diets used in salmon hatcheries has now been accentuated by serious commercial interests. Feed is the largest single cost of intensive fish production, and adequate nutrition is an important influence on the ability of fish to reach their potential for growth and reproduction. The feed and feeding regime fish farmers adopt depend on their production goals, which in turn are determined by the genetic potential of the fish, the types of feed available, and the local environment. The main objectives of our research are to formulate nutritionally balanced feedstuffs, and to design feeding regimes which will optimize production and yield a high-quality product at the lowest possible cost.

Research into salmonid nutrition

In 1979, a program was started to develop new diets for use in federal salmon hatcheries and, incidentally, by the few commercial growers of Atlantic salmon then in operation. The emphasis was to improve nutrition in order to reduce the prevalence of bacterial and viral diseases in young fish and to improve the survival and rate of return of salmon smolts used in enhancement programs. Because little was known about the nutrients and energy required by salmon in order to swim, to form new tissue, muscle, bone, nerves, and so on as the fish grow or repair wounds, and to fuel all the normal life processes, researchers relied on some of the results of work done with other species. This in effect "jump started" the development of diets for Atlantic salmon in full culture conditions, including diets for use in salt water, which is where salmon are now grown to market size. Subsequently, comprehensive research was undertaken to determine the chemical composition and digestibility of common feed ingredients, the stability of micronutrients during food processing and storage, and the palatability of plant protein and fishery by-products. Designer feeds were also developed for each stage of the young fish's life: "starter", "grower", and smolt diets. The performance of fish that were given these diets was evaluated under controlled laboratory conditions, in field trials in federal hatcheries, and, later, at the Salmonid Demonstration and Development Farm in St. George, New Brunswick. Dry and moist feed formulas developed at the Halifax Fisheries Research Laboratory are now widely used by the fish feed industry in Atlantic Canada.

Dry feeds based on fish meal and fish oil are processed into pellets, using either steam or an extrusion process. These feeds have certain advantages, such as a longer shelf life, and can be used in automatic feeding systems. Moist-feed formulations, which contain fresh herring or capelin by-products, underexploited fish species, and other local bycatches, as well as vitamins and minerals, were originally developed for use on smaller farms in response to the absence of suitable local sources of dry feeds. Being fresh and moist, they spoil fairly rapidly and are more difficult to handle, but they give extremely good results, particularly when the water is very cold (fig. 1). Moist feed is now produced industrially and is the major source of food for Atlantic salmon reared in sea cages in the Maritimes. Silage made from waste products from the herring roe fishery can be used as a substitute for raw herring in moist feeds, providing a good source of protein and lipids. Silage is made by grinding whole fish or fish-processing wastes with acid or fermentable carbohydrates. Natural enzymes break down the protein and liquify the fish, and the acid prevents microbial spoilage.

Nutritional requirements of salmon in sea water: Although much research had been conducted on fish grown in fresh water, studies of the nutritional requirements of salmon living in sea water were limited. In marine environments, fish can absorb some minerals (calcium, magnesium, sodium, and potassium) directly from the water, but phosphorus and trace elements can be obtained only from their food (Lall, 1989). However, not all that is added to the food can be absorbed, and excess phosphorus released from uneaten food and excreta enriches the water and stimulates algal growth. This, in turn, degrades the downstream environment and is not acceptable. Therefore, experiments are underway to identify feed ingredients which have highly digestible forms of phosphorus while supplying the smallest amount required for the diet to minimize the environmental impacts of hatcheries and fish farms.

Because salmonids utilize carbohydrates less efficiently than do terrestrial animals, they require a higher percentage of protein in their diets, some of which may be metabolized for energy. In sea water the requirement for protein is also slightly higher than in fresh water. Marine fish oils are incorporated into diets to supply energy and essential fatty acids (EFAs), as fish cannot synthesize the latter. Since dietary lipids are used more efficiently than protein as a source of energy, commercial salmon diets contain a high proportion of fat (24 to 30%), thus conserving protein to maximize growth. The basic mechanisms by which salmon synthesize and convert fatty acids, and deposit them in their flesh, are the same in both fresh water and sea water, but there are significant differences in the fatty-acid composition of fish raised in the two types of environments. (The lipids of fish from fresh water may contain both n-6 and n-3 EFAs, but salmon reared in sea water contain higher proportions of n-3 fatty acids.)

Broodstock nutrition: Both the quality and the quantity of parental diets affect reproductive success and the subsequent development of the offspring. Variations in the chemical composition of nutrients are reflected in the quality of eggs (their colour, weight, and size), milt (or sperm), and newly-hatched fry (Lall, 1991). The act of spawning leaves salmon physiologically exhausted; in nature most Pacific salmon, and some Atlantic salmon, die. Early efforts to recondition spawned Atlantic salmon were met with severe mortality among the next generation of eggs and a low survival rate among the fingerlings. These problems were shown to be due to inadequate concentrations of zinc, manganese, and vitamins A, C, and E in the mother's diet, and to the inadequate transfer of these materials from her to the eggs. This finding was taken into account when diets for commercial broodstock salmon for the aquaculture industry were formulated (Ritter, 1989).

We now know that the n-3 type of fatty acids are essential in broodstock diets; they play an important role at each stage of egg development, and are required for normal spawning and to ensure that the eggs will hatch (Leray *et al.,* 1985). Excess carbohydrates in the diet may be harmful, producing abnormally high levels of glycogen in the liver and increasing susceptibility both to infections and to poisoning by minerals,

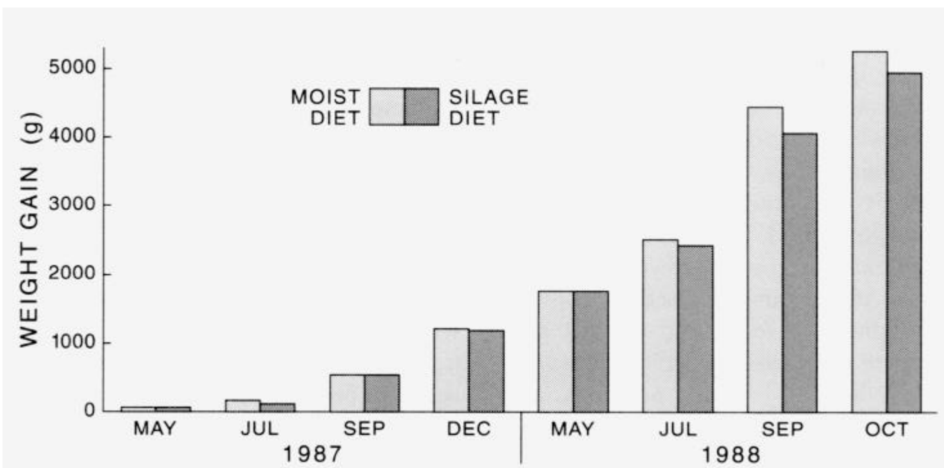


Figure 1. The weight gain of Atlantic salmon fed moist and silage-based diets for a period of approximately 17 months.

such as cadmium, which are already present in the diet. Carotenoid pigments such as astaxanthin and canthaxanthin, derived from sources like shrimp and lobster, impart colour to the flesh of salmon and their eggs, which range from pink to red, but the exact biological role of these pigments is not known. Essential nutrients are critical for egg quality, and the correct feeding rate is important because of its effect on the number of eggs produced.

The role of vitamins and trace elements in immune response and disease resistance: Fish diseases have sometimes been related to a lack or imbalance of trace elements, to marginal vitamin deficiencies, or to rancid food, and such factors are frequently at the root of much of the infection-related mortality observed on fish farms. Nutritional deficiencies influence the integrity of skin and epithelial tissues and the composition of tissues and body fluids, and they reduce mucous secretions, thus predisposing fish to infections. Often, signs of nutritional deficiency are masked by the symptoms of viral or bacterial diseases, and proper diagnosis requires the examination of blood and tissues, the measurement of tissue-nutrient concentrations, and an analysis of the histopathology.

Most of the diseases caused by nutritional deficiency develop slowly, but it is obviously in the farmer's interest to detect and treat such problems as early as possible. Subclinical signs of vitamin deficiencies have been determined by measuring specific enzyme activities in the liver, kidney, or red blood cells. For example, the activity of erythrocyte transketolase is reduced by thiamin deficiency; that of muscle amino transferase, by lack of pyridoxine; and that of liver acetyl CoA carboxylase, by a deficiency of biotin.

Both essential and nonessential nutrients, if consumed in excess over a prolonged period, become toxic. Furthermore, excessive use of growth stimulants, preservatives, binders (used to improve the stability of feed), and nutrient supplements may also affect the health of fish. Nutrient toxicity problems are primarily caused by a surplus of fat-soluble vitamins and of copper salts, selenium salts, and fluoride salts. Natural toxicants in feed include compounds of microbiological origin (bacterial, fungal, and algal toxins, etc.), compounds of animal origin (thiaminase, avidin, etc.) and nonessential heavy metals (lead, cadmium, mercury, etc.). Toxic compounds may also form while the feed is being processed and stored.

An excellent example of fish becoming predisposed to a bacterial disease as the result of nutrient deficiencies occurred at the Margaree Fish Culture Station. Here we were able to show a relationship between the concentration of iodine in the diet and the incidence and severity of bacterial kidney disease. The iodine level was low in both the water and the food, but by adding small amounts of potassium iodide or ethylene diamine dihydro iodide to the food, the incidence of the disease could be largely controlled.

Research into lobster nutrition

The Invertebrate Nutrition Research Program at the Halifax Fisheries Research Laboratory was initiated in December 1970 with an emphasis on lobsters, although minor projects on molluscs such as oysters and scallops were also undertaken. Prior to this, the standard diet for lobsters held in the laboratory was a combination of beef liver and herring scraps, and although they survived, their overall condition was poor compared to that of freshly captured lobsters (Stewart *et al.*, 1972).

Feeding trials were conducted by giving captured adult lobsters a diet based on casein (a protein purified from milk), which had originally been formulated for rainbow trout. It was determined that approximately 50% of the dry weight of the lobsters' food had to be protein (Castell and Budson, 1976), that fish oils containing omega-3 fatty acids were superior to vegetable oils, and that the optimum lipid content of the diet was about 5% (Castell and Covey, 1975).

These feeding experiments took a long time to yield results, since growth could be observed only at moulting, which in adult lobsters occurs about once a year. In order to obtain more rapid results, we decided to use juvenile lobsters, which would moult about five times over the course of a 3-month experiment. This required that we set up a lobster hatchery so that the animals used in the experiment would all be of the same size, age, and genetic background.

The importance of cholesterol: While adult lobsters had survived on casein-based diets for periods exceeding two years and suffered no apparent detrimental effects, it was soon discovered that juvenile lobsters on the same diets died within two months. This created a serious problem, until we discovered the dietary factors responsible for the mortality. The possible detrimental effects of cholesterol on human health have been well publicized, so it was something of a paradox to discover that the deaths were due to a lack of cholesterol in the casein-based diets. Although the cod liver oil used in preparing the diet was 1 to 2% cholesterol, this was not sufficient to meet the needs of growing juvenile lobsters. The diet only contained 0.1 to 0.2% cholesterol even with a formulation of 10% cod liver oil. Eventually, we demonstrated that juvenile lobsters require cholesterol at approximately 0.5% of the dry weight of the diet (Castell *et al.*, 1975).

Moult death syndrome: a problem associated with vitamin-free casein: Initially, casein-based diets supplemented with 0.5 to 1.0% cholesterol yielded good growth and survival among juvenile lobsters. However, in 1974 some change in the quality of commercially supplied vitamin-free casein began to cause lobsters to die while they were moulting; the condition was termed moult death syndrome, or MDS (fig. *2).*

It is possible that the deaths were due to changes in the physical characteristics

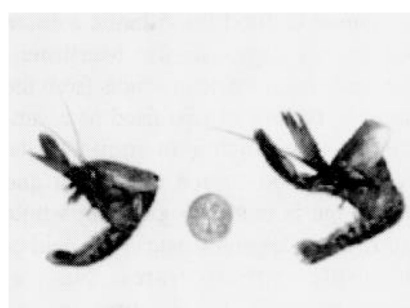


Figure 2. Juvenile lobsters that died of the moult-death syndrome (MDS) after being fed a casein-based, semipurified diet for 35 days. The animals were unable to complete the moult process.

of the casein, which affected its ability to bind the diet and to reduce the leaching of water-soluble nutrients. Researchers at the University of California determined that the casein-induced MDS could be reduced or prevented by adding soy lecithin (a water-insoluble emulsifing agent) to the diet in a concentration of 6 to 10%. Nevertheless, the problem stimulated a search for a more suitable protein. In co-operation with Dr. Andrew Boghen of the Université de Moncton, the Invertebrate Nutrition Group discovered that excellent results could be obtained by using a protein extracted from the rock crab *Cancer irroratus,* a natural prey of the lobster (Boghen *et al.,* 1982). When casein was replaced with this nutrient-balanced crab protein concentrate (CPC) in experimental lobster diets, there was no longer any requirement for supplemental lecithin (Kean *et al., 1985).* In addition, the protein requirement was decreased from 50% of the diet to between 25% and 30%, and the cholesterol requirement was halved.

Trace elements: copper, silver, and cadmium: Identifying the concentrations of trace elements required in the diet of marine organisms is complicated by the presence of trace elements in the water, and by the ability of many aquatic animals to absorb these directly through the gills and skin or from the water they drink. In addition, there is sometimes a very small difference between the required amount and the level that is toxic. This has led to close cooperation between the toxicology and nutrition research groups, and some very interesting information has emerged.

For example, in lobsters the respiratory protein that carries oxygen in the blood is hemocyanin, which contains copper, unlike the hemoglobin of mammals, which contains iron. The toxicology group had observed a direct relationship, a natural balance, between the levels of copper and silver in the tissues of several crustaceans (Chou and Uthe, 1978). As the copper content of experimental diets fed to juvenile lobsters was increased, there was a corresponding increase in the concentration of copper in the animals' tissues (especially the hepatopancreas), which was itself accompanied by an increase in the level of silver (Chou *et al.,* 1981). Since no silver was present in the diets, the lobsters must have been absorbing it directly from the sea water in order to maintain the silver-copper balance. Although lobsters can absorb copper directly from sea water, the addition of 16.2 mg of copper for each kilogram of feed improves growth, but diets with concentrations of 40 mg or more per kilogram retard growth and reduce survival. The toxicity of excess dietary copper can be offset by a supplement of silver.

Marine crustaceans accumulate trace elements, such as cadmium, in the hepatopancreas; wild lobsters have been known to have in excess of 700 mg/kg of cadmium in the hepatopancreas (Uthe *et al.,* 1982). Although cadmium is toxic to fish, diets containing 45 mg/kg had no effect on the growth or survival of juvenile lobsters, even though the concentration of cadmium in the hepatopancreas reached 260 mg/kg (Chou *et al.,* 1987). It is not yet known whether lobsters require cadmium, but it is interesting that this element, which is dangerous to humans, has a much wider safety margin in lobster diets than does copper, which is an essential element for these animals. Waste from plants that process lobster and shrimp is frequently used in commercial fish feeds. Since these waste materials contain much hepatopancreas and may have a high cadmium content, it is essential to monitor toxic trace elements, like cadmium, in cultured fish in order to ensure that the products are safe for human consumption.

Growth acceleration: The growth of crustaceans such as the lobster is controlled by a moult-inducing hormone produced by a gland at the base of the antenna, and by a moult-inhibiting hormone produced by a gland in the eyestalk. Removal of the eyestalk accelerates moulting, but the lobster rarely survives more than one or two postoperative moults unless careful attention is given to its diet (Mauviot and Castell, 1976). Lobsters on which this growth-acceleration technique has been used have been reared to market size (500 g) in 13 months, compared with the three years required for intact lobsters grown under identical conditions. Lobsters without eyestalks also respond more rapidly to differences in experimental diets (Castell *et al.,* 1976). Cooperative studies of this growth-acceleration technique were conducted at the St. Andrews Biological Station in New Brunswick (Castell *et al.,* 1977), as well as by a commercial lobster dealer (Bishop and Castell, 1978) and at Dalhousie University (Koshio *et al.,* 1989, 1990).

Development of international standards for experimental diets: Over the past 20 years, the nutrition research group has participated in a number of international task forces and working groups, and through these it has played a key role in standardizing the techniques used in aquatic nutrition research. In 1984, an international cooperative study began to evaluate the lecithin-supplemented casein-based diet (developed at the University of California) and the crab protein-based diet (developed at the Halifax Fisheries Research Laboratory) as possible standard reference diets. Experiments were conducted with 28 different crustacean species (Castell *et al.,* 1989; Castell, 1990). Subsequent studies which we conducted in Nova Scotia, California, Sweden, and China have investigated the optimum ratios of protein to energy and the amounts and types of essential fatty acids required in crustacean diets.

Research into molluscan nutrition

The study of the nutrition of bivalve molluscs is even more difficult than that of fish or crustaceans. Oysters, scallops, and mussels are filter feeders which ingest single-celled micro-algae, bacteria, and suspended detritis. They also absorb dissolved organic molecules and inorganic salts directly from the water. If prepared feeds are used, the extremely small size of the particles results in serious losses of water-soluble nutrients. Despite such problems, we were able to demonstrate that oysters *(Crassostrea virginica)* also require the omega-3 fatty acids found in marine oils, rather than the omega-6 type found in corn oil (Trider and Castell, 1980). This conclusion was further supported by studies in which the lipid composition of algae fed to oysters was manipulated by varying the conditions under which the algae were cultured (Enright *et a/.,* 1986). Because of the leaching of water-soluble compounds from prepared feeds, it is impossible to determine exactly what is consumed by oysters. But if some type of thin membrane could be wrapped around each food particle, the problem of leaching would be solved.

Micro-encapsulation and microparticulate diets: Feeds have been successfully encapsulated in a thin membrane of nylon-casein, a synthetic nylon-protein membrane developed at Laval University (Chang *et al.*, 1966). Initial attempts at the Halifax Fisheries Research Laboratory to use these feeds with year-old American oysters resulted in poorer survival rates, and greater weight losses than those experienced during starvation (unpublished results). However, biologist Joan Kean-Howie is getting much better results using calcium alginate-bound micro-particulate feeds in her research with the giant scallop *(Placopecten magellanicus)*. This technique holds much promise, as does study of the nutrient composition of cultured algae and the effect of differences in algal composition on the survival, growth, and health of molluscs.

New initiatives in marine fish nutrition

The potential for culturing species such as the Atlantic halibut *(Hippoglossus hippoglossus)* has stimulated several research projects in Canada, the United States, and Europe, and our group now plans to study species other than crustaceans which hold promise for commercial culture in Atlantic Canada. A stumbling block in the development of culture techniques for marine fish is the difficulty of rearing these fish through their early larval stages. Species like the halibut have much smaller eggs and larvae than do salmonids, and hence salmonid feeds are quite inadequate. Successful efforts to raise halibut larvae have used live food organisms, such as brine shrimp, rotifers, algae, and copepods, which must themselves be cultured or captured and somehow concentrated. An important feature of these organisms is a relatively high concentration of the long-chain omega-3 fatty acids. In the future, research will focus on the factors which control the content of these essential fatty acids in live food organisms, their transfer through the food chain, and the subsequent development of microparticulate formulations suitable for larvae and juveniles. As with salmonids, an important factor in the survival of cultured marine fish larvae will no doubt be the quality of the parental diets, which affect the viability of the eggs and sperm. Discovering the role of lipids in broodstock nutrition and in the subsequent growth, survival, and health of the larvae, and developing suitable diet formulations to support the next major expansion of aquaculture, is a thrilling and rewarding challenge.

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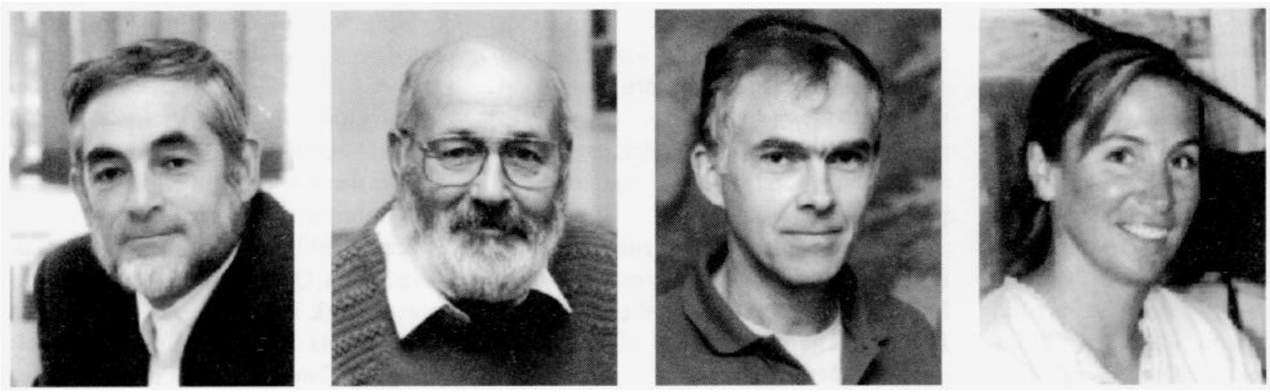
Shellfish culture in Nova Scotia

R. E. Lavoie, D. J. Scarratt, K. Freeman, and B. Bradford



R. E. Lavoie *D. J. Scarratt* *K. Freeman* *B. Bradford*

Shellfish culture has been practiced for a long time. Oysters were cultivated in Europe during Roman times (Bardach *et al.,* 1972) and, in America, "oyster planting" has been employed in New Jersey since 1810 (Stafford, 1913). In Canada, the practice began officially in 1865, when the Government of Prince Edward Island passed a statute providing for the leasing of specific areas for the purpose of oyster culture (Mathieson, 1912; Lavoie, 1989).

Until the 1970s, the American oyster *(Crassostrea virginica)* was the only molluscan species under cultivation in Atlantic Canada. Its culture was encouraged at the beginning of this century largely as a result of a severe decline in production by the wild fishery, which fell from a peak in 1882 of approximately 5,860 t to a low of 2,475 t in 1907. Culture methods were imported from France, England, Japan, and the United States, and provincial governments devoted considerable effort to research in oyster biology, the adaptation of the culture methods, and the transfer of technology to fishermen.

Early attempts by government to secure seed supplies led to the importation of oysters from the United States to Prince Edward Island. It is widely believed that this American seed caused the Malpeque disease, which killed more than 80% of Prince Edward Island's stocks in 1915 and 1936. Although the disease spread to waters around the Nova Scotia mainland in 1954, oysters living in the waters of the Northumberland Strait today appear to be disease-resistant. The Bras d'Or Lakes also remain disease free.

The culture of the blue mussel *(Mytilus edulis)* became popular in Nova Scotia in the 1970s. Its success, and the industry's desire to diversify, led to increased interest in other species. At present, there are three species of molluscs under cultivation in Nova Scotia: the American oyster *(Crassostrea virginica)* and the blue mussel *(Mytilus edulis),* both of which are indigenous to the Maritimes; and the European oyster *(Ostrea edulis),* which was introduced to the region. Culture of three more species -the giant scallop *(Placopecten magellanicus),* the quahog *(Mercenaria mercenaria),* and the bay scallop *(Argopecten irradians)* - is in the development stage (fig. 1).

This article briefly describes the current status and potential of cultivated

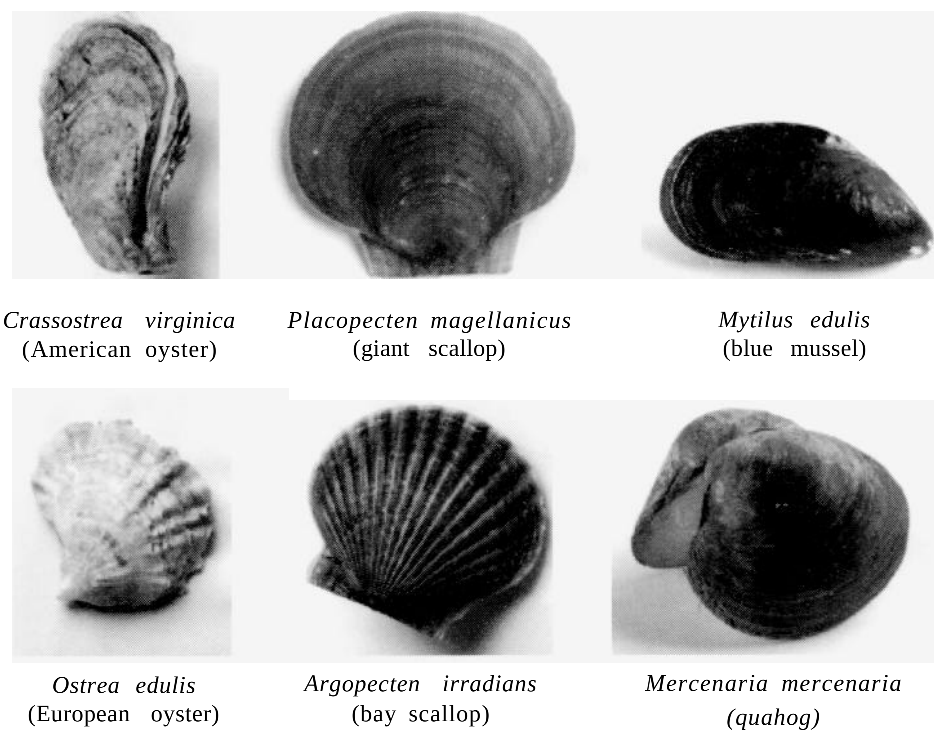


Figure 1. Shellfish species whose culture is currently being pursued in Nova Scotia.

species and presents some early results regarding species currently under development. It also describes ongoing research and identifies some of the pressing research needs.

Species under cultivation: Status and potential

Mussels: Following experimentation in the 1970s mussel culture in Nova Scotia has undergone a steady expansion. Reported landings of cultivated stock since 1985 demonstrate an increase to 500 t in 1990 (fig. 2). The leasing of inshore sites initially proceeded rapidly, but the subsequent development of farms has been slow. Full exploitation of existing leases alone would result in a seven- to ten-fold increase in annual production. Furthermore, not all suitable Nova Scotian sites have been occupied. This contrasts sharply with Prince Edward Island, a province with less space for aquaculture, but whose best sites are fully occupied and whose reported production is ten times that of Nova Scotia. There is opportunity for major expansion in Nova Scotia, but its timing and extent are difficult to predict because the decisions of lease owners depend on other factors, principally economic, but also related to market development.

To date, commercial mussel cultivation in Nova Scotia has been characterized by the usual growing pains of any beginning industry, including insufficient or inappropriate regulation, unproven technology, and deficient marketing policies. Variable prices have resulted in unpredictable sales, and the lack of product certification has sometimes resulted in shellfish of inconsistent quality being produced by poorly trained or uncaring entrepreneurs. Problems specific to shellfish, such as the domoic acid crisis of 1987, make monitoring programs and research support necessary in order to promote consumer confidence, and minimize market damage in the event a problem arises.

Nonetheless, mussel culture offers employment opportunities to those looking for alternatives to the traditional fisheries. The development of secondary product lines will expand local markets, and the imposition of regulations will ensure that all mussels sold are properly grown and inspected, thereby improving consumer confidence as consistent high quality becomes established. In short, the future of the industry is good.

American oysters: In Nova Scotia, the American oyster grows naturally along the shores of the Northumberland Strait, from River Philip to the Strait of Canso, and in the Bras d'Or Lakes and Aspy Bay in Cape Breton. The species has been harvested from the province's waters for a long time (Stafford, 1913). Landing statistics for the period from 1876 to 1909 situate the peak of 392 t in 1891, followed by steady decline. Jurisdictional disagreements between the province and the federal government prevented the development of oyster culture until 1912, when an amendment to the Fisheries Act made it possible to lease parcels of sea bottom for the purpose of growing the molluscs.

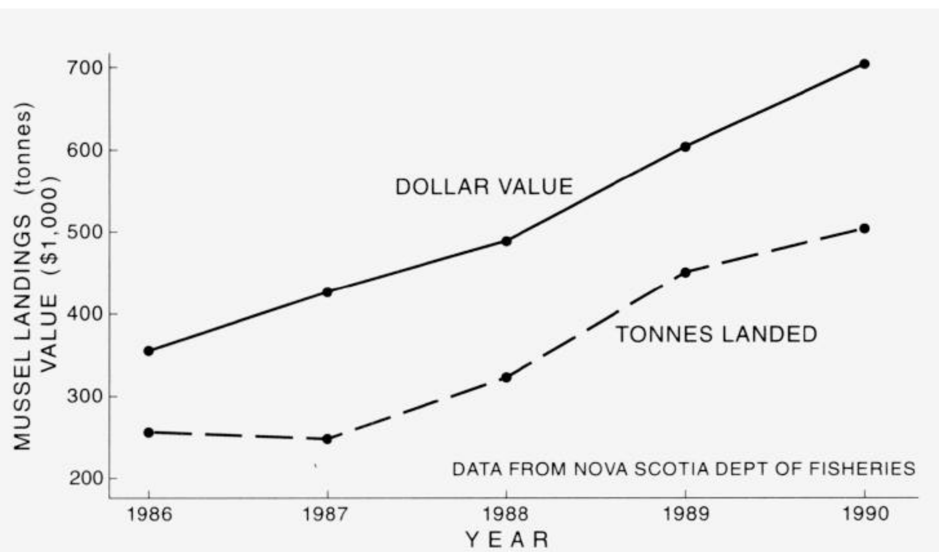


Figure 2. The increase in mussel landings since 1985.

In 1989, the culture of American oysters in Nova Scotia involved 270 leases covering 562 hectares of sea bottom. Reported production was 135 t with a landed value of $210,000. Seed is available from natural sources in Cape Breton and from hatcheries elsewhere. Grow-out methods include the use of off-bottom trays and on-bottom culture to produce the cup oyster demanded by the half-shell markets of Nova Scotia, Quebec, and Ontario. Development work includes juvenile grow-out experiments in upwellers and salt marshes. Constraints on development include coastal water pollution, theft of oysters from leases, inconsistent quality, and a lack of knowledge on the part of prospective producers. However, the potential is considerable. It is estimated that the 2,000 hectares of appropriate sea bottom in the province could produce 4,000 t of oysters annually. Assuming that this production would be of suitable quality for the half-shell trade, this crop could be worth $6 million annually.

European oysters: The European, or Belon, oyster was introduced into the Maritimes in the late 1950s as a potential supplement to the culture of the native oyster, and was first brought to Nova Scotia in 1970 (Muise *et al.*, 1986). It was thought that this species could be cultivated in the colder, relatively saline waters between the Strait of Canso and Yarmouth. In the following 15 years, much research and development work was conducted. By 1983, the species had been studied and tested at 17 sites along the province's Atlantic coast. At present, 17 leases covering 146 hectares are licensed to grow the Belon.

This species is highly ranked in the marketplace, where it fetches top prices as a luxury item. The Belon offers the additional attraction of being in high demand in Europe, where natural and cultivated stocks have been decimated by diseases. At current prices, shipping oysters to Europe by air appears to be economical.

For many years, the major obstacle to developing the culture of this species was seed supply, but that is now assured by a modern hatchery. The next hurdles to overcome include the development of technologies for culturing juveniles, the selection and testing of grow-out sites in previously untested areas, and the training of new growers.

Species under development: early results

Giant scallops: A cold-hardy native of Maritime waters, the giant scallop supports traditional fisheries worth in excess of $100 million annually. Its high price and established markets also make it an attractive candidate for culture.

To obtain giant scallop seed for cultivation, wild spat are collected and grown in fine-mesh bags in Passamaquoddy Bay, New Brunswick, or in Port-au-Port Bay, Newfoundland. After a year they are transferred to pearl nets (fig. 3) and left to grow for another year. For the final grow-out stage, the juvenile scallops (40 mm) are transferred to lantern nets or ear-hanging lines. Grow-out sites require water depths of 10-30 m in semisheltered, ocean-influenced locations. The equipment is usually placed well below the surface in order to achieve optimal growth, reduce wear and tear, and make it less visible.

Cultivated scallops can reach market size (75-90 mm) in 28 to 30 months (fig. 4). The product is then marketed whole in the European manner or, if there are local or seasonal problems with toxins, the meats may be marketed alone.

As of 1991, two scallop farms were nearing commercial production in Nova Scotia and four others were under development. By 1993, it is expected that close to a quarter of a million scallops will be ready for market.

Bay scallops: Bay scallops were first introduced to the Maritimes in the late 1970s from southern New England (Drinnan, pers. comm.). The species is an annual: larvae spawned in the early summer will be almost full-grown by fall and will mature, spawn, and die the following spring. This brief lifespan makes the bay scallop ideal for aquaculture, for it is the only shellfish species which can yield a cash crop in one growing season: spat set out in June in pearl or lantern nets will be marketable in November. However, bay scallops will not survive the northern winter, and brood stock must be brought into the hatchery for overwintering and subsequent conditioning. Breeding is then started in February in order to ensure that sufficient spat are available for planting out once the ocean begins to warm up.

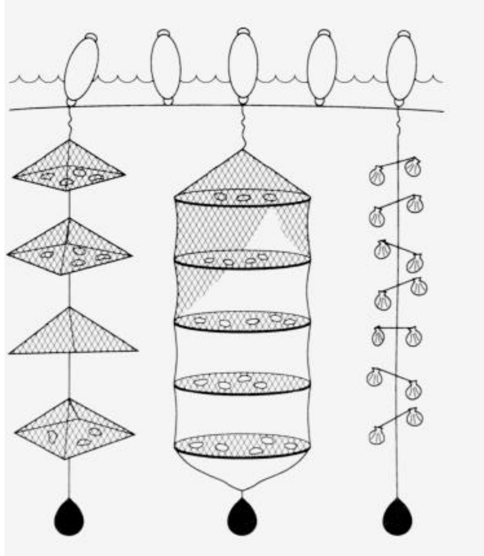


Figure 3. Diagrammatic representation of pearl nets, lantern nets, and ear-hanging lines (left to right), used in the culture of giant scallops.

In 1991, two growers in Nova Scotia were working with this species and annual production was about 15 t. The development of the industry is currently slowed by uncertainties about introducing new diseases, but ongoing research should soon resolve this concern.

Quahogs: Quahogs occur naturally in the Maritimes in the comparatively warm summertime waters of the Northumberland Strait and in the shallow bays of northern Prince Edward Island. In the 25 years prior to 1980, natural populations supported landings of less than 250 t per year. Thereafter, with increased demand and rising prices, annual landings rose to around 600 t.

American experience in quahog culture (Carver and Mallet, 1991) has stimulated local studies of the hatchery production of spat and subsequent out-planting. At present, the only commercial source of cultured quahog spat in Nova Scotia is S.F.T. Venture, in Blandford. This firm has provided spat to Little Harbour Fisheries, where investigative work has been conducted into a combined upweller and tray rearing system, followed by bottom culture. This process brings the quahogs to marketable size in 3 to 4 years.

Ongoing research

Dimorphism among mussels cultivated in Nova Scotia: While the early pioneers of the mussel culturing industry believed that the Nova Scotia mussel was *Mytilus edulis*, it has now been discovered that two "blue" mussels, *M. edulis* and *M. trossulus*, are present, with their hybrids, in varying proportions along the Atlantic coast. The latter species has been identified only within the last few years (Koehn *et al.*, 1984), although it has undoubtedly been here for some time. Some growers had recognized independently that mussels of a certain shape (since shown to be *M. trossulus)* tended to be fractured by processing machinery, thereby causing higher losses than would normally be expected. Furthermore, a recent study (Freeman *et* al., 1991) has shown that, among mussels of similar length, *M. trossulus* contains less meat than *M. edulis.* Although they occur together in sheltered locations that are well-protected from general coastal circulation, an

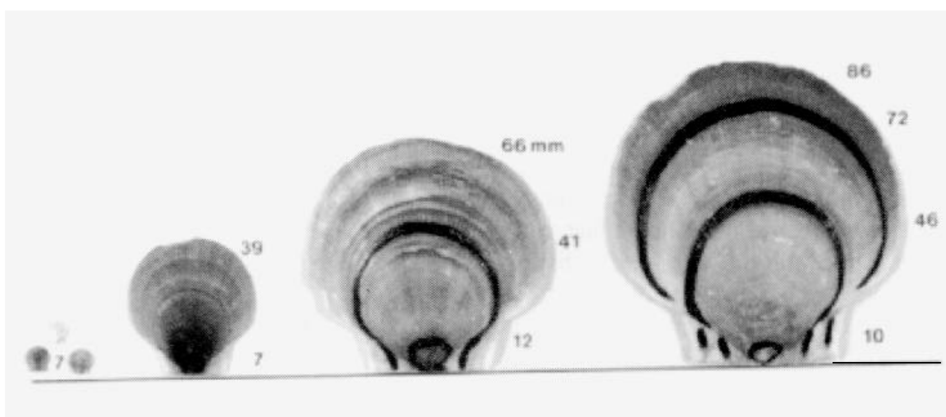


Figure 4. Sea scallops at 7, 12, 24, 30 months of age (7, 39, 66, and 86 mm respectively).

as-yet-unknown mechanism has allowed these species to maintain their identities, despite some hybridization.

Field and laboratory studies of the reproduction and recruitment of the two species show that their spawning times are almost identical, as are the times to metamorphosis of their larvae. Separating naturally occurring spat in the field, or preferentially selecting for one of the species, will be difficult if spat settlement times also coincide, unless there are other behavioural differences which can be exploited. Spat have been collected at one site since they began to settle in June 1991, and the ratios of the two species will be determined when the animals are large enough to be analyzed. Unfortunately, they cannot be distinguished by eye until they approach market size, and reliable identification requires the analysis of isoenzymes.

Improvement of bay scallop broodstock: Nova Scotia's original bay scallop broodstock was derived from a handful of animals first brought to Prince Edward Island and raised in quarantine through several generations. At times, the number of spawning adults in the populations was very small, and by 1988 there were strong suspicions that the poor breeding success of hatcheries was attributable to repeated inbreeding. In April 1989, a new group of mature bay scallops was brought from Cape Cod for breeding at the Halifax Fisheries Laboratory's quarantine unit. After being inspected for diseases, the laboratory-reared spat were released to the industry in order to augment the older stock. This new stock is now in its second generation and is proving reasonably successful, although some technical difficulties in the hatcheries must still be overcome to ensure better survival of the larvae.

Parasites and studies of their transmission: Notwithstanding the insistence on quarantines and careful inspections, it appears that bay scallops do, in fact, carry a parasite *(Perkinsus karlssoni)* which is new to science. It does not appear to be harmful to the scallop, and all experimental attempts to transfer it to native species appear so far to have been unsuccessful.

This microsporidian parasite lives scattered throughout the gonads and other tissues of infected individuals and releases small, sticky, biflagellate infective cells. It is theorized that these may stick to the surface of newly released eggs or of the developing embryos and infect them at some later time. The parasite has not been detected in bay scallops younger than 4 or 5 months, so the actual stage at which infection occurs is not yet known. Attempts are underway to develop a procedure for disinfecting the eggs before parasite transfer to the new generation is complete. Until the nature of the infective process, and the host-specificity of the parasite, are fully understood, bay scallops will be cultivated in Nova Scotia only in the dozen or so areas where they have previously been grown.

Accumulation and elimination of phytotoxins in mussels: Phytotoxin accumulation is a recurrent problem in the shellfish industry, but it was believed that protocols established 50 years ago to test for paralytic shellfish poisoning (PSP) were sufficient to protect consumers and the industry. However, the toxic shellfish crisis of 1987, which caused amnesic shellfish poisoning (ASP) and led to the discovery that domoic acid from the diatom *Nitzschia pungens* was a potential contaminant of cultured shellfish, caused these protocols to be re-evaluated. The more recent, and by now not unexpected, detection of diarrhetic shellfish poisoning (DSP) in mussels off Nova Scotia has added yet more urgency.

With PSP, the toxin binds very tightly to shellfish tissues and is eliminated very slowly. Domoic acid, on the other hand, is very soluble in water and can be eliminated (or depurated) rather quickly (fig. 5). Sufficient data have now been acquired to establish a depuration protocol for mussels containing not more than 100 ppm of domoic acid; the process uses recirculating sterilized seawater. Depuration to below 2 ppm can be accomplished in less than 48 hours, and no individual mussel is to exceed the control level of 20 ppm. This offers the hope that farms contaminated with domoic acid can remain in operation during a toxic phytoplankton bloom and that marketing opportunities can be safely preserved. The establishment of protocols for all species of shellfish exhibiting high levels of contamination awaits a significant natural "toxic event", since meeting the requirement for bulk culture of toxic *Nitzschia pungens* remains elusive given current rearing techniques. The elimination rates of diarrhetic shellfish toxins are not known, but research on this question is planned.

Required research

Optimizing culture methods: The diversity of the bathymetry, currents, microregimes of temperature, and primary production of the bays and estuaries where mussels are cultured is such that optimizing production is not simply a matter of applying different cultivation methods. Suspending the mussels on longlines is the basic method used in the Maritimes, but variations in the depth at which they are placed, the length of the socks (mesh tubes) in which they are held, the density at which they are stocked, and even the variety of seed can have significant effects on the level of production at a

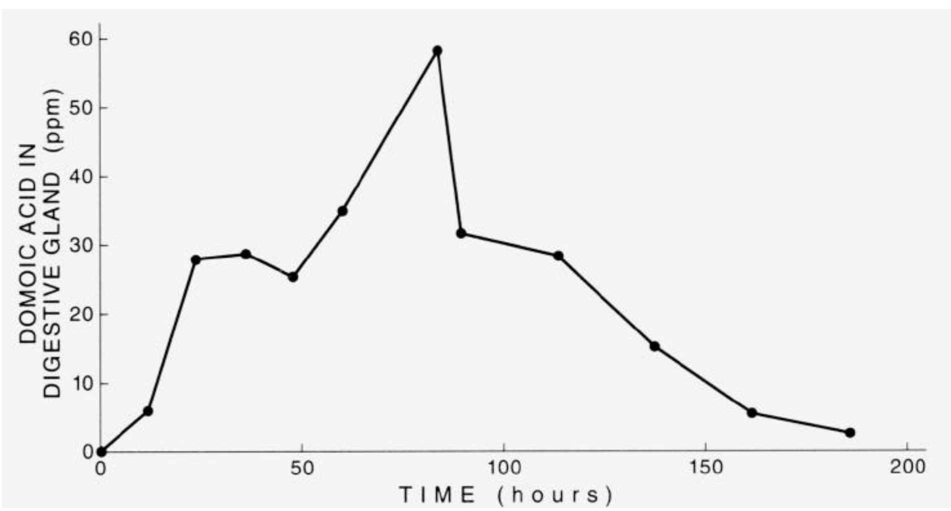


Figure 5. Uptake and elimination of domoic acid by bay scallops at 10°C.

given site (Mallet and Carver, 1991). Not all possible combinations of stocks and sites have been tried, and comparative studies will continue in order to optimize yields from different farms. An understanding of the commercial value of resocking undersized mussels culled at harvest is needed, particularly in areas where *M. trossulus* is present. Since this is a commercially inferior species, returning the culls to the socks may be counterproductive in the long term. There is also a need to develop methods for preferentially collecting *M. edulis*, or identifying local, pure populations from which commercial quantities of spat can be collected for grow-out elsewhere.

European oyster growers need more information in the areas of broodstock selection, high-density rearing of larvae, larval survival, juvenile rearing techniques, and predator-prey relationships. The research required to address these questions will likely involve nutrition and diet studies, the methodologies and results of which may apply to more than just this species. Detailed environmental data for potential culture areas and criteria for selecting grow-out sites are needed in order to give growers the advantage of knowing where optimal conditions exist for growing the oysters in Nova Scotian waters.

Research on the culture of giant scallops has so far been undertaken primarily by the industry. The first priority is for a hatchery able to produce a superior, fast growing scallop seed and the development of successful setting techniques. Much has been accomplished privately but the results are not publicly available. To complement these efforts, DFO is currently funding a survey of Nova Scotia's coast in order to locate a dependable source of wild seed. Because spat collectors at seven sites have yielded low catches, more intensive sampling will be required (M. J. Dadswell, pers. comm.).

Scallops grown experimentally in suspension grow faster than those grown on the sea bottom. However, this may not be so for commercial quantities, and little is known about the carrying capacities of different sites. The mortality of spat and juveniles is almost negligible but increases as scallops approach market size. Although the cause remains unknown, it should be resolved.

Additional research needs involve comparisons of grow-out techniques, including manual and mechanical ear-hanging methods, different types and sizes of nets, and bottom culture. Information on the shelf life and on shipping and handling procedures is also required as the market develops for whole, in-shell scallops. Implicit is the need for standardized, mandatory testing for all possible shellfish toxins and contaminants.

Last but not least on the list of research candidates are quahogs, whose natural settlement is capricious and, as a result, causes many natural spat to be lost to predation. Thus, the development of quahog culture will depend upon hatchery production of a reliable supply of genetically improved, fast-growing seed and the development of nursery technology to bring the seed through the vulnerable juvenile stages. Trials of various rearing methods (such as upwellers, trays, and on-bottom culture) need to be continued, and alternative sites must be evaluated.

Establishing transfer protocols: The culture of shellfish requires the regular transfer of seed from the hatchery or collection site to the farm, and of brood stock from the farm to the hatchery. The process of moving any living organism is accompanied by the risk of transferring diseases and parasites and, in the case of shellfish, other species which may not normally live in the receiving zone. For example, the unintentional introduction of shellfish diseases to France destroyed the native European oyster stocks.

Thus, there is a pressing need for comprehensive regulations which will ensure that, in their zeal to establish new industries and maximize the aquaculture potential, developers do not bring in debilitating diseases or strange bedfellows with their cultured stocks. This will be accomplished in part by amendments to the Fish Health Protection regulations which, for the first time, will include shellfish and shellfish diseases and require that stocks be free of named diseases and parasites before they can be transferred or introduced. There will also be requirements to ensure that alien species are not transferred with shellfish shipments. Even now, in the absence of such regulations, hatchery operators and growers are requesting that their shellfish be inspected for diseases, since they do not want to put existing stocks at risk. There is still much to learn about shellfish diseases, and in the short-term the prudent approach will be best.

Controlling the effects of contaminants: Nova Scotia is fortunate in that, with a few notable exceptions, little of its shoreline is contaminated by industrial pollution. However, this is not the case with domestic sewage discharges: at present, about one-third of the province's coastal zone is off limits for shellfish culture.

The long-term solution is for improved sewage treatment systems onshore, but there are some short-term options which merit exploration. First, these nutrient-enriched nearshore zones could be used as nursery areas to allow the accelerated growth of the juvenile spat of a number of species before they are transferred to clean sites for final grow-out and finishing. Bay scallops, quahogs, and European oysters are likely candidates. A second option is to explore more fully the use of depuration techniques for cleansing shellfish that are grown to market size in marginally contaminated areas. In some locations, this might be more cost-effective than a full-scale municipal sewage plant, and might even be municipally funded.

Conclusion

Molluscan culture in Nova Scotia still has far to go before it reaches its full potential. The history of oyster production on the Northumberland Strait indicates that the environment is suitable for the activity. The Atlantic coast's myriad bays and estuaries offer many sites that are protected from storms, and on the south shore of Nova Scotia several areas are ice free. Yet why is development so slow? Some of the reasons may be scientific, and some social.

Several species appear to be good candidates for commercial shellfish culture. This could, over time, provide a healthy diversification of products. In the short term, however, simultaneous attempts to develop several species create large and diversified demands for new information. At present, government and industry do not have sufficient resources to acquire such information through research and integrating it into the culture processes and tradition that accompany shellfish culture.

New legal and administrative structures must be put in place and tested in order to protect and control aquaculture activities and to ensure the safety and quality of the products. Coastal communities must be sensitized to the requirements and benefits of aquaculture before it is fully accepted and supported. Like any process requiring human evolution, molluscan culture in Nova Scotia needs more input from science, industry, and the community before it matures to its full potential. The promise is still there, and it is more attractive than ever.

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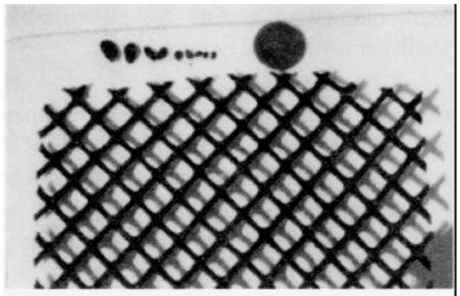
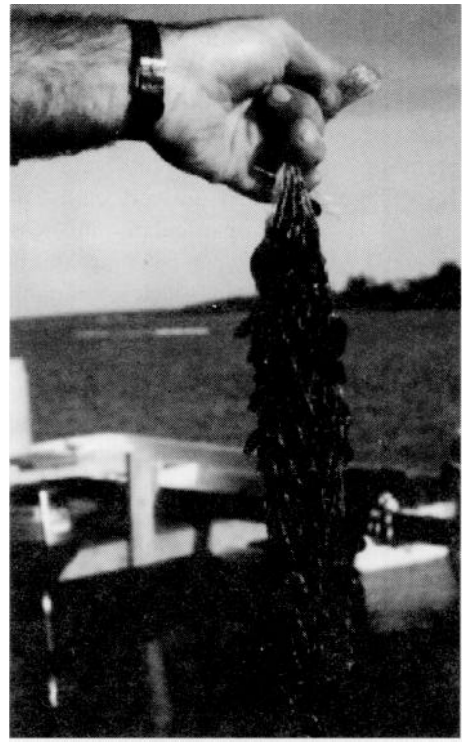
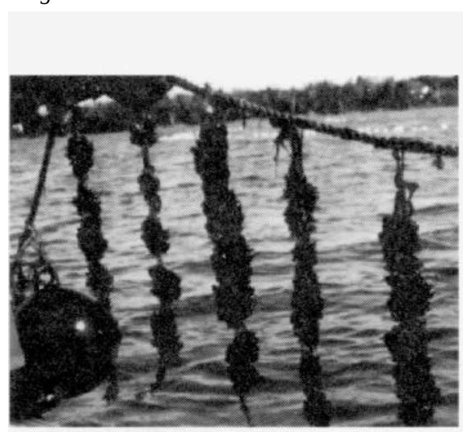


Baby mussels attach themselves to plastic "collectors".

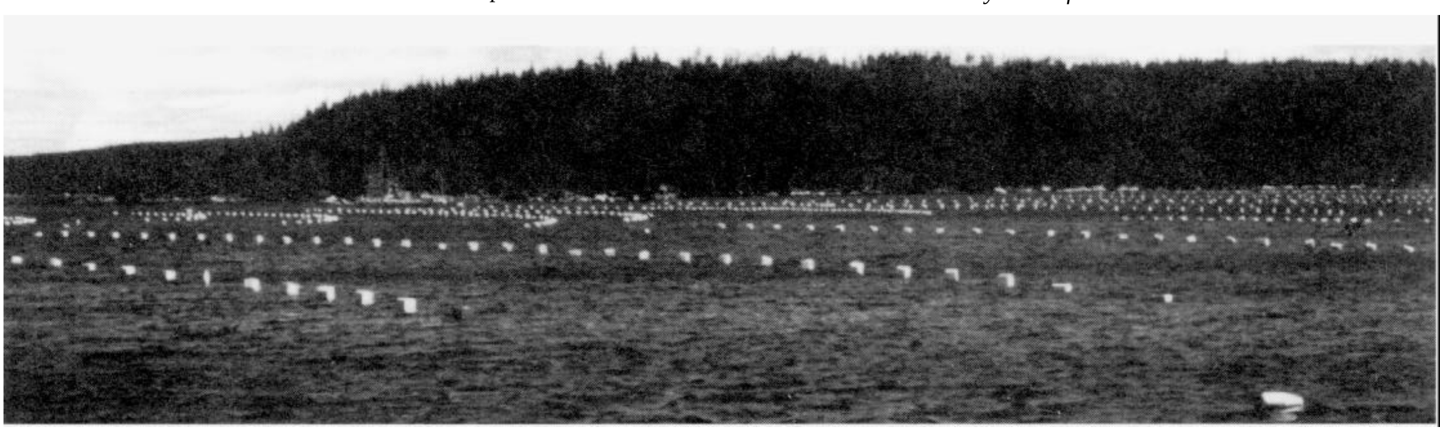
Mussels from collectors are placed in plastic mesh "socks".



Mussels in the socks are hung on the long lines.



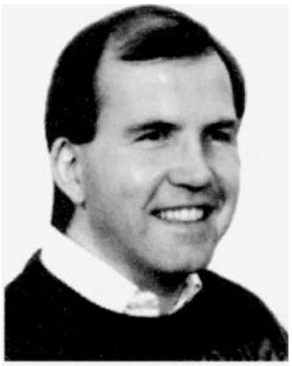
Mussels in sosks grow on long lines for a year before harvest.



Mussels are grown underwater on "long line.s", which are ropes attached to buoys

Lobster habitat ecology research in the Bay of Fundy

P. Lawton and D. A. Robichaud


P. Lawton


D. A. Robichaud

Obtaining a comprehensive understanding of the habitat requirements of the lobster *Homarus americanus* is problematic. The species exhibits a complex life cycle *(sensu* Wilbur, 1980), with a pelagic larval phase, metamorphosis prior to settlement (Charmantier *et al.,* 1991), and a protracted benthic life phase. During the benthic phase, the lobster can grow from approximately 5 mm in carapace length (CL) at settlement to greater than 250 mm CL (Wolff, 1978), and the animal's natural life span is thought to be between 20 and 100 years (Elner and Campbell, 1991). Lobsters over 200 mm CL are routinely captured in the deep-water trap and mobile gear fisheries of the Bay of Fundy and in the Canadian offshore lobster fishery. In our diving studies, conducted from 1989 to 1991, lobsters captured in shallow inshore waters (less than 20 m deep) ranged from 5 mm to 217 mm CL. Clearly, a discussion of lobster habitat ecology has to focus on well-defined life phases.

Wahle and Steneck (1991) recognized, from their experience and a review of earlier literature, three benthic life phases. The early benthic phase refers to lobsters from the time they settle until they reach approximately 40 mm CL - perhaps the most cryptic segment of lobster life history. Adolescent-phase lobsters are larger, pre-reproductive lobsters which dominate nearshore habitats, foraging nocturnally (Lawton, 1987), but only moving several km a year (Campbell and Stasko, 1986). Following sexual maturity, which depends on temperature and varies geographically (Aiken and Waddy, 1980), reproductive-phase lobsters are more mobile, moving toward deeper waters and possibly dispersing offshore (Campbell and Stasko, 1986), or making distinct seasonal return migrations between shallow and deep water (Campbell, 1986).

The Invertebrate Fisheries Section at the St. Andrews Biological Station provides biological advice on the Bay of Fundy lobster fishery, which recorded landings in 1989 of 984 t, valued at $6.9 million. Other lobster fishing areas within the Scotia-Fundy Region are monitored by scientists at the Halifax Fisheries Research Laboratory, who have their own research programs within the broad context of lobster habitat ecology. A unique aspect of the research conducted by the St. Andrews team is that, in addition to meeting a fisheries assessment mandate, the work has been directed to respond to demands for advice about the impacts that a burgeoning local salmon aquaculture industry might have on the existing lobster fishery. Cook and Lavoie (1991) provide a brief review of recent aquaculture development in the Bay of Fundy.

It is commonly believed that salmon aquaculture has little or no adverse effects on lobsters. As mobile opportunistic scavengers, lobsters may well immigrate into aquaculture areas to exploit locally increased benthic productivity, or, conversely, are able to emigrate should environmental quality deteriorate. Nevertheless, lobsters during their early benthic and reproductive phases (particularly those that are carrying eggs, or are "berried") use their habitat in ways that can make them more susceptible to changes in benthic habitat conditions, such as those associated with salmon farms.

Early benthic-phase lobsters

Following postlarval settlement (Wahle and Steneck, 1991), early benthic-phase lobsters adopt a cryptic life-style. Initially, they may continue to exploit plankton through suspension feeding (Lavalli and Barshaw, 1989) before adopting a fully benthic foraging mode (Elner and Campbell, 1987). The few field studies conducted to date indicate that rocky bottoms between 5 and 10 m in depth, and cobble bottoms in particular, are prime recruitment habitats.

There is presently no consensus among lobster biologists over a hypothesis advanced by Wahle and Steneck (1991) that the availability of early benthic habitat may be a limiting resource for lobsters. One of the long-term goals of the early benthic phase research being conducted by the St. Andrews team is to help resolve this debate. Early benthic-phase lobsters have limited mobility, are susceptible to predation, and occupy nearshore rocky habitats year-round. It thus seems possible that they might be harmed by the changes in bottom conditions and increases in predatory fish abundance that occur adjacent to salmon aquaculture sites.

Between 1989 and '91, synoptic diving surveys were carried out in the Fundy Isles region of the Bay of Fundy (from Campobello Island to Point Lepreau). The survey method involved capturing lobster of all sizes encountered in belt transects (150 m by 2 m) set perpendicular to the coastline, over depths ranging from 20 m to the low-tide mark. This sampling technique was considered to yield quantitative density estimates for lobsters greater than 40 mm CL. While smaller lobsters, down

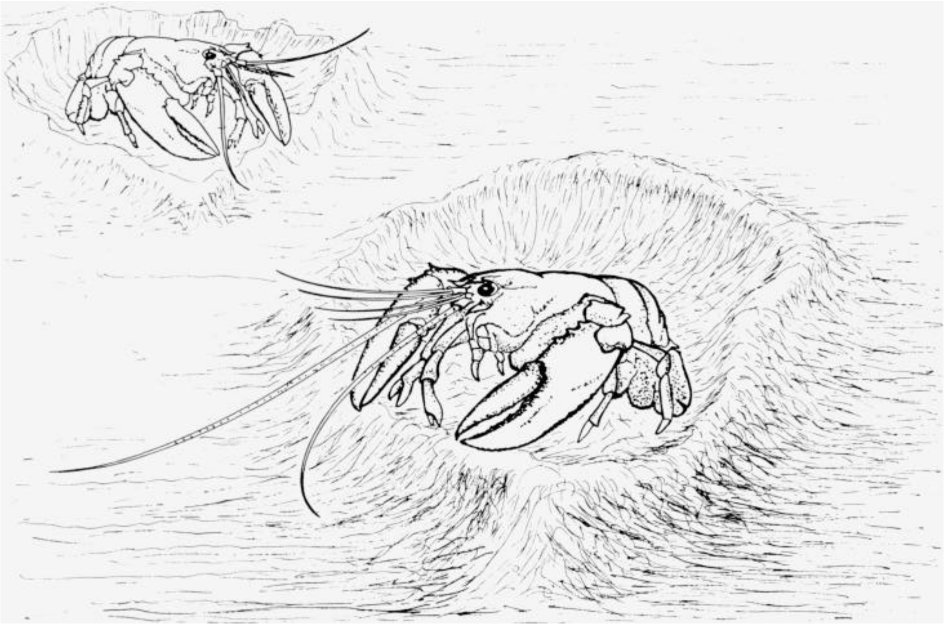


Figure 1. Lobsters occupying depressions excavated in a sandlsilt substrate at Flagg Cove, Grand Manan Island (drawing by D. E. Aiken, St. Andrews Biological Station).

to 7 mm CL, were routinely encountered, these were not considered to be sampled quantitatively. Peak juvenile densities (approximately 2 lobsters/m^2) were found at sampling locations in embayments and along the New Brunswick shore. Within Passamaquoddy Bay, only locations in the northern portion of the bay yielded comparable lobster densities (Lawton and Robichaud, unpubl.). Information gained from these surveys has been used extensively in inter-agency and industry consultations regarding salmon aquaculture sites in the Fundy Isles region.

If lobsters less than 40 mm CL are captured in a benthic habitat, one can infer that postlarval settlement occurs at that location. Accordingly, direct censuses for postsettlement-stage lobsters were made in the Beaver Harbour area in 1991 with air-lift samplers (after a design by Benson, 1989) and sampling protocols similar to those used by Wahle and Steneck (1991). Early benthic-phase lobsters were found in cobble/boulder habitats at depths of 10 to 15 m at a density of 3.95 lobsters/m^2 (with a standard deviation of 3.89 lobsters/m^2) across 78 quadrats - a discovery which challenges speculations in Wahle and Steneck (1991) that postlarval settlement does not occur in the Bay of Fundy, and that the population is supported by the immigration of benthic-stage lobsters.

Reproductive-phase lobsters

Reproductive-phase lobsters are generally regarded as relatively solitary, highly migratory animals. Yet tagging and diving research conducted in the late 1970s and early 1980s yielded an intriguing observation of temperature-related, seasonal, shallow- to deep-water migration of lobsters off the eastern coast of Grand Manan Island. Seasonal aggregations of reproductive-phase lobsters, principally berried females, were discovered in shallow waters (less than 20 m deep) in the vicinity of North Head, Grand Manan (Campbell, 1990). Subsequent to these studies, a small-scale salmon farm was established near this lobster spawning and egg incubation area.

Early in 1989, an expansion request from the operator of the salmon farm underwent a federal and provincial interagency review and was subsequently approved. The St. Andrews team was requested to document the existing distribution of lobsters in relation to the historical database and to follow changes in lobster distribution as the farm expanded. Diving surveys in September 1989, which used survey techniques employed in the earlier studies, generated a pattern of habitat use remarkably similar to that observed in 1982 and ‘83. Flagg Cove lobsters characteristically excavate shallow depressions in the sand/gravel/silt substrate, in which they then reside (fig. l), making it easier for their population density to be estimated.

During 1990, efforts were made to obtain a more complete picture of the seasonal use of inshore habitats. To this end, surveys were conducted at monthly intervals between June and November, and the sex ratio and frequency distribution of population size at Flagg Cove were compared with those at other coves on Grand Manan (fig. 2). The salient details were that lobsters use such areas from late June to early October, with an autumn migration to deep water likely triggered by storm surges. The highly skewed sex ratio at Flagg Cove and the high proportion of berried females were not seen in the lobster population censused at Seal Cove, although Whale Cove, to the north of Flagg Cove also accommodated berried lobsters (fig. 3).

For divers, one of the most striking, and initially intimidating, aspects of the shallow-water spawning area at Flagg Cove was the high densities of large-sized lobster they encountered. The highest

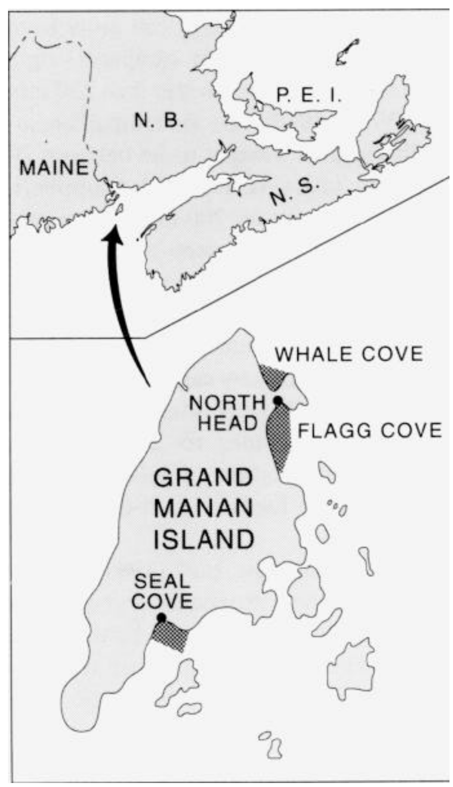


Figure 2. The study areas (shaded) off Grand Manan Island, New Brunswick, which were surveyed during 1990 in order to examine the seasonal patterns of shallow-water habitat use by lobsters.

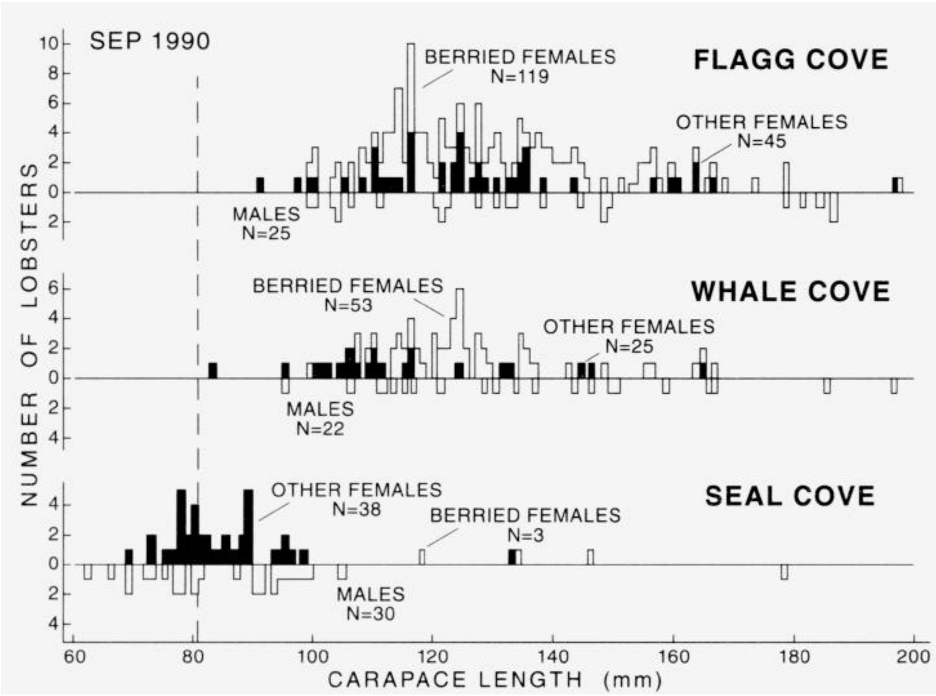


Figure 3. Size-frequency distribution of lobsters sampled during September 1990 at Flagg Cove, Whale Cove, and Seal Cove, Grand Manan Island. The dashed vertical line indicates the minimum legal carapace length in the commercialfishery. The geographical locations are shown in figure 2.

density recorded in 25 m long transect sections (2 m bandwidth; 50 m^2) was 11 lobsters (122 to 217 mm CL), representing a wet weight biomass of 570 g/m^2. A typical lobster biomass on inshore fishing grounds off Nova Scotia is between 5 and 13 g/m^2 (Miller, 1985). In another series of field observations, minimum distances of 0.7 m were recorded between the centres of adjacent, occupied depressions.

Over the three years during which the seasonal use of Flagg Cove has been studied, the centre of distribution of the resident lobster population has markedly varied from year to year (fig. 4). Although cause and effect relationships are not clear, it is interesting to note that the number of cages and the consequent bioloading at the aquaculture site increased between 1989 and 1990, dropping to only one early in 1991. This latter change followed a decision by the New Brunswick Department of Fisheries and Aquaculture to relocate the site outside of Flagg Cove, due in part to concern over the ability of passenger ferries to enter North Head harbour. Follow-up surveys will be conducted in September 1992 and in 1993, in order to produce a time series of seasonal habitat use by lobsters over the course of the entire production cycle of the aquaculture operation.

Future research

In the general context of population regulation in lobsters, there is currently considerable focus on early benthic-phase ecology. The St. Andrews team is now well-placed to conduct manipulative field research in this area. Earlier fisheries monitoring (Robichaud and Campbell, 1991), based on lobster size distribution in at-sea trap samples, indicated that the lobster fishery at the head of the Bay of

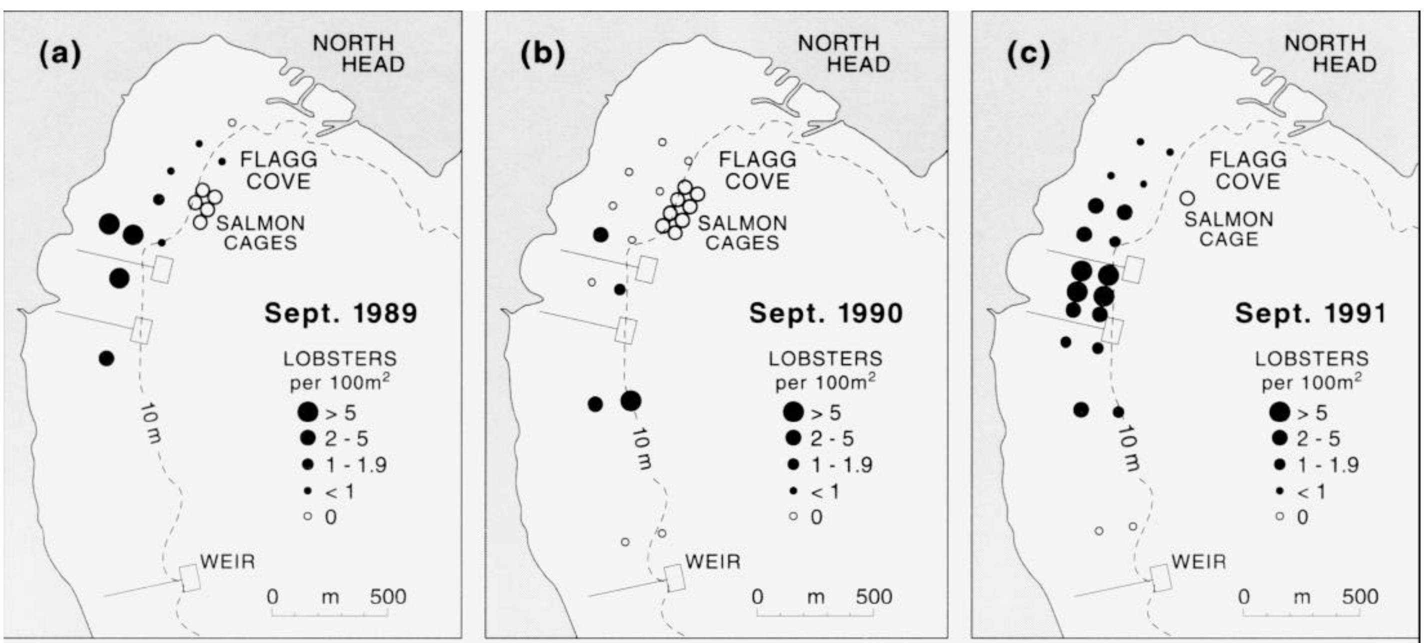


Figure 4. The lobster density (number of lobsters/100 m^2) at Flagg Cove during (a) September 1989, (b) September 1990, and (c) September 1991. Note the location and number of salmon cages present in each month. The filled circles denote lobster density, as explained in the key.

Fundy was largely supported by seasonal migration of reproductive-phase lobsters. Recently, there have been indications of enhanced local recruitment, and a significant challenge will be to ground-truth this phenomenon using either directed trapping programs, or diving surveys in the dynamic environment of the upper Bay of Fundy.

There remain many intriguing aspects of reproductive-phase behaviour to be addressed through experimental studies at Flagg Cove. Due to typically low population densities and a depth distribution usually beyond effective dive planning, detailed field observations on the social behaviour of mature lobsters are very rare (see, for example, Karnofsky et al., 1989). However, the comparatively high lobster population densities at Flagg Cove have afforded the opportunity for research to begin addressing residency time, activity patterns, and behavioural interactions.

The challenge during the period from 1989 to '91 was to respond to management requests for advice on the relationship between the traditional lobster fishery and salmon aquaculture, while mounting a research program that was targeted at fundamental questions about lobster population ecology. The definition of important lobster spawning areas and key settlement habitats, which was initiated during this review period, together with the focused studies now underway, should substantially improve our understanding of the life history cycle of lobsters within the Bay of Fundy.

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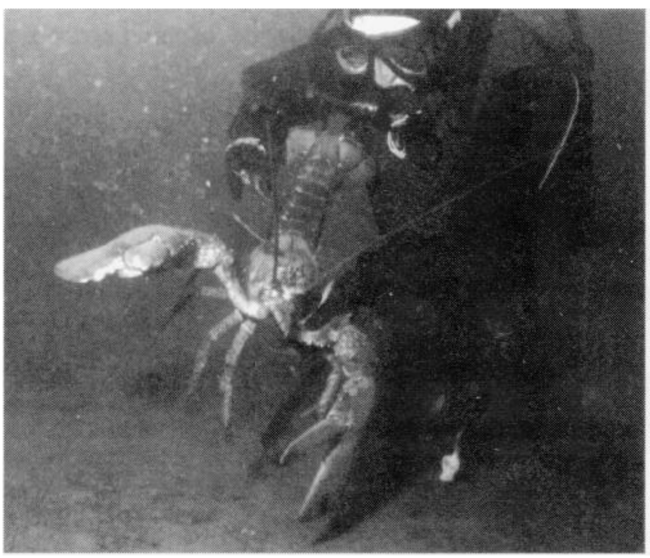
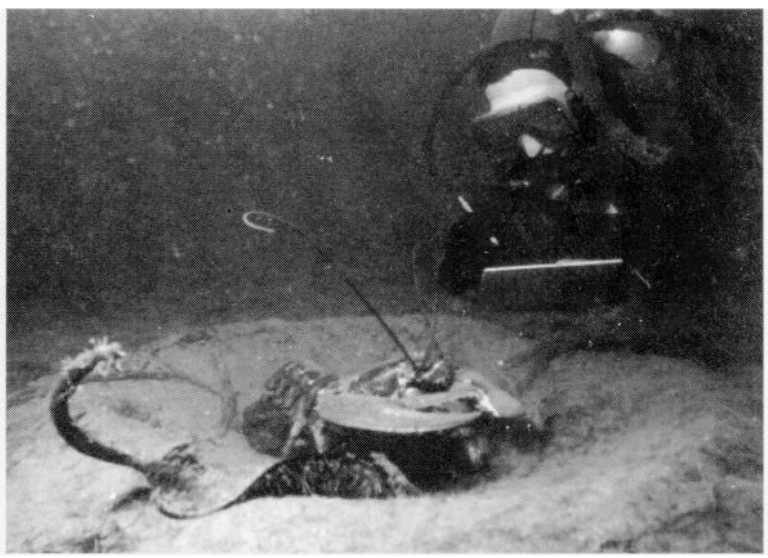


Diver taking measurements of lobster.



Diver recording details of habitat use by lobster in shallow water.

Physics and biology of the Georges Bank frontal system

J. W. Loder, R. I. Perry, K. F. Drinkwater, J. Grant, G. C. Harding, W. G. Harrison,
E. P. W. Horne, N. S. Oakey, C. T. Taggart, M. J. Tremblay, D. Brickman, and M. M. Sinclair

Standing (1.-r.): M. M. Sinclair, N. S. Oakey, J. Grant, P. Cranford, C. T. Taggart. Seated (I.-r.): K. F. Drinkwater, E. P. W. Horne, J. W. Loder, R. I. Perry, and W. G. Harrison. Not Present: D. Brickman, G. C. Harding, and M. J. Tremhlay.

Georges Bank is one of the most productive oceanic areas in temperate latitudes and one of the prized fishing grounds in the Northwest Atlantic, with annual landings valued near $200 million. It has been intensively studied over the past 75 years, but the reasons for its high productivity are still not completely understood. In recent decades, concerns have been raised about possible adverse impacts that oil and gas exploration might have on the bank's fisheries resources. We describe here the results of recent studies directed at answering why Georges Bank is so productive and what would be the potential impacts of hydrocarbon exploration.

The dominant physical oceanographic factors on Georges Bank are the strong tidal currents (2 to 3 knots) and persistent patterns in the temperature and salinity distributions. These generate a clockwise circulation gyre over the bank which narrows into an intense current jet along the bank's northern edge (fig. la). The shallow central part of the bank remains vertically well-mixed all year, primarily due to the strong tidal currents. A frontal zone, in which water properties change markedly, separates the mixed area from the surrounding stratified waters.

The rate of phytoplankton production (primary production) on Georges Bank is among the highest on the world's continental shelves. In the central mixed area, this production is driven by nutrients excreted from animals and bacteria. However, an external source of nutrients is required to maintain the overall high production rates. Transport and/or mixing associated with the frontal system, storms, and Gulf Stream rings have been suggested as important factors in supplying external nutrients, but the relative roles of these processes have not been established.

Compared to the high primary production, zooplankton production (secondary production) on the bank is unusually low. The reasons for this are unknown but may include zooplankton losses from the bank by transport and mixing, and heavy predation by fish. The level may also appear lower than it really is, due to the difficulty of obtaining adequate measurements. Despite the apparently low level of secondary production, fish production on Georges Bank is very high, particularly among bottom fishes, scallops, and lobsters. Proposed explanations include the retention of larvae on the bank by the circulation gyre, the persistent transport of the larvae to nursery areas, and ready availability of prey for various species.

Several of the proposed physical influences on Georges Bank's biological production appear contradictory: namely, that primary production is high because the transport of nutrients onto the bank is high; that secondary production is low because plankton are transported off the bank; but that fish production is high because the circulation retains eggs and larvae on the bank. Simultaneous measurements of the circulation and the distributions of nutrients, plankton, and larvae are required in order to resolve this apparent paradox.

The frontal system surrounding the bank has been suggested as an important regulator of horizontal exchange because of its persistence, its expected circulation, and its location along the bank's periphery. It is most strongly developed from spring to fall, precisely the period when nutrient demands are greatest, when phytoplankton and zooplankton production is maximized, and when most fish species are spawning or in their early life stages. Furthermore, on the Northeast Peak, presently the most important fishing region on Georges Bank, the frontal zone lies near the bank's densest scallop beds, and important spawning and nursery areas for cod and haddock (fig. lb).

What are the physical and biological processes associated with the frontal zone that might enhance the supply of external nutrients and either retain or disperse zooplankton and larval fishes? What would be the likely movement and concentration of any pollutants (for example, oil from a spill, or drilling discharges) released near the biologically productive

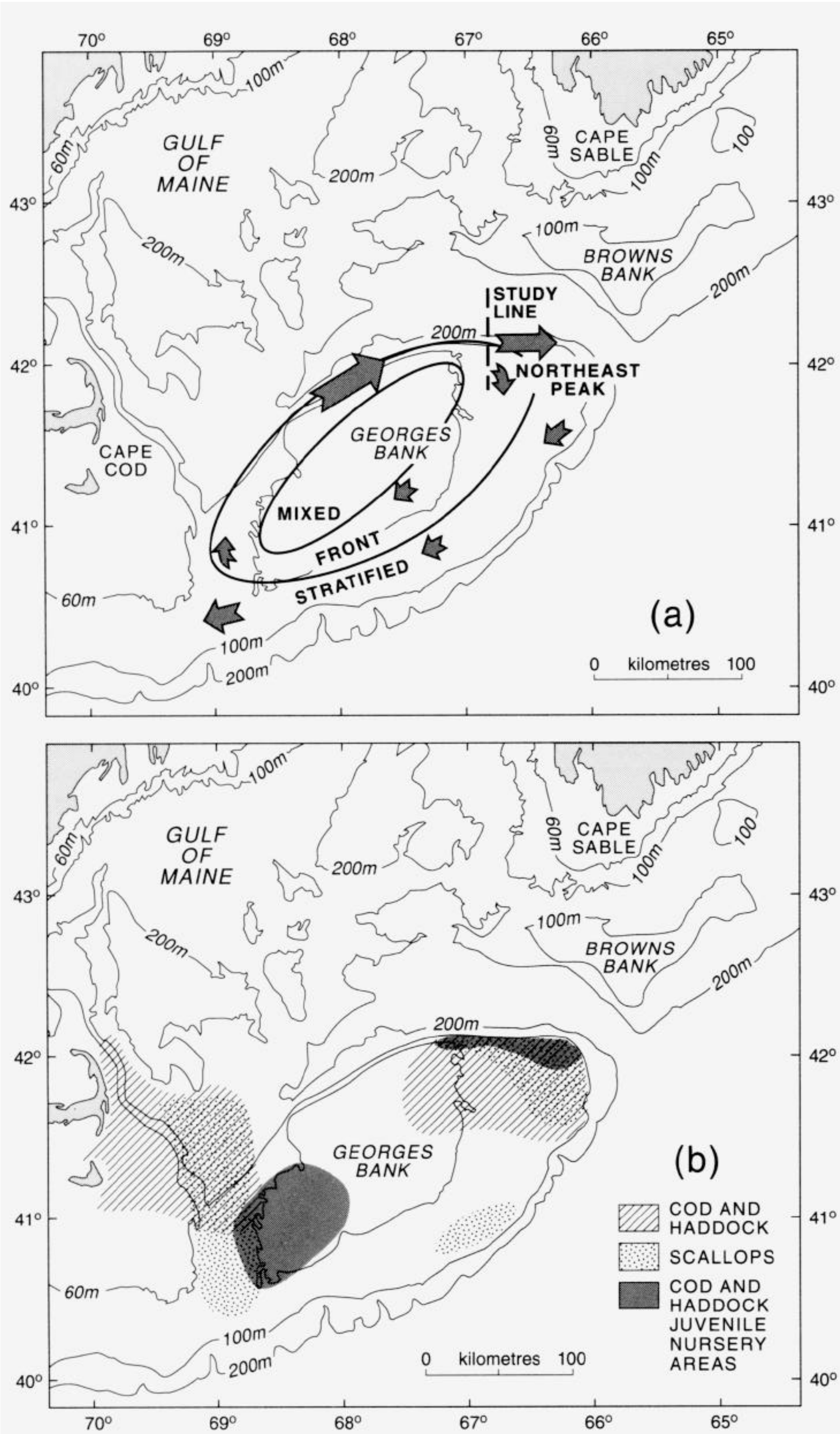


Figure 1. Bathymetric map of the Georges Bank region showing (a) key physical features and (h) selected fisheries distributions. The physical features shown are the frontal zone bounded by the mixed and stratified areas, and the circulation gyre (arrows). The fisheries distributions include the major concentrations of adult cod, haddock, and scallops, and the nursery areas for juvenile cod and haddock. The study line is shown in (a).

areas? These questions were the focus of the Georges Bank Frontal Study, which was conducted in 1988-89 along the northern edge of the bank. The study area was chosen because the physical processes are most energetic there, and because of its potential significance to the Northeast Peak.

The study's goals were to determine the circulation, water-property variations, and mixing rates in the vicinity of the frontal zone, and their influences on the distributions of nutrients, primary production, plankton, and larval fishes. The results are being used to evaluate the importance of the frontal system to the input of nutrients and the retention of plankton on the bank, as well as the potential impacts of hydrocarbon exploration.

Measurements were concentrated along a line (fig. la) across the front where moored instruments continuously monitored currents, temperature, and salinity from June through October of 1988. Higher-resolution sampling of the physical environment was obtained from a towed vertical-profiling Batfish/CTD system (which measured temperature and salinity), a ship-mounted acoustic current profiler, conventional CTD and nutrient sections, repeated drops of the turbulence profiler EPSONDE, the tracking of drifting buoys using satellite and Loran C navigation, and satellite images of sea-surface temperature.

The biomass, production rate, and nitrogen uptake rate of phytoplankton were measured along the line in late August using standard techniques. Zooplankton and larval fish distributions on the line were repeatedly sampled in July, August, and October with a multiple-net (BIONESS) system and a Tucker trawl. Higher-resolution and size-structure information on the phytoplankton and zooplankton distributions was obtained from a fluorometer and an optical plankton counter mounted on the towed Batfish. Shipboard scallop production, respiration, and feeding experiments were conducted with samples from the study site.

The physical oceanographic observations that were made have provided detailed quantitative information about physical features that were already known to exist, and have also revealed structures

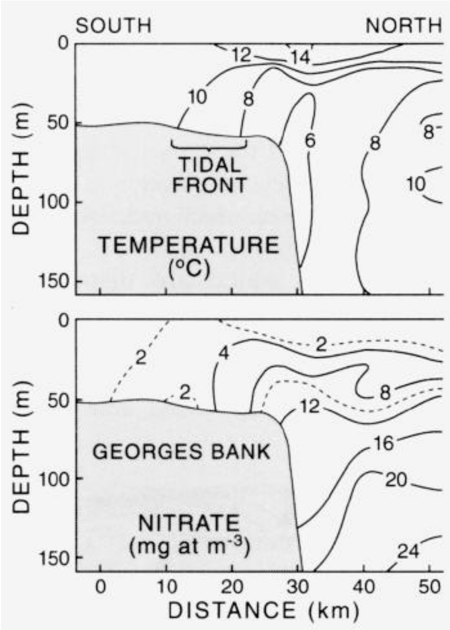


Figure 2. Typical distributions of temperature and nitrate on the study line, from a CTD/nutrient section in July 1988. Nitrate, which is required to support new primary production in the near-surface region, is depleted in the mixed area but available at depth in the stratified area.

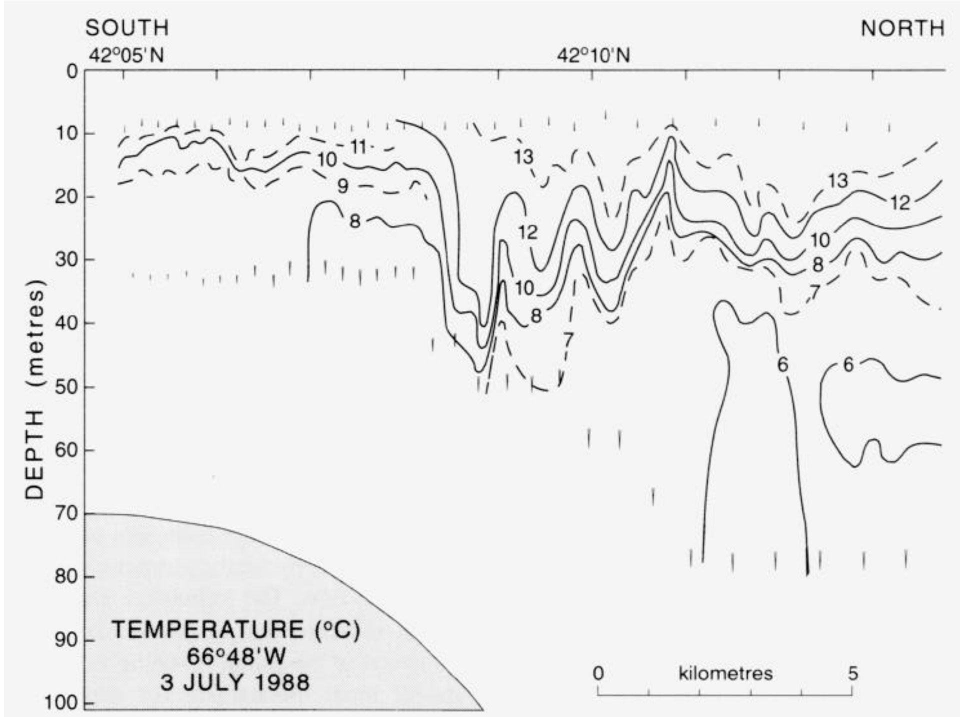


Figure 3. Detailed distribution of temperature on the study line, from a Batfish section during off-bank tidal flow in July 1988. Internal waves are apparent at the bank edge. The abrupt vertical displacement of the 8-12°C isotherms is called an internal hydraulic jump.

which had not been previously documented on Georges Bank. The turbulence measurements confirm that vertical mixing rates are generally much higher in the central mixed area and vary in response to the changing tidal current. There are sharp changes in the concentration of ‘nitrate (the most abundant external form of the key nutrient, nitrogen) across the frontal zone (fig. 2), suggesting that cross-frontal exchange is critical to the supply of external nutrients to the bank. The current jet flows persistently along the bank’s northern edge, with a peak speed in early summer near 0.5 m/s (1 knot), and total transport exceeding 3 km^3/hr (70 times greater than the St. Lawrence River’s flow). It is the primary summertime pathway for water exiting the Gulf of Maine and a dominant factor regulating property distributions in the region.

The physical features identified during the study include the spreading of a portion of the current jet across the Northeast Peak, a variety of internal (subsurface) waves near the bank edge, and a line of surface convergence in the frontal zone. The spreading of the current jet is associated with a downstream divergence of the isobaths in the vicinity of the study line (fig. la). The internal waves originate at the bank edge during off-bank tidal flow when an “internal hydraulic jump” (an abrupt vertical displacement of water parcels) develops (fig. 3). The jump subsequently evolves into large-amplitude internal waves, which propagate into the frontal zone and provide an additional energy source for vertical mixing. The surface convergence occurs near the mixed-area boundary, and results in drifting materials slowly converging as they spiral around the bank in the current jet

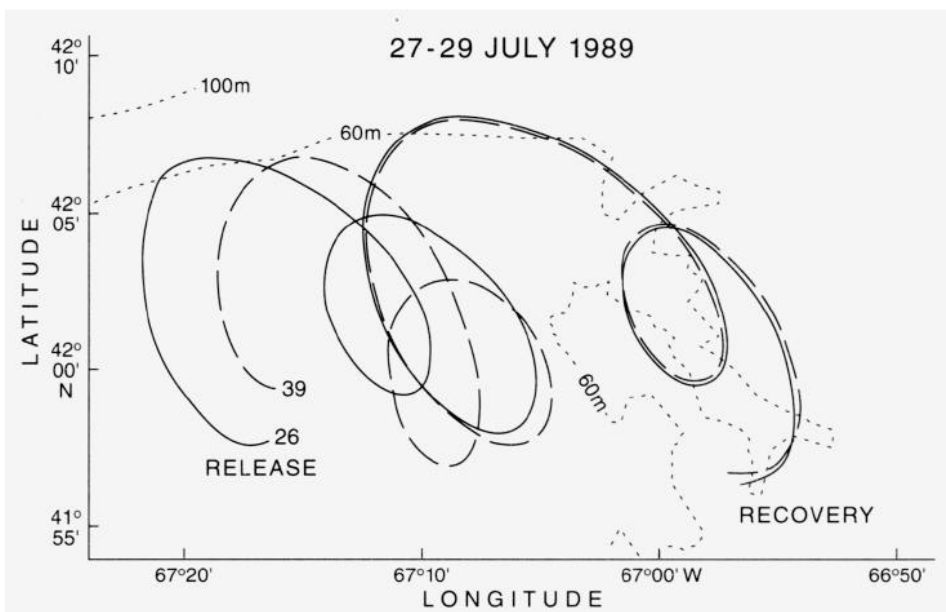


Figure 4. Trajectories of two Loran C drifting buoys (#‘s 26 and 39) released in the frontal zone to the west of the study line. The drifters, released about 4 km apart, were recovered about 2 days later less than a km apart in a surface convergence line.

and tidal current (fig. 4). This provides a mechanism for concentrating floating materials in the frontal zone.

The biological measurements that were made confirm that the phytoplankton biomass and production rate are highest in the mixed area, and generally decrease with the increase in stratification across the frontal zone (figs. 5a and b). However, the f-ratio, which is the fraction of the primary production that uses nitrate as the source of nitrogen, peaks both in the tidal front near the mixed-area boundary and over the bank edge (fig. 5c). These measurements were taken in late summer, when the frontal zone extends furthest onto the bank. We suspect that the regions of elevated “new production” (that is, those which use nitrate) overlap during early summer, when the frontal zone is more closely confined to the bank edge.

The physical observations made during the study suggest that these two

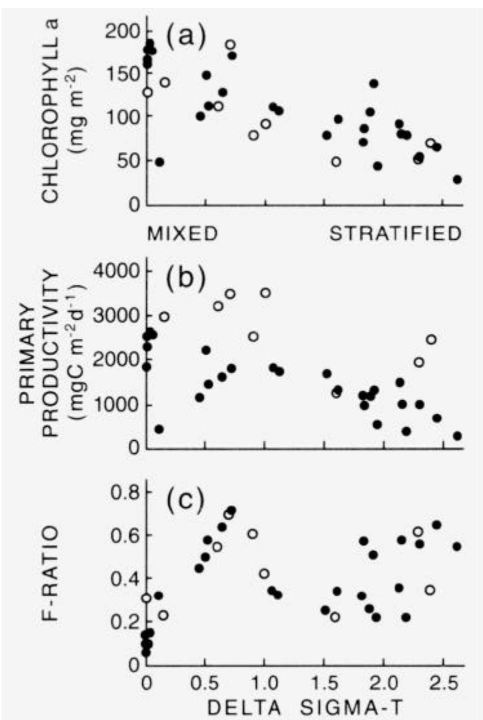


Figure 5. Distributions of (a) phytoplankton biomass (chlorophyll a), *(b) primary production rate, and (c) f-ratio along the study line in August 1988 (solid circles). The data are plotted against the density difference (sigma-t units) between the surface and 50 m. Data from an earlier study (July to August 1985) are also included and are represented by open circles.*

regions of new production are associated with tidally driven mixing processes. The turbulence measurements, and energy estimates for the tidal currents and incoming internal waves, indicate that vertical mixing in the frontal zone can supply substantial amounts of nitrate to the phytoplankton in the near-surface region. The nitrogen reservoir at depth in this zone is maintained by the spreading of the current jet onto the bank. The frontal-zone peak in new production is therefore consistent with the classical explanation that tidal fronts have high primary production rates as a result of optimal conditions of light and nutrient supply. The new-production peak at the bank edge coincides with the location of the hydraulic jump during off-bank tidal flow. The turbulence measurements indicate that vertical mixing is enhanced in the jump, resulting in a persistent local mechanism for supplying new nutrients to the near-surface region.

Tidally driven physical processes also influence the dispersion and retention of plankton on northern Georges Bank, thereby regulating the distributions of zooplankton and larval fishes in the region. The simultaneous measurements of temperature, salinity, chlorophyll fluorescence, and plankton abundance from the undulating Batfish show coincident patterns in the distribution of small particles (phytoplankton and small zooplankton) and the vertical displacement of density surfaces by the internal waves. In contrast, the distribution of larger particles (zooplankton) is not as closely related to the internal wave displacements, probably due to the greater swimming ability of the larger animals.

The distribution of zooplankton across the frontal zone, as represented by the net samples, also shows apparent size-dependent differences related to the physical processes. Small zooplankton, such as copepods *(Acartia* sp.), peak in abundance near the mixed-area boundary (fig. 6), while differences in the abundance and species composition of larger zooplankton (for example, *Metridia lucens* and euphausiids) are greater at the bank edge. The frontal zone has a zooplankton composition that is transitional between the mixed area and the stratified waters in the Gulf of Maine.

The spreading of the current jet across the Northeast Peak acts to retain both zooplankton and phytoplankton on the bank and contribute to their accumulation in the mixed area. The extent of transport toward the centre of the bank should be greatest for plankton in the upper layers or those which undertake daily vertical migration. However, some zooplankton which are distributed predominantly in near-surface waters, such as certain small copepods and late stages of lobster larvae, were found across the front from the mixed area to the

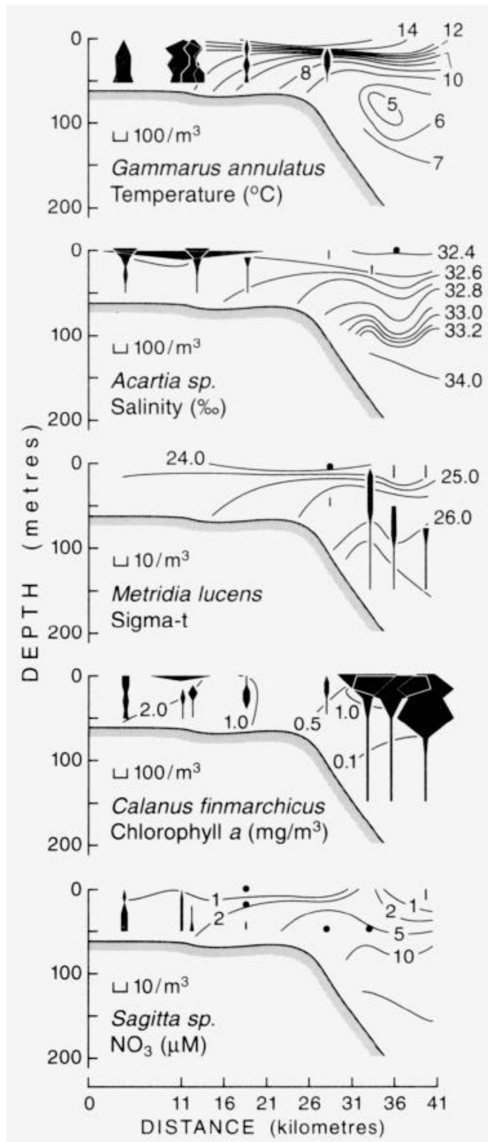


Figure 6. Depth distributions of representative zooplankton species along the study line in July 1988, and concurrent distributions of temperature, salinity, density, chlorophyll, and nitrate. The width of the shaded “kite” is proportional to the abundance of each species at that depth.

stratified region. The origin of these discrepancies is unclear, but they may be related to different species having different upstream distributions and/or to spatial or temporal variations in the flow upstream. Nevertheless, the observations indicate that the frontal zone plays an important role in keeping plankton and fish populations on the bank separate from those of surrounding regions.

On a bank-wide basis, previous estimates have suggested that the supply of external nitrogen and the subsequent new production by phytoplankton on Georges Bank are sufficient to meet the annual production requirements of the bank's extensive scallop beds. Because of the current jet, the nutrient supply mechanisms and elevated new production along the bank's northern edge are particularly favourable for providing food for the dense scallop beds on the downstream Northeast Peak (fig. lb). Tidal mixing redistributes nutrients upward to phytoplankton in the near-surface region and carries particulate matter downward to scallops on the seafloor. Studies elsewhere have shown that water-column primary production can be important to the nutrition, growth, and reproduction of bivalves, and our shipboard measurements indicate that the Georges Bank scallops have relatively high filtration rates. Seasonal and tidal (spring-neap) variations in frontal (and current jet) position on the Northeast Peak provide a sprinkler-like mechanism for wide distribution of the food supply in summertime.

In addition to its dense scallop beds, the Northeast Peak is an important nursery ground for newly settled cod and haddock juveniles during July and August (fig. lb). Their survival in this area may be enhanced by the presence of the frontal region and the elevated concentrations of zooplankton prey that it provides. The predominant prey of these juvenile fish include the euphausiid *Meganyctiphanes norvegica* and the amphipod *Themisto compressa*. Both of these species are distributed principally in deep water off the bank but are brought into the frontal zone by the on-bank flow component of the current jet at this location.

As a result of our recent studies, a new conceptual model for the interrelation of the physical and biological regimes on northern Georges Bank is emerging (see fig. 7). Physically, the regime has characteristics of both a classic tidal mixing front (a transition zone between mixed and stratified waters) and a stratified shelf break (or bank edge) with strong tidal forcing. In combination with stratification and the abrupt topography of the bank edge, the strong tidal currents result in a variety of persistent and energetic phenomena: a frontal system, a current jet, internal waves, turbulent mixing, and a surface convergence zone. These processes have strong influences on the distribution of materials and organisms in the water, whether they be dissolved nutrients, plankton, fish eggs and larvae, or pollutants.

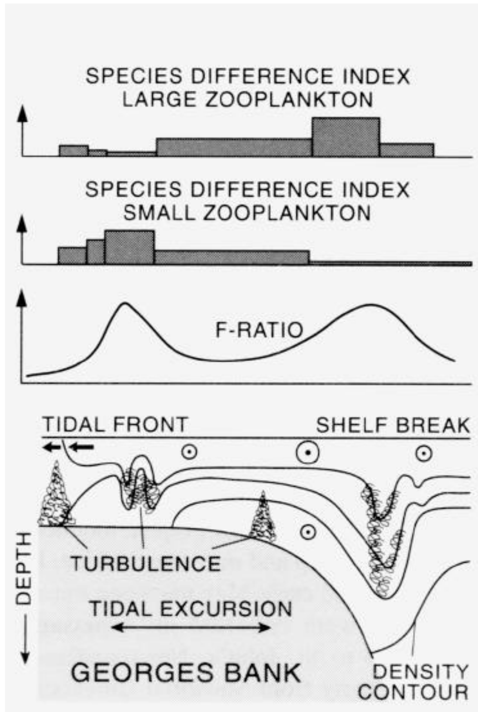


Figure 7. Schematic summary of the physical and biological regimes on northern Georges Bank in summer. The physical regime (bottom panel) includes strong tidal currents and large tidal excursions, a tidal front with a surface convergence (arrows), an along-bank current jet (dots within circles), internal waves which cause vertical displacements of the density contours, and intense small-scale turbulence. The f-ratio distribution (second panel from bottom) shows the regions of elevated new primary production associated with the tidal front and the bank edge. Species difference indices for zooplankton abundance and composition (top panels; higher histograms imply greater differences) indicate that the greatest differences occur at the bank edge and tidal front for large and small zooplankton, respectively.

Peak levels of new primary production and distributional boundaries for many zooplankton species coincide with the persistent physical structures (fig. 7). The dense scallop beds and the nursery areas for juvenile cod and haddock on the Northeast Peak are situated in the downstream path of this biologically productive system, which originates along the bank's northern edge (fig. 1). The frontal system on northern Georges Bank thus makes substantial contributions to the bank's high primary production, the retention of plankton on the bank, and its rich fisheries production. The potential impact of hydrocarbon activities is the subject of ongoing study, but the intensity and close coupling of the physics and biology on Georges Bank provide the potential for both amplified and reduced effects compared to other regions; for example, pollutants might tend to concentrate in the convergence zone or be rapidly dispersed by the currents and mixing.

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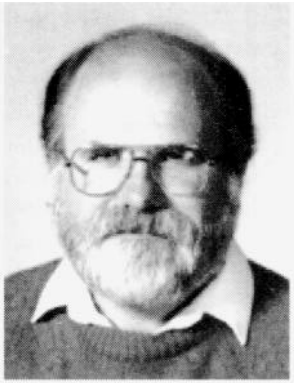
Gravity and magnetic surveys with C.S.S. *Baffin*

B. D. Loncarevic and G. C. Rockwell



B. D. Loncarevic *G. C. Rockwell*

".. Baffin, commissioned in 1956, was . . . the supremely complete hydrographic ship operating in Canada . . . But it's generally acknowledged that she is probably the last of a breed."

S. Fillmore and R.W. Sandilands: The CHARTMAKERS (*1983)*

The last voyage of C.S.S. *Baffin*

On a dark and stormy night, in the early hours of the 5th of December 1990, with a grinding noise and a bump against the jetty at the Bedford Institute of Oceanography (BIO) which opened a gash in the hull near the port side cargo doors, 34 year old *C.S.S. Baffin* came alongside her BIO berth for the last time. We did not know it at the time, but she was never to sail again under her own power (fig. 1).

The projects undertaken during 1990, the *Baffin's* last season, were typical of the work that she accomplished throughout her career. In March and April she was off Newfoundland participating in the international LIMEX Project, monitoring the break up and movement of ice. In late April and early May magnetic measurements were collected on a passage from BIO to St. John's, Newfoundland, where a party from Memorial University came on board to carry out near bottom microbiological investigations. For the next two months she was the mother ship and base for six launches charting inshore areas of Bonavista Bay, Newfoundland.

On the 23rd of July, *Baffin* went on a three month long *Northern Voyage,* the type of project for which she was uniquely outfitted. She carried out standard hydrographic charting in Hudson Bay, including launch work, with an observer on board who monitored the behaviour of marine mammals. On completion of the hydrographic work, during her last two weeks up north, a party of geologists from the Atlantic Geoscience Centre (AGC) at BIO used seismic profiling and bottom sampling gear to study sea floor sediments. *Baffin* returned to BIO on the 26th of October and sailed on her last project, the continuation of the Nova Scotia Shelf gravity and magnetic charting surveys, on the 5th of November.

Figure 1. Departure of C.S.S. Baffin from her berth at BIO. This photograph appeared in the Halifax Mail-Star on 10th December 1991, with the following caption.. "The Canadian Survey Ship (C.S.S.) Baffin made an unceremoniousfinal voyage Friday morning from the Bedford Institute of Oceanography to the Magazine Dock. With little fanfare, the 35-year old hydrographic surveying ship, owned by the Department of Fisheries and Oceans, has been mothballed. The 345-foot, 3,511-t vessel was built in 1956 and boasted a complement of 29 hydrographic staff.'"

Multidisciplinary surveys

Between 1960 and 1990, many hydrographic survey projects were multidisciplinary, involving geoscientists collecting geophysical and geological data simultaneously with the charting of the sea floor by hydrographers (fig. 2). The earliest marine geological study from a CHS ship was conducted in 1960 on the first great Northern Voyage (Buckley, 1971). The C.S.S. *Baffin* gravity and magnetics charting surveys were initiated in 1963; they are listed in Table 1.

Over that period the projects evolved from two solitudes sailing on the same ship to fully integrated operations.

The idea for multidisciplinary surveys was a simple one. Since hydrographers were already conducting systematic offshore surveys along closely spaced and well controlled survey lines, why not have geologists and geophysicists collect other compatible measurements underway, while thus increasing the productivity of the vessel?

In practice there were two obstacles to be overcome. By tradition, hydrographers were responsible for the quantity and quality of bathymetric survey data collected in the field. Anything that interfered with the "survey-miles collected" was considered a nuisance. The hydrographers had to be convinced that collecting the additional parameters was just as useful and productive as was the somewhat larger number of survey-miles of bathymetry alone. Younger hydrographers understood this and enthusiastically adopted gravity and magnetic measurements as a part of offshore hydrographic surveys.

The second obstacle was a technical/ logistics problem of controlling the ship's speed and course. For traditional hydrographic surveys only the position of soundings was important; they were concerned about the constancy of speed/ course only as required for interpolation between the soundings. In gravity measurements, however, the constancy or smooth, gradual change of speed/course is of great importance. The measurements are affected by the east-west component of ship's velocity, since this adds or subtracts from the rotational speed on the surface of the earth. It was important to learn that conning the ship had to be a gradual process. If the ship had drifted off the intended survey line, then sharp course changes had to be avoided and the track corrected gradually. As navigation improved, it became easier to compensate for the effects of wind, tides and currents so that a minimum of course correction was required to keep the ship on the line, thus greatly improving the quality of gravity measurements.

Table 1

C.S.S. *Baffin* Multidisciplinary Cruises

	Cruise N°	Area of operations	Gravity	Magnetics
1.	64 - 019	Bay of Fundy	7,233	12,400
2.	66 - 008	Grand Banks	5,862	
3.	67 - 014	Grand Banks	58,203	82,000
4.	68 - 021	Gulf of St. Lawrence	58,922	74,800
5.	69 - 021	Gulf of St. Lawrence	46,321	65,600
6.	71 - 017	Grand Banks	62,331	94,800
7.	73 - 014	Gulf of St. Lawrence Eastern Arctic	25,156	30,000
8.	74 - 015	Gulf of St. Lawrence	5,880	22,000
9.	75-011	Fox Basin		30,000
10.	76-001	Scotian Margin	56,433	85,200
11.	76 - 012	Gulf of St. Lawrence		33,600
12.	77 - 008	Gulf of St. Lawrence		31,200
13.	78 - 010	Labrador Sea		15,200
14.	79 - 015	Scotian Shelf	8,562	52,800
15.	80-031	Labrador Sea	20,368	23,600
16.	82 - 039	Scotian Shelf	12,339	54,800
17.	83 - 035	Scotian Shelf	18,363	26,400
18.	84 - 044	Scotian Shelf	36,426	39,200
19.	88 - 039	Scotian Shelf	32,700	179,000
20.	89-031	Scotian Shelf	31,957	182,238
21.	90 - 029	Scotian Shelf	35,300	187,140

Note 1: The data in this Table were compiled from GSC Open Files 1232 (Woodside et al., 1986), 1504 (Verhoef and Macnab, 1987) and Cruise reports.

Note 2: The last three *Baffin* cruises retained all 10 sec magnetometer readings resulting in a substantially larger data volume.

Note 3: Between 1972 and 1981 there were nine additional multidisciplinary cruises on other BIO and charter ships.

Survey operations at sea

Information about the development, practices and achievements of the underway multidisciplinary surveys is scattered through Cruise/Project reports, Conference Proceedings, inter office memoranda and internal BIO publications; a comprehensive account is yet to be written. An early account was given by Loncarevic (1975, 1976) and updated by Macnab (1983). Recent issues of the *Science Review* have carried several accounts of improvements in survey techniques (Grant and McKeown, 1987; Kerr, 1987; Verhoef and Sherin, 1990). Loncarevic and Woodside described in some detail *Baffin* operations in 1988 and 1989 (Loncarevic and Woodside, 1991).

Joint charting surveys were an opportunity to collect gravity and magnetic data at a marginal increase in cost, and thus provide an example of the benefits of multiuse of facilities. The priorities for survey areas were set by the hydrographic charting requirements, and geophysicists went along as far as the manpower resources allowed. In most cases, the geophysicists would be on board for only a part of the survey season. During that time, the ship would establish a broad net of track lines with spacing five to ten times larger then the survey specifications. After the departure of geophysicists, the rest of the season would be spent interlining the remaining lines.

Members of the Canadian Hydrographic Service played the major part in multidisciplinary surveys by planning the layout of the ship's tracks and arranging for the installation of navigational aids as necessary; by maintaining the operational control of the ship, including all dealings with the Captains and officers of the watch; and by plotting the ship's track and maintaining round the clock watch on all the equipment. Geophysicists maintained the gravity and magnetics instruments and were responsible for the geophysical data quality and for processing those data. A team of six or seven hydrographers and three geophysicists could operate around the clock for as long as the project lasted.

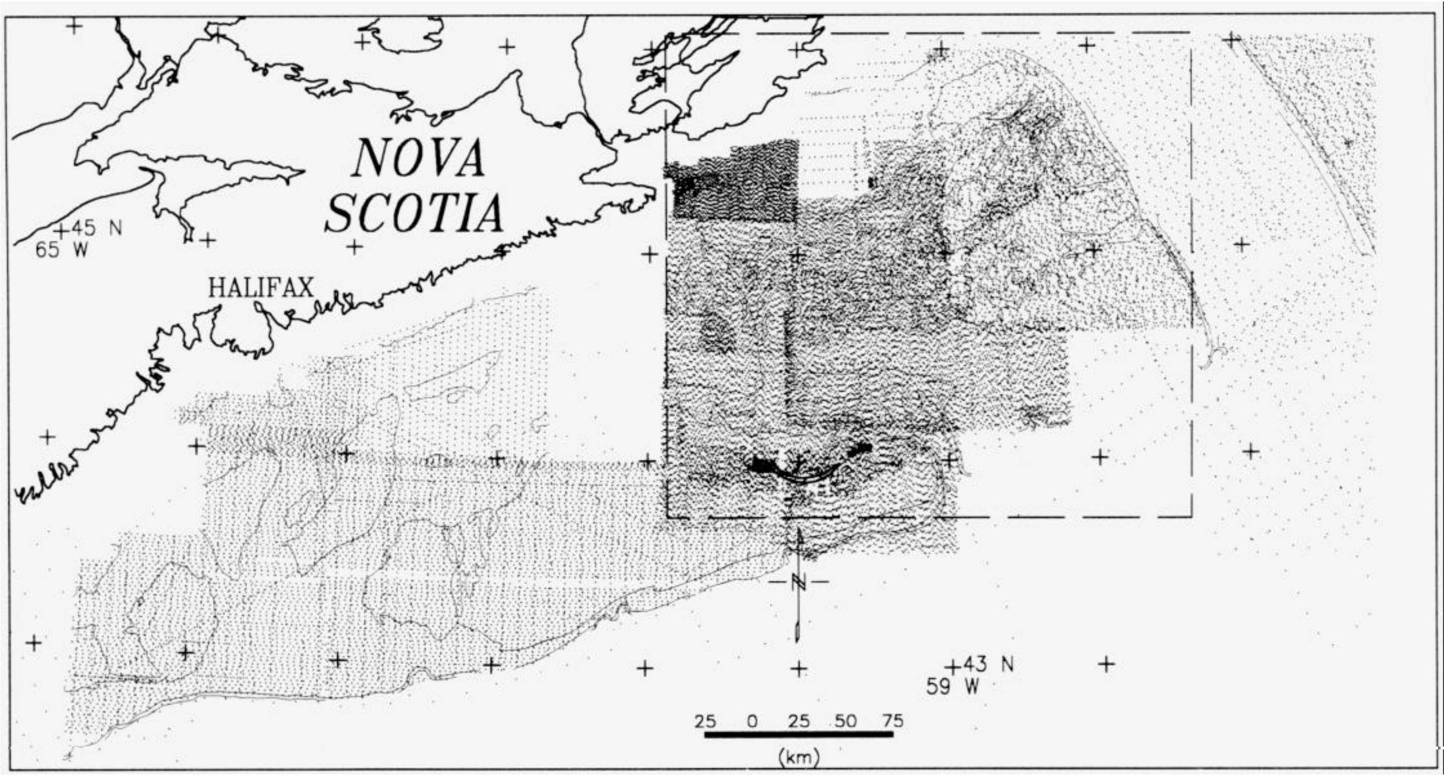


Figure 2. C.S.S. Baffin *surveys of the Nova Scotia continental shelf, 1979-1990. The area west of 61° West was covered during the last three seasons of multidisciplinary surveys. Thirty-five launch parties participated in the surveys of the eastern section. These surveys have produced an invaluable database (Loncarevic* et al., *1992).*

Data handling

Before the first gravity and magnetic survey cruise, it was recognized that a large volume of data would be collected and that special techniques for data handling had to be developed. Digital data processing was perceived as a way of the future and suitable equipment, named GEODAL, was developed and built at BIO in 1964 (Mason, 1966). The equipment was hardwired so that the input data format was fixed. The output was on punched paper tape because magnetic storage was too expensive at that time and considered unreliable for continuous operation on board ships. Punched paper tape had the advantage that a watchkeeper could read it at any time and verify that the data were recorded properly.

A few years later a more versatile data acquisition system was built and code-named BIODAL. This equipment was based on all solid-state electronics. An integral part of the equipment was a highly accurate ship's clock which distributed correct time throughout the ship. The outstanding engineering design and construction enabled us to use BIODAL continuously for 20 years; something of a record in the age of rapid innovation in electronics.

The problem with both GEODAL and BIODAL was a fixed data format. The equipment became obsolete when the supply of spare parts dried up and when the new instruments with digital output could not be easily accommodated. It was then recognized that a new unit must be under software control.

The next data acquisition equipment was CIGAL (Loncarevic and Coldwell, 1987), based on an HP Series 200 computer. This equipment is still in use but its capacity is limited, and plans are now developed to replace it within the next year or two.

In the early days data were processed ashore. The first general purpose minicomputer, a PDP-8 with 4K memory, was installed on *Baffin* in 1967, thus initiating digital data processing in the field. This was followed by HP Series 1000 computers in the early '70s and by DEC Microvax II computers in the early '80s. On the last cruise in 1990, there were over 20 desktop computers on board, in addition to three DEC Microvax II mini computers and one SUN workstation.

Adjusted navigation is required to carry out the data processing on board. A great emphasis is placed on accurate positioning on all hydrographic surveys, and *Baffin* was always equipped with the latest available technology. With the advent of navigational satellites an integrated navigational system was developed (BIONAV) which was at the forefront of technology for a number of years (Grant and McKeown, 1987).

Results

The annual surveys were routine and ongoing in nature, not problem-oriented; it was not expected that the results of any one season's work would directly address a specific geological problem. The value of the project was in compiling a vast and perhaps unique database which became increasingly more useful as the quantity of observations and the area of coverage grew.

The use of hydrographic data for marine geological interpretation was pioneered by L. H. King and resulted in a series of unique surficial geology maps.

(King, 1967; King et al., 1974). The achievements of geological investigations were summarized by Pelletier and Buckley (1974).

The exploitation of the potential offshore field database is documented in over 100 scientific publications over the past 25 years. Only a few highlights from this literature can be mentioned here.

The major accomplishment, utilizing all the available data, is the publication of the volume *Continental Margin of Eastern Canada* (Keen and Williams, 1990). This volume synthesized our current knowledge of the region in 15 long chapters, many of which used the magnetic and gravity data collected by C.S.S. *Baffn* and other BIO ships. Part of the volume was a series of eight charts at a scale of 1:5,000,000 showing many geological features, including the distribution of the gravity and magnetic field anomalies. Production of these charts (GSC Maps 1708A and 1709A) represents an important synthesis of almost 30 years of underway surveys and data collection.

The above data set was used by Woodside and Verhoef (Woodside, 1989; Woodside and Verhoef, 1989) for a more detailed description of the geology of the Labrador Continental Shelf. This work clearly demonstrated the importance of the interpretation of gravity and magnetic data as a reconnaissance tool in areas of potential hydrocarbon accumulation.

Srivastava has used the data in a different way to study the history of ocean spreading and continental drift in the Labrador Sea. By carefully matching the magnetic anomalies on opposite sides of the Mid-Labrador ridge he was able to show that the opening of the Labrador Sea occurred 92 million years ago (see fig. 3) (Srivastava, 1978; Roest and Srivastava, 1989). The ocean floor spreading changed direction 59 million years ago to north-south, with a shearing motion through Davis Strait that probably caused its fragmented crustal structure.

Our third example is from the geophysical interpretations of surveys around Newfoundland by R. T. Haworth and others (Haworth, 1978; Haworth, 1980; Haworth, 1981; Haworth and Jacobi, 1983; Haworth and Lefort, 1979). These studies unravelled some of the structural problems in the crustal basement rocks around Newfoundland. They traced the extension of Appalachian structures offshore and used this information to

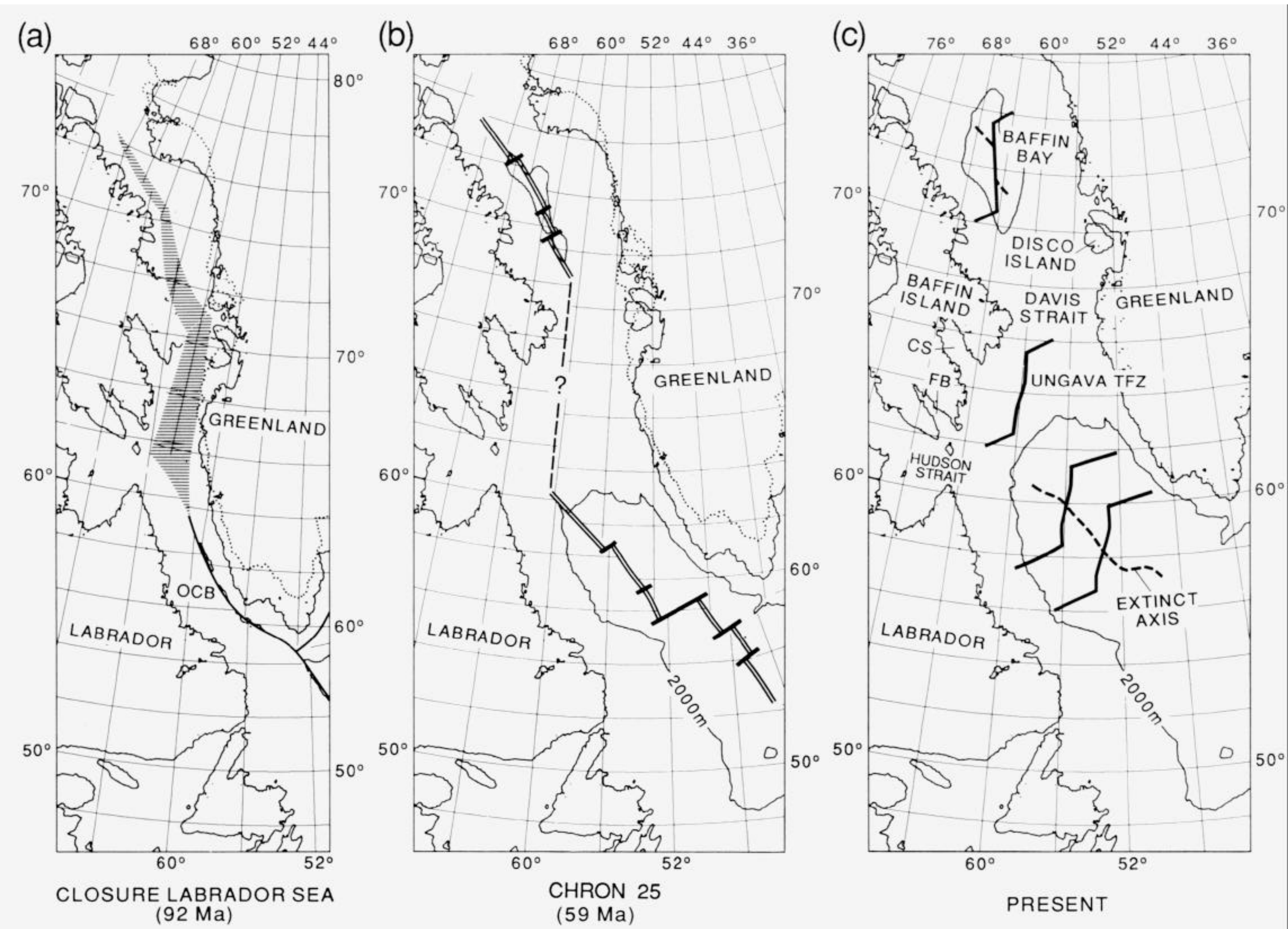


Figure 3. Evolution of Labrador Sea, shown in three stages: (a) at the time of initial opening (92 Ma); (b) at chron 25 (59 Ma); and (c) atpresent. Area of overlap (shaded in (a)) represents the amount of stretching that tookplace in Davis Strait and Baffin Bay before sea-floor spreading started there, at about chron 31 (from Roest and Srivastava, 1989).

establish Trans-Atlantic geological correlations. This was important independent evidence for the fit of continents before the opening of the Atlantic and served as a constraint on the evolutionary models of sea-floor spreading as developed by Srivastava and others from the study of magnetic lineations.

Conclusions

In spite of the results obtained from the interpretation of multidisciplinary surveys mentioned above, the exploitation of the *Baffin's* database has only begun. The data collected so far, augmented with continuing surveys, represent a national treasure, a part of the scientific infrastructure which will help us in the continuing search for new resources, at the same time making it possible to implement responsible environmental management.

The achievements

- 1956: built in Montreal by Canadian Vickers.
- January 1957: commissioned at Quebec City, then proceeded to Halifax, her home port for the next 34 years.
- April 1957: commenced operations with an offshore sounding program off Southeast coast of Nova Scotia using conventional DECCA.
- July 4, 1957: ran aground on Black Rock (southeast Nova Scotia) suffering extensive damage below the water line.
- 1958: first voyage to the Arctic; surveys in Frobisher Bay.
- 1960: circumnavigation of Baffin Island (see fig. 4).
- 1962: CAE plotting table installed in the drawing office, ushering in automated hydrography. It was a bold concept but at least 20 years ahead of the technological capabilities.
- Winter 1964: British Virgin Islands Survey. A hydrographic shore party was based at Tortola while the ship carried out an oceanographic program at Aruba which involved mooring a large air/sea interaction tower buoy.
- Winters 1965-69, 1973, and 1974: training surveys in Antigua, Barbados, Jamaica, St. Kitts, St. Vincent, Montserrat, Dominica and Guyana.
- April 1967: visited Monaco, for the IXth International Hydrographic Conference.
- 1970: circumnavigation of North America during which the "pingo" area in the Beaufort Sea was surveyed.
- Winter 1976: multidisciplinary survey on the continental shelf of Senegal and Gambia, sponsored by CIDA.
- Winter 1977: study of marine productivity, focussing on anchovies, off Peru.
- 1982: "Mid-Life" refit to increase oceanographic capability and improve the safety of launch handling.
- Winter 1989: substituted for the *Hudson* (in mid-life refit) on a major oceanographic program in Denmark Strait area. Visited Glasgow, Scotland and during the course of the cruise endured several severe North Atlantic storms.
- April 1991: quietly retired, without a sailpast or decommissioning, after 34 years of service for Canada; a victim of age and reduced funding.

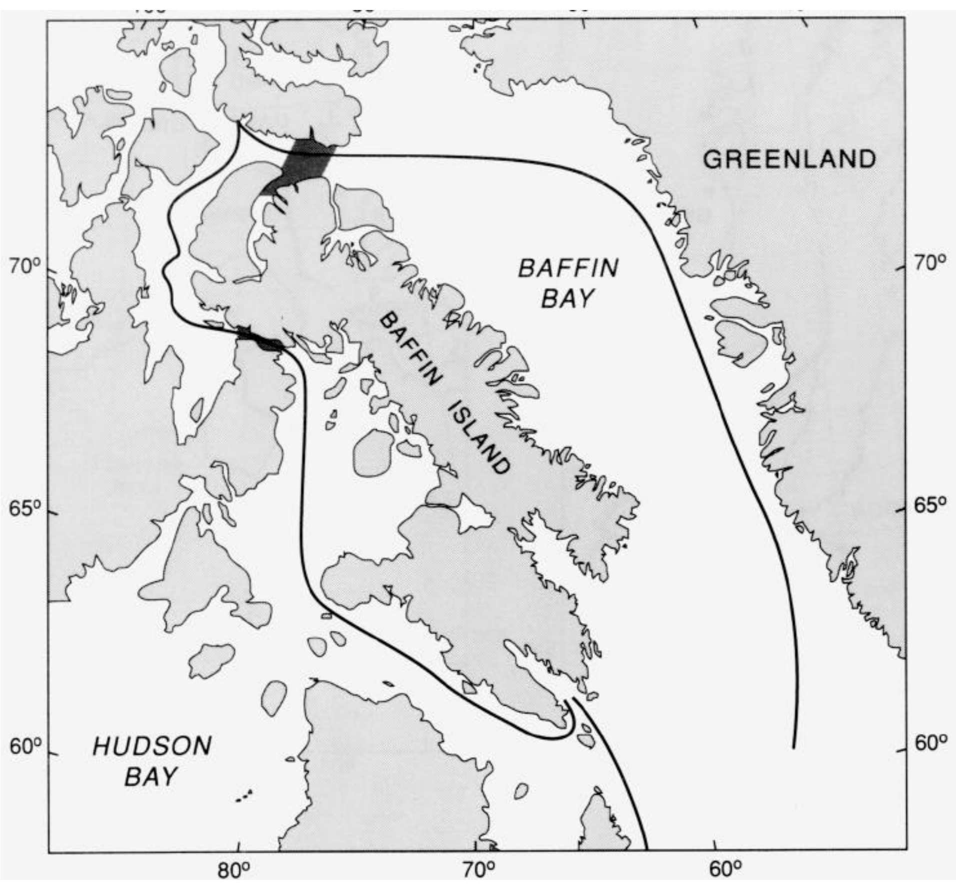


Figure 4. Track chart of the first circumnavigation of Baffin Island by C.S.S. Baffin *in 1960.*

Acknowledgements

This account was written in recognition of many contributions by colleagues in CHS and AGC who sailed on C.S.S. Baffin. We also thank the BIO Library for historical material, and the Ship Division (BIO) for statistics.

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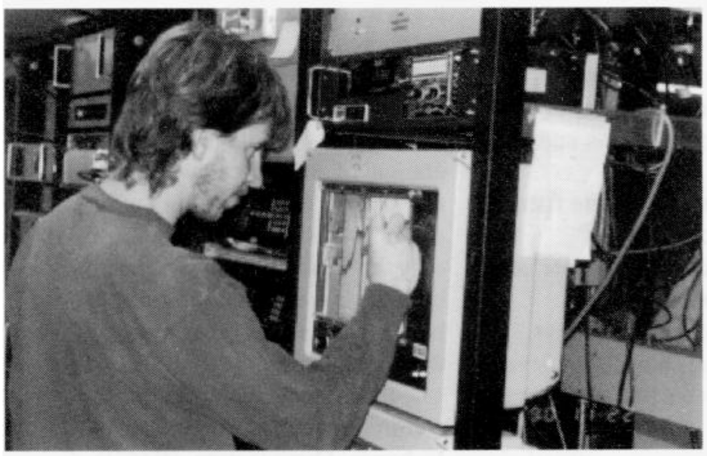

Hydrographers at work during the last voyage of the Baffin.

The Atlantic Fisheries Adjustment Program

R. O'Boyle, K. Drinkwater, B. Petrie, T. Rowell, and P. Vass

R. O'Boyle *K. Drinkwater* *B. Petrie* *T. Rowe11* *P. Vass*

In the summer of 1989, a crisis hit the Nova Scotia groundfish industry. The fleets had caught most of their annual quota by June. The resultant disruption in the fish supply caused plant closures, layoffs, and severe hardship for those dependent upon the fishery. This crisis was the symptom of fundamental ills that had been growing in the fishery since the early 1980s. Thus, in July, the Minister of the Department of Fisheries and Oceans (DFO), Tom Siddon, commissioned the Scotia-Fundy Groundfish Task Force, led by J.-E. Haché, to study the region's fishing industry and make recommendations to ensure its future.

By December of 1989, after extensive consultations with all sectors of the fishery, the task force had compiled its report (Haché, 1989), which outlined what it heard and what changes it felt were needed. The minister accepted the recommendations and created the Atlantic Fisheries Adjustment Program (AFAP) to implement them.

Science issues played a prominent role in the task force's recommendations and, therefore, in AFAP. The guiding philosophy was to ensure that science programs are relevant to fishermen's needs and that such programs foster two-way information exchange between scientists and members of the fishing industry. The recommendations covered a wide range of topics, including the following:

- furthering cooperation between scientists and fishermen with regard to the study of biological and environmental factors influencing fishing activity;
- developing an understanding of how environmental factors, such as temperature, influence the distribution and productivity of fish populations;
- studying the effects of seals and sealworm on fish populations and fish quality;
- studying the effects of longline fishing on fish populations;
- studying the effects of gillnets and trawling on the habitat;
- improving DFO's scientific surveys.

Scientific programs have been developed through AFAP in each of these areas. In this brief article, we cannot adequately cover progress on all topics. Indeed, in some programs the results are too preliminary to report at this time. Consequently, we present some highlights. For those readers who are interested, more detailed information can be obtained from the senior author.

Cooperative studies between science and industry

Fishermen spend much of their life at sea, harvesting the fish populations on which their livelihood depends. They are continually making observations about the biology of these complex creatures and thus are a valuable source of information to scientists. However, their understanding is sometimes coloured or "biased" by local conditions, particularly their need to find and harvest commercially profitable fish aggregations. Scientists, on the other hand, design sampling programs that attempt to avoid these biases and endeavour to provide the "big picture". These efforts, however, cannot hope to reach the level of sampling of the fish population that the commercial fishing fleets maintain. Through the cooperation of scientists and fishermen, we can achieve the best of both worlds. Interaction on issues of joint interest will not only improve our understanding of fish biology but will also ultimately lead to better assessment and management of these resources.

In order to examine the biology of cod in Sydney Bight (Northwest Atlantic Fisheries Organization (NAFO) division 4Vn), a cooperative study between science and industry has been developed. The management of this fishery has been plagued by the mixture of cod from adjacent areas. In particular, cod from the Gulf of St. Lawrence migrate into 4Vn during the period from January to April each year. The presence of this much larger stock in the Bight may have hidden the depletion of the smaller resident stock in recent years.

To date, the study has focused on defining the spawning and juvenile nursery areas of the local cod stock. Early in 1991, discussions were held with fishermen to identify probable spawning and nursery areas. Then, using this information, seven cruises, each of about ten days' duration, were designed and

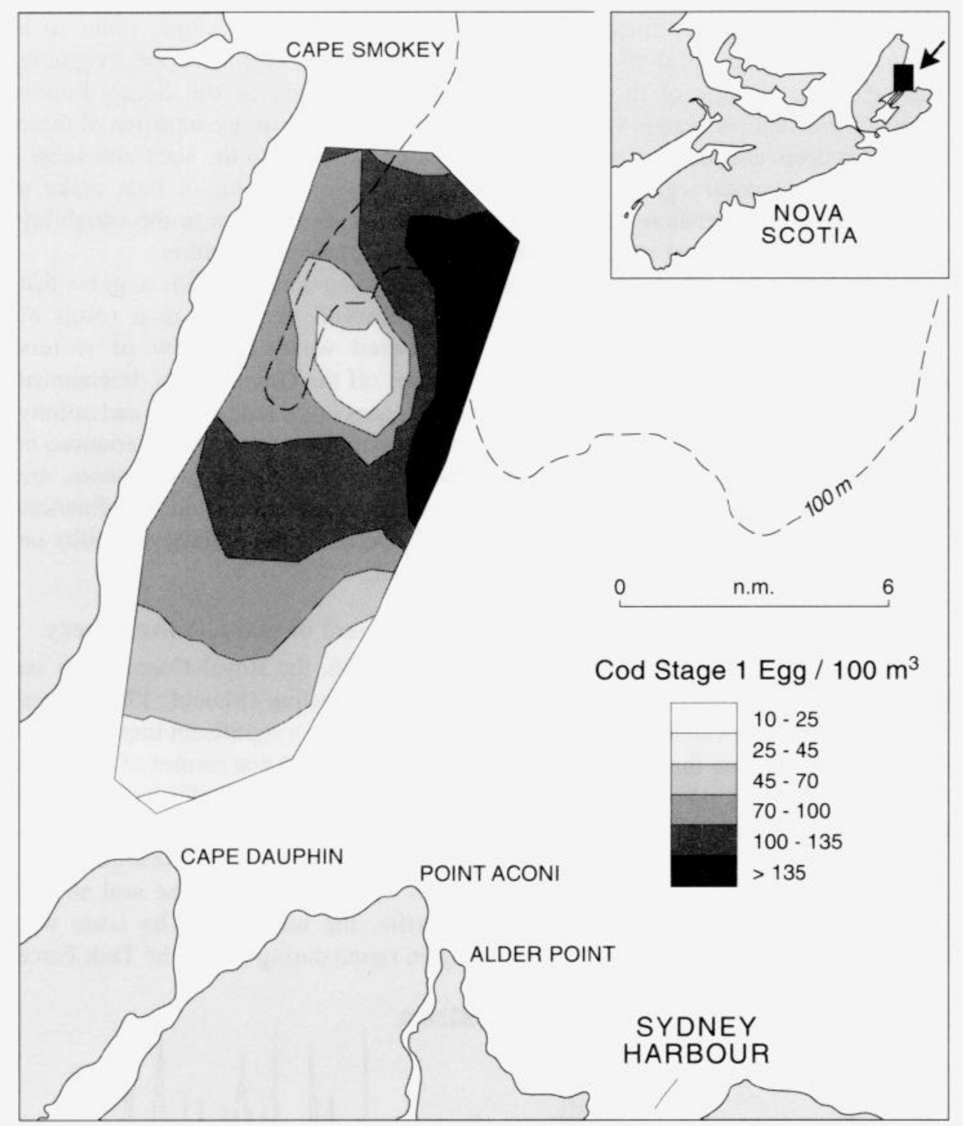

Figure 1. Location of cod eggs spawned in the Sydney Bight during 9-10 May 1991, as determined by egg survey.

conducted at roughly monthly intervals from April to November 1991. Sampling included fine-mesh net tows for fish eggs and larvae, bottom trawling for juveniles and water samples collected to measure temperature and salinity. Close contact was maintained with fishermen to keep up to date on the seasonal movements of cod, and this information was used to adjust the sampling sites.

The results showed that cod spawning occurs in April on Smoky Bank (fig. 1) and in Bras d'Or Lake. It is as yet unclear what the association is between the cod in Sydney Bight and those in the Lake. Initial analysis of the plankton samples indicated low levels of spawning. Once the analysis is completed, it may be possible to provide an estimate of the minimum size of the Sydney Bight cod stock.

Aggregations of juvenile cod (10-20 cm in length) were routinely and almost exclusively located near Bird Islands. If this proves to be the nursery area for the stock, it opens the possibility for a routine annual survey and thus development of an index of year-class strength for use in stock assessment.

Fishermen have long regarded water temperatures as having a major influence on fish movements and thus the catch. In the spring of 1991, cod catches in Sydney Bight were abnormally low, coincident with low water temperatures observed on **DFO's** surveys. Given this, it appears that the fishermen's anecdotal observations are based on a genuine biological process. In the coming year, this phenomenon will be further investigated with the assistance of fishermen who will be using water-temperature recorders, supplied by DFO's Biological Sciences Branch, during routine fishing operations.

These water-temperature recorders have been developed as part of another AFAP initiative in southwest Nova Scotia. In this case, a group of about 35 fishermen is cooperating with DFO scientists to study how catch rates are influenced by temperature, wind, tide, and so on. While it is too early to present the results here, the study illustrates the interest that fishermen throughout the region have in understanding how environmental influences affect the fish stocks and catch rates.

Environmental influences on fish productivity

Fluctuations of the temperature and salinity of continental shelf waters are known to influence fish distributions, and possibly to affect recruitment and fish abundance. Recent interest in ocean variability has been stimulated by the decline in several important groundfish stocks and predictions of possible CO,-induced climate change.

As a first step toward incorporating information about ocean climate change into fisheries management, an AFAP working group of physical oceanographers and fisheries biologists has been established to coordinate work investigating this phenomenon within the Scotia-Fundy Region. An extensive examination of the historical data has already begun in an effort to identify the temporal and spatial scales over which temperature and salinity vary.

The study will also investigate the forces controlling local climate change and will place these changes into geographical perspective through comparisons with variations in other areas of the northwest Atlantic. A program to monitor climatic variability on the Scotian Shelf and in the Gulf of Maine will be established on the basis of the project's results.

As a first step, existing time series of oceanographic, meteorological, and hydrological data or indices have been assembled in order to provide an initial description of the scales of ocean variability and their relationship to possible meteorological and hydrological forces. As well, additional historical temperature and salinity data for the Scotia-Fundy Region have been assembled from the National Archives in Canada and the United States, having been augmented by data from other sources. These data are presently being used to assess existing ocean climate indices and to define new ones, where appropriate. Initial results based upon analysis of these climate indices are provided below.

While previous studies have concentrated on patterns of sea-surface temperature, the AFAP-funded climate study is focusing on changes in the subsurface waters. Upon analysis of long-term records from Emerald Basin in the central Scotian Shelf (Petrie et al., 1991), we have found that a large component of the subsurface temperature variability occurs over long periods (10-20 years). The records (fig. 2) show that, following a maximum in the early 1950s temperatures declined gradually to a minimum in the mid-1960s rose rapidly until the early 1970s, and since then have remained relatively level or have declined slightly. This pattern is exhibited at all depths in Emerald Basin in spite of the different origins of the shallow waters (those less than 100 m deep) and the deep waters; the former are from coastal regions, while the latter are from the offshore slope area adjacent to the continental shelf. Similar temperature patterns are found in the deep waters of the Gulf of Maine, the Bay of Fundy, and the Gulf of St. Lawrence, as well as in coastal sea-surface temperatures recorded at sites in Nova Scotia, New Brunswick, and Maine. These indicate that the long-term changes in the region’s subsurface waters are coherent over a broad geographic scale.

Most interesting was the discovery that the maximum amplitude of the long-term temperature variability in Emerald Basin occurred at depths of 100 to 150 m. With regard to near-surface waters, the amplitude was approximately half that at 100 m, which suggests that these changes were not caused by local atmospheric heating and cooling. This result has recently been confirmed by a computer model developed by colleagues at Dalhousie University. These larger variations, which occur in the water masses originating over the slope, point to a largely oceanic origin for the long-term climate changes in the Scotia-Fundy Region. The subsurface intrusion of these oceanic waters onto the shelf and subsequent upward mixing of heat make a substantial contribution to the variability of near-surface temperature.

Ongoing investigations suggest that the observed changes are a result of increased westward flow of waters formed off the Grand Banks. Interannual differences in the temperature and salinity of these offshore waters, and variations in the air-sea heat exchanges offshore, are presently being considered as influences on temperature and salinity variability on the shelf.

The impact of seals on the fishery

In 1986, the Royal Commission on Seals and Sealing (Malouf, 1986) stated that seals have a significant impact on the fish resource and that control of the herds might have beneficial effects. It did not recommend a cull, but considered that work should be done to investigate other methods to control both the seal and its parasite, the sealworm. The issue was again raised during the Haché Task Force

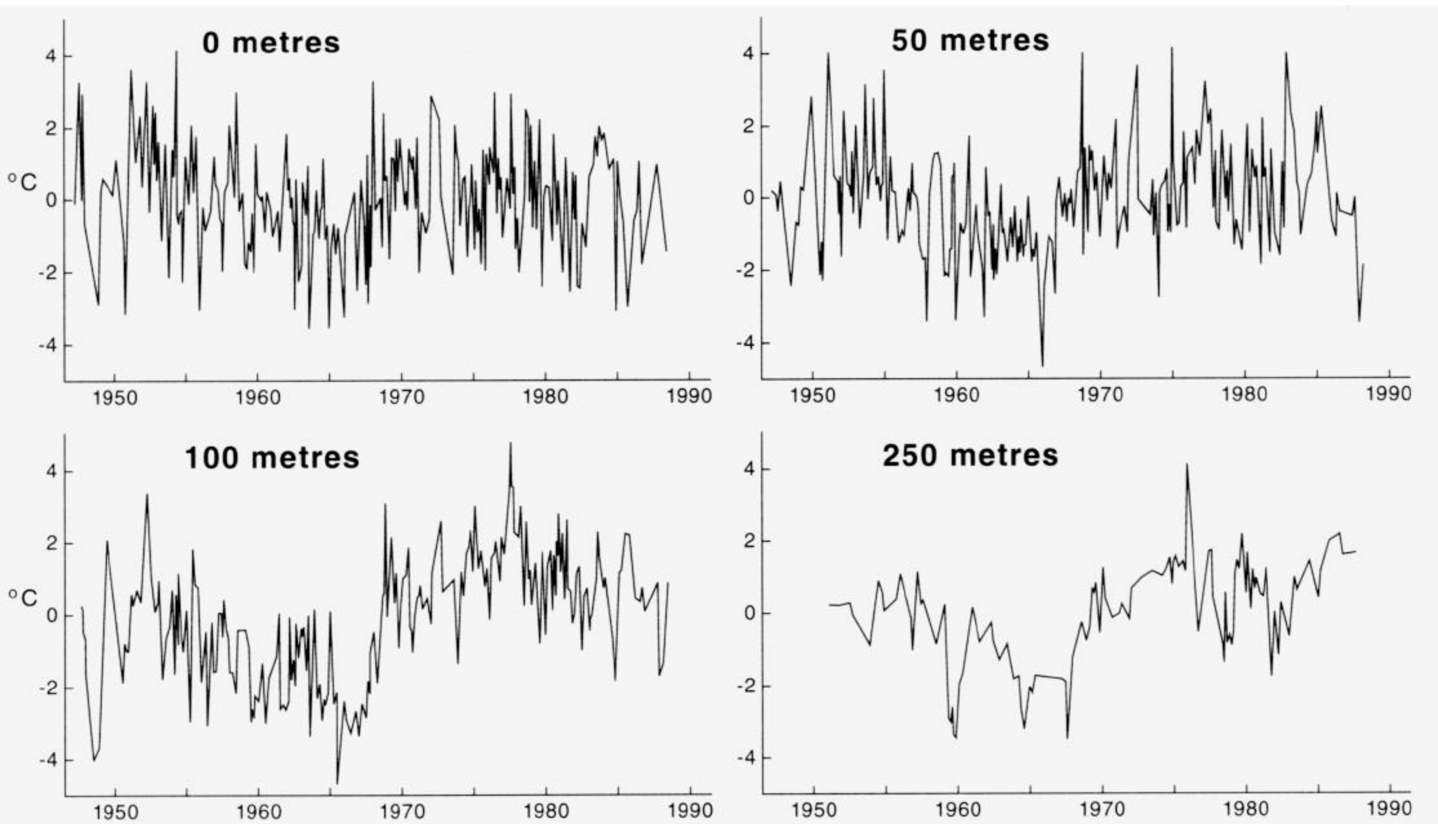

Figure 2. Temperature anomalies for Emerald Basin at 0, 50, 100, and 250 m for the period 1946-88.

consultations, and consequently the scientific work initiated by the commission has continued under AFAP.

The project is composed of two parts. The first, referred to as the Sealworm Intervention Program (SWIP), investigates chemical and immunological methods that could potentially be used to control seal production and sealworm infestation. The second part, called the Seal/ Sealworm Ecology Program (SSEP), studies the life history of the seal and sealworm and will provide the analytical basis for assessing the relationship among the size of seal and fish populations and the abundance of sealworm in the marine environment. Together, the results of these two programs will provide policy makers with the information they need in order to decide if and how control of the seal herds should be undertaken.

SWIP: This program, conducted in association with Dalhousie University, is investigating the feasibility of controlling the number of sealworm parasites through the use of drugs such as the anthelminthic (or deworming drug) Ivermectin and a newly developed vaccine. It is also studying the control of fertility in female grey seals with an immunocontraceptive.

In laboratory experiments, Ivermectin has been shown to be effective in reducing the fecundity of sealworms resident in seal stomachs. SWIP has developed a slow-release formulation which produces drug-serum levels in the seal that last twice as long and reach levels several times higher than those obtained from commercial Ivermectin. Although high serum levels of the drug have been maintained, the efficacy of the drug is still uncertain. Further work will be conducted on the formulation before field trials are undertaken.

The aim of the immunology study is to reduce sealworm burdens by immunizing seals with selected sealworm proteins to initiate an allergic response. Such a response would cause seals to eliminate worms, either by causing the seals to reject fish containing worms or by causing worms to be voided by the digestive tract. Thus far, the program has concentrated on identifying the active ingredients in the sealworm's proteins.

The sealworm has been found to have two immunogenic proteins - one a unique type of hemoglobin, and the other collagen. A third, smaller protein has also been discovered which is similar to that found in other worm-like parasites. Preliminary results indicate that immunization with some of these proteins may reduce the worm burden of infected animals. Further studies require large quantities of the pure immunogenic proteins, which can be obtained by the fast and effective method of cloning. Consequently, the complete gene for the hemoglobin and a partial segment of the collagen protein have been cloned. Scientists with the program also plan to clone the gene for the third protein. Field tests with these immunogenic proteins may be possible in 1992.

SWIP is also examining the use of glycoproteins from the *zona pellucida* (the egg's surface membrane) to effect immunocontraception in grey seals. This procedure has been used successfully in wild horse and deer populations, but seals present some unique problems. They are accessible only for 3 to 4 weeks once a year; therefore, if immunocontraception is to be practical it must be based on a single injection. Research has focused on a delivery system capable of effecting birth control for up to 5 years after only one dose. Laboratory studies to develop pilot systems have been successfully completed, and a field trial involving about 200 seals was undertaken in January and February 1992. The results from this field experiment should be available in 1994.

Studies with captive seals are designed to complement the field trials - in particular, to investigate further delivery systems for immunocontraception. At present, use of a modified vaccine produces antibody levels which are 200-400% higher than those known to be immunocontraceptive. Furthermore, continuous monitoring indicates that these high levels are persistent. The monitoring program has been in operation since the summer of 1991 and will continue for at least a year. Based on these results, seals captured in February 1992 will be used to investigate delivery systems which can be applied to the immunization of large numbers of seals under field conditions.

SSEP: This program focuses on the abundance of seals and the sealworm parasite. The ecological linkages between the two species, particularly through the seal's diet, are also being studied.

Research on population trends shows that the number of grey seals born on Sable Island has been increasing at about 13% per year, from 2,000 pups in the mid-1970s to over 10,000 in 1990 (fig. 3 - Stobo and Zwanenburg, 1990). In the past, field surveys were conducted to physically count and tag the pups. But their rapidly growing numbers are necessitating the use of new survey techniques, such as aerial photography. This particular method is currently being ground-truthed and will be the preferred survey procedure in the future. Information is also being collected on the re-sightings of grey seals branded at birth. These data will provide improved estimates of both the mortality and the reproductive success of grey seals.

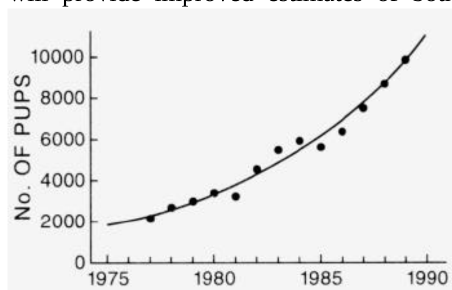

Figure 3. Total grey seal pup production observed on Sable Island between 1977 and 1989 (Stobo and Zwanenburg, 1990).

Sealworm infection in fish has also been on the rise. A comparison of data previously collected by fish inspectors with that collected more recently indicates that the percentage of fish infected with sealworm, and the number of parasites in individual cod and American plaice from the Breton and Scotian Shelves, increased significantly between 1958 and the early 1980s.

Between 1980 and '90, surveys of American plaice were conducted at more than 50 sites in eastern Canada. These indicate that, while levels of infection remained unchanged off Labrador, northeastern Newfoundland, and on the Grand Banks, the abundance of sealworm in plaice from southern Newfoundland, the Gulf of St. Lawrence, the Breton and Scotian shelves, and Georges Bank continued to increase. Indeed, sealworm numbers in plaice increased as much as tenfold in some areas of the southern Gulf and Scotian Shelf.

A 1989-90 survey of more than 24 species from the Breton Shelf, Sable Island Bank, and southwest Nova Scotia showed that the sealworm parasite has become increasingly abundant in other commercially important species, including haddock, redfish, grey sole, yellowtail flounder, and lemon sole. Heavy infections were also found in monkfish, cusk, and hake, as well as in rockling, lumpsucker, various eelpouts, and sculpins. Although these species are of little commercial importance, they may play an important role in the transmission of the parasite to commercial species and to grey seals.

In addition, comparative studies of the diets of three species of flatfish from Sable Island Bank indicate that small, shrimp-like crustaceans, known as mysids, appear to be an important source of sealworm infection in these species. These findings fill an important gap in our knowledge of the early life cycle of sealworm. To further this knowledge, the abundance of the sealworm parasite in grey seals on Sable Island and at coastal locations from Cape Breton to the Bay of Fundy is also being monitored.

The critical link among seal, sealworm, and fish is through the seal's diet. Consequently, a number of studies are being conducted to determine the seal's food and energy requirements, the prey composition of the seal's diet, and how these change with both location and season. For the results of these studies, see the essay in this Review titled "Population energetics of seals on the Scotian Shelf'.

The impact of fishing on the habitat

Both before and during the Haché Task Force, concerns were raised about the possible short- and long-term impacts that trawling, dragging, and dredging have on the seafloor and the organisms that live there. Fishermen felt that the continued disturbance of the bottom by fishing activity might be causing long-term changes to the ecosystem, both in species composition and levels of productivity. Our state of understanding of this complex topic was recently reviewed by DFO scientists (Messieh *et al.*, 1991) and was found to be weak in several areas. Thus, a study was initiated under AFAP to enhance our knowledge of this subject.

The intertidal area in the Minas Basin at the head of the Bay of Fundy, regularly fished by small inshore trawlers, provided a unique opportunity to examine the impacts of fish trawling on the sea bottom. Here, when the tide runs out, it is possible to walk out onto the flats, examine the tracks made in the mud by a trawl, and thus directly assess the physical and biological impacts of fishing.

In the fall of 1990, a vessel was chartered to tow a small flounder trawl at various locations in this area. The resulting physical changes that the trawl caused on the bottom were found to remain visible at least 9 months later (fig. 4). In this case, the tracks were 23 m wide, which corresponded to the size of the trawl used. Detailed examination of the tracks showed that the greatest degree of bottom disturbance was caused by the trawl doors, each of which weighed 181 kg and left a mark 5 cm deep and 0.75-0.85 m wide. In the area of bottom over which the net and rollers passed, the sediments appeared to be only slightly compressed and there was little evidence of scraping or sediment movement. Again, there was little sign of disturbance in the bridle area between the net and the doors. Overall, only 12% of the area swept by the trawl and doors was physically disturbed.

The biological impact on the benthic community resident in the disturbed area also appeared to be limited. This partly reflected the general paucity of invertebrates in the area; the biota was almost entirely infaunal (burrowed) and consisted primarily of marine worms or polychaetes. The most abundant organism inhabiting the sediments was the polychaete *Clymenella torquata,* which burrows to depths of 10-15 cm, well below the depths of the observed disturbances. Other macrofauna present in the area were free-living and, although some might

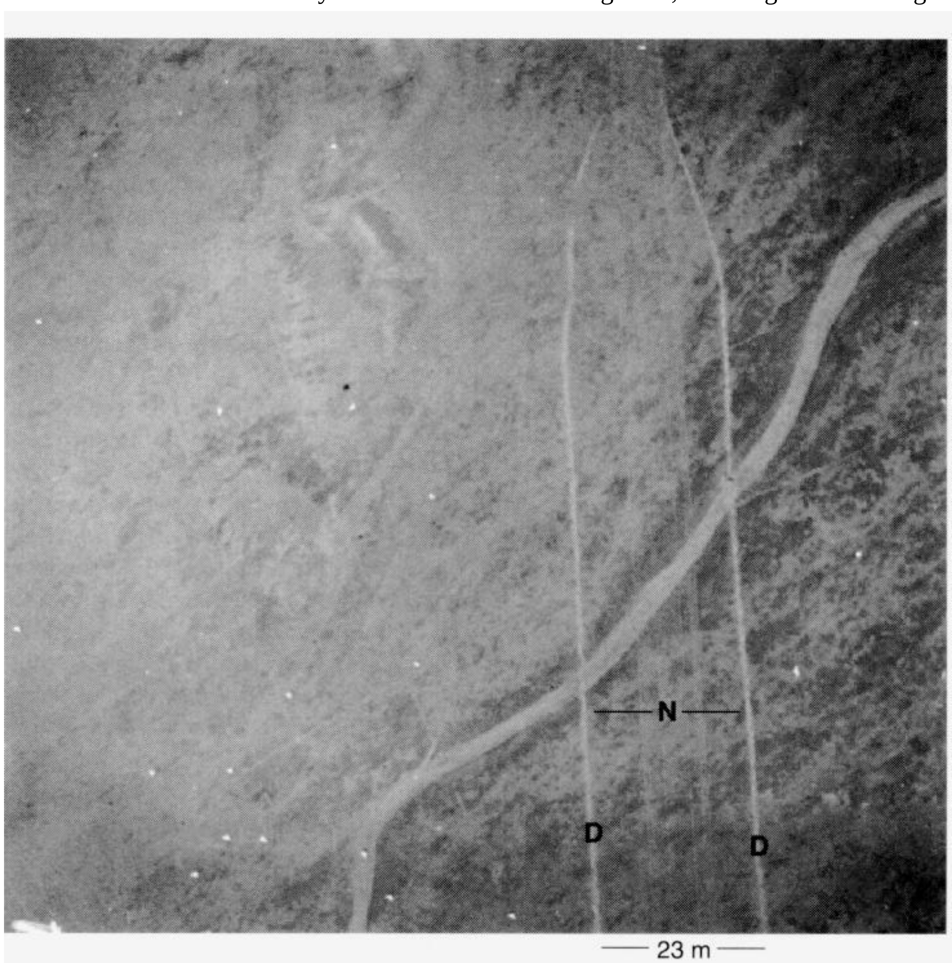

Figure 4. Track made over intertidal area off Dehaven Beach by a 18 m flounder trawl (N) and trawl doors (D). Photo from an altitude of approximately 150 m.

have been damaged (there was little evidence of this), most were probably only displaced. No crustaceans, molluscs, or echinoderms were found. Had they been present, the observable biological impact may well have been greater.

A three-year study, in collaboration with scientists at the Northwest Atlantic Fisheries Centre in St. John's, Newfoundland, has also been initiated in order to investigate the impacts of trawls on the Grand Banks and the Scotian Shelf. Westem Bank has been chosen as the study site on the Scotian Shelf. About half of this bank has been closed to fishing by mobile gear since 1986 as a haddock conservation measure. By examining the seabed both inside and outside the closed area, we will be able to assess what the impacts of trawling have been since the imposition of the closure. In addition, experimental trawling in the closed area is planned so that the short- and long-term impacts of fishing can be evaluated.

Contrary to the study in the Minas Basin, sampling of the seabed offshore presents unique problems. For instance, one cannot simply wait for the tide to go out before one starts sampling. Consequently, during 1991 this phase of the project focused on the development of a suite of gear that will allow comprehensive sampling of the bottom. Included in this arsenal is a side-scan sonar which is towed behind the research vessel and provides scientists with information on the bottom's surficial features. Eventually, this equipment will be mounted on the BRUTIV (Bottom Referencing Underwater Towed Instrument Vehicle), a sled that "flies" over the sea bottom. Also available is an epibenthic sled which is equipped with a video camera. This instrument is towed over the bottom, much like a scallop dredge, and collects animals from the seafloor.

To obtain samples of animals burrowed into the sea bottom, a bottom grab, equipped with a high-resolution video system, will be available. Once an area of interest has been located by the other gear, the grab is lowered to the bottom, the immediate locale is selected with the video system, and the hydraulic jaws of the grab are triggered shut to collect a bottom sample. The sample is then brought to the surface for detailed examination. The above assemblage of sampling gear is now ready for use in 1993.

Beside questioning the impacts of trawl gear, fishermen have also stated that lost gillnets continue to fish and cause high mortality in fish stocks. They have called for severe limitations to be imposed on gillnetting in order to avoid this so-called ghost-fishing. Little information exists on this phenomenon and, consequently, DFO's Science Branch, in association with the Fisheries Development and Fisherman's Services Division (now the Industry Services and Native Fisheries Branch) is conducting a study under AFAP to describe the situation.

Georges Bank is an area where fishermen believe "ghost" (or lost) gillnets are a significant problem. A research cruise to document the extent of the problem was run on the *Alfred Needler* in September 1991. Prior to the cruise, discussions were held with representatives of the longline and mobile gear sectors to identify areas where gear had probably been lost. As well, a representative of the Shelburne County Longliners' Association participated in the cruise itself.

The search was concentrated along the 50-fathom isobath on the northern edge of Georges Bank and consisted of tows using a grapnel. The 236 tows resulted in the recovery of 19 gillnets or parts of gillnets, which contained the remains of 94 fish (cod, hake, dogfish, and unidentified skeletons). As well, lost or abandoned fishing gear of one sort or another (longlines, trawl warps, codends, gillnets, and parts of scallop drags) was found in 26% of the tows.

Studies were also carried out to determine how long various types of fish remain in gillnets once they are caught. The first experiment, completed in November 1990 in St. Margarets Bay, indicated that the residence time (the time required for scavengers to consume all the flesh of entangled fish) averaged 2 days and varied from 1 to 5 days. No correlations were evident between residence time and water temperature or the location of the fish in the nets.

Further work was conducted in 1992 when researchers tested the feasibility of using dual-frequency side-scan sonar to locate lost gillnets. This involved the setting and attempted sonar detection of test nets over various types of sea bottom off Halifax. A final experiment will examine the relationship between the population density of scavenging amphipods and the residence time of captured fish.

Groundfish survey improvements

Scientists in the Scotia-Fundy Region have conducted long-term groundfish-monitoring surveys on the Scotian Shelf every July since 1970, and on the Eastern Shelf and Georges Bank every March since the mid-1980s. These surveys have used statistically rigorous methodology and gear procedures that have remain essentially unchanged since their inception. Thus, changes in fish abundance indicated by the survey can safely be assumed to be due to biological and/or environmental factors, rather than a consequence of survey technique. These surveys are an essential component of the region's assessments of the groundfish stocks.

They are, however, expensive to run and compared to commercial fishing operations which generate thousands of tows each year, only generate a relatively small, albeit standardized data set. It is therefore of considerable importance to investigate ways in which we can extract as much information as possible from these surveys.

The first study under the AFAP project addressing these issues examines how the survey trawl fishes under different operational conditions. Since 1989, on each tow of the standard July survey, gear performance has been measured by electronic sensors attached to the trawl doors and the head-line rope. At the same time, information has been collected on the ship's speed and direction, the gear depth, the tide condition, and so on.

The study has shown that gear depth plays an important role in the shape and size of the trawl mouth opening. In shallow water, the door spread decreases while the head-line height increases. The opposite is true in deep water. How these changes affect the ability of the trawl to catch fish is currently under study. In the coming year, if required, operational procedures will be investigated to determine how to compensate for these changes in trawl mouth opening.

Survey catch rates are also influenced by the availability of fish to the trawl. Fish such as pollock and cod can wander off the bottom and thus become unavailable to the fishing gear. Therefore, the second part of this project involves examining how acoustical technology can be used to quantify fish abundance throughout the water column. During 1991, the project focused on the development of a user-friendly dual-beam acoustics system. After much testing, both in the lab and at sea, the system is now ready for implementation during the remainder of the AFAP project. The equipment will be used on standard groundfish surveys in tandem with trawling, both to determine the optimal operational configuration and to allow comparison of the acoustic and trawl data sets.

Conclusion

The crisis of 1989 brought into focus a number of problems in the management of our fisheries. It was clear from the onset that DFO's Science Branch had a central role to play in addressing these problems and, thus, in the recovery of the industry. What was required was a concerted effort by scientists, in cooperation with industry, to work on resolving the broad range of issues identified by the Haché Task Force.

With support through AFAP, significant progress has been made in several areas. Upon completion, some projects will have immediate management implications (for example, the studies of the impacts of trawls and gillnets). Other projects, such as the study of environmental influences, will provide the basis for long-term understanding of resource productivity. This mix of short- and long-term studies is a major strength of the AFAP initiative and will ultimately lead to the wiser long-term husbandry of our fish resources.

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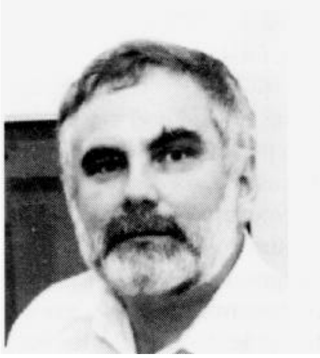
Water-level instrumentation and data dissemination: A look at the present and the future

C. T. O'Reilly, G. D. Steeves, S. de Margerie*, and T. Millen**
(* ASA Consulting Ltd. ** Correpro Atlantic Ltd.)



C. T. O'Reilly

G. D. Steeves

Accurate sea-level data are needed by a large number of disciplines. Oceanographers use them for distinguishing variations in the movement of water masses, and as input to numerical models of ocean circulation, the trajectory of oil spills, and predictions of iceberg drift. Long-term measurement is required in order to differentiate changes in mean sea level resulting from regional crustal movement and global sea-level fluctuations. The concern about the effects of global warming has recently focused attention on the reliability of sea-level data.

Geodesists and surveyors also use long-term data about sea level to identify geopotential surfaces for use in establishing vertical datums for land and for marine mapping purposes. Mariners and fishermen use tidal information on a daily basis as a navigational tool. Other users of water-level data include biologists, geophysicists, search and rescue agencies, and coastal engineers, as well as special interest groups such as environmentalists, aquaculturists, and tourist bureaus.

Until recently, the large majority of water-level data came from analog recorders which used a stilling well with either a float and pulley coupling or some sort of pressure sensor. This technology, although capable of reasonable accuracy, has become extremely difficult to maintain, primarily due to obsolete instrumentation and labour-intensive data processing. As well, there is a rapidly growing demand for the dissemination of accurate, real-time water-level data - something that is difficult, if not impossible, with analog equipment.

During the 1970s, a digital water-level recorder was introduced by the Canadian Hydrographic Service (CHS). Called the Tidal Acquisition and Telemetry System (TATS), the system has become the primary source of water-level data at most measuring stations in the Scotia-Fundy Region, with some analog gauges continuing in use as backup units. Although they have performed well, the TATS gauges are very limited in design and are not commercially available. As a result, technical support is becoming a major problem.

Instrumentation

At present, there is almost universal movement toward the use of digital dataloggers as the next generation of water-level recording instruments. A large variety of dataloggers are being linked to an even greater variety of sensors, from the conventional float/pulley to pressure-sensitive strain gauges and quartz crystals. Acoustic reflection sensors and bubbler technology (which utilizes the rate of gas bubbles as a function of pressure) are also common.

In eastern Canada, CHS has selected the SOCOMAR Model TMS1000 datalogger for use in the Permanent Water Level Network (PWLN). Over the next 5 to 10 years, systems are required to gauge approximately 18 sites in the Scotia-Fundy Region and 27 sites in the Quebec Region. During this time, rigorous assessments of all datalogger and sensor hardware will be carried out, including ongoing comparisons of the data with that collected by existing conventional gauges, as well as detailed statistical studies of multiple sensor deployments. Field operation of the gauges will be assessed with a particular emphasis on software menus and ease of installation. All software is written in the "C" programming language and operates on standard low-cost CMOS 80C188EB architecture.

The SOCOMAR datalogger has the capability of interfacing multiple sensors, including absolute and differential sensors and a low-cost diaphragm type similar to present analog portable gauges. The absolute sensors have built-in digital barometers to allow for atmospheric corrections, while the differential and diaphragm sensors are mechanically compensated for changes in barometric pressure. The differential sensors are actually groups of sensors which measure conductivity, salinity, and temperature and are used to correct for changes in water properties. Each sensor group functions completely independently of the others and shares only the time reference. Having multiple sensors uses redundancy to detect real-time errors without having to wait for human verification.

In the initial years of gauge deployment, sites using stilling wells will be compared with those using sensors in open water. This will be done to assess not only data quality, but also operating costs. This monitoring is essential to ascertaining the optimum site configuration; the long-term goal is, of course, to maximize data return with minimum cost.

Digital dataloggers allow a great deal of flexibility if various combinations of sensor inputs are mixed and matched.

Conventional clock-timing errors, which have plagued analog gauge data processing in the past, should be essentially eliminated. Digital clocks can be checked and reset remotely as often desired, with time drifts measured in seconds instead of minutes and hours.

Options for the SOCOMAR datalogger include a remote telephone, a radio (UHF/VHF), and satellite (ARGOS) communications. Global cellular coverage should be available by the end of the decade. Other options include several weather-monitoring sensors (up to 24), to measure variables such as wind speed, wind direction, precipitation, and snow depth. A multi-channel GPS option and a speech synthesizer have also been announced.

Coastal Ocean Water Level Information System

The Coastal Ocean Water Level Information System (COWLIS) was developed in recent years with two objectives in mind: to provide a tool for the acquisition, quality control, and dissemination of water-level data for the CHS; and to supply a working prototype for generalized ocean information systems. COWLIS' key objectives are flexibility and ease of access to information.

The concept of COWLIS was proposed by ASA Consulting Ltd. in 1987, and resulted in a government-funded development project in 1989. CHS has played a leading role in supporting and promoting COWLIS.

The initial development project was completed and delivered to CHS in 1990, and the system is currently operational, on an experimental basis. In 1991, a technical transfer agreement was signed and an enhanced system is presently being developed. This new version will integrate the TMS1000 tide gauges as well as use an off-the-shelf database structure.

With the development of COWLIS, the private sector is playing a major role in the further development and marketing of ocean information systems. The need for these systems arises from both the demand for data and the supply of data, as follows:

- coastal and ocean resources are under increasing pressure, and the rational management of these resources requires more and better information;
- advances in remote sensing technologies are rapidly increasing the rate at which ocean data are acquired. Without information systems to automatically organize and extract useful information from these data streams, the masses of incoming data can hinder, instead of assist, management decision-making.

Real-time data acquisition, processing, and dissemination are essential if these new needs for ocean information are to be satisfied. For example, COWLIS assists CHS in its mandate to acquire, quality check, and disseminate water-level information in coastal Canada. With COWLIS, these tasks can now be performed in real time, with benefits to:

- the internal productivity of CHS;
- the management of harbour traffic in depth-limited ports;
- surveying and dredging activities;
- the ability to provide flood warnings in coastal areas.

The main functions of COWLIS are water-level measurement, data processing, and data dissemination. The infrastructure needed to serve these functions consists of a data network, a database, and data processing facilities.

The data network connects data source (tide gauges) and user access platforms (PCs) to the database. For simplicity, COWLIS was designed with a central database and processing facility. The top portion of figure 1 shows the physical hardware components of COWLIS. The Datapac telecommunications network was selected due to its availability throughout Canada and its conformity to the international x.25 communications protocol, which allows the system to be implemented worldwide. The system is

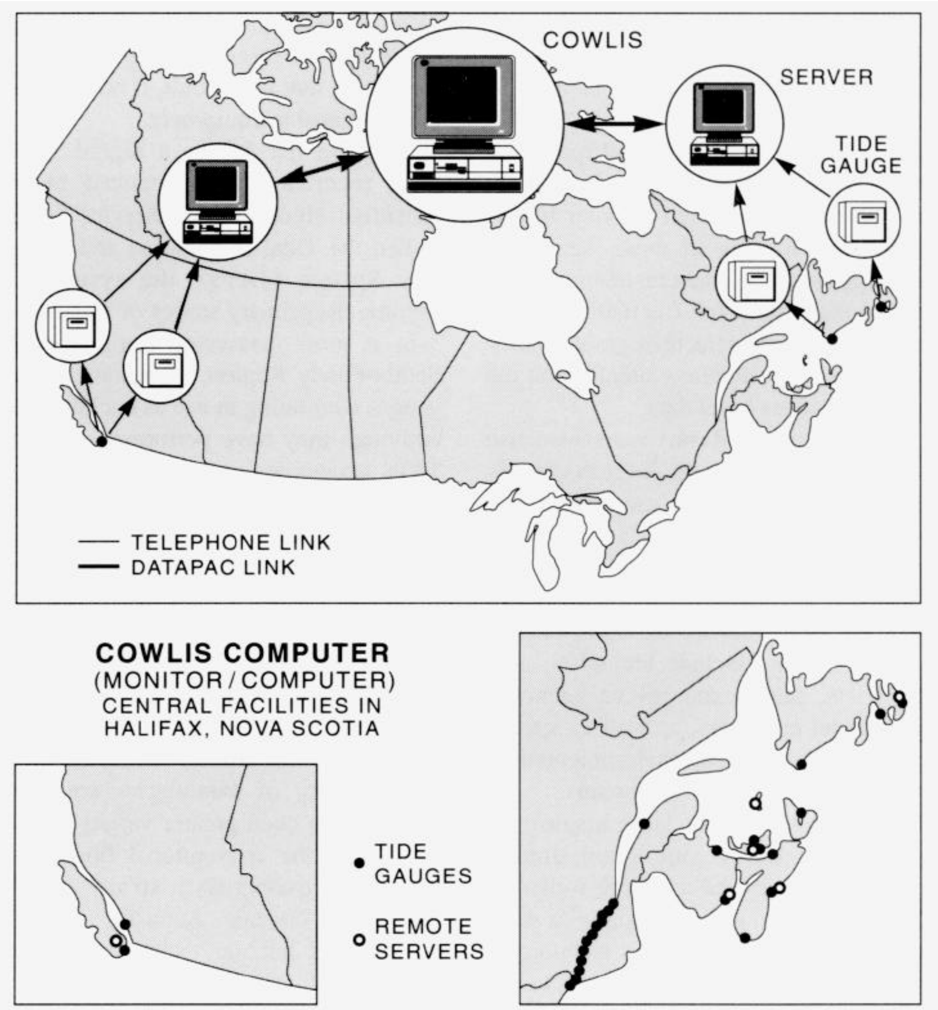


Figure 1. The network of tide gauges and servers through which COWLIS acquires information about coastal ocean water levels.

presently designed to be accessed through readily available MS-DOS personal computers.

The processing software resides entirely on the central computer. For the purposes of data acquisition and dissemination, software must be resident on the central computer as well as on remote platforms (the tide gauges and the user's computer), so that communication can be orchestrated over the network. Throughout the system, a modular design increases flexibility and allows expansion. COWLIS automatically updates all software and control files on the remote platforms if they become corrupted, or when new upgraded versions are installed.

The design of the data acquisition system allows the communications interval to be set individually for each tide gauge site on the network. This increases system flexibility and cost effectiveness by allowing:

- frequent- communication for stations where water levels are more variable or of special interest (for example, for storm forecasting or harbour maintenance control);
- infrequent communication for stations where water levels are stable or where there is no pressing real-time interest;
- expansion to include other ocean parameters which may require shorter or longer monitoring intervals.

The bottom portion of figure 1 shows the location of the Permanent Water Level Network gauges and remote servers that are currently integrated into COWLIS. Communication over data networks requires a degree of intelligence on the part of the monitoring instruments which is beyond the capability of the existing TATS units. To remedy this problem, remote server microcomputers were installed in the field to orchestrate long-distance communication with the central system via Datapac. These servers communicate with one or more tide gauges through local phone calls. The need for remote servers can eventually be eliminated through the use of more intelligent tide gauges, such as the SOCOMAR.

The private sector is heavily involved in all aspects of COWLIS development. Liaison between the private and public sectors benefits both partners: the public sector gets new capabilities in data collection and dissemination, while the private sector ends up with a globally marketable product. A notable private-sector joint venture related to COWLIS is the development of OCEANFAX.

OCEANFAX allows access to COWLIS via any common fax machine. The user requests data by checking off items on a special order form, and faxing it to the OCEANFAX computer. There, proprietary software automatically decodes the form, and transmits the requested data back to the user's fax machine within minutes. This option eliminates the need for the user even to have a computer.

Remote arctic tide gauge

Long-term accurate water-level data are required in remote areas of the Canadian Arctic. Information about Arctic water levels is especially important for monitoring global sea-level change, an increasingly sensitive issue. Yet success in measuring long-term water levels in this region has been very limited and extremely expensive.

The successful gauging of the Arctic lies in the development of new and cost-effective technology. A project has been underway since 1987 to develop a stand-alone system which can endure the harsh arctic rigors. The basic approach uses separate recorders above and below the water surface in order to avoid the very difficult problem of cables travelling through the ice-water interface. A digital barometer which operates unattended for up to a year in temperatures as low as minus 55°C was designed, built, tested, and transferred to private industry.

The next stage of the project was to devise methods for communicating between the outside world and the units above and below the water surface.

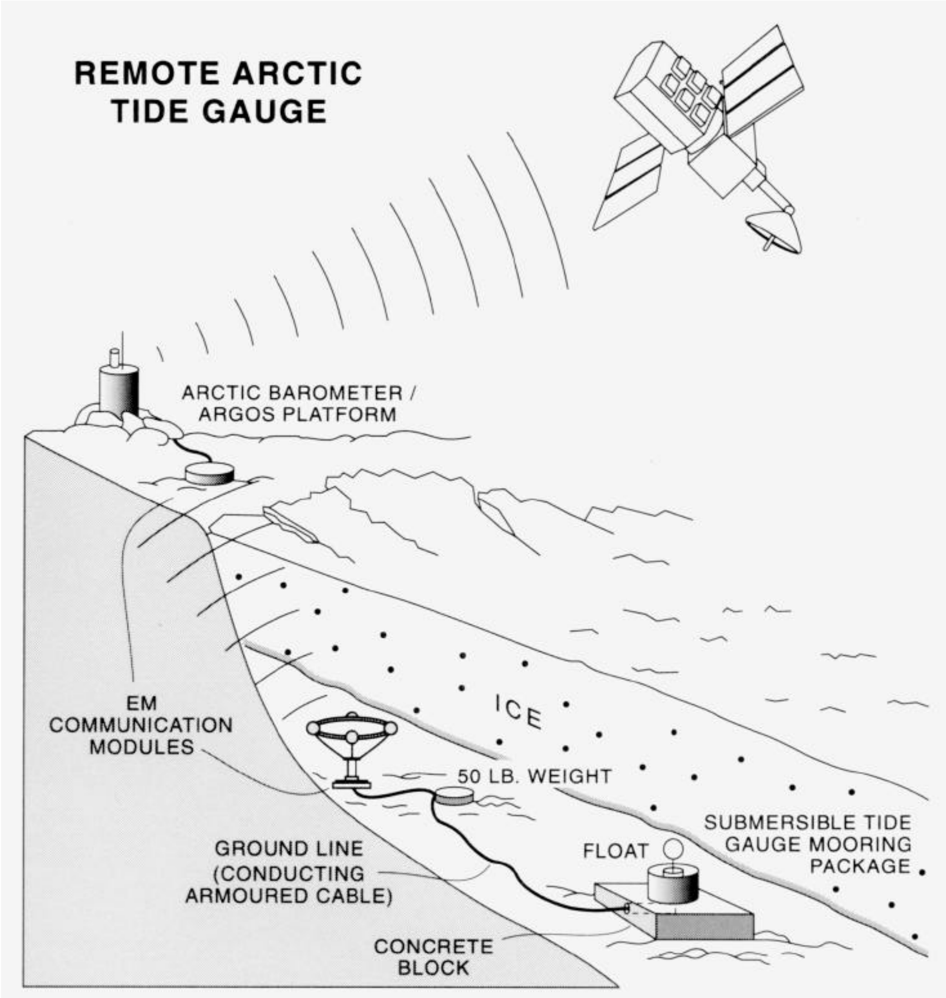


Figure 2. The stand-alone system for use in the Arctic with an electromagnetic (EM) communications link, a satellite uplink, and the submerged tide gauge.

Correpro Atlantic Ltd. is now developing a prototype of an underwater communications system which will use digitally encoded ultra-low-frequency radio waves; the unit is scheduled for field testing during 1992. The digital barometer has been modified to accept data from the submersible gauge and to transmit them in near real-time via an ARGOS satellite link. Figure 2 illustrates the deployment of the system.

The future

Technology is the obvious key to the future of Canada's requirements for water-level measurement and data dissemination. The use of digital dataloggers introduces a large degree of flexibility and cost-effectiveness to the acquisition of accurate water-level information. The introduction of a ocean data collection system such as COWLIS provides real-time data access, rapid quality control, and data dissemination to a variety of users. These developments allow for vast improvements in the forecasting of storm surges and the management of harbour and seaway traffic, while streamlining internal data processing and management. Development must maximize the flexibility to integrate ongoing technical advances with future user demands.

Promising developments which are currently under investigation include the integration of multi-channel GPS receivers as a way of relating water-level data to dynamically determined ellipsoidal surfaces. On-line numerical forecast models which assimilate real-time observations can maximize the value of remotely sensed data. The use of GPS interfaces, and integration with the development of the electronic navigation chart, promises to simplify user access and bring ocean information to where it is often needed the most - at sea. Along these lines, a prototype of a COWLIS option that displays bathymetry and tidal currents driven by either observed or forecasted water levels is presently available for two ports in eastem Canada. In addition, the integration of existing capabilities to model the fate and trajectories of oil spills is proposed for the purposes of responding to emergencies and managing environmental information.

The tide gauge of tomorrow may well be a complete ocean-monitoring system, collecting long-term measurements of sea level, temperature, salinity, and variations in atmospheric pressure. The infrastructure described in this paper offers the potential for a variety of data about the ocean and environmentally sensitive issues to be collected, managed, and distributed.

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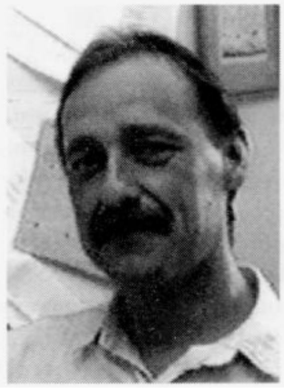
Digital techniques for sidescan sonar and seismic data acquisition and display

D. R. Parrott, B. C. Nichols, J. R. Currie, R. G. Currie, and R. C. Courtney


D. R. Parrott


B. C. Nichols


J. R. Currie


R.G. Currie


R.C. Courtney

The Geological Survey of Canada **(GSC)** has recently introduced a marine Digital Initiative, a joint project involving the Atlantic Geoscience Centre (AGC) and the Pacific Geoscience Centre (PGC), which will provide the basis for the repeatable, quantitative, and geographically accurate mapping of the seafloor and underlying sediments. This initiative will help address Quaternary geoscience issues such as environmental assessment, seabed mapping, and pollution monitoring in the coastal zone and on the continental shelf.

The studies performed by the GSC require information about the morphology and character of the seafloor and underlying sediments, information which is collected through such techniques as swath bathymetry, sidescan sonar, and high-resolution seismic reflection (or subbottom profiling) surveys. Through cooperation with the Canadian Hydrographic Service, which is presently enhancing its capability to provide detailed water depth information through the use of swath bathymetry techniques, detailed information on the topography of the seafloor is available.

Acoustic pictures of the seafloor are provided through sidescan sonar surveys. Inclined transducer arrays are used to send sound waves to the seafloor, on both sides of the survey track, and echoes from both the natural small-scale roughness of the seafloor as well as changes in topography are detected. Information about those changes is taken from the detailed bathymetry surveys and used to separate the effects of topography from the effects of small-scale roughness. High-resolution seismic reflection and subbottom profiler data provide a vertical cross section of the seafloor and underlying sediments, enabling interpretation of their structure and distribution. Together, this information allows geologists to reconstruct the 3-D geological history of the seabed sediments.

The information provided by these surveys fosters an understanding of the processes fundamental to such questions as the transport and deposition of materials ranging from toxins to sands and gravels. Data acquisition and processing tools are being acquired to aid the transition from traditional qualitative analog methods currently in use to more effective digital technology. During the first part of the project, digital data acquisition and processing capabilities have been enhanced for use with existing sidescan sonar and seismic reflection systems. This capacity has been used to produce true-scale sidescan sonar and seismic images of the seabed in a geographically referenced (or georeferenced), scale-corrected format, and mosaics (composite images) of the seafloor from adjacent survey swaths. In coming years, the project will acquire specialized hardware to study the distribution of seafloor sediments, and to determine sediment properties.

The method

The objective of using digital techniques for data acquisition and enhancement is to extract more information from the data than is available through the interpretation of analog graphic records of sidescan sonar and subbottom profiler records. When traditional analog techniques are used, most of the data processing and graphic-record generation is done during the survey and often represents the only working copy of the data. Replaying data from analog magnetic tape generally allows application of the same techniques which had been used when the data were acquired - for example, simple bandpass filtering, time-varied gain, or presentation at different scales to improve the appearance of the graphic record.

In contrast, digital data acquisition systems allow shipboard acquisition of sidescan sonar and high-resolution seismic data at rates up to 100,000 samples per second. The use of 12-bit digital acquisition results in higher-fidelity recording than is possible with analog techniques. Data are recorded in industry-standard format (SEG-Y - see Barry et al., 1975) on high-capacity 8-mm digital tape. Navigation data are encoded into the data header in order to allow georeferencing of the data. To ensure that no irreversible procedures are applied to the digital data, only raw unprocessed data are recorded. Preliminary enhancements of the field display, such as slant-range correction, gain adjustments, and bandpass filtering, are then performed by the data acquisition system before the data are displayed.

Separate hardware is being used for data acquisition and data processing. The data acquisition hardware is dedicated to recording and replaying data, with options available for minimal data processing to enhance the quality of the graphic record and ensure that good-quality data are being captured. The main data processing activities are performed on dedicated, high-speed UNIX workstations.

The processing of digital data begins with editing and application of a time-series analysis, including digital filters, gain equalization, and deconvolution. This is followed by geometric corrections (for seismic migration, aspect ratio, and slant range) to produce a spatial data set from the time series data. More advanced image-processing techniques may then be applied to condition the spatial data and produce sidescan sonar mosaics and seismic fence diagrams. At any stage in the processing, data may be imported into a digital publishing package to allow features such as record annotation, scale, and interpretations to be added. The annotated image can then be output to a variety of devices, including colour slide copiers, thermal graphic recorders, and laser printers.

Portable processing and enhancement software is being implemented using the X-Windows/Motif™ windowing environment available under the UNIX operating system. A "point and click" Graphical User Interface (GUI) is being developed to isolate the user from the complexities of the UNIX operating system.

High-resolution sidescan sonar surveys can produce up to 160 megabytes of data per hour. The data sets are transferred from the field tapes, which are produced by the digital data acquisition system, to UNIX workstations, where the final processing is done. The field processing systems provide an operating environment and processing steps identical to those at the onshore facility.

Field tests

The data acquisition and processing tasks occur at the same time. Many of the data presented in this paper have been digitized from analog field recordings and, as a result, do not show the increased fidelity expected from data recorded digitally in the field. Rather, they are used to demonstrate the processing techniques currently under development. The quality of data and ease of processing should both improve as digital logging becomes more routine.

During a recent survey offshore Vancouver, British Columbia, sidescan sonar and high-resolution subbottom profiler data were collected on a series of closely spaced lines, so that the geomorphology, sediment type, and sediment distribution of the Fraser Delta could be studied (Hart *et al.,* 1991). Sidescan sonar data were collected with a 100 kHz Klein 595 sidescan sonar system; high-resolution subbottom profiler data were collected with a Huntec Deep Towed Seismic system. Navigation was provided by an integrated system using Loran C, the TRANSIT satellite, and the Global Positioning System (GPS). These data were selected as a test case for acquisition and processing in a digital format. Figure 1 shows the bathymetry of the survey area. Note the deep channels near the Steveston Jetty and Canoe Passage.

Processing sidescan sonar data

For the survey, sidescan sonar data were recorded in analog format and

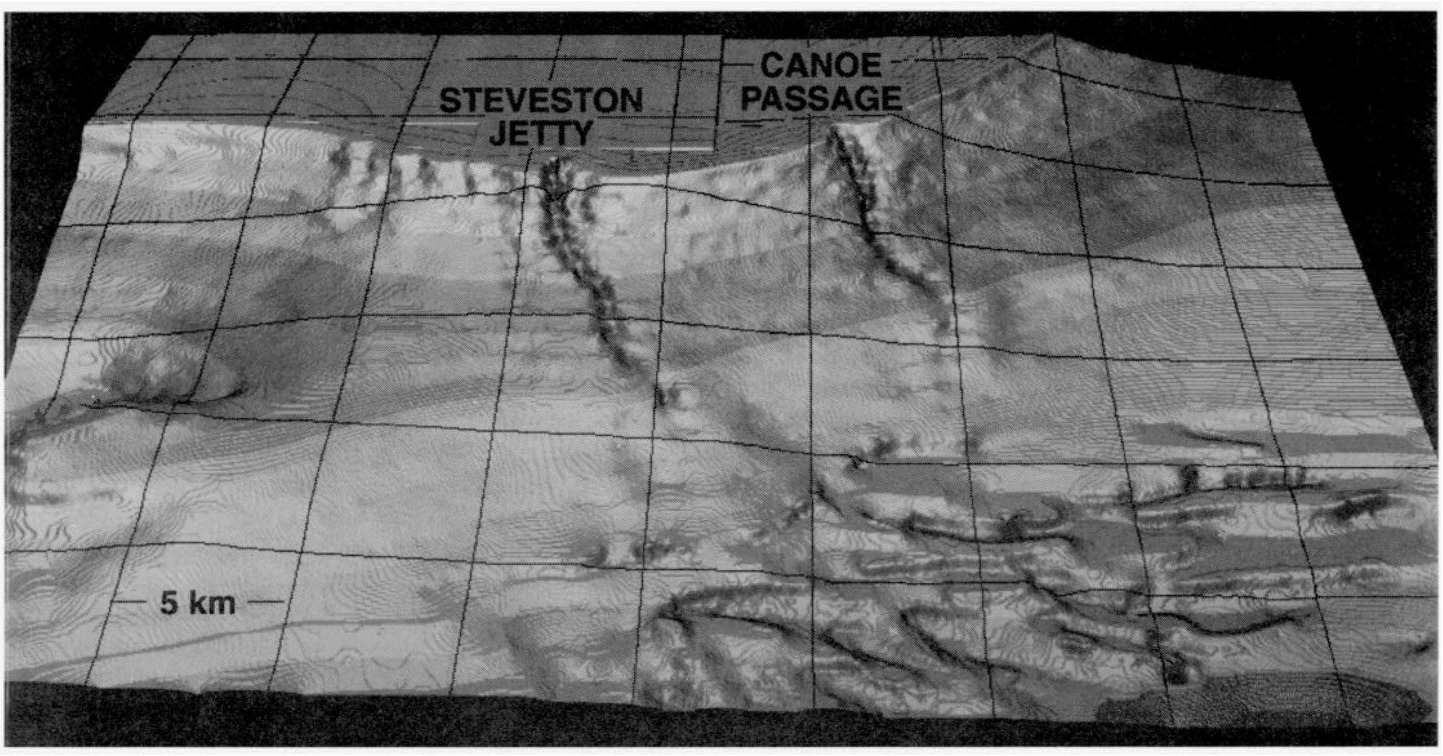


Figure 1. A three-dimensional view of the bathymetry of the Fraser Delta, Vancouver, British Columbia.

digitized after the cruise using an SE880 digital acquisition system manufactured by GeoAcoustics Ltd. (formerly Ferranti-ORE) of England. This provided 2,100 pixels across the 300-m range of the sidescan sonar, giving a theoretical resolution of about 0.15 m. The data were copied to a Silicon Graphics Iris 4D/35 computer workstation, and the original tapes were archived for future use.

Processing can be performed on the entire suite of data in order to utilize all of the available resolution, or the data can be decimated to reduce the amount of computation time. Generally, decimated data are used to generate mosaics, and full-resolution data are used to study features of particular interest identified on the mosaics.

The sidescan sonar data are processed using techniques derived from those employed by the United States Geological Survey (Danforth et al., 1991). The georeferenced data are processed to remove the geometric distortions introduced by towing the sensor at varying heights above the seafloor. The process, referred to as "slant-range correction", removes the effect of the height of the sensor and repositions the data points across the entire swath.

Removal of these geometric effects requires a known height of the sensor above the seafloor, obtained by determining the location of the seafloor return signal on the unprocessed digital data. Automated routines for locating the seabed on sidescan sonar and seismic data are subject to error, so an interactive technique has been developed which gives the operator full control over the selection of the seafloor return. With this procedure, the uncorrected sidescan sonar data are displayed on the monitor, and the operator uses a mouse-controlled pointer to select the position of the seafloor on the image. These control points are used to guide the process of locating seafloor position across the entire file. On the unprocessed sidescan sonar data in figure 2 the deep channel near Steveston Jetty is quite evident and the seafloor is easily identified.

The data are then processed to compensate for geometric distortions and for the nonlinear beam pattern of the transducer arrays over the width of the swath. Since the beam pattern is not generally known *a priori*, it is deduced from data collected in an area with homogeneous seafloor characteristics, and an inverse filter is designed to compensate for the effect of the beam pattern over the entire data set. The data are then processed to remove geometric distortions and are displayed as shown in figure 3.

After processing, each line can be output to a graphic recorder, or terminal, in proper geographic coordinates. Adjacent survey lines are used to produce a mosaic of the data, and the data sets are "painted" into an array using the navigation and swath width. Lines are placed into the array, and any overlapping areas of the swaths are weighted and averaged. The resulting file is a georeferenced data set of sidescan sonar images precisely located on the seafloor and provides information on the morphology and nature of sediments throughout the survey area. This file can be output to a display device, as shown in figure 4, or exported to a Geographic Information System (GIS) and merged with other data sets to assist in interpretation, feature extraction and measurement, and the generation of geologic maps.

At any stage in the processing, the data can be displayed on the monitor. The operator can view any portion of data at a larger scale by simply selecting the area of interest, cropping the image, and enlarging it to fill the entire screen. The data can easily be viewed in their correct aspect ratio, or enlarged in either the along-track or cross-track direction.

Processing the seismic reflection data

A suite of processing software has also been developed to assist with the interpretation of seismic reflection records, a process which in many ways parallels that already described for sidescan sonar data. Seismic reflection data are processed to allow the presentation of sections of graphic records, which have been corrected for variations in the ship's speed and in the speed at which sound travels through the seafloor sediments, and to prepare the data for subsequent analysis.

Figure 2. Unprocessed sidescan sonar data from the Fraser Delta showing a deep channel and turbidity flow..

Figure 3. Sidescan sonar data from figure 2 after processing to remove geometric distortion and beam pattern.

Figure 4. Mosaic of sidescan sonar data from adjacent lines. Notice how the channel can be traced throughout the mosaic.

In order to produce the record shown in figure 5, high-resolution seismic data were digitized using a sample interval of 20 microseconds in a sampling window of 200 milliseconds' duration. As the data were also digitized from analog tapes, they had to be time-referenced in the same manner as used for the sidescan sonar records. While the file was displayed on the screen, a mouse was used to digitize bathymetric information by indicating points on the seafloor. Navigation data were smoothed and merged with the digital seismic data based on the times contained in the record headers. Since sidescan sonar and subbottom profiler data are generally collected by separate towfish, separate files of seafloor location are maintained for these data sets.

The next step was to approximate a velocity function. In the case of the data displayed in figure 5, the speed of sound was assumed to be 1,500 m/sec in the water column and 1,800 m/sec in the first 15 m of the subbottom. A speed- and depth-corrected section was then interpolated at a specified spatial interval, scale, and vertical exaggeration using the geographic position, water depth, and velocity function associated with each shot.

After spatial transformation and assembly of the data from adjacent survey lines into a mosaic of seismic reflection profiles, the data were processed for display. The section of data shown in figure 5 was cropped from the processed data, converted to a bitmap image, and annotated using a computer graphics package.

Data presentation

It is possible to make a hardcopy of an image in a variety of formats at any stage in the processing sequence. Presently, large-format (up to 75 cm wide and several metres long) colour or black and white images can be generated on a Versatec model 8944 colour plotter. Smaller-sized, higher-resolution images may be printed on the same type of digital thermal graphic recorders used during the data acquisition phase of field surveys - for instance, the Raytheon TDU900 or the EPC9000 series and Alden 9315 CTP thermal printers. Images may also be transmitted from the processing computer to a colour-slide maker. In a similar fashion, images can be transmitted to colleagues around the world.

The final stage of data presentation entails the preparation of publication-quality figures. With traditional analog techniques it was still necessary, after

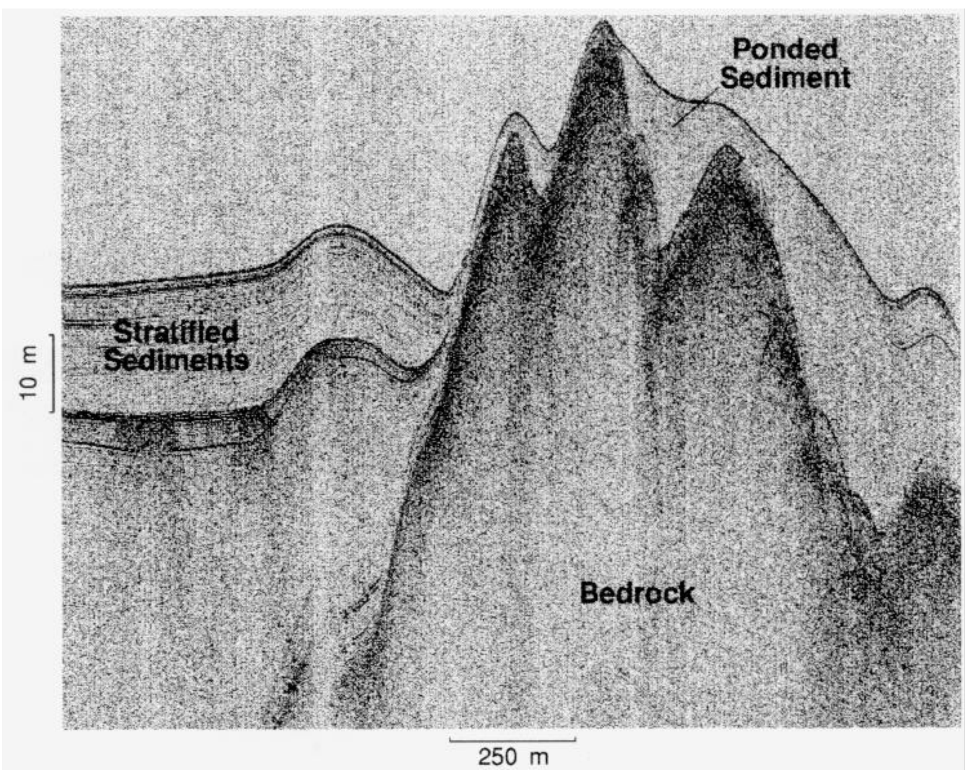


Figure 5. A subbottom profiler record showing sediments deposited over a bedrock high.

production of the sidescan sonar or seismic reflection graphic record, to rely on the services of a draftsperson and photographer to produce an image of the record that contained the necessary scales, geographic location fixes, and interpretations. The process was time-consuming and often involved producing large-scale photographic negatives, generating and overlaying labels on the image, and then rephotographing the combined images and labels.

All of the images presented in this paper have been produced using completely digital techniques. The data were transformed and imported into a publishing package, where alphanumeric text information, as well as line-drawn images, could be incorporated. The annotated images were then output as a graphic record (as shown in figures 1 and 5) and as colour slides.

Conclusion

The use of digital techniques provides an opportunity for an improvement in the way seismic and sidescan sonar data are collected, processed, and presented. The infrastructure now exists for the production of digital mosaics of sidescan sonar and seismic reflection data. These mosaics present the data in a manner which allows the scientist to quickly obtain an overview and determine the geographic relationships of geological features. The scientist can then use the computer to study features of interest; the data can be digitally processed to remove unwanted noise and artifacts such as surface multiples, and portions of the mosaic can be selected and enlarged in order to help identify fine-scale structures. After processing, the sidescan sonar or seismic image can be saved in a format which can be imported into a computer graphics package where labels, scales, and interpretations may be overlain on the image prior to output as a graphic record or colour slide.

Data can be handled in a completely digital format from the time of acquisition, through the processing sequence and the final production of the published results, and during the preparation of lecture materials such as slides and overheads. The digital data can also be output in a format appropriate for inclusion in a GIS.

The use of digital techniques for data acquisition and processing has resulted in an improvement in the dynamic range and quality of the data available for interpretation. More information can be extracted by enhancing the graphic record and by providing quantitative analyses of variations in the data. It is anticipated that the use of digital techniques will lead to improvements in the efficiency of data analysis and interpretation and will improve the cost effectiveness of collecting, processing, and interpreting sidescan sonar and seismic reflection data.

Acknowledgements

The Digital Initiative Project is a GSC project involving input from scientists from AGC and PGC. A portion of the research carried out under this project is supported by the Offshore Geotechnics Program, Tasks 61103 and 63203, of the federal Panel on Energy Research and Development. The data used for illustrations in this article were collected during surveys performed by PGC and AGC.

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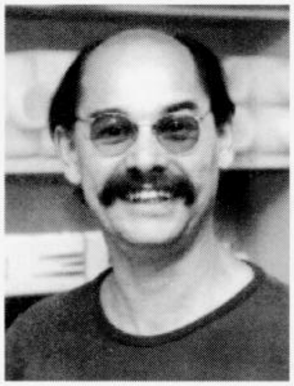
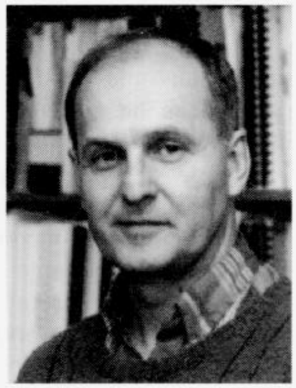
Concerns addressed in the ocean dumping permit process

D. Peer, N. Prouse, and G. Seibert


D. Peer


N. Prouse


G. Seibert

In the past, unwanted materials were commonly disposed of in the oceans without much thought given to potential impacts. As environmental awareness grew and the limits of the coastal marine environment's ability to dilute wastes became evident, nations began to recognize that the oceans and marine resources must be protected.

In 1975, Canada joined 50 other countries in ratifying the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (the London Dumping Convention), designed to prevent the indiscriminate disposal of wastes and to provide a basis for the regulation of ocean dumping. Canada, as signatory to the London Dumping Convention, passed the *Ocean Dumping Control Act* (ODCA) in the same year. ODCA actively regulated ocean dumping until 1988, when it was replaced by Part VI of the *Canadian Environmental Protection Act* (CEPA). CEPA mandates the identification, assessment, and control of hazardous substances in order to protect the environment and human health. Part VI under the CEPA addresses ocean dumping.

The regulatory regime

Under CEPA Part VI, anyone wishing to dump material at sea applies for a permit to the Toxic Chemicals and Waste Management Branch of Environment Canada. The application must detail the source and kind of material to be dumped, its amount, the rate of disposal (along with the proposed method of containment or packaging of the spoil, if any is deemed necessary), the dredging and dump site locations, the transport method and route, and the chemical, biological, and physical characteristics of both the spoil and the dump site. Chemical data are included with the application and assessed to ensure that concentrations are within regulated limits set by CEPA Part VI.

Possible effects of the ocean dumping process, and the properties of the dumped material, must be carefully assessed before a permit can be approved. As part of the approval process, the permit applications are reviewed by technical and scientific experts in several disciplines. At the Bedford Institute of Oceanography (BIO) this is carried out by the Department of Energy, Mines and Resources, which reviews the geological and geophysical characteristics of the dredged material and the dump site, and by the Department of Fisheries and Oceans, which considers potential impacts on marine organisms and habitat, and on navigation and marine safety.

In terms of quantity, most material to be disposed of at sea comes from the maintenance dredging of existing channels and harbours to navigable depths (fig. 1); however, wastes from fish processing and vessels at sea also contribute a significant amount. To ensure that dumped materials and disposal methods will not pose an environmental risk or create a human health problem - for example, through the contamination of edible fish - it is important to assess the potential impacts of chemical constituents.

CEPA lists two classes of substances that, alone or in combination, are potentially harmful: prohibited substances and restricted substances.

Prohibited substances are those known to cause serious harm and include such materials as cadmium and mercury, and their compounds; oil and grease; organohalogenated compounds, e.g. PCBs; plastics, and other synthetic materials that do not readily decompose; and high-level radioactive materials. Prohibited substances are under strict control and cannot legally be dumped if they exceed predetermined limits.

Restricted substances are those that are potentially hazardous, and can only be dumped with extreme care. Such substances have no predetermined limits, e.g. arsenic, lead, copper, zinc, beryllium, chromium, nickel, and vanadium (and their compounds); cyanides; fluorides; pesticides not listed as prohibited; organosilicons, e.g. water repellents; containers and scrap metal; low-level radioactive materials; and bulky wastes (which could present hazards to fishing and shipping). Concentrations of some restricted substances in disposal material are flagged when they exceed the regional averages. A permit application may be rejected if there is any indication that such levels might adversely affect the marine environment or pose a risk to human health.

At present, there are over 30,000 chemical substances in common use within Canada, and new introductions and importations are ongoing. To manage these, a Priority Substance List has been established under CEPA. Currently 44 chemical substances are being evaluated for their environmental and health risks. Information collected through literature and research is being used to determine safe levels, whether each substance should be controlled, and how high a priority that action has. For example, concentrations of cadmium and total polycyclic aromatic hydrocarbons (PAHS) in every dredge spoil sample must be below 0.6 $mg.g^{-1}$ and 2.5 $mg.g^{-1}$ dry weight, respectively, if the material is to be approved for ocean dumping. Where concentrations are exceeded, the application is returned, along with a description of the chemical basis for the objections, and the permit may be denied. Often, samples exceeding the acceptable level require verification through resampling.

Similarly, levels of restricted substances are examined and any that exceed the general background concentrations are noted. Levels of trace metals measured in eastern Canadian marine sediments by Loring (1982), among others, provide values for comparison. Unusually high concentrations require biological assessment, especially if chronic or acutely toxic effects on marine organisms or human health have been previously observed.

Dumping of dredge spoils

Increases in suspended solids and changes to the seabed are the main physical impacts of dredging and dumping on the benthic environment. Dredging can destabilize the seabed and resuspend solids, as was observed in Miramichi Bay (Kranck and Milligan, 1989). Benthic organisms may be killed by dredging. Spoil disposal might bury others. However, studies on fish and lobster entrainment by the dredge head (Burton, 1979; Pelletier and Wilson, 1981) indicated that entrainment is not a problem for species that can move freely. However, benthic infauna, e.g. clams and burrowing worms, will be entrained and buried.

Reestablishment of the benthic community depends on the topography and hydrographic conditions. If the original conditions are not restored, a benthic community in equilibrium with the new conditions will develop over time. Species will move into the disturbed region from nearby areas. Initially these are small species with short life spans, e.g. polychaete worms. If the sediment is continually resuspended, such small organisms will be the only species able to live in the area. However, under more stable conditions, larger, longer-lived species, like lobsters, also reestablish themselves.

The particle-sizes of dredge spoil samples are analyzed and assessed because of the possibility of burying benthic organisms and disrupting habitats. Siltation can particularly affect eggs and larvae of some marine species. For example, sediment deposited onto herring eggs increased mortality (Messieh et al., 1981). Siltation may also delay metamorphosis of lobster larvae. Free-swimming lobster larvae will not settle onto sandy or muddy bottoms and will delay settling and moulting until favourable rocky conditions are found (Cobb, 1968). After lobster larvae have settled, dredging or smothering of “nursery” areas occupied by juveniles could have serious consequences for future recruitment into fishing areas (Pottle and Elner, 1982). For these reasons, a proposed dump site must not be near major nursery or rearing areas and dumping activity must be timed to avoid critical periods, e.g. bivalve “spatfall”.

A further consideration in ocean dumping is that suspended solids (turbidity) could have lethal and sublethal effects on marine organisms. A literature review by Appleby and Scarratt (1989) stated that suspended solids have the potential to cause histological and haematological damage and induce physiological and behavioural changes in fish and shellfish. This review noted “eggs and larvae are less tolerant to suspended solids than adults, and larvae are more sensitive than eggs”. For example, suspended material from dredge spoils inhibited feeding by herring larvae, and concentrations as low as a few parts per million resulted in juvenile herring avoiding the area (Messieh *et al.,* 1981).

Appleby and Scarratt suggested that “many species of adult fish and shellfish survive in concentrations of suspended solids far greater than those commonly observed in nature”. This tolerance also varies between species and among the various types of suspended particles: larger or jagged particles appear to be more harmful than smaller or smoother particles. Organisms may also be exposed to higher concentrations of contaminants associated with the suspended solids.

To minimize the problems associated with the resuspension of dredge spoils, Appleby and Scarratt recommended dumping in sheltered (poorly flushed) areas, or in deep water, or on land. They cautioned that this solution is not always straightforward because dumping in a poorly flushed area would increase biological oxygen demand (BOD), creating additional problems.

Figure 1. Hydraulic dredge in operation

Dredging and dumping activity can also lead to increased coastal erosion and wave action. Removal of material that naturally maintains barrier islands and sand beaches can lead to their erosion.

Dumping fish waste

Solid waste from fish processing (offal) is the second largest amount of material disposed of by ocean dumping in the Atlantic region. Such waste, which can amount to hundreds of tonnes from a single plant over a season, is disposed of at designated ocean dump sites. The major concerns are the potential impacts on nearby fisheries, habitat disruption, the high BOD of the waste, and the organic contaminants associated with it. Aesthetics is a further consideration. The review of applications to dump offal must verify that it will be well-dispersed at the dump site and that floating material will not foul beaches. An interesting sidelight is that gulls eat dumped fish waste and thus may gain a competitive advantage over other marine bird species such as terns.

Fish meal processing produces large amounts of liquid waste, called stickwater, which has a high BOD and could increase eutrophication if dumped in areas of limited circulation. Every year, many foreign factory ships apply to dump such waste after processing over-the-side purchases. These applications are approved provided the dumped waste will be well-dispersed and will not affect fishing grounds or recreational areas.

Scuttling vessels

A permit is required before vessels can be scuttled at sea. The scuttling must not interfere with navigation and the disposal site must be in deep water away from fishing grounds. All hazardous materials must be removed prior to scuttling. The chief chemical concerns are that petroleum products and their associated wastes, polychlorinated biphenyls (PCBs), mercury-filled bearings, and ammonia from refrigeration systems might be released and contaminate the dump site. Non-degradable litter, which could pose a threat to turtles, seabirds, and marine mammals through ingestion or entanglement, must be removed.

Research needs

The foregoing underscores the importance of assessing the physical and chemical behaviour of dredged material in the marine environment, particularly the degree and extent of chemical contamination and turbidity plumes generated during the dredging or dumping operations. The short-term fate of material may be analyzed by using numerical models (Johnson and Holliday, 1978; Johnson, 1988). Simulations can be carried out to predict, among other things, the maximum lateral movement and subsequent thickness of the disposed material, and the conditions under which sediment will be resuspended or deposited. Accurately predicting the long-term fate of dumped material cannot be done at present. Monitoring dump sites is costly, and as the time scale increases, it becomes difficult to separate natural and human-caused changes.

We note that assessing the potential impacts of ocean dumping does not guarantee the absence of impacts, because it is often difficult or impossible to demonstrate scientifically that an impact has or has not occurred. In fact, what constitutes an impact is still debatable (Kester et al., 1983). However, critical and careful evaluation minimizes these impacts and preserves valuable resources.

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Swordfish research and assessment

J. M. Porter

J. M. Porter

The Canadian swordfish industry, located primarily in the Scotia-Fundy Region, annually harvests approximately 15,000 fish, valued at $6 million. Work by the Department of Fisheries and Oceans in the 1960s and ’70s focused on collecting data on the basic biology of large pelagic fishes, and an extensive tagging program was conducted (Burnett et al., 1987).

In 1989, the Scotia-Fundy Region re-established at the St. Andrews Biological Station a large pelagic fisheries program, dealing with swordfish, tunas, and sharks. (The program had been dormant for several years.) In addition to building on the base of the historical studies, the current program includes participation in the international assessment of swordfish and a variety of research projects in support of this activity. Scientists work closely with industry in order to fulfill the department’s zonal mandate to provide the best advice for current management of swordfish stocks.

Distribution in the Atlantic

Swordfish *(Xiphias gladius)* are widely distributed throughout the entire Atlantic Ocean, ranging in the northwest from the Gulf of Mexico to the Grand Banks of Newfoundland (Scott and Scott, 1988). In the Scotia-Fundy Region, swordfish are harvested along the edge of the Scotian Shelf and the Grand Banks of Newfoundland from June to October, when they are most abundant. Tibbo et *al.* (1961) proposed a swordfish migratory pattern as north and east in the summer (as far as the Flemish Cap), and south and west in the autumn, with spawning in the Caribbean and Gulf of Mexico. Between 1961 and 1981, a total of 281 swordfish were tagged and released in the Canadian Large Pelagic Fish Tagging Program; 26 of these were later recaptured (fig. 1; Burnett *et al.*, 1987).

Recent analyses show that most tagged swordfish were caught close to their release sites, although after considerable periods at large (an average of 3.2 years, a maximum of 15.1 years). In particular, the large (adult) swordfish (85 to 210 kg - see fig. 1) were caught within 200 km of their release sites, usually at the same time of year and several years later, which suggests their tendency to return to the same northern feeding areas each year.

The smaller (mostly immature: 45 to 84 kg) swordfish showed similar localized nondirected movements after release, with two movements of longer distance: from the tail of the Grand Banks of Newfoundland to Nova Scotia, and from Sable Island Bank to the Bahamas.

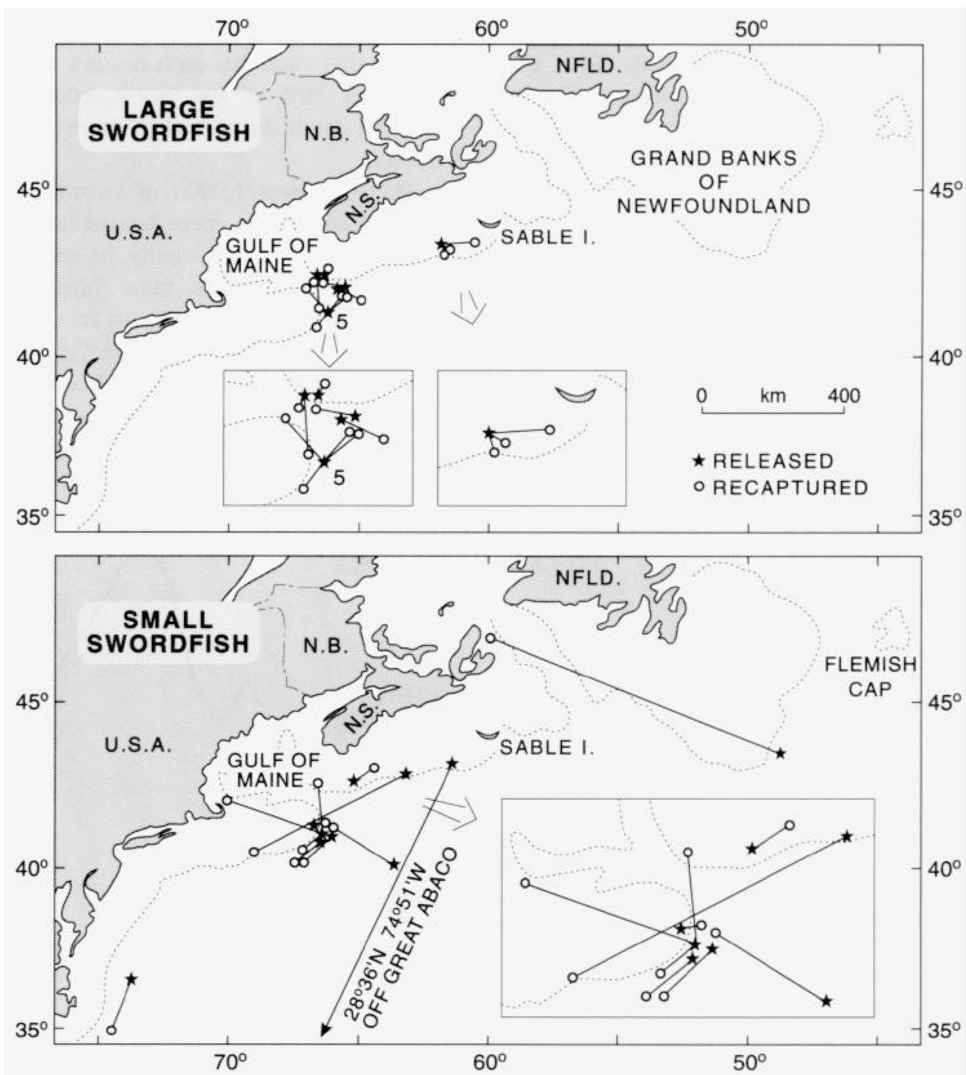

Figure 1. Release and recapture points for large (adult: 85-210 kg) and small (mostly immature: 45-84 kg) swordfish tagged in the Canadian Large Pelagic Fish Tagging Program, 1961-86.

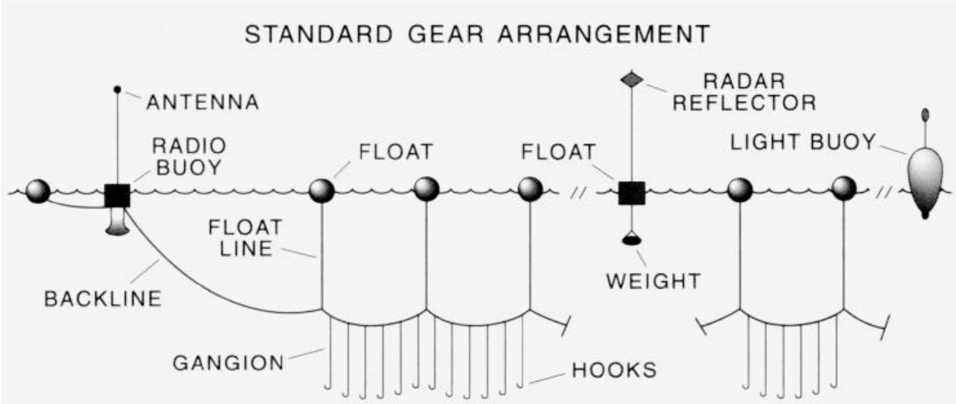

Figure 2. The standard arrangement of gear for swordfish surface longlining.

The fishery

The Canadian swordfish fishery began in 1903 and overtook its American counterpart in importance in 1940 (Stephenson and Power, 1985). Prior to 1963, this was a harpoon fishery, taking large, almost exclusively female fish. Longlining was introduced in 1962, and the fleet rapidly converted its gear (fig. 2). The catch increased dramatically to 7,482 t in 1963, but dropped to about 5,000 t in the late 1960s (fig. 3). During that time, there was a decrease in the average size of fish landed, and catches included both males and females.

Until 1971, Canada was the major swordfish-fishing nation in the Atlantic. But in that year its fishery all but ceased, because the mercury content of swordfish tissues exceeded an American market restriction of less than 0.5 ppm. Spain and Japan continued to fish the species during the 1970s. In 1978, relaxation of the American mercury restriction was accompanied by an increase in Canadian catches, which now average about 1,000 t. In the late 1970s and ’80s catches by the United States and Spain increased dramatically, such that each country now lands over 30% of the North Atlantic swordfish catch, for a total of more than 13,000 t.

In 1991, over 1,000 t of swordfish, valued at $6 million, were landed in the Scotia-Fundy Region, mainly in southwest Nova Scotia and near Sambro. Surface longlining now accounts for over 90% of the swordfish landings in Canada (fig. 3), and there are 53 active licenses. In addition, several hundred harpoon licenses were issued, but these are generally only used opportunistically rather than in a directed fishery. Swordfish longline fishermen set their gear where there is a temperature gradient of several degrees in water depths between 100 and 1,000 m. The best fishing occurs in areas where warm water meets the edge of an offshore bank; thus, the canyons and edges of Georges, Browns, and the Newfoundland Grand banks are prime longlining areas. Vessels fish between 22 and 60 km of gear per day, with hook depths ranging between 5.5 and 20 m.

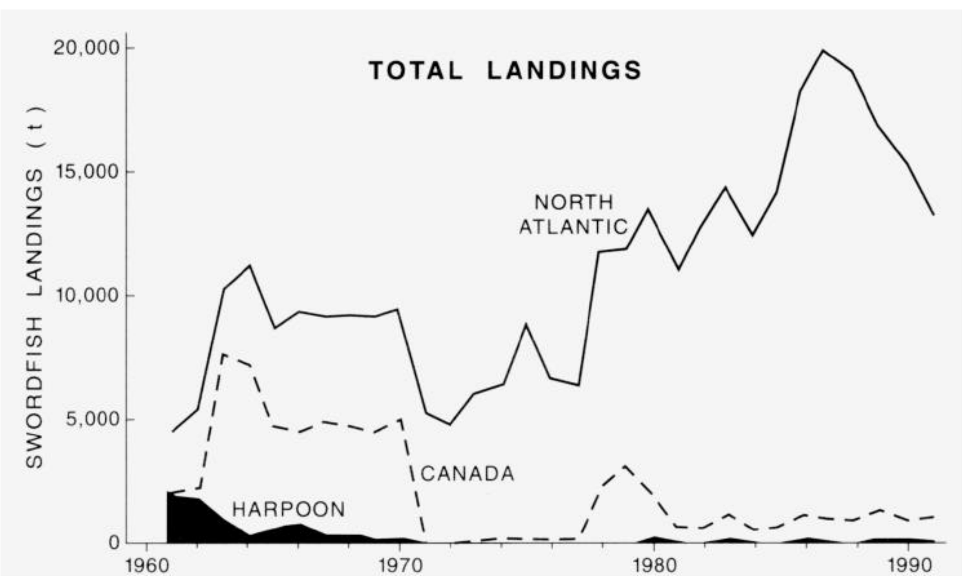

Figure 3. Swordfish landings in the North Atlantic from 1961-91, including the total Canadian catch, which was taken mostly by longline, and the portion of the total Canadian catch taken by harpoon.

During the 1980s there have been improvements in hooks, gangion and backline material, and setting procedure. Further developments in the longline fishery have centred around the attachment of light lures, luminous beads, and rattles to the gangion lines above the hook. Our own studies have shown clearly that catch rates are enhanced by the use of light sticks (fig. 4). On an experimental fishing cruise in 1990, 25% of the 1,710 gangions had light sticks on them. However, 71% of the 41 swordfish captured were on gangions with light sticks, demonstrating a positive attraction to these lures (Porter, unpublished).

Management

Swordfish fished in Canadian waters are believed to be part of a single North Atlantic stock (Anon., 1992). Hence, swordfish are monitored on an Atlantic-wide basis by the International Commission for the Conservation of Atlantic Tunas (ICCAT), established in 1966. Prior to 1971, swordfish fishery was not managed. From 1971 to ‘78, landings in the U.S. and Canada were regulated by markets (that is, the American regulation on the mercury level in tissues). In 1979, Canada introduced strict licensing regulations and quotas for Canadian vessels. In 1991, regulatory measures were recommended by ICCAT for the first time.

ICCAT scientists, including Canadians, are concerned about the decline in the size of the spawning stock (ages 5+) since 1978, and the high catches of small fish (Anon., 1992). The new regulatory measures reduce the catches of the most active fishing nations, limit countries such as Canada to recent catch levels, and introduce a minimum-size restriction. Canada, because of its own strict management practices, has been little affected by these

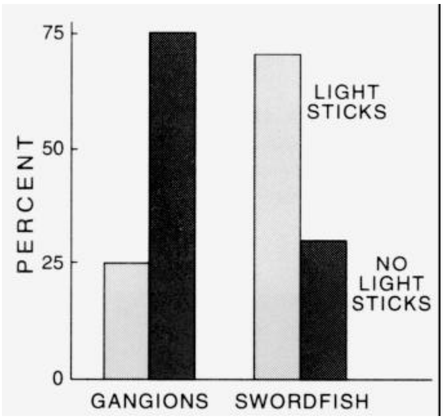

Figure 4. The results of experimental longline sets using artificial lures show the percentage of gangions with light sticks on them and the percentage of swordfish captured on those gangions. Significantly more swordfish were captured on gangions with light sticks (x_1^2 = 45.3, $p < 0.05$).

new regulations. The average size of fish caught in Canada (about 60 kg) is well above the average in the northwest Atlantic (fig. 5), the result of larger fish apparently feeding in the cooler, productive waters along the edge of the Continental Shelf.

To achieve the reduction in the catch of small swordfish recommended by ICCAT scientists, small fish must be avoided entirely by longlines; if the small swordfish are captured and released, they will probably die. Recent analyses of our historical tagging studies show that only 2.3% of the 216 fish that were caught by longlines, then tagged and released, were subsequently recaptured. In comparison, 26.9% of the 78 fish that were caught with harpoons and then tagged and released were recaptured (fig. 6). This difference is presumably due to the different degrees of stress the fish were exposed to during initial tagging; harpoon-tagged fish were not handled at all but were simply tagged with a specially adapted harpoon, while fish caught by longline might remain on the line for hours before being hauled in, tagged, and released.

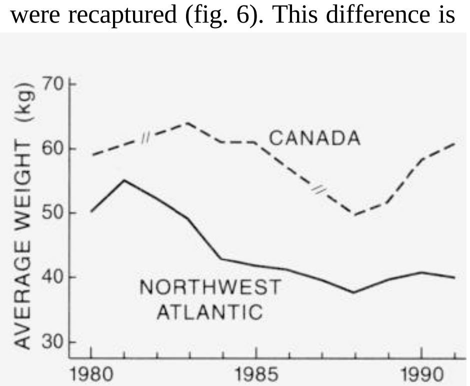

Figure 5. A comparison of the average weights (kg round) of swordfish caught in the northwest Atlantic and in Canada from 1980-91.

Scientific basis for swordfish management

In order to make a numerical assessment of a fish stock, certain basic information must be collected over time. This includes a definition of the stock structure, landing or catch statistics, a measure of effort - that is, how difficult it is to catch the fish - and information on the age or size of the fish in the catch. In addition, information about fecundity and maturity, and an understanding of the basic biology of the species, are important.

Standard research surveys are not practical for swordfish because the fish are quite dispersed, making it difficult to catch enough for a representative sample. In addition, an individual fish is valued, on average, at $500 (100 lb at $5 per lb) and so is too valuable to sacrifice to a survey. As an alternative, personnel from the St. Andrews Biological Station have worked closely with industry during the past four seasons in order to improve landing statistics, collect details of the fishing techniques as documented on log records, and determine the weight of individual fish.

Initially, the fundamental problems of identifying the age, growth, and fecundity of swordfish are being addressed, as they are essential to the age-based assessment models. The current swordfish research program was established with the recognition that a lack of information on basic population parameters and a general understanding of swordfish biology is a major shortcoming of the current assessment process. In particular, although it is known that swordfish are fast-growing and that females seem to grow faster than males (Porter and Smith, 1991), our knowledge of their growth is scant and contradictory; because adult swordfish do not have scales and their otoliths are minute, the usual aging methods are difficult to apply.

Swordfish in the future

Because of concern over the decline in the size of the spawning stock and the high catches of small swordfish, regulatory measures were introduced by **ICCAT** in 1991. For a decade, Canada has had strict management practices, although a reduction in quota and a minimum-size restriction were implemented in the 1991 and 1992 Atlantic Swordfish Management Plan in response to the **ICCAT** ruling. There is still serious concern about the rapid increase in the catch from the southern Atlantic in recent years, and the possibility that these fish are part of a single Atlantic swordfish stock cannot be ruled out. However, at present they are managed as separate North Atlantic and South Atlantic stocks.

There are many unanswered questions regarding swordfish biology, including the uncertainty of its stock structure. These issues are being examined through a dedicated research effort in Canada and elsewhere in the Atlantic. In the near future, there will be pressure for further conservation measures, especially by the major fishing nations. Through strict management practices and careful scientific monitoring, a stock recovery and a sustained fishery can be realized.

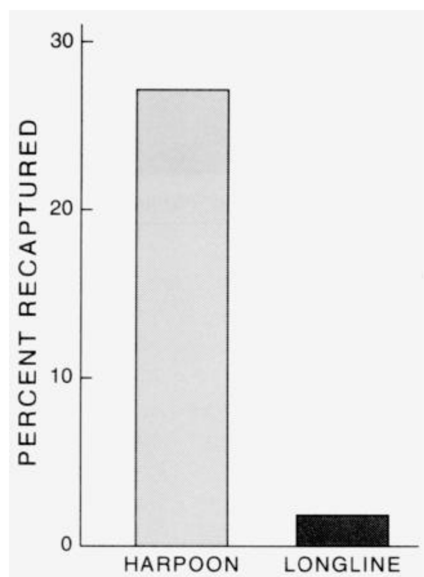

Figure 6. Recapture rates by gear type for swordfish captured, tagged, and released during the Canadian Large Pelagic Fish Tagging Program, 1961-86. Far more of the fish caught by harpoon and tagged were recaptured (x_1^2 = 43.0, $p < 0.05$).

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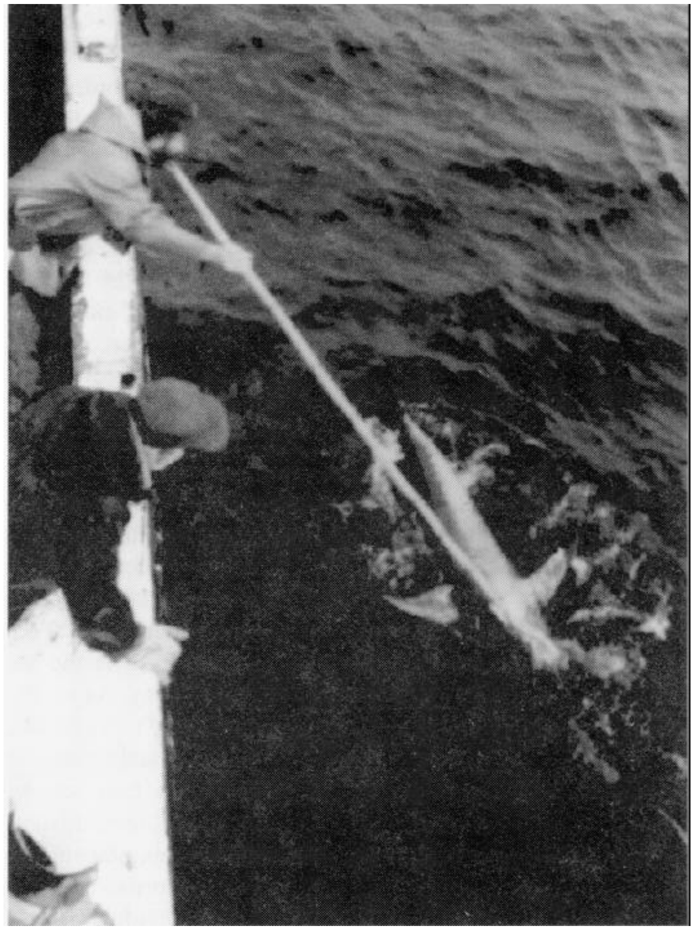
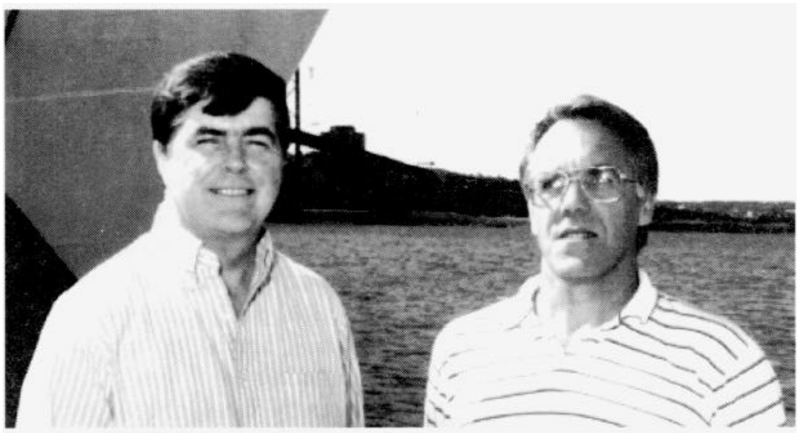
Waiting for the proper moment.



Researcher affixing tag to swordfish.

Monitoring the properties of sea ice for coupled ice-ocean modeling and ice forecasting

S. J. Prinsenberg and G. A. Fowler



G. A. Fowler- and S. J. Prinsenberg

For most Canadians, the term “sea ice” conjures up an image of broken ships manned by scurvy-ridden men awaiting their fate in its frigid grip. Today, the risk to human life has been reduced with the advent of modem ships, radar, and a host of forecasting techniques, but the effects of a frozen sea are still very real. Oil exploration, fisheries, and transportation off the Labrador and Newfoundland coasts have placed increasing demands on our ability to monitor and predict the properties and movement of the annual pack ice throughout the winter and spring.

But in spite of all its negative aspects, the melting edge of the ice creates an opportunity for the fishery, since this is where vertical oceanic mixing stimulates biological activity. In addition, through mechanisms that are just now beginning to be understood and quantified, ice has a profound effect on climate.

The study of ice properties, such as its growth, movement, and eventual decay, is a difficult proposition. Observation sites are remote, the environment is harsh and often treacherous, and ice is almost always on the move. Ship- and helicopter-based studies are expensive and can provide only a time-limited glimpse of the overall situation.

Fortunately, new satellite imagery techniques are now at our disposal, making it possible to obtain a good picture of the distribution and type of ice economically and without risk. However, the use of remote sensing does have its limitations; it is still in its infancy, and must be complemented by *in situ* measurements of the atmosphere, the ocean, and the ice. In fact, there may always be a need for field operations in order to meet all of the measurement requirements of scientists interested in this challenging environment.

Recent developments have allowed the required *in situ* data to be obtained using the Argos System, another satellite-based technology. This system employs a pattern of polar-orbiting satellites which, in addition to recovering limited amounts of data from a platform transmitter terminal (PTT) in near real-time (256 bits 6 to 10 times per day), is also capable of “fixing” the PTT’s location with an accuracy (standard deviation) of 0.2 km. These capabilities are employed in order to evaluate and enhance remotely sensed data and identify environmental contributions to the properties of pack ice.

This article will describe some of the instrumentation that has been developed at BIO and by local industry for the purpose of obtaining data from the mobile pack ice and adjacent atmospheric and oceanographic environments.

Ice movement

One of the most significant characteristics of sea ice on Canada’s east coast is its movement in response to atmospheric and oceanic forcing. Ice is formed along the Labrador shore and, like a giant conveyor belt, moves across the shelf where it is joined by ice formed in the Arctic. It then swings south with the Labrador Current and is eventually consumed by the warmer waters around the Grand Banks.

Tracking this movement in satellite images is difficult by visual means alone, requiring the use of computer-assisted pattern recognition techniques which are still under development. On the other hand, the Argos System is ideally suited to this task as it requires only that a simple transmitter be placed on the ice to produce track plots. The device used to accomplish this task was the ice beacon, developed by Hermes Electronics. A beacon was simply a sealed can containing a transmitter with a specific identification number, an antenna, and enough batteries to keep the package working for six months under arctic conditions. The devices were economical enough to be expendable, and were allowed to fall off the ice and sink when the ice melted, thus signaling the end of the southward journey of the ice the beacon was on.

As noted above, it is possible to fix a position to within 0.2 km, which translates to a standard deviation in velocity of 0.3 cm/sec for fixes one day apart. When the ice is actually moving, measured velocities fall in the range of 10 to 50 cm/sec, yielding velocity measurements with an accuracy of 0.6 to 3%, an acceptable range.

Between 1985 and 1989, 42 satellite-tracked ice beacons were deployed by helicopter on the mobile pack ice off the Labrador coast to study the response of sea ice to atmospheric and oceanographic forcing (Peterson and Symonds, 1988). Generally, ice-borne beacons move southward at 18 km/day over the shelf and at 45 km/day over the shelf break, advected by southerly directed oceanic currents and by prevailing northwesterly

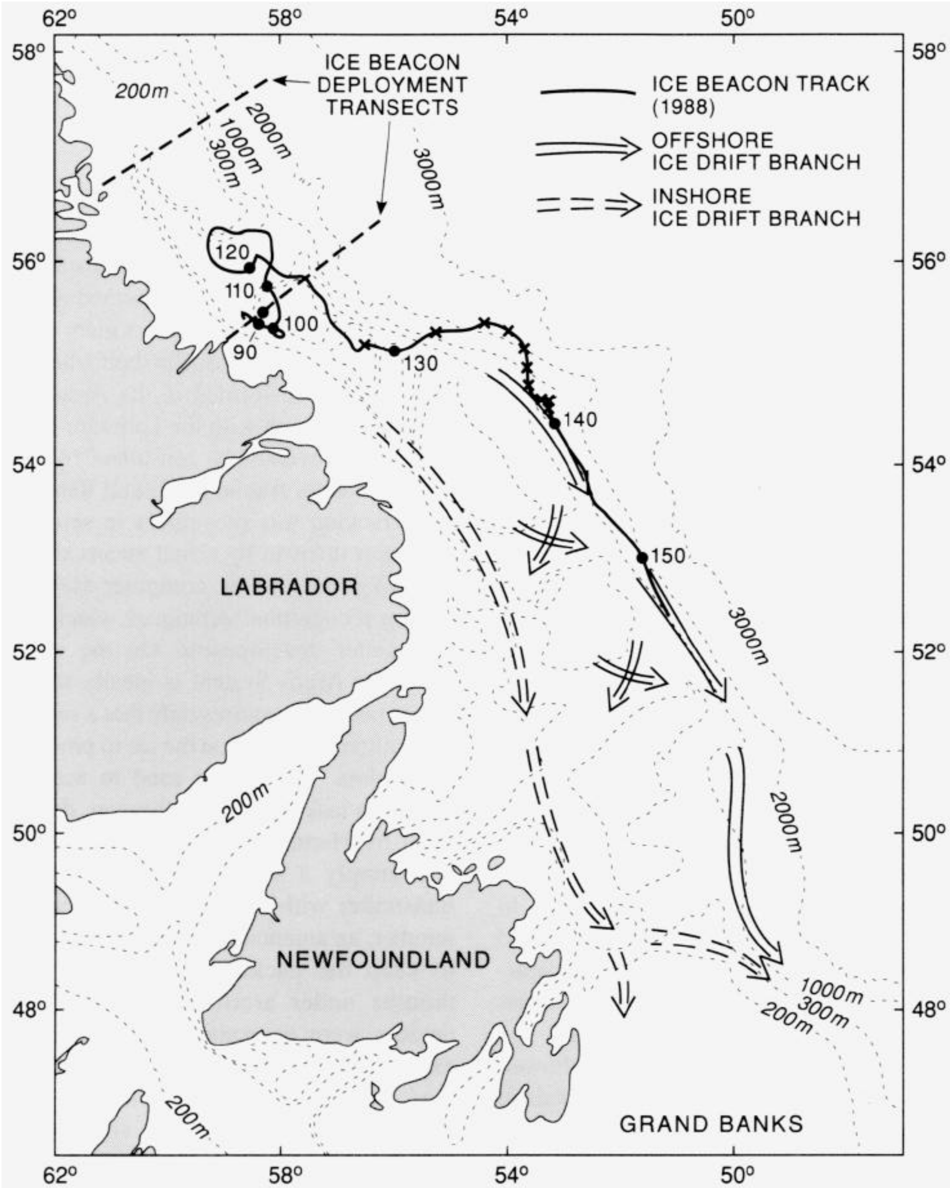


Figure 1. The mean path of the trajectories followed by ice beacons deployed off the northern coast of Labrador. The highlighted trajectory is for the temperature chain beacon, the data for which are shown in figure 5.

winds (fig. 1). Beacons deployed in mid-January and mid-February on floes along the northern Labrador coast drifted to the northern flank of the Grand Banks (a distance of 800 km) in 1.5 to 2.0 months before turning eastward along the Grand Banks. When not blown offshore, where their floes melted, beacons followed two preferred routes: one inside and one outside Hamilton Bank, located at a latitude of 54°N. Ice-drift rates can reach up to 100 km/day when moving southward in the Labrador Current under the influence of strong northerly winds.

Miniaturization in electronic design, combined with the optimization of battery requirements for the subarctic conditions experienced on the Labrador coast, has led to the development of a new generation of miniature ice beacons. These beacons, designed by Metocean Data Systems of Dartmouth, are considerably more compact than their predecessors, yet they retain all the other features of previous models. In addition, this type of beacon can be deployed in the air from fixed-wing aircraft, which significantly increases their range of operation.

Ice drift data are now routinely available from these devices. In addition, their data are used to calibrate numerical models which attempt to predict the advance and retreat of the seasonal ice pack.

Ice growth and decay

The rate at which ice grows or decays is primarily a result of the balance between the thermodynamic forcing of the atmospheric and oceanic environments. When the air above the ice cools it more than the water below warms it, the ice gets thicker. The ice melts either when the reverse is true, or when both the atmosphere and ocean heat the ice. Precipitation build-up on the ice surface, although less important, can with time form new ice or, depending on the circumstances, act as an insulator to retard ice formation.

To quantify these effects, beacons have been developed that take advantage of the Argo System's ability to transmit some data along with positional information. This is accomplished by equipping standard Argos PTTs with electronic interfaces which, when appropriately programmed, can accommodate the data collected by sensors of various types.

For thermodynamic studies, the most economical and commonly used device is the thermistor, which responds to a temperature change with a repeatable and easily calibrated change in electrical resistance. Strings of thermistors configured in various ways can define a vertical temperature profile, the slope of which can be used to calculate heat flux through the ice, water, or atmosphere.

The ice monitoring platform (IMP) from Metocean Data Systems (fig. 2) collects temperature profiles, such as those shown in figure 3, from the surface water, ice, and atmosphere. The sensor module consists of a rigid fibreglass tube housing an array of thermistors mounted along its length, and also containing the system's battery pack. The data shown in figure 3 were collected at a landfast ice station on the Labrador coast at latitude 54°N from January 24 - April 28, 1988. During this period, the ice thickness increased from 55 cm to 90 cm (Peterson *et al.*, 1991). The data are used to estimate the growth rate of the ice and the balance of heat flux between the ocean and the atmosphere.

Of particular interest in the data is the point of inflection in the temperature

Figure 2. Ice monitoring platform being installed in ice off Labrador with an anemometer-equipped ice beacon in the background.

profiles. This discontinuity defines the ice/water interface, since seawater cannot remain in its liquid state below -1.8°C. The use of a temperature profile to determine ice thickness is limited by its reliance on a strong negative air temperature to provide a distinct discontinuity at the ice/water interface. As the air temperature increases, the discontinuity disappears, making this method inappropriate for monitoring ice thickness during thaws. The IMP can operate effectively in ice up to 2 m thick and was deployed in the Coordinated Eastern Arctic Experiment (CEAREX) in the winter of 1988-89.

The successful field operations of the IMP and miniature ice beacons has led to the development of a smaller version of a temperature staff specifically for the ice conditions on the Labrador Shelf (fig. 4). The instrument consists of two subcomponents, of which one is an electronics package consisting of a transmitter, a data interface, and a battery pack. The second is a cable-connected sensor package which collects 2-metre-long temperature profiles from the air, ice, and water, resulting in data similar to that shown in figure 3. The system is modular, permitting the attachment of different sensors depending upon the application. This feature lends itself to economies in production costs, making the collection of data quite cost-effective.

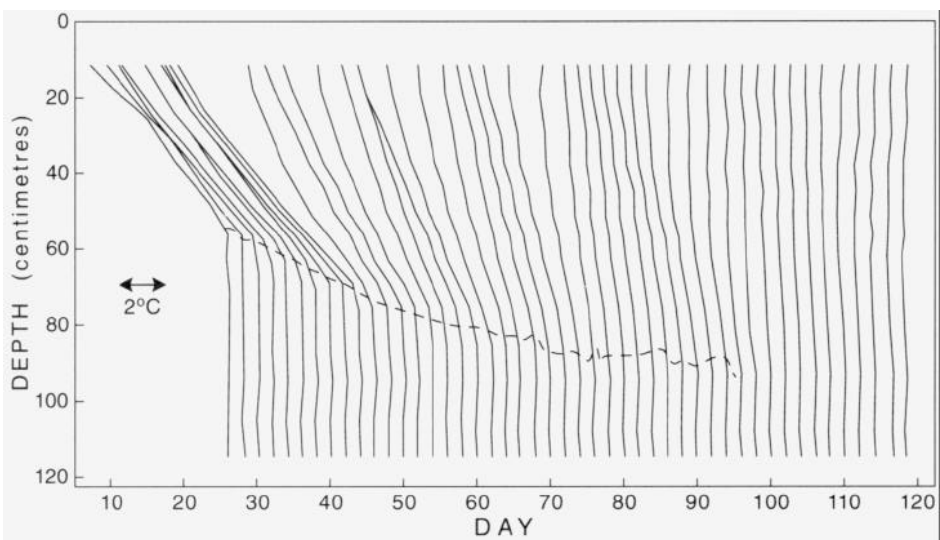


Figure 3. Daily mean temperature profiles from the ice and upper water column for every second day from Julian day 25 to 119 (the latter being April 28) 1988.

When temperature data from deeper oceanic layers is needed, a flexible thermistor chain can be suspended from the surface and connected to an Argos reporting system (Fowler and Bugden, 1987). Taking temperatures in deeper levels, in concert with those nearer to and in the ice, permits the estimation of the contribution of oceanic heat flux to ice melting. It is important to place a pressure transducer on the chain's bottom so that depths of temperature measurements can be corrected for vertical excursion caused by drag as water flows past the flexible chain.

In April 1988, a prototype temperature-chain buoy deployed off northern Labrador first moved northward before coming southward (see the trajectory in figure 1). The thermistor chain provided instantaneous temperature data at depths of 0.7, 3, 5, 7, 20, and 50 m below the air-ice interface and did so 6 to 10 times per day. The temperature sensors 10 and 50 m deep eventually failed, as did the air-temperature sensor at a height of 0.5 m. But the system did operate for several months, and survived the transition from being "frozen in" to floating in open water without incident.

Depth-corrected data (Prinsenberg *et al.*, 1991) shows a thin layer of meltwater 2 m deep (fig. 5) which started to appear above the cold surface-mixed layer by the end of April (Julian days 119-122). The ice carrying the buoy moved southeastward parallel to the coast at 23 km/day during the next 7 days before moving offshore at up to 50 km/day over deeper and warmer water. By May 11 (day 132), the surface-mixed layer was above 0°C and had a negative vertical temperature gradient. Surface cooling, caused either by the atmosphere or by ice melting, is noted. Between May 11 and the time the beacon dropped off the outer ice edge on May 27 (day 148), it moved parallel to the coast at 18 km/day in the area where the Labrador Current is located. Negative vertical temperature gradients continued to be present. Eventually, the surface water warmed to 2°C the open water condition outside the pack ice. The vertical profiles (fig. 5) show the different stages of the temperature field: the homogenous cold-water conditions over the shelf before day 130.5; the rapid change to warmer

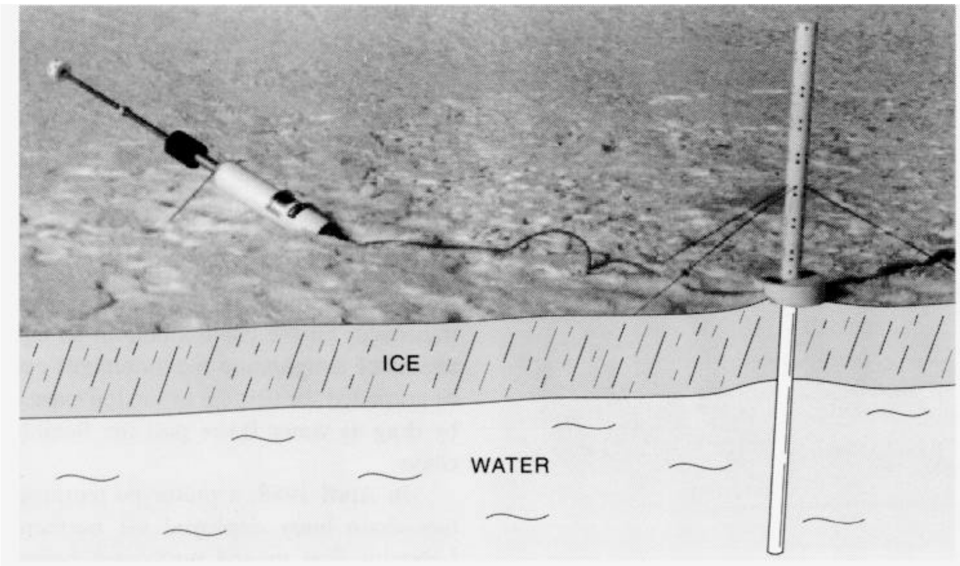


Figure 4. A miniature ice beacon deployed on the Labrador pack ice off Cartwright. Temperature sensors mounted on the staff collect temperature profiles from the air, ice, and upper portion of the water column.

conditions over the slope on day 131; the offshore stratified conditions starting at day 132; and the less-stratified conditions after day 137, when the surface water and deeper water warmed up. Due to the success of the prototype buoy, beacons equipped with thermistor chains were prepared for use in the winter of 1992.

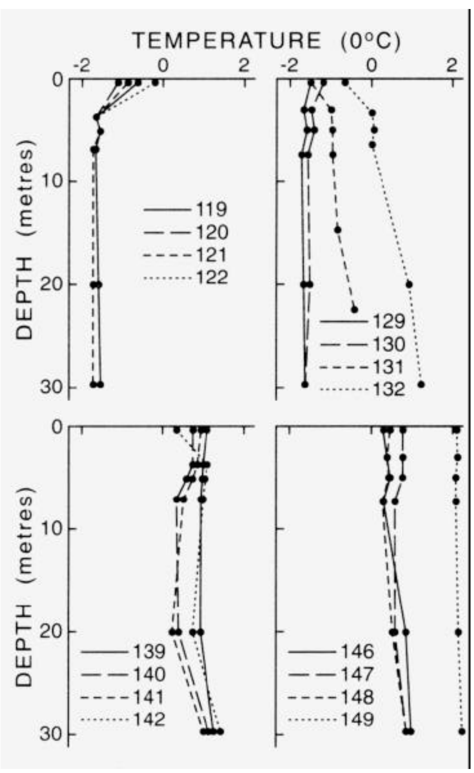


Figure 5. Ice and water temperature profiles collected by the thermistor chain, the trajectory of which is shown in figure 1.

Further analysis of the data indicates that ice melted slowly over the shelf, at a rate of 4 cm/day, and much faster over the shelf break, at up to 12 cm/day. In both cases, most of the heat was provided by the ocean. This translates to the ice edge melting back at the remarkable rate of 18 km/day, caused by up to 700 watts/m^2 of heat flux from the ocean (Prinsenberg *et al.*, 1991).

Forces acting on the ice

As noted above, the ice moves primarily under the influence of wind and water, although other factors such as the effects of waves and the earth's rotation do play a minor role. It is essential to quantify the size of these effects to assure that the numerical models under development have a solid basis upon which to generate their predictions.

Obtaining an estimate of the wind is a fairly straightforward matter, accomplished by fitting a commercial anemometer to an ice beacon, as shown in figure 6. Wind direction is measured relative to the beacon, and the beacon itself carries a compass so that the true wind direction can be recorded. In current practice, data are collected each hour and added to a "stack" of five previous data sets, all of which are transmitted to assure that there are no gaps in the hourly data. By modifying the internal software, the transmitter and the data interface are capable of handling the extra data demands, but there is a penalty to pay when the cost of the extra sensors is considered. This additional cost makes these instruments less useful in situations where the risk of losing them too quickly is high.

At the present time we are able to make only the roughest estimates of oceanic forcing, but this can be accomplished without adding more complex sensors. Beacons and buoys equipped with thermistor chains can give an approximation of the average shear between ice and water because the bottom of the chain will experience a vertical excursion in response to flow-induced drag. By physically inverting a mooring designed by a computer model (Hamilton, 1989), it is possible to infer average water current from the shape of the suspended cable, which is defined by the vertical excursion.

Data from beacons deployed to date have shown that, along the Labrador coast, the pack ice drifts in the direction of the upper-air wind and at 1.8% of its speed (Peterson and Prinsenberg, 1989). Data obtained by beacons and the prototype thermistor chain indicate that, on average, the pack ice moves southward at 16 km/day over the shelf and at 45 km/day over the shelf break. The monthly mean drift caused by ocean currents acting on the underside of the ice is 8 km/day over the shelf and 35 km/day over the shelf break.

Future work

A complete understanding of the life cycle of sea ice and its properties will require the development of new sensors and equipment. These will provide more detailed information and thus will enable scientists to study the physical processes in the marginal ice zone and calibrate numerical models. In the short term, buoys with the ability to provide real-time data on the ocean and atmosphere and some capability to survive deployment on the ice are being developed. These will operate next to the ice edge. Instruments to measure the internal stresses in the ice are being considered for inclusion with the remote-data recovery systems already in place at BIO. In the longer term it may be possible to deploy sensor systems from aircraft, have them set themselves by boring holes through the ice, and have unattended two-way communication with the sensors capable of returning data from the atmosphere, ice, and ocean. The technology for these systems is now in its development stage.

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Figure 6. An anemometer beacon.

Science and salmon management in the 1990s

J. A. Ritter and R. E. Cutting

J. A. Ritter

R. E. Cutting

The Atlantic salmon, *Salmo salar,* is eastern Canada's premier anadromous fish species. It is found widely in coastal rivers from the Maine border to Ungava Bay, and in tributaries of the St. Lawrence River upstream as far as Quebec City. The presence of salmon in a river system is widely considered as indicative that the quality of the river environment has not been significantly degraded, especially by water pollution.

The species has also been economically and socially important because of its use for recreational, commercial, and Native food purposes and its widespread availability.

Harvests of Atlantic salmon in Canada have declined since the turn of the century, as is the case with most fish resources that rely on the freshwater environment for part or all of their life cycle (fig. 1). Catches peaked about 1930, quite possibly as the result of the Great Depression, when "fishing down" of the stocks was probably common.

In recent decades, resource utilization has altered as a result of changes both in resource allocation and in stock conservation measures. Management restrictions have had a greater impact on commercial fisheries than on recreational fisheries, although the former has continued to be the greatest user of the resource (fig. 1). In the past few years, aboriginal people have demonstrated a growing interest in fishing for salmon and, accordingly, an increasing portion of the Canadian catch is being taken in Native food fisheries.

The current management regime, which was introduced in 1984, dramatically reduced both catches and effort in the licensed commercial fishery and made the by-catch of salmon illegal. As well, the recreational fisheries in the Maritime Provinces and on insular Newfoundland have been restricted to harvesting salmon less than 63 cm long. The objective is to conserve further the larger and older maturing salmon, of which two-thirds or more are female and which, in many rivers, are responsible for depositing most of the eggs. Canadian salmon are also harvested off the west coast of Greenland, but quota management since 1975 has served to reduce losses of Canadian fish to this foreign fishery.

The Atlantic salmon divides its life between fresh water and the salt water of the Atlantic Ocean. Maturing fish enter the rivers and spawn in October and November. In the Scotia-Fundy Region, the juveniles produced by the spawning activity typically spend 2 or 3 years in the faster water sections of the rivers. After growing to about 15-18 cm long, juveniles undergo a physiological change that permits them to make a springtime migration downstream to salt water. At this stage they are called smolts.

Once in the sea, most salmon undertake a feeding migration that involves many hundreds of miles and lasts 1 or 2 years. When fish reach a size in the range of 2-5 kg, many start maturing sexually and begin to migrate back toward the river where they spent their juvenile lives. Other fish spend a longer marine growth

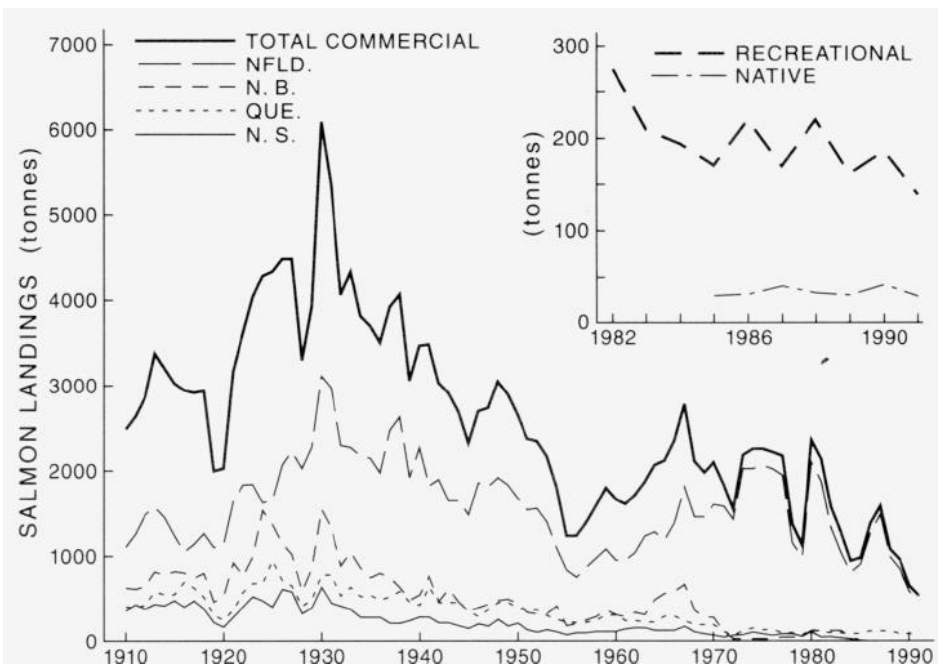

Figure 1. Canadian Atlantic salmon landingsfor commercialfisheries (from 1910-91). recreational fisheries (from 1982-91), and Native food fisheries (from 1985-91). Commercial landings are shown for four provinces.

period. Adult fish stop feeding, and enter the home river between May and October in preparation for the fall spawning activity.

Variations among stocks primarily involve differences in the size and age of smolts, in the location and timing of the marine migration, in the time at which the adults enter the home river, and in the proportions of salmon of different sea ages in the spawning runs. This last characteristic can be attributed to variations in the rate at which spawners survive to spawn again, and in the length of time between when the fish enter the sea as smolts and when they return to the home river for the first time.

The opportunity for expressing different characteristics, coupled with the reproductive isolation achieved by spawners separating into their home river or tributary, have resulted in genetic differences in stocks among and within rivers. Each stock since the Wisconsin Ice Age has developed adaptations to its own environment with its perturbations, within the species' limits of adaptability. In the Scotia-Fundy Region alone, 132 rivers have recorded angling catches (99 in Nova Scotia and 22 in New Brunswick, plus 11 tributaries of the Saint John River) and other smaller streams are known to have spawning stocks. It is expected that future studies of behaviour and biochemical genetics will identify additional partitioning of stocks, particularly in some of the larger rivers, and this finding will necessitate further stock-specific management measures.

The concept of the stock complicates management of the salmon resource. Humans can exterminate various separate salmon stocks - particularly the smaller ones - through exploitation. The fact that the entire female component of the annual spawning stock migrates through a confined area, such as a river mouth or estuary, makes the salmon resource more vulnerable to exploitation than most other fishes. Thus, the current salmon management regime strives to conserve the multiple and diverse stocks.

Management framework

In Canada, the federal government has the administrative and legislative mandate to manage the country's Atlantic salmon resource. The provinces have a proprietary right to control access to the recreational use of the resource. In Quebec, the federal administrative responsibility for salmon management is delegated to that province.

The Department of Fisheries and Oceans' (DFO) management program for the Atlantic salmon resource has as its principal goals:

- to manage (that is, restore, develop, and maintain) the resource for production levels consistent with habitat capacities throughout the species' range in Atlantic Canada (that is, New Brunswick, Nova Scotia, Prince Edward Island, and Newfoundland);
- to generate optimum socioeconomic benefits through balanced and appropriate allocation among all authorized user groups;
- to foster cooperation among levels of government and with the private sector in managing the resource;
- to conserve and protect the Atlantic salmon resource throughout its entire Northwest Atlantic range.

In 1990, a fifth goal was added as a result of the Supreme Court of Canada's ruling in the case of *R. v. Sparrow:* to uphold the aboriginal rights of Native peoples to fish for the Atlantic salmon for food, social, and ceremonial purposes. The Court held that such rights are constitutionally protected and that, after conservation needs have been met, Native peoples exercising such rights have priority over other users of the resource.

DFO's management process is based on zones, whereby stocks are grouped according to similarity and by geographic areas called salmon fishing areas (SFAS). Users have the opportunity to contribute to management decisions through SFA meetings. Annual fishing plans developed for the different SFAs are then reviewed by the Atlantic Salmon Advisory Board, an Atlantic-wide board consisting of government representatives and resource users; the advice is passed on to the Minister of Fisheries.

Main problems confronting the fisheries managers are the allocation of the harvest among the various user groups, and the availability of stock-specific information upon which to base management decisions. It is in the latter area that DFO's Science Sector provides crucial input, in the form of target numbers of spawners, adult returns to rivers, and exploitation patterns for as many stocks as possible.

The main components of the Science program for salmon are service and research. The service role provides up-to-date technical and biological advice to the fisheries and habitat managers, and to the public. The goal of the research is to improve the methods for preparing the service advice and to improve the effectiveness of the resource enhancement initiatives, be they for fish or for habitat. Execution of the enhancement activities, which may involve hatchery stocking and developing and improving fish passages, is a further role for Science.

Fisheries management: The main goal of the fisheries management effort is the conservation of each stock. The definition of conservation which was adopted by DFO for fisheries resources, and which is based on the "World Conservation Strategy" produced in 1980 by the United Nations Environment Program, is as follows:

> That aspect of renewable resource management which ensures that utilization is sustainable and which safeguards ecological processes and genetic diversity for the maintenance of the resource concerned. Conservation ensures that the fullest sustainable advantage is derived from the resource base and that facilities are so located and conducted that the resource base is maintained.

This generalized definition of conservation was translated by the Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC) into an operational definition which prescribes that Atlantic salmon eggs be deposited at a rate of 2.4 eggs/m^2 of fluvial rearing habitat and, in Newfoundland, an additional 368 eggs/hectare of lacustrine habitat. These levels of egg deposition are intended as interim targets until more appropriate river-specific levels are demonstrated. Optimum egg deposition targets, aimed at maximizing yield, are expected to vary among and within rivers. CAFSAC cautioned that adopting egg deposition levels that continue to be lower than these targets (or below more appropriate river-specific levels that are expected to be defined in the future) is not without risk to the integrity and future capability of the stocks.

The operational definition for conservation clearly identifies three areas requiring input from Science. The first is the quantification of the productive capacity of individual rivers. Productive capacity is generally based on the number of square metres of river bed capable of producing smolts, as is the egg deposition requirement. For Scotia-Fundy rivers, both capacity and the egg deposition requirement are prorated according to a habitat quality function described by stream gradient. Stream pH is also of major importance in defining productive capacities and egg requirements for many of the mainland Nova Scotia rivers, in which salmon production is affected by seasonally lethal pH conditions. Because of low pH levels, several rivers in the province no longer produce salmon, and most rivers along the Atlantic coast of mainland Nova Scotia have reduced salmon productivities.

A second Science requirement is for the biological characterization of the individual stocks. Such information is required in order to convert egg deposition requirements to numbers of adult spawners, identified both by age and by sex, that are needed to seed the habitats used by the different stocks. As well, harvest regimes are customized to the biological characteristics of the stocks.

The third area of Science input involves advising on the available harvest; such information includes the numbers of fish by size and age, and where, when, and by what means returning adults might be harvested. The available harvest, generally defined as the number of adult returns in excess of those required for conservation, is calculated as the difference between a pre-season forecast of adult returns and the target spawning requirement. For certain stocks, scarcity of information prohibits pre-season forecasting of adult returns, and therefore the available harvest is often assumed to be equal to the current level of harvest.

The process of providing advice suffers from a lack of both existing information and stock forecasting capabilities. The common operational definitions of conservation for fluvial habitats (2.4 eggs/m^2) and Newfoundland lacustrine habitats (368 eggs/hectare) are still used, even though it is known that the actual conservation requirement varies with the stock, the river, and the habitat type. Pre-season forecast models are few, and those that do exist have generally performed poorly at providing predictions of adult returns. Detailed stock-specific information does not exist for most rivers and, hence, stock status and biological characteristics can usually be inferred only from the performance of a neighbouring index stock or from existing harvest statistics. Recreational catches, which comprise the most broadly based, long-term data series, now provide only general estimates of stock strength.

Despite the problems with the use of both index rivers and recreational catches, however, both systems have contributed to an understanding of the status of the stocks. Because all significant stocks yield some form of recreational harvest, recreational catch statistics seemingly offer the most cost-effective opportunity to monitor individual stock performance in the future. This presumes, however, that models can be developed that will enable stock strength to be estimated on the basis of recreational catch.

Habitat management: The main goal of DFO's policy on managing fish habitat is to achieve a "net gain". Through the department's regulatory and research functions, the policy's objectives are the conservation, development, and restoration of fish habitats. Fundamental to the conservation objective is the principle of "no net loss".

Demands on Science in support of the objectives are for advice and supporting research. For salmon, this support is aimed largely at providing guidelines for regulating developments that might impact on freshwater habitats, or affect instream migrations. In addition, the Atlantic salmon is the primary species of concern in the acid rain research and monitoring program in the Scotia-Fundy Region.

Currently absent from the Science arm of the habitat program is research aimed at defining the attributes of salmon habitat. Clear definition of what constitutes good salmon habitat is required in order to guide efforts to develop or restore salmon habitat areas.

Stock enhancement: The goal of salmon enhancement is to produce more salmon for greater individual and community benefit. More salmon are required in order to meet current and new fishery demands.

Science is responsible for conducting the salmon stock enhancement program, whose two main activities are hatchery stocking and providing fish passage for migrating salmon. All enhancement activities are integrated into the resource management program.

In the Scotia-Fundy Region, at least one-quarter of the adult salmon produced outside of aquaculture originate from hatchery stocking. The main stocking activities aim to mitigate losses in productive capacity due to acid rain, in most rivers along the Atlantic coast of mainland Nova Scotia, or to compensate for production losses caused by hydroelectric development, such as on the Saint John River in New Brunswick. Most recently, stocking programs have been initiated to establish local recreational fisheries. Comparable new stocking programs are now being sought that would create new Native food fisheries.

Maintaining Scotia-Fundy's salmon resource depends heavily upon fish passage being available (through fishways) or provided (through trapping and trucking); however, few opportunities exist for expanding the resource base by opening up new habitats with fishways. Of those few possibilities in Scotia-Fundy, only the development of fish passage facilities at Grand Falls on the Saint John River offers major stock enhancement potential, of more than 10,000 adult salmon. Development of that $1-2 million facility awaits completion of an initial environmental assessment, and is dependent upon local public interest groups raising the required funding, or lobbying successfully for it.

Consultation and participation: DFO is committed to administering the management program for Atlantic salmon in cooperation with the provincial governments, user groups, and other interested parties. Science personnel spend increasingly more time consulting with user groups, working with angling associations, and, recently, talking and working with Native communities, on a wide range of activities, including stock enhancement, habitat improvement, stock assessment, research, and public awareness and education programs. To assist in these activities, angling associations provide volunteers and contribute funds that have been raised through their respective associations, or secured from government programs other than those at DFO. In program areas like stock enhancement and habitat improvement, the funds spent by or through salmon angler organizations often exceed those contributed by DFO. For example, in the Scotia-Fundy Region, public sponsorship of job creation programs funded by the Canada Employment and Immigration Commission is contributing towards repairing and upgrading government-owned facilities, such as hatcheries and fishways.

Native community involvement with DFO in Science activities is in its infancy, but it should increase dramatically as DFO moves forward into a new era of co-managing the resource with Native bands. Science staff are also being asked to provide biological and engineering advice on aquaculture projects being considered by Native communities for economic development.

The increased consultations and expanding involvement of angling associations and Native communities in Science activities are resulting in both the delivery of a more comprehensive salmon management program, and in an enhanced public understanding and awareness of salmon conservation. At the same time, however, these increased demands consume much Science staff time, and this pressure is diminishing necessary supporting research.

Future directions

DFO's salmon management program requires increased scientific input for several reasons. These include: the continuing depressed state of many of the stocks; the heightened demands of Native peoples to exercise their right of access to the resource; more rigid requirements for environmental assessment of development activities; and the desire of user groups to be better informed and more involved in resource program activities, particularly those involving stock enhancement, habitat improvement, and collection of biological information. Areas requiring increased emphasis in Scotia-Fundy Region's Science program include:

- providing stock-specific advice for more stocks, in support of the move toward managing the salmon resource on the basis of individual rivers, rather than SFAs;
- customizing the interim operational definition of conservation for fluvial habitats to individual rivers or main tributaries in order to register the variable productive capacity of the individual stocks, rivers, and habitats;
- developing improved pre-season and multi-year forecasting models to enhance flexibility and confidence in negotiating stock allocations among user groups;
- developing and expanding in-season forecasting techniques to enable in-season changes to fishing activities;
- modelling the effects of low pH conditions on the productive capacity, conservation requirement, and stock-enhancement potential of salmon habitats in order to identify the options for managing the Nova Scotia stocks affected by acid precipitation;
- developing models that utilize recreational catch data as an index of stock abundance so such models can subsequently be used to assess stock status and forecast run size;
- expanding ongoing investigations in order to identify the cause of the marine failure experienced in 5 of the last 6 years by the salmon stocks of the 20-some rivers rimming the inner Bay of Fundy;
- improving understanding of the attributes of salmon habitats and of the technology by which degraded and poorer habitats can be improved or restored:
- in accordance with the Environmental Assessment and Review Process, providing advice to enable the assessment of an increasing number of development activities that may impact on species dependent on fresh water;
- developing new Native food fisheries through hatchery stocking;
- expanding access for natural production, where it is technically feasible and desirable, by opening up new areas (for example, above Grand Falls on the Saint John River) with fish passages placed at man-made and natural obstructions to migration;
- increasing the involvement of biological and technical staff in public consultation processes and in overseeing or directing Science-oriented projects undertaken by Native communities and recreational fishing associations;
- intensifying research on salmon stock-recruitment in order to improve understanding of environmental and density-dependent effects on growth, survival, age-at-maturity, and egg deposition requirements for different habitats and stocks. This area is in greatest need of increased emphasis.

Some of these areas are already part of the ongoing efforts by DFO's Freshwater and Anadromous Division. However, implementing this enhanced program will require extension of field investigations to new rivers and stocks, expansion of fundamental research into the mechanisms affecting salmon recruitment, better usage of existing information, and more staff time devoted toward working with Native peoples and anglers. As always, progress depends upon the resources available to the program.

The contribution from Science will move the salmon management program toward a more stock-specific approach, something which is desired by user groups and visualized by biologists but currently limited in application. The stock assessment program will be driven by modelling exercises to identify new data and research requirements. The 1990s promise to be exciting for salmon biologists, because never before have the challenges been more clearly understood and the opportunities to make a difference so great.

Authors' note: Since the writing of this article, federal Fisheries Minister John Crosbie has announced a five-year moratorium on insular Newfoundland's commercial salmon fishery, along with the voluntary buy-back of associated licences. Despite this significant change, the Science direction discussed in this article is still consistent with current regional priorities for Atlantic salmon.

Impacts of nearshore sedimentary processes on hydrocarbon development in the Beaufort Sea

S. Solomon

S. Solomon

The Canadian Beaufort Sea has been the site of hydrocarbon exploration for the past two decades, and has proven reserves of oil and gas. However, development of these reserves has not yet taken place, due in part to our lack of understanding of the distinctive set of physical processes which control this environment. The Northern Oil and Gas Action Program (NOGAP) is a federal program charged with acquiring information for regulating hydrocarbon-related development in the north. It involves numerous government departments and includes work on issues as diverse as archaeological resources, socioeconomic impacts, and oceanographic processes. NOGAP focuses on the physical properties of materials and oceanographic processes occurring in the coastal zone, particularly in the vicinity of Richards Island, a location chosen as a potential pipeline landing site for oil and gas from the Amauligak field offshore.

The nearshore and inner-shelf region of the Beaufort Sea is a particularly dynamic environment, and is therefore a critical area of concern in planning hydrocarbon production and pipeline facilities. The highly variable and rapidly changing character of these extensive shallow-water regions is largely due to a combination of unconsolidated ice-rich coastal materials, abundant sediment supply from the Mackenzie River, and thermal stability of the seabed.

A hypothetical development option might consist of a 50-km pipeline, installed within a dredged trench in water depths as great as 30 m and as shallow as those at the shoreline. Such a pipeline would cross a broad coastal zone up to 20 km wide with water depths less than 6 m, and the inner part of the zone (an area approximately 5 km wide) would be less than 2 m deep.

Some of the issues related to such a development are the timing and methods used to trench the seabed, and the stability of the pipeline in the presence of shallow permafrost, rapid coastal erosion, active spit and bar development, variable geotechnical properties, and pack-ice processes. In order to gain a better understanding of these phenomena, measurements must be made of the properties and distribution of sediments and the effects of oceanographic processes. Once modem processes are understood, we can attempt to explain the present distribution of recent sediment properties and to make predictions about how their future distribution might be affected by natural causes or human activities.

This paper summarizes a series of NOGAP-funded field programs designed to address some of the issues outlined above. Although the Geological Survey of Canada (GSC) program involves personnel both from the Atlantic Geoscience Centre (AGC) based at the Bedford Institute of Oceanography, and from the Terrain Sciences Division in Ottawa, this article will focus on activities undertaken in 1991 by AGC. Preliminary results will be discussed in light of proposed development options.

The study area

Surficial geology and thermal conditions: The area in which AGC undertook its studies is shown in figure 1. The

Glossary

aggradation Deposition of sediment upward rather than seaward (see “prograded spit complex”).

fetch Uninterrupted distance over the water which allows the wind to blow and create waves.

ground ice Ice particles found within the ground, sometimes coalesced to form large masses of almost pure ice.

heave Movement upward and downward while remaining essentially horizontal.

hummocky Describes a surface consisting of mounds and hollows.

ice bonding A process by which panicles are bound together by ice, as in ice-bonded sediments.

isobath Line of equal water depth.

lacustrine Of, or pertaining to, lakes.

lenses Lens-shaped masses within the sediments.

pack ice A large area of floating ice, consisting of pieces of ice which have rafted together.

permafrost Perennially frozen ground.

prograded spit complex An area of sediment deposition which builds seaward from a point of land and is partially above the water.

shore-normal lines Survey lines which run at right angles to the shoreline.

storm surges High (positive) or low (negative) water levels, caused by winds which drive the water onto or off the land, respectively.

thermokarst A description of landforms which are caused by the melting of subsurface ice. The landforms typically consist of mounds of high ground with intervening hollows, often forming small lakes and ponds.

transgressive deposit Sediment deposited during a period of rising sea level.

unconsolidated coastal bluffs Steep coastal cliffs which consist of loose sand and silt.

visible ice Ice found in sediments and which can be seen with the naked eye.

wedges Masses found within the sediments, widest at the surface and then tapering downward.

yaw Rotational movement in the horizontal plane.

onshore surficial geology of the North Head area consists of discontinuous till underlain by sands of the Kittigazuit and Kidluit formations (Rampton, 1988). Well within the zone of continuous permafrost, the area contains abundant evidence of active thermal processes. Permafrost reaches thicknesses up to 700 m (Rampton, 1988). Ground ice (as ice bonding or visible ice) occurs in most of the sediments (Rampton, 1988), and massive ice is present in a variety of lenses and wedges. In some locations ice may represent up to 13% by volume of the upper 8 m of ground (Wolfe, 1989); ice wedges can be up to 1 m wide and 5 to 8 m deep.

Degradation of massive ice results in the development of thermokarst topography. On Richards Island and the Tuktoyaktuk Peninsula, the land surface is mottled with thermokarst lakes (inset of fig. 1, and fig. 2). The lakes enlarge progressively by melting at their edges, producing distinctive retrogressive thaw-flow slides. Taliks (unfrozen zones) tens of metres thick form beneath the lakes as a result of the permafrost's thawing underneath the accumulated water. The coastline adjacent to thermokarst-dominated areas is convoluted, attesting to recent relative sea-level rise and consequent breaching and drowning of the lakes.

Climatology and coastal processes: Dominant storm winds, waves, and sediment transport are from the west and northwest. However, the ability of the wind to generate waves during the 4-month open-water season is limited by the presence of sea ice offshore. The sea surface is invariably ice covered within 200 km of Richards Island, and in poor ice years (such as 1991), pack ice is present within 20 km. The ice-limited fetch results in relatively small waves (with heights of less than 4 m and periods of less than 8 seconds), and the extremely shallow slope of the nearshore zone further reduces the effects of waves by attenuating their energy over the soft bottom.

In spite of this relatively mild wave climate, coastal erosion is rapid, typically 2 m/year with a maximum rate of up to 20 m/year (Forbes and Frobel, 1985). This occurs because of thermal instability of the ice-bonded coastal bluffs, the particles of which are not consolidated. Downdrift transport of the eroded material produces extravagant spits and submerged nearshore platforms (for example, Pullen Island, shown in fig. 1).

Water levels are governed more by storm surges than tides. The tidal range is less than 30 cm, whereas log debris lines show maximum storm surge levels of up to 2.4 m above mean sea level (Harper et *al.*, 1988). In the Richards Island area,

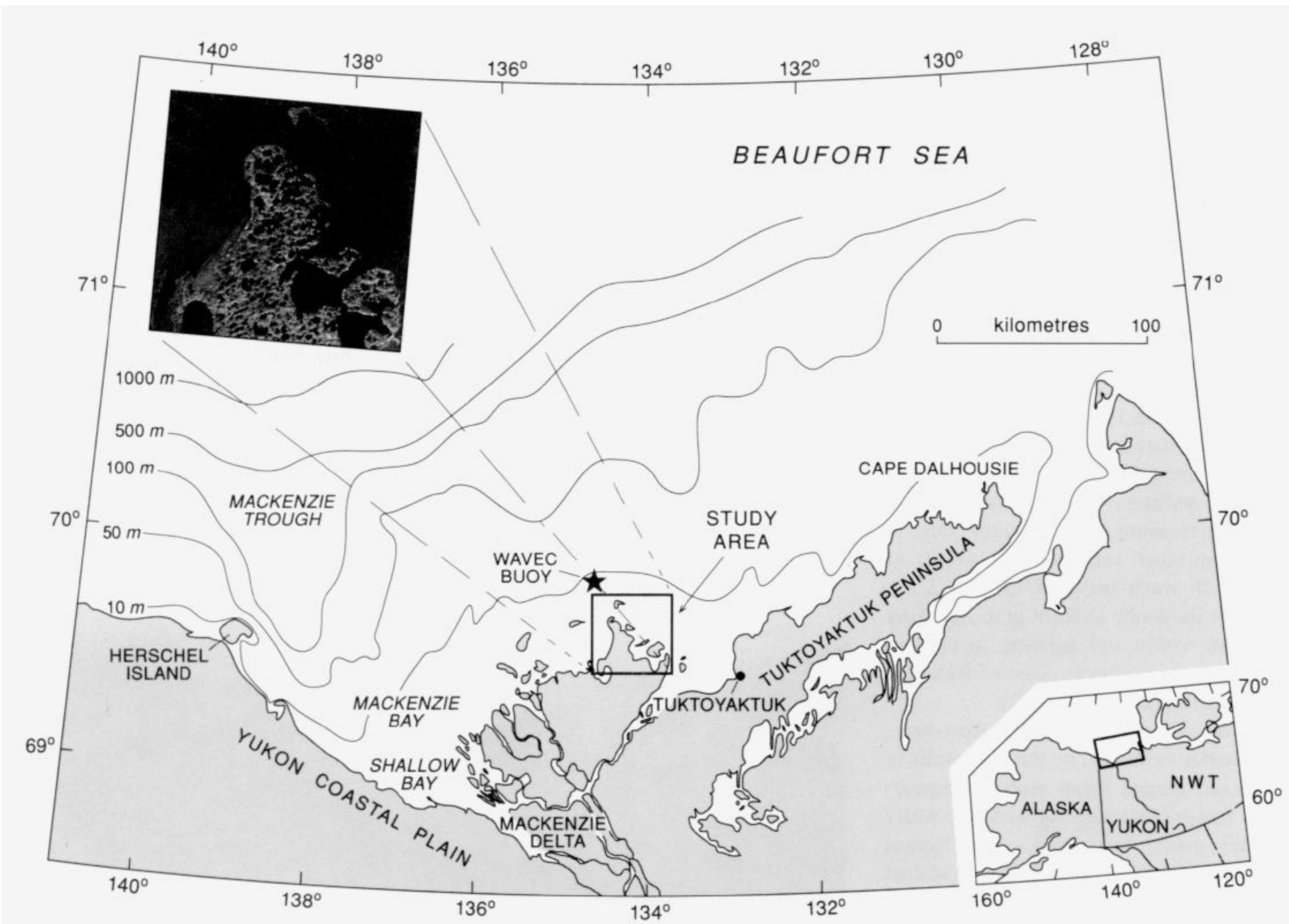

Figure 1. AGC's study area. Note the position of the Wavec directional wave buoy.

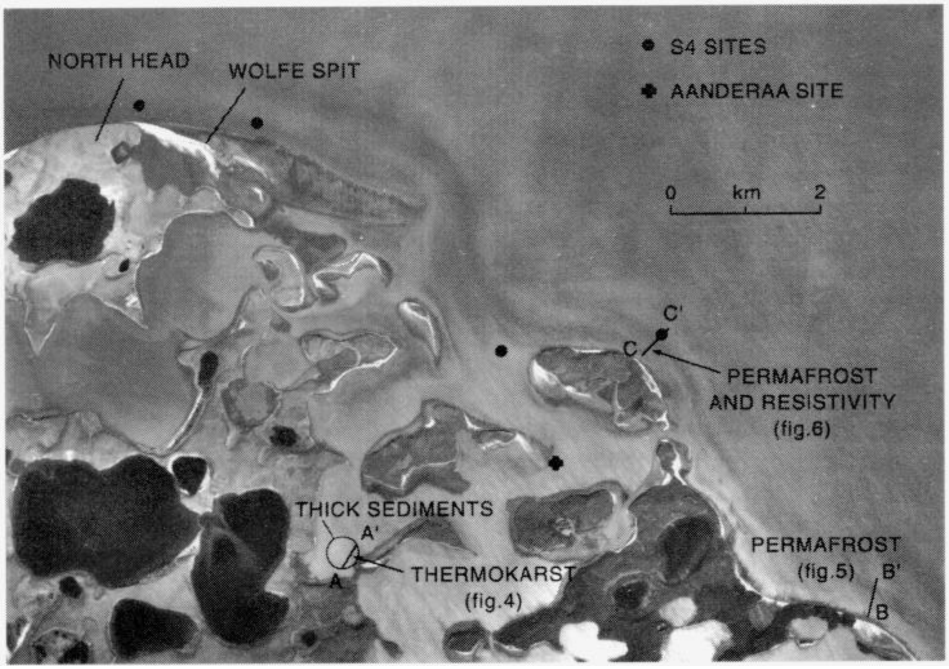

Figure 2. An aerial photograph of the study area showing the location of the S4 cur-rent and wave meters, the Aanderaa current meter, and the geophysical lines illustrated in figures 4, 5, and 6. Thermokarst lakes and embayments occupy much of the area of the photograph. A thick accumulation of sediments is outlined within one of these embayments and represents deposition from a combination of Mackenzie River sediments and lacustrine infill.

northwest winds cause positive surges and easterly winds cause negative surges. A l-m variation in water level over the course of 12 hours is not unusual.

Offshore geology: Within the study area, silty clays are currently being deposited on the inner shelf in water depths greater than 5 m. The Mackenzie River supplies copious quantities (about 35 to 182 x 10^6 t/year (Hirst *et al.,* 1987)) of suspended material to its delta during the summer months. Inshore of the 5 m isobath, sediment textures range from muds to medium sands. Muddy sand is the dominant sedimentary material present in water between 1.0 and 2.5 m deep, as shown by a recent grab-sampling program within and adjacent to embayments on the northeast coast of Richards Island (Hill and Frobel, 1991).

The inundation of permafrost-bearing coastal sediments by the sea results in increased annual mean seabed temperatures and gradual thawing when the water depth is greater than about 1.5 m (Taylor, 1991). Under these conditions, the seabed is separated from overlying ice by an insulating layer of water. Two boreholes in the vicinity of a large, recently prograded spit complex extending southeast from North Head (informally named Wolfe Spit) encountered ice-bonded sediments to a depth of more than 20 m (Dyke, in Dallimore *et al.*, 1991). A third borehole in deeper water (1.7 m) was ice-bonded to a depth of only 1.5 m.

The extensive distribution of onshore permafrost and ground ice, and its impact on the regional geomorphology, suggest that thermal conditions within the coastal and nearshore zones may play a significant role in the distribution of sediments and geotechnical properties. To date, investigations within these areas have been limited to borehole studies by the GSC (Kurfurst, 1984, 1986, 1988; Hill *et al.,* 1986) and by industry. High-resolution geophysical surveys are required to provide a framework for these studies, but they had not been undertaken before the 1991 survey because the water depths are too shallow for conventional survey vessels. The recent NOGAP field programs have been designed to address this problem by using innovative technologies.

Methods and results

Three complementary surveys were undertaken in the summer of 1991 to investigate NOGAP-related issues as outlined above. *Arktos-91* consisted of a high-resolution geophysical survey which utilized a unique Canadian vehicle for operations in extremely shallow water *(0* to *4* m). The *Arktos* program was aimed at collecting data on shallow stratigraphy in the coastal zone, with particular emphasis on characterizing the onshore-to-offshore transition. *Nahidik-91* comprised high-resolution acoustic surveys in 3 to 9 m of water and an extensive vibracoring program on a number of shore-normal lines. This survey was designed to collect data on nearshore stratigraphy in order to provide a framework for detailed studies of pipeline routes and coastal stability, while also providing input into issues of sediment transport and onshore/offshore stratigraphy. The *Shorezone-* program used a variety of current, wave, and suspended-sediment monitors, along with conventional surveying techniques. Its object was

Figure 3. *The* Arktos-91 *after modification by the Geoloqical Ssurvey of Canada for high-resolution geophysical surveying.*

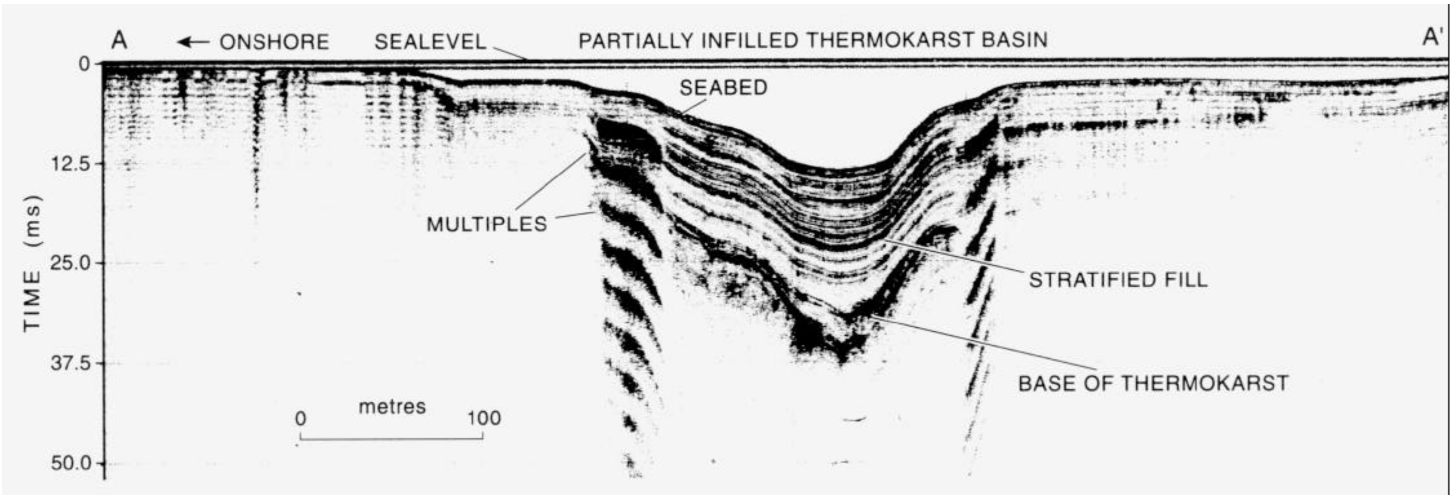

*Figure 4. An acoustic line (acquired with a Seistec^{TM} receiver) through a depression within the seabed about IO m deep. The depression is partially infilled with stratified sediments draped over a hummocky surface. In shallower water and along the edges **of** the basin, the seabed is acoustically very hard and produces numerous multiple reflections (multiples). The position, size, and shape **of** the basin suggest that it is a thermokarst feature which has been drowned by a rise in relative sea level.*

to investigate erosion and sediment transport in the littoral and nearshore zones.

The logistics of working in remote locations add unavoidable and significant complications to operations in the study area. For instance, approximately 15,000 kg of equipment and 11 staff members had to be transported to the Beaufort Sea for these surveys. After mobilization at the facilities of the Polar Continental Shelf Project in Tuktoyaktuk, the field operation was moved to a camp on Richards Island, where we lived and worked for 3 weeks. Both the *Arktos* and *Shorezone* survey programs operated out of the same camp. Following camp demobilization, the *Nahidik* program was mobilized in Inuvik at the Inuvik Research Centre and at the Coast Guard wharf in East Channel.

Geophysical survey methods: The *Arktos* β (fig. 3) is an amphibious vehicle which was designed and manufactured as an arctic escape-and-rescue craft by Watercraft Offshore Ltd. of Richmond, B.C. The vehicle is owned and operated by the Canadian Coast Guard. It uses a combination of tracks and jets to propel itself through ice-infested waters and over pack ice, shoals, and land. Its rated speed is 4 knots in the water and 20 knots on land using standard diesel fuel. Preliminary sea trials in 1990 established the ability of *Arktos* β to carry out high-resolution acoustic surveys in shallow water (Lewis, 1991). Refinements identified in these initial trials were implemented as part of the 1991 field program in order to improve the safety and efficiency of *Arktos* β during surveying operations. The main changes were the fabrication and mounting of decks and the raising of the mounting point of the forward boom.

High-resolution acoustic survey equipment was then deployed from the forward boom. These instruments consisted of a Uniboom^{TM} acoustic source, Seistec^{TM} and Nova Scotia Research Foundation Corporation (NSRFC) receivers, a sidescan unit, and an echosounder. In addition, an electrical-resistivity sounding system was provided by the Centre for Cold Oceans Resources Engineering (C-CORE). The vehicle navigated with a Global Positioning System (GPS) receiver which was connected to a portable computer.

Surveys were conducted in many of the protected bays and inlets within a few hours' steam of the Richards Island campsite. Efforts to survey in less-protected waters were thwarted by unanticipated problems with the method used to deploy the acoustic gear.

The C.C.G.S. *Nahidik* is used to maintain the navigation aids in the Mackenzie River and much of the Beaufort Sea. Custom-built laboratory and accommodation modules are fitted on the vessel when they are needed for scientific purposes. For Nahidik-91, acoustic equipment was deployed over the side of the vessel using a combination of booms, mounts, and cranes. A 3 m vibracorer was deployed using a 10 t crane on the forward deck of the ship. The acoustic equipment used for this survey was the same as that used for the *Arktos* survey. The resistivity system was not available. A GPS receiver was used for navigation.

To achieve the objective of the *Nahidik* survey, high-resolution acoustic data were collected in a series of shore-parallel and shore-normal lines from the west side of Pullen Island to Crumbling Point (fig. 1). Vibracore transects were undertaken along five of the shore-orthogonal lines in order to ascertain nearshore-to-offshore changes at sites exposed to varying wind and wave climates.

Geophysical survey results: The protected embayments along the east coast of North Head contain a variety of acoustically defined environments. Where thermokarst lakes have been inundated, well-stratified sediments are found draped over and conforming to the preexisting topography (fig. 4). Acoustic penetration is excellent in these locations where surface grab samples indicate a soft, muddy substrate.

At the opposite extreme, in some areas where water depths are less than 2 m, the seabed is acoustically very hard and could not be penetrated; however, grab samples indicated that these sediments are comprised of relatively soft mud and sand. Thus, the absence of acoustic penetration in these locations may be due to ice-bonded material being present near the surface.

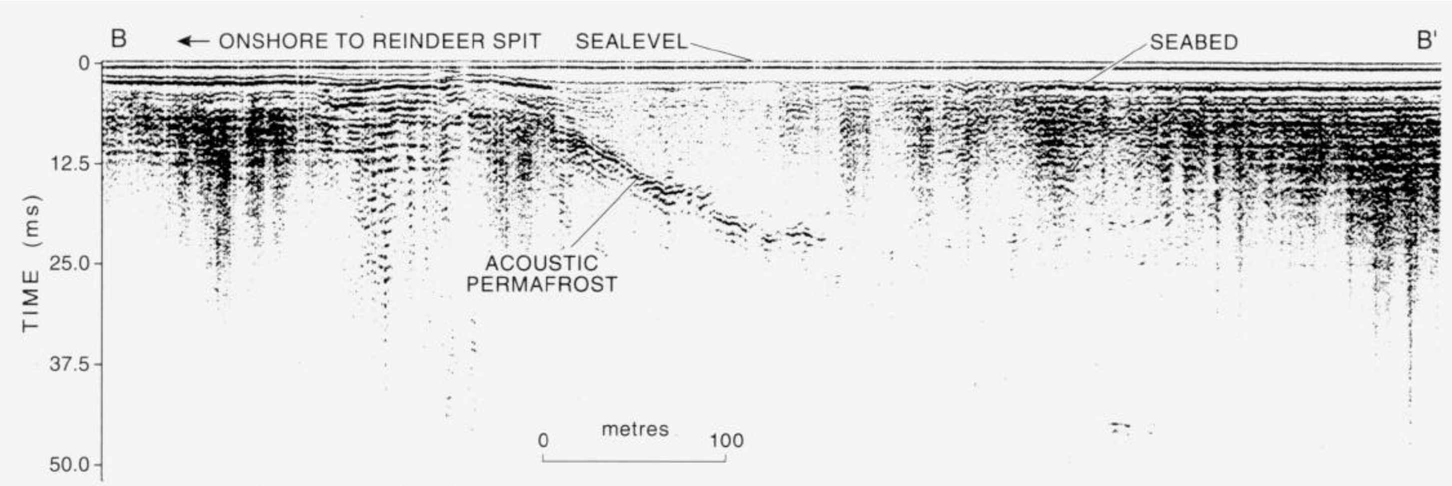

Figure 5. An acoustic line (acquired with an NSRFC receiver) offshore onto an exposed spit. The line illustrates an acoustic permafrost (APF) reflector rising through the sedimentary sequence toward the surface. Water depth decreases from about 3 m to I m. Gas within the seabed partially masks the subsurface stratigraphy in the offshore.

Finally, in water depths greater than 2 m, acoustic records reveal a sequence of relatively transparent to irregularly layered material overlying an undulating, highly reflective surface. The layer below the surface contains discontinuous reflectors which are truncated by the overlying surface. This is similar to acoustic stratigraphy further offshore and along the Tuktoyaktuk coast, where the upper unit is interpreted to be a transgressive deposit and the lower unit represents an older sequence overlain by an unconformity surface (Blasco *et al.,* 1990; Héquette and Hill, 1989).

In many locations, a discontinuous, high-amplitude, low-frequency reflector has been tentatively identified as acoustic permafrost (APF). The interpretation is most unambiguous where the APF reflector is seen rising towards the seabed surface as land is encountered (fig. 5). Although electrical resistivity measurements are not usually performed in marine

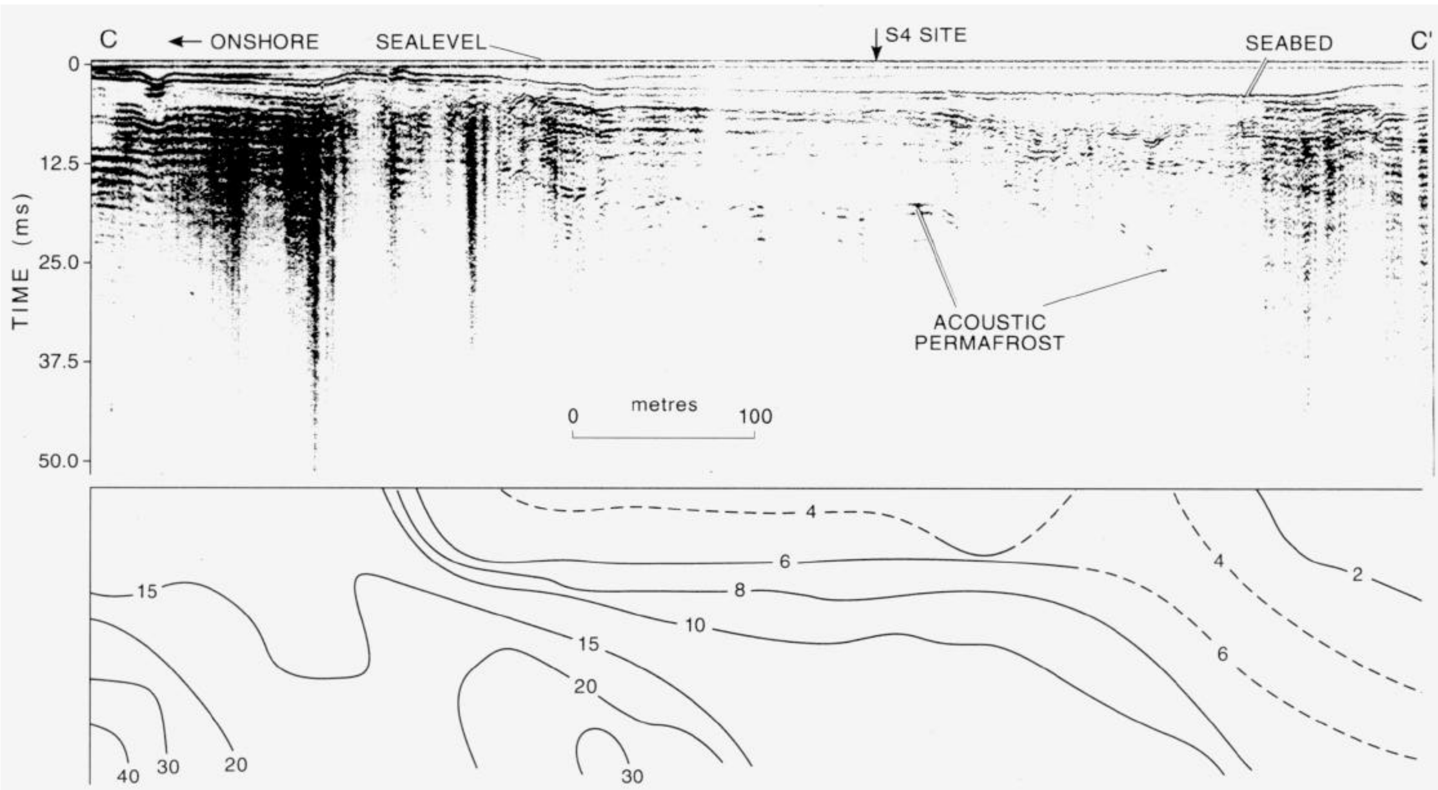

Figure 6. An acoustic line (also acquired with an NSRFC receiver, and similar to that in figure 5) which was run over an S4 deployment site onto the shore. Again, APF can be seen rising through the sequence, although it is not clear whether it cuts across lithologies. Water depth decreasesfrom left to right, from about 3.5 m to 1 m. Below the acoustic line, resistivity contours are shown in ohm-metres (depths are represented only relative to one another). Electrical resistivity at the seabed surface rises dramatically, from less than 2 Ohm.m to 15 Ohm.m. Resistivity at depth rises from 4 Ohm.m to more than 40 Ohm.m over the interval in which APF can be seen.

environments, in this case they proved to be a very useful adjunct to conventional acoustic methods by corroborating interpretations of frozen sediments (fig. 6).

The resistivity of unfrozen surficial sediments in the offshore is typically in the range of 0.5-5 Ohm.m (ohm.metres). In contrast, the resistivity of onshore "cold" permafrost ranges from 1,000 to more than 5,000 Ohm.m. As profiles were run from unfrozen offshore areas toward (and in one case, onto) the shore, intermediate values of resistivity were measured as acoustic permafrost reflectors rose through the sediments. In several locations, sediments with high resistivity were found without a corresponding acoustic permafrost signature. These locations will be the subject of modelling experiments in order to try to determine the cause of the excess resistivity. One possible explanation is the presence of a relatively high-resistivity lithology (that is, gravel) within or beneath a lower resistivity unit.

The depth to frozen material in the nearshore environment is largely dependent on the water depth and the length of time since thermal conditions were conducive to permafrost aggradation at that location. In some locations, the depth to frozen material may be out of equilibrium with the existing thermal regime imposed by the overlying water depth, because it is a relict of a previously existing topography. Recognizing the presence of these relicts and mapping them will help prevent expensive miscalculations in designing pipelines. and planning dredging operations.

Outside the protected embayments, barred shorelines give way to extremely smooth inner shelf zones with very shallow slopes (approximately 0.05%). Acoustic penetration is variable in these locations due to the presence of shallow gas. The gas rises through the sediments and, acting like an acoustic mirror, effectively masks any reflecting stratigraphic horizons which might be found below. In some cases the gas is seen to penetrate the interface between the sediment and the water and rise into the water column. Pockmarks have been identified on the seabed in some of the gas-bubble localities. Gas appears to exist in the sediment column as pockets or lenses, so that intermittent "windows" reveal the acoustic structure, which is very similar to that observed in deeper water in the sheltered bays. Acoustic permafrost exists within some of these more exposed environments, but its distribution has not yet been mapped. When compiled, it will provide critical information, both about the stability of the seabed for emplacing structures, and about the ability to dredge the materials to allow pipeline construction.

The uppermost acoustic unit of sediments varies in thickness from less than 1 m to approximately 15 m (assuming an acoustic velocity of 1,500 m/sec). It is interesting to note that the thickest package of these sediments is found within some of the smaller embayments within the Reindeer Islands (fig. 2). These accumulations may be due to infilling of the embayments with lacustrine sediments, before they were breached and subsequently drowned by a rising sea level. Alternatively, the infill may represent rapid sedimentation from the Mackenzie River plume. Dating and geochemical analysis of the sediments may provide some of the answers to these questions.

Shorezone survey methods: Sediment transport and coastal oceanographic issues were addressed by measuring waves and currents, suspended sediment concentrations, and beach profile changes in a variety of sheltered and exposed locations (see figure 2 for the locations of the current meters). Directional waves were monitored in collaboration with the Marine Environmental Data Service (MEDS). They provided a Wavec directional wave buoy which was deployed in 7 m of water west of Pullen Island (fig. 1). The location was chosen so that exposure to northwest storms was maximized, and the potential for interaction with pack ice was minimized.

Unfortunately, during the year of the study there was pack ice throughout the field area, and the wave buoy was carried by ice more than 30 km to the southeast after approximately three weeks of data acquisition. An Argo satellite transmitter allowed us to track the buoy, and it was retrieved by the C.C.G.S. *Nahidik.* Our original plan called for the deployment of two buoys, one on each side of Pullen Island in 10 m of water, but ice conditions, and the lack of a functioning Argo transmitter on the second buoy, precluded data collection at the eastern location. During the functioning lifetime of the western buoy, data on pitch, heave, and yaw were collected and archived for 34 minutes every hour.

Further inshore, currents and waves were measured using S4 electromagnetic current meters, Aanderaa current meters, and time-lapse video (fig. 2). These measurements will provide the data to

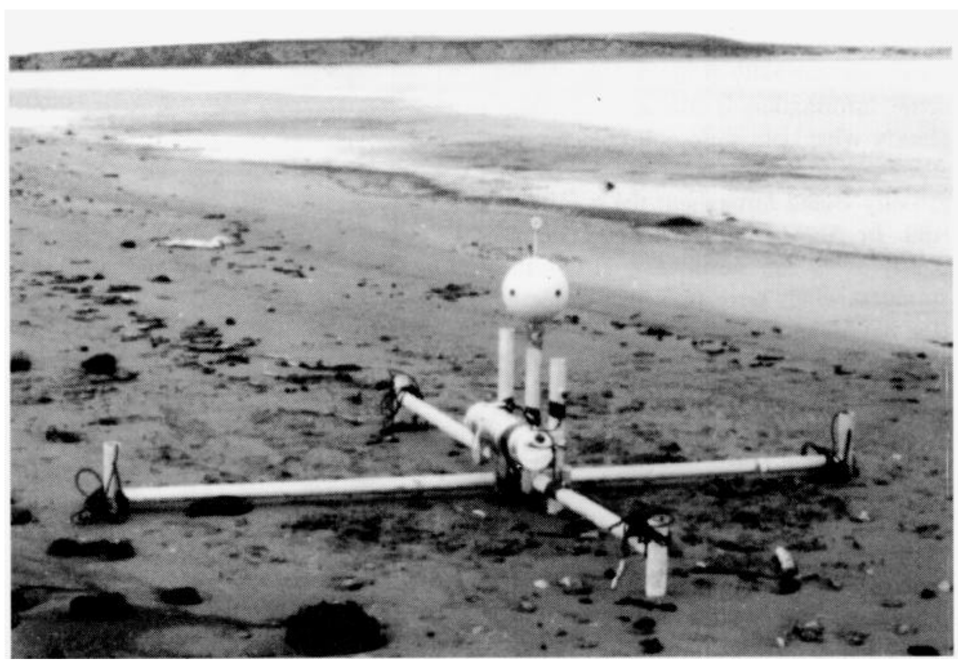

Figure 7. The S4 current meter (a 25-cm globe) and OBS units mounted on the stand and ready for deployment. Lead weights are lowered over the 4 corners.

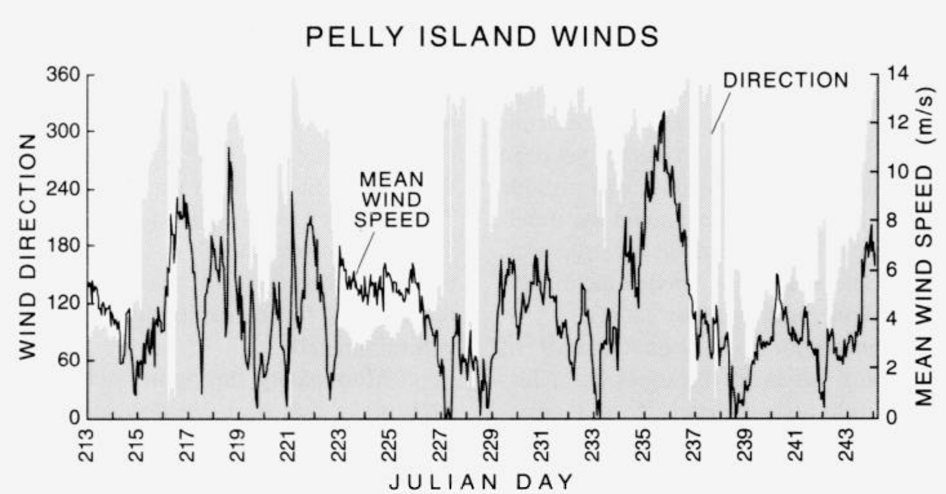

Figure 8. AES wind data from Pelly Island showing the direction and speed for the month of August 1991 (Julian days 213-243). Note the high-magnitude events on days 218 and 236 (August 5 and 23) and the prolonged period of northwest winds from day 227 to 238 (August 14-25).

construct models of wave shoaling over the extensive muddy shallow shoals that comprise much of the coastal and nearshore area. Suspended sediment concentrations were measured with optical backscatter sensors (OBSs) and in one instance with streaming sediment traps. The S4 and OBS instruments were mounted on custom-designed and fabricated stands (fig. 7). The primary design considerations were that they be deployable and recoverable from rubber boats, and be stable under storm conditions.

Shorezone survey results: Coastal and nearshore oceanographic measurements are currently being analyzed, but some information is already available. Hourly wind data were collected by the Atmospheric Environment Service (AES) at Pelly Island throughout the study period. In August, winds were predominantly from the northwest; all of the strongest winds were from that quadrant (fig. 8). Mean and median hourly wind speeds were about 4 m/sec. Peak wind gusts during the most severe storms exceeded 12 m/sec.

Directional wave data from west of Pullen Island were logged via computer and checked occasionally in the field. Maximum wave heights of about 1.5 m were recorded during field data checks on August 4. The maximum hourly wind speed that day was about 9 m/sec. Further inshore, currents measured by S4 current meters occasionally exceeded 1 m/sec. Wave heights were generally low (less than 1 m). Video recordings suggest that the small wave heights may be a function of the instruments being located within the zone of wave breaking during the most severe weather. This occurs because waves lose energy when they break, resulting in lower wave heights when they form again. Optical backscatter detectors recorded time-averaged suspended sediment concentrations within 20 cm of the seabed, some of which were up to 5 g/litre during storm conditions (fig. 9).

Current velocity data collected from a channel inside one of the embayments illustrates the presence of a strong semi-diurnal tidal signal - a surprising result given the very small tidal range in this region. Storm surges superimposed upon the tidal cycles produced unidirectional

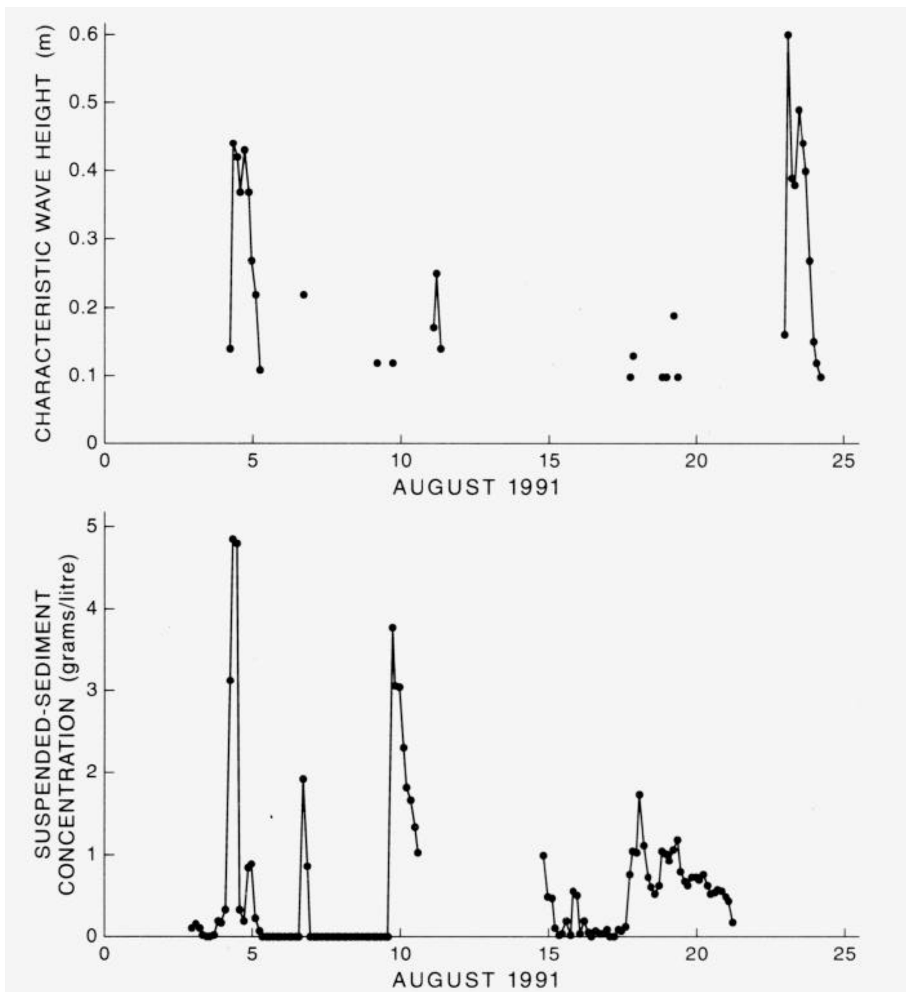

Figure 9. The wave heights and the OBS-derived suspended-sediment concentration for the month of August 1991. Wave data are shown only for times of significant wave height. Several wave events (for example, on August 5, 7, and 18) are accompanied by elevated sediment concentrations.

currents within the embayments of more than 0.5 m/sec. Currents of this magnitude are capable of transporting fine-grained sediment (for example, see Blatt, Middleton, and Murray, 1972, p. 93), indicating that the perennial channels found in these embayments are likely to be active sediment conduits. These are the first measurements of this kind inside the protected embayments of the region. The fate of these channels, and the formation of new ones as the oceanographic regime is modified by coastal erosion, are issues of concern for the building and maintenance of pipelines.

Discussion and future directions

Data from recent NOGAP projects provide new insights into the magnitude of coastal and nearshore processes in areas of the Beaufort Sea which are currently being considered for development. The data provide quantitative evidence that the sediment transport regime is very active and that rapid changes are possible within the design lifetime of a pipeline, even in relatively protected embayments. Further data analysis will concentrate on the modelling of wave transformation as shoaling occurs and on changes in coastal morphology due to erosion. This information can then be used by the appropriate regulatory agencies to evaluate new and existing development proposals. The information collected also provides an opportunity to study the spatial distribution of materials in, and the morphology and stratigraphy of, a modem, transgressive, ice-dominated, delta-margin environment and to use the formation as an analog for ancient deposits.

The distribution of ice-bonded materials in the nearshore zone will be a significant factor in determining both the methods and costs of development. For the first time, geophysical surveys have been performed in the extensive shallow-water region surrounding potential development sites. These data permit the mapping of acoustically defined permafrost and the continuity of acoustic units where considerable variation is anticipated. Before engineering design parameters can be evaluated, core samples must be collected in typical sedimentary and thermal regimes in order to verify the geophysical interpretation and to provide quantitative information on physical properties. These data will be collected within the next year and incorporated into the final NOGAP report.

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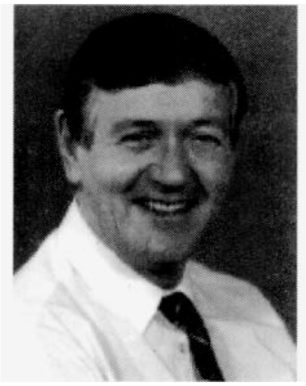
The effect of flow on the suspension feeding of molluscs

D. J. Wildish



D. J. Wildish

Suspension-feeding molluscs include the familiar and commercially important giant scallops, blue mussels, and soft-shell clams. All of these molluscs feed by capturing microscopic particulates, or seston, present in seawater in small amounts. Seston may include resuspended sediment, detritus, bacteria; microalgae, and small zooplankters. The precise ciliary mechanism by which seston is removed from seawater by molluscs is not fully understood, although the process involves an active ciliary pump and the capture of seston on the gills, followed by the exhalation of filtered seawater.

Because of the heterogeneous nature of the food of suspension-feeding molluscs, it is difficult to devise a single biochemical indicator of seston quality. Yet, the quality and quantity of the ingested seston determine the extent to which a mollusc, such as the giant scallop, is able to maintain its body condition and grow. Measures such as the amount of chlorophyll a and the cell densities of the dominant microalgae (fig. 1) do not provide a very good indication of natural growth potential in the giant scallop (fig. 2). The growth as shell and whole wet weight increments of juvenile scallops correlate best with temperature, although in the adult this relationship is not apparent, due to the loss of growth potential associated with spawning.

The seawater movements that affect suspension feeding by molluscs result

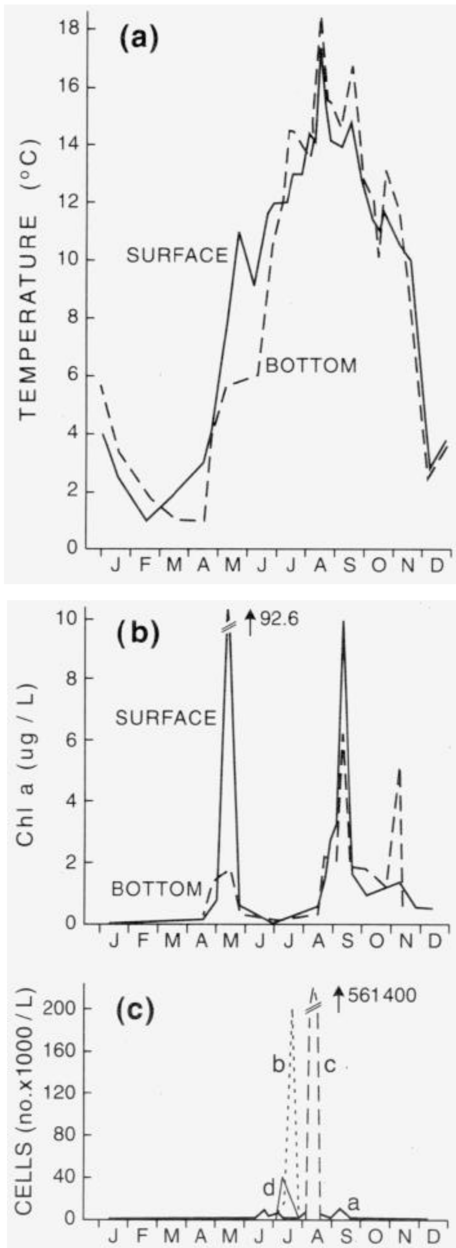


Figure 1. Measurements taken near the St. Andrews Biological Station in 1989. the top graph shows seawater temperature; the middle graph shows chlorophyll a *concentration in µg/litre; and the lower graph shows microalgal density as cells/ litre. The types of microalgae represented in the bottom graph are: (a)* Mesodinium rubrum; *(b)* Leptocylindrus minimus; *(c)* Nitzschia pseudodelicatissima; *and (d)* Nitzschia closterium.

from three major physical forces: tidal circulation, various types of nontidal circulation (for example, reaction currents), and wind stress on the surface of seawater. With regard to a feeding mollusc, two characteristics of seawater movement are important: direction and velocity near the inhalant opening. Kirby-Smith (1972) was the first to show that individual bay scallops were inhibited in feeding at higher velocities; thus this work initiated physiological paradigm studies of flow. Wildish (1977) and Wildish and Kristmanson (1979) initiated studies of the effect of velocity on population growth, and hence the ecological paradigm, of suspension-feeding molluscs.

The physiological paradigm

The inhibited filtering and/or feeding which Kirby-Smith (1972) found that the bay scallop exhibits at higher velocities has been confirmed in other species such

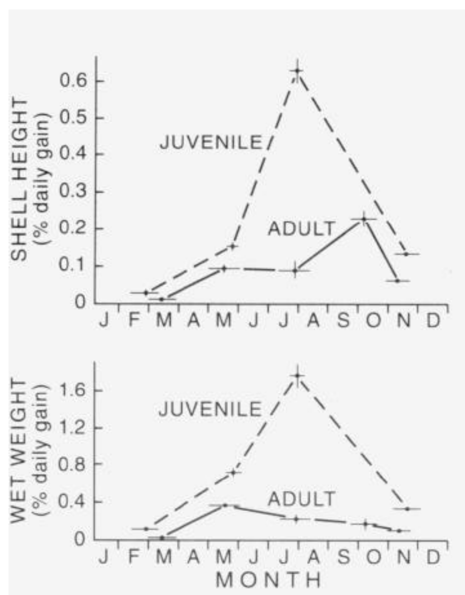


Figure 2. Specific daily mean growth rates represented as shell height increments (top graph) and wet weight increments (lower graph). The horizontal bars indicate the growth period, and the vertical bars indicate the growth range.

as the giant scallop (Wildish *et al.*, 1987) and the blue mussel (Wildish and Miyares, 1990). These results can be generalized as shown in figure 3. In a1, very low velocities around the mollusc may cause localized depletion, thereby limiting feeding because the bivalve pump is processing partially depleted seawater. In b1, however, feeding is unaffected by velocity. In c1, velocity has a marked inverse effect on inhibiting feeding and growth.

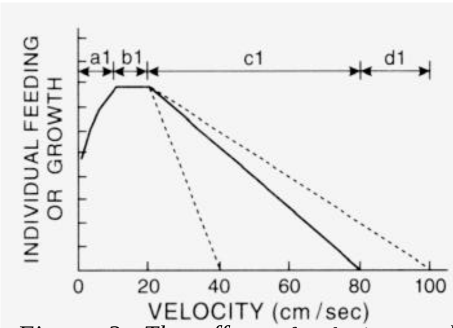


Figure 3. The effect of velocity on the suspension feeding or growth rate of individual molluscs. The dashed lines indicate the range of effects which are dependent on seston concentration.

Recently, it has been shown that the seston concentration itself influences the response of the giant scallop to increased velocities (Wildish *et al.*, 1992). Thus, there is an optimum seston concentration for achieving the maximum feeding rates at b1, and the steepness of the c1 slope depends on the seston concentration. If the seston concentration is low, the velocity at which the giant scallop will cease to feed will be lower than if the seston concentration is high. The high velocities in d1 are considered to be beyond the capacity of the mollusc to continue feeding.

Because the effect velocity has on feeding is so important to the unanswered question of the ciliary pump mechanism in suspension-feeding molluscs, the hypotheses being considered in order to explain velocity-inhibited feeding have special interest. The most likely ones (Wildish *et al.*, 1987) are that molluscs simply close their valves, thereby reducing pallial volume and reducing pump efficiency (Jorgensen, 1990), or that they shunt inhalant water past the gill ciliary filter so that the seston is exhaled unfiltered (Famme and Kofoed, 1983). Recent observations suggest that feeding inhibition is primarily due to valve closure controlled by velocity; these were made in a new flow-simulation laboratory at the St. Andrews Biological Station, with a video camera focused on the scallop inhalant and exhalant opening during flume experiments. However, this type of evidence does not preclude the possibility of a shunt flow also occurring.

Many molluscs are bilaterally symmetrical, and some of their locomotory activity serves to orient them so that their inhalant siphon is opposed to the major tidal currents. Giant scallops, if forcibly oriented with their exhalant to the flow axis (achieved by gluing them to the flume floor), grow more slowly than those glued with the inhalant facing the flow (Wildish and Saulnier, 1992). These and similar results demonstrate the importance of flow direction in mollusc feeding.

The ecological paradigm

Field observational data collected from the Bay of Fundy show that a population of suspension-feeding molluscs - such as horse mussels - increases logarithmically as a positive function of averaged velocity in the water column (Wildish and Peer, 1983). Because of methodological problems in the field measurement of velocities within the benthic boundary layer (BBL), the data currently available do not allow these field results to be directly compared with the results of the flume experiments mentioned above. However, because the decrease of velocity within the BBL is logarithmic, field flows near the mussel inhalant are probably similar to the inhibiting velocities determined in the laboratory.

A conceptualization of the effect of velocity on population growth within a mussel bed is shown in figure 4. The bed has a specified path length aligned along the major flow axis and consists of a given density and size range of mussels which are feeding at specific rates. In the earliest model (Wildish and Kristmanson, 1979), turbulent flow within the BBL was considered with estimates of seston flux rates (seston concentration times velocity) and the amount of seston consumed (C_0 - C_1) by the population. The downstream "seston depletion effect" was considered a factor limiting mussel bed growth and spatial extent. Studies have confirmed these effects in small laboratory populations (Wildish and Kristmanson, 1984, 1985). Within the ecological paradigm, density can be adjusted by increases (through immigration and spat settlement) or decreases (through competition and mortality) according to the seston flux rates in the particular area. If the seston concentration is sufficiently high, velocity-inhibited mussels may grow at a rate equal to or greater than optimally feeding mussels growing in conditions where the seston concentration is lower.

Recently, more realistic ecological models have considered the availability of advective/diffusive contributions of seston (fig. 4) to the mussel bed (Frechette

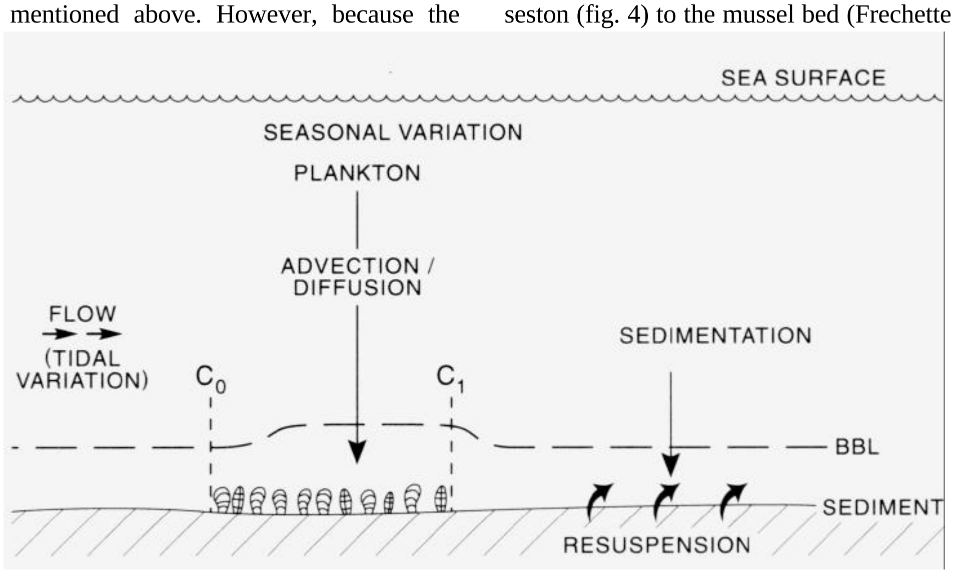


Figure 4. A conceptual view of the effect of velocity and seston concentration (C_O = initial, C_1 = final) on the population growth of suspension-feeding molluscs.

et al., 1989). Whether resuspension was an important factor in the population growth of an intertidal bed of blue mussels was considered by Frechette and Grant (1991). In the particular locality studied, resuspension was found not to contribute to the trophic resource of the mussels.

Conclusions

The flow of seawater affects many levels of biological organization and, in particular, the way in which some species of molluscs feed. Although an understanding of suspension feeding in molluscs is still incomplete, such knowledge has many practical applications. One example is the selection of sites for mussel and scallop aquaculture. It is clear that extrapolations from the physiological paradigm will not give accurate predictions about the ability of a site to support a particular level of mollusc production. In regard to ecological models, which are better for this purpose, further work is needed in order to determine the growth responses of individual molluscs when density and seston flux rates are varied. Physical oceanographic field measurements of velocity within the BBL near mollusc beds are also required in order to determine whether field and laboratory results agree.

Feeding by suspension-feeding molluscs is one way in which the red-tide toxins produced by microalgae enter the food chain. A current research objective is to determine whether toxic microalgae inhibit mollusc feeding. It has been claimed that ectocrines produced by some microalgae are able to do this, although the issue is still controversial. The demonstration that seston concentration influences the filtering and feeding rates of molluscs means that seston levels must be kept constant during mollusc feeding bioassays. However, current feeding bioassays involve seston depletion, and the technology required to keep seston concentration constant is not yet available.

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Understanding oil and gas distribution in offshore sedimentary basins: A research strategy for the 1990s

M. A. Williamson and K. D. McAlpine

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Virtually all the world's non-renewable fuel resources are found in sedimentary basins, and Canada's east coast is not without its share. Eastern Canada's oil and gas potential became apparent over the course of its exploration history. During Canada's year of Confederation, 1867, and just nine years after North America's first "deliberate" oil discovery at Oil Springs, Ontario, an oil well was drilled at Parsons Pond in northwest Newfoundland. In 1909, oil was discovered at Stony Creek, a field in southern New Brunswick that is still producing today. Both these onshore areas contain oil that accumulated in Paleozoic sedimentary rocks deposited more than 250 million years ago.

Since the early 1900s technological advances have broadened the frontiers of oil and gas exploration. In the 1950s and '60s, systematic marine geophysical surveys by government and university research institutions in the United States and Canada began to reveal the presence of deep Mesozoic-Cenozoic sedimentary basins lying offshore, containing a rock record of the last 245 million years (fig. 1). This stimulated the interest of the petroleum industry, and in 1966 the first offshore exploration well was drilled.

Exploration during the ensuing years was punctuated by the discovery of gas on the Scotian Shelf in 1969, gas on the Labrador Shelf in 1974, and the giant Hibernia oil field on the Grand Banks of Newfoundland in 1979. So far, the petroleum industry has drilled almost 300 offshore wells, and acquired over a million line-kilometres of multichannel seismic data. This multibillion-dollar venture has led to 48 oil and gas discoveries (table 1). It has also generated an enormous database of geological, geophysical, geochemical, and engineering information. Thanks to favourable government regulations, this vast body of industry data, which is curated by the Canada-Nova

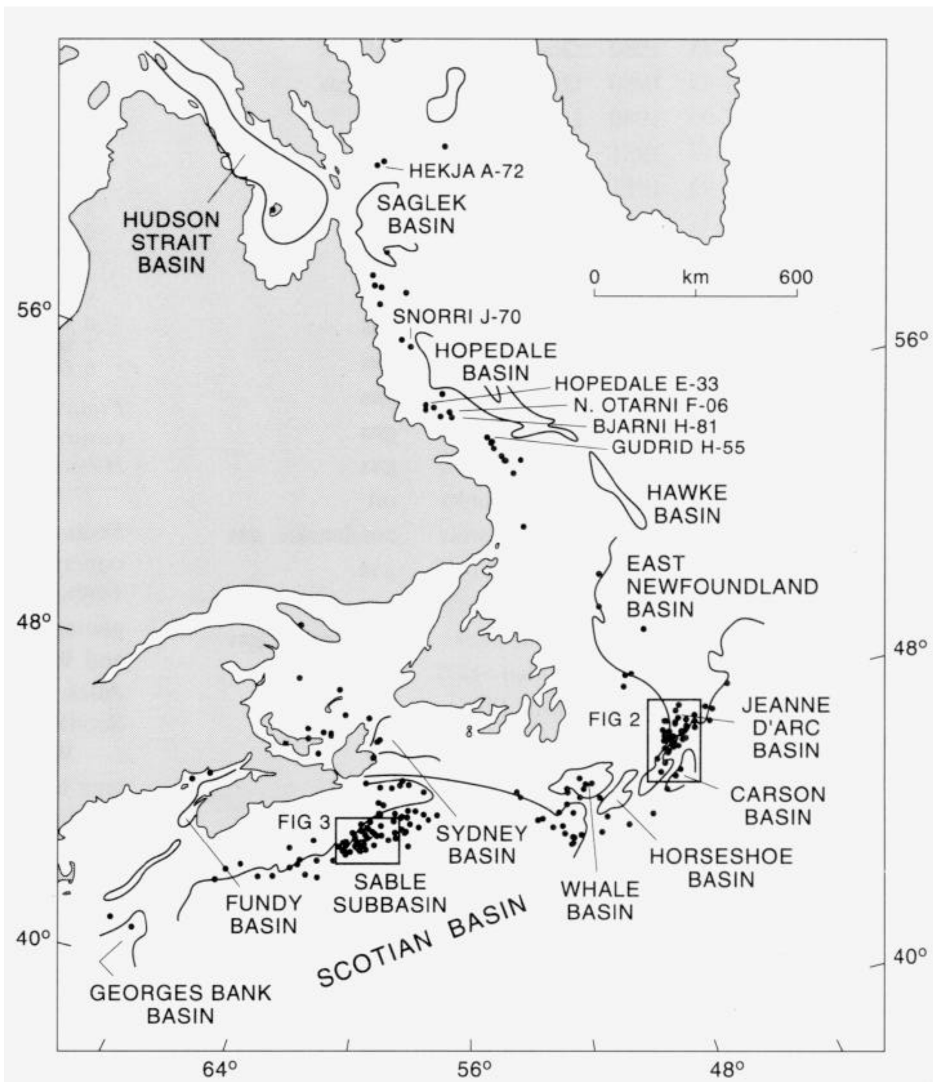

Figure 1. Principal Mesozoic--Cenozoic sedimentary basins and the nearly 300 well locations represented by small black dots offshore of eastern Canada.

Table 1
Chronological listing of hydrocarbon discoveries Offshore eastern Canada

Discovery well	Year	Area	Product
Onondaga E-84	1969	Scotian Shelf	gas
Sable Island E-48	1971	Scotian Shelf	condensate, gas
Sable Island O-47	1971	Scotian Shelf	gas
Primrose N-50	1972	Scotian Shelf	oil, condensate
Eagle D-21	1972	Scotian Shelf	gas
Thebaud P-84	1972	Scotian Shelf	gas
Cohasset D-42	1973	Scotian Shelf	oil
Bjami H-81	1973	Labrador Shelf	gas
Citnalta I-59	1974	Scotian Shelf	gas, condensate
Intrepid L-80	1974	Scotian Shelf	gas, condensate
Gudrid H-55	1974	Labrador Shelf	gas
Snorri J-70	1975	Labrador Shelf	gas
Hopedale E-33	1978	Labrador Shelf	gas
Venture D-23	1978	Scotian Shelf	gas, condensate
Hibernia P-15	1979	Grand Banks	oil
Hekja A-72	1979	SE Baffin Shelf	gas
Ben Nevis I-45	1980	Grand Banks	oil, gas
South Tempest G-88	1980	Grand Banks	oil, gas
North Bjami F-06	1980	Labrador Shelf	gas
Hebron I-13	1981	Grand Banks	oil
Nautilus C-92	1981	Grand Banks	oil
Banquereau C-21	1981	Scotian Shelf	gas
Olympia A-12	1982	Scotian Shelf	gas
South Venture O-59	1982	Scotian Shelf	gas
North Dana I-43	1982	Grand Banks	gas
Bluenose 2G-47	1982	Scotian Shelf	gas
Arcadia J-16	1983	Scotian Shelf	gas
Glenelg J-48	1983	Scotian Shelf	gas
Uniacke G-72	1983	Scotian Shelf	gas
Terra Nova K-08	1983	Grand Banks	oil
Trave E-87	1983	Grand Banks	condensate, gas
Alma F-67	1983	Scotian Shelf	gas
Chebucto K-90	1984	Scotian Shelf	gas
South Mara C-13	1984	Grand Banks	condensate, gas
West Venture C-62	1984	Scotian Shelf	gas
Whiterose N-22	1984	Grand Banks	gas, oil
West Ben Nevis B-75	1984	Grand Banks	oil
Mara M-54	1984	Grand Banks	oil
North Ben Nevis P-93	1984	Grand Banks	oil
Beothuk M-05	1985	Grand Banks	oil
West Olympia O-51	1985	Scotian Shelf	gas
North Triumph G-43	1985	Scotian Shelf	gas
Whiterose L-61	1986	Grand Banks	condensate, gas
Fortune G-57	1986	Grand Banks	condensate, gas
Panuke B-90	1986	Scotian Shelf	oil
South Sable B-44	1988	Scotian Shelf	gas
Springdale M-29	1989	Grand Banks	oil
Balmoral M-32	1991	Scotian Shelf	oil

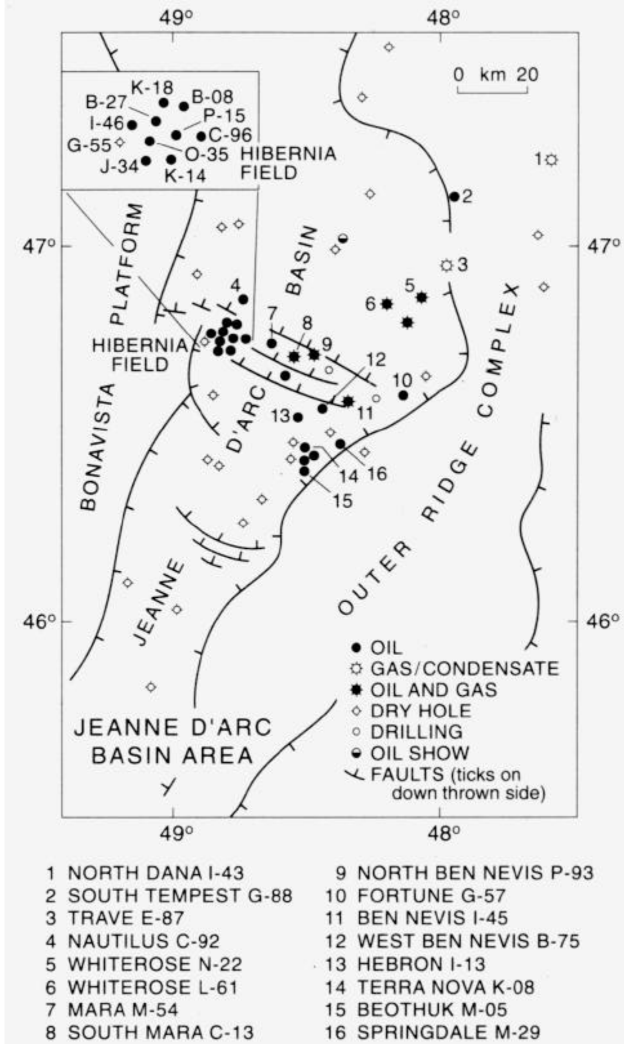

Figure 2. Detail of drilling activity and petroleum discoveries in the Jeanne d'Arc Basin Area, including the Hibernia Field.

Scotia and the Canada-Newfoundland offshore boards, underpinned several research syntheses during the late 1970s and '80s. Examples of these are: a series on the geology of Canada's eastern continental margin (Keen and Williams, 1990), and the ongoing East Coast Basin Atlas Series (Bell, 1989, Labrador Shelf; Cant, 1991, Scotian Shelf).

Work on some aspects of the data available from the area has allowed fundamental advances to be made regarding continent breakup, rifting processes, and basin creation and fill (for example, Beaumont *et al.*, 1982; Mackenzie *et al.*, 1985; Keen, 1979; Keen and Beaumont, 1990). An inherent difficulty facing traditional subsurface studies is that a complete understanding of an area develops only gradually; a basin is really well known only when most of its petroleum potential has been determined. Such comprehension is achieved only through the continuous gathering and processing of new data and the compilation of more complete and reliable syntheses.

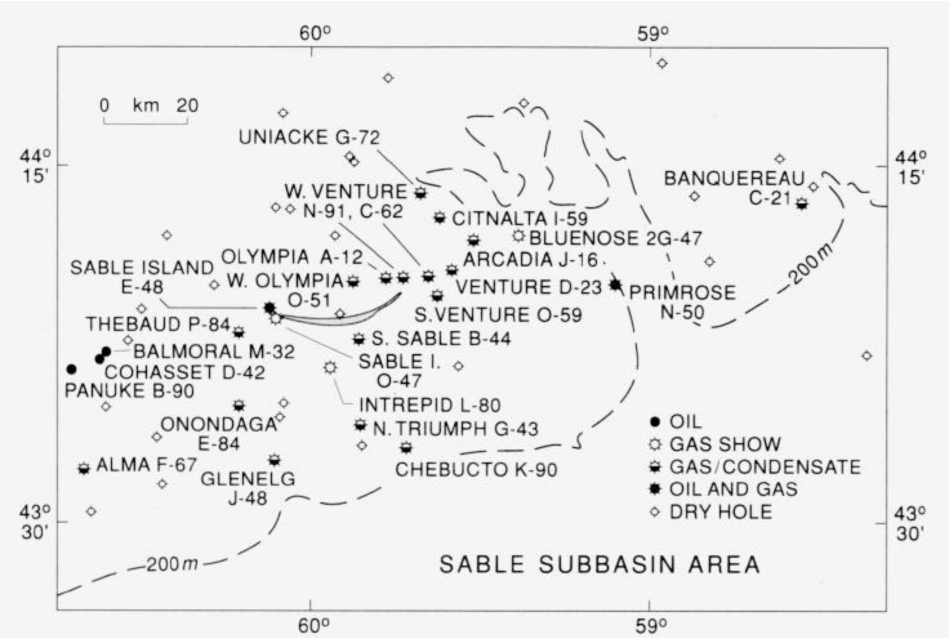

Figure 3. Detail of drilling activity and petroleum discoveries in the Sable Subbasin Area, including the Panuke-Cohasset, Sable, Venture, and Glenelg discoveries.

On Canada's east coast, AGC has initiated a new research strategy, the Hydrocarbon Charge Modelling Project, to develop a quantitative understanding of the chemical, physical and geologic phenomena that have controlled oil and gas distribution in the region's subsiding sedimentary basins. Our research, therefore, has evolved from the initial phase of gathering and interpreting data through to the fully comprehensive syntheses mentioned above; it continues into the next stage, applying new and emerging quantitative basin-simulation technologies, as well as data processing and interpretation tools (at small, fast, powerful workstations), to previously derived interpretations and data. The research does not aim merely to provide a sophisticated description of currently observed hydrocarbon distributions, but will develop predictive tools to assist exploration and production strategies, basin prioritization, resource assessment, and resource management. Although the ultimate output of the project is clearly pragmatic, it will require scientific innovation to successfully solve hitherto intractable problems of hydrocarbon generation, expulsion, and accumulation.

The challenge in putting together and executing this strategy is, and will be, to provide the balance that was referred to in the previous issue of the *Science Review* (see Best and Mudford, 1991). That is, numerical simulation techniques, such as pore pressure and fluid flow modelling (Mudford and Best, 1989), must be merged with information on the measured physical and chemical properties of the rock column and the basic stratigraphic and structural characteristics of the basins.

Petroleum geoscience

Over the years, cooperative efforts to gather, interpret, and assimilate geophysical, geological, and engineering data gathered in Canada's eastern offshore regions have produced a comprehensive knowledge base. Whether databases or interpretive basin atlases, this knowledge underpins our petroleum geoscience research strategy. The process of interdisciplinary integration is represented in figure 4, which shows a network of disciplines and/or databases linked by powerful data interpretation, processing, and simulation workstations. Many of the projects contributing to the broader objectives of the research reside under the umbrella project (hydrocarbon charge modelling), which has a four-fold division of scientific tasks. These tasks are geared to develop the following:

- quantitative descriptions of source rock systems;

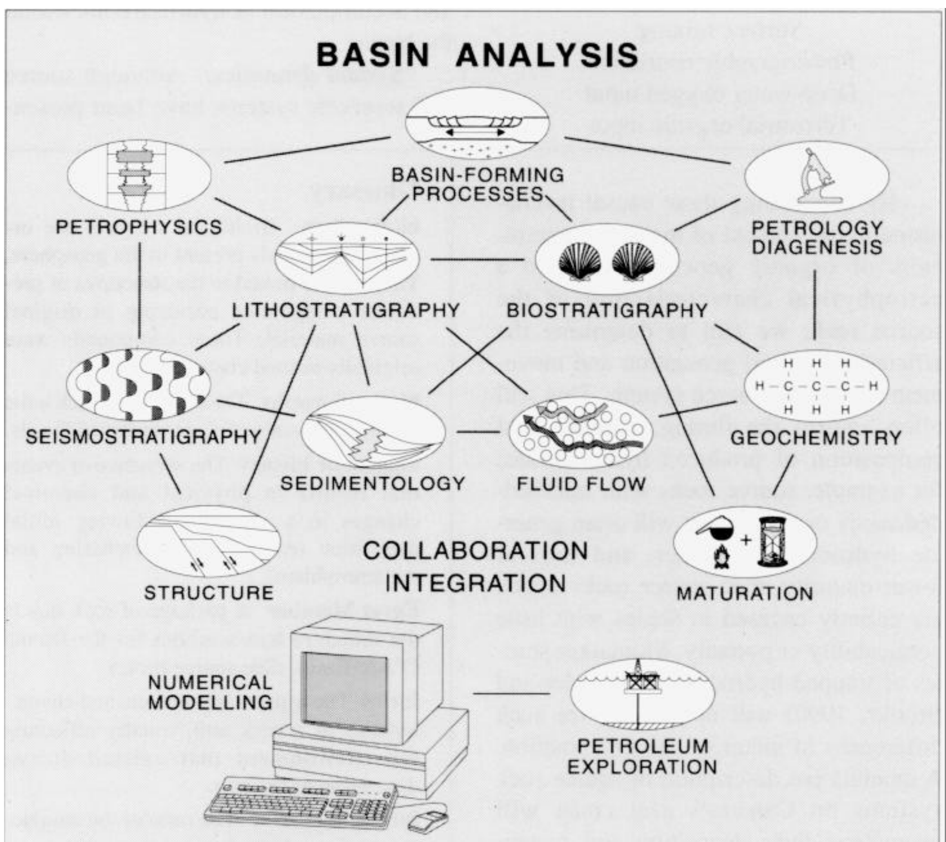

Figure 4. A conceptualization of the integration of disciplines and data required for comprehensive petroleum geosciencelbasin analysis.

- quantitative descriptions of reservoir and trapping systems;
- a dynamic description of the structural evolution and connectivity of these systems; and
- quantitative descriptions of hydrocarbon fluid movement within these systems.

Source rock systems: Research into source rock systems is directed at an understanding of the physical, chemical, and geological controls on the deposition and preservation of hydrocarbon-prone organic matter. (Table 2 summarizes some of these controls.) It is important, for example, to understand how these controls have influenced the development of the Egret Member source rock within the Jeanne d'Arc Basin (McAlpine, 1990).

Table 2
Some factors controlling the deposition and preservation of source rocks:

Sedimentation rate
Water depth
Distance from clastic source
Mixed-layer depth
Organic loading
Surface mixing
Physiographic restriction
Deep-water oxygen input
Terrestrial organic input

By considering these causal mechanisms in the context of measured parameters of organic geochemistry and a petrophysical characterization of the source rock, we aim to determine the efficiency of fluid generation and movement within the source system. This will often control the timing, volume, and composition of produced hydrocarbons; for example, source rocks with interbedded sandy or silty layers will often generate hydrocarbons earlier, and thus at lower maturity, than source rocks which are entirely encased in shales with little permeability or porosity. Biomarker studies of trapped hydrocarbons (Fowler and Brooks, 1990) will help recognize such differences in maturity and composition. A quantitative description of source rock systems on Canada's east coast will reconstruct their deposition and preservation history and will track their compaction, thermal, diagenetic and pore-pressure evolution.

Reservoir and trapping systems: Reservoir systems are characterized by greater porosities, permeabilities, and pore-storage capacity than are source systems. Understanding such systems involves the reconstruction of their compaction, thermal, pore-pressure, and diagenetic histories. Of particular importance is understanding the influence of this history on the ability of the reservoir system to allow hydrocarbon migration. For example, we are currently able to measure such parameters as porosity, permeability, tortuosity, and formation factors - all of which affect the hydraulic conductivity of the system. What we then need to determine is how these parameters developed through time. What were their characteristics during peak periods of hydrocarbon generation? Within reservoir and trapping systems, it is just as important to understand the nature and distribution of barriers to flow as it is to understand the controls on unrestrained buoyancy-driven flow. The geometrical and mechanical evolution of these barriers is what controls the final distribution and accumulation of hydrocarbons within the basins.

System dynamics: Although source and reservoir systems have been presented here as being separate, a comprehensive hydrocarbon-charging history can be developed only when they are placed in frameworks that describe their dynamic interaction and connectivity through time. In general terms, the source system produces the hydrocarbons and expels them into the reservoir and trapping systems. What we want to know more specifically is what the controls are on this transfer. Are the reservoirs and source system interbedded lithologically, or do they rely on vertical conduits (faults or fractures) for connectivity? What is the fluid transmission history of these vertical conduits? These questions are being addressed by resolving the geometric and dynamic evolution of source and reservoir systems through detailed structural and paleostructural mapping, producing, for example, maps of paleo-hydrocarbon flow and drainage.

Fluid movement: The two systems (source and reservoir) described above, together with their geometric, dynamic framework, will be used to trace hydrocarbon flow and charging history, from the initial deposition of organic-rich source rocks, through the creation of hydrocarbons, to their migration and final entrapment. This will be achieved through numerically simulating fluid movement

Glossary

biomarkers Biological markers are organic compounds present in the geosphere. They can be linked to the structures of precursor compounds occurring in original source material. These compounds were originally termed chemical fossils.

biostratigraphy The division of rock units through the study of their contained fossils.

diagenetic history The sequence of events that results in physical and chemical changes to a sediment following initial deposition (exclusive of weathering and metamorphism).

Egret Member A package of rock that is the source of hydrocarbons for the Jeanne D'Arc Basin. (See source rock.)

facies The aspect, appearance, and characteristics of a rock unit, usually reflecting the environment that existed during deposition of the unit.

formation factor The ratio of the conductivity of an electrolyte to the conductivity of a rock saturated with that electrolyte.

hydraulic conductivity The ability of a body of rock or unconsolidated sediment to transmit fluids.

permeability The degree to which a rock can transmit fluid.

porosity The ratio of the volume of void spaces in a rock or sediment to its total volume.

reservoir A subsurface volume of porous and permeable rock in which oil or gas has accumulated.

trap A volume of rock sealed by low-permeability barriers (rock or fault) and containing accumulations of fluids.

source rock An organic carbon-rick rock from which hydrocarbons will be expulsed given certain physical and/or chemical conditions.

tortuosity Reflects the path directions of fluids within a rock body -that is, tortuous as opposed to direct. Specifically, the inverse ratio of the length of a rock to the length of the equivalent path of fluid within it.

within them. The basic physical driving forces that control fluid movement within source systems differ from those within reservoir systems, which are predominantly buoyancy-driven. A major challenge is the coupling of fluid-flow models to link the two systems.

The integrated frameworks described above will provide predictive models to test against observations - that is, do our models satisfactorily explain the currently observed hydrocarbon distribution (figs. 2, 3) throughout the basin of interest? This will afford confidence in the model's capacity to quantify risk associated with undiscovered resources.

We have provided here only a brief glimpse of the major research elements of the project. Each of these elements is made up of many individual subprojects that draw upon a wide range of specific expertise and abilities. For example, some are investigating the assumptions made during routine geological basin analysis; others are addressing significant knowledge or gaps in data. One ongoing important task is the assimilation of the results of contributory research into the broader science plan.

The science plan

Our vision of how the specific research within the described elements will combine during the life of the project is shown in figure 5, which depicts our science plan. All the projects currently underway are generally able to fit into one of the boxes.

Research into physical and chemical properties (box A2) is providing basic data regarding the rock column and its fluid content - for example, permeabilities, porosities, water, gas and oil saturations and compositions, relative permeabilities of the fluids, fission track age and temperatures, basic mineral components, biostratigraphies and lithostratigraphies, kerogen typing, and kinetics. It is important to understand how these properties have been affected through time by compaction, temperature, and pressure changes.

Geological and geophysical mapping projects (box A3) allow the reconstruction of the geometric, dynamic, and structural evolution of the systems. Basic research on how we numerically simulate such processes as fluid transmission through faults, or the flow of fluid through media with high or low porosities and permeabilities, is also being conducted (box A4). Box A1 covers the efforts to place the other projects into a dynamic framework.

Merging information from type A projects provides the quantitative descriptions of the source rock and of reservoir and trapping systems and, importantly, defines the temporal and spatial evolution of these systems through time (box B). Combining results from box B with those from box A3 aims to provide the dynamic understanding of system interactions (box C). At any point in the overall science plan it may be necessary to adjust, redefine, or correct models based on new information from type A projects.

Finally, the output of box D will represent integrated hydrocarbon charge models, to trace and predict hydrocarbon movement throughout the dynamic source and/or reservoir and trapping system. These will be at a variety of scales, ranging from explanations of the charging history of individual pools (within an oil or gas field) to charging histories of regions or basins.

An example: Figures 6 and 7 illustrate the research involved in the project. The maps (fig. 6) show computer-predicted levels of the organic maturity of the Egret Member source rock in the Jeanne d'Arc Basin some 120, 100, 80, 60, and 0 million years before the present, with Egret Member having been deposited approximately 152 million years ago. (Organic maturity levels indicate how advanced an organic-rich sediment is toward a thermal state that allows the expulsion of hydrocarbons.) The map is derived from the consideration and syntheses of a broad variety of data types.

The subsidence, compaction, thermal, and maturation history is calculated for each data point (representing exploration wells) within the basin. The calculations are based on biostratigraphic data (that is, age-depths), lithostratigraphic data (the components of the rock), petrophysical data (assumptions about porosity reduction and decompaction, and estimates of thermal conductivity in order to determine thermal histories), and chemical reaction kinetics (gauging the rate at which chemical bonds break down in organic matter, a process which governs maturation and hydrocarbon expulsion processes). From this information, the programs compute the compaction, thermal, and maturation state of the source rock for any time throughout its geological history. The ability of these models to predict measured, present-day conditions in a particular well is used to give confidence in the model-predicted maturity, compaction, and thermal histories.

As an example, figure 7 compares model-predicted (solid and dashed lines),

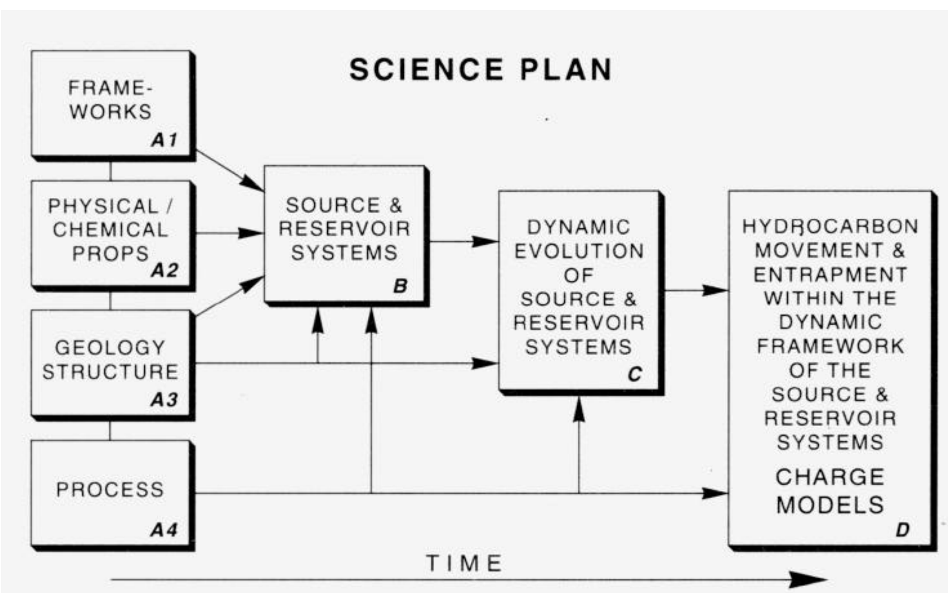

Figure 5. A science plan for the coordination of petroleum geoscience activities contributing to the Hydrocarbon Charge Modelling Project.

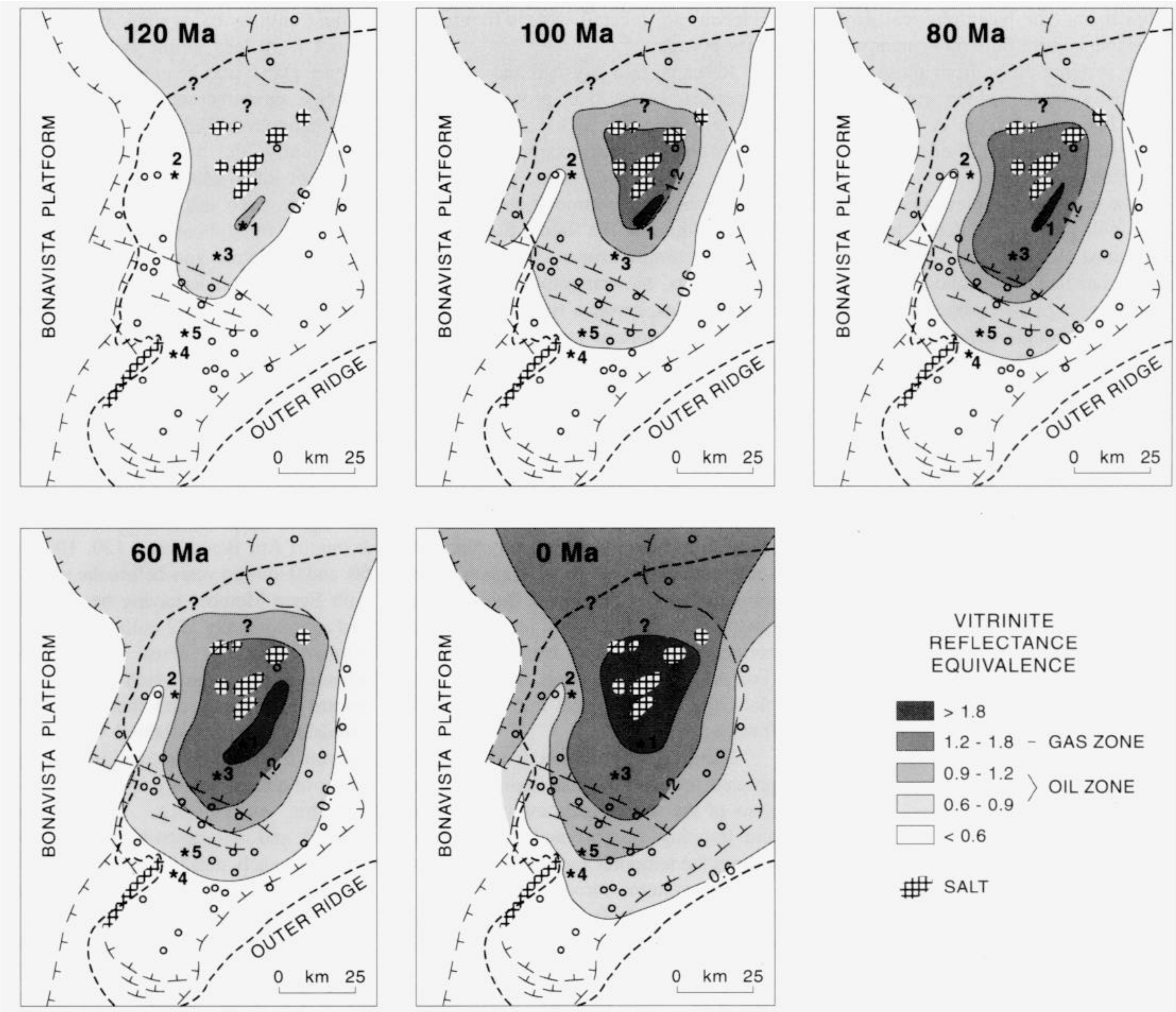

Figure 6. The evolution of source rock maturity within the Jeanne d'Arc Basin off Newfoundland, as extrapolated by computer. The maps show organic maturity levels at 120, 100, 80, 60, and 0 million years before the present. The shading, which corresponds to a VRE level of 0.6 to 1.2, represents the potential to generate and expulse oil. ("VRE" stands for Vitrinite reflectance equivalence and is a microscope-based measure of organic maturity.)

present-day, maturity-at-depth and temperature-at-depth (asterisks and crosses) profiles with direct observations of these parameters from well information and analyses. Repeating these computations for all wells in the basin allowed the mapping of maturity levels at any time in the basin's history (fig. 6). This example of type A research (fig. 5) provides a temporal and spatial framework which, when merged with detailed petrophysical, geochemical, and facies information about the actual source rock (shown in fig. 8), will contribute to the quantitative description of the source rock system (box B, fig. 5).

Research collaborators: With such a broad, interdisciplinary approach as described above, it is important to recognize significant gaps in the data and knowledge and to have access to motivated experts who are interested in contributing to the broad project. In order to expand resources available to the project, AGC has initiated links with the petroleum exploration and production industry, and with Dalhousie University's Department of Earth Sciences. Some of the companies involved are providing research funds through Dalhousie for graduate student theses applying to projects under the umbrella of hydrocarbon charge modelling.

In addition to AGC, other Geological Survey of Canada divisions involved include the Mineral Resources Division in Ottawa, which provides a rock mechanics/petrophysics focus, and the Institute of Sedimentary and Petroleum Geology in

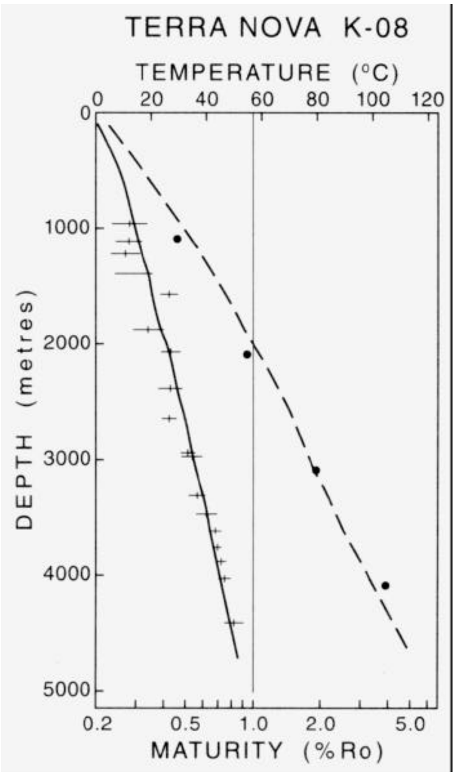

Figure 7. Computer-modelled, present-day profiles of maturity-at-depth (solid line) and temperature-at-depth (dashed line), in comparison with maturity-at-depth and temperature-at-depth profiles based on actual measurements (+). The closeness of the fits allows confidence in the extrapolation of computer-modelled data back through time.

Calgary, which brings to the project considerable organic geochemical expertise. At AGC the project draws upon petroleum geology research from the Basin Analysis Subdivision, but it also benefits from collaboration with the deep-crustal studies group in the Regional Reconnaissance Subdivision.

Summary

The distribution of discovered oil and gas accumulations within offshore sedimentary basins of eastern Canada is shown in figure 1. Research in these and other basins around the world has shown that hydrocarbon distribution within sedimentary basins is the result of the interaction, through geologic time, of a complex series of physical, chemical, and geologic phenomena. Our understanding of this distribution off eastern Canada is the result of billions of dollars worth of exploration activity (exploration wells, seismic surveys, and person-years) in the area during the past 25 years or more. This large investment is only recently being translated into production activity, represented by the Hibernia and Panuke-Cohasset oil field projects offshore Newfoundland and Nova Scotia, respectively. These projects are bringing the history of hydrocarbon exploration and production on the east coast into a new phase.

During the remainder of the 1990s and into the 21st century, both the oil and gas industry and the federal government will continue to be faced with difficult policy and investment choices. For industry, these will generally involve the consideration of the comparative economics of, for example, conventional and unconventional sources of oil, primary and secondary/tertiary recovery schemes, domestic and foreign exploration, frontier oil and gas, and western Canadian oil and gas. The federal government's policy on energy issues is very broad-reaching. However, one goal in terms of future energy sources will likely be to ensure not only the availability to Canadians of a number of energy options (for example, oil, gas, coal, hydro-electric and nuclear power, as well as power from renewable sources) but also the availability of the maximum amount of information to help Canadians make the right choices, given prevailing economic conditions and environmental considerations. Both industry and government will only make correct choices on the basis of accurate and

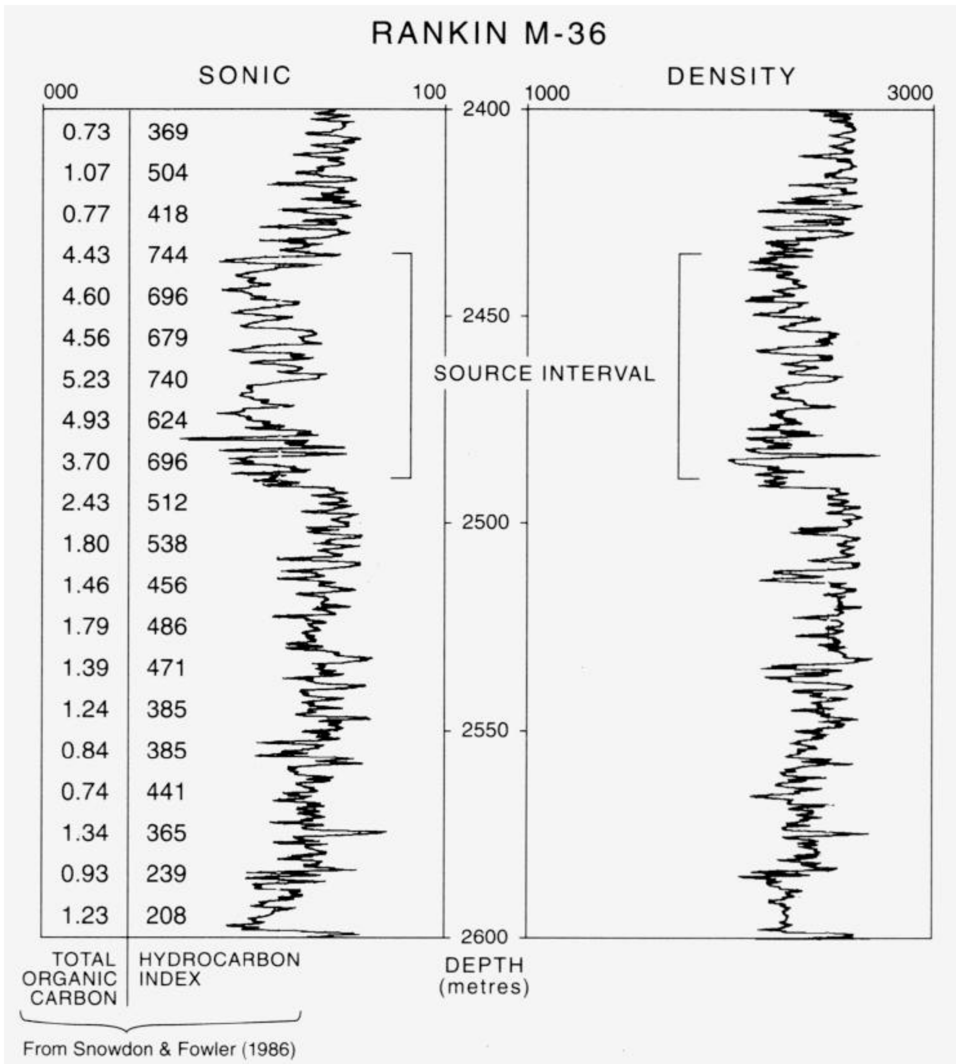

Figure 8. A digital log response pattern (showing both sonic and density responses) typical of the Egret Member source rock in the Jeanne d'Arc Basin. Also shown are the geochemical characteristics of the source interval derived through Rock-Eval analysis of well samples.

comprehensive information on the nature of the options available.

The research strategy outlined in this document intends to provide such information for at least one of Canada's future energy-investment options: that of east coast frontier oil and gas. The strategy is designed to build upon some of the geoscientific achievements of AGC, particularly with respect to understanding basin tectonic and stratigraphic frameworks and petroleum geology. These achievements, which are most recently manifest in the East Coast Basin Atlas Series (Bell, 1989; Cant, 1991), provide the framework to develop quantitative models of the hydrocarbon charge histories of east coast frontier basins.

The results of the project will interest petroleum explorers, producers, regulators, and policy-makers. The numerical modelling of basin charge histories will facilitate more accurate predictions of the resource potential of basins and, importantly, will provide a quantitative platform for the development, examination, and testing of new ideas about hydrocarbon generation, migration, and entrapment within Canada's east coast frontier basins. This information will secure for Canadians a more complete geoscientific understanding of potential and existing energy options.

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Organization and Staff

The Bedford Institute of Oceanography (BIO), the Halifax Fisheries Research Laboratory (HFRL), and the St. Andrews Biological Station (SABS) are research establishments of the Government of Canada and are operated by the Department of Fisheries and Oceans (DFO), both on its own behalf and, in the case of BIO, for the other federal departments that maintain laboratories and groups at the institute. There are two such departments: the Department of Energy, Mines and Resources (DEMR); and Environment Canada. The former maintains a major unit at BIO, the Atlantic Geoscience Centre of the Geological Survey of Canada. Environment Canada maintains two units at BIO: the Marine Wildlife Conservation Division of the Canadian Wildlife Service; and the Regional Laboratory of the Atlantic Region's Environmental Protection organization. In leased accommodation at BIO are the following private companies, which do work related to the marine sciences: ASA Consulting Ltd. and Brooke Ocean Technology Ltd.

Presented below are the major groups at BIO, and their managers, as at December 1, 1991. In addition to the three research establishments, several staff are located in an office building in Halifax called the Hollis Building (HB). Telephone numbers are included. Note that all numbers at BIO, the Halifax Laboratory and the Hollis Building should be preceded by 902-426.

DEPARTMENT OF FISHERIES AND OCEANS

Scotia-Fundy Region

Regional Director-General
N.A. Bellefontaine HB/2581

Regional Science Director
S.B. MacPhee BIO/3492

Marine Assessment and Liaison Division
H.B. Nicholls, Head BIO/3246

Scientific Computing Services
D. Porteous, Head BIO/2452

Biological Sciences Branch
M. Sinclair, Director BIO/3130
R.E. Lavoie, Asst. Director BIO/2147

Marine Fish Division
R.N. O'Boyle, Chief BIO/4890

Benthic Fisheries and Aquaculture Division (and Director, Halifax Fisheries Research Laboratory)
J.D. Pringle, Chief HFRL/6138

Biological Oceanography Division
T.C. Platt, Chief BIO/3793

Freshwater and Anadromous Division
J.A. Ritter, Chief HB/3573

Habitat Ecology Division
D.C. Gordon, Chief BIO/3278

Aquaculture and Invertebrate Fisheries Division (and Director, St. Andrews Biological Station)
R.H. Cook, Chief SABS/(506)529-8854

Physical and Chemical Sciences Branch
J.A. Elliott, Director BIO/8478

Marine Chemistry Division
J.M. Bewers, Head BIO/2371

Coastal Oceanography Division
C.S. Mason, Head BIO/3857

Metrology Division
D.L. McKeown, Head BIO/3489

Ocean Circulation Division
R.A. Clarke, Head BIO/2502

Hydrography Branch
Canadian Hydrographic Service (Atlantic)
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Field Surveys Division
R.C. Lewis, Manager BIO/2432

Nautical Publications
S.L. Weston, Manager BIO/7286

Hydrographic Development
R.G. Burke, Manager BIO/3657

Data Management and Planning
S.T. Grant, Manager BIO/2411

Tides, Currents and Water Levels
C. O'Reilly, Manager BIO/3846

Management Services Branch
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Marine Services
J. Wheelhouse, Chief BIO/7292

Engineering and Technical Services
D.F. Dinn, Chief BIO/3700

Facilities Management
A. Medynski, Chief BIO/7449

Materiel Management
J.M. Broussard, A/Chief BIO/5226

Information Systems Services
C.B. Crowe, Chief HB/9315

Library Services
A. Fiander, Chief BIO/3675

Administrative Services
H.S. Leonard, A/Chief BIO/7037

Comptroller Branch
G.C. Bowdridge, Director HB/6166

Accounting and Treasury Operations
S. Lucas, Chief HB/3552

Financial Planning and Analysis
L.Y.N. Seto, Chief HB/7060

Communications Branch
J. Gough, Director HB/3550

Science Communications
M. MacDonald BIO/6414

DEPARTMENT OF ENERGY, MINES AND RESOURCES

Geological Survey of Canada

Atlantic Geoscience Centre
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Basin Analysis
K.D. McAlpine, Head BIO/2730

Environmental Marine Geology
D.B. Prior, Head BIO/7730

Regional Reconnaissance
J. Verhoef, Head BIO/5687

Program Support
K.S. Manchester, Head BIO/3411

Administration
G. McCormack, Head BIO/2111

ENVIRONMENT CANADA

Atlantic Region

Marine Wildlife Conservation Division (Canadian Wildlife Service)
E.H.J. Hiscock, Chief BIO/6314

Regional Laboratory (Environmental Protection)
K.G. Doe, A/Chief BIO/3284

Projects

Presented below is a list of the projects and individual investigations being undertaken by the Department of Fisheries and Oceans' laboratories in the Scotia-Fundy Region, by the Atlantic Geoscience Centre of the Department of Energy, Mines and Resources, and by Environment Canada units at BIO, during the review period.

For more information on these projects, many of which are continuing, please write to the: Regional Director of Science, Scotia-Fundy Region, Department of Fisheries and Oceans, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2.

DEPARTMENT OF FISHERIES AND OCEANS

SCOTIA-FUNDY REGION

BIOLOGICAL SCIENCES BRANCH

A. MARINE FISH AND MARINE MAMMAL STOCK ASSESSMENTS AND ASSOCIATED RESEARCH

1. Herring Assessment and Associated Research (Subarea 4)
   R. Stephenson
2. Herring Assessment and Associated Research (Subarea 5)
   G. Melvin
3. 4TVW Haddock Assessment and Associated Research
   K. Zwanenhurg
4. 4X Haddock Assessments and Associated Research
   P. Hurley
5. 5Ze Haddock Assessments and Associated Research
   S. Gavaris
6. 4Vn Cod Assessments and Associated Research
   T. Lambert
7. 4VsW Cod Assessments and Associated Research
   P. Fanning
8. 4X Cod Assessment and Associated Research
   S. Campana
9. 5Ze Cod Assessments and Associated Research
   J. Hunt
10. Pollock Assessment and Associated Research
    C. Annand
11. Silver Hake Assessment and Associated Research
    D. Waldron
12. Redfish Assessment and Associated Research
    K. Zwanenburg
13. Flatfish Assessment and Associated Research
    J. Neilson
14. Continental Shelf Margin Studies, Including Argentine Assessment
    R. Halliday
15. Seal Diet and Energetics
    W.D. Bowen
16. Population Ecology of Sealworm
    G. McClelland
17. Seal Population Monitoring
    W. Stobo
18. Population Ecology and Assessment of Seals
    W. D. Bowen
19. Seal Research Infrastructure
    W.D. Bowen
20. Grey Seal Research - Dalhousie University
    R. O'Boyle
21. Groundfisheries Management Research
    R. Halliday
22. Stock Assessment Methods
    R. O'Boyle
23. National Sampling Program (Groundfish)
    K. Zwanenburg
24. International Observer Program (IOP) Management Research
    D. Waldron
25. Groundfish Trawl Surveys
    J. Hunt
26. Groundfish Age Determination
    J. Hunt
27. Ichthyoplankton Studies
    P. Hurley
28. Fisheries Recruitment Variability
    K. Frank
29. Otolith Studies
    S. Campana
30. Finfish Tagging Studies
    W. Stobo
31. Ecosystem Size Process
    L. Dickie
32. Large Pelagics Assessment and Associated Research
    J. Porter
33. Pelagic Acoustics Surveys
    U. Buerkle
34. Oceanography and Fish Distribution
    I. Perry
35. Juvenile Fish Ecology and Surveys
    J. Neilson
36. Pelagic Fisheries Management Studies
    T. Iles
37. Reproductive Strategies of Marine Fish
    T. Lambert
38. EDP Support
    R. Branton
39. Statistical Research and Collaborative Studies
    S. Smith
40. Cooperative Science-Industry Groundfish Research and Communication
    P. Hurley
41. Dynamics of Recruitment Processes for Gulf of Maine Gadids
    E. Trippel
42. Groundfish Ecosystems: Harvesting Data
    R. O'Boyle
43. Groundfish Ecosystems: Research Information - Survey Data
    S. Gavaris
44. Groundfish Ecosystems: Research Information - Geographic Distribution
    R. O'Boyle

45. Longliner Project
R. Halliday
46. Communications with Fishermen
R. O'Boyle
47. Stock Structure Studies
K. Zwanenburg

B. INVERTEBRATE AND MARINE PLANT STOCK ASSESSMENTS AND ASSOCIATED RESEARCH

1. Informatics
D. Swetnam
2. Larval Ecology and Lobster Assessment in LFA 33
M. Tremblay
3. Scallop Assessment and Research
G. Robert
4. Offshore Clam Assessment and Research
D. Roddick
5. Scallop Research
E. Kenchington
6. Cape Breton Crustacean Assessment and Research
R. Elner
7. Marine Plants Assessment and Research
G. Sharp
8. Lobster Stock Assessment (LFAs 40 and 41) and Related Research, Including Offshore Scotian Shelf Lobster Stocks
D. Pezzack
9. Lobster Habitat Research and Assessment Methodology
R.J. Miller
10. Lobster Resource Science
C. Hudon
11. Lobster Resource Science - Larval Biology
G.C. Harding, J. Pringle
12. Lobster Resource Science and Assessment - LFAs 31 and 32
J. Pringle
13. Lobster Assessment and Related Research in Southwest Nova Scotia (LFAs 33 and 34)
D. Pezzack, J. Tremblay
14. Wild Mussel Resource Assessment and Research
G. Sharp
15. Resource Mapping and Special Projects
G. Black
16. Soft-Shell Clam Fishery Research
S. Robinson
17. Bay of Fundy Scallop Population Dynamics and Assessment
S. Robinson
18. Lobster Stock Assessment (LFAs 35, 36, and 38)
P. Lawton
19. Population Dynamics and Ecology of Bay of Fundy Lobsters
P. Lawton
20. Invertebrate Biology
S. Waddy
21. Resource Potential of Underutilized Invertebrate Species
S. Robinson, P. Lawton

C. ANADROMOUS SPECIES STOCK ASSESSMENTS, SALMON ENHANCEMENT, AND ASSOCIATED RESEARCH

1. Salmon Assessment Research
T. Marshall
2. Non-Salmonid Assessment Research
B. Jessop
3. Salmon Enhancement Research
R. Cutting
4. Enhancement and Fish Passage Engineering
H. Jansen
5. Fish Culture Engineering
H. Jansen
6. Finfish and Invertebrate Introductions and Transfers
R. Cutting
7. Hatchery Operations and Production
G. Robbins
8. Fish Culture Research
G. Farmer
9. Anadromous Species Statistical Data Collection and Analysis
S. O'Neil

D. AQUACULTURE RESEARCH

1. Salmon Genetics Research Program
R.H. Cook
2. Salmonid Growth, Smolting, and
R.L. Saunders
3. Phytotoxin Research
D. Wildish
4. Marine Finfish Aquaculture
K. Waiwood
5. Aquaculture Ecology Research
D. Wildish
6. Environmental Requirements for Early Fish Development
R. Peterson
7. Invertebrate Fisheries Research and Aquaculture
D. Aiken
8. Invertebrate Nutrition
J. Castell
9. Fish Nutrition
S. La11
10. Fish Disease Research
G. Olivier
11. Parasitology
C. Morrison
12. Molluscan Culture and Phytotoxin Research
D. Scarratt
13. Fish Health Services Unit
J. Cornick

E. BIOLOGICAL OCEANOGRAPHY

1. Bio-Optical Properties of Pelagic Oceans
T. Platt
2. Respiration, Nutrient Uptake, and Regeneration of Natural Plankton Populations
W. Harrison
3. Physical Oceanography of Selected Features in Connection with Marine Ecological Studies
E. Horne
4. Physiology of Marine Microorganisms
W. Li
5. Carbon Dioxide and Climate: Biogeochemical Cycles in the Ocean
T. Platt
6. Analysis of Pelagic Ecosystem Structure
A. Longhurst
7. Carbon and Nitrogen Utilization by Zooplankton and Factors Controlling Secondary Production
R. Conover
8. Secondary Production and the Dynamic Distribution of Micronekton on the Scotian Shelf
D. Sameoto
9. Biological Stratification in the Ocean and Global Carbon Flux
A. Longhurst
10. Nutrition and Biochemistry in Marine Zooplankton
E. Head
11. Feeding Dynamics of Zooplankton and Micronekton of the Eastern Arctic
D. Sameoto

12. Year Round Plankton Research in the Arctic
R. Conover
13. Shore-Based Studies of Under-Ice Epontic and Pelagic Plankton Communities
R. Conover
14. Summertime Shipboard Studies in the Eastern Canadian Arctic
E. Head
15. Dynamics of Microbial Metabolism and Particle Flux
P. Kepkay
16. Mathematical Models of Marine Pelagic Communities
G. White

F. HABITAT RESEARCH

1. Fish Habitat Assessment Advice
D.C. Gordon
2. Microbial Ecology
J.E. Stewart
3. Microbial-Marine Toxin Interactions
J.E. Stewart
4. Physiological Ecology of Toxic Algae
S.R.V. Durvasula
5. Kelp and Seagrass Habitat Studies
K.H. Mann
6. Inshore Clam Stock Assessment and Related Research
T.W. Rowe11
7. Inshore Molluscan Habitat Studies
T.W. Rowe11
8. Scallop Habitat Research
P. Cranford
9. Zooplankton Habitat Studies
G.C. Harding
10. Benthic Habitat Studies
D.L. Peer
11. Coastal Phytoplankton Dynamics and Phytoplankton Monitoring Program - Nova Scotia
P.D. Keizer
12. Evaluation of Ships' Ballast Waters as a Potential Source of Algal Blooms in Eastern Canada
S.R.V. Durvasula
13. Effect of Fishing Activity on Fish Habitat
W.P. Vass
14. Benthic/Pelagic Exchanges
P.D. Keizer
15. Fish and Habitat Interactions
S.N. Messieh
16. Bioenergetics of Marine Mammals
P.F. Brodie
17. Size-Dependent and Bioenergetic Processes in Fish Production Habitats
S.R. Kerr
18. Interactions between Physical and Biological Processes in Marine Habitats
K.H. Mann
19. Evaluation of Estuarine and Continental Shelf Habitats
W.L. Silvert
20. Contaminant Fluxes in Marine Food Webs
B.T. Hargrave
21. Long-Range Transport of Airborne Pollutants (LRTAP) Organic Studies
B.T. Hargrave
22. Instrumentation Support
D.P. Reimer
23. Acid Rain Research (Nova Scotia)
W. Watt
24. Freshwater Fish Habitat Assessment and Related Research
W. Watt
25. Effects of Low pH on Salmonid Development
R. Peterson
26. Impacts of Acid Rain on Salmonid Ecology
G.L. Lacroix

PHYSICAL AND CHEMICAL SCIENCES BRANCH

A. OCEAN CLIMATE SERVICES

1. Humidity Exchange over the Sea (HEXOS) Program
S.D. Smith, R. Anderson
2. Microstructure Studies in the Ocean
N.S. Oakey
3. Near-Surface Velocity Measurements
N.S. Oakey
4. Investigations of Air-Sea Fluxes of Heat and Momentum on Large Space and Time Scales using Newly Calibrated Bulk Formulae
F.W. Dobson, S.D. Smith
5. The Spin-Down and Mixing of Mediterranean Salt Lenses
N.S. Oakey
6. Laboratory Measurements of Velocity Microstructure in a Convective System using Photographic Techniques
J.M. Hamilton
7. Labrador Sea Water Formation
R.A. Clarke, N.S. Oakey
8. Modelling of the Labrador Sea
C. Quon
9. Labrador Current Variability
R.A. Clarke
10. Moored Measurements of Gulf Stream Variability: A Statistical and Mapping Experiment
R.M. Hendry
11. Newfoundland Basin Experiment
R.A. Clarke, R.M. Hendry
12. Problems in Geophysical Fluid Dynamics
C. Quon
13. Norwegian/Greenland Sea Experiment
R.A. Clarke, P. Jones
14. Studies of the North Atlantic Current and the Seaward Flow of Labrador Current Waters
J.R.N. Lazier
15. North Atlantic Upper Ocean Climatology
F.W. Dobson
16. Thermodynamics of Ocean Structure and Circulation
E.B. Bennett
17. Shelf Dynamics - Avalon Channel Experiment
B.D. Petrie, C. Anderson
18. Batfish Internal Waves
A.S. Bennett
19. Data Management
D.N. Gregory
20. Eastern Arctic Physical Oceanography
C.K. Ross
21. Water Transport through and in the Northwest Passage
S.J. Prinsenberg, E.B. Bennett
22. Seasonal and Interannual Variability in the Gulf of St. Lawrence
G.L. Bugden
23. Tidal and Residual Currents - 3-D Modelling Studies
K. Tee
24. Circulation and Air/Sea Fluxes of Hudson Bay and James Bay
S.J. Prinsenberg
25. Developing an Efficient Method for Modelling Three-Dimensional Shelf and Slope Circulations
K. Tee
26. CTDs and Associated Sensors
A.S. Bennett
27. Handling and Operational Techniques for Instrument/Cable Systems
J.-G. Dessureault, R.F. Reiniger

28. Climate Variability Recorded in Marine Sediments
J. Smith
29. The Carbonate System and Nutrients in Arctic Regions
E.P. Jones
30. Distribution of Sea Ice Meltwater in the Arctic
F.C. Tan, P. Strain
31. Intergyre Exchange: Flow Across 50°W South of the Grand Banks
R.M. Hendry
32. CO, Exchange at the Air-Sea Interface
S.D. Smith, B. Anderson, F.W. Dobson, P. Jones
33. CTD System for Ship-of-Opportunity Programs
J.-G. Dessureault, R.A. Clarke, B. Beanlands, S. Young
34. Turbulent Mixing Studies during the North Atlantic Trace Release Experiment (NATRE)
N.S. Oakey
35. Oxygen Isotopes and Mixing on the Scotian Shelf
P. Strain, F. Tan, P. Smith
36. WOCE Studies
R.A. Clarke, R. Hendry, J.R.N. Lazier

B. MARINE DEVELOPMENTS AND TRANSPORTATION

1. Oil Trajectory Analysis
D.J. Lawrence
2. Winter Processes in the Gulf of St. Lawrence
G.L. Bugden
3. Point Lepreau Environmental Monitoring Program
J. Smith
4. Marine Emergencies
E.M. Levy
5. A Novel Vibracorer for Surface, Subsurface Remote, or ROV Support Operation
G.A. Fowler

C. OFFSHORE ENERGY RESOURCES

1. Studies of the Growth of Wind Waves in the Open Seas
F.W. Dobson
2. Labrador Coast Ice
S.J. Prinsenberg, I. Peterson
3. Gulf of St. Lawrence Ice Studies
G.L. Bugden
4. Wind Sea Dynamics
W. Perrie, B. Toulany
5. Current Measurements near the Ocean Surface
P.C. Smith, D.J. Lawrence, J.A. Elliott, D.L. McKeown
6. Modelling of Ice and Icebergs Flowing along the Labrador and Baffin Island Coasts
M. Ikeda
7. A Large-Scale Circulation in the Labrador Sea and Baffin Bay
M. Ikeda
8. Labrador Ice Studies - Field Program
I. Peterson, S.J. Prinsenberg
9. Dynamical Origins of Low-Frequency Motions over the Labrador/Newfoundland Shelf
D. Wright, J.R.N. Lazier, B.D. Petrie
10. Labrador Ice Margin Studies
C.L. Tang, M. Ikeda
11. Oceanography of the Newfoundland Continental Shelf
B.D. Petrie, D.A. Greenberg
12. Study of Current Variability and Mixed Layer Dynamics on the Northeastern Grand Banks
C.L. Tang, B.D. Petrie
13. Anemometers for Drifting Buoys
J.-G. Dessureault, D. Harvey
14. Ship-Referenced Acoustic Positioning Systems
D.L. McKeown
15. Development of a Lagrangian Surface Drifter
D.L. McKeown, G.A. Fowler
16. Bottom-Mounted Acoustic Current Profiler
D. Belliveau, N.A. Cochrane
17. Petroleum Hydrocarbon Components
E.M. Levy
18. Enhanced Biodegradation of Petroleum in the Marine Environment
E. Levy, K. Lee
19. Petroleum Hydrocarbon Stress to Juvenile Fish
J.H. Vandermeulen
20. Contaminant Cycling in Estuarine Waters
J.H. Vandermeulen
21. Measurement of Ocean Waves During CASP
F.W. Dobson
22. A Trawl-Proof Bottom Mount for Oceanographic Instruments
J.-G. Dessureault
23. Horizontal and Vertical Exchange on Georges Bank
J.W. Loder, K. Drinkwater, E. Horne, N.S. Oakey
24. Oceanic CO,
E.P. Jones
25. Tainting of Scallops by Oil-Based Drilling Mud Cuttings
R.F. Addison
26. Oil Volatilities
E. Levy
27. Wave-Wind Field Interactions
F.W. Dobson, S.D. Smith, W. Perrie
28. Oceanographic Data Management System
D.N. Gregory, G. Boudreau
29. Wave and Ice Dynamics
W. Perrie, B. Toulany
30. Ocean Currents over Atlantic Canada Waters Using Satellite Altimeters and Models
M. Ikeda
31. Pollution from the Offshore Oil Industry: Putting It Into Perspective
E.M. Levy
32. Development of an Ice-Resistant Mooring Assembly (IRMA)
G.A. Fowler, D. Belliveau, J.M. Hamilton
33. Development of Continuous Ocean Data Acquisition Systems (CODA)
D. Belliveau, J.M. Hamilton, G.A. Fowler
34. Development of a Platform for Atmospheric Data in Real Time (PADIRT)
J.M. Hamilton, G.A. Fowler, D. Belliveau
35. Sea-Ice Flux onto Newfoundland Shelves
S.J. Prinsenberg
36. CASP II Oceanography
P.C. Smith, M. Ikeda
37. Modelling Wind-Generated Waves
W. Perrie, B. Toulany
38. Development of Low Cost Ice Beacon/Instrumentation
G.A. Fowler, S.J. Prinsenberg, J.M. Hamilton
39. 3-D Circulation Model
J.W. Loder, D. Greenberg
40. Data Assimilation and Oceanographic Applications
W. Perrie
41. Sea-Ice Thickness
S.J. Prinsenberg

D. LIVING RESOURCES

1. Circulation off Southwest Nova Scotia: The Cape Sable Experiment
P.C. Smith, K. Tee, R.W. Trites
2. The Shelf Break Experiment: A Study of Low-Frequency Dynamics and Mixing at the Edge of the Scotian Shelf
P.C. Smith, B.D. Petrie
3. Long-Term Monitoring of the Labrador Current at Hamilton Bank
J.R.N. Lazier
4. Long-Term Temperature Monitoring
D.N. Gregory, B.D. Petrie, E. Verge
5. Development of a Remote-Sensing Facility
C.S. Mason, B. Topliss, L. Payzant
6. Horizontal and Vertical Exchange on the Southeast Shoal of the Grand Bank
J.W. Loder, C.K. Ross
7. Towed Biological Sensors
A. Herman
8. Optical Properties of Canadian Waters
B. Topliss
9. Biological Arctic Instrumentation
A. Herman, D. Knox
10. Automatic Winch Control for Towed Plankton Samplers
M. Mitchell, J.-G. Dessureault, A. Herman, S. Young, D. Harvey
11. Multi-Frequency Acoustic Scanning of the Water Column
N.A. Cochrane
12. Fish Aging from Pb^{210}/Ra^{226} Measurements in Otoliths
J.N. Smith
13. Growth Rates of the Sea Scallop *[Placopecten Magellanicus]* Using the Oxygen Isotope Record
F.C. Tan, D. Roddick
14. Effects of Hudson Bay Outflow on the Labrador Shelf
K. Drinkwater
15. Larval Transport and Diffusion Studies
R.W. Trites, T.W. Rowell, E.G. Dawe
16. Climatic Variability in the NAFO Area
R.W. Trites, K. Drinkwater
17. Environmental Variability - Correlations, Patterns, and Response Scales
K. Drinkwater. R.W. Trites
18. Baffin Island Fjords
R.W. Trites
19. Variability and Origin of the Cold Intermediate Layer on the Labrador and Newfoundland Shelves
S.A. Akenhead, J.R.N. Lazier, J.W. Loder, B.D. Petrie
20. Mapping Particle Distributions with a ROV
D.L. McKeown, D. Sameoto, N.S. Oakey, G. Steeves
21. Ocean Feature Identification via Multi-Spectral In-Situ and Remote-Sensing Techniques
B. Topliss
22. TLC (Temperature, Light, Current) Recorder
J.-G. Dessureault, B. Beanlands
23. Exchange between Offshore Waters and the Estuaries, Inlets, and Coastal Embayments of the Scotia-Fundy Region
G.L. Bugden
24. Physical Oceanography in Conjunction with the Phytoplankton Profiling Program
G.L. Bugden
25. Classification of Estuaries, Inlets, and Coastal Embayments
R.W. Trites, B.D. Petrie
26. Quoddy Region Oceanography
R.W. Trites
27. Halifax Harbour Studies
D.J. Lawrence, B.D. Petrie
28. Acoustic Doppler Current Profiler Sidelobe Deflectors
D. Belliveau
29. Advanced Technology Multi-frequency Sonar
N.A. Cochrane
30. Development of Finite Element Models for Coastal and Shelf Circulation
D. Greenberg
31. Laser Particle Counter
A. Herman, E.F. Phillips, D. Knox, M. Mitchell, S. Young
32. Optical Microzooplankton Detector
A. Herman, E.F. Phillips, D. Knox, M. Mitchell, S. Young
33. Diagnosis of Current Measurement Problems with Aanderaa Paddle-Wheel Current Meters in High Flows
J.M. Hamilton, G.A. Fowler
34. Three-Dimensional Lagrangian Drift Studies off Southwest Nova Scotia
K. Tee, P.C. Smith
35. The Temporal and Spatial Scales of Current Variability on Western Bank
K. Drinkwater, J.W. Loder
36. Climate Variability in the Water Mass Characteristics of the Shelf Waters in the Scotia-Fundy Region
K. Drinkwater, J.W. Loder, B.D. Petrie, P.C. Smith
37. Fiber Optic Fluorometer
M. Mitchell, A. Herman, S. Young
38. Benthic Survey System - The Platform
D.L. McKeown

E. BIOGEOCHEMISTRY

1. Estuarine and Coastal Trace Metal Geochemistry
P. Yeats, D.H. Loring
2. Sediment Geochronology and Geochemistry in the Saguenay Fjord
J. Smith
3. Trace Metal Geochemistry in Estuarine Mixing Zones
P. Yeats, J. Dalziel
4. Trace Metal Geochemistry in the North Atlantic
P. Yeats, J. Dalziel
5. Radionuclide Measurements in the Arctic
J. Smith
6. Carbon Isotope Studies on Particulate and Dissolved Organic Carbon in Deep Sea and Coastal Environments
F.C. Tan, P. Strain
7. Joint Canadian/German Caisson Experiments
D.H. Loring, F. Prosi
8. Development of Methods for Studies of the Atmospheric Input of Organochlorines to the Northwest Atlantic and Arctic
R.F. Addison, G.C. Harding, B.T. Hargrave
9. Trace Metal Transport into the Western North Atlantic
P. Yeats
10 Low Molecular Weight Hydrocarbons: Potential Contributions to the Carbon and Energy Requirements of Offshore Scallops and Prey of Juvenile Galoids on Georges Bank
E.M. Levy, F.C. Tan, K. Lee
11 The Contribution of Natural Seepage to Benthic Productivity on the Continental Shelf off Baffin Island
E.M. Levy, F.C. Tan, K. Lee

12. Defining Depositional Conditions from the Grain-Size Spectra of Bottom Sediments
K. Kranck

13. The Role of Flocculation in the Flux of Particulate Matter in the Marine Environment
K. Kranck

14. Chemical Reactivity in the Surface Ocean
P. Strain

15. Composition and Reactions of Marine Colloidal Matter
S. Niven

F. TOXICOLOGY, CONTAMINANTS, AND HABITAT

1. Marine Analytical Chemistry Standards Program
J.M. Bewers, J. Uthe, P. Yeats, D.H. Loring

2. International Activities
J.M. Bewers, P.A. Yeats, D.H. Loring, J. Uthe, R. Mist-a, R.F. Addison

3. Heavy-Metal Contamination of Sediments and Suspended Matter on the Greenland Shelf
D.H. Loring, G. Asmund

4. Risk Assessment of Toxic Chemicals
J. Uthe, R. Misra, C.L. Chou, N. Prouse

5. Habitat Assessment and Related Research - Acid Rain
J. Uthe, P. Yeats, G.B. Sangalang

6. Risk Assessment of Organic Chemicals to Fisheries
V. Zitko

7. Biochemical Indicators of Health of Aquatic Animals
K. Haya, B.A. Waiwood, L.E. But-ridge

8. MFO Enzyme Induction by PCBs and PCB Replacements
R.F. Addison

9. Organochlorines in Seals
R.F. Addison

10. Sub-Lethal Contaminants: Long-Term Fate and Effects of Petroleum Hydrocarbon Pollution in Aquatic Systems
J.H. Vandermeulen

11. Aquatic Toxicology of Marine Phytotoxins
K. Haya, L. But-ridge, B.A. Waiwood

12. Investigations into Amino Acid Shellfish Toxins
R. Pocklington

13. Molluscan Toxins, Techniques, and Improvements
V. Zitko

HYDROGRAPHY BRANCH

A. HYDROGRAPHY

1. Coastal and Harbour Surveys (Atlantic Provinces):

Port de Grave, Nfld.
Twillingate to Fogo Island, Nfld.
Black Island to Twillingate, Nfld.
Botwood, Nfld.
Island Run Harbour, Nfld.
Approaches to Twillingate, Nfld.
J. Goodyear

Bonavista Bay, Nfld.
G. Rockwell, D. Blaney

Liscomb, N.S.
Halifax Harbour, N.S.
W. Burke

Petty Harbour, Nfld.
Southern Harbour, Nfld.
Cape Farewell, Nfld.
Change Island Tickle, Nfld.
South Twillingate Island to Black Island, Nfld.
St. Margarets Bay, N.S.
J. Goodyear

2. Coastal and Harbour Surveys (Labrador):

Smokey, Punch Bowl, Fox Harbour
J. Goodyear

3. Offshore Multi-Disciplinary Surveys: Scotian Shelf, N.S.
G. Rockwell

4. Sweep Surveys - Ports and Harbours on the Atlantic Coast:

Sydney Harbour, N.S.
Cheticamp, N.S.
Comer Brook, Nfld.
Port aux Choix, Nfld.
Port Saunders, Nfld.
Meteghan, N.S.
St. John's, Nfld.
Saint John, N.B.
Conception Bay, Nfld.
Stephenville, Nfld.
Halifax Harbour, N.S.
J. Ferguson

Point Tupper, N.S.
Neils Harbour, N.S.
Cow Head, Nfld.
Port aux Basques, Nfld.
Sydney Harbour, N.S.
B. MacGowan

5. Revisory Surveys:

Fredericton, N.E.
Belle Isle Bay, N.B.
Saint John River, N.B.
Lunenburg, N.S.
Caribou, N.S.
Graham's Pond, P.E.I.
Cardigan, P.E.I.
R. Hasse

B. TIDES, CURRENTS, AND WATER LEVELS

1. Ongoing support to CHS Field Surveys and Chart Production
C.T. O'Reilly, C.P. McGinn, G. Lutwick, F. Carmichael, R. Palmer

2. Operation of the Permanent Water-Level Network
C.T. O'Reilly, C.P. McGinn, G. Lutwick, F. Carmichael, R. Palmer

3. Review and Update of Tide Tables and Sailing Directions
C.T. O'Reilly, R. Palmer

4. Scientific and Engineering Project support
C.T. O'Reilly, C.P. McGinn, G. Lutwick, F. Carmichael, R. Palmer

C. NAUTICAL PUBLICATION PRODUCTION

1. Chart Production

16 New Charts
6 New Editions
10 Chart Correction Patches
125 Notices to Mariners
S. Weston, F. Miller, A. Huntzis, E. Lischenski

2. Publication of Sailing Directions, Nova Scotia (Atlantic Coast) and Bay of Fundy
S. Weston, R. Pietrzak

D. DATA MANAGEMENT AND PLANNING

1. Long-range Hydrographic Survey and Chart Production Plans
S. Grant, G. Henderson, G. Rockwell

2. Hydrographic Data Centre: Update and Maintenance of the Source Directory Files Management System
K. MacDonald, S. Nickerson, J. Lockhart

Interaction with the Validation Unit
K. MacDonald, S. Nickerson, J. Lockhart

Development of a National Files Management System
K. MacDonald

Renumbering Project (International SDS compatible numbers)
C. Day-Power, J. Lockhart, J. Griffin

3. Validation of New Charts and Editions

New Charts:

4209 Shelburne and Lockport Harbours
7482 Winter Island to Cape Germain
4170 Glace Bay
7489 Longstaff Bluff to Navy Channel
4116 Black's Harbour to Saint John
7481 Foxe Channel
D. Fleming, B. McCorriston, M. Jay, D. Nicholson

New Editions:

4391 Conquerall Bank to Bridgewater
4395 Riverport to Conquerall Bank
4145 Mactaquac Dam to Newburg Junction
4141 St. John to Evandale
W. Burke, F. Burgess, P. Parks, D. Nicholson

Validation of Sailing Directions Diagrams, Chart Patches, Notices to Mariners;
D. McCarthy, F. Burgess, B. McCorriston, J. Ferguson, W. Burke, P. Parks, K. MacDonald, D. Nicholson

4. Navigation:

BIONAV Maintenance and User support
H. Boudreau

Loran-C Chart Latticing
N. Stuifbergen

Navigation - User Support and Training
H. Boudreau, N. Stuifbergen

5. Data Base Management Systems:

Development and Testing of Hydrographic Hyperspatial Code (HH Code) Concept
H. Varma, H. Boudreau

Transfer of HH Code to ORACLE Canada Ltd.
P. Bellemare, S. Grant

E. HYDROGRAPHIC DEVELOPMENT

1. Research Coordination and Development
R.G. Burke

2. COMS (Coastal Ocean Mapping System) Program
R.G. Burke, G. Costello

3. Large Data Set Processing
S. Forbes, G. Costello

4. Implementation of a CHS LAN (Local Area Network)
S. Forbes

5. Enhancing Computer-Assisted Chart Production Techniques
S. Forbes, K. White

6. Informatics Support and Coordination
R.G. Burke, S. Forbes

DEPARTMENT OF ENERGY, MINES AND RESOURCES

ATLANTIC GEOSCIENCE CENTRE

A. COASTAL GEOLOGY PROGRAM

1. Beaufort Sea Coastal Zone Geotechnics
S. Solomon

2. Geological Mapping of the Coastal Zone
R. Taylor

3. Sediment Dynamics and Depositional Processes in the Coastal Zone
D. Forbes

4. Relative Sea-level Changes and Coastal Response
J. Shaw

5. Nearshore Sediments and Non-Fuel Minerals - Nova Scotia MDA 2
G. Fader

6. Inner Shelf Sediments and Minerals off Newfoundland
D. Forbes

B. GEOLOGY OF COASTAL INLETS

1. Littoral Investigation of Sediment Properties (LISP) in the Bay of Fundy
C. Amos

2. SEDFLUX: On Transfer of Sediments from Landmass to Continental Shelf
J. Syvitski

3. Temperature Response of Nearshore Benthonic Foraminifera Experiment
C. Schafer

C. GEOLOGY OF THE SOUTHEASTERN CANADIAN MARGIN

1. Surficial and Shallow Bedrock Geology of Grand Banks and Scotian Shelf
G. Fader

2. Computer-based Map Series - Offshore Eastern Canada
G. Fader

3. Engineering Geology of the Atlantic Shelf
R. Parrott

4. Quaternary Geological Processes on the Continental Margin
D. Piper

5. Ice Scouring of Continental Shelves
M. Lewis

6. Physical Property Studies of Canadian Eastern and Arctic Continental Shelves and Slopes
K. Moran

7. Quaternary Geological Processes on Continental Slopes
D. Piper

8. Stability and Transport of Sediments on Continental Shelves
C. Amos

D. EASTERN ARCTIC AND SUB-ARCTIC GEOLOGY

1. Eastern Baffin Island Shelf and Hudson Strait: Bedrock and Surficial Geological Mapping Program
B. MacLean

2. Ice Island Sampling and Investigation of Sediments
P. Mudie

3. Quantitative Quaternary Paleoecology, Eastern Canada
P. Mudie

4. Quaternary Biostratigraphic Methods for Marine Sediments
G. Vilks

5. Surficial Geology, Geomorphology and Glaciology of the Gulf of St. Lawrence, Labrador Shelf and Hudson Bay
H. Josenhans

6. Temporal and Spatial Variations of Deep Ocean Currents in the Western Labrador Sea
C. Schafer

7 20th Century Pollution Chronologies: Lower St. Lawrence Estuary
C. Schafer

E. WESTERN ARCTIC GEOLOGY

1. Surficial Geology and Geomorphology, Beaufort Sea Continental Shelf
   S. Blasco

F. GEOCHEMISTRY

1. Diagenesis and Geochemical Cycling
   R. Cranston
2. Early Diagenesis in Quaternary Marine Sediments of Eastern and Arctic Canada
   D. Buckley
3. Environmental Marine Geology of Halifax Inlet and Approaches, Nova Scotia
   D. Buckley

G. REGIONAL GEOPHYSICAL SURVEYS

1. Interpretation of Potential Field Data
   J. Verhoef
2. Magnetic and Gravity Anomalies over Sedimentary Basins
   B. Loncarevic
3. Magnetic Data Compilations
   R. Macnab
4. Regional Geophysics of Mesozoic-Cenozoic of Newfoundland Margin
   K. Coflin

H. HYDROCARBON RESOURCE APPRAISAL

1. Hydrocarbon Inventory of Sedimentary Basins of Eastern Canada
   D. McAlpine
2. Maturation Studies
   D. McAlpine
3. Overpressure Studies of the Offshore Sedimentary Basins of Eastern Canada
   D. McAlpine

I. BIOSTRATIGRAPHY

1. Biostratigraphic Zonation of the Mesozoic and Cenozoic Rocks of the Atlantic Shelf
   P. Ascoli
2. DSDP Late Cretaceous-Cenozoic Dinoflagellates
   G. Williams
3. Quantitative Stratigraphy in Paleoceanography and Petroleum Basin Analysis
   F. Gradstein

J. GEOLOGICAL DATABASES

1. Sample and Data Curation
   I. Hardy
2. Palynological Data Base
   G. Williams
3. Information Data Base - Offshore East Coast Wells
   G. Williams

K. GEOLOGICAL TECHNOLOGY DEVELOPMENT

1. Large Diameter Piston Corer Development
   W. McKinnon
2. Development and Implementation of Remotely Operated Vehicle Technology
   K. Manchester
3. Systems Development
   D. Hefler

L. SPECIAL GEOLOGICAL PROJECTS

1. Basin Atlases - Offshore Eastern Canada
   D. Ross
2. Bedrock Geology of Hudson Bay and Gulf of St. Lawrence
   A. Grant
3. Ocean Drilling Program (Planning)
   D. Ross
4. Provision of Scientific Advice to Developing Countries
   D. Ross

M. INVESTIGATION OF DEEP GEOLOGICAL STRUCTURES

1. Arctic Ocean: Seismic Refraction and Related Geophysical Measurements
   R. Jackson
2. Evolution of Deep Ocean and Adjoining Sedimentary Basins off Eastern Canada and Western Greenland
   S. Srivastava
3. Crustal Properties
   M. Salisbury
4. Geophysical Study of the Gulf of St. Lawrence Region
   F. Marillier
5. Marine Deep Seismic Reflection Studies - Eastern Canada
   C. Keen
6. Seismic Refraction - Labrador Sea and Baffin Bay
   R. Jackson
7. Seismic Studies of Continental Margins and Ocean Basins - North Atlantic
   I. Reid
8. Dynamic Modelling of Canadian Cratonic Basins -Western Canada and Hudson Basins
   R. Courtney
9. Ocean Drilling Program in the Labrador Sea and Baffin Bay
   S. Srivastava

N. THEORETICAL GEOPHYSICAL MODELLING

1. Rift Processes and the Development of Passive Continental Margins
   C. Keen

O. BASIN ANALYSIS AND PETROLEUM GEOLOGY

1. Compilation of Geoscientific Data in Upper Paleozoic Basins of Southwestern Canada
   R. Howie
2. Lithologic Evolution and Fluid Migration in Offshore Basins of Eastern Canada
   A. Fricker
3. Palynostratigraphic Atlases
   R. Fensome
4. Regional Geology of the Mesozoic and Cenozoic Rocks of the Atlantic Continental Margins
   J. Wade
5. Stratigraphy and Sedimentology of the Mesozoic and Tertiary Rocks of Atlantic Continental Margin
   L. Jansa
6. Sedimentary Basin Evolution of the Continental Margin of Newfoundland, Labrador and Baffin Bay
   D. McAlpine
7. Hydrocarbon Charge Modelling Offshore Eastern Canada
   M. Williamson

ENVIRONMENTCANADA

ATLANTIC REGION

MARINE WILDLIFE CONSERVATION DIVISION (CANADIAN WILDLIFE SERVICE)

A. DISTRIBUTION AND ECOLOGY OF SEABIRDS IN ATLANTIC CANADA AND THE EASTERN CANADIAN ARCTIC

1. Distribution and Population Trends of Coastal Seabirds in Atlantic Canada (Gulls, Terns and Cormorants)
A.R. Lock
2. Studies of Tern Reproduction and Survival, and Management for Population Enhancement
A.R. Lock
3. Habitat Use and Winter Populations of Birds Using Wetlands on the Pacific Coast of Mexico
A.R. Lock
4. Marine Pollution Impacts on Seabirds
A.R. Lock
5. Seabird Colony Registry - Computerized Database Management System for Colonially Breeding Seabirds in Eastern Canada
D.N. Nettleship, G.N. Glenn
6. Seabird Gazetteers of Northeastern North America: I. Seabird Colonies in Labrador
D.N. Nettleship, G.N. Glenn
7. Distribution and Abundance of Breeding Seabirds in Northeastern North America
D.N. Nettleship
8. Development of Management Methods for Populations of Threatened Seabirds
D.N. Nettleship
9. Seabirds as Monitors of Changing Marine Environments
D.N. Nettleship
10. Seabirds and Commercial Fisheries Interactions
D.N. Nettleship
11. Thick-Billed Murres *Uria lomvia* in Arctic Canada & Greenland: Status, Recent Changes, and Management
D.N. Nettleship
12. Modelling the Effects of Hunting on Thick-Billed Murres *Uria lomvia* Breeding in Eastern Canada and West Greenland
D.N. Nettleship, J.W. Chardine
13. Reintroduction of the Atlantic Puffin *Fratercula arctica* to Former Breeding Sites in Maine
D.N. Nettleship, S. Kress
14. Monitoring Alcid Populations at Machias Seal Island, N.B.
D.N. Nettleship
15. Education and Seabird Conservation: A Conceptual Framework for Action
D.N. Nettleship, K.A. Blanchard
16. A Gazetteer of the Principal Sites for Breeding and Non-Breeding Seabirds in Atlantic Canada
R.G.B. Brown
17. Investigations of Recent Changes in the Fall Migration Patterns of Red and Red-necked Phalaropes *Phalaropus fulicarius* and *P. lobatus* through the Bay of Fundy
R.G.B. Brown
18. Reduction of Losses of Cultured Mussels to Sea Ducks
E.H.J. Hiscock

B. LIMNOLOGICAL STUDIES OF WATERBIRD HABITATS

1. Kejimkujik LRTAP Studies (Integrated Monitoring) Coordination
J. Kerekes
2. Monitoring of Piscivorous Birds in the Kejimkujik Watersheds
J. Kerekes
3. Development of a Volunteer Loon Population Survey in the Atlantic Provinces
J. Kerekes
4. Effects of Fertilization on Acidic Wetlands
J. Kerekes, M. Brylinsky
5. Habitat Use of Winter Populations of Aquatic Birds in Coastal Lagoons in Mexico
J. Kerekes, F. Contreras, R. Acuna

REGIONAL LABORATORY (ENVIRONMENTAL PROTECTION)

1 Sublethal Toxicity of Chlorothalonil and its Major Metabolite
K.G. Doe, J.D.A. Vaughan
2. Influence of pH, Temperature and Dissolved Oxygen on Toxicity of Trichlopyr
J.D.A. Vaughan
3. Toxicity Test Methods Development
K.G. Doe, S.J. Wade
4. Mussel Watch, Chemical Analysis
P.A. Hennigar
5. Improved Oil Match Analysis Methodology Using GC/MS Biomarkers
P.A. Hennigar
6. Analysis of Thiophanate-Methyl in Environmental Samples
P.A. Hennigar
7. Analysis of Lead in Sediments, Water, and Tissues of Ducks
O.C. Vaidya
8. Industrial Emissions Compliance (Fisheries Act and CEPA). Analyses for Inorganic, Organic, and Toxicity Parameters
O.C. Vaidya, P.A. Hennigar, K.G. Doe
9. PCB Congener Identification in Paint Pigments
P.A. Hennigar

Voyages

This section describes the vessels that the federal Department of Fisheries and Oceans (DFO), Scotia-Fundy Region, operates for the purpose of scientific research and hydrographic surveys. It also lists the voyages that these vessels made during 1990 and '91 and the types of research that were conducted. Cruises on vessels not operated by the department but which involved scientific personnel from DFO's Scotia-Fundy Region and DEMR's Atlantic Geoscience Centre are included as well.

In the following pages, these abbreviations are used:

AGC	Atlantic Geoscience Centre
BSB	Biological Sciences Branch
CHS	Hydrography Branch, Canadian Hydrographic Service
FHM	Fisheries and Habitat Management
INRS	Institut National de la Recherche Scientifique
MALD	Marine Assessment and Liaison Divison
MSD	Marine Services Division
NCSP	Northern Cod Science Program
PCS	Physical and Chemical Sciences Branch

C.S.S. *BAFFIN*, a diesel-driven ship, was designed for hydrographic surveying but was also used for general oceanography. The ship was owned by DFO and was operated by the department's Scotia-Fundy Region. The *Baffin* was retired from service in 1991.

Hull . . . . Lloyds Ice Class I
Built 1956
Length . . . . 86.9 m
Breadth . . . . . 15.1 m
Draft . . . . 5.7 m
Freeboard to working deck ..3.3 m
Displacement . . . . 4,987 tonnes
Gross tonnage . . . . 35 1 1 tonnes
Full speed . . . . 15.5 knots
Service speed . . . . 10 knots
Endurance . . . . 76 days
Range at service speed . . . . 18,000 naut. mi.
Complement . . . . 29 hydrographic staff
Twin screws
Bow thruster for holding position
Micro-VAX computer
Heliport and hangar
Drafting, plotting, and laboratory space
Six survey launches
1990 Time at sea: 201 days Distance steamed: 20,705 naut. mi.
1991 Decommissioned.

YEAR & NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	OBJECTIVES OF VOYAGE
	1990			
89-41	Mar. 25 - Apr. 14	C. Tang, PCS	Eastern Newfoundland, ice margin	LIMEX ice-sea interactions
90-04	Apr. 24 - 28	B. Loncarevic, AGC	Grand Banks	Geology
90-04b	Apr. 29 - May 8	B. DeYoung, Memorial University	Conception Bay	COPE physical oceanography
90-06	May 9 - July 6	C. Rockwell, CHS	Bonavista Bay	Hydrographic charting
90-17	July 23 - Oct. 4	E. Thompson, CHS	Hudson Bay	Hydrographic charting
90-24	Oct. 4 - 20	H. Josenhans, AGC	Hudson Bay, Great Whale River	Geophysics: seafloor processes at river mouth, baseline environmental data collection
90-29	Oct. 31 - Dec. 5	G. Rockwell, CHS	Scotian Shelf	Joint AGC/CHS geophysical survey and offshore Hydrographic charting

C.S.S. *DAWSON*, a diesel-driven ship, was designed and used for multi-disciplinary oceanographic research, hydrographic surveying, and handling of moorings in deep and shallow water. The ship was owned by DFO and was operated by the department's Scotia-Fundy Region. The *Dawson* was retired from service in 1991.

Hull . . . . steel
Built 1967
Length . . . . 64.5 m
Breadth . . . . . 12.2 m
Draft . . . . 4.6 m
Freeboard to working deck . . 1.5 m
Displacement . . . . 2,007 tonnes
Gross tonnage . . . . 1,311 tonnes
Full speed . . . . 14 knots
Service speed . . . . 10 knots
Endurance . . . . 45 days
Range at service speed . . . . 11,000 naut. mi.
Complement . . . . 13 scientific staff
Twin screws
Bow thruster for holding position
Computer suite
Heliport and hangar
87 m^2 working space in four laboratories
One survey launch

1990 Time at sea . . . 172 days Distance steamed . . 22,037 naut. mi.
1991 Time at sea . . . 192 days Distance steamed . . 24,296 naut. mi. Decommissioned 15 December 1991.

YEAR & NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	OBJECTIVES OF VOYAGE
	1990			
89-36	Jan. 2 - 7	R. Lively, PCS	Gulf of St. Lawrence	Physical oceanography (CTD profiles) in support of ice-forecast studies
90-02	Apr.5- 12	D. Piper. AGC	SW Scotian Slope	Geophysics; seismics and coring between Shelf edge and Continental Rise
90-03	Apr. 25 - 27	D. Lawrence, PCS	Grand Banks, Scotian Shelf	Physical oceanography; mooring, CTD profiles
90-05	May 3- 15	A. Herman, PCS	Scotian Shelf Basins	Secondary Production in deep basins: zooplankton abundance and distribution
90-08	May 28 - June 8	S. Narayanan, PCS, Newfoundland Region	NE Newfoundland Shelf	Physical Oceanography: current meter moorings, CTD transects. This cruise was effectively cancelled due to mechanical problems.
90-12	June 29 - July 11	J. Lazier, PCS	Labrador Sea	Physical Oceanography: CTD and current meter moorings
90-16	July 12 - 25	S. Narayanan, PCS, Newfoundland Region	NE Newfoundland Shelf	Annual oceanographic survey
90-14a	Pt. Aug. 2; Aug. 7 - 19	N. Oakey, PCS D. McKeown, PCS	Scotian Shelf	Instrument and Remotely Operated Vehicle (ROV) trials
90-21	Aug. 22 - Sept. 10	R. Parrott, AGC	Grand Banks	Geophysics: sidescan sonar mapping of iceberg scour; seismostratigraphy
90-25	Sept. 13 - 21	E. Levy, PCS	Georges Bank, Scotian Shelf	Methane distribution and uptake of particulates by scallops; deployment of oceanographic mooring

C.S.S. *DAWSON* continued...

90-26	Sept. 25 - Oct. 5	D. Sameoto, BSB	Scotian Shelf	Secondary Production in deep basins: zooplankton abundance and distribution
90-14b	Oct. 9 - 16; Oct. 22 - 24	N. Oakey, PCS D. Lawrence, PCS	Scotian Shelf	Instrument trials (**BUD** probe); Physical Oceanography: moorings for various instruments deployed
90-27	Oct. 26 - Nov. 9	S. Narayanan, PCS Newfoundland Region	Trinity Bay, NE Newfoundland Shelf	Physical and biological oceanography
90-30	Nov. 16 - 26	R. Lively, PCS	Gulf of St. Lawrence	Annual "ice-forecast" physical oceanographic observations
90-32	Nov. 27 - Dec. 9	J. Plourde, BSB Quebec Region	St. Lawrence estuary	Chemical oceanography: petroleum pollution
	1991			
90-41	Feb. 18-22	D. Beliveau, PCS	Scotian Shelf, Western Bank	Physical oceanography: moorings and CTD
91-03	Apr. 11 - May 2	K. Drinkwater, PCS	Scotian Shelf, Western Bank	Physical oceanography associated with OPEN program
91-11	May 7 - 21	S. Narayanan, PCS Newfoundland Region	NE Newfoundland Shelf	Deploy, retrieve current meter moorings, CTD survey, cod acoustic tags
91-16	May 24-31	D. Peer, BSB	Grand Banks, Scotian Shelf	Baseline benthic sampling for trawl impact study
91-18	June 4-21	G. Fader, AGC	Nova Scotia nearshore	Geology: mineral and aggregate potential, surficial sampling
91-26	June 24 - July 8	J. Shaw, AGC	Newfoundland Shelf	Nearshore surficial geology
91-29	July 10 - 19	A. Aksu, Memorial University	Orphan Knoll, Cape Freels	Geology: seismics, piston cores and gravity cores
91-30	July 20 - Aug. 7	S. Narayanan, **PCS** Newfoundland Region	NE Newfoundland Shelf, Hamilton Bank	Physical oceanography: **CTD,** current meter moorings
91-35	Aug. 26 - 29	D. Muschenheim, BSB	Georges Bank	Particulate and microbial studies over scallop grounds
91-38	Sept. 3-18	A. Herman, PCS	Scotian Shelf	Zooplankton studies: production, abundance and distribution in deep basins
91-41	Sept. 24 - 27; Sept. 30 - Oct 4	N. Oakey, PCS	Scotian Shelf	Instrumentation: BUD, EPSONDE; moorings
91-46	Oct. 8 - 22	J. Anderson, BSB Newfoundland Region	Conception and Trinity bays, NAFO Div. 3KL	O-group cod and capelin; oceanographic survey
91-42	Oct. 25 - 28	J. Wrobleski, Memorial University	Newfoundland Shelf, Bonavista Bay	Cod inshore-offshore migration with telemetry
91-52	Nov. 1 - 20	S. Narayanan, PCS Newfoundland Region	NE Newfoundland Shelf. Hamilton Bank	Physical Oceanography: current meter moorings, **CTD** transects
91-58	Nov. 23 - Dec. 5	R. Lively, PCS	Gulf of St. Lawrence	Annual "ice forecast" oceanographic survey
91-60	Dec. 9 - 11; Dec. 12	A. Herman, PCS T. Rowell, BSB	Scotian Shelf, Emerald Basin, and Halifax Harbour	Recovery of moored OPC; gear trials for AFAP trawl impact study

M.V. *LADY HAMMOND* is a converted fishing trawler owned by Northlakes Shipping Limited and is chartered by DFO specifically for fisheries research. The ship is operated by the department's Scotia-Fundy Region; its main user is the Biological Sciences Branch which has components at BIO, in Halifax, and in St. Andrews, New Brunswick.

Hull . . . . steel
Built 1972
Length . . . . 57.9 m
Breadth . . . . . 1 1 .0 m
Draft . . . . **4.8** m
Freeboard to working deck . . 2.5 m
Displacement . . . . 930 tonnes
Gross tonnage . . . . 897 tons
Full speed . . . . 15.0 knots
Service speed . . . . 12.5 knots
Endurance . . . . 30 days
Range at service speed . . . . 8,000 naut. mi.
Complement . . . . 9 scientific staff
1990 Time at sea: 177 days
Distance steamed: n/a
1991 Time at sea: 151 days
Distance steamed: n/a

YEAR & NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	OBJECTIVES OF VOYAGE
	1990			
90-H210	May 6- 13	B. Nakashima, BSB Newfoundland Region	Conception Bay	Capelin tagging
90-H211	May 14 - 22	E. Dawe, BSB Newfoundland Region	Conception Bay	Snow crab survey and survey gear tests; recruitment studies
90-H212	May 23 - 31	D. Taylor, BSB Newfoundland Region	NAFO Div. 3K	Snow crab survey; distribution study
90-H213	June 1 - 6	E. Dalley, BSB Newfoundland Region	East Newfoundland, NAFO Div. 3KL, Conception Bay	Capelin tagging
90-H214	June 11 - 25	J. McRuer, BSB	SW Nova Scotia	Abundance of juvenile haddock
90-H215	June 27 - Juy 7	R. Tallman, BSB Gulf Region	Gulf of St. Lawrence	Seasonal survey to determine distribution and movements of cod at various times of year
90-H216	July 26 - Aug. 3	W. Hickey, FHM	Scotian Shelf	Gear trials with shrimp separator trawl; gear/fish behaviour using underwater video and SCANMAR
90-H217	Aug. 6 - 17	J. Martell, BSB	E. Scotian Shelf	Distribution of sealworm in groundfish species, trend monitoring
90-H218	Aug. 20-31	D. Gascon, BSB Quebec Region	Gulf of St. Lawrence, NAFO Div. 4RST	Comparative fishing with *AIfred Needler* during 4RST Redfish/shrimp survey
90-H219	Sept. 3-21	D. Swain, BSB Gulf Region	S. Gulf of St. Lawrence	Annual NAFO Div. 4T groundfish survey

M.V. *LADY HAMMOND* continued...

90-H220	Sept. 24 - Oct. 12	W. Hickey, FHM	Scotian Shelf	Evaluate trawls equipped with separator panels and grates for sorting shrimp and fish; underwater video viewing of lost gill nets.
90-H221	Oct. 15 - 23	G. McClelland, BSB	Scotian Shelf	Distribution of sealworm in groundfish species, trend monitoring
90-222	Oct. 27 - Nov. 15	M. Power, BSB	Georges Bank	Monitor resurgence of Georges Bank herring stock with larval survey and trawling
90-223	Nov. 19 - 30	M. Hansen, BSB	S. Gulf of St. Lawrence	Seasonal groundfish survey
	1991			
91-224	Apr. 1 - 7	D. Taylor, BSB Newfoundland Region	Grand Banks	Snow crab survey
91-225	Apr. 10 - 17, 25	P. Pepin, NCSP Newfoundland Region	Newfoundland Shelf	Northern Cod Science Program: Ichthyoplankton survey
91-226	May 3	J. Anderson, NCSP Newfoundland Region	Newfoundland Shelf	Northern Cod Science Program: Ichthyoplankton survey
91-227	May 12-29	G. Rose, NCSP, Newfoundland Region	Newfoundland Shelf	Feasibility of obtaining acoustic biomass estimates for northern cod
91-228	June 1 - 15	P. Pepin, NCSP Newfoundland Region	Newfoundland Shelf	Northern Cod Science Program: Ichthyoplankton survey
91-229	June 18-29	J. Anderson, NCSP Newfoundland Region	Newfoundland Shelf	Northern Cod Science Program: Ichthyoplankton survey
91-230	July 1 - 8	J. Anderson, NCSP Newfoundland Region	Newfoundland Shelf	Not-them Cod Science Program: Ichthyoplankton survey
91-230a	July 17 - 28	P. Koeller, MALD	Eastern Scotian Shelf	*Alfred Needler* summer groundfish survey conducted on this vessel due to mechanical problems with the regular vessel
91-231	Sept. 1 - 23	D. Swain, BSB Gulf Region	S. Gulf of St. Lawrence	Annual groundfish abundance survey
91-232	Sept. 25 - Oct. 6	B. Nakashima, BSB Newfoundland Region	Newfoundland Shelf, NAFO Div. 2J, 3K, 3L	Capelin tagging
91-233	Oct. 9 - 20	L. Dickie, BSB	Scotian Shelf, Western and Sable Island Banks	Acoustic survey for adult cod and haddock, OPEN program
91-234	Oct. 22 - 25	G. McClelland, BSB	E. Scotian Shelf	Sealworm survey
91-235	Oct. 27 - Nov. 11	G. Melvin, BSB	Georges Bank	Study of Georges Bank herring stock resurgence, including larval survey

C.S.S. *J. L. HART*. IS a stem trawler used for fisheries research, including light trawling operations (bottom and midwater), ichthyoplankton surveys, oceanographic sampling, and scientific gear testing. The ship is owned by DFO and is operated by the department's Scotia-Fundy Region. It is stationed at the St. Andrews Biological Station in St. Andrews, New Brunswick, and conducts most of its work locally, in Passamaquoddy Bay and the Bay of Fundy.

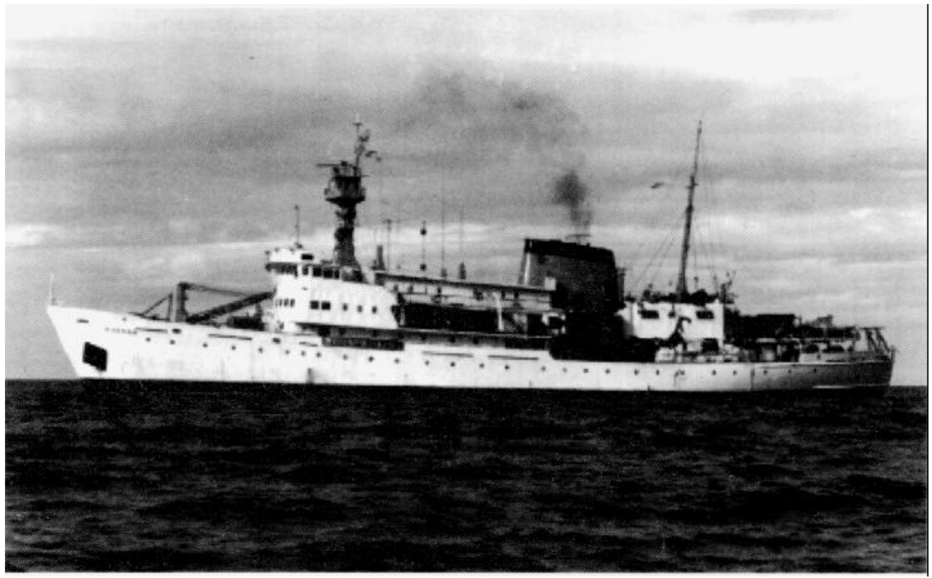
Hull . . . . steel
Built 1974
Length . . . . 19.8 m
Breadth . . . .6.1 m
Draft . . . . 3.65 m
Freeboard to working deck . . 0.5 m
Displacement . . . . 109 tonnes
Gross tonnage . . . . 89.5 tonnes
Full speed . . . . 10 knots
Service speed . . . . 8.5 knots
Endurance . . . . 7.5 days
Range at service speed . . . . 2,000 naut. mi.
Complement . . . . 3 scientific staff
1990 Time at sea . . . 107 days
Distance steamed . . . 6,486 naut. mi.
1991 Time at sea . . . 79 days
Distance steamed . . . 5,129 naut. mi.

YEAR & NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	OBJECTIVES OF VOYAGE
	1990			
90-79	Apr. 17 - 19	G. Fawkes, BSB Newfoundland Region	Passamaquoddy Bay	BRUTIV trials
90-80	Apr. 25 - May 18	K. Howes, BSB	Bay of Fundy	Collection of live fish for aquaculture development
90-81	June 11 - 14	H. Sampson, BSB	Passamaquoddy Bay	Collection of food fish for aquaculture facilities
90-82	June 18-29	M. Lundy, BSB	Bay of Fundy	Scallop assessment survey
90-83	July 3 - 19	S. Robinson, BSB	Upper Bay of Fundy	Scallop assessment survey
90-84	July 23 - 27	J. L. Martin, BSB	Bay of Fundy	Toxic phytoplankton blooms
90-85	July 30 - Aug. 11	G. Chouinard, BSB Gulf Region	Gulf of St. Lawrence	Juvenile cod survey
90-86	Aug. 13 - 25	R. Stephenson, BSB U. Buerkle, BSB	Gulf of Maine, Bay of Fundy	Juvenile herring; herring acoustics, stock structure
90-87	Aug. 27 - 30	J. L. Martin, BSB	Bay of Fundy	Toxic phytoplankton blooms
90-88	Sept. 4 - 14	S. Robinson, BSB	Bay of Fundy	Scallop assessment survey
90-89	cancelled			
90-90	Sept. 24 - 25	J. L. Martin, BSB	Bay of Fundy	Toxic phytoplankton blooms
90-91	Oct. 1 - 5	S. Robinson, BSB	Bay of Fundy	Scallop gear trials
90-92	Oct. 8 - 12	M. Lundy, BSB	Bay of Fundy	Scallop assessment survey

C.S.S. *J. L. HART* continued...

90-93	Oct. 15 - 19	M. Strong, BSB	Passamaquoddy Bay	Gear trials with rockhopper trawl
94, 95, 96 numbers not used				
	1991			
91-97	May 13-Jun7	K. Howes, BSB	Bay of Fundy	Collection of live haddock and halibut for aquaculture
91-98	June 10 - 14	P. Hurley, BSB	SW Nova Scotia	Inshore groundfish abundance surveys
91-99	June 17-28	E. Kenchington, BSB	Bay of Fundy	Scallop assessment survey
91-100	July 2 - 12	K. Frank, BSB	SW Nova Scotia	Inshore juvenile gadoid survey
91-101	July 16-26	S. Robinson, BSB	Passamaquoddy Bay	Scallop assessment **survey**
91-102	July 29 - Aug. 1	J.L. Martin, BSB	Bay of Fundy	Phytotoxin survey
91-103	Aug. 6 - 8	P. Lawton, BSB	Bay of Fundy	Lobster trawling/diving survey
91-104	Aug. 12 - 15	P. Hurley, BSB	St. Mary's Bay	Inshore juvenile gadoid survey
91-105	Aug. 25 - 29	E. Kenchington, BSB	Bay of Fundy	Scallop assessment survey
91-106	Sept. 3 - 10	S. Robinson, BSB	Grand Manan	Scallop assessment survey

C.S.S. *HUDSON* is a diesel-electric-driven ship designed and used for multi-disciplinary marine science research. The ship is owned by DFO and is operated by the department's Scotia-Fundy Region. The Atlantic Geoscience Centre of the Department of Energy, Mines, and Resources is a major user of this vessel.



Hull . . . . Lloyds Ice Class I
Built 1962
Length . . . . 90.4 m
Breadth . . . . . 15.2 m
Draft . . . . 6.3 m
Freeboard to working deck . . 3.2 m
Displacement . . . . 4,847 tonnes
Gross tonnage . . . . 3,721 tonnes
Full speed . . . . 17 knots
Service speed . . . . 13 knots
Endurance . . . . 80 days
Range at service speed . . . . 23,000 naut. mi.
Complement . . . . 31 scientific staff
Twin screws
Bow thruster for holding position
Computer system
Heliport and hangar
205 m^2 of laboratory space
Four survey launches
1990 Time at sea . . . 206 days Distance steamed . . 30,008 naut. mi.
1991 Time at sea . . . 238 days Distance steamed . . 32,424 naut. mi.

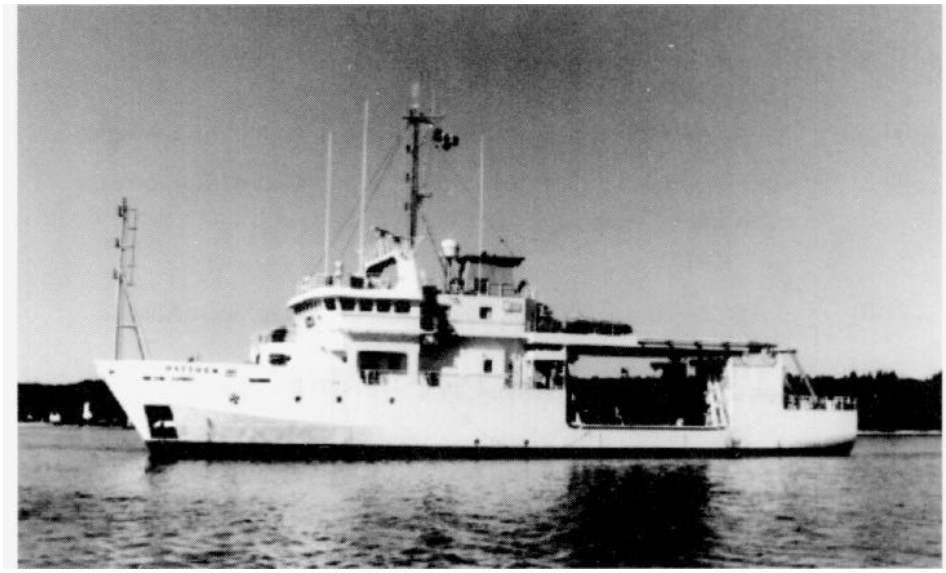
YEAR & NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	OBJECTIVES OF VOYAGE
	1990			
This was the vessel's first field season after her mid-life refit.				
89-37	Jan. 2 - 29	R. Hendry, PCS	Grand Banks, Southern Newfoundland Basin, Labrador Current	Physical oceanography: to determine water transport in the Gulf Stream, Labrador Current, and North Atlantic Current
89-38	Feb. 19 - Mar. 9	K. Moran, AGC	Bermuda Rise and Baltimore Canyon	Sedimentation study: Long coring and seismics
90-39	Mar. 18-30	C. Amos, AGC	Georges Bank	Sediment transport study
90-01	Apr. 5 - 28	T. Platt, BSB	Northwest Atlantic	JGOFS Plankton production and carbon flux studies at two stations
90-07	May 7 - 27	P. Mudie, AGC	Grand Banks, Orphan Knoll, Milne Seamount, N. Newfoundland Basin, Newfoundland Slope	Geophysics: bathymetry, seismics and Long coring for pollution and paleo-oceanographic studies
90-13	May 29 - June 22	C. Hillaire-Marcel, Université du Québec à Montreal	SW Greenland, NE Labrador	Geophysics: seismic reflection, sedimentology, geochemistry, biostratigraphy
90-15	July 10 - 31	D. Piper, AGC	St. Pierre, SE Scotian Slope	Geophysics: instability of continental slopes; sedimentary processes
90-19	Aug. 10 - 29	I. Reid, AGC	Labrador continental margin	Geophysics: Deep crustal structure and heat flow

C.S.S. *HUDSON* continued...

90-22	Aug. 31 - Sep. 18	C. Ross, PCS	Davis Strait, Baffin Bay	Physical oceanography: current meter moorings, CTD survey
90-23	Sept. 18 - Oct. 22	B. MacLean, ABC	Hudson Strait	Geophysics: glacial and climatic history, sediment transfer and accumulation rates
90-28	Oct. 30 - Nov. 17	H. Josenhans, AGC	Gulf of St. Lawrence	Geophysics: Quaternary geology
90-31	Nov. 19 - Dec. 5	G. Vilkes, AGC	Gulf of St. Lawrence	Geophysics: glacial and postglacial sedimentary and oceanographic history
	1991			
91-01	Apr. 3 - 20	T. Platt, BSB	Northwest Atlantic	JGOFS investigation of the development of the spring bloom
91-07	Apr. 24 - June 4	R. Hendry, PCS	North Atlantic	Physical and biological oceanography in support of JGOFS and WOCE objectives
91-20	June 11 - July 4	D. Piper, AGC	Flemish Cap, Scotian Slope	Geophysics: seismics and coring; investigation of gas hydrates; dinoflagellate distribution
91-27	July 6 - 26	F. Marillier, AGC	Strait of Canso, Grand Banks	Geophysics: deep seismics on Appalachian structures
91-39	Aug. 15 - Sept. 20	R. Jackson, AGC	Baffin Bay, Labrador Shelf	Geophysics: seismic refraction survey of continental margins and deep ocean
91-33	Sept. 22 - Oct. 12	R. Syvitski, AGC	Lake Melville	Geophysics: Arctic Delta Failure Experiment (ADFEX)
91-45	Oct. 14 - Nov. 7	A. de Vernal, Université du Quebéc à Montreal	Davis Strait, Labrador Slope, SW Greenland, Labrador Sea	Geophysics: sedimentology along inshore/offshore transects
91-55	Nov. 10 - 25	F. Dobson, PCS	Grand Banks	Calibration/validation of ERS-1 satellite's synthetic aperture radar (SAR)
91-59	Nov. 28 - Dec. 10	P. Smith, PCS	Grand Banks	Physical oceanographic observations for CASP II

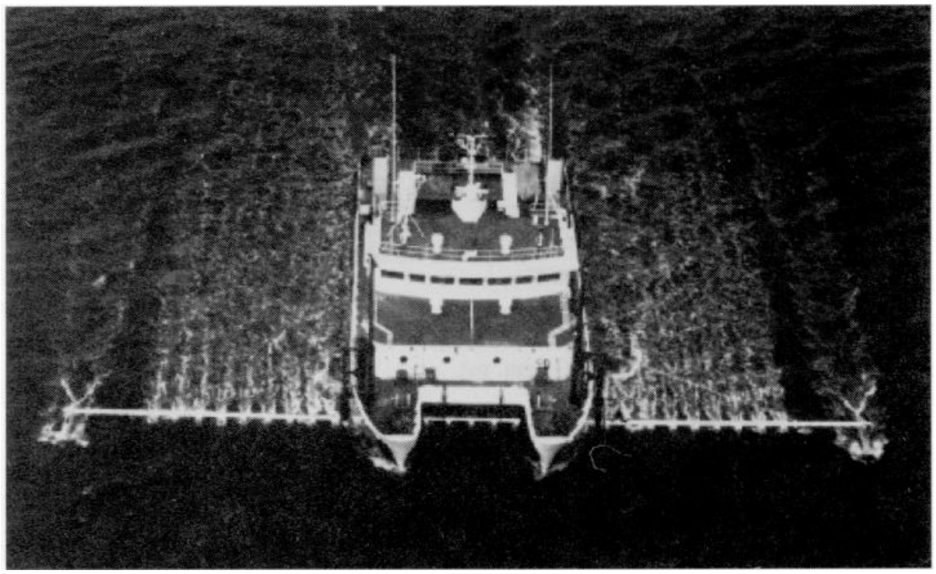
C.S.S. *MATTHEW* is a multi-disciplinary science vessel primarily used by the Canadian Hydrographic Service. The vessel was constructed at Versatile Pacific Shipyards in 1990 and arrived in Scotia-Fundy Region in May of 1991, after being transferred from the Newfoundland Region. The ship is owned by DFO and operated by Scotia-Fundy Region.

Hull . . . . steel
Built 1990
Length . . . . 51.2 m
Breadth . . . . . 10.5 m
Draft . . . . 3.2 m
Freeboard to working deck . . 1.1 m
Displacement . . . . 745 tonnes
Gross tonnage . . . . 857 tonnes
Full speed . . . . 12 knots
Service speed . . . . 10 knots
Endurance . . . . 20 days
Range at service speed . . . . 4,000 naut. mi.
Complement . . . . 7 scientific staff
EM100
Auto pilot
Various positioning systems
1991 Time at sea . . . 103 days
Distance steamed . . . 5,662 naut. mi.



YEAR & NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	OBJECTIVES OF VOYAGE
This was the vessel's first field season.				
	1991			
91-08	June 22 - July 29; Aug. 9 - Oct. 28	J. Goodyear, CHS	Nova Scotia and Newfoundland coasts	Hydrographic charting, ISAH Questar Tangent trials
91-31	Nov. 1 - 18	G. Costello, CHS	Conception Bay	DOLPHIN trials

C.S.S. *F.C.G. SMITH* made its maiden voyage in 1986. The ship is owned by DFO and is operated by the department's Scotia-Fundy Region. The vessel is primarily used by the Canadian Hydrographic Service as an acoustic sweep vessel in the coastal areas of the maritime provinces.



Hull . . . . steel
Built 1985
Length . . . . 34.8 m
Breadth . . . . . overall 14 m
Breadth . . . . . single hull 4 m
Draft . . . . 2.1 m
Freeboard to working deck . . 1.3 m
Displacement . . . . 370 tonnes
Gross tonnage . . . . 438 tonnes
Full speed . . . . 12 knots
Service speed . . . . 10 knots
Endurance . . . . 7 days
Complement . . . . 4 scientific staff
Integrated sweep transducers
Auto-pilot Laser-ranging positioning system
Onboard data processing
Up to 500,000 depth measurements daily
1990 Time at sea . . . 92 days
Distance steamed . . . 3.685 naut. mi.
1991 Time at sea . . . 66 days
Distance steamed . . . 766 naut. mi.

YEAR & NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	OBJECTIVES OF VOYAGE
	1990			
90-09	Apr. 30 - June 28	J. Ferguson, CHS	Atlantic coast of Nova Scotia and Bay of Fundy, including Halifax Harbour, La Have River area, Meteghan, N.S., and Saint John, N.B.	Hydrographic sweep surveys
90-20	July 16 - Oct. 31	J. Ferguson, CHS	Newfoundland Coast, including Conception Bay, St. John's, Stephenville, Corner Brook, Port aux Choix, and Port Saunders: Georgetown, P.E.I.; Halifax Harbour, Cheticamp, and Sydney, N.S.	Hydrographic sweep surveys
	1991			
91-10	May 8 - July 28	G. Henderson, CHS	Maritimes, including Point Tupper, Neils Harbour, Mulgrave, and Port Hawkesbury, N.S.; Souris, and Cardigan Bay, P.E.I.	Hydrographic sweep surveys
91-32	Sept. 9 - Oct. 2.5	B. MacGowan, CHS	Newfoundland coast, including Cow Head, Port aux Basques and Burgeo Village	Hydrographic sweep surveys

C.S.S. *NAVICULA* is a fishing vessel owned by DFO. It is operated by the department's Scotia-Fundy Region and is used for research in biological oceanography.

Hull . . . . wood
Built 1968
Length . . . . 19.8 m
Breadth . . . . . 5.85 m
Draft . . . . 3.25 m
Freeboard to working deck . . 2.5 m
Displacement . . . . 104 tonnes
Gross tonnage . . . . 78 tonnes
Full speed . . . . 10 knots
Service speed . . . . 9 knots
Endurance . . . . 8- 10 hours
Range at service speed . . . . 1,000 naut. mi.
Complement . . . . 3 scientific staff
1990 Time at sea . . . 116 days
Distance steamed . . . 6.590 naut. mi.
1991 Time at sea . . . 138 days
Distance steamed . . . 7,766 naut. mi.

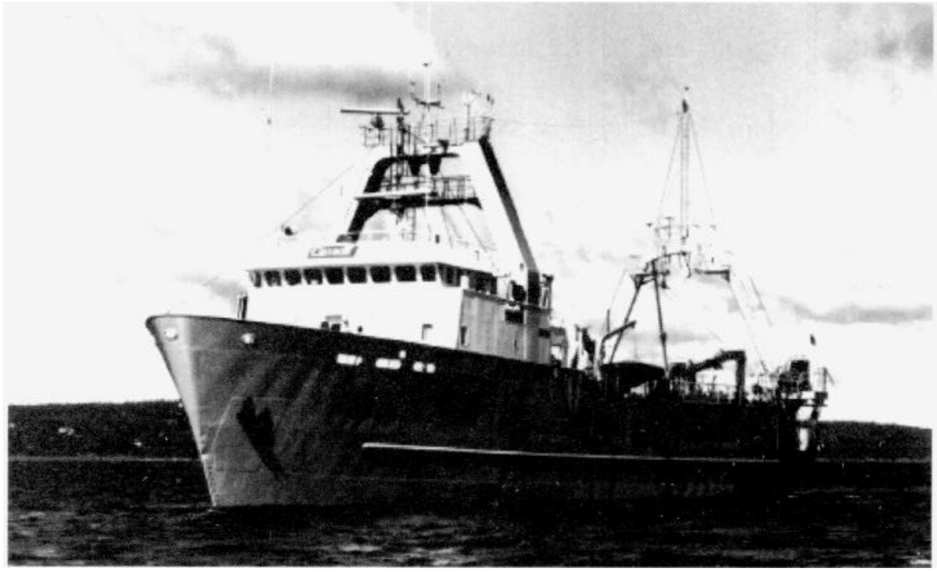
YEAR & NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	OBJECTIVES OF VOYAGE
	1990			
From January 29 to April 8, the Navicula *was on fisheries patrol, replacing F.P.V.* Cobequid Bay *in Southwest Nova Scotia.*				
90-10	May 23 - June 6	G. Fader, AGC	Halifax Harbour	Seismic survey
90-34	July 11 - 17	P. Vass, BSB	St. Margarets Bay	Plankton and benthic survey for lobsters
90-35	July 23 - Aug. 20	J. Shaw, AGC	E. Newfoundland coast	Nearshore geophysical survey
90-36	Aug. 26 - Sept. 21	R. Tallman, BSB Gulf Region	Southern Gulf Northumberland Strait, Fisherman's Bank	Herring spawn survey; flatfish behaviour on herring spawning grounds
90-37	Sept. 24 - 27	D. Willis, PCS	Sydney Harbour	Interaction of enzyme systems and hydrocarbon load
90-38	Oct. 9 - 25	R. Miller, AGC	Nova Scotia Eastern Shore	Surficial geology, potential for aggregate recovery
90-39	Oct. 30 - Nov. 9	J. Smith, BSB Gulf Region	Eastern P.E.I. area	Toxic algal blooms in relation to environmental conditions
90-40	Nov. 14 - 15	J. Buckland-Nicks, St. Francis-Xavier University	St. Margarets Bay	Benthic collections for embryological studies
	1991			
91-06	Apr. 29 - May 11	T. Lambert, BSB	Nova Scotia Eastern Shore, Bras d'Or Lakes	Eastern Shelf Program: Plankton survey
91-09	May 14 - 16, 24, 28, 30	G. Fowler, PCS	Halifax Harbour	Testing weather buoy, acoustic doppler current meter, thermistor chains, etc.

C.S.S. *NAVICULA* continued...

91-12	May 21 - 23; 27	D. Mossman, PCS	Halifax Harbour	Collection of benthos, fish and water samples for hydrocarbon analysis
91-17	May 30 - June 7	T. Lambert, BSB	Nova Scotia Eastern Shore	Eastern Shelf Program: Plankton survey
91-19	June 10 - 11; 18 - 19	D. Willis, PCS	St. Georges Bay	Collection of hydrocarbon, winter flounder samples
91-21	June 20 - 25	J. Smith, BSB Gulf Region	Ballantyne Cove, St. Georges Bay	Collection of phytoplankton for toxin studies
91-25	June 27 - 28; July 3 - 6	T. Lambert, BSB	Nova Scotia Eastern Shore	Eastern Shelf Program: Plankton survey
91-28	July 29 - 30	D. Mossman, PCS	Halifax Harbour	Collection of hydrocarbon, winter flounder samples
91-31	July 31 -Aug. 18	J. Shaw, AGC	NE Newfoundland coast	Inshore surficial geology
91-37	Aug. 26 - Sept. 19	F. Gallant, BSB Gulf Region	Gulf of St. Lawrence, Fisherman's Bank	Winter flounder behaviour during herring spawning in the area
91-40	Sept. 20 - 27	J. Smith, BSB Gulf Region	Gulf of St. Lawrence, Cardigan Bay, and Georges Bay	Collection of phytoplankton for toxin studies
91-44	Sept. 30 - Oct. 10	T. Lambert, BSB J. McRuer	Sydney Bight	Eastern Shelf Program: Ichthyoplankton survey
91-51	Oct. 16 - Nov. 1	T. Lambert, BSB	Sydney Bight	Eastern Shelf Program: Ichthyoplankton survey
91-53	Nov. 5- 11	J. Smith, BSB Gulf Region	Gulf of St. Lawrence, Cardigan Bay	Collection of phytoplankton for toxin studies
91-57	Nov. 15 - 28	T. Lambert, BSB	Sydney Bight	Eastern Shelf Program: Ichthyoplankton survey

C.S.S. *ALFRED NEEDLER* is a diesel-driven stern trawler owned by DFO. It is operated by the department's Scotia-Fundy Region and is used for fisheries research including acoustics, juvenile fish ecology, and recruitment studies.

Hull . . . . steel
Built 1982
Length . . . . 50.3 m
Breadth . . . . . 11.0 m
Draft . . . . 4.9 m
Freeboard to working deck . . 2.5 m
Displacement . . . . 877 tonnes
Gross tonnage . . . . 925 tonnes
Full speed . . . . 13.5 knots
Service speed . . . . 12 knots
Endurance . . . . 30 days
Range at service speed . . . . 3,000 naut. mi.
Complement . . . . 10 scientific staff
1990 Time at sea . . . 188 days
Distance steamed . . . 25.419 naut. mi.
1991 Time at sea . . . 215 days
Distance steamed . . . 29,071 naut. mi.



YEAR & NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	OBJECTIVES OF VOYAGE
	1990			
89-N131	Jan. 5 - 26	U. Buerkle, BSB	Chedabucto Bay	Acoustic herring survey
89-N132	Feb. 1 - 14	G. McClelland, BSB	Scotian Shelf	Sealworm survey
89-N133	Feb. 19 - Mar. 9	J. Hunt, BSB	Georges Bank	Groundfish trawl survey
89-N134	Mar. 13 - 22	P. Fanning, BSB	Eastern Scotian Shelf	Groundfish trawl survey
89-N135	Mar. 26 - 30	M. Showell, BSB	Scotian Shelf	International Observer training
90-N136	Apr. 9 - 12	M. Showell, BSB	Scotian Shelf	International Observer training
90-N137	Apr. 18 - 26	I. Perry, BSB	Georges Bank	Ichthyoplankton; hydrography
90-N138	May - June	W. Cottle, MSD	Halifax	Installation of maintenance-free engine room
90-N139	July 3 - 19	P. Fanning, BSB	Bay of Fundy, S. Shelf	Groundfish trawl survey
90-N140	July 23 - Aug. 1	S. Smith, BSB	Eastern Scotian Shelf	Groundfish trawl survey
90-N141	Aug. 20 - Sept. 14	E. Laberge, BSB Quebec Region	Gulf of St. Lawrence	Redfish and shrimp trawl survey
90-N142	Sept. 19 - 24; Sept. 25	M. Showell, BSB V. Marriatt, BSB	Scotian Shelf	International Observer training; live fish collections
90-N143	Oct. 1 - 11	U. Buerkle, BSB	Georges Bank	Groundfish/herring acoustics
90-N144	Oct. 23 - Nov. 18	D. Cairns, BSB Gulf Region	Southern Gulf of St. Lawrence	Herring acoustic survey
90-N145	Nov. 19 - Dec. 5	I. McQuinn, BSB Quebec Region	Gulf of St. Lawrence, east Newfoundland	Herring acoustics, juvenile cod

C.S.S. *ALFRED NEEDLER* continued...

90-N146	Dec. 8 - 16	C. Annand, BSB	Gulf of Maine	Pollock tagging
	1991			
90-N147	Jan. 4 - 29	C. Dickson, BSB	Chedabucto Bay	Herring acoustic survey
90-N148	Feb. 12 - 28	M. Strong, BSB	Georges Bank	Groundfish trawl survey
90-N149	Mar. 4 - 18	P. Fanning, BSB	Eastern Scotian Shelf	Groundfish trawl survey
91-N150	Apr. 2 - 12	E. Dawe, BSB Newfoundland Region	Conception Bay	Crab survey
91-N151	Apr. 16 - 30	T. Hurlbut, BSB Gulf Region	Southern Gulf of St. Lawrence	Groundfish trawl survey
91-N152	May 3 - 8	B. Nakashima, Newfoundland Region	Grand Banks, St. Pierre Banks	Capelin tagging
91-N153	May 9 - 17	R. Tizzard, BSB Newfoundland Region	NAFO Divs. 2GH, Hamilton Bank	Exploratory fishing
91-N153b	May 20, May 24 - 30	J. Morgan, BSB Newfoundland Region	Grand Banks, NAFO Div. 3L	AFAP cod spawning survey
91-N154	July 3 - 13	J. Hunt. BSB	Bay of Fundy, Western Scotian Shelf	Groundfish trawl survey
91-N155	July 15 - 26	P. Koeller, MALD	Eastern Scotian Shelf	Groundfish trawl survey cancelled due to mechanical problems; conducted on M.V. *Lady Hammond*
91-N156	Aug. 2 - 16	W. Hickey, FHM	Scotian Shelf and slope	Deep-sea exploratory fishing and gear trials
91-N157	Aug. 24 - Sept. 20	D. Gascon, L. Savard, BSB, Quebec Region	Northern Gulf of St. Lawrence	Groundfish trawl survey
91-N158	Sept. 23 - Oct. 3	P. Vass, BSB	Scotian Shelf, Georges Bank	AFAP project, distribution of ghost gill nets
91-N159	Oct. 8 - 25	H. Dupuis, BSB Gulf Region	Southern Gulf of St. Lawrence	Herring acoustics
91-N160	Nov. 5 - 7	J. Spry, BSB	Scotian Shelf Basins	Basin zooplankton sampling
91-N161	Nov. 12 - Dec. 3	C. Bishop, BSB Newfoundland Region	NAFO Div. 2GH	Groundfish trawl survey
91-N162	Dec. 6 - 15	C. Dickson, BSB	Chedabucto Bay	Acoustic herring surveys

C.S.S. *E.E. PRINCE* is a stem trawler used for fisheries research including experimental and exploratory fishing and resource surveys. The ship is owned by DFO and is operated by the department's Scotia-Fundy Region.

Hull . . . . steel
Built 1966
Length . . . . 39.6 m
Breadth . . . . . 8.2 m
Draft . . . . 3.65 m
Freeboard to working deck . . 0.7 m
Displacement . . . . 580 tonnes
Gross tonnage . . . . 406 tonnes
Full speed . . . . 10.5 knots
Service speed . . . . 10 knots
Endurance . . . . 14 days
Range at service speed . . . . 3,000 naut. mi.
Complement . . . . 6 scientific staff
1990 Time at sea . . . 185 days
Distance steamed . . . 23.599 naut. mi.
1991 Time at sea . . . 172 days
Distance steamed . . . 20.535 naut. mi.

YEAR & NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	OBJECTIVES OF VOYAGE
	1990			
89-P394	Mar. 23 - 30	L. Dickie, BSB	Scotian Shelf	Groundfish acoustics with dual beam system
90-P395	Apr. 5 - 12	D. Robicheau, BSB	Bay of Fundy and Grand Manan Basin	Abundance and distribution survey of lobsters in deep water; lobster tagging
90-P396	Apr. 18 - 19	D. Heffler, AGC	Emerald Basin	Gear trials for OBS to be used under polar ice pack
90-P397	Apr. 25 - May 3	G. Thouzeau, BSB	Georges Bank	Collection of live scallops for eco-physiological studies
90-P398	May 7 - 17; May 22 - 23	M. Lundy, BSB D. Lawrence, PCS C. Morrison, BSB	Scotian Shelf	Scallop abundance survey; MINIMET mooring; live fish collections
90-P399	May 25 - 30	D. Marcogliese, BSB Quebec Region	Scotian Shelf	Benthic survey for invertebrate sealworm intermediate hosts
90-P400	June 5 - 30	M. Castonguay, M. Peloquin, J.-M. Sevigny, BSB, Quebec Region	Gulf of St. Lawrence	Annual mackerel egg survey for determining spawning stock biomass; collection of live fish for aquaculture studies; fish sampling for biochemical, genetic, and pathological studies
90-P401	July 1 - 8	M. Lanteigne, BSB Quebec Region	Gulf of St. Lawrence, Northumberland Strait	Juvenile scallop survey and underwater observations
90-P402	July 11 - 20	H. Dupuis, BSB Gulf Region	Gulf of St. Lawrence, Chaleur Bay, Northumberland Strait	Distribution and abundance of juvenile herring
90-P403	Aug. 7 - 17	G. Robert, BSB	Georges Bank	Annual scallop abundance survey

C.S.S. *E.E. PRINCE* continued...

90-P404	Aug. 17 - 31	G. Thouzeau, BSB	Georges Bank	Juvenile scallop survey
90-P405	Sept. 2 - 14	J. Porter, BSB	Browns Bank	Swordfish age, growth, fecundity, metabolism, and population structure
90-P406	Sept. 18 - Oct. 5	D. Marcogliese, BSB Quebec Region	Gulf of St. Lawrence	Incidence of sealworm larvae in groundfish and benthic invertebrates; live fish collections for aquaculture
90-P407	Oct. 10 - 19	W. Hickey, FHM	Scotian Shelf	Shrimp/fish separator trawl gear trials
90-P408	Oct. 25 - Nov. 6	J. Sochasky, BSB	Bay of Fundy	Annual larval herring abundance survey
90-P409	Nov. 14 - 22	C. Bourque, BSB Gulf Region	Gulf of St. Lawrence, Baie des Chaleurs	Acoustic herring survey for biomass and distribution
90-P410	Nov. 26 - Dec. 19	H. Dupuis, BSB Gulf Region	Gulf of St. Lawrence, Baie des Chaleurs	Juvenile herring survey
	1991			
91-P411	Apr. 24 - 26	C. Morrison, BSB	Scotian Shelf, Chebucto Head	Live fish collections for pathological studies
91-P412	Apr. 30 - May 9	W. Hickey, FHM	Scotian Shelf	Gear trials with silver hake trawls and separator panels; mesh selectivity studies
91-P413	May 13 - 24	G. Robert, BSB	Scotian Shelf, Browns Bank, Georges Bank	Annual scallop abundance survey
91-P414	May 28 - Jun. 9	M. Castonguay, BSB Quebec Region	Gulf of St. Lawrence	Acoustic mackerel survey and CTD transects during annual migration into the Gulf
91-P415	May 10 - 14	M. Measures, BSB Quebec Region	St. Lawrence estuary, Cabot Strait	Collection of live fish for aquaculture research
91-P416	May 16 - 28	F. Gregoire, BSB Quebec Region	Gulf of St. Lawrence	Mackerel egg survey
91-417	July 25 - Aug 2	U. Buerkle, BSB	Bay of Fundy	Herring acoustic survey
91-418	Aug. 7 - 23	G. Robert, BSB	Georges Bank	Annual scallop survey
91-419a	Aug. 27 - Sept. 1	J. Porter, BSB	Browns Bank	Tuna tagging
91-419b	Sept. 4 - 14	R. Stephenson, BSB	SW Nova Scotia	Herring acoustic survey
91-420	Sept. 24 - Oct. 2; Oct. 3 - Oct 7	J. Porter, BSB	Scotian Shelf, Browns Bank	Swordfish and tuna tagging
91-421	Oct. 12 - 24	R. Bradford, BSB Quebec Region	SW Newfoundland, Anticosti Island	Demersal/pelagic survey of juvenile cod and haddock
91-422	Oct. 31 - Nov. 15	J. Sochasky, BSB	Bay of Fundy	Larval herring survey
91-423	Nov. 18 - Dec. 3	I. McQuinn, BSB Quebec Region	Gulf of St. Lawrence, NE Newfoundland coast	Herring acoustics
91-424	Dec. 7 - 17	H. Dupuis, BSB Gulf Region	Southern Gulf of St. Lawrence	Juvenile herring survey

PARTICIPATION IN OTHER RESEARCH CRUISES

VESSEL / COUNTRY	VOYAGE DATES	CANADIAN PARTICIPANTS	AREA OF OPERATION	OBJECTIVES OF VOYAGE
	1990			
M.V. *Skogaloss* (Iceland)	Jan., Apr., July, Dec.	F. Dobson, PCS	Northern North Atlantic, Cape Race to Reykjavik	Line of XBT profiles to estimate heat content in area of operation
F.C.G. *Creed* (Canada)	Jan. - Aug.	J. Goodyear, M. Lamplugh, CHS	Northeast Newfoundland	Evaluation of SWATH vessel for hydrographic and oceanographic surveys
Alcor (West Germany)	Apr. 7 - 12	A. Herman, PCS	Bornholm Basin, Baltic Sea	Cod egg survey with Optical Plankton Counter
Meteor (West Germany)	Apr. 13 - May 15	P. Yeats, J. Dalziel, PCS	Eastern South Atlantic	IOC open ocean baseline study of chemical contaminants
Evrika (U.S.S.R)	May 14 - July 6	C. Bourbonnaise, D. Waldron, BSB	Browns Bank to Sable Island Bank	Distribution of silver hake relative to oceanographic conditions
Maltsevo (U.S.S.R)	Oct. 17 - Nov. 31	C. Bourbonnaise, W. MacEachern, M. Showell, BSB	Scotian Shelf	Juvenile silver hake survey
Meetpost Noordivijk (The Netherlands)	Nov. 12 -Dec. 7	S. Smith, R. Anderson, PCS	North Sea	VIERS-1 Program, wind stress, heat flux, evaporation and wave state measurements, CO, flux at sea surface
	1991			
M.V. *Skogaloss* (Iceland)	Jan., Apr., July, Dec.	F. Dobson, PCS	Northern North Atlantic, Cape Race to Reykjavik	Line of XBT profiles to estimate heat content in area of operation
Scotian Surf (Canada)	Mar. 30 - Apr. 8	D. Roddick, BSB	E. Scotian Shelf	Exploratory survey for small commercial-sized offshore clams
Arctic (Canada)	May 3 - 20	R. Conover, J. Spry, BSB	Northern Baffin Bay	Zooplankton grazing study
Laurentian (U.S.A.)	Aug. 18 - Sept. 7	C. Lewis, AGC	Lake Huron and Georgian Bay, Great Lakes	Seismostratigraphy and sedimentary record of Late Quaternary-Holocene climate change
Oden (Sweden)	Aug. 1 - Oct. 14	E. Jones, F. Zemlyak, PCS	Arctic Ocean, Nansen Basin, Amundsen Basin, Makarov Basin	Origin and circulation of water masses in the Arctic Ocean in relation to global climate change
Polarstern (Germany)	Aug. 1 - Oct. 14	K. Moran, K. Manchester, F. Jodrey, AGC	Arctic Ocean, Nansen Basin, Amundsen Basin, Makarov Basin	Study of seafloor spreading within the Arctic Ocean basin
Lady Eileen (Canada)	Sept. 30 - Oct. 24	C. Dale, M. Showell, BSB	Scotian Shelf	Gear selectivity, longline versus otter trawl
Lady Sharrel (Canada)	Sept. 30 - Oct. 24	D. Lyon, W. MacEachern, BSB	Scotian Shelf	Gear selectivity, longline versus otter trawl
Minerva (Italy)	Oct. 22 - Nov. 11	B. Topliss, PCS	Tyrrhenian Sea	Collection and groundtruthing of remotely sensed data
Maltsevo (U.S.S.R.)	Oct. 15 - Nov. 28	S. Bond, M. Showell, BSB	Scotian Shelf	Juvenile silver hake survey
Grenfell (Canada)	November	G. Costello, CHS	Conception Bay, Newfoundland	Evaluation of Coastal Ocean Mapping System and DOLPHIN handling system
Cape Hatteras (U.S.A.)	Dec. 14 - 21	A. Herman, PCS	Cape Hatteras	Menhaden egg survey with Optical Plankton Counter

Charts and Publications

Chart production

The Scotia-Fundy Region of the Canadian Hydrographic Service (CHS) has a cartographic staff of 23 and responsibility for 400 nautical charts covering Canada's east coast from Georges Bank to Prince of Wales Strait in the Arctic.

The charts produced by CHS are divided into three types. A New Chart is the first chart to show an area at that scale or to cover an area different from any existing chart. These charts are constructed to the metric contour style in bilingual form using new formats. A New Edition is a new issue of an existing chart showing new navigational information and including amendments previously issued in Notices to Mariners. A Reprint is **a** new print of a current edition that incorporates amendments previously issued in Notices to Mariners. Reprints for the Scotia-Fundy Region are produced by CHS headquarters in Ottawa.

In addition to the New Charts and New Editions listed below, about one hundred chart amendments and fifteen paste-on patches are issued through Notices to Mariners each year.

1990

New Charts

4230 Little Hope Island to Cape St. Mary's
4255 Georges Bank-Eastern Portion
4850 Cape St. Francis to Baccalieu Island and Heart's Content
5023 Cape Harrison to Nunaksaluk Island
7566 Cape Jameson to Cape Fanshawe

New Editions

4394 LaHave River, West Ironbound Island to Riverport
4395 LaHave River, Riverport to Conquerall Bank
4448 Port Hood, Mabou Harbour and Havre Boucher

1991

New Charts

4210 Cape Sable to Pubnico Harbour
4227 Country Harbour to Ship Harbour
4233 Cape Canso to Country Island
4851 Trinity Bay-Southern Portion
5030 Green Bay to Double Island
5031 St. Lewis Sound and Inlet
7488 Air Force Island to Longstaff Bluff

New Editions

4145 Mactaquac Dam to Newburg Island
4211 Cape LaHave to Liverpool Bay
4340 Grand Manan
4437 Pictou Harbour
4466 Hillsborough Bay
4616 Burin Harbours

Publications

We present below alphabetical listings by author of publications produced in 1990 and 1991 by the staffs at BIO from the Department of Fisheries and Oceans (DFO), the Department of Energy, Mines and Resources, and Environment Canada, and by DFO science staff at the Halifax Fisheries Research Laboratory and the St. Andrews Biological Station. Articles published in scientific and hydrographic journals, books, conference proceedings, and various series of technical reports are included. The style and format of these references are as supplied by each unit. For further information on any publication listed here, contact: Marine Assessment and Liaison Division, Department of Fisheries and Oceans, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia, Canada B2Y 4A2; or call (902) 426-3559.

DEPARTMENT OF FISHERIES AND OCEANS

SCOTIA-FUNDY REGION

OFFICE OF THE REGIONAL DIRECTOR, SCIENCE

1990 and 1991

Koeller, P.A. 1990. Controlling the variability of survey gear performance. ICES C.M. 1990/B: 3:24 p.

Koeller, P.A. 1990. Fish Capture Committee report of 1989 activities to the International Committee for the Exploration of the Sea. Canadian Report. C.M. 1990/B: 1.

Koeller, P.A. 1990. Report on Canadian research to the Northwest Atlantic Fisheries Organization. Section III. Scotia-Fundy Region. In: Canadian Research Report, 1989, NAFO SCS Doc. 90/07: 17-21.

Koeller, P.A. 1991. Report on Canadian research to the Northwest Atlantic Fisheries Organization. Section I. Scotia-Fundy Region. In: Canadian Research Report, 1990, NAFO SCS Doc. 91/06: 1-4.

Koeller, P.A. 1991. Approaches to improving groundfish survey abundance estimates by controlling the variability of survey gear geometry and performance. J. Northw. Atl. Fish. Sci. 11: 51-58.

Koeller, P.A. 1991. Fish Capture Committee report of 1990 activities to the International Committee for the Exploration of the Sea. Canadian Report. C.M. 1991/B:l.
McKone, D., S. Walsh, and P. Koeller. 1990. Improving the performance of groundfish survey trawls - a discussion paper on possible research directions. DFO internal report to the Assistant Deputy Minister, Science.
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