ENVIRONMENTAL STUDIES FOR SUSTAINABLE AQUACULTURE (ESSA): 2002 WORKSHOP REPORT

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(Editor)

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Bedford Institute of Oceanography
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ABSTRACT

Hargrave, B.T. (Editor). 2002. Environmental Studies for Sustainable Aquaculture (ESSA): 2002 Workshop Report. Can. Tech. Rep. Fish. Aquat. Sci. 2411: v + 112 p.

This report summarizes oral presentations, discussions, recommendations and external reviewer's comments arising from a three-day workshop held during the second year of the Environmental Sciences Strategic Research Fund study "Environmental Studies for Sustainable Aquaculture" (ESSA) held at the Bedford Institute of Oceanography, Dartmouth, NS, (16-18 January, 2002). The first day of the meeting consisted of a joint workshop of ESSA science staff with members of the National Habitat Management Working Group on Aquaculture. Four presentations dealt with issues arising from habitat management questions relevant to predicting potential far field environmental effects of salmon aquaculture. This was followed over the next two days by presentations from ESSA project members that summarized progress in developing methods and models for quantifying and predicting far field environmental effects of finfish aquaculture. Research on physical circulation models, chemical, geochemical and biological methods suitable as candidates for detecting and mapping far field effects of finfish aquaculture was summarized. A general discussion of progress and plans for the final year of the ESSA project concluded the workshop.

RESUMÉ

Le présent rapport résume les présentations orales, les discussions, les commentaires des examinateurs externes et les recommandations auxquels a donné lieu un atelier de trois jours tenu au cours de la deuxième année de l'étude environnementale sur l'aquaculture durable (ESSA), financée par le Fonds de recherches stratégiques en sciences de l'environnement. Cet atelier a eu lieu à l'Institut océanographique de Bedford, à Dartmouth (N.-É.), du 16 au 18 janvier 2002. La première journée consistait en une séance commune entre le personnel scientifique de l'ESSA et le Groupe de travail national de gestion de l'habitat sur l'aquaculture. Quatre présentations portaient sur des questions de gestion de l'habitat ayant trait à la prédiction des éventuels effets environnementaux à rayonnement lointain de l'aquaculture du saumon. Au cours des deux journées suivantes, des présentations des participants à l'étude ESSA ont résumé les progrès accomplis dans l'élaboration de méthodes et de modèles visant à quantifier et à prédire les effets environnementaux à rayonnement lointain de la pisciculture. On a brossé un tableau des recherches sur les modèles de circulation physique ainsi que sur les méthodes chimiques, géochimiques et biologiques susceptibles de permettre de déterminer et d'inventorier les effets à rayonnement lointain de la pisciculture. L'atelier s'est terminé par une discussion générale de l'état d'avancement de l'étude ESSA.

INTRODUCTION

The Department of Fisheries and Oceans (DFO) project "Environmental Studies for Sustainable Aquaculture" (ESSA) under the Environmental Sciences Strategic Research Fund was initiated in April 2000. The multi-disciplinary study involving DFO staff from three regions (Newfoundland (NF), Maritimes (NB) and British Columbia (BC)) consists of developing methods and models in Bay d'Espoir (NF), the Western Isles Region (Letang inlet, NB) and in the south-central coast of Vancouver Island (Broughton Island Archipelago, BC). The first annual ESSA workshop was held in January 2001 to bring together all project participants, members of the steering committee and invited reviewers. The aim was to have an annual meeting to document progress and refine objectives with respect to Habitat Management issues and to establish linkages with other relevant strategic science projects within DFO. This report summarizes the results of the second ESSA workshop held at the Bedford Institute of Oceanography, 16-18 January 2002.

ESSA PROJECT OBJECTIVES

The four objectives or main questions addressed in the ESSRF project are:

1. How can assimilative capacity be determined for wastes produced by marine finfish aquaculture?
2. What measurements can be made to document changing patterns and rates of sedimentation?
3. How can material released from aquaculture sites be tracked within a coastal system?
4. How can these environmental objectives be used by habitat managers to mitigate potential environmental effects such that a Harmful Alteration, Disruption or Destruction (HADD) of fish habitat does not occur?

During the first two years of the project, these broad questions have been focused and addressed by specific research activities. Preliminary results are given in italics following each objective.

1) To identify and evaluate sensitive water column and sediment variables in three coastal regions in Canada (Bay d'Espoir (NF), Letang inlet (NB) and the Broughton Archipelago (BC)) where salmon aquaculture is concentrated.

Hydrographic factors of water depth, the proportion of time current velocity is less than a minimum threshold, dissolved oxygen concentrations, water column and benthic respiration, total sulfides ($S^{=}$) and organic matter in sediments have been found to be sensitive variables for predicting far field effects of salmon aquaculture. Observations of the extent of macroalgal mats coverage of intertidal sediments, bacterial antibiotic resistance to oxytetracycline, and trace metal levels in sediments have been assessed as indicators to quantify potential far field effects of finfish aquaculture.

2) To observe and develop dispersion/sedimentation models for particulate matter produced by salmon farms.

Grain size distributions of sediments are the net result of sedimentation and resuspension events determined by levels of turbulence and concentrations of dissolved and particulate matter in the water column. Aggregation of fine particles that contribute to increased vertical flux and accumulation of fine-grained sediments appear to be important processes in areas of intense salmon aquaculture. Flocculation and aggregation of suspended particles may determine the flux of fine-grained sediments to the bottom in areas where water exchange is restricted and currents are low.

3) To use physical circulation models to predict residence times and transport to make oxygen and nutrient mass balance calculations and to develop a general method for assessing potential impacts of salmon farm sites.

A finite element model predicting tidal properties, residual circulation, and particle movement has been used to describe water mixing, horizontal particle dispersion and differences in particle trajectories. Water depth and the minimum sustained current were found to be critical variables for continued oxygen supply to finfish farm sites.

4) To identify effective management tools to assist with siting and management decisions for sustainable salmonid aquaculture in Canada

Critical thresholds for reduced dissolved oxygen, and increased sediment organic matter and $S^{=}$ may be exceeded at distances >50 m from cage sites if low current velocities are maintained for a sufficient duration over a tidal cycle. Simple mass balance models have been used successfully to compare cumulative oxygen demand and nutrient input from natural processes with additions due to cultured salmon.

NHMWGA/ESSA JOINT MEETING

The first day of the workshop consisted of a joint meeting of the DFO National Habitat Management Working Group on Aquaculture (NHMWGA) and ESSA project participants. Invited presentations reviewed priority issues for finfish aquaculture-environment interactions identified by the NHMWGA. ESSA science presentations followed over the next two days to review research progress and planned work in the final year of the project. Three external reviewers were invited to assess the project with respect to stated aims based on presentations made during the workshop.

The purpose of the joint NHMWGA/ESSA meeting was to provided a forum for DFO scientists to up-date DFO Habitat Management staff on aquaculture and fish habitat research initiatives needed for informed management decisions under three key topics:

1) Siting criteria and modelling for aquaculture operations to minimize potential for a HADD,

2) Thresholds for variables useful for identifying Harmful Alteration, Disruption and Destruction (HADD) in water and sediment habitats, and

3) Cost effective monitoring tools/techniques for assessing potential far and near-field effects.

An introductory presentation identified Habitat Management's major needs from science with respect to aquaculture. Four reviews followed that considered modelling the dynamics of dissolved oxygen in inlets subject to finfish aquaculture development, cost effective benthic monitoring tools and methods, identifying critical lobster habitat, and thresholds for water column and sediment variables that might be useful for determining a HADD. Following presentations in morning and afternoon plenary sessions, participants were divided into breakout groups to discuss the issues and provide regional perspectives. Rapparteurs summarized main points raised by each group. The joint meeting facilitated discussion about new and emerging issues to help identify potential science requirements and priorities of Habitat Management. It also created an opportunity for DFO Habitat Management and science staff to meet and exchange information, to strengthen working networks, and to explore innovative ways of working together.

ESSA 2002 WORKSHOP

The following two days of the workshop consisted of brief presentations by ESSA project members that reviewed research progress during 2001, the second year of the project. The format was similar to the first ESSA meeting reported in Can. Tech. Rep. Fish. Aquat. Sci. 2352. ESSA project members discussed research plans for the following year at the end of the workshop. Following the workshop all contributors prepared brief abstracts that are compiled in this report.

NHMWGA/ESSA JOINT MEETING

IDENTIFYING HABITAT MANAGEMENT'S MAJOR AQUACULTURE-RELATED SCIENCE REQUIREMENTS

Jim Ross
Department of Fisheries and Oceans, Habitat Management, Ottawa

DFO has a statutory obligation under the Fisheries Act to ensure the protection of fish habitat. To help proponents meet their responsibilities under the Fisheries Act, Habitat Management has developed a Guide to the Application of Section 35 (S35) of the Fisheries Act to Salmonid Cage Aquaculture Developments. As a result of this responsibility and the guide, several areas are identified as requiring further research. To one degree or another, they are encompassed in the three key issues of this workshop: (1) siting criteria and modelling, (2) thresholds for variables useful for identifying habitat change, and (3) cost effective monitoring tools and methods. These were identified as key issues by the NHMWGA in the management of finfish aquaculture development to address the questions of how to a) avoid critical habitat, b) regulate discharge and c) monitor the discharge. In addition, the recent National Co-ordinating Committee of the Environmental Science Program (NCC-ESP) identified these areas in general terms as priority areas of habitat research.

Each of the science requirements, referenced generally below, was discussed briefly in relation to the Fisheries Act and/or other acts, policies and guidelines that drive its need.

- development of scientifically-defensible siting guidelines
- establish links between performance-based standards (PBS), benthic impacts, and productive capacity
- validation or ground-truthing of PBS or development of more applicable ones as required
- cumulative effects tools are being developed through the ESSA project
- development of ecosystem-based objectives
- development of defensible criteria to identify critical habitats
- research that will enable the development of compensation options for various habitat types in the marine environment
- development of data management systems that will ensure data is of use both to Science and Habitat Management
- methods of remediation and fallowing to address ongoing monitoring concerns and for site decommissioning

Questions must be developed and refined around these requirements that meet both regulatory responsibilities and the goals of the industry. In addition, national consistency with respect to enforcement of S35 must be ensured.

RESEARCH TOOLS IN SUPPORT OF HABITAT MANAGEMENT PRIORITIES

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INTRODUCTION

Habitat Management has identified three priority topics for research related to the effects of finfish aquaculture on marine ecosystems. These priorities are 1) establishment of siting criteria to minimize potential for harmful alteration, destruction or disruption of habitat (HADD), 2) identification of thresholds for variables used in identifying HADD, and 3) development of cost-effective tools and techniques for monitoring. In this paper we present some preliminary results of an ongoing project investigating the effects of salmon net pen operations on benthic ecosystems at six aquaculture sites in British Columbia. These results illustrate some of the progress that has been made in this area as well as the technical and political challenges facing research in support of Habitat Management.

SITING CRITERIA

The establishment of siting criteria for aquaculture operations requires delineation of the spatial boundaries of ecological effects. To this end, we have used acoustic mapping techniques in conjunction with sediment traps, benthic grabs and core sampling to characterize sedimentation rates, substrate texture, sediment chemistry and benthic community structure in the vicinity of net pens at study sites. These data can be used to map the spatial boundaries of waste dispersal and disturbance to benthic organisms resulting from fish farms (i.e., footprints), allowing for evaluation of siting criteria.

Wastes generated by net pen operations typically include organic matter and nutrients from faeces and uneaten feed pellets, as well as trace metals used in feed supplements. Increased organic matter inputs result in oxygen depletion and sulphide (S) production in sediments below and adjacent to floating net pens. Preliminary data suggest that the spatial arrangements of these effects may be highly variable. Contour maps of total organic carbon (TOC), nitrogen and zinc (Zn) in sediments indicate asymmetrical footprints, with the highest values not necessarily being observed directly under the net pens (Fig. 1). Moreover, the extent and shape of the footprint is different for each variable. Complex interactions of bathymetry and current regimes at the site in question and the physical-chemical properties of the elements being measured shape these patterns. As a result, footprints may vary significantly among sites and among the different variables used in monitoring and assessment. These findings illustrate the difficulties associated with establishing universally applicable siting criteria and the extent to which these may be influenced by the choice of variables used in monitoring and assessment.

THRESHOLDS FOR IDENTIFYING A HADD

The establishment of thresholds for variables used in identifying a HADD requires an understanding of the relationships between the physical and chemical effects of finfish aquaculture and the responses of benthic organisms. Preliminary data suggest that organic matter, trace metals and S may be useful indicators for a HADD affecting benthic ecosystems near fish farms. Abundance of polychaete worms is inversely related to both TOC and Zn in sediments, and bivalve abundance is inversely related to sediment TOC. Laboratory experiments involving the benthic copepod *Tigriopus californicus* show that mortality rates increase with increasing concentrations of total S. These data are amenable to regression analyses defining the functional dependence of benthic invertebrate decline on sediment TOC, Zn or S, and as such may be used to identify threshold values corresponding to different levels of ecological impairment.

Challenges here relate to identifying the most appropriate organisms and physicochemical variables for use as indicators. Given the potential for additive and synergistic effects among various elements within the benthic environment, more than one physicochemical indicator might be needed to identify a HADD. For example, TOC is not necessarily a cause of invertebrate decline in itself, but is a correlate of other variables with more direct toxicological effects. Similarly, S toxicity is exacerbated by sediment anoxia, and high S concentrations may influence the bioavailability of trace metals, confounding the effects of S and metal toxicity. Monitoring S concentrations without concurrent investigations of other physicochemical variables may therefore yield an incomplete picture of potential effects on benthic organisms.

COST-EFFECTIVE MONITORING TOOLS

A sediment coring technique has been developed as a means to collect intact sediment profiles at water depths beyond those feasible for scuba diving, as frequently occur on the Pacific coast. The Pedersen corer is deployed from a small boat with a hydraulic winch. It is triggered by gravity and, when retrieved, collects a sediment core up to 3 m long, depending on the length of a detachable Plexiglas barrel. Using small syringe corers and a commercially available, portable ion meter, subsamples may be collected from the barrel and analysed for S, dissolved oxygen (DO) and redox potential (Eh). This technique can be used to create a vertical profile of sediment chemistry (e.g. Fig. 2) at a wide range of sites.

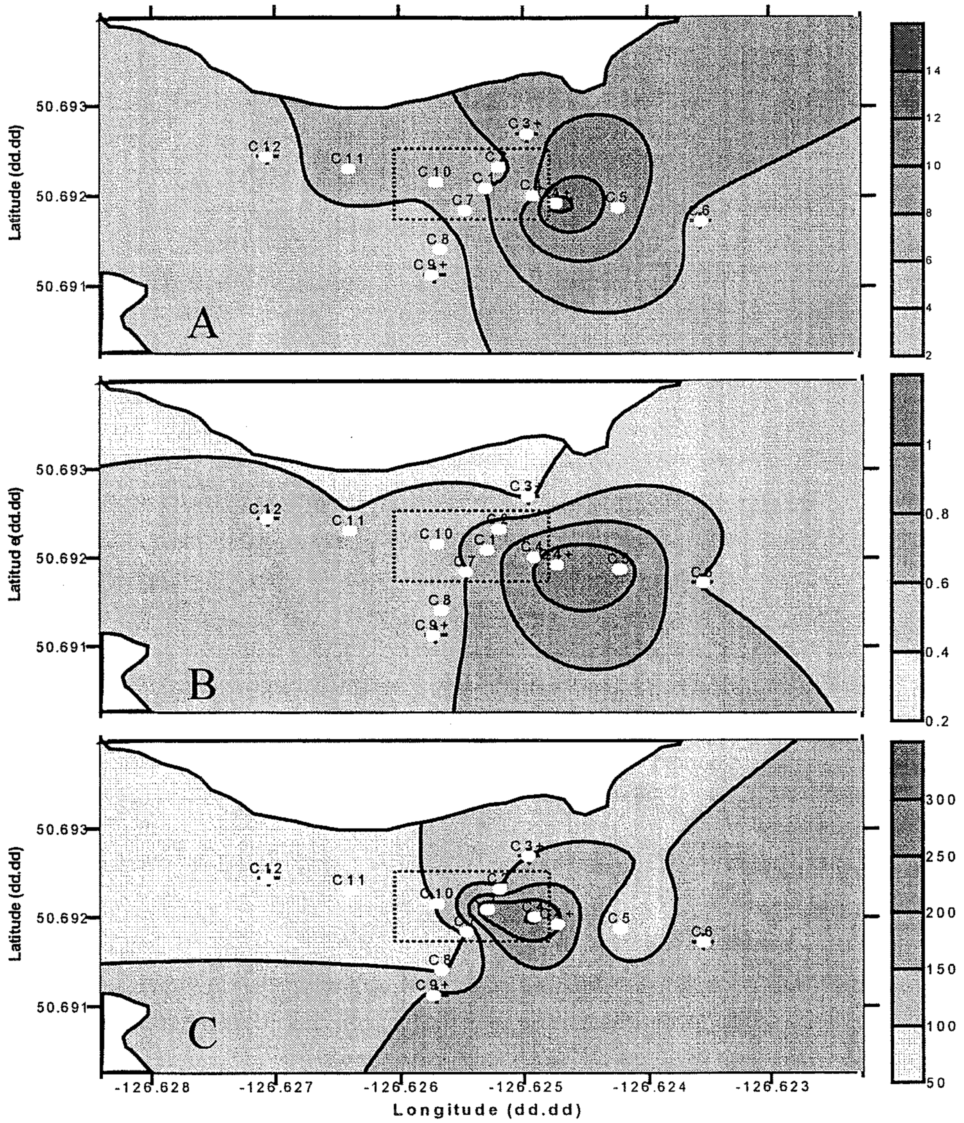

Figure 1: Contour map of (A) % total organic carbon, (B) % nitrogen, and (C) zinc concentration (μg/g) in sediments near an abandoned salmon aquaculture site in the Broughton Archipelago, British Columbia. Dotted lines mark the former perimeter of the floating net pens. Open circles represent grab sampling stations.

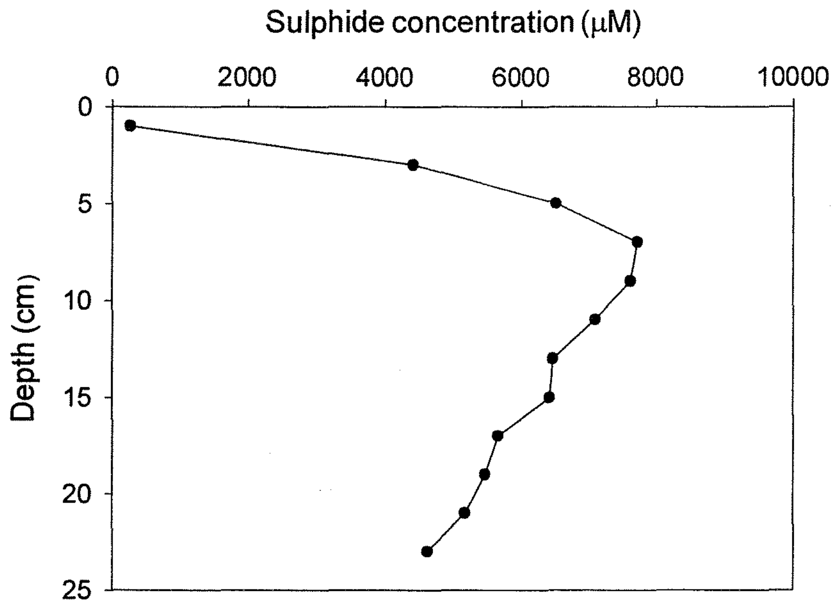

Figure 2: Vertical profile of total sulphide concentrations (μM) in sediments near salmon net pen aquaculture operations, based on samples collected with the Pedersen corer.

PRIOR EVALUATIONS OF SENSITIVE LOBSTER FISHERY HABITAT IN RELATION TO SALMON AQUACULTURE AND NEW MONITORING APPROACHES

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INTRODUCTION

Potential for interaction with lobster fishery habitat has been a recurring issue in aquaculture site evaluation in southwestern New Brunswick, but has not been a consistent feature in DFO science priority setting. The presentation reviewed lobster life history sensitivities, and prior contributions to the aquaculture site evaluation process. Comments were made on science capacity for resolution of cause-effect relationships.

Lobster fishery concerns from aquaculture development include changes to productive capacity of lobster habitats; displacement of fishing activity; ecotoxicological effects through pathways of interaction from chemical and thereputant use; and potential lobster quality and market implications. Fishery activity displacement was not rated highly in early site assessments. Commercial-sized lobsters exhibit seasonal and annual movements that encompass distances of 10s up to 100s kilometres. Thus, it was considered that there was potential for relocation of commercial trapping activity beyond initial aquaculture lease areas. However, the industry has subsequently increased to over 80 growout sites, with recent expansion into areas of major commercial lobster fishing activity. This growth, along with increases in individual lease areas, has increased lobster fishing industry concerns over cumulative impact of aquaculture development.

LIFE HISTORY SENSITIVITIES

In the Bay of Fundy, reproductive phase lobsters move into shallow coastal waters during summer months to complete molting, mating and egg extrusion processes. Lobsters can be resident in specific locations, such as sandy-bottomed coves, for periods of one to two months, and may be present at high densities. Females carry their eggs externally for 9-12 months, moving to deeper water in winter. Egg release occurs in shallow water areas the following summer, often from localized areas of aggregation. Some female lobsters may return to the same summer location following over-wintering in deep water, but most lobsters may be expected to return to different locations.

There are four pelagic larval stages, for which ecotoxicological pathways of concern have been identified from laboratory studies. However, to date there have been no field manipulative studies or oceanographic modelling related to assessment of the potential for impact during the period in the summer during which lobster larvae are present in coastal waters. Ecotoxicological work was not covered in this presentation.

The fourth stage makes the transition to a benthic life habit. In their early juvenile life history, lobsters occupy cryptic benthic habitats, such as cobble and boulder reefs. They can be present at high densities, and occupy such areas year-round for possibly 3 to 5 years. Available information suggests that juvenile lobsters have a restricted annual range of movement. There are clear potential ecological consequences from reduced habitat suitability, related to increased predation risk if lobsters move away from affected areas, or a reduced growth rate and other potential chronic effects if they remain in impacted nursery habitats.

PRIOR EVALUATIONS DURING INITIAL INDUSTRY DEVELOPMENT

Targeted studies by DFO Science on the distribution of benthic stage lobsters in the Fundy Isles Region of the Bay of Fundy commenced in 1989. Through a collaborative project with the Province of New Brunswick (conducted between 1990-93), a large number of coastal locations were sampled by SCUBA-based transect survey approaches to determine the location of adult spawning and juvenile nursery areas. Each annual site application process predicated the dive survey locations in a given year. Nonetheless, the study yielded synoptic information on location of sensitive lobster fishery habitats, from which general geographic areas of concern were defined for input into the site review process during initial industry development.

CASE STUDY 1: SPAWNING AREA USED ON GRAND MANAN

One specific area where a seasonal aggregation of reproductive phase lobsters occurs is Flagg Cove, adjacent to the port of North Head, on Grand Manan Island. Diving- and trapping-based studies by DFO Science in the early 1980's had provided information on the characteristic pattern of distribution of lobsters over summer months in this shallow, sandy-bottomed cove. Subsequently, an aquaculture site was established in this cove in 1989, generating a request to monitor the site for potential changes in spawning area function (see Fig. 1 for location of farm site and monitoring subareas A, B, and C).

To inventory lobster habitat use, divers conducted 300 m x 2 m transect searches for lobsters, measuring lobster size, sex, and reproductive condition (Fig. 1). Lobster density was catalogued by 25 m transect sections, yielding a minimum sample unit of 50 m^2. In general terms, this seasonal assemblage is dominated by large berried (external egg bearing) lobsters in an approximate ratio of 7 berried: 2 non-berried: 1 male lobster. The aquaculture site was only active between 1989 and 1991. During the period of site occupation, a shift was noted in the habitat use by reproductive phase lobsters (Fig. 2). Prior to the farm site establishment the density of lobsters was higher towards the port of North Head (Area A>B>C). During the period of site occupation, densities in this area were reduced (Area A<B=C). Following site removal, the historical pattern of site occupation was re-established (Fig. 2).

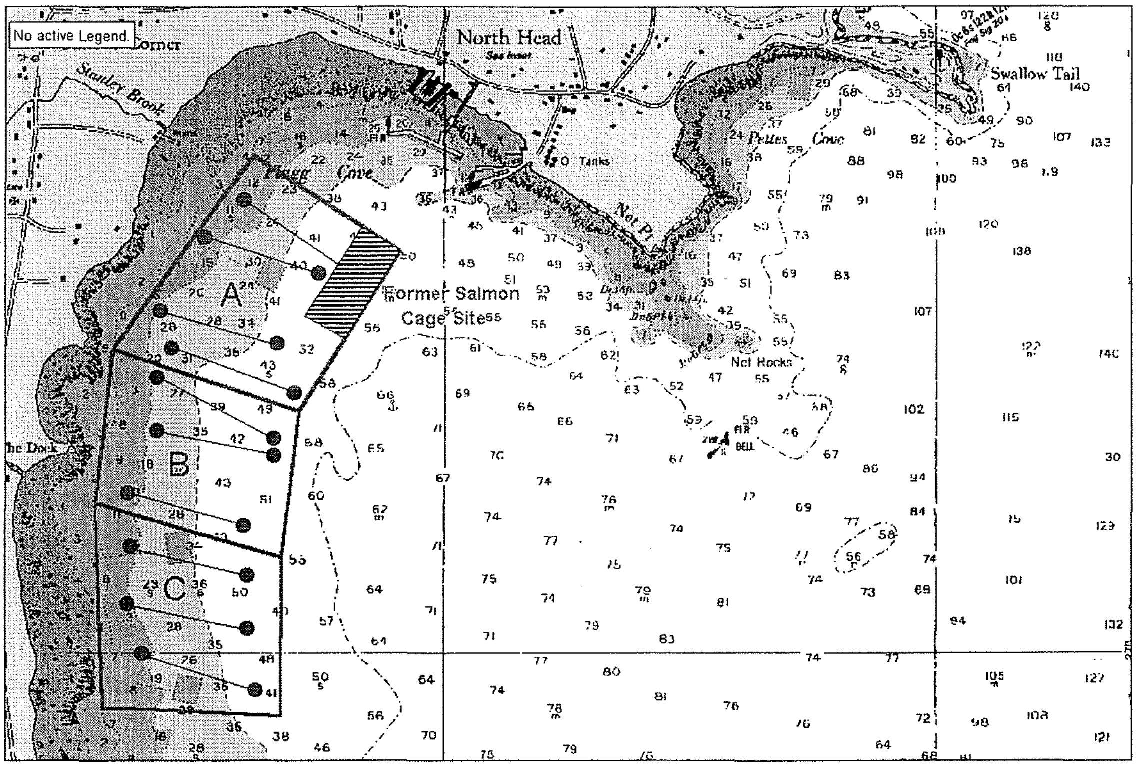

Figure 1: Spawning area in Flagg Cove, adjacent to port of North Head, Grand Manan Island. Lines bounded by filled circles represent general location of 300 m transects in each subarea.

It is important to note that the dive-based monitoring was not designed to evaluate cause-effect relationships; the change in habitat use pattern is consistent with an effect from the farm site, but this cannot be proven.

This location has been monitored on an annual basis since the initial farm site study was completed. The primary area of occupation has remained subarea A. Although population densities have shown a rising trend, and there have been changes in lobster size structure, lobster densities in Area C have never risen to the levels seen when the farm site was occupied.

RESEARCH TECHNIQUE DEVELOPMENT

During the mid- to late-1990's significant advances were made in research capacity for evaluating lobster habitat use, under funding from DFO's High Priority research project CLAWS (Canadian Lobster Atlantic Wide Studies). Much of this work involved consideration of techniques to document the spatial pattern of lobster habitat distribution using marine geomatics approaches such as side-scan sonar. Additionally, redesign of Informatics approaches has better serviced needs to document lobster habitat sensitivity at different temporal and spatial scales. A Crustacean Research Information

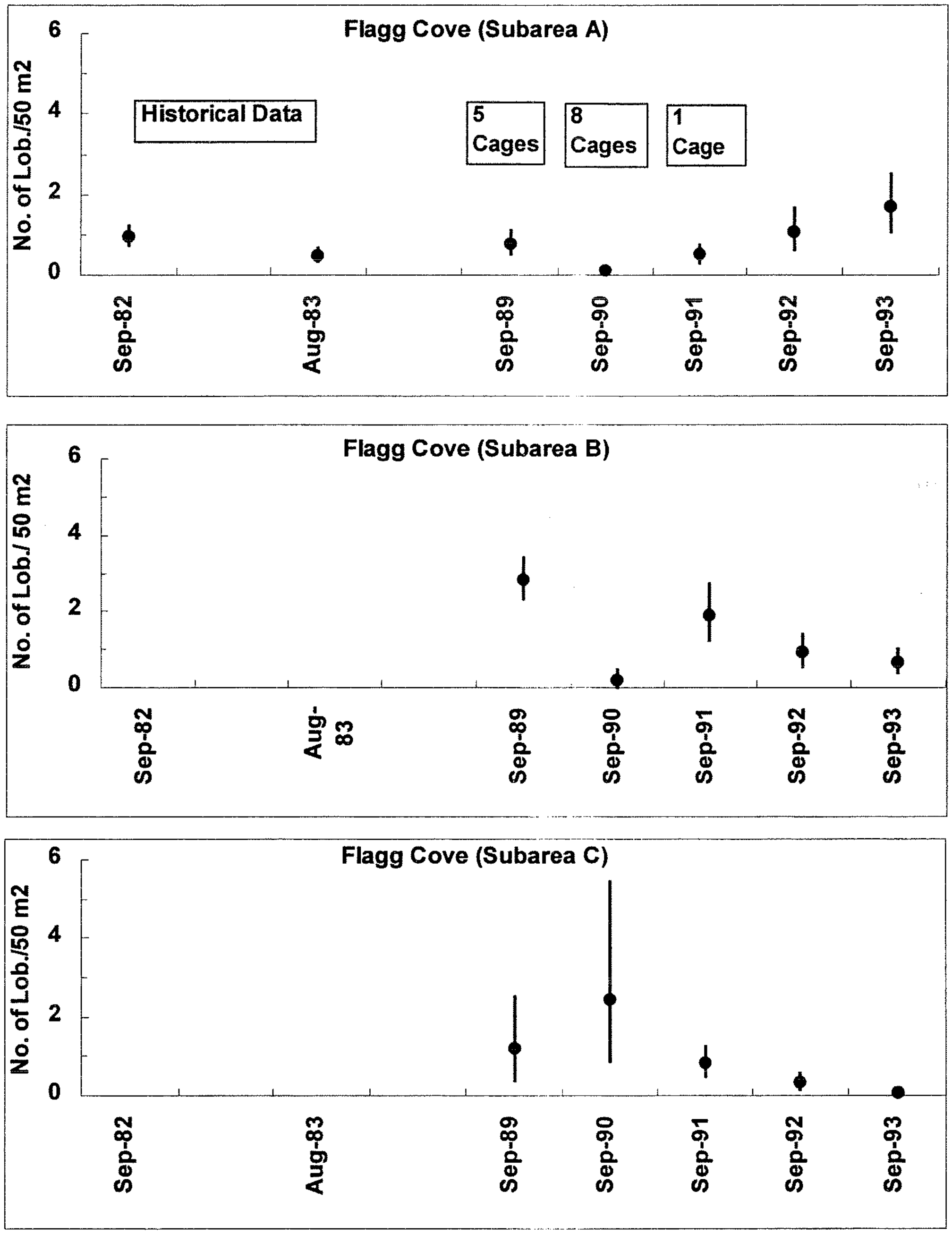

Figure 2: Changes in habitat use by lobsters in Flagg Cove, 1982-1993. Density (mean ± SE) of lobsters in three subareas, derived from SCUBA-based transects.

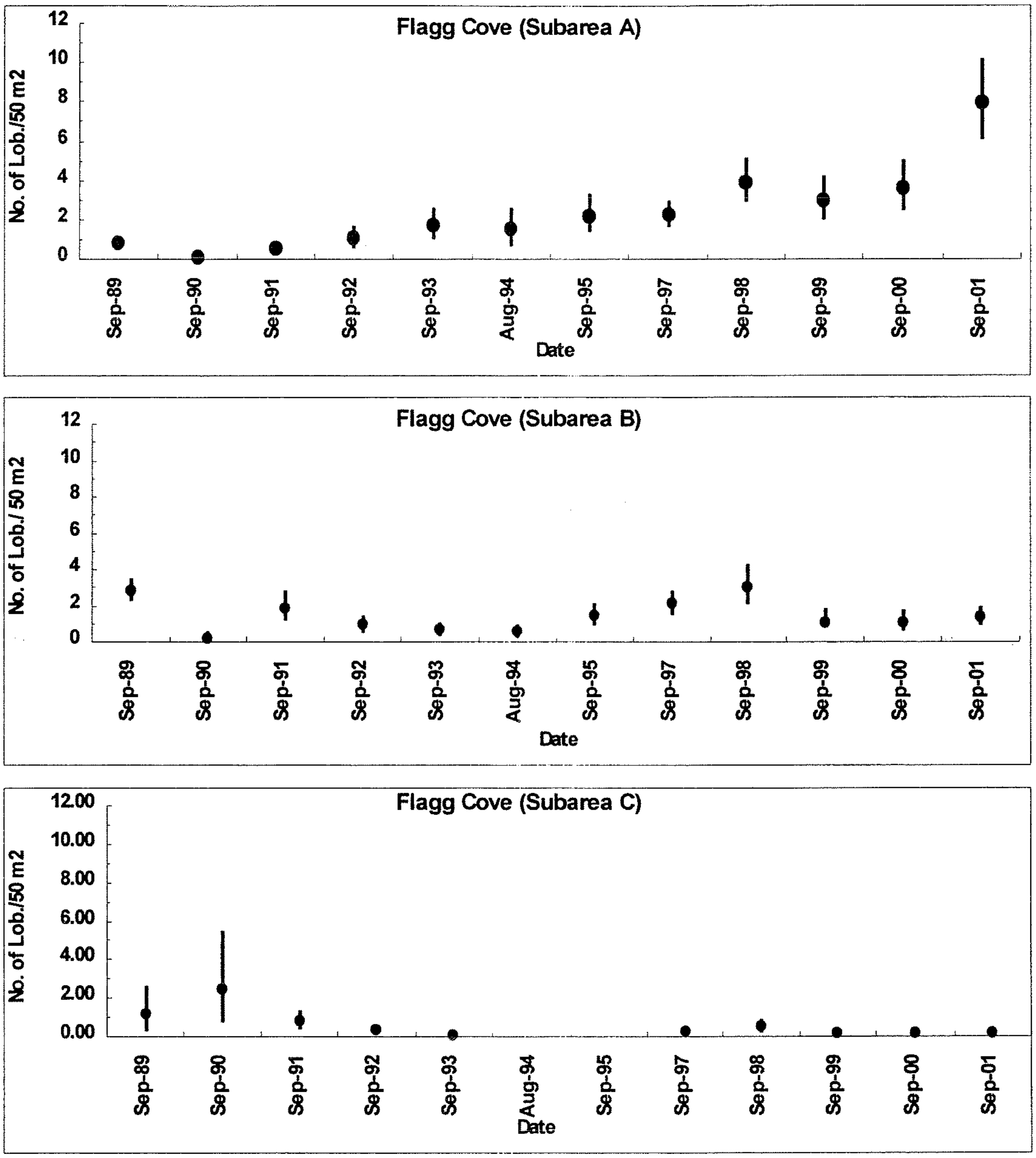

Figure 3: Changes in habitat use by lobster in Flagg Cove, 1989-2001. Density (mean ± SE) of lobsters in three subareas derived from SCUBA-based transects.

System (CRIS), developed between 1997 and 2000, comprises geo-referenced Oracle databases for lobster fishery data and habitat research projects. Adoption of Virtual Data Centre\ SQL Query Library approaches allows for efficient response to ad hoc requests for advice on lobster habitat sensitivity in relation to farm site applications.

From diving and trapping studies conducted under the CLAWS project we have been able to construct decadal scale contrasts in lobster size structure and relative population density in a number of specific locations where there were comprehensive historical surveys. Areas were selected where no farm sites had yet been approved directly adjacent to historical survey locations. Resurveyed locations have shown temporal persistence in nursery and spawning habitat function. The actual densities observed have varied over time (increasing during the 1990's), reflective of general recruitment trends seen in lobster populations in the Bay of Fundy-Gulf of Maine area. Thus, our prior evaluations of habitat function, conducted in the early 1990's, are considered to be still pertinent to current site reviews.

NEW MONITORING APPROACHES FOR CONDITIONAL INDUSTRY EXPANSION

During 2001, two aquaculture site proposals in areas of concern from a juvenile lobster habitat perspective were provided with conditional approval. Enhanced environmental monitoring and an integrated research program were established in 2001. Industry contributors include the two aquaculture companies, and the New Brunswick Salmon Growers Association, with program services provided by consultants CoastalSmith Inc., AMEC Earth and Environmental Ltd., and Canadian Seabed Research Ltd. The Provincial/Federal partners include the New Brunswick DAFA; ACOA; and DFO as the Lead Agency under its CEAA responsibilities.

Relative to the new program, monitoring/research components established in 2001 are monitoring for change in habitat characteristics and function using physio-chemical sediment sampling; habitat characteristics from video analysis; repetitive side scan monitoring of control and potential effect areas, and suction sampling for lobster density estimation.

Under the program, associated hydrographic assessments will provide for a better coastal oceanographic characterization and testing of effect and control area designations. Industry partners are providing associated farm activity documentation, and committing to a trigger/response plan. In light of the identified concern on juvenile lobster habitat quality and uncertainty over the power of the monitoring to detect change, trigger points for action under the existing industry Environmental Monitoring Guide have been elevated.

The program has a comprehensive management program involving a Science review committee, which reports to a multi-agency Steering Committee. Recommendations from the Steering Committee are made to DFO, which is identified as the agency responsible for decision making.

SUMMARY

Relative to general assessment of site applications, decadal-scale comparisons of lobster habitat use in a few key locations in the Fundy Isles Region indicates a temporal persistence in nursery and spawning habitat use, although actual densities vary over time (increasing during 1990's). This means that prior evaluations of habitat function remain pertinent to current site reviews.

In relation to the site review process and effects monitoring, the review process is still largely constrained by site-specific approaches. The existing provincially mandated pre-site monitoring guidelines are inadequate for full evaluation of lobster habitat concerns. This has led to a reliance on available DFO information and capitalization on information gaps by proponents.

New agreements for research and monitoring protocols, linked to specific triggers and management responses for aquaculture development projects in areas of concern from a lobster habitat perspective, provide the potential for more rigorous evaluation. However, there is only limited capacity to expand these research projects to determine cause and effect relationships. The site review and approval system would benefit from the definition of a series of categories of concern. Restrictions on additional permitting should be introduced when an unresolved concern is already being addressed through a conditional development agreement, such as that described in Case Study 2.

Finally, there is a need for reassessment of existing aquaculture sites in relation to current concerns. New monitoring approaches and insights derived from current research at conditional development projects should be applied back to prior-approved sites to determine whether or not there has been persistence of lobster habitat function generally at sites where there has been long-term farm activity.

SALMON AQUACULTURE, DISSOLVED OXYGEN AND THE COASTAL HABITAT: SCALING ARGUMENTS AND SIMPLE MODELS

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INTRODUCTION

One of the important water quality characteristics fish farmers need to be concerned about is the concentration of dissolved oxygen (DO). Salmon growth rates are reduced when the fish are reared in low oxygen conditions. Concentrations less than 6-7 $mg{\cdot}L^{-1}$ often result in increased levels of stress and hence greater susceptibility to disease and levels below about 2 $mg{\cdot}L^{-1}$ may result in death to salmon (Davis 1975). Reduced DO concentrations are also a potential environmental impact of aquaculture and hence should perhaps be considered to be an environmental variable to be monitored and regulated by habitat managers.

Independent of the presence of salmon farming, ambient DO concentrations in coastal zones vary seasonally. Typically, levels are near saturation during the winter, may be super-saturated in the spring, and under-saturated in the fall. Hence, DO available to caged salmon vary seasonally. The consequence of this variability to caged fish depends upon the actual ambient concentrations, the local oxygen demand by a farm or farms within an area and the rate at which the water is moved through a farm and bay.

One approach to estimating the impact of ambient DO on caged salmon, and to estimate the impact of caged salmon on ambient oxygen levels, is to use models that consider the supply and demand of oxygen. Hence, in the following we briefly describe a relatively simple model that estimates DO concentrations in a fish farm based on the ambient oxygen concentration, the demand for oxygen by caged salmon and water current.

MODEL DESCRIPTION

We consider the concentration of DO inside a fish cage to be controlled by three processes. The removal of DO from within the cage occurs through the respiration demand generated by the fish and the movement of water into and out of the cage which supplies water with an ambient DO concentration and removes water from the cage with the internal DO concentration. The model assumes that water within the cage is instantaneously and completely mixed. The model can be expressed in words as the time rate of change in DO inside the cage equals the flux in minus the flux out minus the internal sinks. The corresponding differential equation is

$$\frac{dC}{dt} = \frac{U \cdot Ca}{L} - \frac{U \cdot C}{L} - R \cdot M \cdot N$$

where C and Ca are the DO concentrations within and outside the cage (the ambient concentration), respectively. U is the effective speed of the horizontal water current entering and exiting the cage, L is the length scale of the cage, R is the specific respiration rate of the salmon, M is the weight of the individual salmon and N is the number of salmon in a unit volume of water within the cage. R was estimated by deriving an equation from the literature that estimates R as a function of fish weight, swimming speed, water temperature and feeding rate.

MODEL RESULTS

We derived analytical and numerical solutions to the above equation and used these to explore the time dependant behaviour of DO in a fish cage and the sensitivity of the behaviour to the various inputs. Our inputs were based on environmental and husbandry information gathered and modelled over the years from the Quoddy Region of southern New Brunswick in the Bay of Fundy.

For a fixed set of parameter values, and a positive current speed (U>0), the model predicts that DO concentrations in a cage will decrease exponentially with time to a steady-state level (Fig.1). Whether the DO reduction is of biological consequence depends upon the critical concentration of DO. Several hypothetical examples of this concentration are labelled as Ccrit in Figure 1. Whether these critical concentrations are achieved in a fish cage depends upon whether the water current remains at the modelled speed for at least the length of time required for the DO concentration to decrease from ambient to the critical level. If there is no current (U=0) the concentration of DO decreases linearly until the fish die due to lack of oxygen.

To explore how the predicted DO concentrations within a cage vary over the grow-out cycle of a year-class of fish reared at a typical stocking density (4 fish$\cdot$m^{-3}) we used the model in conjunction with input time series of ambient DO, water temperature, fish sizes and fish densities. As described by Page and Martin (2001) there is an annual cycle in the ambient concentration of dissolved oxygen in the Quoddy region (Fig. 2). The model suggests that the caged fish have the potential to amplify the seasonally low in the ambient DO concentrations in late summer and fall months. During the first year of grow-out the caged fish in the example do not reduce the DO to critical levels. However, during the second year of growth, when the fish are much larger with correspondingly higher respiration rates, DO levels are reduced to critical concentrations. The amplification potential is greatest for cages with fish having the highest growth rates.

Whether the potential amplification occurs depends upon whether the current remains at a sufficiently low speed for long enough to allow the DO within the cage to be reduced to the critical concentration. In general, it appears that this is not the case during the first year of growth. However, during the second year, the length of time needed to reduce the DO concentration to the critical level by fish respiration is less than 1 hour. Examination of a current meter record from a location near a fish farm in the Quoddy Region (Fig. 3), indicates that the current can in fact be sufficiently weak (<0.01-0.02 m$\cdot$s^{-1}) for the periods of time that are required for the pre-market caged fish to reduce the DO concentration to a critical level. Preliminary experience with the model suggests that, as a crude rule of thumb, current speeds of 2 $cm \cdot s^{-1}$ or less for time periods of 1 hour or more indicate a potential for reducing DO to critical levels.

In addition to the above brief overview of the modelling approach, we have used a tidal circulation model for the Quoddy Region of southern New Brunswick (Greenberg 2001) to identify locations where critical combinations of current speed and duration are predicted to occur. We have also extended the model to include the case of several fish cages within a farm and used it to consider the influence of the fish-generated DO deficits on bay-wide areas.

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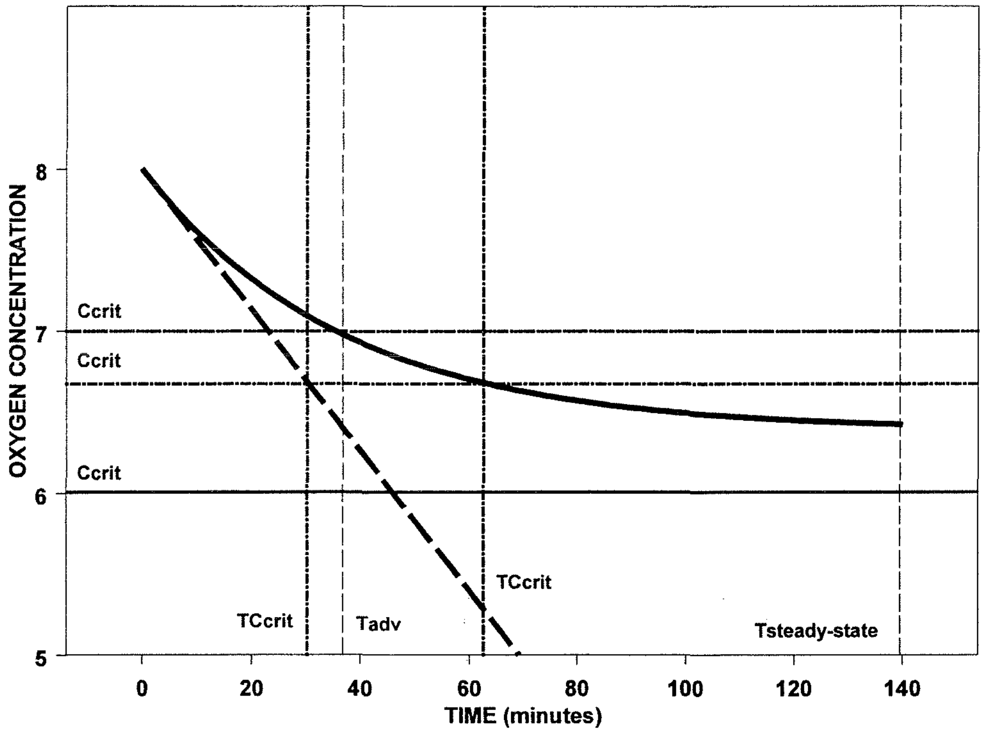

Figure 1: Model predicted time dependant behaviour of the concentration of dissolved oxygen when the model parameters are held constant. The heavy solid curve corresponds with a positive water current (U>0) and the heavy dashed line corresponds with no current (U=0). The slopes of this curve and line vary with the values of the input parameters. The horizontal lines are examples of critical values of DO. The vertical lines are examples of the time for the DO to become depleted to the critical values (Tcrit) and the time for the water to move through a cage (Tadv).

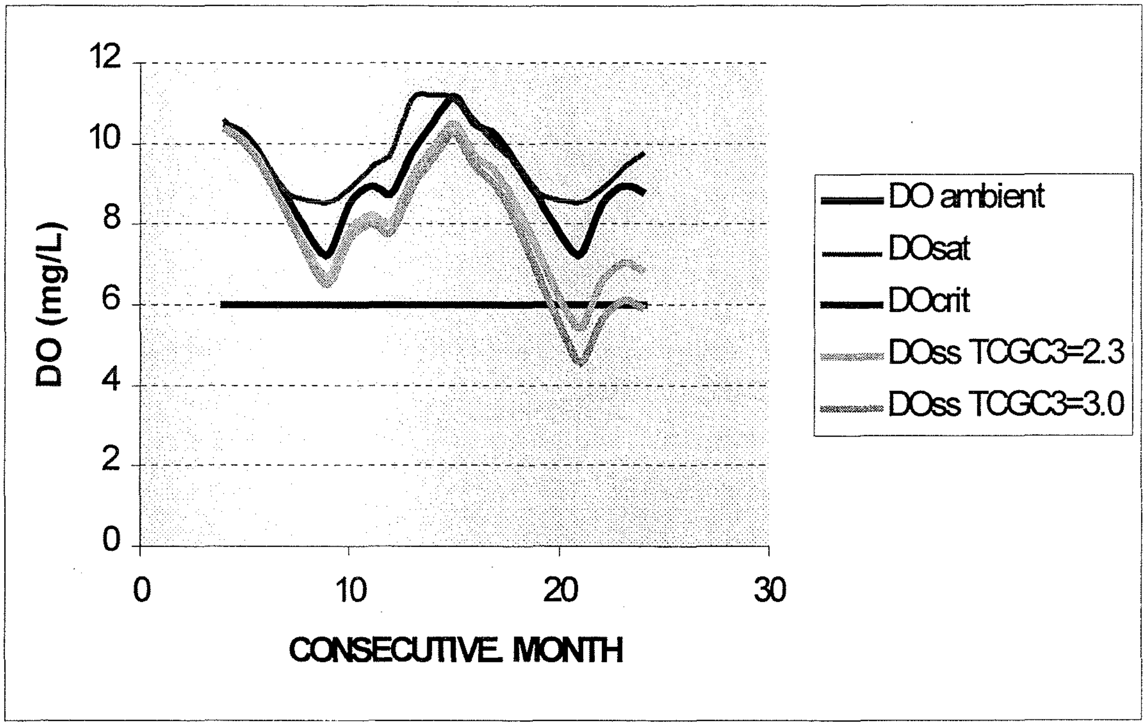

Figure 2: Example time series of the model predicted steady-state concentrations of dissolved oxygen within a salmon cage experiencing a flow of water. The output was generated by assuming the current speed (U) was $0.01 m \cdot s^{-1}$, the fish were not feeding and were stocked at a density of 4 $fish \cdot m^{-3}$. The model assumed temperatures varied according to the monthly means recorded within a salmon farming area within the Quoddy Region. The saturated (uppermost curve) and ambient (solid heavy black curve) concentrations of dissolved oxygen are shown for comparison. Solid gray curves show the DO concentrations for low (light grey) and high (dark grey) growth scenarios. The scenarios correspond with low (2.3) and high (3.0) temperature compensated growth coefficients (TCGGC3). The horizontal solid line indicates a critical DO concentration of 6 $mg \cdot l^{-1}$. The month begins in January of the first year of growth in the sea cages and extends throughout the second year.

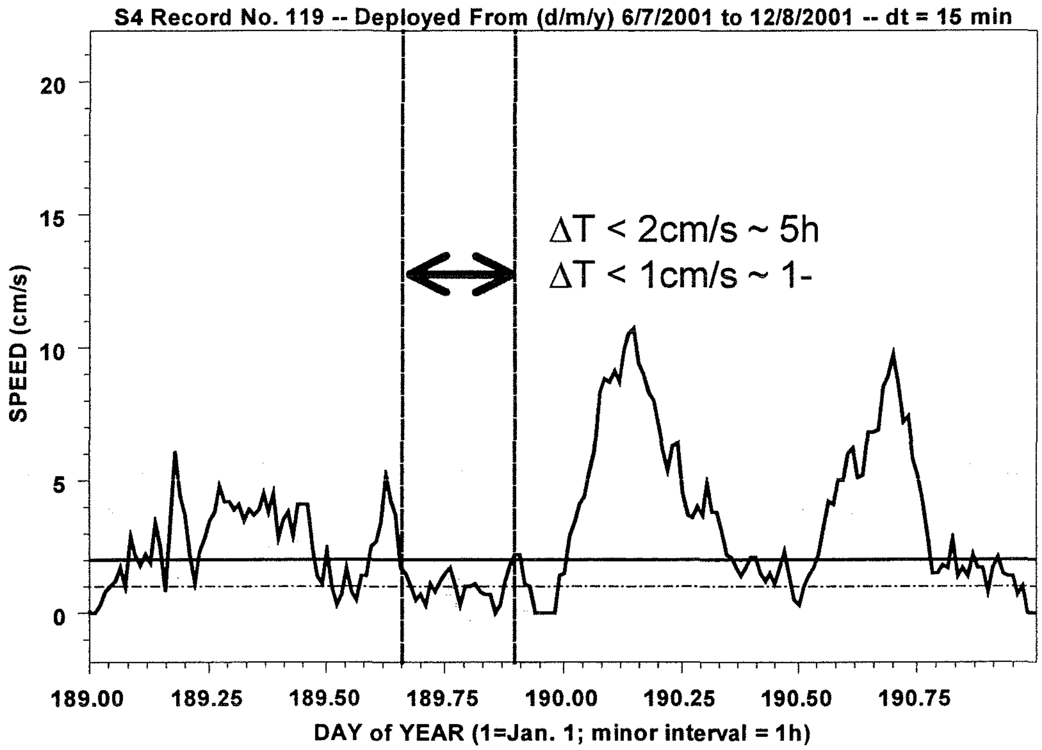

Figure 3: Example of a portion of a current meter time series showing a period when the current speed was less than 2 $cm \cdot s^{-1}$ for approximately 5h and less the 1 $cm \cdot s^{-1}$ for 1-2 hours.

THRESHOLDS FOR ASSESSING ORGANIC MATTER ASSIMILATIVE CAPACITY IN MARINE SEDIMENTS

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Published literature was reviewed to identify general empirical relationships that might be used as a basis to determine thresholds for a Harmful Alteration, Disruption and Destruction (HADD) in marine habitats as a result of development of finfish aquaculture sites. Three types of broad-scale ecosystem changes that might be observed distant from farm sites as a result of finfish aquaculture were identified: 1) increased nutrient supply (eutrophication), 2) increased sedimentation and 3) changes in benthic food web structure and function.

EUTROPHICATION

Eutrophication, the process of natural or man-made enrichment of aquatic systems with inorganic nutrient elements, results from the additions of both dissolved inorganic and organic nutrients and increased biological oxygen demand (BOD) from oxygen-consuming material from all sources (Strain et al. 1995, Cloern 2001). Dissolved inorganic nutrients released by finfish culture and regenerated from sediments enriched with sedimented organic matter under fish pens may stimulate phytoplankton production and increase oxygen demand. It is important to emphasize that additions from finfish aquaculture will be cumulative with other natural and man-made sources of nutrient and BOD inputs. Models can help to determine the relative amounts of organic loading from all sources (river discharge, tidal exchange, rainfall, phytoplankton and macroalgal production) and human inputs due to sewage and industrial discharges (Valiela et al 1997). The degree of additional nutrient enrichment due to net pen mariculture will be influenced by the scale of aquaculture, local hydrographic characteristics, and the magnitude of other sources relative to internal processes such as uptake by phytoplankton, algae, internal (recycling), resuspension of fine material, and uptake by biofouling communities that colonize net pens.

A documented relationship between phytoplankton primary production and increased dissolved inorganic nitrogen supply (Fig. 1) has relevance to predicting eutrophication effects due to release of dissolved nutrients by aquaculture operations. A doubling of inorganic nitrogen input into areas where water exchange is restricted could increase phytoplankton production by approximately 1.6 times. While it may be less often observed, increases in dissolved nutrient concentrations that stimulate phytoplankton primary production may also be positively correlated with an increase in phytoplankton biomass measured as higher concentrations of suspended chlorophyll (Fig. 2).

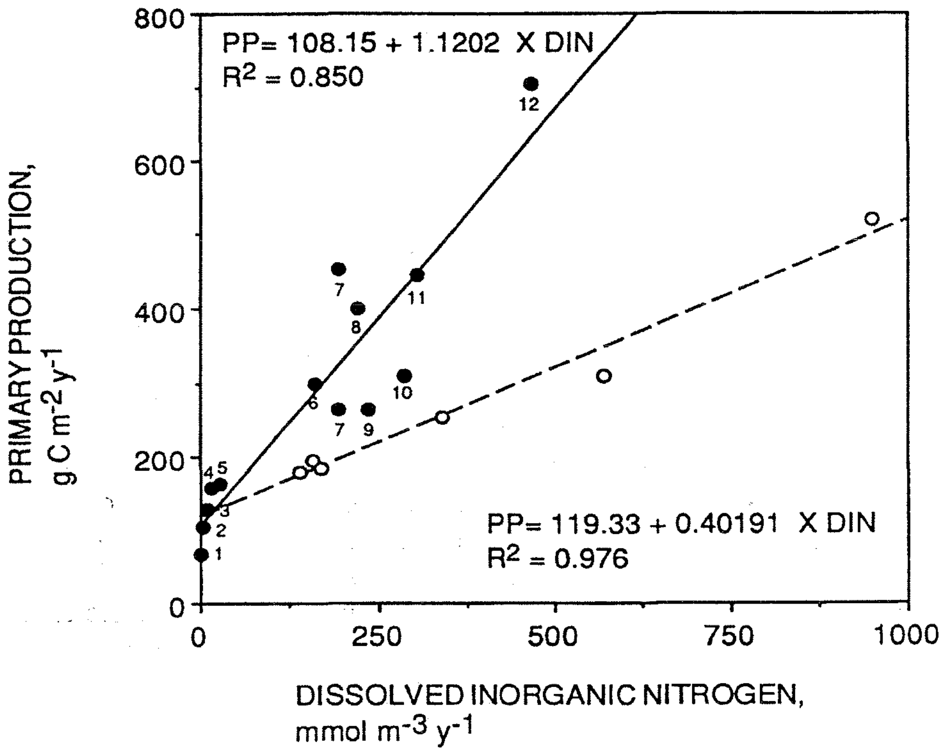

Figure 1: Comparison of phytoplankton primary production in various coastal marine and estuarine areas (solid points) and experimental mesocosms (open circles) and rates of dissolved inorganic nitrogen supply (redrawn from Nixon 1995).

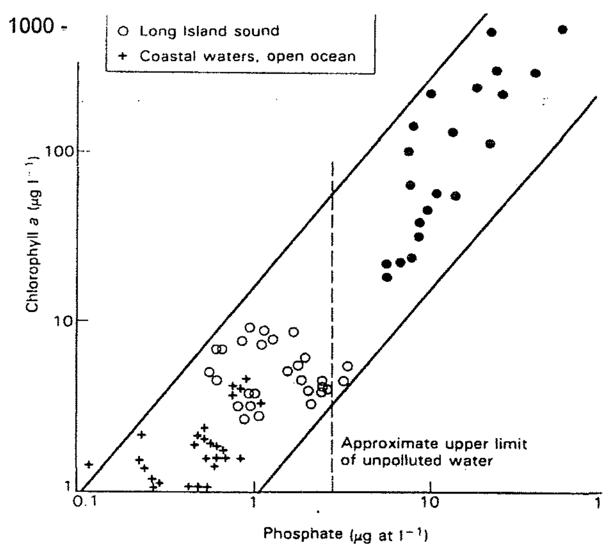

Figure 2: Relationship between inorganic phosphate and chlorophyll *a* concentrations in different water bodies (redrawn from Ketchum 1969).

SEDIMENTATION

In a comparison of data from different northern temperate latitude aquaculture sites Hargrave (1994) concluded that a threshold (~1 g C m^{-2} d^{-1}) existed for sedimentation such that at higher rates oxic surface sediments were replaced by anaerobic deposits. An earlier study under blue-mussel culture lines showed that sedimentation rates >1.7 g C m^{-2} d^{-1} led to increased microbial sulfate reduction and sulfide accumulation (Dahlbäck and Gunnarsson 1981). The enhancement of anaerobic metabolism and formation of anoxic sediments with increased organic loading was similar to a relationship described by Sampou and Oviatt (1991) for a simulated eutrophication gradient with nutrients added to experimental mesocosms. Findlay et al. (1995) and Findlay and Watling (1997) quantified relationships between carbon loading and benthic response at finfish aquaculture sites in coastal Maine. They derived regression models linking benthic respiration (O_2 and CO_2 sediment-water exchange), organic matter sedimentation and oxygen supply (calculated from current velocity). Omori et al. (1994) also described a numerical model that linked aerobic and anaerobic oxidation of organic matter in sediments to sedimentation and sulfide accumulation. These empirical relationships can be used to predict changes in organic matter consumption and storage in sediments with increasing rates of organic loading.

New techniques using multibeam swath bathymetry may provide a method for identifying depo-centers (regions where fine particles accumulate). Tlusty et al. (2000) used EM3000 multibeam acoustic methods to produce detailed bathymetric maps in Roti Bay, where salmon aquaculture sites are established seasonally in Bay d'Espoir, NF (Fig. 3).

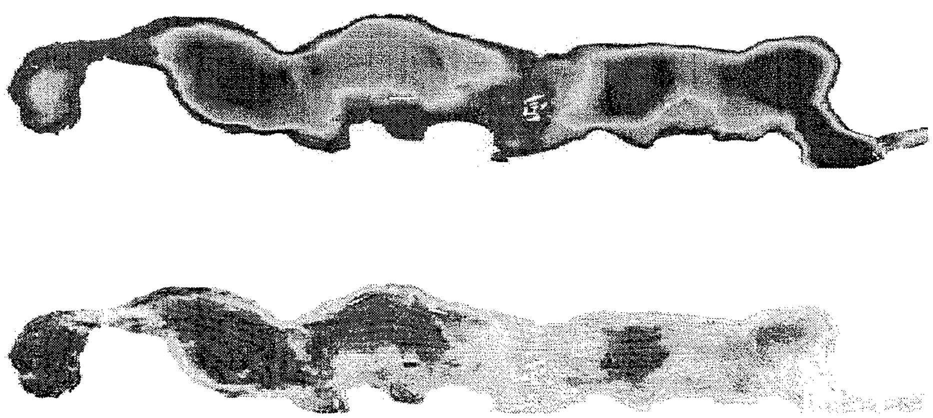

Figure 3: Comparison of acoustic multibeam EM3000 bathymetry (upper panel) and backscatter (lower panel) from Roti Bay, Bay d'Espoir, NF (from Tlusty et al. 2000). Dark grey areas in each panel indicate deeper regions behind sills where fine particles are deposited within the multi-basin inlet.

Variations in acoustic signals (backscatter) that differentiate hard substrates (erosional) and fine-grained sediments (depositional) may also be used to locate areas within an inlet where far field deposition of particulate waste products from aquaculture sites might be deposited. With ground-truthing, correlations between digitized values of backscatter strength and inter-related sediment variables such as porosity, organic matter, sulfide concentrations and measures of sediment oxygen demand may be derived. This allows mapping of inlet-wide sedimentary properties to identify areas of oxic and anoxic sediment in regions of transport and accumulation. The creation of a HADD could be quantified by observations of increased area of anoxic sediments. By deriving empirical relationships between backscatter values and sedimentary geochemical variables at geo-referenced site, it would be possible to map areas of oxic and anoxic sediment. As with all remote sampling, extensive ground-truthing is required to derive algorithms applicable throughout the area of interest.

BENTHIC FOOD WEB FUNCTION

Meyer-Reil and Köster (2000) summarized critical points through which sequential changes associated with eutrophication in coastal waters can be identified. Evidence of enrichment includes increases in inorganic and organic nutrients, microbial biomass and enzymatic decomposition of substrates, nitrification, denitrification and benthic nutrient fluxes. Evidence is also accumulating to show that with increasing eutrophication the ratio of autotrophic to heterotrophic microbial processes is reduced with progressively more organic matter respired in sediments than in the water column (Rizzo et al. 1996).

In oligotrophic and mesotrophic coastal marine systems where high turbidity does not limit phytoplankton production, material flow and cycling predominantly occur in the water column. For example almost two-thirds of total annual oxygen consumption in Chesapeake Bay occurred in the water column (Kemp et al. 1992). In eutrophic, nutrient-rich areas, heterotrophy predominates based largely on stored organic matter in sediments. In coastal areas, this fundamental shift in ecosystem structure may be reflected seasonally during spring and late summer following input of organic matter to the benthos from settled products of algal blooms. A similar shift in pelagic and benthic respiration could occur on an inlet-wide scale in coastal areas as a result of finfish aquaculture activity if increases in sedimentation of fine-grained particles and associated organic matter are sufficient to cause sulfide accumulation in sediments.

Sedimentation rates measured as organic carbon at non-aquaculture sites are usually below a threshold (<1 g C m^{-2} d^{-1}) that would create anoxic conditions in most marine coastal areas (Hargrave 1994). When flux rates are low, deposited organic material is rapidly decomposed and remineralized resulting in minimal accumulation of reduced metabolic by-products and low amounts of organic matter storage in deeper sediment layers. However, under hypertrophic conditions with very high rates of organic sedimentation and restricted oxygen supply, anaerobic processes such as sulfate reduction predominate. This leads to the build-up of $S^{=}$ and H_2S gas within surface sediment layers.

The transition from predominantly aerobic to anaerobic metabolism along a benthic enrichment gradient can be measured by sulfide accumulation and by incubating undisturbed sediment cores and following changes in dissolved O_2, CO_2 or dissolved nutrients in supernatant water. Measurements of benthic metabolism at net pen and reference sites >500 m away in the Letang area, NB, show the change from predominantly aerobic to anaerobic respiration at a threshold sulfide concentration between 200 and 300 μM $S^{=}$ (Fig. 4).

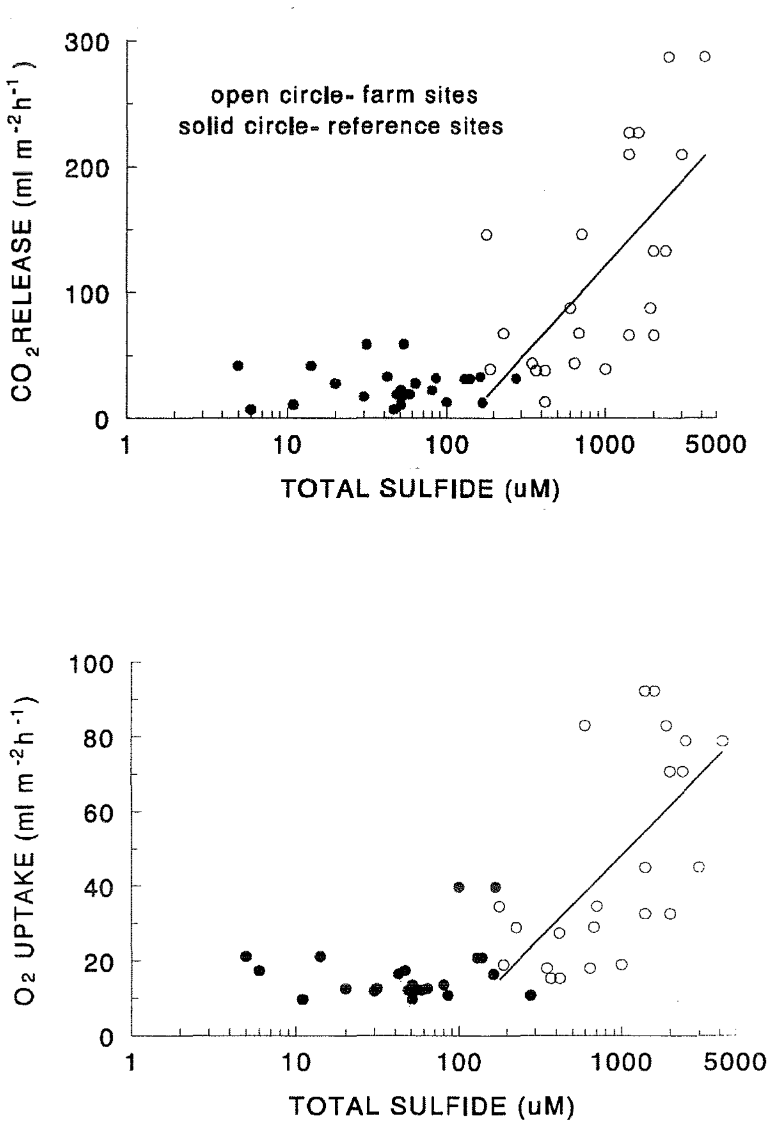

Figure 4: Changes in benthic O_2 and CO_2 flux related to $S^{=}$ accumulation in sediment along an organic enrichment gradient associated with salmon farm aquaculture sites and reference sites >500 m away in southwestern New Brunswick, Bay of Fundy. Redrawn from Hargrave et al. (1997).

Highest levels of $S^{=}$, gas exchange and NH_4^+ release occurred at farm sites that had experienced high rates of organic loading. Only a few locations had elevated flux rates at distances >100 m from farm sites, although some reference locations had slightly higher rates of benthic respiration and ammonium flux than average values for sites away from cage sites. The observations show that changes in benthic community metabolism may be useful as indicators of thresholds for organic enrichment that reflect a shift from predominantly aerobic to anaerobic respiration.

BENTHIC FOOD WEB COMMUNITY STRUCTURE

Changes in benthic infaunal community species composition (structure) are often associated with increased nutrient and organic matter additions. Some small-sized benthic fauna capable of rapid growth rates (e.g. nematodes and polychaetes) and tolerant of low oxygen conditions and reduced sulfides are able to thrive under conditions of high organic sedimentation and sulfide accumulation. The presence/absence of these 'indicator' faunal groups may be used to indicate a transition from low levels of organic matter supply to higher deposition rates. Moderate increases in organic matter supply may stimulate macrofauna production and increase species diversity. However, with increasingly higher rates of organic input, diversity and biomass usually decrease. Only fauna tolerant of low oxygen conditions are able to survive under conditions of high organic sedimentation and accompanying high concentrations of sulfide (Nilsson and Rosenberg 2000). The distribution of sulfide-tolerant benthic infauna around aquaculture sites may therefore be used to show a transition from background levels of organic matter supply to high deposition rates.

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NHMWGA/ESSA WORKSHOP SUB-GROUP DISCUSSION

GROUP 1 (Facilitator- Barry Hargrave, Rapparteur-Jennifer Nener)

Throughout the day, some very informative research results were presented addressing three key issues:

1. Siting Criteria, and modelling for aquaculture operations to minimize potential for a HADD;
2. Thresholds for variables useful for identifying HADD in water and sediments – Marine Environmental Quality Indicators
3. Cost Effective Monitoring Tools/Techniques – water and sediment variables for application to assessing potential for far and near-field effects.

The sub-groups were intended to discuss the information presented and whether the work underway will adequately address/respond to the key issues, and identify any additional key issues that need to be addressed. Key items of discussion are summarized under the three general areas identified above.

Siting

Appropriate farm siting is key to ensuring a viable farm for proponents, and to minimizing environmental impact of the farm. Proponents formerly located finfish farms in areas that were relatively sheltered, which often resulted in benthic impacts due to deposition of farm wastes. Proponents are now being advised to locate farms in areas with higher currents that can disperse farm wastes and increase the opportunity for assimilation by the receiving environment. These sheltered areas with lower currents tend to have lower natural productive capacity, while areas with higher flushing usually support greater species diversity and comparatively high natural productive capacity. It was identified that the approach being taken with finfish aquaculture is, from some perspectives, inconsistent with other industries, which are normally directed away from highly productive environments. As well, when farms are located in areas with greater immediate dispersion, far-field impacts may result from deposition occurring away from the farm site. Effects may go undetected because they occur beyond the area where environmental monitoring occurs. Some biologists question the rationale of locating farms in areas with higher habitat values where it is more difficult to assess impacts, versus locating them in low-current areas were impacts can be more easily measured, and remediation results assessed. This question may be addressed over time by results of ongoing research on far-field effects, and via environmental monitoring programs that most finfish farms are required to implement.

For the first time, models are being developed that couple physical and ecological factors to provide a means of predicting the ability of an area to support finfish farms. Such models could be used both for planning purposes by industry and government, and for assessment of individual project proposals. Unfortunately, most of Canada's coastal areas do not have models that could provide this predictive function.

Underwater mapping (e.g. using multi-beam) can provide valuable information for use both as a planning tool, and for assessing site suitability. Again, such information is not available for many areas of Canada's coasts. When backscatter information is ground-truthed with environmental variables, multi-beam acoustic methods can also provide a valuable monitoring tool by revealing areas of impact (near-field and far-field), and identifying areas where sampling efforts should be focussed.

Thresholds for Determining a HADD

More work needs to be done to establish linkages between biological variables and chemical surrogates, if chemical variables are to be used as a means for determining a HADD. Such work is underway in several DFO regions, however, sediment characteristics vary considerably and this can complicate interpretation of information. As well, relationships between key variables can be influenced by natural environmental conditions. For example, large inputs of Dissolved Organic Carbon (DOC), and high levels of wood fibers or other organic matter in sediments may complicate linkages between sediment sulfide levels and redox potential. Ultimately, it would be useful to compile and assess the results of studies being done across Canada to develop guidance regarding thresholds for impacts or HADDs, and how they might best be measured or assessed for different natural sediment types.

Monitoring Tools/Techniques

There was some general discussion about the importance of understanding present circumstances at finfish sites, so that we can "hind cast" and avoid further impacts to the environment in the future. Achieving both of these goals requires working with biologically meaningful monitoring parameters.

Participants discussed the value of focussing on variables that are relevant to all aspects of finfish projects (i.e. from site selection, pre-operational baseline assessment, environmental monitoring during farm operation, and post-production remediation). This is key to both working with thresholds of concern with respect to producing a HADD, and for cost-effectiveness. There may be a need to conduct more research on appropriate tools for monitoring site recovery, and the linkages between levels of key variables in upper sediment layers with biological recovery.

The partitioning of solid and dissolved wastes, and the need to monitor both, was discussed. To date, most of the research focus on impacts of finfish farms has been on solids. Dissolved substances can cause both acute (e.g. as a result of application of therapeutants) and chronic effects, and can move much farther than solids, therefore potentially impacting a larger area. Research on effects of chronic and acute exposure to various dissolved substances could be particularly important in areas with high densities of fish farms. This would be of great assistance to resource managers who must consider cumulative environmental effects when completing environmental screenings in accordance with Canadian Environmental Assessment Act (CEAA) responsibilities.

General Conclusions

The research programs in progress are generating some very interesting results that should provide significant guidance to biologists responsible for making resource management decisions. As with all good research, many of the results generate another series of questions. The ongoing research programs are a key step to developing and implementing an appropriate management framework for the aquaculture industry.

GROUP II (Facilitator- Wayne Knapp, Rapparteur- Melanie MacLean)

There was general agreement in our discussion group that ultimately aquaculture development should proceed according to an integrated/coastal zone management (I/CZM) approach rather than the current farm-by-farm siting and adjudication process. It was recognized, however, that much needs to be done before we can adopt such processes and in the short term it will likely be necessary to continue to assess farm applications on a site-by-site basis. We also need to focus not only on new aquaculture sites, but also continue to address impacts and concerns at existing sites.

Research Issues

Much is being learned from the current aquaculture research, however, there will be an ongoing need to improve our understanding of the processes involved with aquaculture if we are to ensure environmentally sustainable development of this industry. Some of the issues and questions, which were raised by the group, include:

- How to deal with natural variability in the environment?
- How to determine cause-effect relationships?
- How to determine thresholds that can be fully supported by science?
- How to predict/monitor long term changes to the environment?
- How to determine appropriate indicators for predicting/monitoring changes to the environment, particularly in an ecosystem context?
- Where should monitoring take place; near field versus far field effects?
- Should specific and/or ecosystem based indicators be used in assessing aquaculture?
- What are the necessary criteria for a healthy environment?

Policy Issues

In addition to the many science questions that need to be addressed there are a number of important policy terms that need to be clarified. For example:

- What is a HADD; more precisely can we define proactively and prescriptively what factors need to be considered, in determining HADDs before they occur?
- What is critical/sensitive/important fish habitat?
- How do we define and apply the precautionary approach to aquaculture?

While Habitat Manager's often turn to Science for advice on these questions, it may not be entirely possible for this to be addressed solely by scientists.

In terms of the move towards a more zonal approach to assessing the siting of aquaculture operations there were a number of comments offered:

- We need to pursue comprehensive mapping programs, detailed characterization of the environment and identify/rate geographical areas of primary concern (i.e. to fish and fish habitat). Over the shorter-term it may be possible to focus on the physical environment (e.g. oceanography, geography) using remote sensing devices (e.g. satellite) because this will often determine the biological environment in a particular area.

- Systems such as a Decision Support System under development to provide a method for consistent evaluation of site suitability for new license applications may be useful towards development of other aquaculture site planning tools.
- There was recognition that the Oceans Act has an important role to play in integrated management and scientists and habitat manager's should involve appropriate staff with direct responsibilities for the Act in their activities, particularly those relevant to aquaculture planning processes.
- Proactive planning that determines where aquaculture will/will not be permitted in specific geographic areas would reduce the amount of time and effort required of aquaculture proponent (i.e. would avoid unnecessary efforts investigating sites that are unlikely to ultimately receive approval).
- There are some examples where integrated culture techniques are being developed (e.g. finfish and shellfish on same site) aimed at potentially reducing nutrient inputs into the environment. Such integrated approaches may to some degree address both regulator (environmental impacts) and culturist (i.e. net fouling) concerns.

Operational Issues

Much of the focus to date has been on regulating the impacts of organic waste deposition on the fish and fish habitat in the marine environment. There are, however, other important operational issues for the industry that must not be forgotten, including:

- Disposal of bloodwater
- Identification of which pesticides are acceptable for use in the marine environment and how they should be handled, controlled, and impacts assessed
- Evaluation of toxins such as copper and PCBs, food waste, drugs/resistant bacteria
- Development of acceptable management practices for these and other issues should be based on scientific knowledge which would provide information on expected environmental effects

There were a number of comments related to monitoring and assessment of aquaculture waste discharges:

- The regulatory strategy to date (e.g. Section 35 Guide) has been focussed on soft bottom sediments. Deposition of waste materials on hard surfaces, in erosional environments (including those involving seasonal waste deposition) in such areas, is not well understood. The assessment and monitoring tools required to better understand effects on these environments need to be pursued.
- How can we apply baseline and monitoring data collection techniques from finfish farms to other types of aquaculture (i.e. smaller versus larger aquaculture operations)?
- There is a need to develop reliable tracers to study far field effects in order to determine if there is a link back to the aquaculture site.

Habitat-Science Collaboration

- There is concern that to date there has been a certain lack of Science involvement in several aquaculture-related initiatives, including development of the Section 35 Guide and the various CEAA information requirement guides. Recognized as a factor was the relatively short time frames available to all sectors for reviewing various drafts of such documents. We need to pursue improved mechanisms for dialogue between Habitat and Science to ensure to the degree possible that these documents are supported by good science.
- Concerns were expressed by Habitat Manager's that it is often difficult to obtain the timely (i.e. within the operational time frames) scientific information/advice necessary to ensure that decisions are scientifically defensible.
- There is a need for improved means of dialogue between Habitat Managers and Science. Integrated Habitat-Science workshops (such as this) were seen as a useful mechanism in this regard.

GROUP III (Facilitator and Rapparteur- Jim Ross)

Terms such as "no net loss' and "productive capacity" that are used in the Policy for the Management of Fish Habitat are very difficult to define. There was general agreement in the group that these may, in fact, be unattainable goals for science to meet. It may be more helpful to Habitat Management's responsibilities to focus on larger-scale options that encompass zonal approaches such as:

- the development of ecosystem objectives
- performance-based objectives (PBS)
- the use of adaptive management to address uncertainty
- using polyculture methods to address specific concerns

The use of such options should be combined with general habitat and resource mapping, industry codes of practice, best management practices, etc., to ensure an environmentally sustainable industry. But, ecosystem objectives cannot be achieved without a mutual understanding of the goals and responsibilities of industry and regulators. Any goals or standards that are set as a result of approaches such as ecosystem objectives should be considered mobile, subject to revision to address changing technologies and better scientific understanding of the effects of impacts.

There are many models available to deliver such large-scale approaches such as:

- Atlantic Coastal Action Program (CAP) [http://www.ns.ec.gc.ca/community/acap/index_e.html]
- Conservation Authorities in Ontario [http://www.svca.on.ca/calinks.htm]
- Guysborough County (NS) Sustainable Aquaculture Initiative - The goal of the project is to develop a GIS-based information support tool to analyze comprehensive aquaculture siting criteria.

Discussion focussed next on making sense of the multiple jurisdictions – who should lead this? To a great extent this depends on the type of delivery model adopted. Historically, success and results seem to decrease with an increase in the number of jurisdictions involved. This points to the need to ensure that the front end of such projects are adequately considered before moving further ahead.

Finally, discussion turned to the fact that monitoring was required to drive this. It is necessary to determine the key parameters to monitor and establish who is responsible to undertake the monitoring. A concern was expressed that different indicators may be appropriate in different situations and monitoring could be developed around already existing databases.

ESSA 2002 PROJECT ABSTRACTS

ESSA PROJECT OVERVIEWS (2001/2002)

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SUMMARY

The overall aim of ESSA is to develop and apply models and assess new methods to determine far field effects of finfish (salmon) aquaculture. The second year of the three year project has been completed. Progress during the past year has included further applications of a finite element model (FEM) to predict water circulation and mixing, dissolved oxygen and nutrient dynamics, particle dispersion and accumulation. Seasonal (summer/fall/winter) observations of sediment geochemical and macrofauna variables have been undertaken and multibeam (EM3000) data to identify areas of soft sediment in depositional areas is now available for all areas. Project status updates were provided to Habitat Management at the national level (National Habitat Management Working Group on Aquaculture), provincial, and industry committees (NB-Aquaculture Environment Co-ordinating Committee, BC-Technical Advisory Group) during 2001. Four students have been involved in the project and partnerships have been formed with industry and universities.

ATTENTION AREAS

A review after the first year of the ESSA project emphasized the need to link physical and biological models with appropriate space/time scales to identify far field effects of finfish aquaculture (Silvert 2001). As the presentations at the ESSA 2002 workshop summarized below demonstrate, there has been progress in identifying the distribution of variables sensitive to organic and nutrient enrichment that can be modelled to assess environmental changes away from cage sites. Progress in modelling is shown by the development and evaluation of oxygen mass balance models linked to physical circulation models. However, there has been less progress in identifying or measuring broad-scale ecological effects.

One recommendation from the ESSA 2001 workshop was that additional effort should be given to communicate results with industry and provincial government departments (Cross 2001). The joint NHMWGA/ESSA workshop summarized in this report represents one effort towards increasing communication between science, managers and industry representatives. The meeting attempted to link science to management questions and represented a forum for habitat managers' concerns with respect to aquaculture to be addressed. During 2001 ESSA project members also contributed to a DFO State-of-Knowledge report on broad environmental effects of aquaculture. This will be published as a DFO Technical Report in 2002. A review of progress in the ESSA project will also be presented at a special session on aquaculture-environment interactions at the annual meeting of the American Society of Limnology and Oceanography meeting in Victoria (June 2002).

DELIVERABLES

Progress was made in developing standard methods for sediment geochemical analysis, but there was a delay in data acquisition to assess stable isotope distributions as a method for tracking waste dispersion. Circulation model development proceeded focusing on the role of physical factors (tidal mixing, water residence time and depth) in controlling dissolved oxygen distributions. Development of mass balance models for oxygen and nutrients is still underway. The importance of seasonal observations for assessing phytoplankton production, water column, sediment and fish respiration was confirmed by observations and model results. ESSA members assisted drafting a workbook prepared as a guide for DFO information requirements under the Canadian Environmental Assessment Act (CEAA) for finfish license applications.

PROJECT BUDGETS AND RESOURCES

The expected project budget for 2001/02 (total 277 $K- 17% to NF and BC, 66% to Maritimes DFO regions) was provided and fully utilized during the past year. The budgeted amount for 2002/03 is 34% less to all regions due to a planned reduction in field work in final year of the project. It has been possible to combine some research effort (for example shared student support) with the related ESSRF project on Toxic Chemicals in Aquaculture in the Maritimes region. There are 18 research scientists and 8 professional/technical support staff involved in the ESSA project across three DFO regions. One or two students are supported in each region. A request for supplemental funding to meet increased field/meeting costs in 2001/02 was not approved. There is a continuing lack of resources (primarily salary $) in all regions. To some extent this has been offset by use of limited A-base funds where regional budgets allow.

NEW TECHNOLOGY

Multibeam (EM3000) data has been successfully used in all three ESSA study areas to derive high resolution inlet-wide maps of bathymetry and backscatter to locate fine sediment depocenters. Similarly, a large-scale 3D finite element circulation model previously developed to predict tidal circulation in the Bay of Fundy and Gulf of Maine is being applied to model the distribution of ecologically sensitive variables in the Quoddy region. This will allow prediction of water residence times in various inlets with different numbers of salmon farms. Water mass trajectories and residence times in specific locations will be used for mass balance models of dissolved oxygen and nutrient distributions and mapping of surficial sediment properties. Progress has also been made to develop and apply standardized sediment geochemical methods that appear to be useful for assessing sediment anoxia and organic matter accumulation. Measurements of Eh and S in surface sediments have been completed to assess regional differences in these geochemical variables that are sensitive to organic enrichment.

THIRD YEAR GOALS AND PROJECT WRAP-UP

In the final year of the ESSA project physical circulation modelling will be coupled to model distributions of ecologically sensitive water column and sediment variables. Mass balance estimates for dissolved oxygen and nutrient budgets will be completed and models of sediment transport and accumulation extended to test their ability to predict particle dispersion proximate to and distant from farm sites. Data collected during the project will be summarized in technical reports and primary papers during the coming year. Effort will be made to ensure data availability by creation of an accessible database to combine all regional observations and data sets used for model calibration and testing. Communication of results from the project both within and outside of DFO will continue.

There are no plans to hold a third ESSA workshop to review research progress as occurred in January 2001 and 2002. Since 2002/03 is the final year of the project and funding levels are reduced, limited resources will be used for data synthesis, testing of models and preparation of publications. Tentative plans are to convene a national meeting involving interested DFO sectors, industry and university representatives to be held in Ottawa during late summer or fall 2003. A proposal will be prepared for submission to the DFO Oceans Applied Science Fund to cover expenses associated with the meeting. It will be jointly organized by ESSA project participants and national representatives from Habitat Management and the Office of Sustainable Aquaculture. The national meeting will follow the general structure of the joint NHMWGA/ESSA workshop held in 2002 summarized here. Questions on critical management issues concerning aquaculture-habitat interactions will be provided by habitat managers. These will be addressed when possible using data from the ESSA project and other relevant information (for example, as summarized in the 2002 DFO State-of-Knowledge report). A publication from this meeting will serve as the final report to summarize ESSA project results from 2000 to 2003.

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MODEL TIDAL DIAGNOSTICS FOR AQUACULTURE SITES IN THE QUODDY REGION

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Numerical studies of the Quoddy region dynamics are being done with a specially developed three-dimensional finite element computer circulation model. This model divides the geographic domain up into triangles. The variable resolution feature of the finite-element model makes it well suited for covering a wide domain of influence with the required detail in areas of interest needed to resolve local characteristics. The model also has the capability of simulating wetting and drying of intertidal areas. Although the generic model code has the capability of including boundary forcing, internal water density and surface winds as current driving forces, the customized model for the Quoddy area has only been run using boundary forcing by the principal diurnal lunar component, the M2 tide, which in this area gives a good representation of the mean tide.

Earlier work with the model centered on tidal properties, residual circulation, and particle tracking. The latter investigations included mixing, dispersion and differences in particle trajectories depending on depth in the water column. Recent work focuses on diagnostics for specific research interests such as the minimum sustained current for continued oxygen supply (Fig. 1) (see Page et al., this volume) and benthic processes (see Stewart and Milligan, and Hargrave and Phillips, this volume). It is hoped that future funding will permit extension of the model to examine more tidal constituents, meteorological forcing and fresh water and salinity influences.

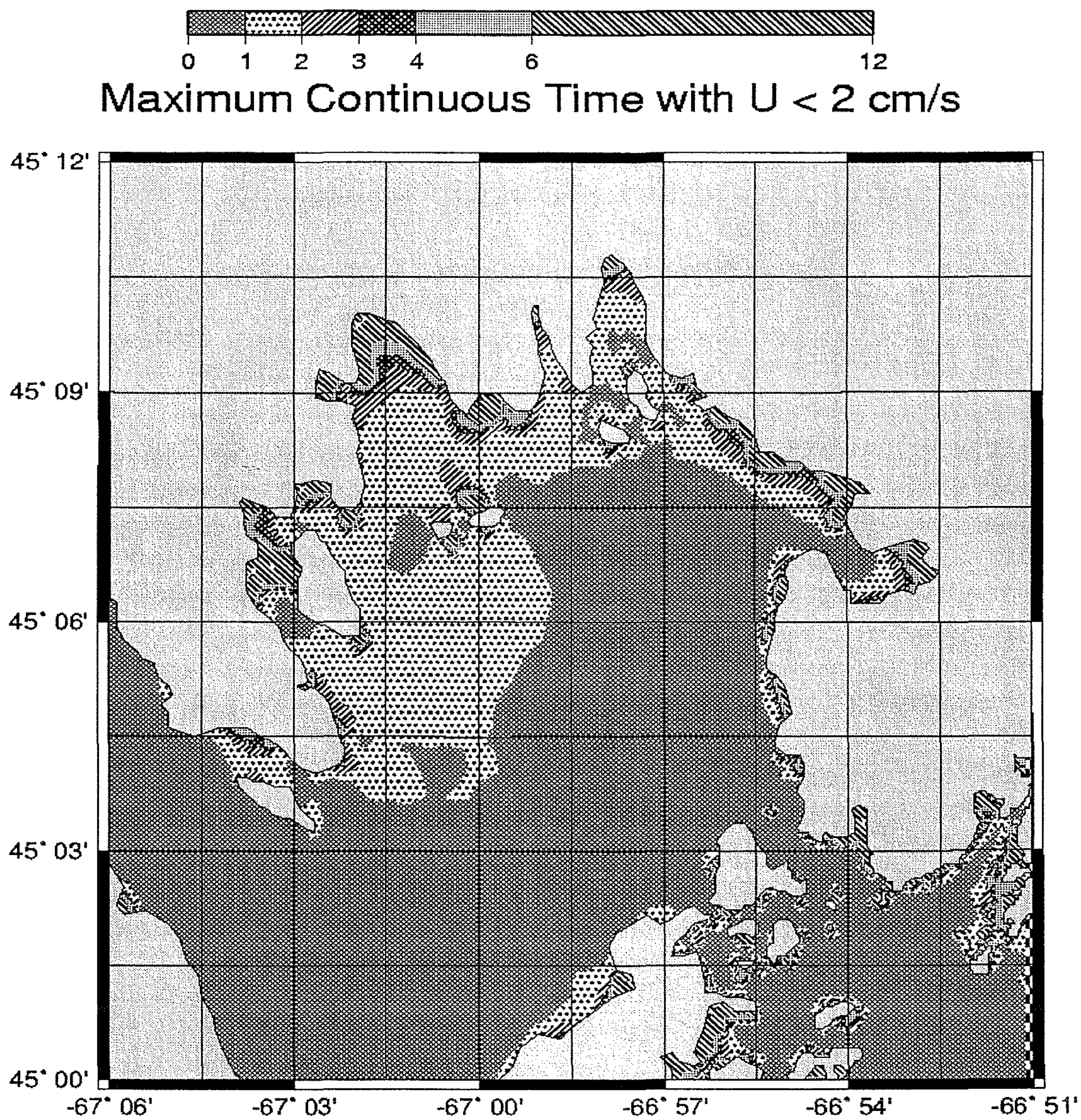

Figure 1: The maximum continuous time (h) the current speed is less than 2 cm s^{-1} in Passamaquoddy Bay and adjacent areas in the Quoddy region of the Bay of Fundy. Prolonged periods of low currents may lead to oxygen deficits in salmon aquaculture sites (see Page et al., this volume).

PROBABALISTIC CHARACTERIZATION OF EXCHANGE AND MIXING WITH APPLICATION TO THE QUODDY REGION

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Predicting the transport, dispersal, pathways and ultimate fate of dissolved substances or suspended particles is of central importance to many coastal zone issues. Robust and reliable parameterizations of the ensemble effects of mixing and exchange processes are needed for many issues, and provide the basis for the construction of box models for ecosystems and biogeochemical processes. Here, we present a low dimension, probabilistic representation of mixing that we hope will prove useful as a means to transfer the results from physical oceanographic models to other disciplines, thereby providing a foundation for the development of process-based water quality and ecosystem models.

Irregular coastlines and topography are characteristic of many coastal environments and often lead to highly structured tidal flows. Advective stirring in these periodic flows, acting together with turbulence, gives rise to a complex mixing regime and enhanced dispersion. In this presentation, we examine the characterization of mixing in such environments using a simple stochastic process: a discrete-time, finite-state Markov Chain. We introduce the notion of Markov Chains and the representation of the ensemble effects of mixing in terms of probability of a particle (or fluid parcel) making a transition from one region to another in a single tidal cycle (the so-called transition probability). The net effect of exchange within and between the various regions of the bay is then described using a simple matrix equation.

The Markov Chain model was applied to the study of horizontal tidal mixing in the Quoddy region of the Bay of Fundy. The domain was divided into discrete regions and estimates for the transition probabilities were determined using stochastic particle tracking (using $\sim 10^5$ particles) based on a flow field from a numerical tidal circulation model of the area. Various derived quantities describing the retention, flushing and exchange properties of the Quoddy region were determined using the Markov Chain model. These were found to compare reasonably well to results based directly on the trajectories of tracked particles.

SPATIAL AND SEASONAL VARIABILITY IN THE PHYTOPLANKTON COMMUNITY STRUCTURE OF THE QUODDY REGION, BAY OF FUNDY WITH COMMENTS ON THE YEAR 2001

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One of the concerns with respect to potential environmental consequences of aquaculture is that enhanced nutrient loading in areas supporting extensive finfish aquaculture may influence the community structure (species richness and abundance) of phytoplankton in the area such that blooms of harmful algae may become more prevalent or severe. Atlantic salmon have been reared in cages within the Quoddy Region since 1978 and the species composition and abundance of phytoplankton have been monitored in the area since 1987 (Martin and LeGresley 2001). The monitoring has taken place at a series of stations over the years (Fig. 1). Only stations 3, 15, 16 and 17 have been sampled for the complete time period. As part of an ongoing effort to analyse this data we have begun to explore the temporal and spatial variability in the phytoplankton community.

SPATIAL VARIATION

Although the Quoddy Region is a relatively small area, approximately 30 km by 30 km, there is freshwater input from several sources and a considerable amount of bathymetric variability that generates spatial variation in the circulation and hydrography of the area. These are likely to contribute to spatial differences in the phytoplankton community structure. However, the differences are smoothed out to some degree by the strong tidal currents in the area which tend to promote mixing. An MDS analysis (Fig. 2) of species composition in phytoplankton samples collected from 12 of the monitoring stations (Fig. 1) at regular intervals throughout the year 1991 indicates that spatial differences (Fig. 2) do exist. The stations tend to ordinate such that the majority of locations show various degrees of similarity to the two estuarine sites (Brandy Cove and Haddock Ledge) and the offshore station (Wolves). This is the pattern that might be expected based on the assumption that plankton communities in the two source areas (estuarine and offshore) are different and are mixed to varying degrees depending upon location.

TEMPORAL STRUCTURE

It is well known from studies conducted around the world that the abundance and species composition of phytoplankton varies seasonally (see reviews by Smayda 1980 and Harris 1986). However, the exact character of the seasonality varies geographically. In general, the annual mean abundance of phytoplankton increases from inshore to offshore. The seasonal pattern in abundance may include a single annual maximum or bloom in the spring or early summer that persists for a few weeks to several months. In some areas it is characterized by two maxima, with one usually in the spring and the other in the fall. The timing of the spring

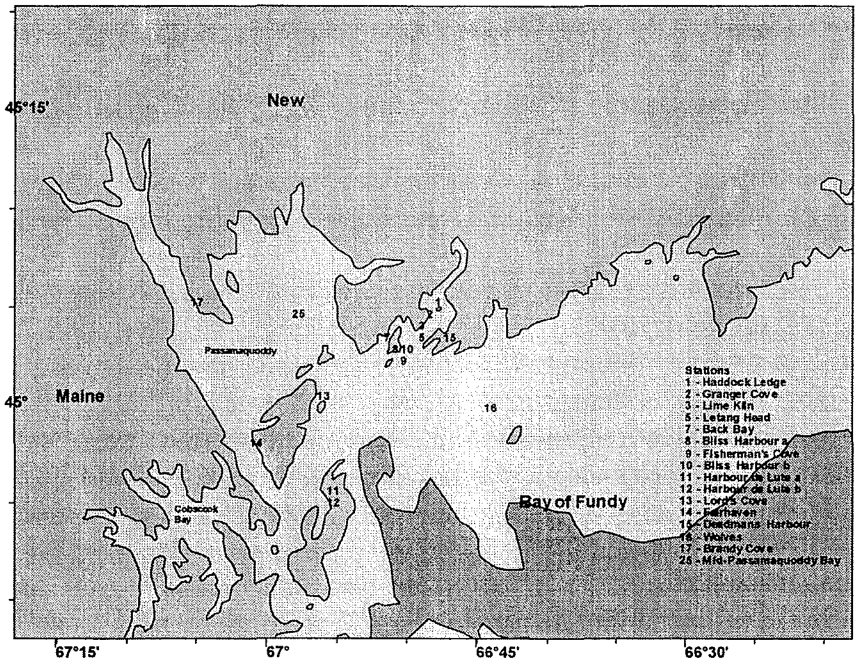

Figure 1: Map of the Quoddy Region showing the location of the sampling stations used in the spatial analyses of phytoplankton community structure.

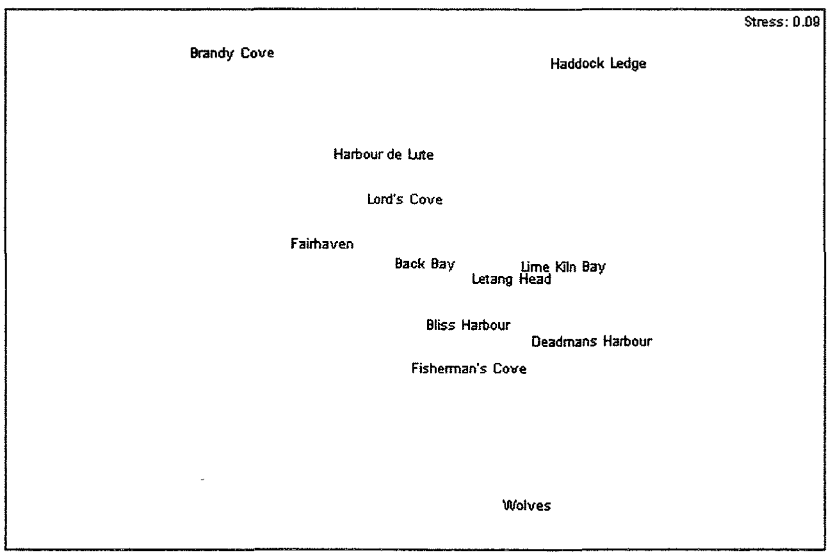

Figure 2: Multi-dimensional Scaling (MDS) ordination plot of phytoplankton samples collected at 12 stations within the Quoddy Region in 1991. The plot is based on the Bray-Curtis similarity between stations calculated between the annual average of the surface abundance of each species within each station. The abundances were fourth root transformed.

bloom is often earliest in deeper offshore waters and later in shallower inshore waters. The magnitude of the spring bloom is usually greater in the deeper offshore waters and smaller in the shallower coastal waters (Robinson 1970). The number of species also varies seasonally. Typically there are relatively few species present during the winter with many more during the spring and fall blooms. The timing and magnitude of this species richness pattern also changes with latitude and distance from shore. Within these general patterns, a characteristic seasonal succession in species composition occurs. A typical bloom pattern is diatoms, followed by flagellates and the dinoflagellates as the season progresses.

The seasonal cycle in phytoplankton within the Bay of Fundy is generally consistent with these broad patterns. Total phytoplankton abundance is relatively low in the winter and late fall and there is a temporally prolonged annual maximum abundance that occurs throughout the summer (Fig. 3). The pattern in species richness is similar with relatively few species present during the winter and late fall and many present during the summer (Fig. 4). Unlike other areas, the timing of the seasonal bloom in total diatom abundance is very similar to the timing for total dinoflagellates (Page et al. 2001). These seasonal cycles in abundance and species richness account for the majority of the temporal variation in the phytoplankton community structure. Multi-dimensional scaling (MDS) ordination plots, based on the Bray-Curtis similarity index, show a cyclical and serial pattern (Fig. 5) that corresponds with the seasonal change in the community structure (species composition and abundance). Interestingly, this pattern persists when the genus-species data is amalgamated into higher taxonomic units such as families, orders and classes and when the data is transformed to presence and absence. We hope to be able to remove this seasonality and examine the data for patterns in inter-annual variability.

TEMPORAL STRUCTURE 2001

The year 2001 had a number of occurrences within the phytoplankton community that were observed from the sampling at the four stations – Lime Kiln, Deadmans Harbour, The Wolves and Brandy Cove (Fig. 1). The spring diatom bloom, which during most years since 1987 has begun in late March, was observed in mid-March. During July the highest concentrations since 1994 of *Alexandrium fundyense* (the organism responsible for producing paralytic shellfish poisoning toxins) were observed. Figure 6 shows concentrations of *A. fundyense* cells at Lime Kiln between 1997 and 2001.

During August 2001, concentrations of *Mesodinium rubrum* exceeded one million cells L^{-1} in Passamaquoddy Bay causing a red colouration of the water. Although this organism has been previously implicated in salmon stress and mortalities (Martin et al. 2001), no adverse effects were observed. *Pseudo-nitzschia* spp. were observed at highest concentrations since 1995, with low levels of domoic acid detected in shellfish from Grand Manan Island.

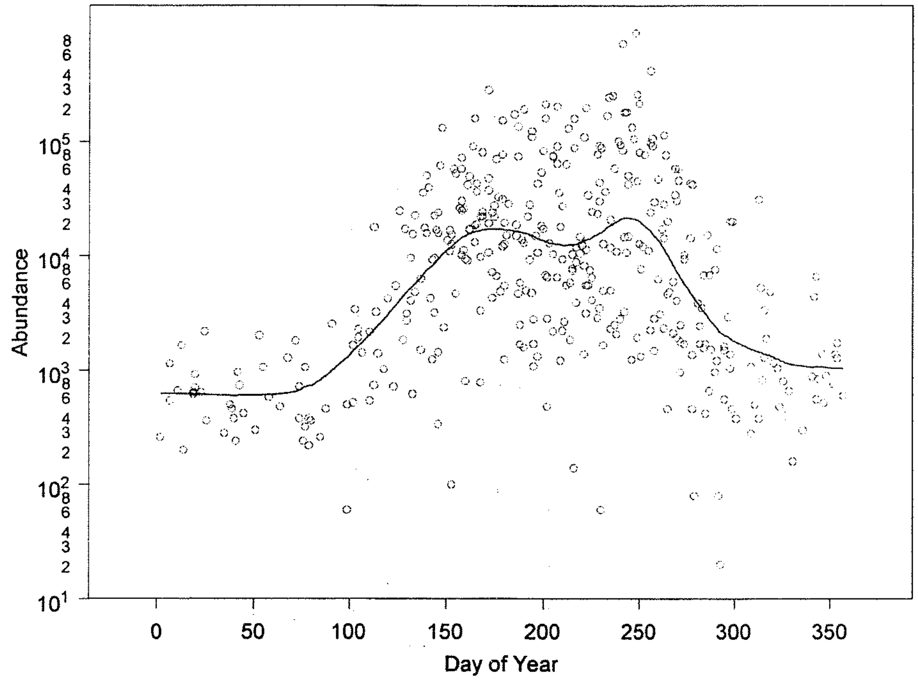

Figure 3: Annual (i.e. seasonal) cycle in the total surface abundance of phytoplankton at station 3 within Lime Kiln Bay. Data points are the total cell counts for individual samples collected at regular intervals throughout the years 1987 through 2000. The smooth line through the data is a Friedman super smoother.

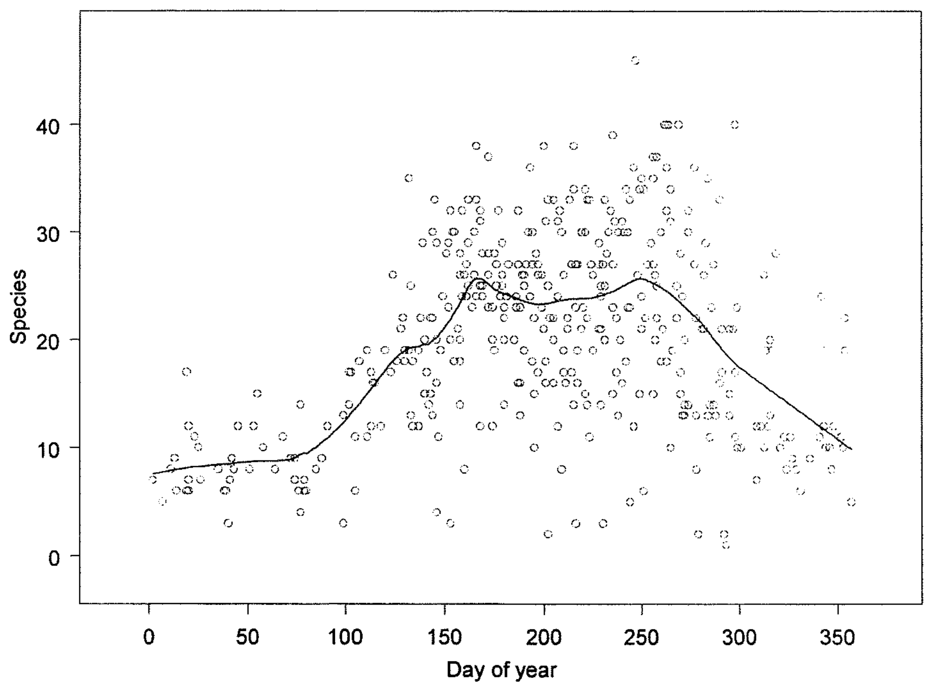

Figure 4: Annual (i.e. seasonal) cycle in the total number of phytoplankton species at station 3 within Lime Kiln Bay. Each dot represents the total number of species found within all depth samples taken at the station from 1987 to 2000. The smooth line through the data is a Friedman super smoother.

Surface chlorophyll values from Lime Kiln and the Wolves from late July 2000- September 2001 (Fig. 7) show elevated levels that coincide with the spring (10.19 mg m^3) and late summer/fall (9.39 mg m^3) diatom blooms. The fall diatom bloom in most years declines during late September but in 2001 it persisted well into November. Samples will continue to be collected during 2002 for comparative purposes.

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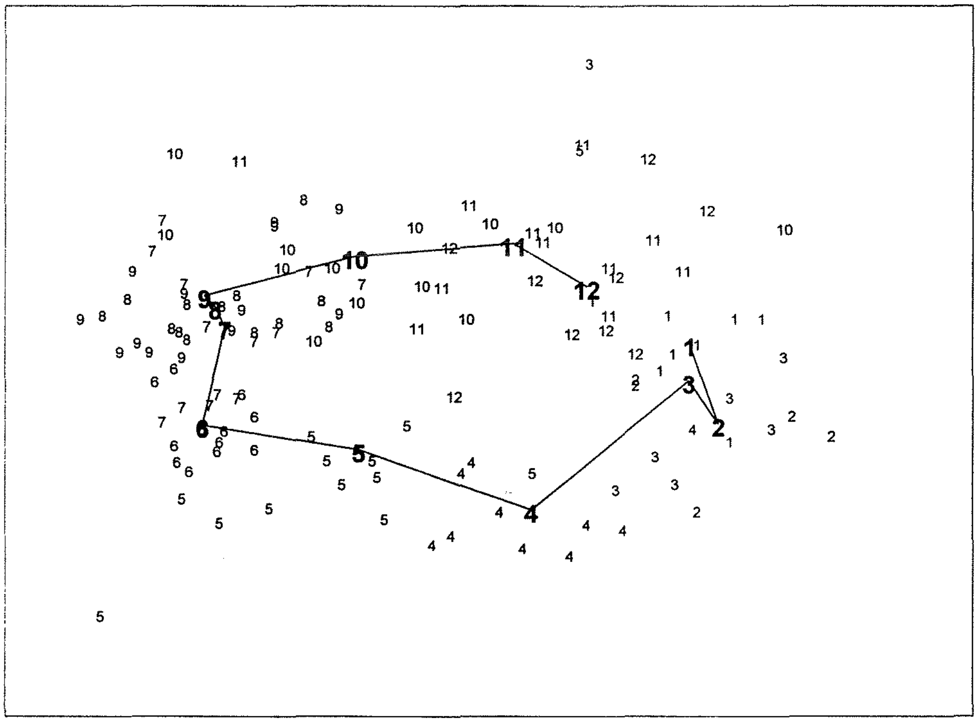

Figure 5: Multi-dimensional Scaling (MDS) ordination plot of phytoplankton samples collected monthly at a monitoring Station 3 within the Quoddy Region from 1988 through 2000. The MDS analyses was conducted on a matrix of Bray-Curtis similarity indices generated from the fourth root transformed monthly averages of the abundance of all phytoplankton species (diatoms and dinoflagellates) enumerated from surface water samples. The solid line connects the centroids for each of the monthly averages. The 2D stress value associated with the MDS is 0.19. Cyclicity was 0.066, P=0.001 and seriation was 0.116, P=0.001.

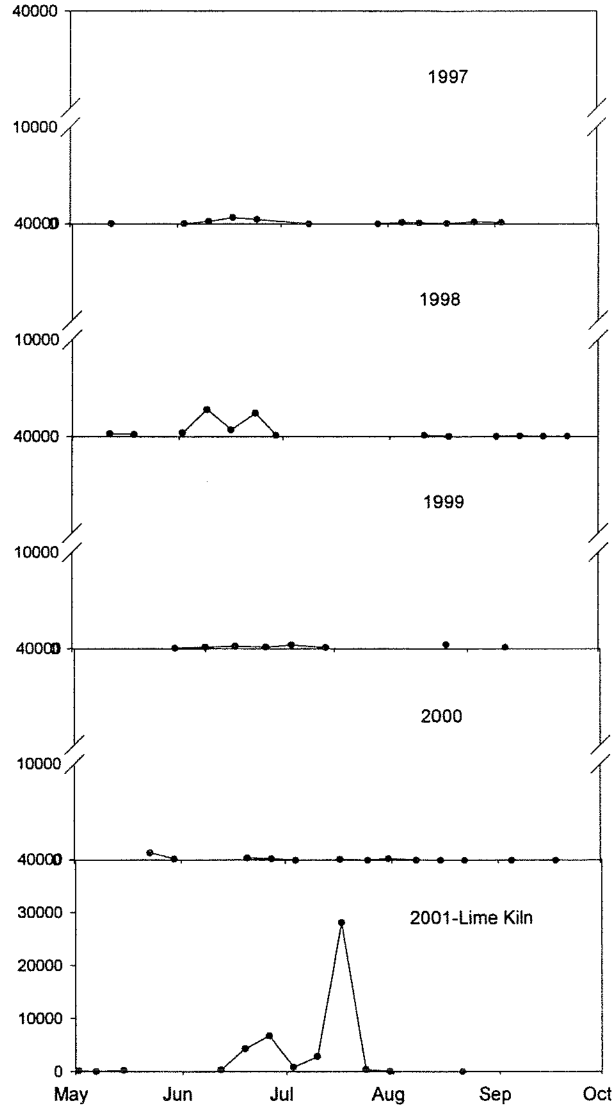

Figure 6: Cells abundance (numbers l^{-1}) of *A. fundyense* in water samples from Lime Kiln Bay (1997-01).

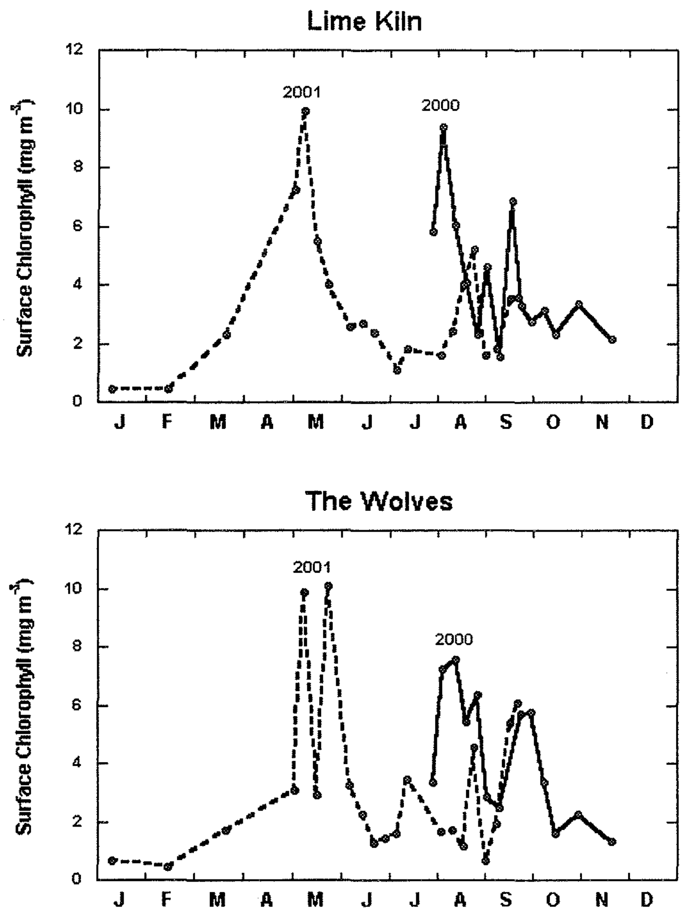

Figure 7: Surface chlorophyll concentrations at Lime Kiln Bay and The Wolves.

MONITORING OF PICOPLANKTON, NANOPHYTOPLANKTON AND BACTERIOPLANKTON IN THE WESTERN ISLES REGION OF THE BAY OF FUNDY DURING 2001

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In 2001, the long-term phytoplankton monitoring program in the Quoddy Region of the Bay of Fundy was expanded to encompass measurements of (i) picophytoplankton - including the cyanobacterium *Synechococcus*, (ii) nanophytoplankton and (iii) heterotrophic bacterioplankton. This document reports the time series of measurements from May to October, 2001 at 5 stations: Brandy Cove, mid Passamaquoddy Bay, Deadmans Harbour, Lime Kiln Bay and the Wolves Islands.

Seawater samples were collected according to established protocols of the monitoring program (Martin et al. 1999, 2001). Microbial plankton were placed into cryogenic vials, preserved in paraformaldehyde (1%) and stored at -80°C. Flow cytometric analyses of phytoplankton and bacterioplankton were performed using standard protocols (Li and Dickie 2001).

Phytoplankton were detected by autofluorescence from cellular chlorophyll. Cells of equivalent spherical diameter (ESD) less than 2 μm were classified as picophytoplankton. In this size category, some cells also emitted orange fluorescence - indicating presence of phycoerythrin: these cells were designated as *Synechococcus* (cyanobacteria). Cells of ESD greater than 2 μm but less than 20 μm were classified as nanophytoplankton. Additionally, a distinction was made between small nanophytoplankton (less than 10 μm) and large nanophytoplankton (greater than 10 μm). Bacterioplankton were detected by green fluorescence after staining with the DNA-binding fluorochrome SYBR Green 1.

In general, a similar pattern of seasonal variation was observed in the picophytoplankton - including the cyanobacterium *Synechococcus*, the small nanophytoplankton, the large nanophytoplankton, and the heterotrophic bacterioplankton. The abundance of cells in each of these groups increased from spring to summer. With some exceptions, maximum values were reached in mid-September near the autumn equinox.

The order of magnitude in abundance (cells mL^{-1}) was 10^6 for bacterioplankton, 10^4 for picophytoplankton and *Synechococcus*, 10^3 for small nanophytoplankton and 10^2 for large nanophytoplankton. The abundance of all cell groups was higher at Brandy Cove and mid-Passamaquoddy Bay than at the other 3 stations (Deadmans Harbour, Lime Kiln Bay and the Wolves Islands). There was no systematic variation of cell abundance with depth in Lime Kiln Bay, suggesting a well-mixed water column to 15 m. On the other hand, at the Wolves Islands, cell numbers were systematically lower at depths greater than 10 m, suggesting water stratification (to varying degrees) through the period of observation.

Samples will continue to be collected and analysed during 2002. No previous observations of picoplankton, nanoplankton and bacterioplankton abundance have been made at any location in the Bay of Fundy. It is important to repeat the 2001 sampling effort to obtain reference data from aquaculture and non-aquaculture sites.

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CARBON LOADING AND CARBON DYNAMICS IN THE QUODDY REGION

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INTRODUCTION

The biological and photochemical oxidation of biogenic carbon creates an oxygen demand. Measurements of both the carbon load and carbon cycling associated with this oxygen demand are important because they define the basic ecosystem properties that regulate the supply of oxygen to aquaculture sites in the Quoddy region.

SEASONALITY OF CARBON LOADING

Of the total organic carbon (TOC) load in the region, 90% is dissolved organic carbon (DOC); particulate organic carbon (POC) is less than 10% of the total. DOC measurements from an aquaculture site and an offshore control site (Fig. 1) indicate that summer is the season when carbon loads are highest.

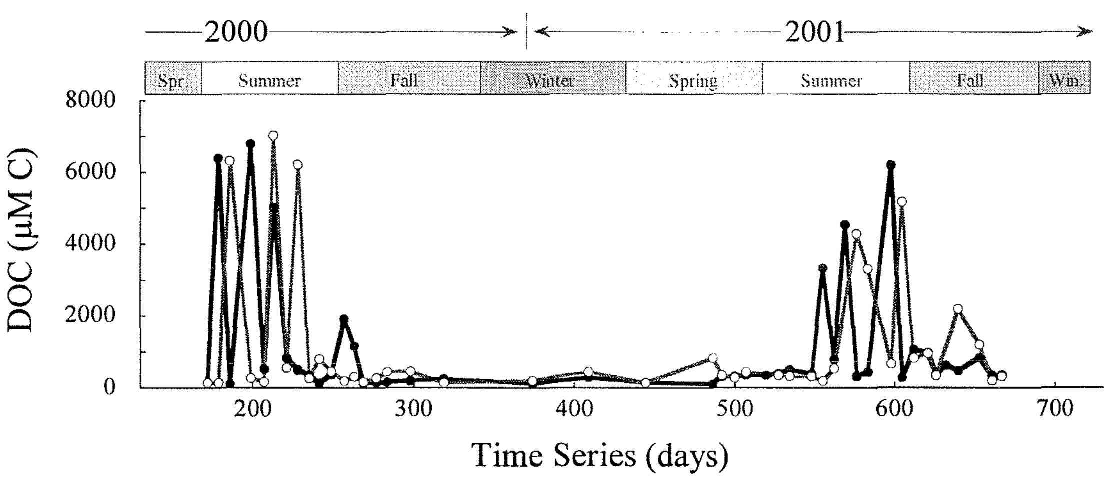

Figure 1: Time series of DOC concentration in surface waters taken from a depth of 5 m at an aquaculture site in Lime Kiln Bay (closed circles) and at an offshore control site (the Wolves).

During summer, carbon load can reach concentrations as high as 6000 µM C; during spring, fall and winter, DOC remains low at 100 - 200 µM C. Chlorophyll times series at the same sites follow a similar pattern. This means that the large and variable carbon loads that are evident during the growing season are linked somehow to changes in phytoplankton biomass. The specific sources contributing to these carbon loads cannot be identified, but the data in Fig. 1 suggest that carbon load moves offshore over time.

SEASONALITY OF PRODUCTION AND RESPIRATION

The data in Fig. 2 suggest that a seasonal succession of plankton physiology is in operation. During the summer, the ecosystem is production-driven, with low respiration (at 11 - 29% of production). In the fall, this gives way to a respiration-driven system - where the consumption of carbon and oxygen can be as high as 878% of production. In turn, this gives way to a respiration-driven system in the winter, but with a less pronounced consumption of carbon and oxygen (at 115 - 286% of production).

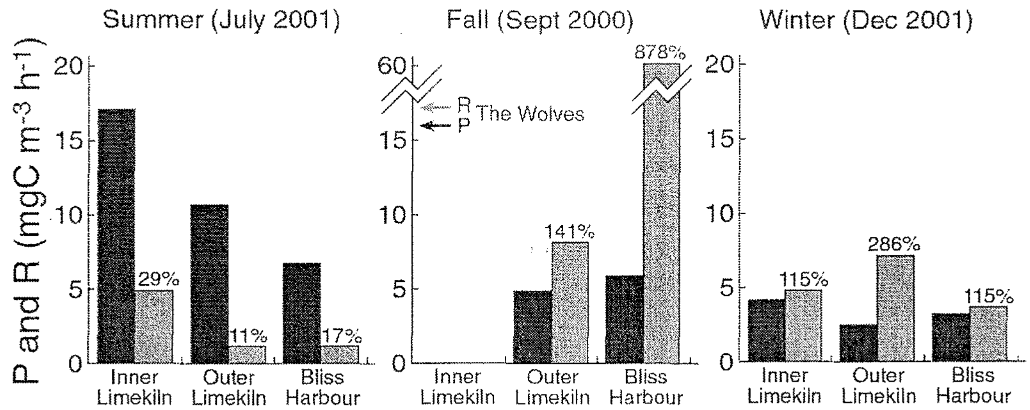

Figure 2: Seasonal variations in phytoplankton production (black) and plankton respiration (grey) in surface waters from aquaculture sites (Inner/Outer Lime Kiln Bay and Bliss Harbour) and an offshore control site (the Wolves). Note the transition from a production-driven ecosystem in the summer to respiration-driven systems in the fall and winter.

This seasonal transition from a production to respiration-driven system is achieved by a 4-fold decrease in production and a 10-fold increase in respiration. Seasonal transitions of this type are characteristic of other ocean environments (such as the Labrador Sea and Gully). In order to obtain a quantitative idea of the effect of the Quoddy ecosystem on the regional oxygen budget, it is essential that these seasonal transitions be taken into account.

NEAR VERSUS OFFSHORE CARBON LOADING

Primary production, chlorophyll biomass and respiration are all higher offshore than nearshore at aquaculture sites (Fig. 2; Harrison and Perry 2001; Kepkay and Bugden 2001). In addition, the offshore waters carry at least as high carbon loads as the coastal sites (Fig. 1). A partial explanation for these differences lies in the possible influence of the St John River plume as it extends south and west into offshore environments in the Quoddy region.

A similar contrast between near and offshore is evident in the sediment accumulation rates established by ^{210}Pb geochronologies (Smith et al. 2002). Sediment accumulates more rapidly at the Wolves and other sites compared to nearshore aquaculture sites in Letang Inlet and Passamaquoddy Bay. Slower accumulation of sediment nearshore is counter-intuitive, but additional data (Fig. 3) suggest that a large fraction of the carbon at aquaculture sites is resuspended - to the point where water-column carbon loads are supplied from the bottom up (by resuspension) as well as the top down (by phytoplankton production and river discharge).

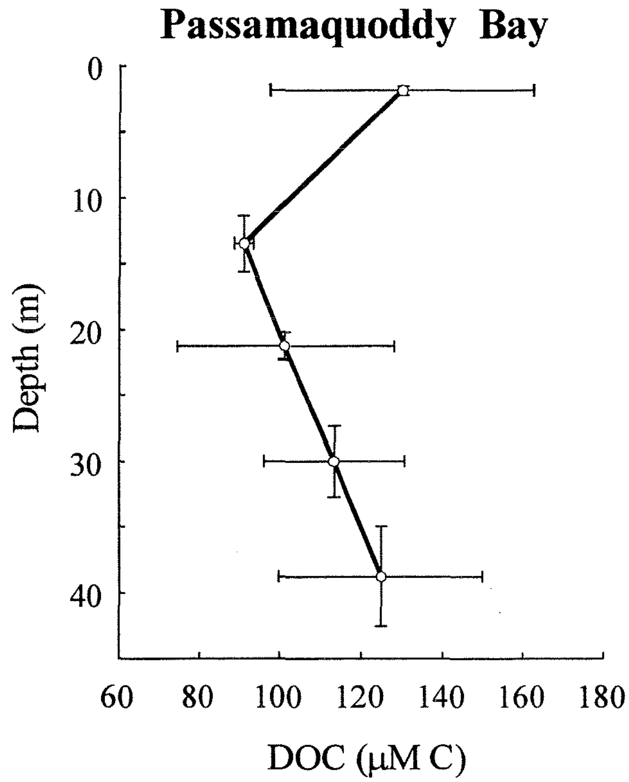

Figure 3: Vertical distribution of DOC concentrations over mean depth in the water column at 9 stations in Passamaquoddy Bay. The error bars delineate ranges of DOC concentration and depth around mean values.

Given that resuspended carbon will exert a strong influence on the biological oxygen demand (BOD) of both water and sediment, the magnitude of near versus offshore resuspension needs to be defined in relation to the currents moving the carbon on and off shore. This shoreward and seaward flux of carbon may well be an important regulator, not only of BOD but also of any other variable linked to carbon cycling. As a result, the offshore and coastal elements of the Quoddy ecosystem cannot be considered in isolation, especially with respect to carbon loading and it's effect on coastal aquaculture.

PHOTOCHEMISTRY AND CARBON DYNAMICS

Even though it is clear that seasonal variations in carbon cycling are important in the regulation of the Quoddy oxygen budget, another factor - photochemistry - should be taken into account. As light-driven processes, photo-degradation and photo-oxidation will be at a maximum during the summer. Together, they could be the missing link that converts the high carbon loads of summer (when respiration is low) to carbon that can be broken down by respiration at it's maximum during the fall.

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WIDE AREA AND NEAR-FIELD DISSOLVED OXYGEN VARIATIONS IN THE BROUGHTON ARCHIPELAGO

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On the BC mainland coast, east of Queen Charlotte Strait, there are numerous salmon net-pen aquaculture operations in amongst a cluster of islands know as the Broughton Archipelago. Northward and eastward from the Broughton Archipelago, Kingcome and Knight Inlets penetrate deeply into the coastal mountain range. The oceanography of Queen Charlotte Strait and that of the adjacent high run-off fjords control the large-scale water property variations at the net-pen sites.

Adequate dissolved oxygen (DO) concentrations are essential to the viability of salmon net-pen operations. To investigate the seasonal variations of dissolved oxygen in Queen Charlotte Strait, we constructed a climatology based on approximately 500 water profiles collected over the last 50 years. The most striking feature of the climatology is the clear seasonal signal in the DO concentrations (Fig. 1). DO concentrations are lowest in late summer (~3 to 4 mg l^{-1}) and highest (8 to 9 mg l^{-1}) during the winter months. The low conditions (<5 mg l^{-1}) that occur in late summer are of great concern to the aquaculture industry because of lost production.

The vertical structure of the DO profiles in the Broughton Archipelago also has a distinct seasonal signal. During the winter, the waters of Queen Charlotte Strait are well mixed or weakly stratified. The opposite is true in the summer months, when increased runoff and thermal heating result in a stratified water column with the lowest DO levels present near the bottom. In the late summer and early fall, low DO waters are brought onto the continental shelf by the upwelling favourable offshore winds. The active estuarine flow in Johnstone and Queen Charlotte Strait then draws these low DO waters into the region.

There are insufficient data from the Broughton Archipelago and Kingcome Inlet to construct a climatology of water property variations. Instead, we examined individual profiles collected throughout the region during our February 2001 cruise, when stratification in Queen Charlotte Strait was weak. Most of the DO profiles in the main passages (Fife Sound, outer Knight Inlet -Tribune Channel and Wells Passage) through the Broughton Archipelago reflect the well-mixed conditions from the adjacent Queen Charlotte Strait. However, in Kingcome Inlet the profiles are distinctly stratified reflecting the effects of the blocking sills and increased freshwater discharge in these more inland locations. In the deep waters of Kingcome Inlet, DO levels drop to <4 mg l^{-1}, and there is a sharp gradient between 50 m and 200 m. The transition from well mixed to stratified profiles occurs abruptly across the sills separating Kingcome Inlet from Queen Charlotte Strait. Most aquaculture operations are in locations that are more influenced by the oceanography of Queen Charlotte Strait, but there are several finfish farms located in the more stratified environment of Kingcome Inlet.

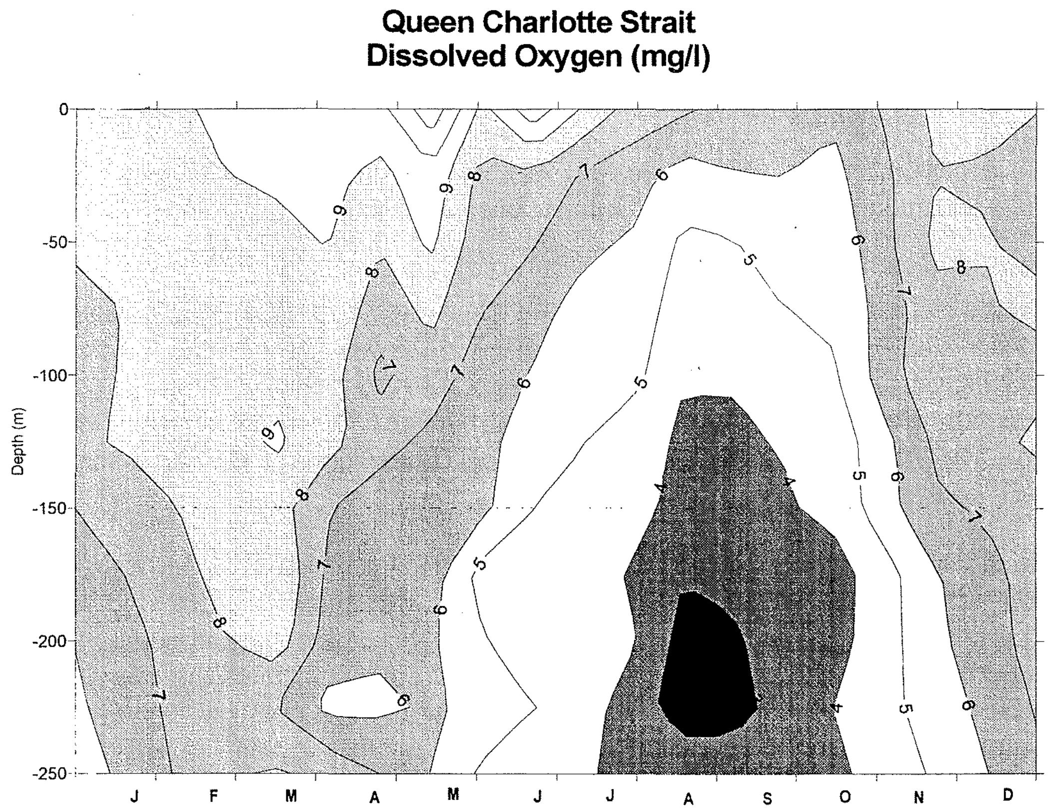

Figure 1: Depth-time contours of dissolved oxygen (mg l^{-1}) in Queen Charlotte Strait based on approximately 500 water profiles collected over the last 50 years.

In the near-field, aquaculture operations may impact the DO concentrations because of the metabolic oxygen demands exerted by the large biomass of fish in the net pens and also because of the enhanced benthic demand generated by the farm wastes. During our cruise in September 2001 we sampled during the flood tide, downstream (~300 m) of salmon net-pen operation at peak production. We sampled the water column for temperature, salinity, DO, nutrients, dissolved organic nitrogen, chlorophyll, turbidity and suspended particulate matter every hour for 7 hours and ended with a control station outside the bay in Knight Inlet. At this time of year the water column was well stratified, and DO levels were low (<5 mg l^{-1}). We could not detect any influence on ambient DO levels from the salmon farm as there was no appreciable variation in DO over the duration of the flood tide. However, one interesting and possibly suggestive observation was that the ambient DO levels in the bay where the fish farm was located were substantially lower (~0.8 mg l^{-1}) than those at the control site some 10 km away. We propose to calculate a DO budget for this location to determine if the observed DO deficit can be explained by the net-pen operation.

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ENVIRONMENTAL IMPACTS OF CHEMICAL WASTES PRODUCED BY THE SALMON AQUACULTURE INDUSTRY

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INTRODUCTION

Salmon aquaculture is an important resource industry but is an anthropogenic source of chemical wastes in the Fundy Isles Region of the Bay of Fundy. There is need to develop methods and criteria to assess the environmental impact of the salmon aquaculture industry. The goal of this project is the identification of the hazard and assessment of the risk to the ecosystem of chemical wastes.

A 3-year DFO Environmental Science Strategic Research Fund (ESSRF) project (Environmental Impacts of Chemicals Produced by the Salmonid Aquaculture Industry) was initiated in 2000. The study is an integrated and co-ordinated multi-disciplinary approach to assessing the impacts on the ecosystem of chemicals used in the Atlantic salmon aquaculture industry. The objectives are: (1) identification of chemicals, their sources, and the quantities released; (2) their distribution, environmental fate and concentrations; and (3) their effect on the ecosystem and important harvest fisheries resources. In addition, it is hoped that potential conflicts with other users may be addressed to provide a basis for improved protection of cultured and wild fisheries resources and their habitat. An overview of this project was presented at last year's ESSA workshop (Haya et al. 2001) and the present paper is an update of the research.

RESULTS

1. Inorganic chemicals in sediments, wild lobsters, and sea urchins near salmon aquaculture sites as indicators of marine environmental quality.

The study was undertaken to assess the marine environmental impacts from feed and waste associated with aquaculture activities. Metal compositions of sediment, sea urchin, lobster, and feed were used to evaluate the extent of detectable effects at 0 m (under the cage) to 100 m distance. Degraded sediment sites showed elevated levels of Cu, Zn, organic carbon, and %<63 μm particles, and reduced Mn and Fe under the cages. At 50 m there was a major reduction in waste chemical impact. Bioindicator species such as lobsters under cages were elevated in Cu compared to control sites. In sea urchins, Ca, Cu, Fe, and Mn were elevated at least to the 75 m distance away from cage site.

Chemical compositions and metal ratios normalised with organic carbon, were used to assess the sediment conditions associated with environmental monitoring program ratings (EMP - normal, hypoxic, and anoxic). Principal component analysis (PCA) was used to explore chemical data at all sites for differentiating normal, hypoxic and anoxic sediment conditions. Selected variables (Cu, Zn, Fe, Mn, organic carbon, and particles <63 μm) were sufficient for the PCA approach with >90% explainable variance of first two components. The groupings based on PCA and cluster analysis were similar to EMP classifications with some exceptions of mis-identification by EMP. The sediment chemistry components were shown to be valid indicators for evaluating marine environmental conditions and for assessing aquaculture operating sites. The developed techniques using chemical variables in combination with EMP and the statistical approach should be useful to predict the impacts of aquaculture practices and the suitability of aquaculture operations. They may also be useful for establishing marine environmental quality guidelines.

2. Organic chemicals in sediment from salmon aquaculture sites sampled in 1998 and 1999.

Feed pellets, and fish oil used as an ingredient in feed, and 44 sediment samples collected around salmon aquaculture cages in 1998 and 1999 were analysed for 31 polycyclic aromatic hydrocarbons (PAHs), 159 polychlorinated biphenyls (PCBs) and 12 pesticides. Five alkylated naphthalenes (aNA) were detected in feed pellets (25-51 ng g^{-1}, per aNA), fish oil (116-180 ng g^{-1}, per aNA) and sediments (<1-45 ng g^{-1}, dry, per aNA), while other PAHs were detected at variable levels in food only or in sediments (e.g. 23-1,605 ng g^{-1}, dry for pyrene). Fourteen PCB congeners and p,p'-DDE were also detected at low levels in all samples.

PAHs in Sediments

	parental	>	alkylated	FLU/PY	PA/AN
1998	63-97%		3-27%	1.2-1.5	2.0-8.8
1999	75-96%		4-25%	1.2-1.4	1.6-7.1
	parental more predominant			ratios similar to combustion products	

- Total PAH's concentrations in sediment increased as distance from site increased.
- The five most abundant alkylated PAH's in feed were 1-MeNA, 2-MeNA, 1,3-diMeNA,1,6-diMeNA, 2,6-diMeNA.
- not the same profile of PAH's in fish oil, food, and sediments that were sampled.
- suggests other sources of PAH's in sediment such as atmospheric input more significant than that from feed.

PCBs in Sediments

- Analysed for 159 PCB congeners, with a detection limit of 10 pg g^{-1} using GC-CIMS (gas chromatography-chemical ionisation mass spectrometry).
- 14 co-eluting congeners detected, with 153/143/168/139 predominating.
- In 1998, concentrations were higher for sediment sampled under the cages than that sampled 25 m from the cage (increased PCB 153, total PCBs, total organic carbon).
- In 1998 and 1999, PCB concentrations and total organic carbon were less in sites with oxic sediments than those with hypoxic sediments which in turn was less than those with anoxic sediments.

3. Aquatic toxicology of chemicals used for the treatment of sea lice infestations of caged Atlantic salmon.

Currently in Canada only one pesticide formulation, Salmosan® (47.5% w/w azamethiphos), is fully registered for use against sea lice infestations on farmed salmon. The recommended treatment regime is a 30- or 60-minute bath treatment at 100 µg L^{-1}. The 48-h LC50 of azamethiphos to larvae and adult lobster ranged from 1.03 to 3.57 µg L^{-1} but the estimates were not significantly different from each other ($p<0.05$). In addition, repeated short-term exposure (15 or 30 minute) to high concentrations (25 and 10 µg L^{-1}) of this formulation resulted in significant mortality. Repeated exposures to lower concentrations did not result in any mortality. Lethality tests were conducted with adult females over a two-year period representing the normal biennial spawning/molting cycle. The 48-h LC50 was found to range from 0.61 µg L^{-1} (in August) during late premolt and early postmolt to 3.24 µg L^{-1} (in April) during the prolonged intermolt period. These data strongly suggest that time of exposure may play an important role in assessing the risk of the use of this pesticide.

4. Assessment of benthic community structure near mariculture sites in Passamaquoddy Bay and the Letang Inlet.

A comparison of three salmon aquaculture sites was undertaken to assess the benthic community structure as a measure of environmental impact along a distance gradient over time. Results are interpreted based on findings of previous studies within the area. Depending on the site, data indicate effects ranging from high to relatively low impact at or near net pens, generally with decreasing impacts over distance. However, one site, within an area of muddy substrate showed the sludge worm *Capitella*, abundant at stations beyond cages. This worm is indicative of highly enriched areas. Other impact indicators corroborate that the impacted area extended beyond the immediate vicinity of operations at that site. Another site with less silty substrate showed little impact on the benthos even near net-pens, demonstrating a wide range of site dependent effects. Results are compared to site ratings based on the New Brunswick Environmental Monitoring Program.

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ESSA FIELD OBSERVATIONS IN BAY D'ESPOIR, NEWFOUNDLAND IN 2001: COMPARISON OF SUMMER AND OVERWINTER SITES

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Salmonid aquaculture in Newfoundland takes place only in Bay d'Espoir, a complex multi-basin fjord heavily influenced by the freshwater outflow from the Upper Salmon hydro-electric development. Production has averaged 1500 – 2500 MT of Atlantic Salmon and Steelhead Trout over the last three years. Aquaculturalists in the Bay move their cages between summer sites in Little Passage and winter sites in Roti Bay where they are protected from ice damage. Provincial regulations require the over-winter sites to be fallowed for 6 months each year.

One of the objectives of the regional study in Bay d'Espoir was thus to determine if the effects of fallowing could be seen in the sediment geochemistry. Another objective was to determine if the redox (Eh)-sulfide (S) continuum approach to classify the oxic status of sediments proposed for other regions (Wildish et al. 2001) is applicable in Newfoundland. Farm sites in Roti Bay and Little Passage were visited in May 2001 as cages were being towed to their summer locations, again in July and in October just prior to the return to the over-wintering sites. Sediment and water column samples were taken at stations around the cages and on a transect away from the cages toward deep water. Samples were also taken at control sites away from the farms in each location. Measurements of Eh and S in surface sediments follow protocols used in previous work in New Brunswick (Hargrave et al. 1997, Wildish et al. 2001).

In July 2001 in Roti Bay, Eh potentials (NHE) (mean ± SD) in surface sediments were +49 (54) mV near the cages and +5 (32) mV 150 m from the farms and at the control site. Redox declined through the summer and fall at the control sites while remaining constant or increasing at the farm sites. Sulfides (mean ± SD) increased from 153 (171) μM in July to 506 (187) μM in October.

In Little Passage, the average (±SD) Eh potential (+123 ±81 mV) in July was higher than measured in Roti Bay but values declined markedly to –90 (39) mV by October. Values at the control site and at 150 m from the cages were always higher than next to the farm. Sulfides in Little Passage were <20 μM directly next to the farm in July but by October concentrations had greatly increased (2190 ± 381 μM). Away from the farm sulfides in surface sediments remained <600 μM in October.

Overall, Eh potentials were higher and sulfide concentrations lower at control sites and distant from cages than they were directly under or adjacent to the net pens at both overwintering and summer sites. There appeared to be a trend to increasing sulfide levels at all sites over the summer, even though the redox potentials increased (indicating improved oxic conditions) at the over-wintering sites as the season progressed.

There was a significant negative relationship between redox and ln sulfide concentration (Eh = 443.7 – 67.45 ln (S), $r^2 = 0.573$, n = 19) when all data were compared for sulfide levels >100 µM.. When total $S^=$ concentrations were <100 µm Eh = 99.8 – 28.57 ln (S), $r^2 = 0.698$, n = 12 The inverse relationship for sediments where total $S^=$ >100 µm. is comparable to regressions reported for these variables in surface sediments from the Western Isles region of the Bay of Fundy. Wildish et al. (2001) used data from 1994-95 to derive the equation Eh = 473.36 – 65.95 ln (S) ($r^2 = 0.672$) for samples from farm and reference sites. Data from farm sites in the same area sampled in 1998 yielded the equation Eh = 494.97 – 58.63 ln (S) ($r^2 = 0.597$). The Eh $S^=$ relationship for Bay d'Espoir differs from that found elsewhere when $S^=$ < 100 µm. Although there is considerable variance in the data sets, our observations of Eh and $S^=$ from Roti Bay and Little Passage Bay conform to the inverse relationship described for these variables in the Western Isles region of the Bay of Fundy for sediments where total $S^=$ >100 µm.

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THE EFFECTS OF SITE HARROWING ON SEDIMENT AND WATER COLUMN PROPERTIES

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The expansion of finfish aquaculture has resulted in concern surrounding its interaction with the environment. It has been suggested that remediation may be applied to aquaculture sites that receive a poor rating based primarily on the oxidation state of the sediment below the cages. Choosing a method of remediation can be difficult due to legal, economic, and technical constraints. The purpose of this study was to evaluate the effectiveness of harrowing as a potential remediation technique.

Recently, a salmon aquaculture lease located in Southwestern New Brunswick, Canada, that had consistently received a poor rating, changed ownership. The former grower was to remove the salmon cages and mooring blocks from the site prior to its occupation. This provided an excellent opportunity to test an active remediation strategy. It was determined that the best course of action, due to budgetary and time constraints, would be to stir up the bottom in attempt to increase the oxidation of organically enriched sediment. A drag, which consisted of a 12' steel bar that had 3 loops of 2" chain attached to it, was towed over the vacated site by a fishing boat for three hours on three consecutive days. The lease site consisted of 9 net pens in a 200 x 80 m area.

Water column and sediment samples were collected a few months prior to the harrowing to collect baseline information regarding the condition of the site. For the sediment sampling, the site was divided into a grid containing 40 cells, of which 8 were randomly subsampled (Fig. 1). Five control stations were located 100 m from the edge of the pens. Water column sampling, at 16 stations (Fig 1), consisted of underwater silhouette camera images, optical backscatter sensors (OBS), and collection of water using 2.0 L Niskins. CTD and ADCP data were collected concurrently. Divers collected sediment core samples and recorded general site observations.

The water depth ranged from 18 - 21 m, with a relatively flat bottom that was covered with a 10 - 20 cm thick layer of black organic material in the vicinity of the cages. Bacterial mats were present and off-gassing was observed. Measurements of redox potential (Eh), sulphide, suspended particulate matter (SPM), grain size, turbidity, oxygen, salinity, temperature, and current speed and direction were made. Currents were generally less than 10 cm s^{-1} and were often 0 cm s^{-1}. Chemicals analyzed included trace metals, mercury, total PAH, total PCB, DDT, DDE, DDD, pesticides, pH, alkalinity, total volatile solids, and nutrients (total P, total Kjelhahl N, NH_3, NO_2, NO_3). Results showed only copper and zinc levels were above background levels

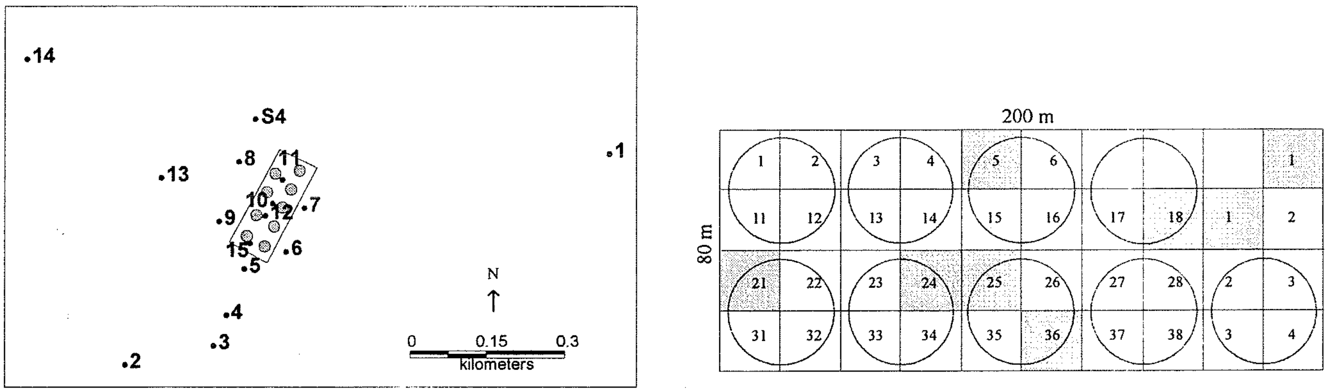

Figure 1: Location of water column stations (black dots) and cages (grey circles) at the study site. The sediment sample grid has been expanded to show the 8 randomly sub-sampled blocks (highlighted areas).

(Loring, 1998). Mercury levels were low (< 0.05 $\mu g\ g^{-1}$). PCB and DDT were not detected, PAH's were detected but at low concentrations. Emamectin was detected in 6 of 8 samples but at levels > 20000 times below lobster LC50.

The same suite of measurements, other than the chemical analyses, were made prior to (April 27), during (May 6), and post (May 10 and 16) harrowing. Ten days after harrowing, Eh levels had improved at only 2 sample sites, and sulphide levels improved at only 1 site (Table 1).

OBS observations indicated that during harrowing, turbidity values in the bottom 2 m were greater and more variable compared to pre-harrowing values (Fig. 2). Turbidity values measured at mid-water depth (10m) showed no differences between pre-harrowing and during harrowing. These results coincide with measurements of grain size. Figure 3 shows the disaggregated inorganic grain-size (DIGS) distributions from water samples collected at station 10 prior to and during harrowing. The DIGS distributions at 10 m depth are nearly identical on both days. However, at 1 m off the bottom, the DIGS distribution of the sample collected during harrowing was dominated by fine material (< 6 um), suggesting that the drag resuspended only the fine particulate fraction of the sediment.

CONCLUSIONS

The harrowing, as was conducted on this site, had little or no effect on sediment properties, specifically Eh and sulphide. Sediment resuspension consisted of only the fine particulate material and was confined to the bottom 2 m. This could prove important in areas of high current because the resuspended material would be subject to horizontal transport away from the site, resulting in the re-distribution of sediment organic matter. Future considerations could include using a different type of harrow to improve resuspension of the particulate material. A longer period of harrowing and time for oxidation of sediment organic matter to occur could also be part of the experimental design if the study was repeated.

Table 1. List of Redox potential (Eh as mV) and Sulphide concentrations ($S^{=}$ as μM) for surficial sediment samples collected beneath and adjacent to a finfish aquaculture site. Site rating is based on Wildish et al. (1999). C1 - C5 represent control stations, 100 m from the edge of the pens.

	27-Apr-01		10-May-01		16-May-01		27-Apr-01		10-May-01		16-May-01	
Sample	Eh	Rating	Eh	Rating	Eh	Rating	$S^{=}$	Rating	$S^{=}$	Rating	$S^{=}$	Rating
5	-175	C	-113	C	-117	C	4620	B	8010	C	2790	B
10	191	A	158	A	-2	B-	348	A	860	A	837	A
18	-152	C	-105	C	-127	C	3980	B	4210	B	2660	B
19	-112	C	148	A	174	A	3160	B	665	A	72	A
21	-103	C	30	B	-68	B-	3750	B	920	A	1360	B
24	-28	B-	-24	B-	-99	B-	1040	A	836	A	1870	B
25	-46	B-	-84	B-	-123	C	2320	B	2230	B	3160	B
36	66	B	78	B	-120	C	1230	A	1130	A	3830	B
C1	123	A	206	A	188	A	177	A	274	A	185	A
C2	151	A	154	A	167	A	201	A	387	A	177	A
C3	270	A	150	A	167	A	66	A	259	A	308	A
C4	177	A	165	A	201	A	17	A	192	A	291	A
C5	116	A	190	A	176	A	168	A	308	A	301	A

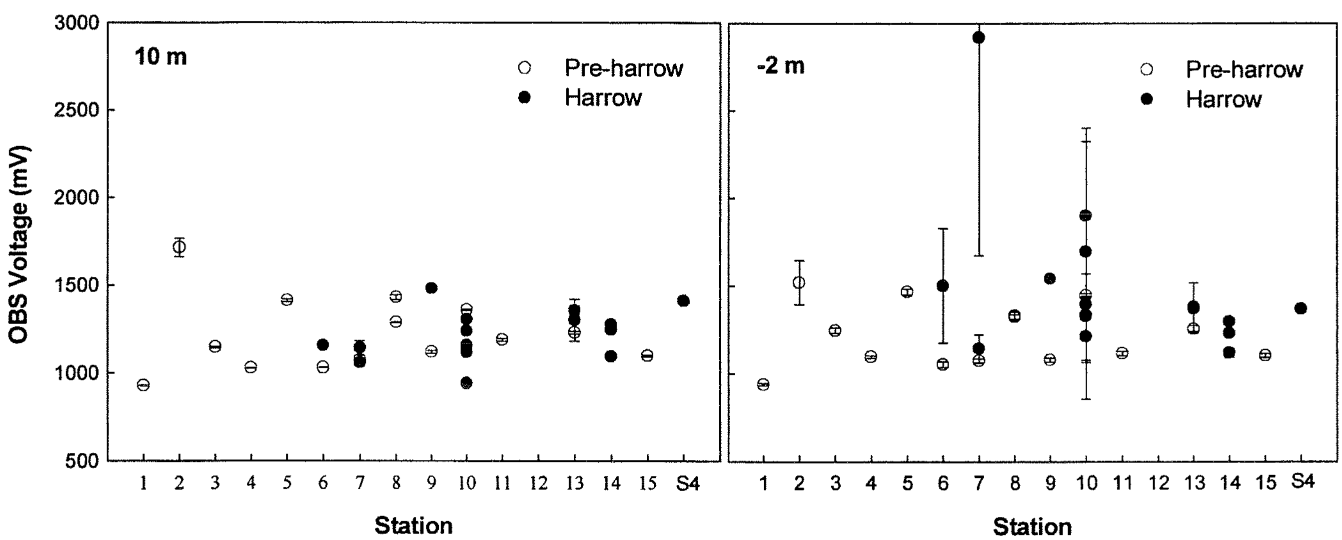

Figure 2: Mean (± 1 SD) optical backscatter values prior to and during harrowing at a depth of 10 m and integrated over the bottom 2 m.

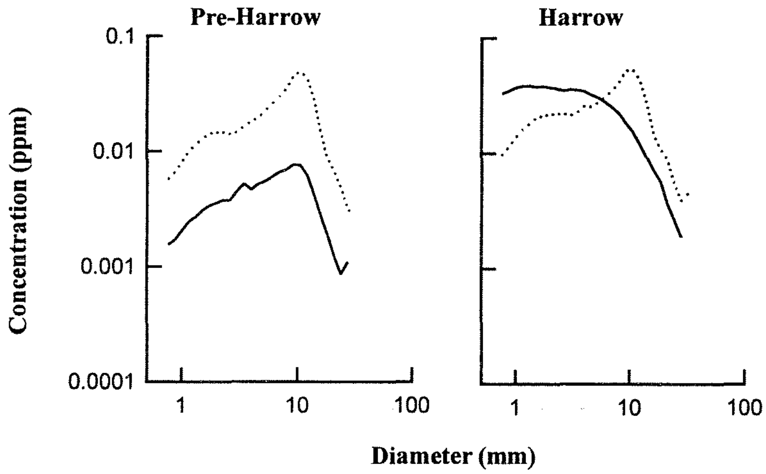

Figure 3: Disaggregated inorganic grain-size distribution from station 10. Water samples were collected at 10 m (dashed line) and 1 m (solid line) prior to and during harrowing.

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A SEASONAL STUDY OF SEDIMENT GEOCHEMICAL VARIABLES AND BENTHIC MACROFAUNA IN LIME KILN BAY, LETANG INLET, NB

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INTRODUCTION

A seasonal study of sediments in Lime Kiln Bay, Letang Inlet, NB, was undertaken from September, 2000 to September, 2001 at two stations approximately 100 m away from the closest salmon net-pens. Lime Kiln Bay has been used continuously for salmon mariculture since the inception of the industry in the late 1970's. Following the outbreak of a virus disease (ISA) in 1998 an extensive fallowing was followed by a new management regime which introduced a single year class (smolts in odd years) in Lime Kiln Bay. This resulted in reduced biomass levels in comparison to pre-1998 levels.

The aim of the study was to document seasonal changes of physical-chemical and biological variables within the sediments of the Bay that would be sensitive to changes in organic matter input and oxygen supply. Observations included chlorophyll a from sedimented pelagic phytoplankton and interfacial diatoms, sediment grain size, organic matter, redox (Eh) potentials, total sulfides and benthic macrofaunal community structure. The study was also designed to answer the practical question as to whether the timing of the annual environmental monitoring program (EMP) during late summer months by the NB Department of Agriculture Fisheries and Aquaculture introduces a seasonal bias in the results.

METHODS

Sampling

Sampling at the two sites was undertaken once per month from September 2000 to September 2001 inclusive. No sampling was undertaken in December 2000. The Pandalus III, W.B. Scott, or a dive tender with two SCUBA divers was used for sampling. The locations for collection of sediment cores were marked by a surface buoy and on the seabed with steel pins. The divers collected 5 Hargrave wedge cores (described in Wildish et al. 2002) at each station taking care to sample contiguously with previous sampling and within a one metre square area.

Variables measured

The two least disturbed core samples were used for photography (SPI) as described in Wildish et al. (2002). Samples withdrawn from various depths using pre-drilled holes (4 cm intervals) were analyzed for Eh, sulfide and chlorophyll a. Samples were taken for sediment organic matter (CHN) and in some months for particle size analysis. Enzymatic hydrolyzable amino acids (EHAA) were determined on two sets of samples from winter and summer months using freeze-dried sediments as described by Mayer et al. (1995). Surface (0-2 cm) sediment from all 5 cores was subsampled for Eh, total sulfides and chlorophyll a. The entire sediment volume from three cores not used for sampling depth profiles was sieved through a

1 mm^2 mesh for identification of macrofauna. Individuals were identified to the lowest possible taxonomic level and total wet weight biomass was determined.

RESULTS

1. SPI and macrofauna results suggest that both stations in Lime Kiln Bay are classified as stage II, transitory (Nilsson and Rosenberg 2000; Pearson and Rosenberg 1978).

2. The high levels of chlorophyll a in sediments support the view that this is a relatively eutrophic system.

3. The EHAA method can be used to determine the availability of carbon sources in the sediment, but the method is time consuming and unlikely to be useful for practical monitoring purposes, unless the procedure can be simplified.

4. There was no evidence of seasonal patterns in sulfide concentrations in surface sediments, but there was strong evidence that Eh values varied seasonally. Lowest values occurred in August and September. This observation is consistent with ecosystem wide-changes (as shown in dissolved oxygen data, D. Wildish and F. Page unpublished observations) that the oxygen consumption (respiration) exceeds rate of oxygen supply in water and sediments during late summer.

5. The seasonality in oxygen balance, with deficits forming in late summer and effects it has on redox means that there is a seasonal bias in redox observations collected for EMP.

6. Sampling during February occurred just after a storm. Marked effects on sedimentary variables were observed but they were transitory.

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MONITORING NEAR-FIELD CHANGES AT MARICULTURE SITES: A COMPARISON BETWEEN MULTIBEAM AND POLE-MOUNTED SIDESCAN

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Two acoustic surveys, 8 months apart, of an active salmon mariculture site in Letang Inlet, New Brunswick, were used to illustrate the temporal variability in the acoustic backscatter signature of the sub-cage seabed sediments.

The first survey, using a 300 kHz multibeam sonar (Simrad EM3000) was conducted in November 2000 (first results were presented at the ESSA meeting in January 2001) (Hughes Clarke 2001). This was part of a regional survey of all of the Letang Inlet system. The second survey, using a 200 kHz fixed sidescan, was conducted in July of 2001 and was timed to coincide with a ground-truthing program (Akagi et al. this volume and Wildish et al. 2002).

The aim of the experiments were to:

1. to compare the performance of the two acoustic imaging methods
2. to see what changes in the acoustic signature could be observed over the 8-month period between the two surveys.

BACKGROUND

The November 2000 EM3000 survey demonstrated the use of both high resolution bathymetry (1-2 m horizontally ~ 30 cm vertically) and 300 kHz bottom backscatter strength maps as tools for characterising regional surficial sediment distribution. The most notable thing observed was pronounced positive (+10-20 dB) backscatter anomalies immediately under salmon cages. These were especially noticeable in areas where surrounding sediments had extremely low backscatter due to fine-grain mud deposits that settle where current velocities are low.

There remain three unanswered questions:

1. What is the cause of the anomalous backscatter signature ? (surface roughness, volume inhomogeneities, gas?).
2. How ephemeral are these features?
3. Can we empirically estimate the degree of organic enrichment using the backscatter signatures?

The first question has in part been addressed from the initial results of the physical sampling program conducted in July (Wildish et al. 2002). Samples taken under the cages and in adjacent reference areas indicate a relationship between the presence of surface food pellets and faecal material and the enhanced backscatter strength. At this time, however, surface roughness, sound speed and bulk density measurements have not yet been made in order to understand the physical controls on the enhanced scattering.

The second question was addressed in two ways:

1. by comparison with historic activity observed in aerial photography and
2. by re-surveying one site (Lime Kiln Bay).

PRIOR EVIDENCE FOR LONGEVITY OF SEABED ACOUSTIC SIGNATURES

It was clear from the November 2000 regional surveys that some historic (abandoned) aquaculture sites still showed a reduced acoustic signature. The question is how long ago were these sites occupied and how quickly does the signature disappear (or does it ever go back to background levels).

We were fortunate that in ~1996 a series of aerial photos were taken at this location by Service New Brunswick. When these photos were registered, the historic position of cages often lined up with the reduced backscatter signatures (Fig. 1).

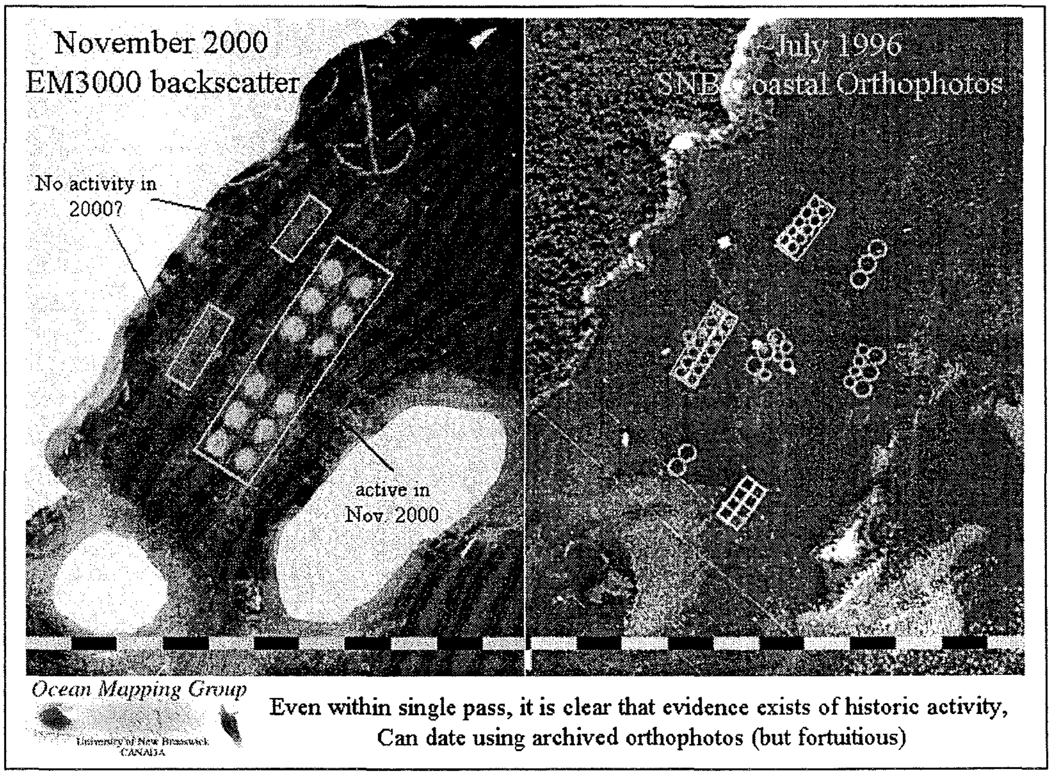


Figure 1: Comparison or November 2000 acoustic signature (active sites indicated) and 1996 aerial photography showing historic cage sites. The area viewed is the Jail Island site in Lime Kiln Bay.

This indicates that these signatures could last for as long as 4 years. This could be less depending on how long after 1996 the cages remained in place.

INTERCOMPARATIVE RESULTS

The Jail Island site within Lime Kiln Bay provides, for the first time, an opportunity to examine temporal changes in the seabed acoustic signatures (Fig. 2). The original cages were removed and a new set of cages was relocated in a similar but offset location between the two surveys.

In the images one can see:

- evidence of the location of the old cage sites and the establishment of a new set of signatures under the new sites. Note that backscatter in the new deposits is not yet as developed as at the older ones. This is presumably due to the fact that the underlying sediments at the new locations are not yet completely blanketed, resulting in more patchy acoustic signatures.

- more noticeable drag marks in the newer image. This may be evidence of where the old mooring blocks were dragged away. It may, however, also be that the drag marks are better defined due to the low grazing angles of the sidescan. The EM3000 does not look shallower than 25° and the image is stencilled to exclude grazing angles lower than 35°. We do not know whether the bottom was disturbed when moorings were relocated (either incidentally or deliberately). At other sites, as part of remediation, operators have deliberately dragged the bottom to try and disperse accumulated deposits under cages.

METHODS FOR ESTIMATING THE DEGREE OF ORGANIC ENRICHMENT

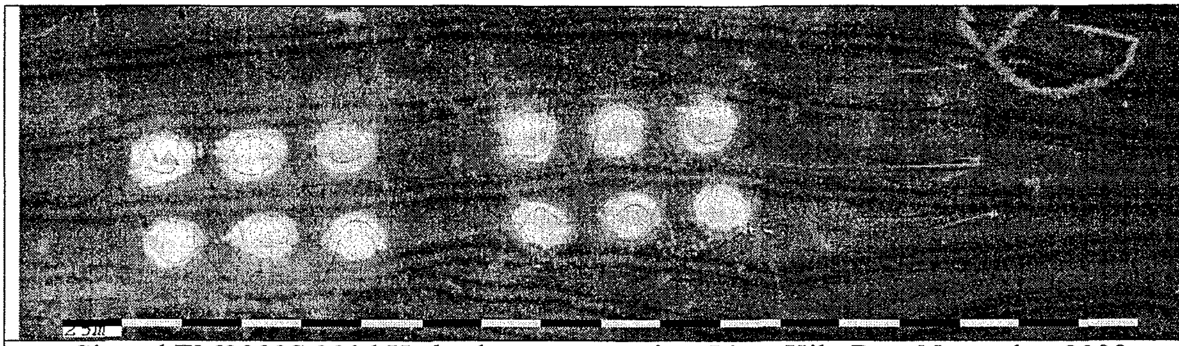
These results show that these acoustic methods allow identification of the spatial extent of the main deposits forming immediately under active cage sites as a result of high sedimentation rates. Methods for uniquely identifying the degree of this organic enrichment are, however, still frustrated by various problems including:

- imperfect sonar- calibration,
- inability to separate other high backscatter material (like gravel or bedrock) from the sub-cage sediment and
- contamination of the acoustic signature by the cage hardware

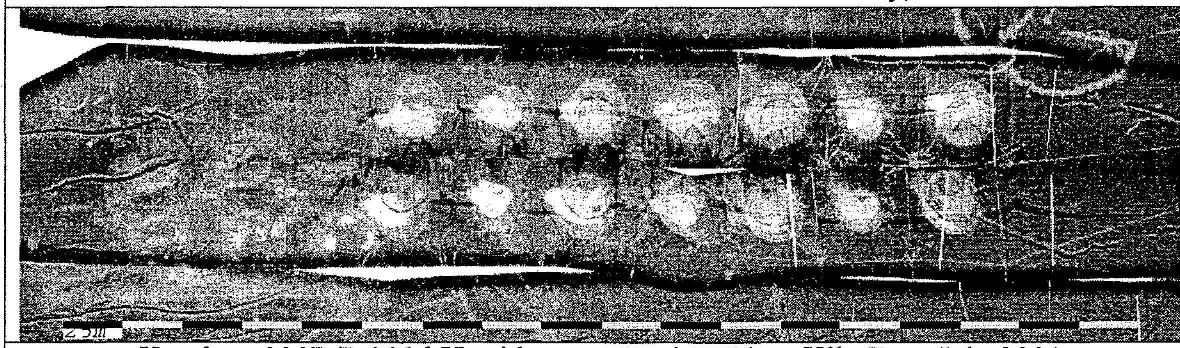
Details of the problems are discussed further in Hughes Clarke et al. (2002).

Future research effort are planned to address a number of these deficiencies. They include:

1. Co-registered, synoptic multi-frequency imaging to attempt to use inter-frequency ratios ("acoustic colour") to provide improved discrimination of the organic deposits with respect to natural high backscatter sediments.



Simrad EM3000S 300 kHz backscatter mosaic – Lime Kiln Bay, November 2000



Knudsen 320B/P 200 kHz sidescan mosaic – Lime Kiln Bay, July 2001

Figure 2: EM3000S 300 kHz backscatter and 320B/P 200 kHz sidescan mages from Lime Kiln Bay, Letang Inlet, NB illustrating the potential for mapping changes in organic enrichment under cages at aquaculture sites. The upper image of backscatter was reduced for source level, pulse length, receiver gains and beam patterns. The uncorrected lower sidescan image shows a simple TVG function (40logR) and an arbitrary mapping to grey scale. The most noticeable problem with the lower image is a gross beam pattern residual.

2. Using a reference site in an area where we believe that no change has yet occurred to try and quantify small changes in the sonar response due to changing hardware or software.

3. Conduct trials through a wide range of sonar settings for the Knudsen in order to quantify beam patterns, absolute power levels, and pulse length settings.

SUMMARY

Recent results from the Letang Estuary have demonstrated that anomalous, organically enriched sediments are detectable with a distinct acoustic signature. Furthermore, these acoustic methods may be used to monitor changes in the spatial extent and accumulation of the deposits over time. Whether this signature is due to high surface roughness, incompletely broken-up food pellets or the build up of gas micro-bubbles within the sediment is still not known.

These acoustic tools provide a rapid and synoptic means to measure the spatial extent of the anomalies (at least in areas with sediments showing contrasting background acoustic signatures). For the first time, this provides a quick means of examining the patchiness of deposits on a regional basis and the data can be used to design an optimal and minimal ground-truth sampling program. Without this step, any grab or coring programs will have aliased results.

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SEDIMENTATION RATES IN THE WESTERN BAY OF FUNDY

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A suite of 10 Lehigh gravity cores was collected in Passamaquoddy Bay and the Letang Inlets in 2000 and subsampled at 1 cm intervals for radionuclide, trace metal and organic contaminant analyses. ^{210}Pb and ^{137}Cs measurements were subsequently carried out on these sediment cores at the Bedford Institute of Oceanography to determine sedimentation rates and sediment geochronologies. Sedimentation rates measured using the naturally occurring radioisotope, ^{210}Pb in Passamaquoddy Bay, Back Bay, Bliss Harbour and Limekiln Bay were 0.40 cm y^{-1}, 0.19 cm y^{-1}, 0.33 cm y^{-1} and 0.55 cm y^{-1}, respectively. Significantly higher sedimentation rates (0.5-2 cm y^{-1}) were determined using the same techniques on cores collected over the past 15 years in the Quoddy region of the Bay of Fundy, north of the Wolves and east of Letang. These results indicate that sediment deposition in the Letang Inlets is dominated by inputs from local sources while the Quoddy region serves as a sink for particle inputs from a much wider range of sources, including cliff erosion and suspended particulate material (SPM) transport from the Saint John River.

The vertical distributions of fallout ^{137}Cs in the Letang cores are in good agreement with predictions based on ^{210}Pb sedimentation rates, indicating that bioturbation or mixing in these cores is minimal. This permits excellent resolution in the sediment geochronologies that will be used to evaluate the history of contaminant inputs to the sediments associated with the aquaculture industry. Higher bioturbation rates signalling more vigorous macrofaunal activity were observed in the deeper offshore sediment regimes in the Quoddy region. Comparisons of ^{137}Cs/^{210}Pb sediment inventory ratios in cores collected throughout the Western Bay of Fundy indicate that the influence of particle deposition from the Saint John River plume may be observable in sediments as far south as Grand Manan Island.

MODELLING ECOSYSTEM ASSIMILATIVE CAPACITY: COMPARISON OF PELAGIC/BENTHIC/SALMON RESPIRATION IN LETANG INLET (SWNB)

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Calculations of assimilative capacity for any coastal ecosystem require an estimation of oxygen consumption by the major ecological compartments - water column, sediment and biota. As part of a larger effort to establish an oxygen budget for the southwestern region of the Bay of Fundy, measurements of pelagic and benthic oxygen uptake were made in the Letang area where the salmon aquaculture farms sites are concentrated in the southwestern area of the Bay of Fundy.

To complement subtidal respiration rates measured in Lime Kiln Bay and Bliss Harbour in September 2000 (reported in Hargrave and Phillips 2001), undisturbed sediment cores were collected from three intertidal areas (Mascarene Shore in Passamaquoddy Bay, Hines Bay in Lime Kiln Bay and Clam Cove on Deer Island) and two subtidal sites in Lime Kiln Bay in July 2001. Samples were incubated for measurements of benthic respiration using methods described in Hargrave and Phillips (2001). Because the Letang region is an area of intense finfish aquaculture, respiration by salmon may be a significant factor for oxygen uptake. Measurements of oxygen uptake by intertidal and subtidal sediments were combined with water column respiration rates and salmon respiration rates estimated from published values for 2-yr adults and 1-yr juveniles to calculate a total oxygen demand. Salmon respiration was expressed as a fraction of total oxygen consumption to indicate subregions in the Letang area where oxygen deficiency due to salmon farms might occur. The larger Letang area was divided into seven subregions for the purpose of comparing the importance of each component in the system (Fig. 1).

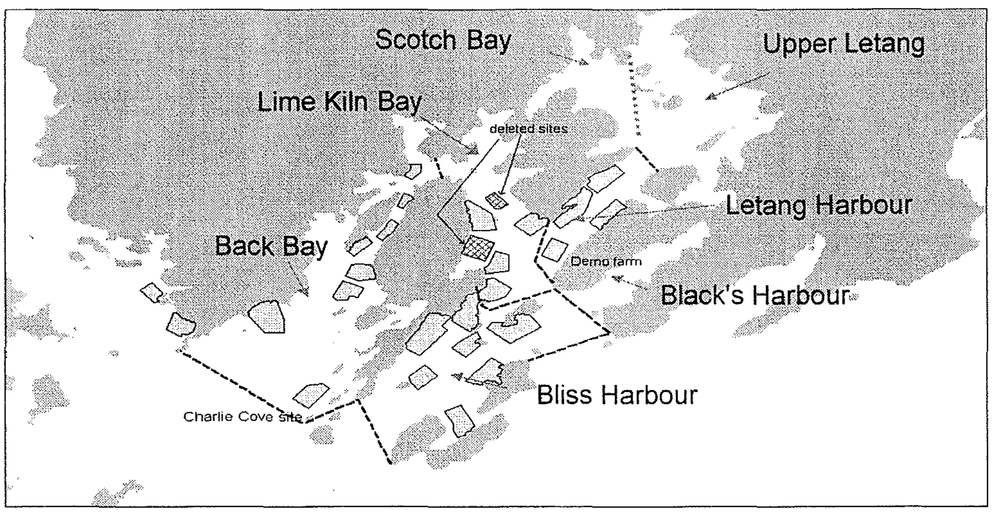

Figure 1: NBDFA approved salmon farm lease sites 2000. Data from B. Chang.

The physical dimensions of each region (water volume, intertidal and subtidal sediment area) were used in conjunction with the experimental data to calculate the respiration rates attributable to the three ecological compartments – water column, sediment and salmon (Table 1). Since extensive regional data was not available, a single average value for pelagic respiration measured in surface (1 m) water in Lime Kiln Bay, Bliss Harbour and at the offshore Wolves site in September 2000 (Kepkay and Bugden 2001) was applied to all sub-regions to calculate water column respiration (moles h^{-1} x volume for each subregion). A correction (x 0.25) was applied values to reflect an order of magnitude increase that occurs in pelagic respiration during fall months over rates measured in summer months (as reported by Kepkay et al. in this volume). Our measurements of subtidal and intertidal benthic respiration, also expressed in moles h^{-1}, are means of values for observations in September 2000 and July 2001. Seasonal differences in benthic respiration between summer and fall months are much less pronounced than observed for water column respiration. The mean rates for subtidal and intertidal sediments were applied to all subregions and multiplied by the areas below and above low water (CD), respectively. Oxygen uptake due to salmon respiration was estimated from license capacity at all sites in 2000 (data provided by B. Chang) assuming a 50/50 mix of one and two year old stock.

The calculations show that the highest pelagic respiration rates during summer months occurred in Bliss Harbour due to the large volume of water in this subregion. Because of its large subtidal area, Bliss Harbour also had the highest subtidal respiration rates. The Upper Letang Region with the highest intertidal area had the highest rate for intertidal respiration among all subregions. Salmon respiration could only be calculated for four subregions (Letang Harbour, Lime Kiln Bay, Bliss Harbour and Back Bay) where salmon aquaculture is carried out (Fig. 1). Calculated salmon respiration as a proportion of total respiration was highest in Back Bay (23%) and lowest in Bliss Harbour (8%).

Figure 2 illustrates data presented in Table 1, with subtidal and intertidal rates combined as 'sediment' respiration, showing the contribution of each major ecological compartment – water column, sediment and cultured salmon – as a percent of the total respiration. The data indicate that oxygen uptake in all Letang subregions is driven by pelagic respiration. Benthic respiration accounts for 4 to 25% of total oxygen demand and is highest in areas where intertidal sediment is greater than 35% of the total area. Average intertidal oxygen uptake is 70% higher than the average subtidal respiration, based on the July 2001 data.

Results to date show that salmon respiration, expressed as a fraction of the total oxygen demand, might be a useful indicator to determine when ecosystem assimilative capacity for organic matter loading is being approached. Based on values for salmon respiration as a percent of total respiration in the four Letang subregions where salmon are raised (8-23%), one might predict that an area such as Back Bay is susceptible to oxygen depletion problems.

Table 1: Physical, experimental and calculated data for determining preliminary oxygen budgets for seven subregions in the Letang area in the Bay of Fundy, southwestern New Brunswick shown in Fig. 1.

LOCATION	Volume at LW (CD) $m^{-3} \times 10^3$	Area at LW (CD) $m^{-2} \times 10^3$	Area at HW $m^{-2} \times 10^3$	Intertidal area % of total	Pelagic Resp.[1] $M h^{-1}$	Subtidal Benthic Resp[2] $M h^{-1}$	Intertidal Benthic Resp.[3] $M h^{-1}$	Total Salmon Resp[4] $M h^{-1}$	Total Resp. $M h^{-1}$	Fish Resp as % of Total	Sediment Resp. as % of total	Water Col Resp. as % Total
Upper Letang	12148	2265	4854	53.3	18150	1839	3556	0	23545	0.0	22.9	77.1
Scotch Bay	6355	1222	2067	40.9	9495	992	1161	0	11648	0.0	18.5	81.5
Letang Hbr	199966	1737	2088	16.8	29877	1410	482	4768	36537	13.0	5.2	81.8
Lime Kiln Bay	24594	2092	3342	37.4	36746	1698	1717	4812	44974	10.7	7.6	81.7
Black's Hbr	4351	616	917	32.8	6501	500	413	0	7414	0.0	12.3	87.7
Bliss Hbr	86309	5823	6967	16.4	128954	4727	1571	12610	147862	8.5	4.3	87.2
Back Bay[5]	27698	2906	47779	39.2	41384	2359	2571	13902	60215	23.1	8.2	68.7

[1]Average value used = 5.98 mM m^{-3} h^{-1} (x 0.25 seas. corr.)

[2]Average value used = 0.81 mM m^{-2} h^{-1}

[3]Average value used = 1.37 mM m^{-2} h^{-1}

[4]one year old salmon weigh 0.4 kg and respire 125 mg O_2 h^{-1}

two year old salmon weigh 2.5 kg and respire 417 mg O_2 h^{-1}

[5]Back Bay areas 72+73 removed from calculation of volume and area

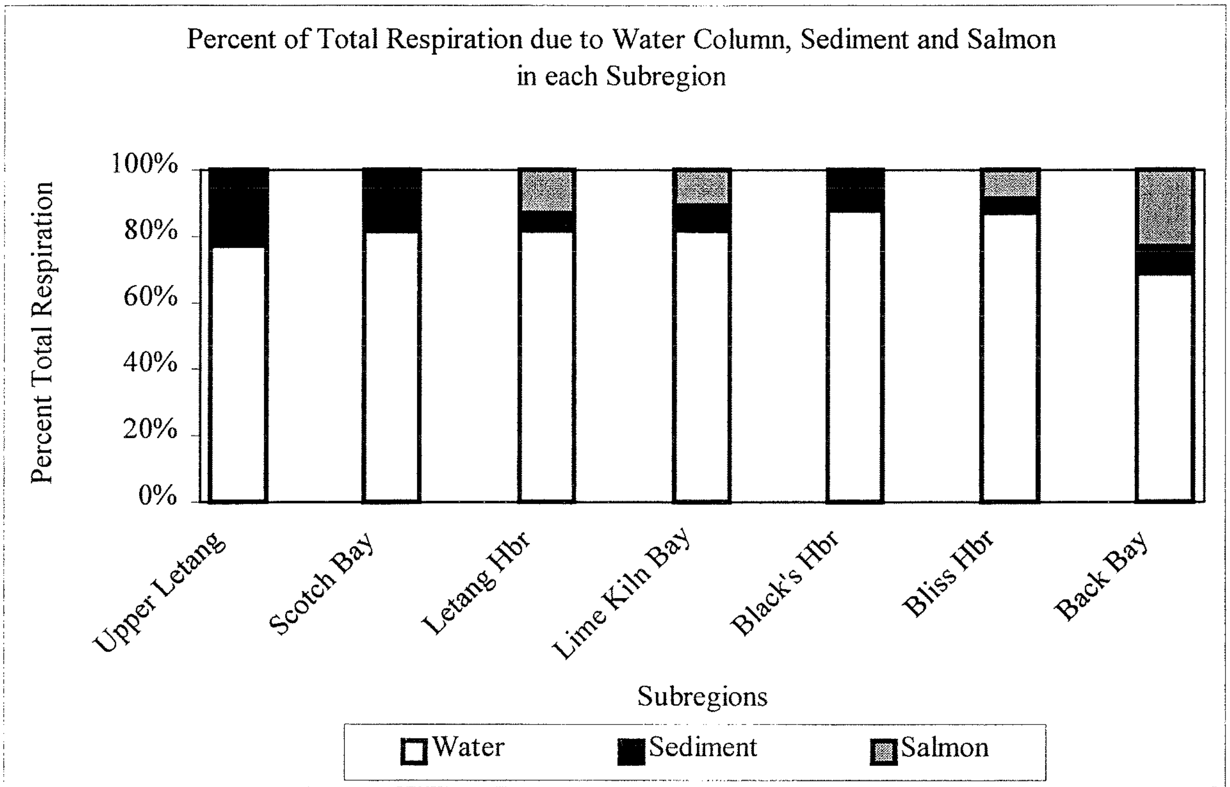

Figure 2: Percentage of total oxygen uptake in the water column, sediment (intertidal + subtidal) and salmon during summer months in various subregions of Letang Inlet based on data presented in Table 1.

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THE EXAMINATION OF POSSIBLE OXYTETRACYCLINE RESISTANCE IN MICROBES ISOLATED FROM SEDIMENTS UNDER AND AROUND FINFISH AQUACULTURE SEA CAGE SITES IN SOUTHWESTERN NEW BRUNSWICK

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Resistance to the antibiotic oxytetracycline (OTC) was determined in aerobic bacteria cultured from surface sediments near and distant from salmon aquaculture farm sites in the Western Isles Region of the Bay of Fundy. A protocol modified from Alderman and Smith (2001) was used to determine OTC minimum inhibitory concentration (MIC) required for growth inhibition. Changes in optical density were followed over 72 h in serially diluted samples placed in Müller Hinton medium in microtiter plate wells. Concentrations of OTC varied from 0 to 160 μg ml^{-1}. All samples (n=52) collected under and around (within 100 m) salmon farms showed OTC resistance above the threshold for establishing resistance (MIC >25 μg OTC ml^{-1}). Controls consisting of a pure culture of *Aeromonas salmonicida* and bacteria cultured from sediments collected >100 m away from salmon net pens, from intertidal areas in Letang Inlet and Passamaquoddy Bay and from a Nova Scotia embayment where salmon aquaculture has not been developed (n=7) showed no resistance to OTC (MIC <5 μg OTC ml^{-1}). Data obtained from one farm site is shown in Fig. 1.

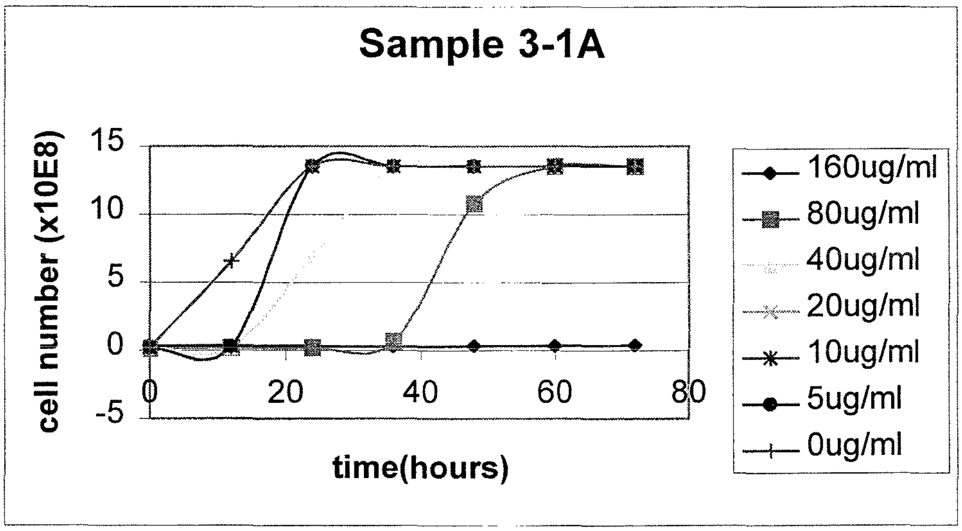

Figure 1: Growth curves for aerobic bacteria isolated from sediment in the presence of different concentrations of oxytetracycline (n=4 for each curve). Surface sediments were collected under a salmon farm site in September 2000 and held frozen (-18 °C) before determination of OTC resistance.

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TRACE METAL TRACERS OF FISH FARM WASTES

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One of the four main questions being addressed in the Environmental Studies for Sustainable Aquaculture ESSRF project is 'How can dissolved and particulate material from aquaculture sites be tracked in the coastal system?' As part of the investigation of this question Tim Milligan and I have looked for tracers of fish farm wastes observable in sediments away from the farm sites. Two possible tracers are (1) zinc (Zn) that is enriched in (or even added to) fish food and (2) copper (Cu) that is commonly found in antifoulant treatments used in the aquaculture industry.

Use of metals as tracers of effluents from fish farm sites has the advantage that metal concentrations in sediments are inexpensive and easy to measure. The disadvantage is that tracer signals must be measured above the natural background signals. So before we can address the tracer problem we need to account for the background concentration. We do this by normalizing the data using lithium (Li) as a grain-size normalizer based on metal vs. Li regressions for non-industrialized, non-impacted sediments. Figure 1 illustrates this process using data from 'pristine' Nova Scotia inlets showing the background regression line and 95% confidence band for Zn.

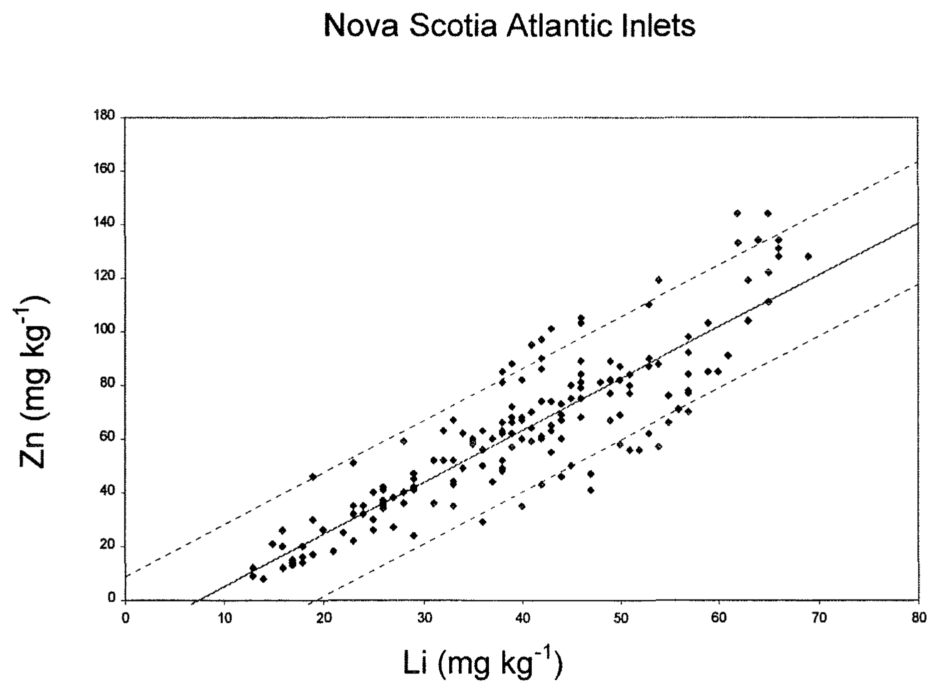

Figure 1: Regression line and 95 % confidence limits for a relationship between Zn and Li in sediment samples from pristine inlets in Nova Scotia. The upper bound of the background line is used to establish a threshold for enrichment.

Analogous plots for Zn and Cu in the Quoddy region based on sediment samples collected in 1999 are shown in Figures 2 and 3.

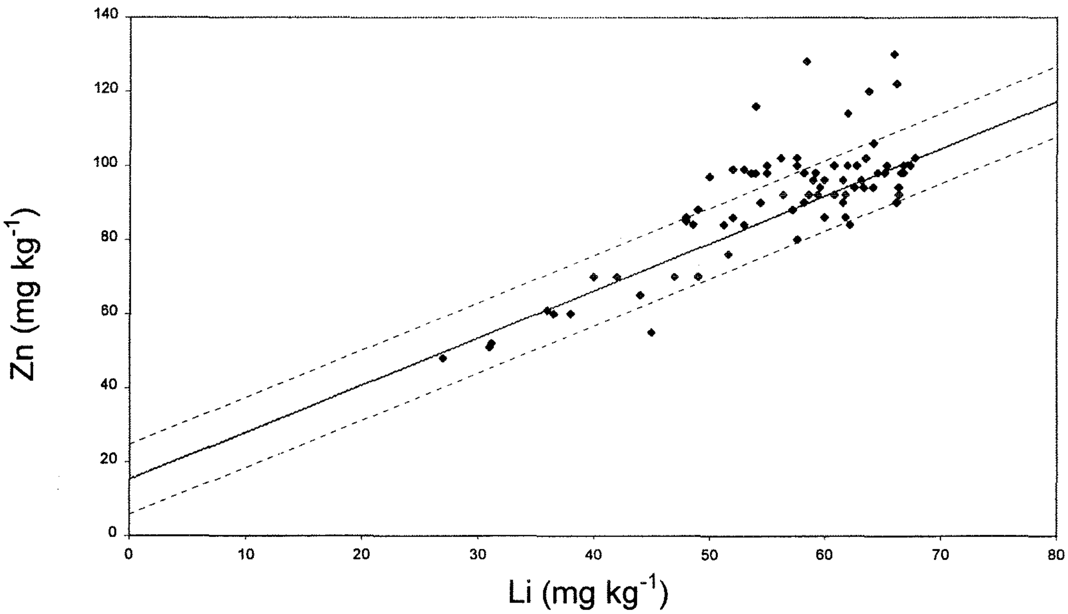

Figure 2: Regression between Zn and Li in sediment samples from Letang Inlet, New Brunswick collected in 1999.

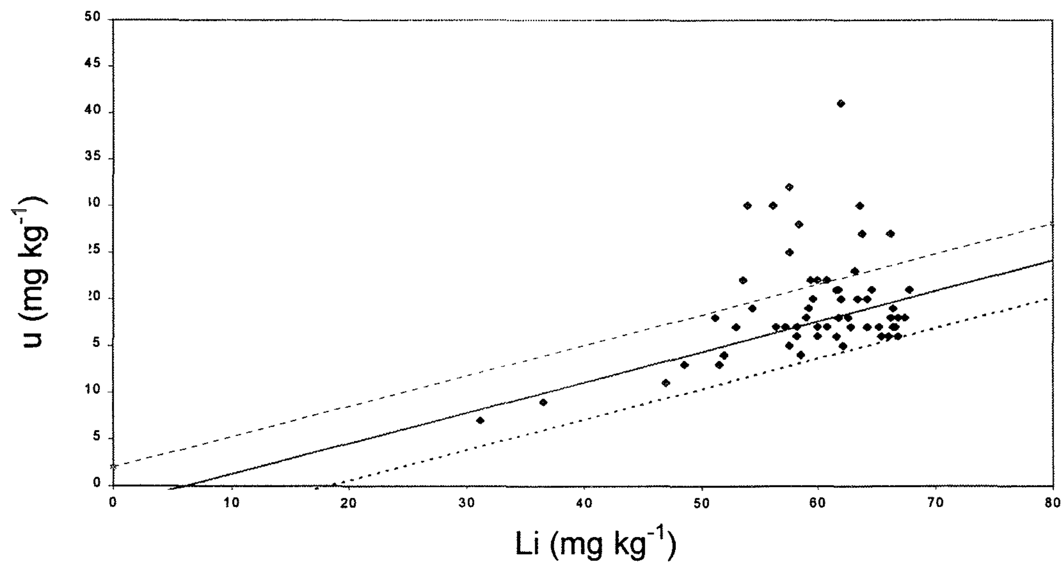

Figure 3: Regression between Cu and Li in sediment samples from Letang Inlet, New Brunswick collected in 1999.

Fig. 4 shows the locations of the samples with anomalously high Zn and/or Cu concentrations (i.e. concentrations above the upper bound of the background regression line). All but one of the samples with high Zn and Cu concentrations are located in Back Bay or Lime Kiln Bay, two bays with a high density of fish farms. However, none of these samples were collected in the immediate vicinity of farms.

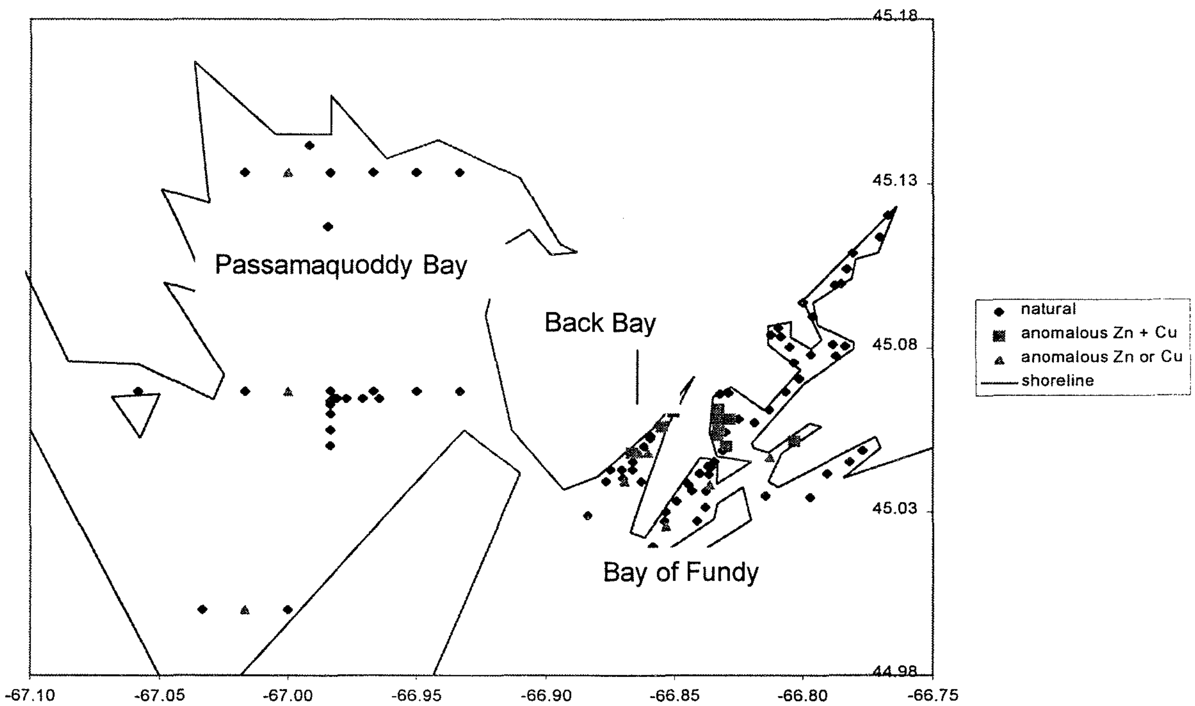

Figure 4: Locations of samples with anomalously high Zn and/or Cu concentrations.

Bliss Harbour, another area with a similar density of farms, does not show any anomalies, probably as a result of greater flushing than in Back or Lime Kiln Bays.

Finally, Fig. 5 shows a plot of Zn vs. Li with some results for samples collected immediately beneath fish cages superimposed on data from other samples collected away from farm sites. The high concentrations found under the cages gives support for the premise that the farms are the source of the Zn.

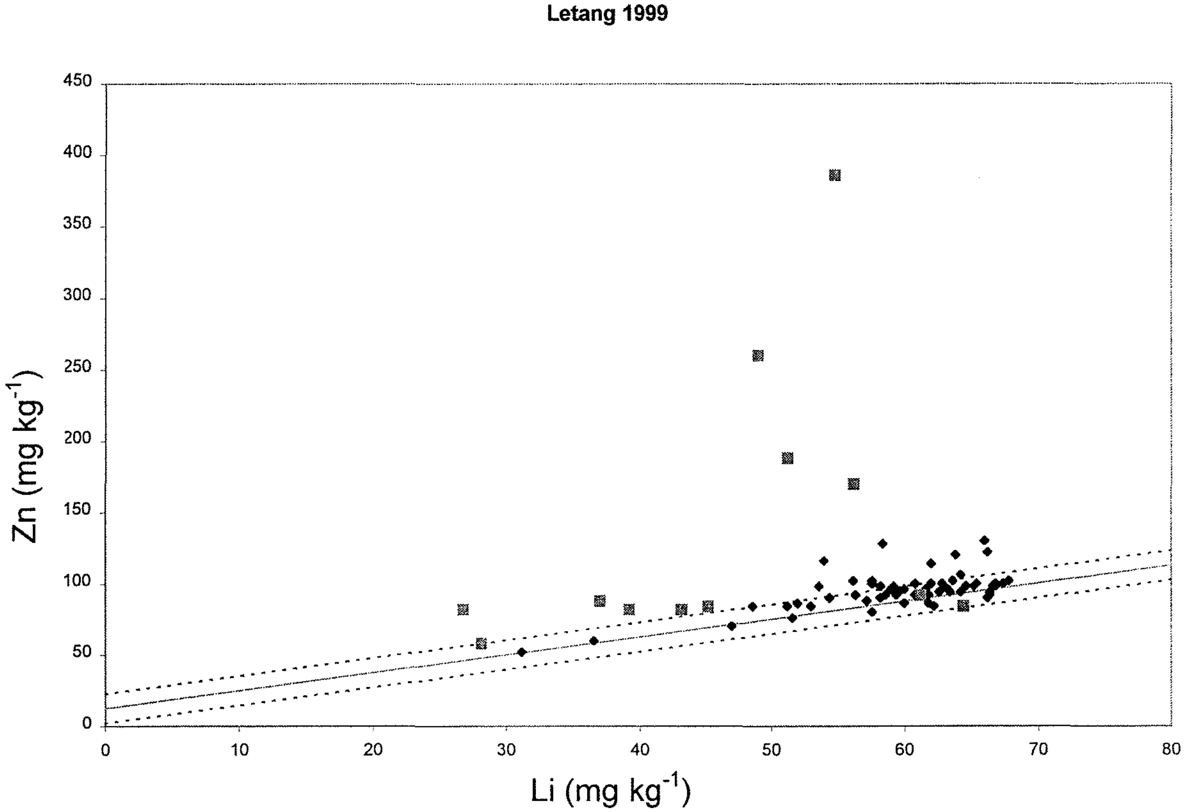

Figure 5: Zn vs. Li in sediment samples from Letang Inlet in 1999 from under (square symbols) and distant from (diamond symbols) fish farm cages.

GREEN ALGAE AND CLAMS: WHAT'S THE STORY?

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INTRODUCTION

Green macroalgal blooms have been observed to increase in many areas worldwide as the degree of coastal eutrophication increases. In southwestern New Brunswick, green macroalgal mats are becoming more prevalent in the head of bays in areas where harvesting of soft-shell clams (*Mya arenaria*) is an important industry. The aim of this study was to 1) document the increase in green macroalgal mats with respect to proximity to salmon aquaculture sites, and 2) determine the effect of algal mats on soft-shell clam behaviour, growth, survival, and body condition.

METHODS

During summer 2001, we measured abiotic and biotic variables at two sites in inlets where several salmon aquaculture farm sites are located: Hinds Bay (inner Lime Kiln Bay), Clam Cove (Deer Island) and at one location (St. Andrews Blockhouse) in Passamaquoddy Bay distant from salmon net pen sites. Abiotic components measured were dissolved organic carbon (DOC), nutrients (N, P, Si), and sediment grain size. Sediment redox potential and sulfide measurements were also carried out.

Green macroalgal (*Enteromorpha* sp.) was quantified by collecting historical aerial photographs as well as chartering aircraft for photography (one over-flight in 2000 and 4 in 2001). Digital analysis of the extent of algal coverage observed in photographs was performed using image analysis software (Optimas 6.2). Random quadrat samples were collected from the experimental beaches to calculate the algal biomass. Nitrogen and phosphorus analysis of the algae is underway at the University of New Brunswick Saint John under the direction of Dr. Thierry Chopin.

We investigated the effect of algal mats on soft-shell clam (*Mya arenaria*) behaviour by investigating burial depth in the field as well as in the laboratory. Soft-shell clams are infaunal bivalves whose main defence mechanism against predation is avoidance by burrowing deeper in the sediment. Clams that are under some type of environmental stress (e.g. low oxygen levels) will likely move towards the surface to reach optimal conditions. This also creates higher risk for predation.

To quantify clam survival and growth in the presence and absence of macroalgae, we conducted a field experiment where clam density was measured by collecting core samples in areas covered and not covered with algae. Body condition was also investigated by collecting clams in the presence and absence of algae. We investigated clam body condition in St Andrews (Blockhouse) and Deer Island (Clam Cove) by dissecting clams in 2 sections: 1) gonad, and 2) somatic tissues.

Based on our field sampling results, we also investigated the effect of algae on soft-shell clam burial depth in the laboratory. Nine aquaria were filled with 10 cm of sediment in which 4 tethered clams were transplanted. *Enteromorpha* sp. was added randomly to 6 tanks (2 cm thick, n = 3 or 6 cm thick, n = 3). Burial depth was measured on a daily basis and the results were plotted as mean burial depth ± SE.

RESULTS AND DISCUSSION

Temporal Changes in Area Covered by Enteromorpha sp.

There was in increasing trend of green algal mat coverage over time from the aerial photographs (Fig. 1). Historical pictures obtained for Deer Island were June 12, 1984 (prior to establishment of aquaculture operations) and June 12, 1999. Algal mats in _

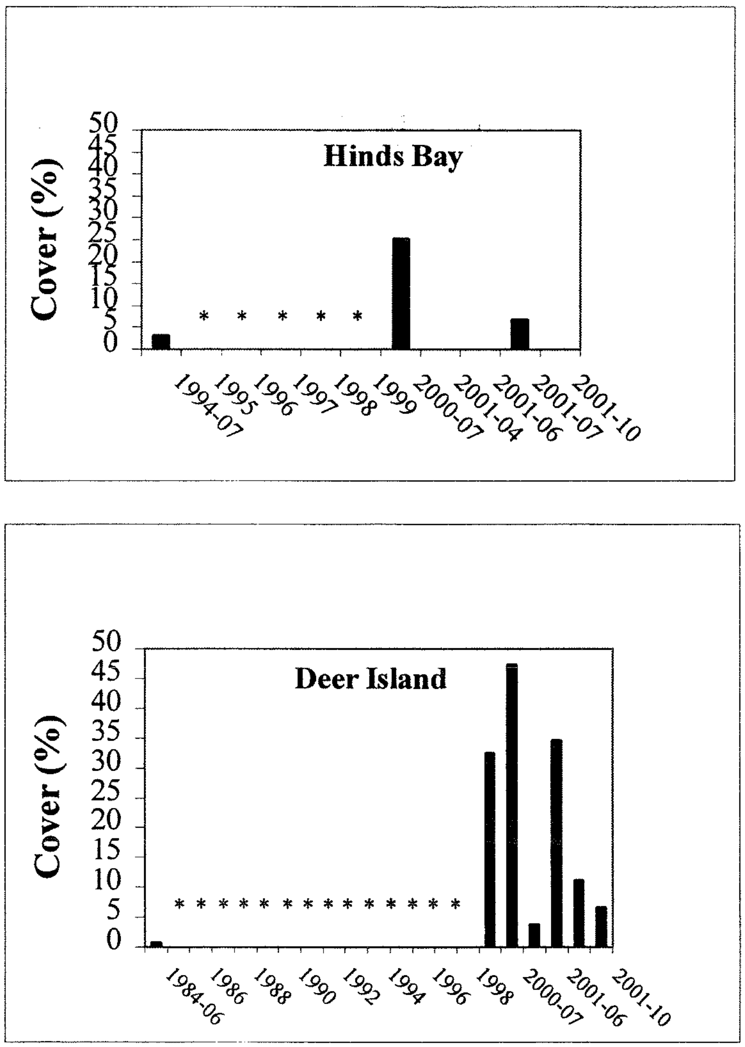

Figure 1: Temporal changes (1984 to 2001) in percent *Enteromorpha* sp. algal mat cover in various intertidal areas, Letang Inlet (Hinds Bay) and Passamaquoddy Bay (Deer Island), NB. * indicates no data available.

Deer Island increased from 0.8% in 1984 to a peak of 47.3 % in July of 2000. The maximum coverage in 2001 was 34.6 % in June. The seasonal variation observed during the 6 months in 2001 might be attributed to seasonal changes in water temperature and photoperiod, and annual variability in the population processes of the *Enteromorpha* sp.

The only historical photographs from Hinds Bay are from July 12, 1994. The results indicate that algal mat cover peaked in July 2000 at 25.3%. During 2001, *Enteromorpha* sp. was only observed in July (6.9% coverage) which was a considerable decrease in coverage from 2000. Changes in environmental conditions are a possible source of observed decline in algal coverage.

Soft-shell clams

Gonad Weight

The morphometric data results suggest that algae had a significant effect on gonad dry mass at the St Andrews site in May ($p = 0.001$), June ($p < 0.001$), and August ($p = 0.008$)(Fig. 2). It is possible that clams under macroalgal mats either 1) spawned earlier which could lead to reproducing in sub-optimal conditions, or 2) produced less gonad mass which would reduce the reproductive effort of the population. More research needs to be done on gonad mass to determine the cause and effect of algae on clam reproduction. Data from Deer Island (Fig. 2) showed that algae had no significant effect on gonad dry mass (May, $p = 0.498$; June, $p = 0.117$; August, $p = 0.085$).

Somatic Tissue

The presence of *Enteromorpha* sp. had a significant effect in lowering the size specific somatic dry mass in St Andrews for the month of May ($p = 0.005$), but the algae had no effect during June ($p = 0.469$) and August ($p = 0.929$) (Fig. 3).

Deer Island results had a significant effect by lowering the size specific somatic dry mass during June ($p = 0.014$), but were non-significant during May ($p = 0.7$) and August ($p = 0.246$). Visual analysis of the results (Fig. 3) suggest that a Type I error may have occurred (i.e. detected a significant effect but it does not appear to exist) for statistically significant results.

Behaviour

Results from the field sampling show that clams under algae are significantly shallower than those in areas clear of algae in Deer Island for the months of June and August (Fig. 4). Burial depth in St Andrews will depend on month and algae cover as a significant interaction (month x algae) was found. Dense algal mats may reduce water flow at the algae-sediment interface that prevented well-oxygenated waters from reaching the infaunal species.

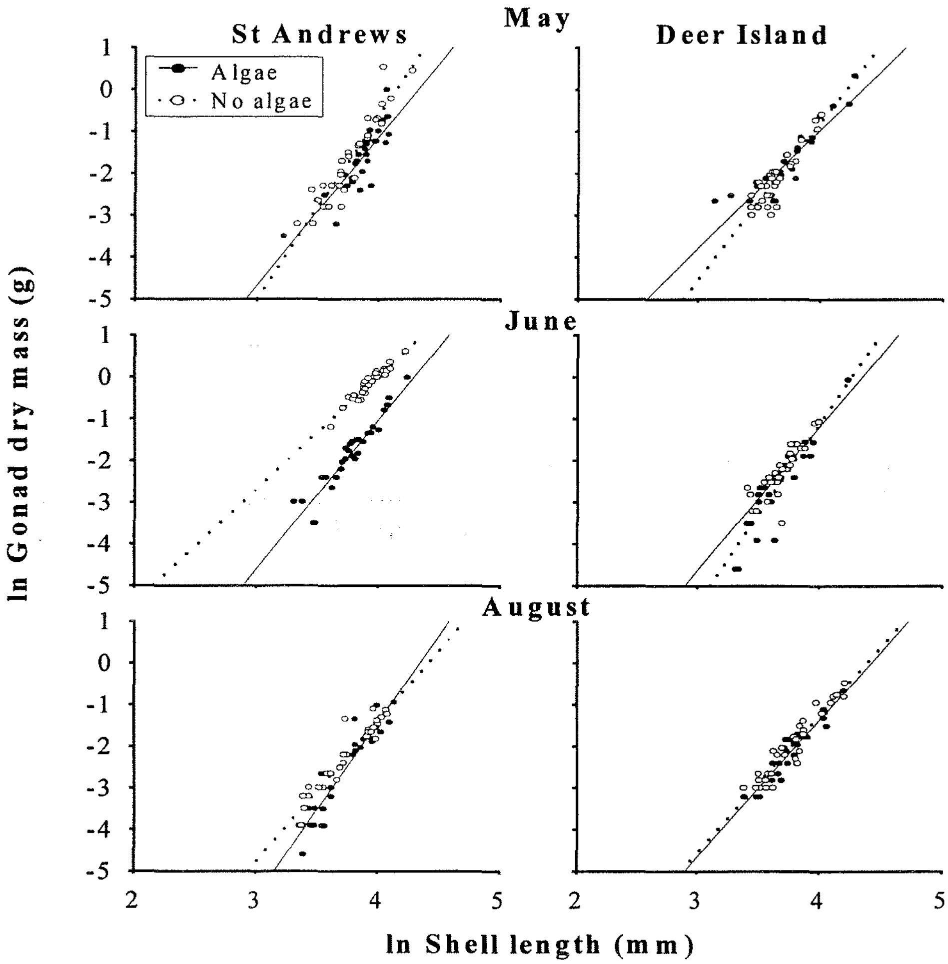

Figure 2: Relationships between shell length and gonad tissue dry weight in *Mya arenaria* between May and August 2000 at two study sites in the Western Isles region of the Bay of Fundy.

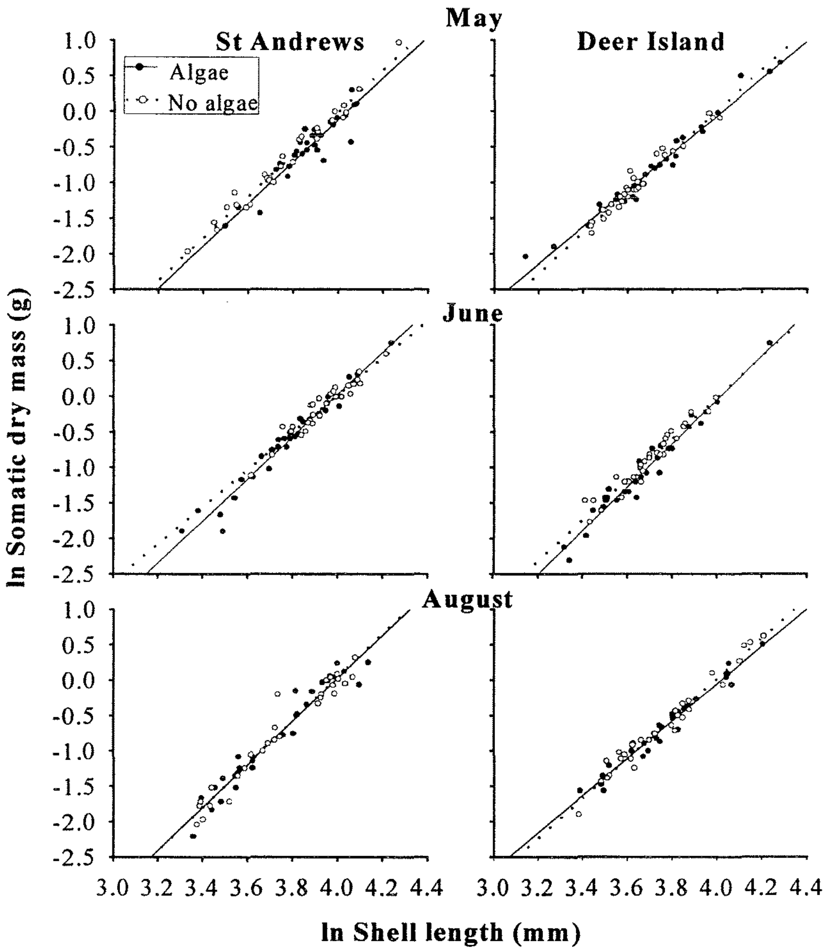

Figure 3: Relationships between shell length and somatic tissue dry weight in *Mya arenaria* between May and August 2000 at two study sites in the Western Isles region of the Bay of Fundy.

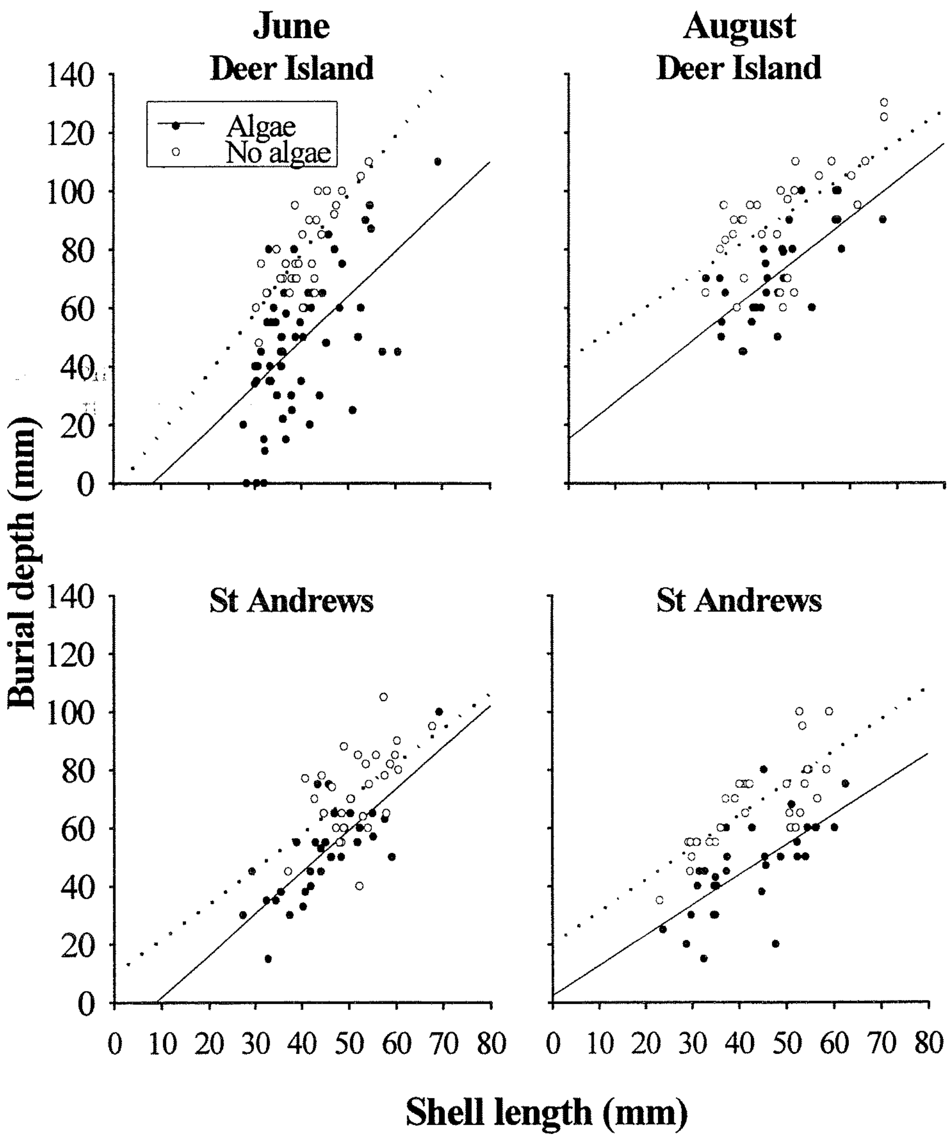

Figure 4: Relationships between shell length and burial depth in *Mya arenaria* between May and August 2000 at two study sites in the Western Isles region of the Bay of Fundy.

In the laboratory burial depth experiment, clams responded quickly to algal addition as burial depth decreased on day 1 to further decrease until day 7 (Fig. 5). We observed that some clams had completely de-burrowed in the 6-cm treatment. This is in agreement with some field observations from Deer Island where some clams under algae had also surfaced. Statistical analysis of these results indicate that algae had a significant effect on clam burial depth during the lab experiment ($p = 0.0005$). On day

7 algae was removed and we let the experiment run for another day to observe if any clams would re-burrow. Clams did re-burrow (Fig. 5) which indicates that algal removal might alleviate the stress imposed by these mats on soft-shell clams.

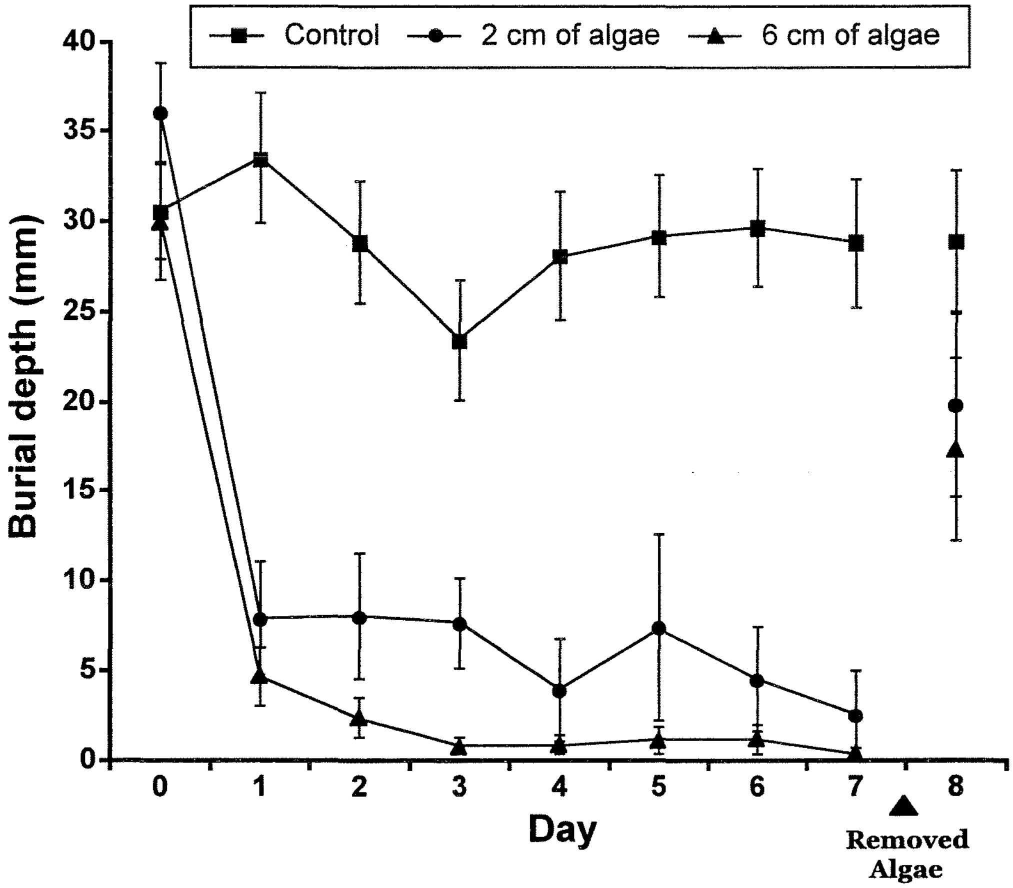

Figure 5: Changes in burial depth of *Mya arenaria* under various amounts of cover by the green macroalgae *Enteromorpha* sp.

CONCLUSIONS

The results indicate that there has been an increasing trend in algal mat coverage over time in the intertidal areas where time series observations exist but there is significant inter-annual variability in the amount of cover. Further research is required to determine the thresholds (i.e. nutrient levels) at which changes in macroalgal mat cover start to occur.

Macroalgal mats were shown to have negative effects on clam gonad mass and behaviour. More studies on the impact of algal mats on soft-shell clam physiology (e.g. stress) and population dynamics (e.g. reproductive output) need to be done, as soft-shell clams are an important economic resource for southwestern New Brunswick.

Coastal eutrophication is best defined as an increase in N and P in coastal waters. Green macroalgal species respond to these increases in nutrients and act as natural 'scrubbers' by forming dense mats. Consideration should be given to bioremediation by utilising more desirable algal species (i.e. nori (*Porphyra* sp.) which would benefit from these eutrophic conditions likely resulting from multiple coastal inputs including municipal, industrial and aquaculture operations.

ACKNOWLEDGEMENTS

We thank Nicola Johnson for help during summer 2001. ESSA team members assisted with analysis of abiotic factors and provided technical support. Personnel from the St. Andrews Biological Station helped in setting up laboratory experiment and provided vehicle support.

GENERAL DISCUSSION

REVIEW OF PROGRESS RELATIVE TO ESSA PROJECT GOALS

Facilitator- Barry Hargrave, Rapparteur-Lisa Doucette

An open-floor discussion following the final workshop presentation was held on January 18, 2002 to consider if the questions asked and approaches used based on the review of current activities, are optimum for the stated goals of ESSA. After the second year of the research program it is fair to ask if there is evidence that the project has moved forward to identify and model far-field effects and if this has been done in a national, rather than strictly regional, context.

Points were raised during the general discussion following the workshop to clarify that the purpose of the ESSA project is to study the effect of aquaculture on the environment, not the effect of the environment on aquaculture. However, both goals may be met using the same ecological models and concepts developed during the ESSA project. Representatives of the salmon aquaculture industry may see the ongoing research as a way to help the industry become more sustainable, but this is not the main purpose of the studies, it is only a secondary benefit. The overall aim under DFO's legislative mandate under both the Fisheries Act and Oceans Act is to find ways to make finfish aquaculture sustainable without harming aquatic habitats and ecosystems.

Evidence was provided by the ESSA 2002 presentations that showed progress in modelling (mass balance, box models and source-sink models) to allow comparisons of distributions of dissolved oxygen, primary production (phytoplankton and intertidal algae), and nutrient loading with calculated fish respiration. There was general agreement that sufficient information is now available to complete models of nutrient inputs and mass balances without making more measurements. Far field effects of nutrification on plant growth may be shown by increased coverage of intertidal sediments by macroalgal (*Enteromorpha* sp.) mats where sea cage sites have been located in NB for more than a decade (Auffrey et al., this volume). More extensive surveys are required to examine macroalgal mat cover in other intertidal areas at varying distances from salmon farm sites. Bacterial resistance to oxytetracycline (the antibiotic currently most widely used as an additive to salmon feed) has also been observed at widely spaced sampling sites through the Letang Inlet, NB, (Friars and Armstrong, this volume) indicating the potential for dissolved and particulate matter released from cage sites to move horizontally from farms.

The suggestion that sampling not be continued during the final year of ESSA (when the project plan was to complete development and evaluation of models) was met with objections. It was felt that there was a need for more seasonal sampling and more spatial resolution. It was also suggested that additional field work in the final year would determine if observations conform to model predictions (i.e. test models such as relationships between sedimentation and sediment nutrient and oxygen fluxes).

Further sampling would also ensure that data from essential areas had been included in modelling efforts.

Concern was expressed that funding within the project is insufficient to fully analyse existing samples (e.g. benthic macrofauna analysis in Maritimes and BC). It was suggested that the "holes" in the data should be identified as a major section in the final report, including new questions that need to be answered and the focus of where research should go after the final year. There was also the caution that a complete foundation is needed for all ecological aspects of potential effects before conclusions are drawn (i.e. expressing opinions based on benthic and sediment data without water column data is dangerous). The opinion was expressed that we should be filling in the "small holes" during the next year, leaving "big holes" for the future. A-base budgets in all regions are insufficient to support continued work on the scale required. There is a recognized need for more exchange of information between regions and provinces, but this will continue to be restricted due to lack of on-going funding.

Limitations of the scope of the current ESSA project that is focused only on environmental variables was emphasized. For example, far field effects considered in the ESSA project do not include studying the spawning habitat of lobsters, interactions with wild fish stocks due to escapement or the epidemeology of environmental linkages to disease within the salmon aquaculture industry.

Discussion then turned to concerns and views of industry and Habitat Management with the opinion that often the time lines of science are too slow to meet current needs of habitat management and industry. It was suggested that time scales can be reduced if habitat management and science work more closely with the industry. There often is a separation between the questions posed by science and answers required by industry to make immediate decisions. For example, growers are making plans and applying for leases during winter months for next year's production cycle, but this occurs without input from science due to the perceived slow pace of obtaining research results.

There are new avenues for project funding available for scientists working in partnerships with the industry to facilitate greater co-operation. For example, a science committee has recently been formed by the NB Salmon Grower's Association to establish protocols and policies for interactions with science with the goal of providing the grower's with accurate and timely information. There is a need to find a way for the science presented in workshops to be conveyed to growers directly since they do not read publications. Specific invitations must be made for direct face-to-face meetings with growers with efforts made to present the information in an understandable way. Several people expressed the need to make science relevant to the grower's needs (i.e. not abstract examples).

A representative from the BC Salmon Industry pointed out that there has been a moratorium on expansion of industry since 1995. There will be no expansion of industry until regulations are in place and grower's are frustrated with the lack of scientific information. It was stated that the benthic monitoring program in NB is probably not applicable to BC due to differences in environmental conditions.

National recommendations from a project such as ESSA may not be well received because of differences in regional environments. It could be misleading to apply information from local site sampling in one area across wide geological areas without comparative studies.

A response to these statements was that these inter-regional comparisons are underway. Results of parallel studies in NF, NB and BC will be combined to try to achieve as comprehensive an understanding of sensitive variables for monitoring and modelling far field effects as possible. It was pointed out that the fact that the three ESSA study regions are so different should make any models or proposals for monitoring variables more robust. It is true that results from one site should not be assumed to be applicable across regions, but overall monitoring/modelling approaches could be nationally applicable. Habitat managers understand that scientists do not want to jump to conclusions before fully analyzing data, however information is needed immediately to proceed and make decisions.

Concerns were expressed by a representative from the NB Salmon Growers Association about how information is transferred from science and habitat management to the public. The public perception of DFO science and the aquaculture industry is often formed piecemeal by bits and pieces of news reported as sensational stories in newspapers. When working with industry scientists need to be cautious about how information is distributed and be responsible in not making unsupported observations detrimental to the industry. One research scientist responded that most responsible investigators will try to speak and write in a balanced way and they cannot be held responsible for what reporters write. Industry representatives must be informed and prepared to defend themselves.

After this general discussion about the need for increased communication and responsible reporting of research results, comments returned to science questions concerning ESSA subprojects and modelling efforts. There were several constructive suggestions as to how to make the most of the funding available in the final year of the project. Some of the comments were:

- We should try to theorise "what if..." scenarios to better predict potential impacts (e.g. if current increases what is the effect on other variables)
- Results of parallel studies in different regions need to be combined more effectively to gain a comprehensive understanding of sensitive variables for monitoring and modelling far field effects

EXTERNAL REVIEWER'S COMMENTS

SCIENTIFIC OVERVIEW OF THE ENVIRONMENTAL STUDIES FOR SUSTAINABLE AQUACULTURE (ESSA 2002) PROJECT STUDIES

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GENERAL

This was the second workshop of the series and came at approximately the end of the second year of the project. It was preceded by a joint one-day workshop (NHMWGA and ESSA).

NHMWGA/ESSA Workshop

The NHMWGA/ESSA Workshop was intended to:

> "1) provide a forum for DFO scientists to update Habitat Management in aquaculture and fish habitat research initiatives under these issues, in order to strengthen the knowledge foundation for informal decision making,
>
> 2) facilitate a discussion about new and emerging issues, in order to help identify potential science requirements and priorities of Habitat Management,
>
> 3) create an opportunity for Habitat Management and science staff to meet and exchange information, in order to strengthen working networks and explore innovative ways of working together."

Three key topics identified by Habitat Management were covered:

> "1) Siting criteria and modelling for aquaculture operations to minimize potential for a HADD (Harmful Alteration Disruption or Destruction).
>
> 2) Thresholds for variables useful for identifying HADD in water and sediments - marine environmental quality indicators.
>
> 3) Cost effective monitoring tools/techniques – water and sediment variables for application to assessing potential for far and near-field effects."

This workshop, although not strictly engaged in providing progress reports on the ESSA Project, did present data related to it. The workshop provided an opportunity for Habitat Management to illustrate to themselves and the research staff their responsibilities and the requirements for more information to permit Habitat Management to discharge their responsibilities.

In this context Habitat Management requires:

Defensible Site Guidelines with linkages to Performance Based Standards mandated by

1) Fisheries Act
2) Need for harmonization with others e.g. the Provinces among others
3) Codes of Practice

Defensible Criteria for the Identification of Critical Habitats derived from

1) Habitat Policy – no net loss
2) Conservation and Protection Guidelines
3) HADD Decision Framework

Compensation and remediation and the need for them was defined as making the best of a situation which would have been better if it had been avoided in the first place.

Thus the case for Habitat Management needs was clearly delineated and through these statements and ensuing discussions it was emphasized once more that there was a clear need by Habitat Management for the results of directed scientific activities to fulfil the provisions of the Canadian Environmental Assessment Act (CEAA) and the Fisheries Act. For this to be successfully achieved full collaboration and cooperation between the two groups was required.

Presentations and Discussions included:

A. Research on Siting Criteria

1) Sedimentary environment (acoustic and benthic mapping)
2) Water quality and determination of water boundaries
3) Multi beam surveys
4) Benthic grab surveys permitting analysis of sediment content

B. Research on Sensitivity Surveys using lobster nursery grounds to illustrate the point

C. A general model for oxygen distribution in relation to aquaculture

D. Thresholds for assessing organic matter assimilative capacity in marine sediments.

All of these presentations and discussions served admirably to define and reinforce the Habitat Management needs for studies to provide methodology, techniques and criteria as well as to set the stage and introduce the review of the progress made in ESSA 2002.

<u>ESSA 2002 Workshop</u>

The stated aims of the ESSA Project were to determine:

1) How can assimilative capacity be determined for wastes produced by marine finfish aquaculture?

2) What measurements can be made to document changing patterns and rates of sedimentation?

3) How can material released from aquaculture sites be tracked within a coastal system?

4) How can these environmental objectives be used by habitat managers to mitigate potential environmental effects such that a Harmful Alteration, Distribution or Destruction (HADD) of fish habitat does not occur?

As was noted for last year's workshop by Silvert (2001), the calibre of this year's presentation was also very good. Additionally, although there were fewer presentations than last year, those that were made were more focused and showed clear advances in understanding the nature of the physical environments in the Passamaquoddy Bay/Letang and immediately adjacent areas, Broughton Islands area and Bay d'Espoir. This has resulted in a Finite Element Model for the southern New Brunswick area which has proved to be of considerable use to a number of the research projects specifically in allowing conclusions to be drawn regarding oxygen levels and dispersal of suspended materials.

It was suggested that the oceanographic picture developed to date could provide the foundation for the construction of box models to be used for predicting waste dispersal, disease spread and tracking waste accumulations via specific indices once these have been proven and selected. To this end, it was encouraging to learn of the techniques being examined to trace several metals and a number of organic molecules in sediments plus the fate of the straight carbon loading that emanates from the fish farms. One of the associated major problems is the interpretation of this kind of data. Although it should be possible ultimately to determine analytically the levels quantitatively and attach physiological consequences (as and when defined by toxicologists) it is difficult to account for and resolve issues associated with patchiness and the periodic and irregular re-mobilization of sediments.

In addition, and as mentioned earlier, considerable effort has been expended in acoustic and benthic surveys in the Broughton Islands area of northern Vancouver Island to trace both near and far-field accumulations emanating from fish farms. In the Bay d'Espoir area there are both summer and winter farm sites; the need to carry out surveys seasonally was emphasized. This, in fact, is being done now in the Lime Kiln Bay area of New Brunswick. Work on near-field changes (i.e. in the vicinity of mariculture sites) is being carried out in the Letang and adjacent areas comparing the high-resolution multibeam back scattering techniques with pole mounted sidescan techniques; the calibration of these two techniques is seen as useful in applying the area-wide determination of Eh and sulfide and relating these to farm practices and environmental conditions. It is anticipated that these and other data will provide the ingredients for the modelling exercises to gauge the Passamaquoddy/Letang and adjacent areas Ecosystem Assimilative Capacity.

Studies of microalgae in the Southern New Brunswick area suggest that despite the increase in nutrients this does not translate into increased microalgal production. The presumed explanation is that this area is unique in that high turbidity resulting from the marked turbulence of the Fundy areas blocks light penetration of the waters and thus prevents the occurrence of large blooms of microalgae.

Additional work on the effects of green macroalgal mats on the populations of soft shell clams in southwestern New Brunswick confirmed the previous year's results. A preliminary conclusion is that the mats arise as a result of the increased nutrients and decrease the oxygen in the area forcing the clams to surface or suffocate. It was believed that the negative effect was site specific and probably results directly from a build-up of nutrients derived from aquaculture sites.

Preliminary results from the year's study on the development of antibiotic [oxytetracycline (OTC)] resistance among bacteria exposed to OTC was reported confirming that this does, in fact, occur here as elsewhere. These studies will continue into the coming year.

A preliminary attempt to accelerate the dispersion of accumulations of fish farm waste by dragging a length of heavy two-inch steel chain crosswise through the waste deposit was not successful. Although better tools would probably break up the mass more effectively it was concluded that this would merely result in spreading the waste around more widely rather than in its dissipation. Physical removal would be effective, but probably prohibitively expensive. There are no plans at present to repeat or extend this work.

In sum and without repeating criticisms of the first year's activities, some of which are unavoidably still valid, it can be said that the project has made considerable progress in its second year. The modelling to develop a Finite Element Model for the New Brunswick area is advanced enough to provide broadly a basis for gauging or predicting oxygen relations and dispersions with reasonable confidence. These predictions can be improved with the use of the multibeam back scattering and sidescan studies. Methodologies involving the use of particular metals as tracers to examine deposits and the rate of deposition are progressing and show promise; approaches to take into account patchiness of deposits and their periodic re-mobilization and transfer still are needed to deal with the dynamics and to link results to effects on biota of the area.

Undoubtedly, it will not be possible to do all of the work required to bring these methods to a state of routine applicability by the end of the third year of the project. Much of the final year will be consumed by the need to analyse samples and data and consolidate the results in the products or deliverables promised at the project outset. The work to date, however, has produced useable results and aided in defining the issues and evaluating possible less expensive approaches. For example, it was suggested that simple box models could be used in particular circumstances rather than always investing heavily in elaborate models.

Comments on Work in Progress

Quantitative work on the source, fates and effects on target organisms of materials emanating from the fish farms, such a carbon, nitrogen, PCBs, dioxins, furans, chemotherapeutants etc. is proceeding. When the extensive list of current and potential materials is considered it is clear that this is an immense and complicated problem that will not yield readily to the limited effort that can be applied with the minimal resources provided to the project. If account is taken of possible interactions of the chemicals in the fish farm wastes and the probable synergisms resulting in the physiological effects, it is clear that this is not an aspect that will be resolved in this project or early in the life of subsequent projects. It will probably be necessary to narrow the testing focus for physiological effects to representative compounds and set rather arbitrary limits for permissible levels based largely on acute effects.

Amplification of these data could and possibly should be based upon whole animal data using stress testing or development of specific assays for elements indicating adverse reactions such as histones. (This aspect has been addressed more fully at the end of this review). Work on the dispersion and fates of the bulk materials or nutrients such as carbon and nitrogen needs to be followed in well-understood oceanographic situations and on a seasonal basis. To understand the influence of fish farms and their nutrients on such phenomena as the initiation or perpetuation of microalgal blooms, studies should be prosecuted under a variety of field circumstances giving a range of conditions. It would appear that the conditions within the southern New Brunswick fish farm area militate against rather than promote phytoplankton blooms.

The major problem identified by Silvert (2001) in last year's assessment of this project concerned the far-field effects; this problem still remains. His comment was "Although there was brief mention of some types of far-field effects that can arise because of high sensitivity of some ecosystem components to aquaculture effects, there does not appear to be any systematic effort to characterize or identify these. The one that was suggested was the possibility that lobster populations can be affected by very low concentrations of chemicals used for sea lice treatment."

The studies of the past year, as mentioned above, have made progress in methods which might be applied as tracers for measuring the transport and deposition of materials in the far-field. This has not yet progressed to the stage where it might be termed routine and reliable and has not yet been applied to area-wide surveys. These methods in any event can only be used to show build-up and possibly something of the dynamics of transport, deposition, re-mobilization and fates. A knowledge of the materials and their concentrations in the build-ups is important, but this alone will not show the all important consequences for the natural biota of the area or even the impact on the captive farmed animals. Data on the consequences of the contributed or waste materials is essential for the full evaluation of the impact of aquaculture on the habitat and its occupants. It must be remembered that the Habitat Management environmental responsibilities are concerned with protecting the overall management area (both habitat and biota) from adverse effects of any and all operations within the defined management areas.

A realistic assessment of the progress made toward addressing the four objectives of the project indicates:

Objective 1) How can assimilative capacity be determined for wastes produced by marine finfish aquaculture?

The methodology to resolve this issue for far-field effects is being developed, but at the moment is far from complete, in fact, it has not been possible yet to select appropriate indices to aid this assessment.

Objective 2) What measurements can be made to document changing patterns and rates of sedimentation?

This objective and Objective #3 are essentially subsets of Objective #1 and together are fundamental to the resolution of Objective #1. To date the main instrument for documenting patterns and rates of sedimentation is the use of site modelling and an understanding of the characteristics of the materials to predict far-field patterns of sedimentation for wastes (particles) emanating from the fish farms. Appropriate tracers (indices), survey frequency and methodology are being investigated, but the methodology is far from complete.

Objective 3) How can material released from aquaculture sites be tracked within a coastal system?

Currently the techniques and procedures are under consideration and development; as stated under Objectives #1 and #2 this work is not complete, in fact, exact courses of action are still being considered and developed.

Objective 4) How can these environmental objectives be used by habitat managers to mitigate potential environmental effects such that a Harmful Alteration, Disruption or Destruction (HADD) of fish habitat does not occur?

As many of the necessary diagnostic techniques and procedures are still under development it will not be possible to offer highly specific advice until these developments are complete especially as regards far-field impacts. It should, however, be possible to draw upon much of the data being collected within the project to aid in developing criteria to avoid problems in the future even before all of the answers sought in the ESSA Project are available.

Although at first glance the foregoing assessment may appear negative, it is not. It must be recognized that the development of approaches to resolve the problems itemized within the four objectives were goals to provide direction rather than an anticipation of their full achievement. The period of time (3 years) and the resources spread over three totally different DFO regions and study locations could not be expected to resolve such complex problems so quickly. It is to the participants' credit that so much has been accomplished in such a short period.

The definition of the issues and the approaches required have been made more apparent. Clearly the project in this regard has been a success and should be considered the foundation for a more rigorously and sharply defined second three-year project. A few thoughts on this aspect are given below as possible aids to the development of targets and approaches to be incorporated in such a second stage project.

Comments Relating to Further Studies

Much of the work done to date has been employed in studies of existing salmon aquaculture sites. This has been convenient and useful for several obvious reasons. It demonstrates the problems posed by real life situations and it allows the studies to accumulate realistic data derived from actual operations. On the other hand, these aquaculture sites were not chosen or put into operation by the growers or operators with the prime intent of avoiding or minimizing the problems underlying the stated four ESSA objectives. It would be interesting and instructive in light of the results of ESSA and other data to carry out a paper exercise for the purpose of drawing conclusions as to whether operations at the three main aquaculture sites (under study in ESSA) should have taken place in these locations.

Much of the work in the past and also for the ESSA project is most useful in gauging near-field conditions. Although these are referred to as environmental impacts they are actually a restricted record of the build-up of materials under the net pens or in the immediate vicinity of the site. In the depositional areas these under-cage conditions are actually or largely azoic. Since the contributed waste materials in such locations continue to accumulate the longer the net pens remain at the site, it is obvious that the wastes are not being assimilated; little data exists for what impact this may have on the far-field or management area at large, or even on the fish held captive in the cages.

As the Habitat Management concerns are for the environmental impacts on the defined management area, bay, inlet etc., it is essential that the far-field effects be defined and determined for the non-farm biota. The impact on the farmed fish should not be ignored as their experiences can be indicative of possible widespread environmental effects and may even be used as early warning systems of problems for the management area at large.

More emphasis needs to be placed on the improved selection of aquaculture sites based upon suitability for culture of the target species. The data from ESSA and elsewhere already provide for site evaluations which would go far toward avoiding many environmental problems. There is sufficient data now on the requirements of various possible aquaculture species (finfish and shellfish) to specify what the minimum conditions must be before a tentative site should be considered worth examining further. This leads to a stepwise approach from an environmental point of view. Using salmon as the example it is possible to specify minimal required site conditions (although given the current high production of salmon and the consequent severe market squeeze it would be wise to develop minimal criteria for other possible farm species as well).

The lower lethal temperature limit for salmonids is - 0.7°C and the upper temperature limit is around 22°C depending upon species. Oxygen levels need to be maintained at all times. The modelling studies reported by Page et al. during the workshops suggest that oxygen levels would be sustained as long as the current velocity did not fall below 2-3 cm/sec for periods greater than 30 min. Studies by Hargrave and Wildish and others provide methods for evaluation of flushing actions. Thus it should be possible to define minimal environmental conditions for salmon aquaculture and provide reasonable margins to ensure safety for the aquaculture operators:

1) Salinities remain relatively constant in most coastal areas, but it should be ensured that they remain constant for the contemplated site and that they remain preferably between 28 and 33 ‰ throughout the culture period.

2) For a potential site to be attractive surveys should show that the temperature regimes over a) the cold weather periods always exceed at least - 0.5°C and preferably do not drop below – 0.2°C or – 0.3°C during the survey period and b) the warm weather periods are preferably always below 18°C. (Much temperature data for eastern Canada areas is already available from the DFO Coastal Temperature Data Series).

3) The current velocities must not drop below 3 cm s^{-1} for periods greater than 15 minutes. These data should be based on current data determined over at least a 29-day survey period.

4) If the foregoing criteria are met, limits on farm loading could be set in relation to oxygen turnover in the bay or inlet (e.g. based upon current and mixing data); the total respiratory load for the bay or inlet, or more particularly some defined portion of it, must be limited to that which would not cause oxygen levels of 7 mg l^{-1} to drop to levels less than 6 mg l^{-1} at any time during the culture period.

5) Data confirming the suitability of the area for salmon culture could be acquired by such measures as Eh and sulfide determinations for pre-culture bottom surveys and/or a prior analysis of the bottom sediments to ensure that the area is not marginal with regard to flushing.

Obviously other more sophisticated techniques can be applied later as they become available, but these measurements are both rapid and simple and, if carried out as part of the prior assessment for gauging the minimum suitability of a site, would eliminate many of the environmental issues currently experienced.

If benthic and pelagic data for a contemplated culture area was assembled from existing data or acquired by pre-culture surveys, the later assessment of the environmental impacts imposed by the culture operations would be simplified. In addition, it should be possible to use individual wild and captive biota for measuring environmental change. For example, changes in intertidal macroalgae following environmental alterations have been noted for culture and non-culture activities as early warning signs; this aspect should be followed more closely to evaluate the extent to which these changes can be used as reliable indicators of environmental impacts.

Finally, as the complexity of the culture operations impacts on the environments (biota and habitat) is tremendous and the methodology slight, it will not be possible to offer comprehensive assessments using all these techniques till well into the future. In the meantime, consideration should be given to using the captive and wild specimens as something of "mine canaries" for the purpose of gauging environmental impacts (i.e. whole animal assays).

There are a number of methods for measuring stress effects in fish; many are not attractive because they are complex and difficult to carry out, or the effects being measured are somewhat ephemeral or require repeated sampling etc. Certain methods, however, do have utility as described by Barton and Iwama (1991) and Pickering (1997). More recently a method for measuring the results of chronic, in contrast to acute, stress has been reported by Robinette and Noga (2001). This involves the straight-forward serological determination of variations in the histone-like proteins in the skin of fish; these proteins are relatively stable and vary with chronic stress applied over lengthy periods (weeks) of exposure; they do not, for example, vary with the acute stress imposed by minimal capture and handling procedures. By placing cages of the appropriate specimens in selected areas and by the judicious use of free-living animals in the management area of interest it should be possible to develop reasonably accurate, but simple to apply, assay techniques to measure the environmental impacts of aquaculture operations or other activities in both the near and far-fields. The advantage of such methods lies in their flexibility i.e. they can be used readily in field situations to gauge overall effects without the necessity of immediately identifying the specific culprit(s). Thus they can be used as broad screening guides and also within laboratory settings as assays to gauge effects of single and multiple mixtures of known materials.

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SCIENTIFIC OVERVIEW OF THE ENVIRONMENTAL STUDIES FOR SUSTAINABLE AQUACULTURE (ESSA 2002) PROJECT

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The ESSA project is a significant advance in understanding the effects of aquaculture on the marine environment. Because this field of study is moving from a local impacts perspective to one of ecosystem level impacts, research arising from ESSA will be indispensable to the development of environmental assessment. The combination of modelling and field work is the optimal approach to these issues, and ESSA benefits from a strong team in both areas. The workshop summarized in the present report is notable in that it was concurrent with a meeting of the aquaculture working group from Habitat Management. This allowed habitat managers to be involved in the science talks and become more informed about the current issues with which research scientists are dealing.

Ecosystem level impacts of aquaculture are inherently difficult to study. In contrast, acute impacts such as reduced Eh that occur below culture sites are well documented for a variety of environments and locations. These localized impacts are too often used as evidence that aquaculture is 'bad for the environment'. The larger question of whether ecosystem function or health is compromised is harder to consider, because it is by definition a diluted effect compared to the acute impacts. Two non-exclusive categories of effect that may be contrasted are those involving dispersal of waste products, and those that influence system rate processes. The spread of organic-rich food/faeces or of therapeutants derived from fish cages is a prime example of waste dispersal, and identification of tracers for these materials are integral to their study. Considered on an estuary-wide basis, the dispersal of tracers is fundamentally a mapping problem. Swath-sonar maps of culture regions are an incredibly powerful too for this goal, and they have been used effectively in ESSA.

Of the rate impacts, one may distinguish direct and indirect effects. Direct effects are in response to known impacts such as organic loading that produce obvious responses such as oxygen depletion in the water column and/or increased anaerobiosis in sediments. Indirect effects are those that occur as a result of more obscure forcing such as changes in phytoplankton community structure. An important class of the latter is that of changes in trophic structure. For example, changes in phytoplankton species composition as a result of aquaculture nutrient loading may affect zooplankton assemblages and thus food for larval wild fish. Both bottom and top down impacts may have far reaching implications for the larger ecosystem, but would be hard to measure or document in the field.

Quantitative evaluation of benthic habitat structure through studies like Peter Lawton (this volume) are a step in this direction, allowing assessment of change at the community level. In the best case, it is difficult to calibrate ecosystem level changes either through community-based measures such as species diversity, or through energy flow measurements. Detecting a potentially subtle system-wide effect such as that due to aquaculture is a challenge. It is too much to expect that ESSA could simultaneously quantify far-field effects of cage culture and their fallout for ecosystem function. The development of methods to document far field impacts and their application to the field is a necessary step in the study of ecosystem-aquaculture interactions, and one in which ESSA is succeeding.

At the end of the day, the question of whether there are far field impacts of aquaculture is rather like the older question of estuarine out-welling; the answer is 'it depends' on where and when. It is the challenge of ESSA to determine under what conditions far field impacts will be detectable, and how severe they will be for the ecosystem. Physical-biological comparisons which at least consider the size and flushing of the receiving body as well as the assimilative capacity of the system are required in addressing these questions.

When ecosystem level questions regarding aquaculture are considered, it is necessary to be rather broad in scope, since this is a lesser known context compared to near field effects. As such, a wide range of research topics have been tackled in ESSA. Fundamental studies of phytoplankton annual cycles (Martin, Page, Dowd) and DOC dynamics (Kepkay and Harrison) have been valuable to ESSA efforts. Potential consequences of eutrophication attributed to culture can only be interpreted in the context of natural variation in the absence of culture. An attempt at this linkage is contained in consideration of harmful microalgae in the phytoplankton work and their frequency of occurrence. Because ESSA is the first concerted effort involving far field effects, a comprehensive approach is appropriate in assuming that it would be difficult to understand ecosystem-level impacts without understanding the ecosystem.

The physical modelling is a very strong component of ESSA and critical to examination of waste dispersion. Greenberg is a long-standing expert on numerical modelling of estuaries and his modelling of Passamaquoddy Bay is an important cornerstone of the Fundy work. One aspect of modelling that generally seems to be missing is an attempt to model deposition of farm wastes. If one were to isolate a single environmental impact of fish farming relevant to both near and far field effects, sedimentation would be at the forefront. Successful models of water transport produced in ESSA are an essential component of suspended sediment models, and so much of the difficult work has already been done within the project. There are a number of research issues surrounding transport of fish farm waste that affect models of its transport, including erosion threshold and sinking speed. The jump from circulation models to 'pollutant dispersion' models is not trivial, but not insurmountable. Extending prediction of the fish farm footprint from local scale to far field is essential, but not obviously included in ESSA modelling efforts. Nonetheless, the modelling participants including Greenberg, Page, and Dowd have a well integrated effort focused on methods for quantifying current regimes and tidal exchange and their implications for material budgets. Dowd is exploring innovative uses of box modelling as a way to describe culture-ecosystem interactions.

Beyond deposition, a second and equally important effect of hyper-eutrophication induced by aquaculture is that of oxygen deficiency. Although it is hard to imagine this effect in tidally energetic Fundy waters, Page et al. studies indicate the potential significance of oxygen depletion amongst farm sites. Stucchi et al. (this volume) conducted similar studies in BC including regions offshore from farm sites. The latter results document the extent of natural hypoxia in local waters, and emphasize the importance of interpreting culture impacts in the context of the natural range of variation in environmental conditions.

Despite the strength of physical modelling in the research, the linkages between some of the modules have not been explicit. For example, circulation models seemed to be tied into oxygen dynamics, but not into the dispersion of nutrients, a topic that is important to the macroalgal bloom studies of Auffrey et al. Secondly, the results of acoustic mapping should be linked to a suspended sediment model, since the latter provides a unique validation data set. These sets of results could be linked in a GIS in which field surveys of sediment texture are overlain with model predictions of deposition.

There are significant attempts in ESSA field studies to investigate tracers of farm waste, including Yeats et al. measurements of various elements normalized to grain size and lithium content, and Haya's research on other chemical wastes from farms. The latter studies have been successful at relating metal content to site classification, an important predictive tool. Smith et al's studies of the sediment column provide the historical/burial component required to interpret the sedimentary record of farm effects, especially in the far field. Their work brings in the effects of the Saint John River on sediment metals, which highlights the fact that as one moves from local culture effects to the broader ecosystem, other large scale processes must be considered. For practical reasons, a balance is necessary between studies of the entire watershed and marine ecosystem, and impacts forced by culture-specific activities.

In addition to tracers, biotic indicators of culture effects have been included in ESSA. Friar's work with tetracycline resistance in bacteria is essential in the management of therapeutants and their impacts beyond the farm. The studies of Sutherland on sulfide tolerance in benthic copepods will aid in defining habitat quality beyond the limits of a farm. Similarly, Auffrey's studies of macroalgal blooms and their consequences for infaunal clams address offsite biotic responses to farm nutrients.

ESSA expands on the established precedent of using sediment redox, sulfides, and oxygen consumption as a measure of benthic impact. In fact, previous studies by ESSA investigators such as Hargrave and Wildish are among the most comprehensive examination of applying these techniques to fish farms. In ESSA, Hargrave et al. attempted to distil this information in a comparison of water column, benthic and salmon respiration. This comparison incorporates farming into a system-wide framework, with the type of scaling that allows comparison of multiple sites. It is these syntheses that promotes an integrated view of aquaculture in the ecosystem. Wildish et al. have conducted attendant studies of faunal responses to organic input.

Benthic studies on the West Coast (Helfield et al. this volume) provide an interesting comparison to Fundy projects, since the environments are quite different. The BC work includes sediment trap measurements, a technique that was surprisingly sparse in East Coast studies. Sediment traps (e.g. tube traps) are a simple and cost-effective tool that provide important ground-truthing data for the quantity and quality of deposited material. Many far field questions can be approached with this technique. They have been used in previous Fundy studies of fish farms, but are not prominent in ESSA.

The fallowing studies conducted by Anderson et al in Newfoundland were valuable because they provide a time scale for recovery of the benthos from farming. This information is important in far-field context because the recovery of habitats in time has parallels to their recovery in distance away from the farm. Work by Stewart et al. on harrowing is interesting as a remediation solution, which if successful would help contain far-field effects.

ESSA has incorporated a number of technological tools into its research programs, including acoustic mapping, which has tremendous potential in far-field studies. One of the issues surrounding sediment deposition is a change in sediment texture and porosity, which appear to be distinguishable in initial mapping results. However, the signal from biodeposition does not seem to be exclusive, and so further verification is needed to calibrate the technique for use over broader areas. The Ocean Mapping Group at UNB obviously has ample capability to structure a GIS database that becomes the focus of ESSA results. Despite this capability, there was very little discussion of GIS as an anchor for the various studies.

While there is a long-term DFO goal involving far field effects, it is not clear how or if the results will be turned into advice. Presumably, as the project winds down (and the money runs out), there will be an assessment of which projects have the most relevance to eventually providing advice. As such, at the end of the project, there might be a set of recommendations providing advice on the following topics:

1) How can ecosystem level impacts be included in environmental monitoring of culture sites?
2) What variables must be measured in order to monitor far field impacts?
3) How can these variables be condensed into some ordinal measure of ecosystem quality or health?
4) Is monitoring at this level logistically feasible and/or cost effective?

These are practical questions oriented solely toward the provision of advice. I did not hear discussions which highlighted similar questions as being the deliverable of the project. In any case, I would recommend that a concerted effort be made to progress toward advice along these lines as a major product of the research, recognizing the limitation of being the first study of this kind.

Based on these perceptions, the most constructive observation that I can make about ESSA research is that there could be more unification of effort and results in the following ways:

(a) models that address a larger component of geochemistry including nutrient distributions and dispersal of therapeutants,
(b) models that include sediment deposition,

(c) extension of some form of scaling exercise or models to other sites to facilitate inter-site comparisons,
(d) inclusion of sediment trapping as a baseline measurement,
(e) incorporation of results into a georeferenced database.

In summary, the ESSA project attempts to provide a comprehensive view of far-field culture impacts. It is breaking new ground in defining these effects. I am familiar with aquaculture research efforts worldwide, and I know of no other concerted effort aimed at ecosystem level questions, and in fact no concentration of researchers directed toward this goal. ESSA has taken a leadership role in environment-culture interactions and its results will form the foundation for many future initiatives.

A REGIONAL INDUSTRY PERSPECTIVE OF PRESENTATIONS FROM THE ESSA 2002 WORKSHOP

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General Comments

The ESSA project group is to be congratulated for the effort that has gone into the planning, implementation, discussion, and reporting of the studies that comprise this important work. As is too often the case scientific involvement in matters of environmental management lags in time behind the activities that would most benefit from the resulting data, information, and knowledge. The ESSA group has recognized this, has taken the initiative, and has accomplished much in a short period. Throughout the ESSA project and in particular at the 2001 and 2002 workshops the group has endeavoured to inform the aquaculture industry. This has taken place during an intense and controversial period for our industry, and the ESSA group should be recognized for this initiative.

The following comments provide a review of the 2002 workshop relative to the objectives of the ESSA project (as given on page 2 of the 2001 ESSA Workshop Report) with consideration of the present status and developmental requirements of the New Brunswick marine Atlantic salmon aquaculture industry. There is only one field season and there are limited financial resources available to this particular study. It is imperative that the remainder of the project and further studies focus on the ultimate goal for all this effort – a sustainable finfish aquaculture industry.

Meeting the Stated Objectives of the ESSA Project

The stated objectives of the ESSA project are that research would be geared toward the study of the interaction between finfish aquaculture and the marine environment, and the application of resulting knowledge to the management of such interactions. Together, these objectives comprise a laudable goal. While the quality and content of the studies are important, there is also a responsibility to provide managers with information that supports decision-making for environmentally and economically sustainable aquaculture.

The project therefore has a responsibility to divide results into those that have direct application to the industry, and those that are more related to general coastal ecology. The presentations from the workshop suggest that this responsibility can be met with the information now available.

The program should make all efforts to relate the studies to actual data and information describing the aquaculture industry and other coastal activities. Much of the science that has been conducted is of limited value to the overall goal simply because it is linked in a limited manner, if at all, to the industry. This is not to understate the importance and need for coastal science in Canada. However, if the science cannot be linked to the management of the industry, its inclusion and emphasis in future aquaculture-related work should be questioned.

Several of the research areas appear to have great promise for application to the management of the industry and efforts should be made to make the necessary bridge. The work on modelling water circulation, analysis of current records, and establishing oxygen budgets has direct meaning to the industry. This work would be enhanced, as noted above, by further use of actual industry data. The pure science should be encouraged and supported, but application of the present science would have immediate benefits. The participants also heard several references to an aquaculture siting decision support system based on the results of this project and other studies conducted by the project team. It was unfortunate that the project team was not in a position to share this with the workshop. This would be of obvious benefit to the industry.

Our industry is continually looking for ways that technology can be applied to enhance sustainability, and the multi-beam sonar work being conducted by the project has stimulated much interest. The ability to apply this technology to the monitoring and study of entire areas rather than spot samples has great potential for bay management. Of concern, however, is the cost of this technology. Many spot samples could be taken and analyzed for the cost of a multi-beam survey. Again, the pursuit of the science is encouraged, but its inclusion and emphasis in future work should be given careful consideration.

Meeting the Needs of the NB Marine Salmon Aquaculture Industry

In addition to the above comment on incorporating actual industry data and information, the following provides some guidance to making the ESSA project and its successors more relevant to the industry.

Science should be related to the areas in which the industry presently operates, as well as areas that are under consideration for development. The overall sustainability of the industry lies in making the most of existing sites, and expanding into new areas. High-energy environments, deep-water columns, and hard bottoms will characterize the new areas. Many of techniques and studies used in the ESSA program will not be applicable to these new sites. Environmental concerns at the new sites will be different from those investigated in the ESSA project. Culture techniques and husbandry practices at new sites and at altered existing sites will be different, as will their interactions with the environment.

Our industry is one of the many industries and activities in the coastal environment. The basic processes of coastal ecology, and how all of these activities interact, are not well understood. While aquaculture has become a flash point for efforts to gain understanding in this field it should not be the sole focus for establishing cause and effect relationships with observed environmental conditions. Results from the ESSA project suggest that factors not related to aquaculture have significant influences on ecological processes. Natural fluctuations in temperature, sunlight, and rainfall could act alone or together with urban, agricultural, or industrial influences to far outweigh the potential effects of aquaculture. The industry supports ongoing science and is making efforts to further its own sustainability, but scientific and regulatory interest should also extend to the remainder of the coastal community.

The ESSA project team has accomplished a great deal of credible science in a short period of time. The responsibility now lies with the group to apply the results of this work and future work towards the sustainability of aquaculture in Canada.

Environmental Studies for Sustainable Aquaculture, January 2002 workshop: Comments from a B.C. Observer

Odd Grydeland

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I really appreciated being invited to participate in this workshop. Unfortunately, I missed half of the first day (January 16), partly due to an unscheduled visit into the snow-filled nature of Nova Scotia, thanks to a taxi-driver that could not stay on the road.

The meeting was of particular interest to me since we are in the final stages of developing Performance Based Environmental Standards for the salmon farming industry here in British Columbia. These Standards may then become a model for the consideration of the other salmon farming jurisdictions in Canada, and perhaps the rest of the world.

One thing that struck me was the apparent lack of projects looking at environmental conditions in an area before a planned fish farm was installed, and then following these conditions over several production cycles. We will have many opportunities for such projects in B.C. over the next years. Some of the new farms here will be established in areas previously undeveloped by aquaculture, and with little other contributions to benthic disturbances.

A second issue that kept coming back to me was the apparent disconnect between researchers and the aquaculture industry. In other words- theory and hypothesis vs. practical knowledge and experience. A couple of examples:

- Fred Page's suggestion that dissolved oxygen levels at a salmon farm are at "critical values" of 6.0 mg l^{-1}, is unrealistic. As Dario Stucchi reported, in some areas of B.C. we regularly experience periods of low oxygen, and most fish farmers are quite happy as long as oxygen levels remain above 4.5 mg l^{-1}. Fish that have been kept off feed for a few days usually survive short periods with oxygen levels as low as 3.5 mg l^{-1}.

- Faron Friar's paper on oxytetracycline resistant microbes in sediments around salmon farms was presented without any correlation to the use of this antibiotic at farms in the area. Furthermore, the assumption that this resistance was a result of salmon farms using antibiotics was made without mentioning the apparent widespread use of oxytetracycline by the lobster pond operators in the same area.

Some discussion took place after the workshop regarding communication between the DFO scientific community and the fish farmers. I believe that these communication lines should be wide open at any time, and DFO scientists should be welcome to ask the farmers for information related to their research. Researchers should also be encouraged to include references to farm activities that could have (had) an impact on the results of their studies. I would be happy to take this up with our Associations, if it would be of help.

I found the discussion with the staff from Habitat Management particularly interesting. The question raised about who should define a HADD- the scientists or the politician- is intriguing. I believe that this determination has to be made by the politician, based on good information provided by the scientists. The main reason for this is that under the federal Fisheries Act, a HADD is "a Harmful Alteration, Disruption or Destruction of fish habitat", and I believe that any scientist can find some level of disruption of fish habitat around a salmon farm, and therefore would have to declare every salmon farm as causing a HADD. Salmon farming, or any other human activity in Canadian waters, would thereby represent a violation of this act, according to basic scientific interpretation. Clearly, that is not the intent of the Act, and therefore it must be up to the politicians to determine what level of impact will be acceptable.

With the acknowledgement that salmon farms must be allowed to have some impact on fish habitat, what is a reasonable and acceptable level of impact? And how should this acceptable level of impact be monitored and regulated? Should every salmon farm be required to obtain an authorization for this impact, and how would the required compensation be negotiated?

In B.C. we have a set of siting criteria that every new salmon farm must meet before approval is considered. These criteria are in place to ensure that salmon farms are located a minimum distance from:

- Significant Salmon Bearing Streams
- Sensitive Fish Habitat
- Shell fish beds
- Other Salmon Farms

In addition, the new farms are now being located in areas with strong currents or flushing so production levels can be maintained, while still meeting the new Performance Based Standards. In other words, salmon farms are already being located in areas of relatively low fish production.

Considering that a salmon farm occupies a small area of the foreshore, and this small area typically produces 5 million pounds of high quality, nutritious and valuable seafood every 2 years, one could reasonably conclude that some disturbance of the ecology around this farm should be acceptable. The net production of fish from this area is certainly increased dramatically by the existence of the farm.

These conditions should, in my mind, enable a politician to set a level of acceptable disturbance based on a few fundamental principles:

- Salmon farming should have no long-term accumulative effect on the marine environment.
- The temporary effects on the marine environment by single farms should be reversible
- These effects should be limited to the areas around the farms

Valuable points were also brought up regarding the need for a zonal approach to siting, where larger areas are cleared for salmon farming, eliminating the need for individual site evaluations and monitoring. There is also an acknowledged need to establish a protocol for underwater mapping and surveys. A proposal from Ellis & Co. of Victoria, B.C. was recently denied funding by the ACRDP program, but it will be re-evaluated later this summer under a new R&D program, soon to be launched by the provincial government. As was pointed out at the meeting, the industry is moving to deep, rocky and coarse bottom sites, and a monitoring program must be developed for these sites- eventually for compliance purposes also.

I also appreciated the comment about the need for better networking prior to the release of information and guidelines regarding aquaculture research.

Further to my comments about studies on oxygen, I was wondering about the ability of the plankton community to replenish oxygen consumed by farmed fish. In other words, does plankton produce more oxygen when levels are low compared to situations where there is oxygen saturation? I would also encourage more research into the periodic drops in oxygen in areas of British Columbia.

Jim Helfield and Terri Sutherland's work (with Colin Levings) on acoustic surveys of salmon farms are promising with respect to the development of effective tools for monitoring of the sea-bottom around salmon farms (and other sites with environmental impacts). Maybe down the road, this technology could be used to identify the (few) farms that would require additional monitoring.

Much of the work done on the East Coast was concentrated in Lime Kiln Bay, and one has to ask if this is appropriate, as much of the industry is located in different environments. I believe there is value in looking at areas of potential extreme impact, as the cause-and-effect conditions are exaggerated, and results can be obtained quicker. The results of this research however, must always be presented in the context of the bigger picture (total industry, and total environment).

I think that the proposed evaluation of inherent biological and environmental differences between the East and West Coast would be valuable, especially for the discussion about national standards for acceptable environmental impact standards.

The last comment I have is directed at communication. It would be very good to have copies of studies and reports sent to our Associations' offices whenever available. Few of us have the luxury of time to constantly be looking for new information. Also, I was wondering if there is a national repository for the ESSA studies and other environmental reports about aquaculture? Do the DFO scientists have the ability and policy of evaluating information from other jurisdictions prior to embarking on studies?

Thank you again for this valuable experience.

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