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# ENVIRONMENTAL STUDIES FOR SUSTAINABLE AQUACULTURE (ESSA): 2001 WORKSHOP REPORT

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## ABSTRACT

Hargrave, B.T. and G. A. Phillips (Editors). 2001. Environmental Studies for Sustainable Aquaculture (ESSA): 2001 Workshop Report. Can. Tech. Rep. Fish. Aquat. Sci. 2352: viii + 73 p.

This report summarizes oral presentations, discussions, and group recommendations arising from a three-day workshop held during the first year of the Environmental Sciences Strategic Fund study "Environmental Studies for Sustainable Aquaculture" (ESSA) being conducted by the Department of Fisheries and Oceans (DFO). Participants, met (17-19 January, 2001) to review physical circulation models, new chemical and biological methods, environmental data and habitat management questions relevant to predicting potential far field environmental effects of salmon aquaculture. Data was presented from recent research for far field studies in Bay d'Espoir (NF), Letang inet (N.B.) and south-central B.C. (Broughton archipelago). Summaries of related projects assessing aquaculture near-field impacts and recovery and evaluation of potential effects of toxic chemicals used in the aquaculture industry were presented. Some major conclusions of the presentations and discussions at the workshop were:

- Assessment of the potential for finfish aquaculture to increase concentrations of dissolved and particulate matter in water and sediments in marine coastal areas must be made in relation to all natural, urban/industrial sources of potential enrichment. All factors that influence levels of dissolved oxygen, organic carbon and inorganic nutrients must be considered in assessing contributions from mariculture in an ecosystem context. In macro-tidal environments such as the Bay of Fundy, calculations must consider sources, sinks and fluxes in extensive intertidal zones.

- Determination of assimilative capacity (the ecosystem's ability to process organic matter in excess of that from natural sources) requires measurements of autotrophic production and heterotrophic respiration in water and sediments.

- Cumulative respiration for cultured fish, calculated from physiological models, can be compared to all other sources of oxygen loss to provide a general measure of potential for impacts of fish farming activity on dissolved oxygen concentrations at a regional scale. Existing circulation models for southwestern Bay of Fundy can be modified to incorporate oxygen demand from various sources to detect regions or times where critical thresholds of low oxygen could occur.

- Observations of benthic biological community structure and some sediment geochemical variables may be useful as indicators of ecological changes due to increased organic loading immediately under and near net-pens. However, it is unclear how variables such as macrofauna biomass and species composition, surface sediment redox potentials and sulfide levels and down-core gradients in geochemical variables can be used to characterize far field environmental and ecological changes. Research is underway to evaluate pigments, stable isotopes,

fatty acids and enzyme hydrolyzable amino acids as tracers of farm wastes distant from net pens.

- In macro-tidal environments such as the Bay of Fundy far field ecological responses to organic enrichment may be found in intertidal areas and in sublittoral depositional areas distant from point sources of enrichment.

- Results from each study location are to some degree site-specific and models developed must be tested for their general application in different areas. For example, relatively high levels of suspended particulate matter in the Bay of Fundy are not found in areas where salmon aquaculture has developed in NF or B.C..

- Multibeam (EM 3000) maps of sediment backscatter intensity are available for sites of varying size in all three ESSA study areas. QTC (a bottom type classification system) surveys have also been completed in Bay d'Espoir and at one site in the Broughton archipelago. Research is underway to determine the potential for using this data to separate erosional and depositional bottom type and to identify areas of gas-filled fine grained sediments. When this data is available for a full inlet system (as is the case in Bay d'Espoir and Letang inlet) sampling for tracers of organic enrichment can be focused on specific areas where sediment accumulation occurs.

**RÉSUMÉ**

Le présent rapport résume les présentations orales, les discussions et les recommandations de groupe issues d'un atelier de trois jours tenue durant la première année des « Études environnementales sur le développement durable de l'aquaculture » (EEDDA) mené par le ministère des Pêches et des Océans grâce au Fonds stratégique des sciences environnementales. Les participants se sont rencontrés (du 17 au 19 janvier 2001) pour examiner des modèles de circulation physique, de nouvelles méthodes d'analyse chimiques et biologiques, des données environnementales et des questions de gestion de l'habitat liés à la prévision des effets environnementaux potentiels à grand rayonnement de l'aquaculture du saumon. On a présenté des données tirées d'études récentes des effets sur de grandes distances de l'aquaculture dans la baie d'Espoir (T.-N.), l'estuaire de Letang (N.-B.) et le centre-sud de la Colombie-Britannique (archipel Broughton). On a aussi présenté des sommaires des travaux de projets connexes visant à évaluer les répercussions sur de courtes distances de l'aquaculture et les mesures de rétablissement à prendre, ainsi que les effets potentiels des produits chimiques toxiques utilisés dans l'industrie de l'aquaculture. Voici certaines des grandes conclusions tirées lors des présentations et des discussions à l'atelier :

- L'évaluation de la possibilité que l'aquaculture du poisson augmente les concentrations de matières dissoutes et particulaires dans l'eau et de sédiments dans les zones côtières maritimes doit tenir compte de toutes les sources naturelles, urbaines et industrielles d'enrichissement potentiel. Tous les facteurs qui influent sur les niveaux d'oxygène, de carbone organique et d'éléments nutritifs

inorganiques dissous doivent être pris en considération dans l'évaluation des contributions d'une mariculture dans le contexte d'un écosystème. Dans les environnements à grandes marées tels que la baie de Fundy, les calculs doivent tenir compte des sources, des puits et des flux dans les grandes zones intertidales.

- La détermination de la capacité d'assimilation (la capacité de l'écosystème à traiter des matières organiques venant s'ajouter à celles provenant des sources naturelles) nécessite des mesures de la production autotrophe et de la respiration hétérotrophe dans l'eau et les sédiments.

- La respiration cumulative des poissons de culture, calculée à partir de modèles physiologiques, peut être comparée à toutes les autres sources de perte d'oxygène afin d'obtenir une mesure générale de l'incidence potentielle des activités d'aquaculture du poisson sur les concentrations d'oxygène dissoute à l'échelle régionale. Les modèles de circulation existants pour le sud-ouest de la baie de Fundy peuvent être modifiés afin d'intégrer la demande en oxygène de diverses sources pour permettre de détecter les endroits ou les moments où des seuils critiques de faible disponibilité de l'oxygène sont susceptibles d'être atteints.

- Des observations de la structure de la collectivité biologique benthique et de certaines variables géochimiques relatives aux sédiments pourraient servir d'indicateurs des changements écologiques dus au chargement organique accru immédiatement sous les parcs en filet et près de ces derniers. La mesure dans laquelle des variables telles que la composition de la biomasse et des espèces macrofauniques, les potentiels d'oxydoréduction des sédiments de surface, les niveaux de sulfide et les gradients de base des variables géochimiques peuvent servir à caractériser des changements environnementaux et écologiques sur de grandes distances n'est pas claire. Des recherches sont en cours pour évaluer l'utilisation des pigments, des isotopes stables, des acides gras et des amino-acides hydrolysables par voie enzymatique pour repérer les déchets d'aquaculture loin des parcs en filet.

- Dans les environnements à grande marée tels que la baie de Fundy, les réactions écologiques à l'enrichissement organique sur de grandes distances pourraient se trouver dans les zones intertidales et dans les secteurs de dépôts infralittoraux situés loin des sources d'enrichissement.

- Les résultats à chaque endroit étudié sont propres dans une certaine mesure à cet endroit, et il faut mettre à l'essai les modèles élaborés à divers endroits pour voir s'ils peuvent être appliqués de façon générale. Par exemple, les niveaux relativement élevés de matière particulaires dans la baie de Fundy ne se retrouvent pas dans les aquacultures de saumon à Terre-Neuve et en Colombie-Britannique.

- On a produit des cartes multifaisceaux (EM 3000) de l'intensité de rétrodiffusion des sédiments à des endroits de diverses tailles dans les trois secteurs d'étude de l'EEDDA. On a aussi mené des relevés QTC (un système de classification des types de fonds) dans la baie d'Espoir et à un endroit de l'archipel Broughton. Des recherches sont en cours pour déterminer le potentiel de l'utilisation de ces données pour séparer les fonds d'érosion et de dépôt, et repérer les sédiments à grains fins remplis de gaz. Lorsque ces données sont disponibles pour un système hydrographique entier (par exemple à la baie d'Espoir et à l'estuaire Letang), l'échantillonnage des indicateurs d'enrichissement organique peut se concentrer sur les endroits

## INTRODUCTION

Globally finfish aquaculture production has increased rapidly over the past two decades. Canadian production was valued at approximately $400 million in 1998 with Atlantic salmon comprising 80% of the total (Linehan 2001). Total production has increased steadily at about 8% $y^{-1}$ over the past 12 years (approximately 5300 MT $y^{-1}$) with the most rapid growth in British Columbia (B.C.) (+3250 MT $y^{-1}$), and a lower rate of increase in New Brunswick (N.B.) (+1460 MT $y^{-1}$). The industry is smaller and growing more slowly in Newfoundland (NF) where in addition to rearing salmon and steelhead, harvested juvenile cod (*Gadus morhua*) are placed in floating net pens and fed to increase their biomass before harvesting. Cold (sub-zero) water prevents over-wintering of cultured stock in all but a few locations on the south and south-west coast of NF.

Protected areas close to shore but with adequate water circulation are needed to allow net pens to be securely moored and to provide sufficient water movement to supply oxygen and remove wastes. However, outbreaks of disease and parasitic infections have occurred in some areas (e.g. N.B. in 1997) and it has become clear that unhindered expansion of the industry is not possible. Lowered growth efficiencies (food conversion ratio) in cultured fish is observed in response to environmental stress. For example, reduced levels of dissolved oxygen or toxic gases such as $H_2S$ may be released from sediments in response to high rates of organic matter sedimentation under cages. This can result in dramatic reductions in feeding and growth rates. Changes in fish physiological health are usually the first sign that limits to the levels of biomass that one particular inlet or embayment may sustain have been exceeded (Stewart 1998).

While there is general recognition that new environmental information is needed to allow prediction of sustainable finfish aquaculture production, there is little agreement as to what should be measured. Near-cage levels of dissolved oxygen, nutrients and suspended particulate matter (SPM) and sediment variables such as organic matter and total sulfide ($S^{=}$) may be changed enough at some locations so as to be easily measured. However, significant environmental changes at greater distances (i.e. >10 to 50 m) are usually less easily measured, especially in non-depositional environments where strong horizontal currents exist (Findlay et al. 1995). This far field area is beyond the zone where environmental monitoring programs are conducted since it is generally assumed that any 'impact' zones do not extend beyond the immediate vicinity of the pens. However, water mixing and advection can create an inlet-wide field for enrichment effects to be detected especially if there is a diffuse input from several farm sites within one embayment system. Decisions about siting must take into consideration the cumulative inputs from all non-point as well as point-sources of enrichment. Principals of integrated coastal zone management also require a broad-scale (far field) view of the marine ecosystem that supports the continued development of the new aquaculture industry.

The project "Environmental Studies for Sustainable Aquaculture" (ESSA) was initiated in April 2000, funded by the Environmental Sciences Strategic Research Fund (ESSRF) within the Department of Fisheries and Oceans (DFO). The multi-disciplinary study involving DFO staff from three regions (Newfoundland (NF), Maritimes and British Columbia) will focus observations and modelling in Bay d'Espoir (NF), the Western Isles Region (Letang inlet) (N.B.) and in the south-central coast of Vancouver Island (Broughton Island Archipelago) (B.C.). An annual ESSA workshop was proposed as part of the on-going three-year study. The purpose was to bring together all project participants, members of the steering committee and invited reviewers to document progress in modelling, development and application of new methods, to 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 first ESSA workshop held at the Bedford Institute of Oceanography, 17-19 January, 2001.

## ESSA PROJECT OBJECTIVES

The four objectives or main questions considered at the workshop were the four questions addressed in the ESSRF proposal:

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?

As the project developed during the first year (2000/01), these broad questions have been addressed by specific research activities:

1. To determine the assimilative capacity in three coastal regions (Bay d'Espoir, NF, Letang inlet, N.B. and the Broughton Archipelago, B.C.) where salmon aquaculture is concentrated. The aim is to compare cumulative and area-wide impacts of multi-source nutrient and organic matter loading in the three types of coastal inlet systems using broad-scale surveys and site-intensive studies.
2. To observe and develop dispersion/sedimentation models for particulate matter in the selected study sites.
3. To use existing circulation and tidal models to predict water residence time and mixing characteristics and make mass balance calculations and to predict suspended particulate matter, dissolved oxygen and nutrient concentrations.
4. To develop a standardized methodology for effective management of sustainable salmonid aquaculture in Canada

**ESSA PROJECT ACTIVITES 2000/01**

The workshop began with reports from the three DFO regions (NF, Maritimes and Pacific) on ESSA research activities during the preceding field season (April-November 2000).

*Newfoundland Region* **(M. R. Anderson)**

- Water quality research has been carried out within Bay d'Espoir (250 $km^2$), southwest coast of NF, where aquaculture of Atlantic salmon and steelhead has been conducted over the past decade since 1993-1995. Approximate total salmon production in the past year (2000) was 2500 MT.
- Bay d'Espoir is a complex fjord with multi-layered circulation through basins separated by sills. A hydro-electric dam controls water discharge into the upper end of the Bay such that freshwater flow is highly regulated with dramatic effects on stratification. Organic matter deposits in four basins separated by sills.
- New work during the ESSA project will identify aquaculture-specific tracers to detect and potentially model where organic matter generated by aquaculture activity accumulates.
- There are currently fallowing practices to minimize benthic impacts at the over-wintering site in Roti Bay (towards the inner end of Bay d'Espoir). Monitoring is required to determine long-term changes at this location.
- A database is currently being developed to summarize all measurements in Bay d'Espoir.

*Maritimes Region* **(B. T. Hargrave)**

- Studies are focused inshore in macrotidal embayments and inlets in the Western Isles region of SWNB (Lime Kiln Bay, Bliss Harbour and Back Bay) where approximately 25 active salmon farms sites are located. The Wolves, a long-term hydrographic and biological monitoring station in the Bay of Fundy, serves as an offshore reference location.
- Autotrophic phytoplankton production was measured or biomass distribution inferred from satellite estimates of chlorophyll distribution throughout the Western Isles region and adjacent off-shore Bay of Fundy regions (July-September 2000). Turbid water conditions in the Bay of Fundy means that production may be more limited by light than dissolved inorganic nutrient availability. (G. Harrison)
- DOC distribution in the Letang area was measured in September 1999 and indicated high local sources not necessarily associated with areas of intensive aquaculture. Water column respiration measured at inshore and offshore locations in September 2000 indicated net heterotrophic conditions (respiration > production). (P. Kepkay)
- Sedimentation patterns of inorganic grain size distribution (measured as particle size spectra with an electronic Coulter Counter) has been used to indicate depositional areas within the Letang inlet system. (T. Milligan)

- Observations from dated sediment cores are being examined to determine if historic changes in rates of sedimentation are recorded in types of particles deposited as indicated by changes in the ratio of single grains/floc deposition. (T. Milligan, J. Smith)
- Organic matter (weight loss on ignition)(OM) and total sulfides stored in sediment, as a measure of organic enrichment above rates consumed through benthic metabolism is being measured monthly (from September 2000) at two (non-farm) locations in Lime Kiln Bay. The study will document natural changes in these geochemical variables and determine if fall/spring monitoring is sufficient to document excessive levels of organic enrichment. Total OM and organic carbon are linearly related over a wide range of values that may be used to separate under-cage and far field sediments. (D. Wildish, B. Hargrave)
- Backscatter images from Simrad EM3000S - 3000 kHz multibeam acoustic survey for Letang inlet shows depositional and erosional areas with clear footprints of occupied cage sites. (J. Hughes Clarke, D. Wildish)

***Pacific Region*** **(T. A. Sutherland)**

- Environmental observations of water column and sediment variables potentially sensitive to changes due to salmon aquaculture in the Broughton Island Archipelago (in a region with 29 active farms) is focused on three different spatial scales:

  (i) near field studies under and adjacent (up to 30 m) to net pens,
  (ii) time series biological and chemical observations in sediments at a fallowed site,
  (iii) far field (> 300 m) studies of similar variables measured in (i)

- The aim is to model suspended particle dynamics in order to predict dispersion
- Sampling of food pellets, surface sediments and particulate matter collected in sediment traps moored at varying distance from a farm site provides material for comparative chemical analysis to identify potential far field chemical tracers.
- Stable isotopes of carbon and nitrogen appear to hold promise as potential tracers for food particle dispersion.

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Linehan, R. 2001. The Canadian aquaculture industry - introduction and current synopsis. Prepared by Salmon Health Consortium on contract with the Department of Fisheries and Oceans, Ottawa, January 2001. 22 pp.

Stewart, J.E. 1998. Sharing the waters: an evaluation of site fallowing, year class separation and distances between sites for fish health purposes on Atlantic salmon farms. Can. Tech. Rep. Fish. Aquat. Sci. 2218, 56 pp.

## REPORT SUMMARIES

### Water Column Productivity, Letang Inlet and The Wolves, N.B.

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One of the critical questions the ESSA project is attempting to answer with regard to far-field effects of the aquaculture industry on the environment is, "How can assimilative capacity in coastal waters be determined for the particulate and dissolved waste products of finfish aquaculture? The approach being considered is to measure phytoplankton productivity and respiration in the water column and underlying sediments to assess the ability of coastal waters to assimilate organic carbon. More specifically, water-column primary productivity and respiration measurements will be compared with standing stocks of particulate and dissolved organic matter associated with organic loading to develop a *productive capacity* index. Combining these estimates with benthic respiration will provide an additional index of *assimilative capacity*.

Preliminary results from field work carried out during summer and fall, 2000 are reported here. Phytoplankton biomass (measured as chlorophyll a) in the water column was determined using standard fluorometric techniques. Particulate organic matter (carbon and nitrogen) was determined by high temperature combustion. Primary productivity (uptake of inorganic carbon, nitrate and ammonium) was determined from stable isotope tracer incubation experiments. Three primary sites were studied during the intensive field work (19-21 September 2000), two in proximity of finfish (salmon) aquaculture farms in Lime Kiln Bay and Bliss Harbour and the Wolves Islands (The Wolves) an offshore reference site. Some additional stations were occupied to evaluate spatial variablilty in phytoplankton: two sections were run, one parallel with and one normal to the shoreline (Fig. 1).

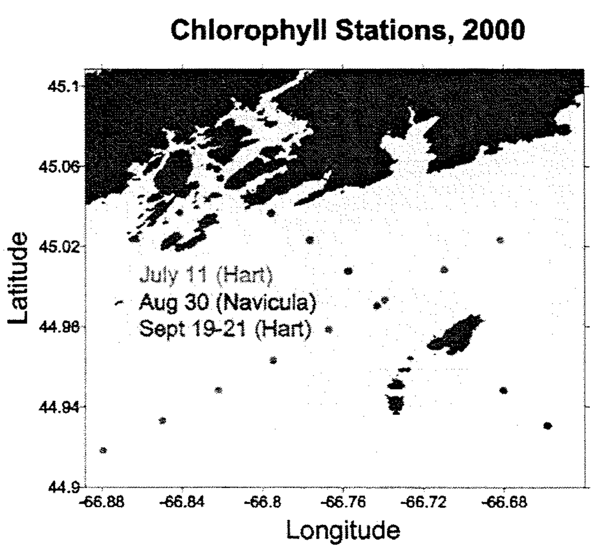


**Fig. 1:** Location of stations sampled along transect lines (sections) (11 July, 30 August) and at fixed sites at The Wolves, Bliss Harbour and Lime Kiln Bay (17-21 September) during 2000.

Sections sampled during July and August, 2000 established clear gradients in phytoplankton biomass with levels highest up the coast and onshore (Fig. 2). An investigation of the temporal variability in chlorophyll biomass over a tidal cycle at The Wolves revealed that concentrations changed by a factor of two (Fig. 3) and by a factor of 4-5 between the summer maximum and late fall decline (Fig. 4).

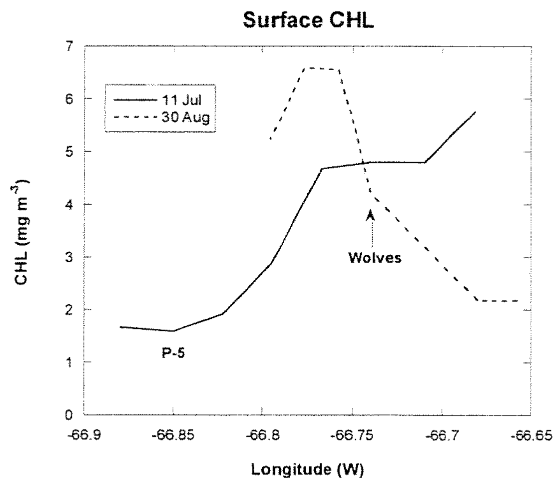


**Fig. 2:** Gradients in phytoplankton (chlorophyll *a*) biomass in SWNB the sampling area shown in Fig. 1.

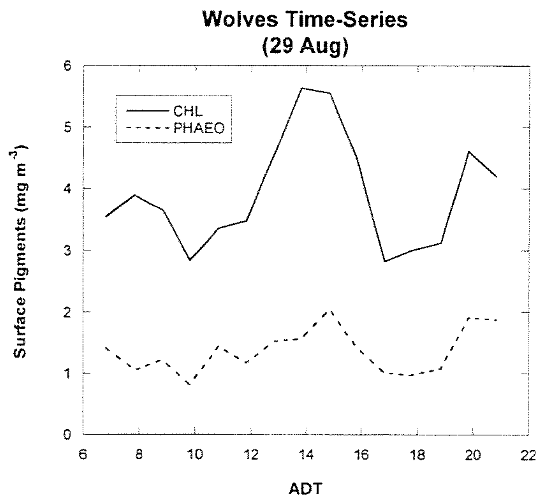


**Fig. 3:** Temporal variations in phytoplankton biomass at The Wolves over a tidal cycle.

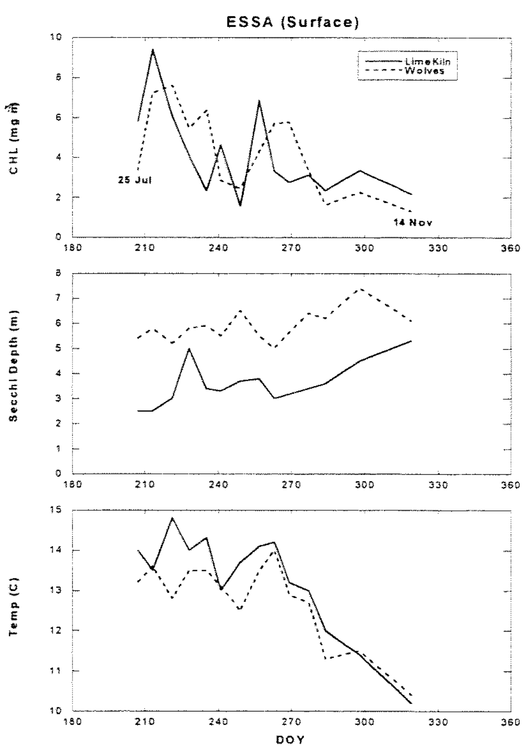


**Fig. 4:** Seasonal variations in chlorophyll *a*, secchi disc depth and temperature at The Wolves (Bay of Fundy offshore site, Fig. 1).

Profiles of phytoplankton biomass during the intensive study 17-21 September 2000 revealed similarities in both the magnitude and vertical structure (i.e. uniform with depth) of chlorophyll *a* at sites within the vicinity of salmon farms (Lime Kiln, Bliss and Letang Channel). Concentrations at The Wolves, in contrast, were significantly higher in the surface 5 m and decreased sharply with depth (Fig. 5).

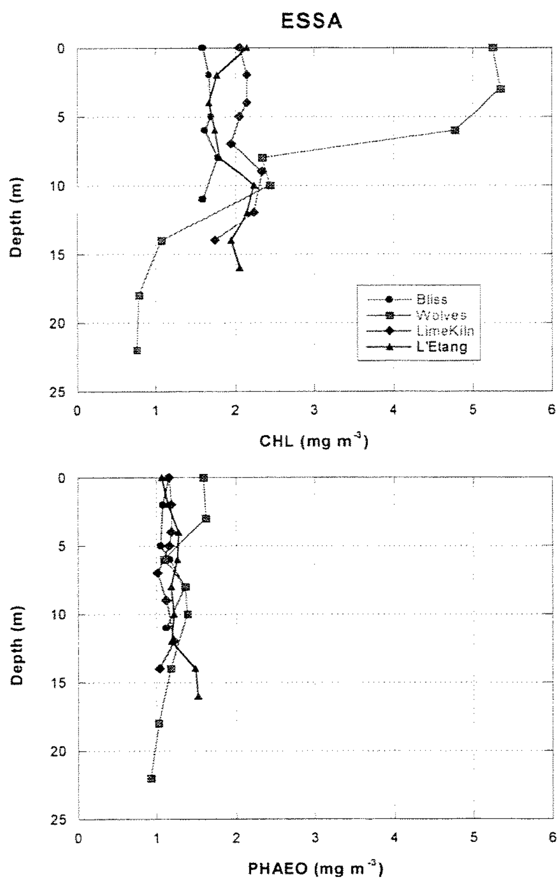


**Fig. 5:** Profiles of phytoplankton pigments (chlorophyll *a* and phaeophytin) with depth at four sampling locations in SWNB shown in Fig. 1.

Distributions of particulate organic matter were similar to chlorophyll *a*. Offshore, particulate organic carbon and nitrogen concentrations were highest in surface waters and concentrations decreased sharply with depth. Inshore, concentrations were lower and uniform with depth. Elemental ratios (C:N) suggested that the chemical nature of the particulates at the inshore stations (particularly Bliss Harbour) differed from the composition of suspended particulate matter at the offshore sampling station. This was also noted in the particulate carbon:chlorophyll *a* ratio (Fig. 6).

Contrasts between inshore and offshore stations were also seen in the concentrations and vertical structure of inorganic nutrients (Fig. 7). For example, nitrate concentrations were high and vertically uniform at the inshore stations and much lower in surface waters and vertically structured and increased with depth at the offshore location. Ammonium concentrations were high and vertically structured inshore and low and vertically uniform offshore.

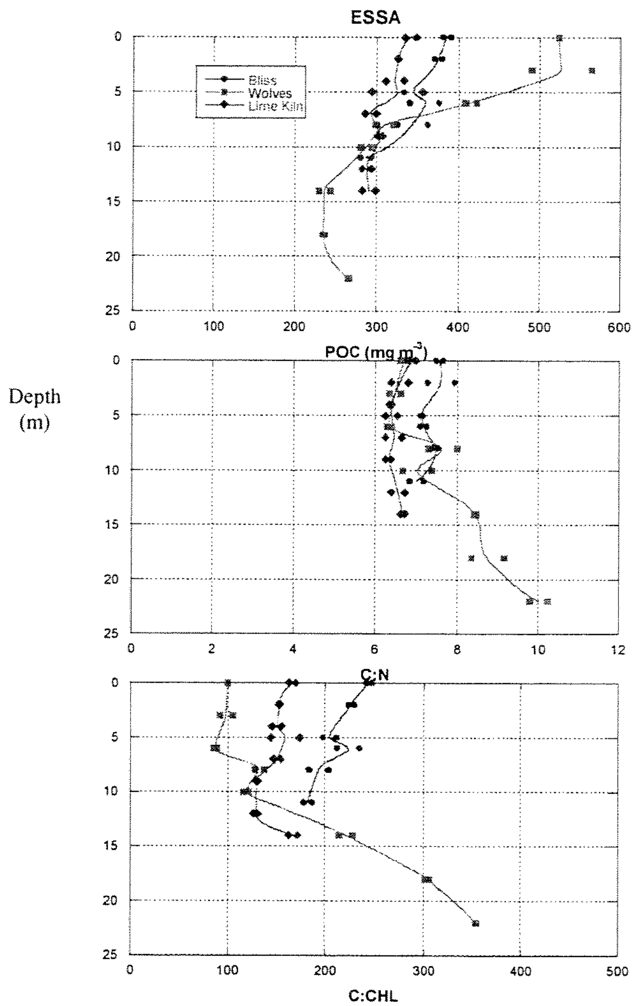


**Fig. 6:** Concentrations and vertical structure of POC and PN and POC:PN at three study sites shown in Fig. 1. (Carol Anstey provided the nutrient data).

Measurements of carbon uptake showed that primary productivity, like chlorophyll *a* biomass, was higher offshore than inshore; daily estimates for Lime Kiln and Bliss Harbour were 646 and 730 mg C $m^{-2}$ $d^{-1}$, respectively, and 1,738 mg C $m^{-2}$ $d^{-1}$ at The Wolves; the latter is considered a very high value. Normalized to chlorophyll a biomass (P:B), however, all stations looked similar, suggesting that the phytoplankton populations at all stations were in similar physiological condition (Fig. 8). The high surface P:B values 7 mg C mg $CHL^{-1}$ $h^{-1}$) are characteristic of healthy growing populations and the steep vertical decrease in values is indicative of light limitation.

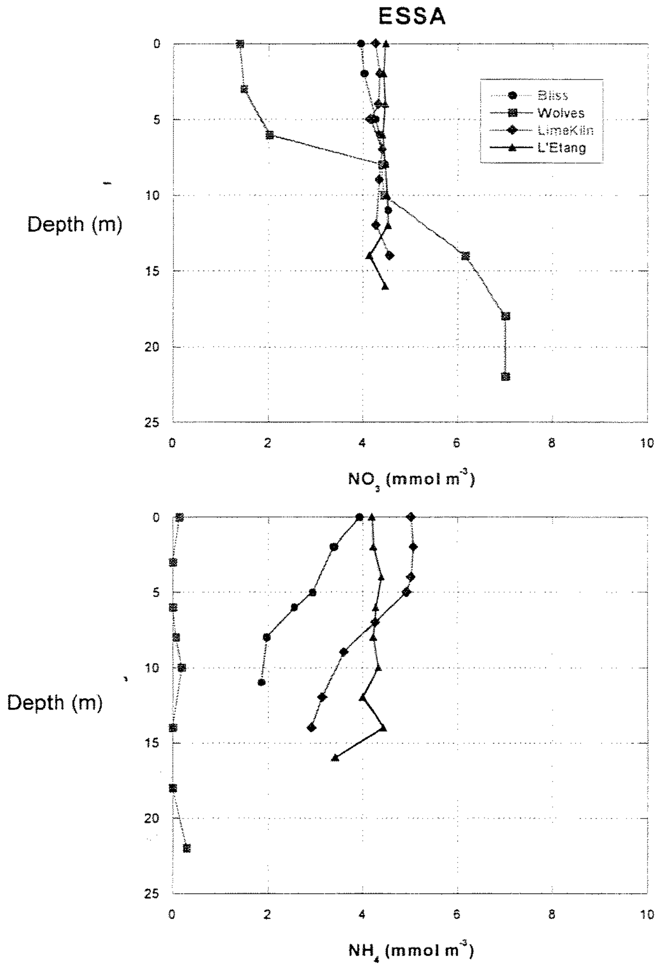


**Fig. 7:** Vertical profiles of dissolved inorganic nitrogen nutrients at four study sites shown in Fig. 1

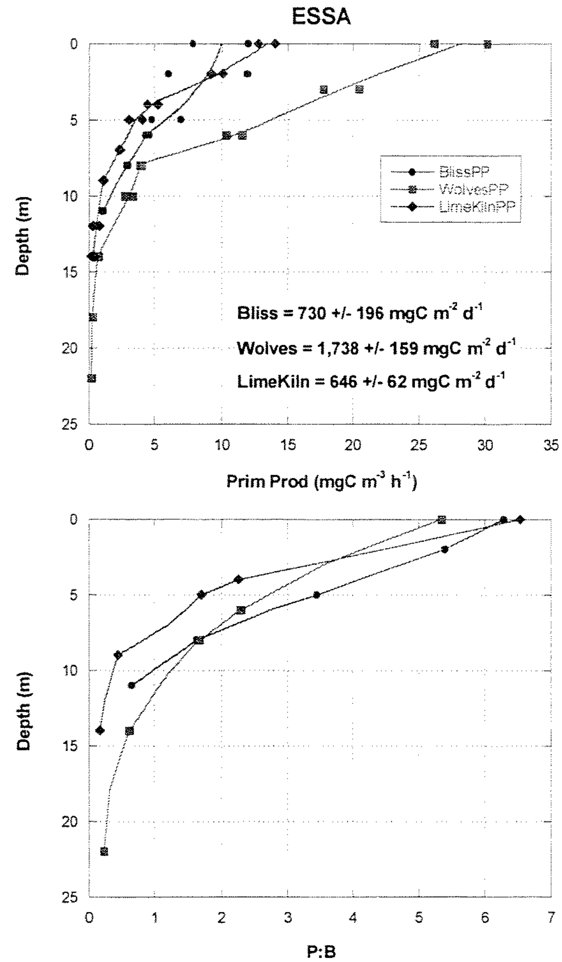


**Fig. 8:** Vertical profiles of phytoplankton production and P:B ratios (production normalized to chlorophyll *a* biomass) at the three sampling stations.

The potential benefits of exploiting new satellite remote-sensing technologies to assess far-field effects of aquaculture on coastal productivity was discussed (Fig. 9).

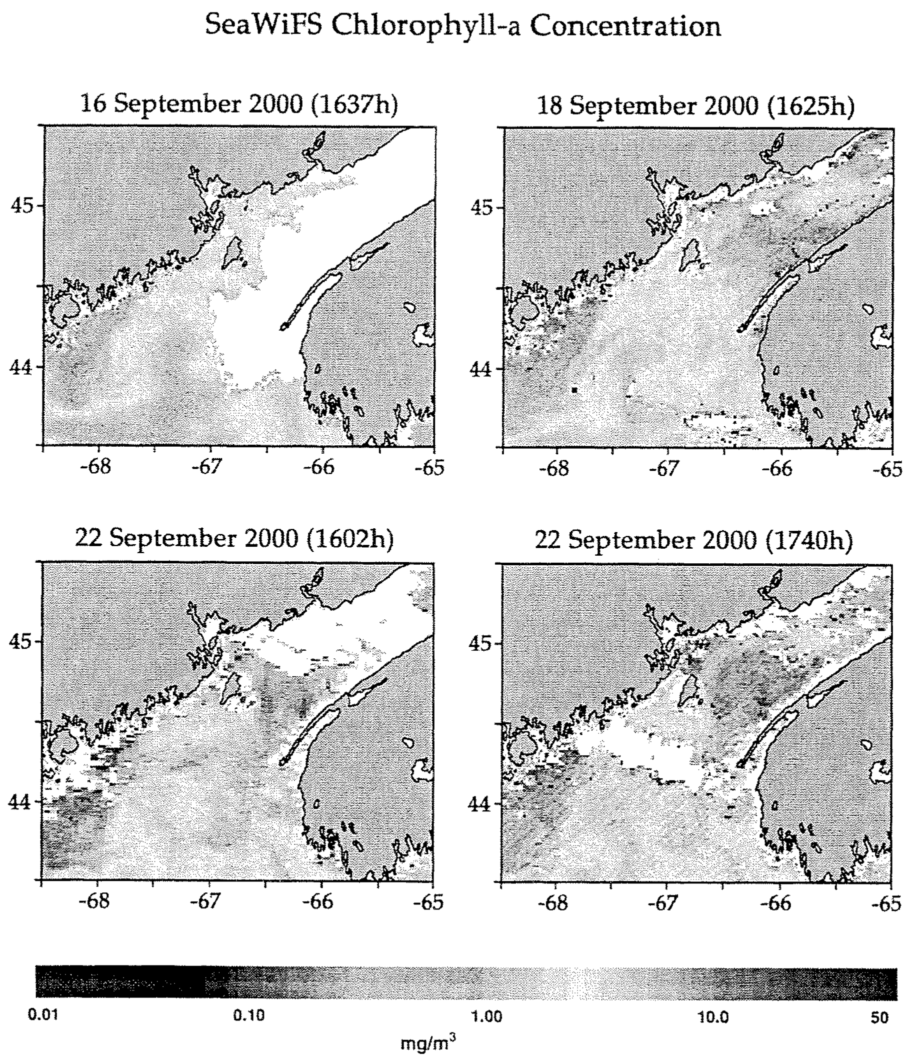


**Fig 9:** Regional maps of chlorophyll a concentrations in surface water in the study area (SWNB) and outer Bay of Fundy derived from SeaWiFS remote-sensing data during the period of intensive sampling (17-21 September, 2000) at three locations described in Fig. 1. White areas indicate cloud obstruction. Progressive day-to-day variations in chlorophyll concentrations are evident at both inshore and offshore locations. Water column profiles of suspended pigment concentrations (Fig. 5) provided data for ground-truthing calculated pigment levels. Concentrations of chlorophyll *a* >10 mg $m^{-3}$ are relatively high for coastal waters in Atlantic Canada particularly during fall months.

# Seawater Oxygen Concentrations in the Quoddy Region and its Relevance to Salmon Culture

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The concentration of dissolved oxygen (DO) in the coastal waters of SWNB varies seasonally. The cycle is represented by data (Fig.1) from a phytoplankton monitoring station (Stn 3) located within Lime Kiln Bay. In the relatively cold winter, DO concentrations are below saturation and are about 10 mg $L^{-1}$. They increase during the spring to supersaturated levels and decrease throughout the summer to a seasonal low of about 8 mg $L^{-1}$ (80-90% saturation). The spring increase is presumably due to the seasonal increase in photosynthetic activity. The seasonal cycle is the regional environment in which the fish contained within the pens of the salmon aquaculture industry are reared. It is useful to the industry and regulators to know what environmental and husbandry conditions may result in stressful levels of DO to the salmon, since the stress results in reduced growth and increased susceptibility to disease. Hence, over the past year or two we have begun to build on the work of others and investigate more fully the environmental and husbandry factors influencing oxygen concentrations in the vicinity of fish farms.

Our preliminary estimations of the oxygen demand generated by salmon suggest that pre-market sized salmon, maintained at recommended stocking densities within sea pens, are able to reduce the concentration of oxygen in their cage to stressful levels (6-7 mg $L^{-1}$) under some combinations of environmental conditions. One such combination occurs in areas with extended periods of slack flow when the water temperatures are near their annual maxima. In the future, we hope to expand on these calculations with the analyses of additional data and the development of oxygen budget models.

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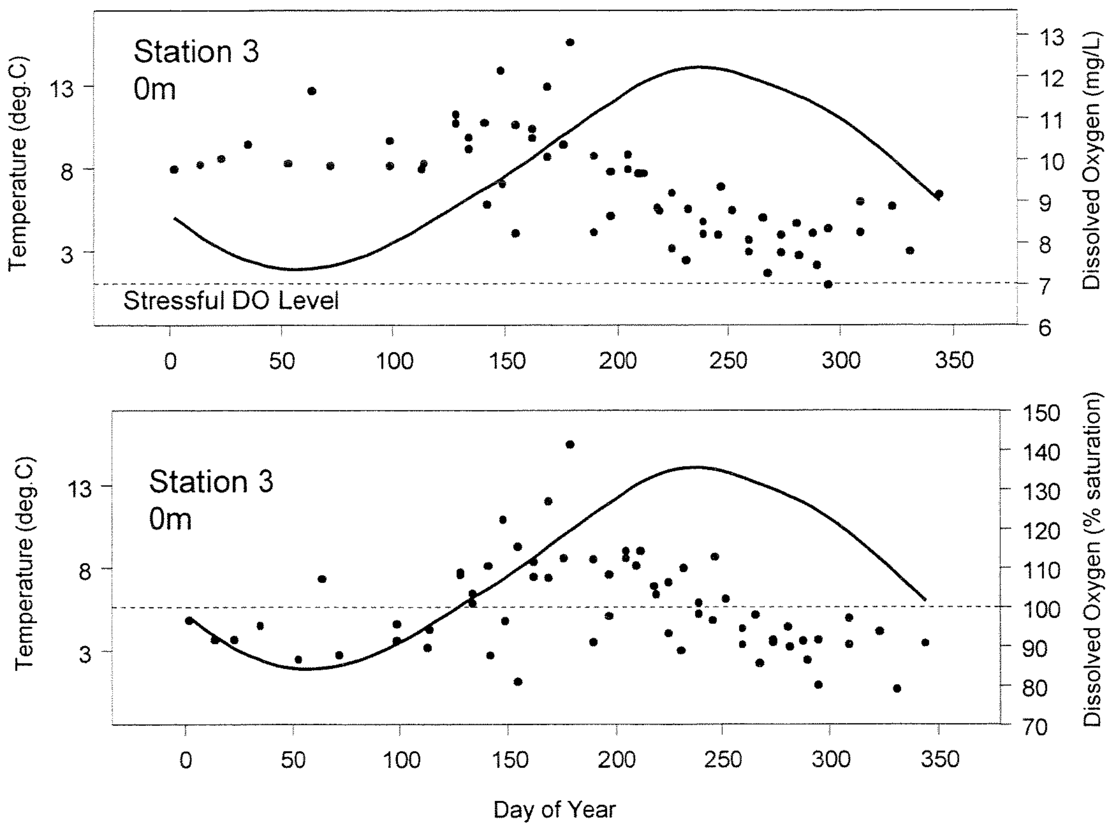


**Fig. 1**: Annual cycles in the near surface concentration of dissolved oxygen and temperature at sampling station 3 located within Lime Kiln Bay. The top panel shows the absolute concentration of dissolved oxygen in mg $dm^{-3}$ (mg $L^{-1}$) and the lower panel shows the same data expressed in percent saturation. The solid line indicating temperature is a spline curve used to smooth the raw temperature data that was collected at weekly to monthly intervals. All of the data were collected during 1990 and 1991 and are given in Martin et al. (1995).

## Phytoplankton – Southwest New Brunswick

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Following the advent of the salmon aquaculture industry, a sampling programme was initiated in the Western Isles region of the Bay of Fundy (southwest New Brunswick) in 1987 to study phytoplankton populations. Initially, 12 sites were sampled with 10 located in the Letang area, where the majority of the aquaculture sites were located at that time and the remaining 2 located in Harbour de Lute (Campobello Island) in close proximity to another aquaculture site. In 1988, the number of sampling sites expanded to 18 with additional sites in Passamaquoddy Bay around Deer Island, Deadmans Harbour and the offshore Wolves Islands site . In 1992, sampling was reduced to the 4 stations that continue to be monitored today. These include: Brandy Cove (a brackish site influenced by the St. Croix River estuary), Lime Kiln Bay (Letang inlet where a number of aquaculture sites are located), Deadmans Harbour (an open bay with offshore influence), and the Wolves Islands (an offshore indicator site). Samples are collected for phytoplankton distribution and abundance as well as plant nutrients (ammonia, nitrate, phosphate and silicate). Additional parameters measured include secchi depth, and depth profiles for fluorescence, oxygen, temperature and salinity. Samples are collected at the surface from all locations and additional discrete depths of 10 m, 25 m, and 50 m at The Wolves.

A total of 191 species of diatoms, dinoflagellates, silicoflagellates, flagellates, ciliates and smaller zooplankton have been observed - with up to 70 different species observed in one sample. Species that have been implicated in salmon stress and mortalities in the region include *Chaetoceros socialis* and *Mesodinium rubrum*. Those observed that have been implicated with salmon mortalities elsewhere are *Gyrodinium aureolum,C. convolutus,* and *C. concavicornis*. *Pseudo-nitzschia pseudodelicatissima*, a producer of domoic acid, has been responsible for closures of shellfish harvesting areas in 1988 and 1995 in the region. In addition, the Bay of Fundy has a long history of annual summertime shellfish closures due to unsafe levels of paralytic shellfish poisoning (PSP) toxins produced by *Alexandrium fundyense*. All species of plankton behave independently with some initiated inshore and others from the offshore. For example, blooms of *A. fundyense* appear to be seeded from the offshore in the gyre in the central Bay of Fundy where concentrations of its over wintering form or cyst exceed 5,000 cysts $cm^3$. Concentrations of vegetative *A. fundyense* cells tend to be greater in the offshore and at The Wolves site than at Lime Kiln near the aquaculture sites and do not seem to be influenced by the industry. Numbers of *A. fundyense* in recent years seem to be decreasing and results from the past 3 yr indicate that concentrations have not exceeded 5,000 cells $L^{-1}$ as compared to early years of sampling where concentrations often exceeded 50,000 cells $L^{-1}$.

Highest and lowest temperatures (0.4 – 15.5° C) were measured at Brandy Cove as well as lowest salinities (23.85 ‰). Silicate values ranged from 0.2 to 16.7 μM; phosphate levels ranged from 0.1 to 2.5 μM; nitrate values were from 0.0 to 11.3 μM; and ammonia ranges between 0.6 to 10.0 μM.

There are varying theories as to whether increased nutrient loading in coastal waters stimulates low-level ambient populations of phytoplankton to initiate blooms, or changing nutrient inputs can affect the fundamental structures of ecosystems. Further analyses are therefore necessary to attempt to determine the role of nutrients and other parameters on the abundance and occurrence of microrganisms in the Bay of Fundy.

# Annual Timing of Phytoplankton Blooms in the Western Bay of Fundy

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As part of a regional toxic phytoplankton monitoring program, phytoplankton has been monitored since 1988 at a fixed station near the Wolves Islands in the western Bay of Fundy. Samples have been collected at four depths (0, 10, 25 and 50m) at weekly to monthly intervals using water-sampling bottles. During the winter months the station has been sampled monthly. In the spring and fall the station is sampled bi-weekly and in the summer it is sampled weekly. Single, 250mL water samples were collected from each depth during each visit to the station. These were immediately preserved with 5 mL formalin:acetic acid. Later, 50-mL sub-samples were settled in Zeiss counting chambers for 16 h. All phytoplankton greater than 5 μm were identified and enumerated using a Nikon inverted microscope. Further identification was done using either a JEOL JSM-5600 scanning electron microscope or an Hitachi S-2400 scanning electron microscope.

We have begun to explore this data set from several perspectives, including that of the annual timing of phytoplankton blooms. For this analysis we consider only the aggregate groups of diatoms and dinoflagellates. We aggregated the cell counts from all depths and taxonomic units within each group for each sample date. We then calculated the cumulative cell counts within each year beginning in January of each year. Each sum was divided by the annual total and plotted against the day of year. These cumulative curves indicated that the annual increase in diatom abundance began around day 110, reached 50% of its annual total between days 150 and 250 and had returned to background levels by about day 275 (Fig. 1).

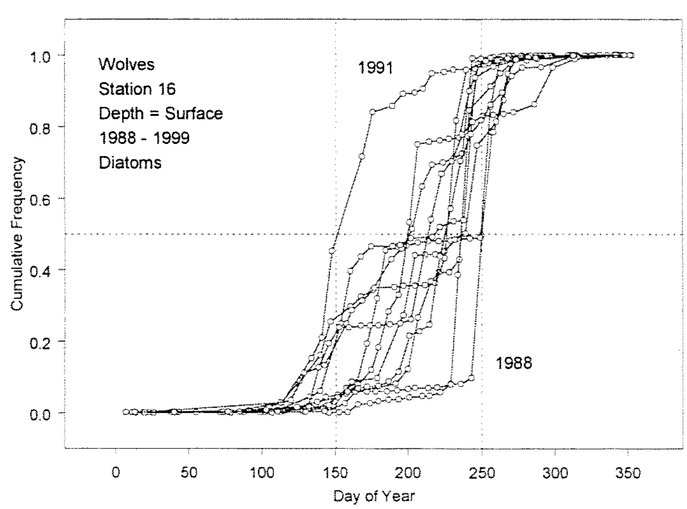


**Fig. 1**: Cumulative abundance curves for total diatom cell counts obtained from 0 m at station 16 during the years 1988 to 1999. Each curve is normalised by the annual total cell count. Station 16 is a phytoplankton monitoring station located near The Wolves in the western Bay of Fundy.

The spread in the median day was due largely to an early increase of diatoms in 1991 relative to the other years. The median day for the remaining 11 years ranged between about days 200 and 250. The cumulative curves for dinoflagellates indicated the annual increase began around day 150 or about 40 days later than for diatoms (Fig.2).

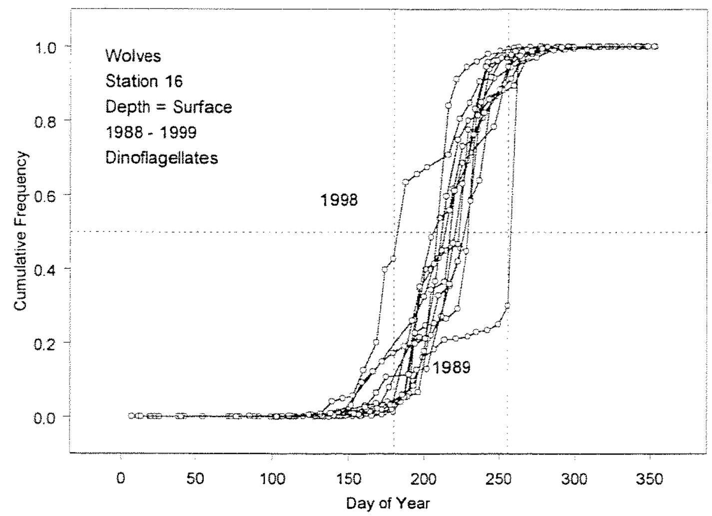


**Fig. 2**: Cumulative abundance curves for total dinoflagellate cell counts obtained from 0 m at station 16 during the years 1988 to 1999. Each curve is normalised by the annual total cell count. Station 16 is a phytoplankton monitoring station located near The Wolves in the western Bay of Fundy.

The range in the median day for dinoflagellates was much narrower than for diatoms and ranged between about days 210 and 230 for most years. In 1998 the dinoflagellate cycle appeared to be early with 50% of the cells occurring by about day 180. A comparison of the cumulative curves for diatoms and dinoflagellates within each year shows that in some years (1988, 1994, 1995, 1998 and 1999) the dinoflagellate cycle preceded that of the diatoms whereas in other years (1989, 1991, 1992, 1993) the diatom bloom preceded the dinoflagellate bloom (Fig. 3). This type of analysis was also conducted for an inshore station located within Lime Kiln Bay in the western Bay of Fundy in the heart of the local salmon aquaculture industry.

In the future we hope to further refine and quality control our database and explore the temporal and spatial variability in the patterns more fully. For example, we hope to apply statistical methods to comparisons of the cumulative curves between years and locations, to detecting significant time patterns in inter-annual variability, for detecting patterns in community structure and for exploring potential associations between the species abundance and environmental patterns.

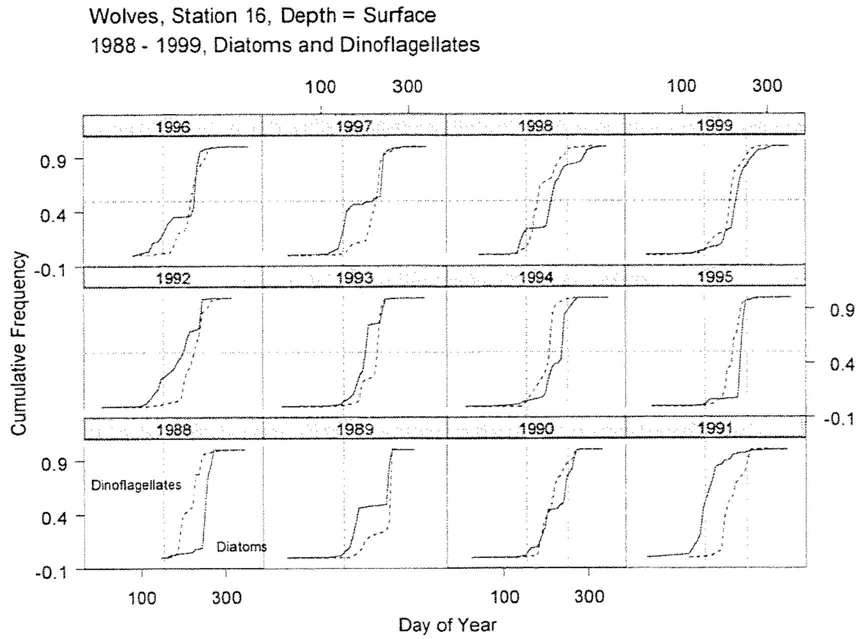


**Fig. 3:** A year-by-year comparison of the cumulative abundance curves for total diatom and dinoflagellate cell counts obtained from 0 m at station 16 during the years 1988 to 1999.

# Carbon Assimilation and Carbon Loads in the South Western New Brunswick (SWNB) Marine Ecosystem

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**Primary Production, Respiration and Biological Oxygen Demand (BOD):**
Primary production by the phytoplankton is a measure of the productive capacity of a marine ecosystem. Plankton respiration is a measure of the ability of heterotrophs in the water column to assimilate the carbon generated by this production and also to assimilate carbon from other sources.

In an open-ocean system (such as the one found in the Gully on the outer edge of the Scotian Shelf), production and respiration in surface waters are more-or-less "in balance" (Fig. 1). Gross production exceeds respiration by a relatively small margin and net productivity is a small fraction (<26%) of the gross production. In a coastal system (such as SWNB), the two carbon-cycling processes are not in balance. Respiration exceeds production by a factor of 1.3 to 10 (Fig. 2) and, at the time of our observations, there was no net production. Instead, the planktonic ecosystem has adapted to handle terrestial and man-made carbon loads that are far greater than the carbon generated by primary production.

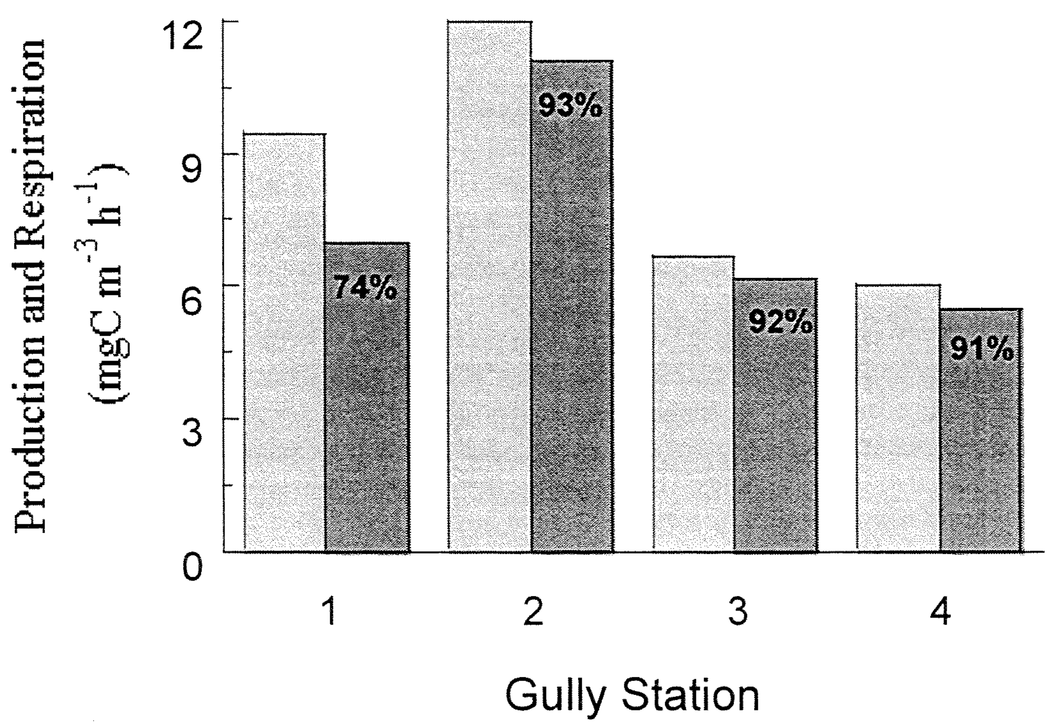


**Fig. 1:** Gross production and respiration at a depth of 10m at 4 stations in the Gully marine protected area. Between 74 and 93% of the gross production is consumed by respiration. As a result, the net productivity of the Gully ecosystem is <26% of measured production.

In Fig. 2, the amount by which respiration exceeds production at a control site (The Wolves) and at inshore sites where fish farm aquaculture occurs (Lime Kiln Bay and Bliss Harbour) is a measure of the ability of the plankton at the three sites to assimilate some, but not all, of the extra carbon load. When added to sediment respiration, this excess respiration in the water column provides a quantitative estimate of the total assimilative capacity of plankton and benthos at each of the three sites.

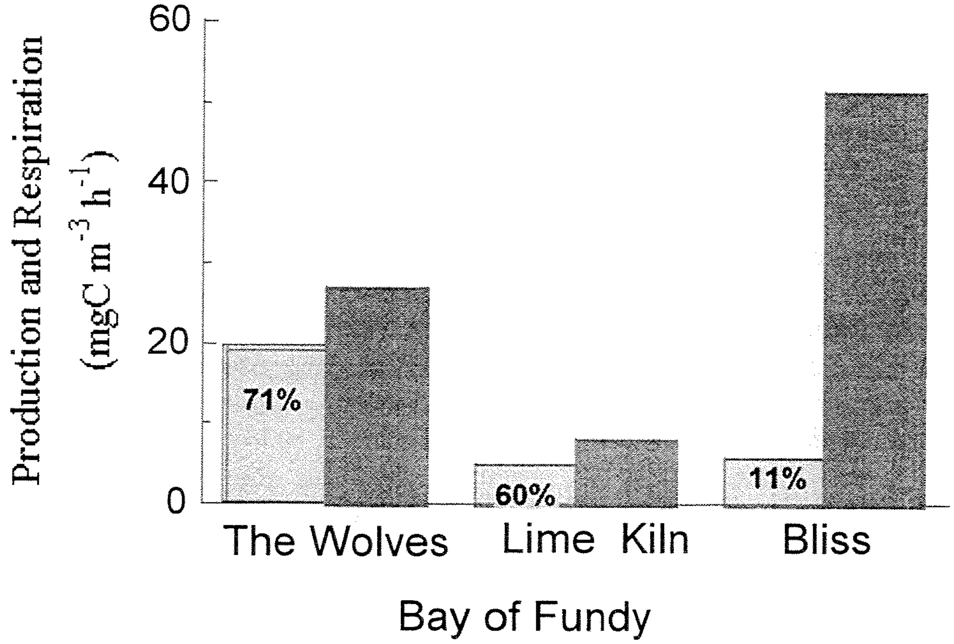


**Fig. 2:** Gross production and respiration at a depth of 2 to 4 m at an offshore control station (The Wolves) and at 2 inshore sites (Lime Kiln Bay and Bliss Harbour) where salmon aquaculture sites are located in the SWNB region of the Bay of Fundy. Note that respiration exceeds production by at least 29% so that there is no net production of carbon in the SWNB ecosystem

As a direct consequence of this carbon assimilation, a biological oxygen demand (BOD) is generated by respiration. The regional implications of BOD in SWNB should be considered in detail, especially with respect to the seasonal decreases in oxygen concentration that have been recorded at both aquaculture and control sites.

**Dissolved Organic Carbon (DOC) and Carbon Loads:**

DOC is by far the largest fraction of biogenic carbon in marine ecosystems, outweighing particulate organic carbon (POC) by more than 10 to 1. As a result, measurements of DOC provide the most direct means of assessing water-column carbon loads.

In Passamaquoddy Bay, DOC accumulates along the northern and western shores (Fig. 3), presumably in response to the discharge of rivers carrying terrestial carbon.

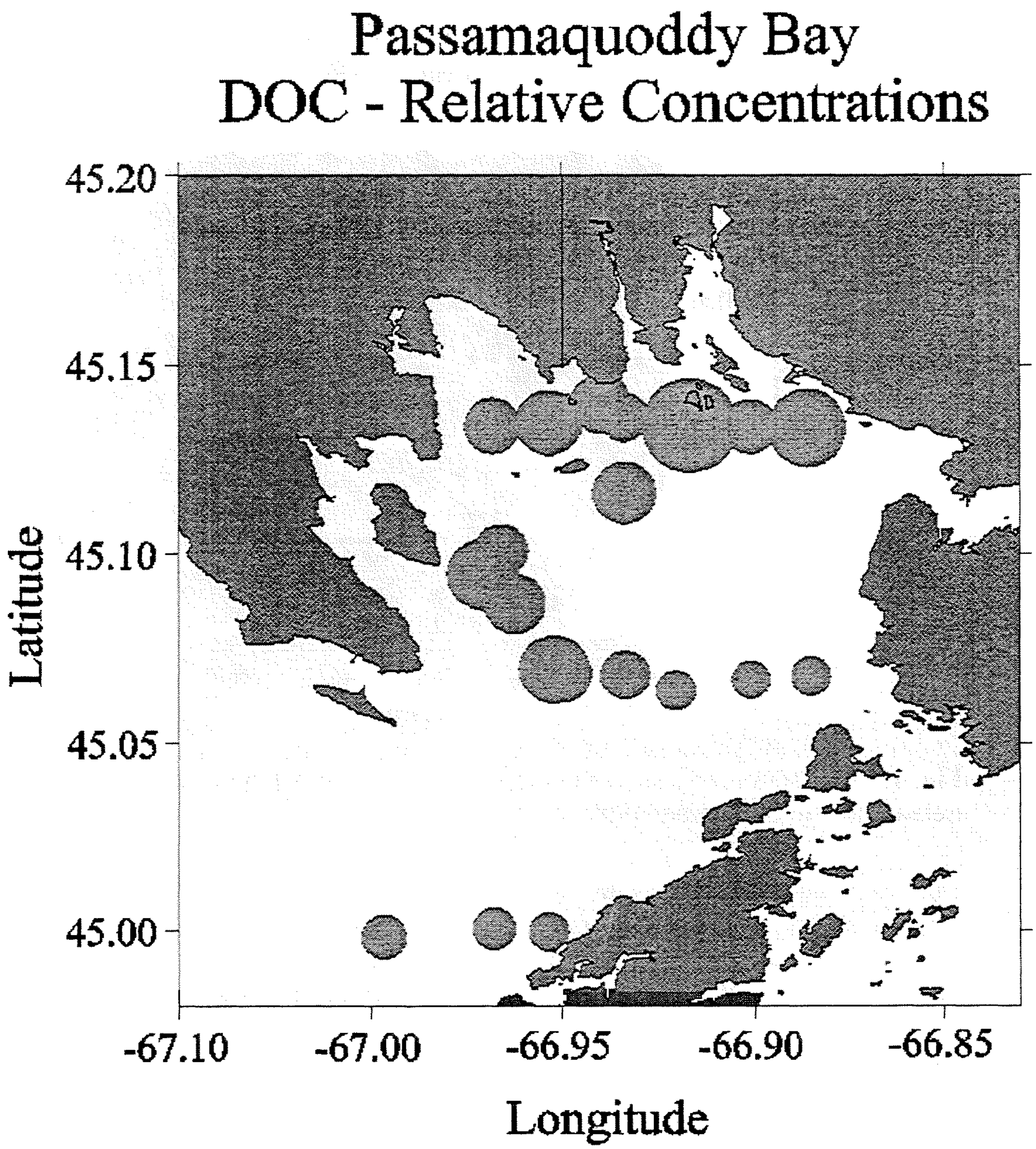


**Fig. 3:** DOC from Passamaquoddy Bay (2 m) is plotted as relative concentrations (where symbol size is proportional to carbon concentration). Note the buildup of DOC over and above the background concentrations of 80 μM C that are evident near Letete Passage and at stations to the southwest.

In the Letang Inlet, the distribution of DOC in surface waters is patchy (Fig. 4). This may be a function of an environment that is both physically and biologically dynamic. But it will also be a function of diverse carbon inputs (eg., from rivers, runoff, sewage and aquaculture).

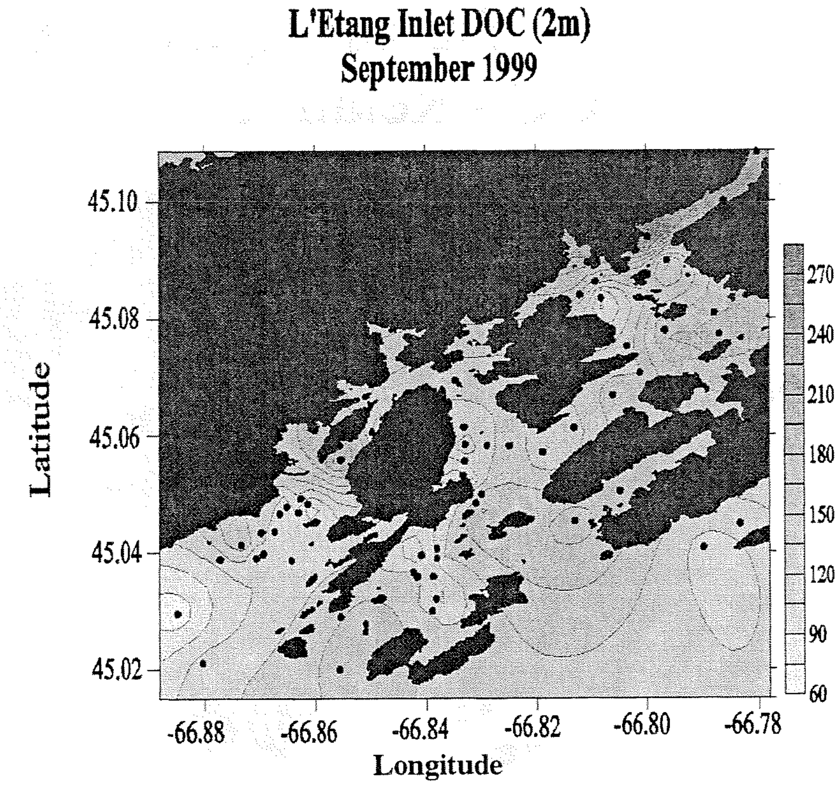


**Fig. 4:** Distribution of dissolved organic carbon (μM DOC) in surface (2 m) water of Letang Inlet in September 1999.

On a regional scale, the results from a seasonal time series of DOC measurements at Lime Kiln Bay and The Wolves control site (Fig. 5) indicate that there can be large (mM C) increases and decreases in the carbon load. The regional sources and sinks of this carbon are not known, and it is also important to keep in mind that DOC measurements will only provide an estimate of total carbon load. DOC is not a measure of the biologically-reactive carbon that can be assimilated by respiration. Even so, if only a small fraction (<1%) of the DOC is bio-reactive, it would have a large effect on regional BOD and any aquaculture practice that contributes to oxygen depletion.

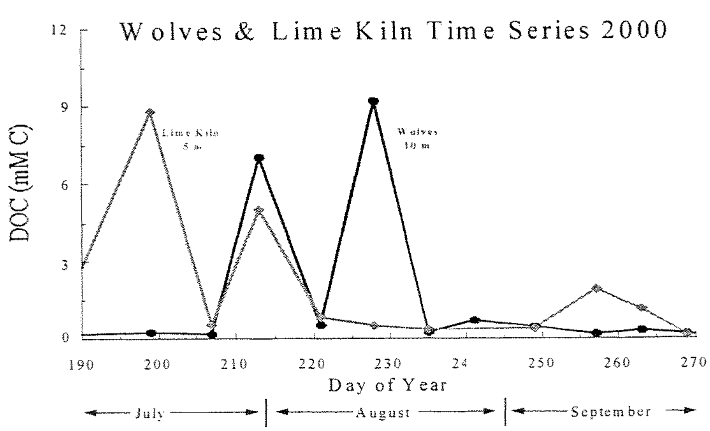


**Fig. 5:** Variations in DOC concentration in Lime Kiln Bay and the Wolves control site. Note the large and similar increases and decreases in DOC (15 to 30 days later at The Wolves compared to Lime Kiln Bay).

# Sediment Respiration in Coastal Areas of the Southwestern Bay of Fundy

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Studies of the assimilative capacity of any water body require an assessment of loss in organic matter through aerobic and anaerobic respiration in water and sediments. If oxygen is present, aerobic respiration can be measured as oxygen consumption by incubating water and sediment samples and measuring uptake over time (Hargrave et al. 1993, 1997 and Kepkay and Bugden in this volume). In September 2000 sediment cores were taken from grabs collected at The Wolves and Bliss Harbour and from diver-collected cores in Lime Kiln Bay at outer (1) and inner (2) bay locations away from fish farm sites. Samples of surface (0-1 cm) sediment from three cores at each location were resuspended in glass-fiber filtered seawater with and without $HgCl_2$ (as a metabolic poison) to separate biological and chemical oxygen demand. The sediment-water slurry was incubated in rotating glass-stopper 30 mL flasks and oxygen uptake measured as described in Hargrave and Phillps (1989). Lowest rates of oxygen uptake were measured at The Wolves with maximum rates (approximately doubled) in Lime Kiln Bay (Table 1A).

**Table 1**: (A) Oxygen uptake (mean) by stirred particles and (B) by undisturbed sediment cores (mean and SD, n=4) incubated at ambient temperatures for samples collected from an offshore location (The Wolves) in SWNB and three inshore sites in Letang inlet.

| | A Oxygen Uptake (Stirred Particles) mL $O_2$ $g^{-1}$ $h^{-1}$ | | B Oxygen Uptake (Cores) mL $O_2$ $m^{-2}$ $h^{-1}$ | |
|---|---|---|---|---|
| | $-HgCl_2$ | $+HgCl_2$ | $-HgCl_2$ | $+HgCl_2$ |
| Wolves | 0.053 | 0.017 | 11.82 (1.9) | 2.45 (1.9) |
| Bliss Harbour | 0.071 | 0.014 | 13.04 (1.4) | 5.13 (0.2) |
| Lime Kiln 1 | 0.113 | 0.018 | 23.1 (17-19) | 4.47 (2.8-6.2) |
| Lime Kiln 2 | 0.115 | 0.016 | 35.5 (30.9-40.2) | 6.51 |

Benthic respiration at the same sites was measured using cores taken from grabs with minmum disturbance. Filtered water was added to cover the intact sediment surface and cores were capped and incubated in the laboratory at ambient temperatures. Pairs of benthic chambers were placed on ther sediment at the two sites in Lime Kiln Bay to provide *in situ* measures of sediment respiration for comparison with rates from core incubations. As with stirred particles, highest rates of oxygen uptake occurred at the two sites in Lime Kiln Bay, with lower rates in Bliss Harbour and minimum rates at The Wolves (Table 1B). Oxygen uptake in the presence of $HgCl_2$ (in both stirred particles and intact cores) reflects residual non-biological (chemical) oxygen demand (COD) that would be expected to be proportional to reduced inorganic material (such as sulfides) accumulated in sediments and pore water. COD for stirred particles were similar from all locations (Table 1A) while values for intact cores showed a gradient of increasing COD from The Wolves to Lime Kiln Bay (Table 1B).

Measures of oxygen demand by stirred particles and sediments can be used to estimate a benthic oxygen demand for developing an oxygen budget for the Letang inlet area. Data for oxygen consumption due to natural heterotrophic processes in the water column and in sediments can be compared to other sinks for dissolved oxygen (e.g. waste products from pulp and paper and fish processing plants, sewage discharge) to determine if oxygen uptake by cultured salmon constitutes a significant fraction of the total oxygen demand in the marine ecosystem of the area.

Data presented in Strain et al. (1995) was used to compare biological oxygen demand (BOD) in different areas of Letang inlet, N.B., used for salmon aquaculture (Fig. 1).

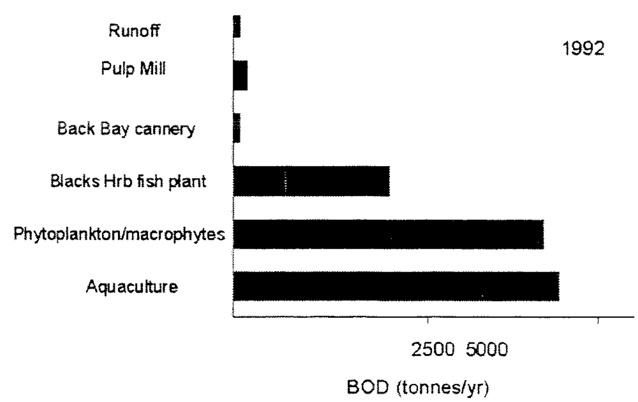


**Fig. 1**. Modified from Strain et al. (1995) to compare estimates of annual oxygen demand from salmon aquaculture with other natural and industrial sources of BOD.

Estimates of respiration by phytoplankton and macrophytes used by Strain et al. (1995) are approximations and must be verified by direct measurements. For example, oxygen consumption by intertidal sediments has not been included in the comparison.

Intertidal sediments comprise an average of 31% of the total area in the Letang inlet system and they are a significant sink for oxygen in areas of the upper Bay of Fundy (Hargrave et al. 1983).

**References:**

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## Finite Element Physical Modelling

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The model of the Quoddy region (Fig. 1) makes good use of the variable resolution capabilities of triangular finite element techniques. In the Lime Kiln, Back Bay area node spacing approaches 30 m in places. The fully non-linear 3D model has been run with the M2 tides and constant density on 21 vertical levels. The model has been adapted at the Bedford Institute of Oceanography to allow for the wetting and drying of intertidal areas. Although the M2 tides is the dominant component of the motion here, other physical forcings could also be important factors in drift and dispersion, particularily for long term predictions. Physical factors not yet considered include: 1. Other tidal constituents giving rise to spring-neap cycles and diurnal inequities, 2. The effects of stratrification and density, 3. Wind and barometric pressure, 4. Fresh water input and 5. The along shore drift from the Bay of Fundy. The inclusion of the terms in the model would take a major effort. Should adequate resources be available, work could begin on a graphics front end that would enable non-modellers to track particles for specific times and places of interest.

References:

Greenberg, D., J. Shore and Y. Shen. 1997. Modelling tidal flows in Passamaquoddy Bay. In *Costal Monitoring and the Bay of Fundy*, Proc. Mar. Atl. Ecozone Science Workshop, St. Andrews, N.B., 11-15 November, 1997.

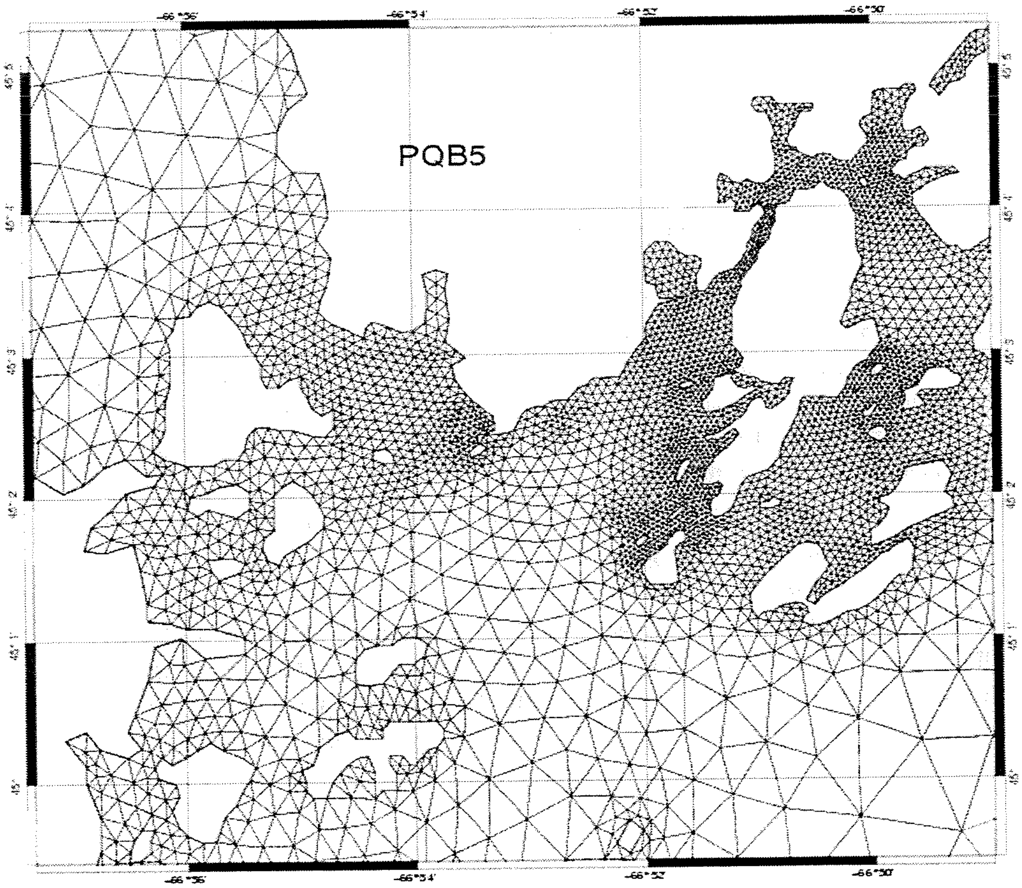


**Fig. 1:** The finite element model domain northeast of Deer Island around Frye Island and the Letang Peninsula. From Greenberg et al. (1997).

# Probabilistic Characterization of Tidal Mixing in a Coastal Embayment: A Markov Chain Approach

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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. 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.

An application which studies horizontal tidal mixing in Passamaquoddy Bay, a tidal inlet of the Bay of Fundy, was used to illustrate the basic concepts of the Markov chain approach. The bay was divided into regions and estimates for the transition probabilities were determined using stochastic particle tracking based on a flow field from a numerical tidal circulation model. Various derived quantities describing the retention, flushing and exchange properties of the bay were determined using the Markov chain.

# Copper Contamination of Letang Harbour, N.B.

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An investigation of heavy metals in Letang inlet, conducted in 1994 to assess metal distributions and identify potential sources, discovered very high levels of dissolved copper (Cu) throughout the Letang Harbour waters. All other trace metals showed highest concentrations at the station nearest to the discharge from the pulp mill and a general decrease in concentration with increasing salinity elsewhere in the system. Concentrations in the outermost part of the study area (Bliss Harbour) were at background levels. The story for Cu was very different with a distribution unlike that of any of the other metals investigated. Concentrations were very high (1.6 to 9.3 µg $L^{-1}$ - 10 to 50 times background) throughout the estuary and in excess of guidelines for protection of marine life. The distribution pattern was also quite different. The highest concentrations were not near the pulp mill discharge and there was no simple pattern indicative of a single major source. A number of dispersed sources seemed to be indicated.

In 1999 and 2000 we planned surveys of Cu in the Letang area to 1) check the 1994 results, 2) pinpoint the sources, and 3) investigate the Cu speciation. For logistical reasons, both of the surveys were less extensive than planned. The results of these two (limited) surveys, both conducted during September, showed much lower copper levels - from coastal backgrounds (0.18-0.21 µg $L^{-1}$) at The Wolves to twice background (0.38-41 µg $L^{-1}$) in Lime Kiln Bay. Although the Lime Kiln Bay samples were somewhat elevated, none of the observed concentrations exceeded the guidelines for protection of marine life.

Anecdotal evidence mentioned at the workshop suggests that use of copper antifoulants by the aquaculture industry has been reduced markedly in the past few years. It has not been possible to clearly establish the source of the high copper concentrations observed in August 1994. The 1999 and 2000 surveys during September indicate lower, more normal, coastal water concentrations with no indication that the aquaculture sites are responsible for high levels of water column copper.

# Environmental impact of chemical wastes produced by the salmon aquaculture industry: Overview

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This is an ESSRF project that is in the second year of the program and is an integrated and coordinated multi-disciplinary approach to assessing the impacts on the ecosystem of chemicals used in the Atlantic salmon aquaculture industry. Chemicals used in aquaculture may be introduced intentionally or unintentionally and fall into three general categories, feed components, medicinals and construction materials. Herring and shark oils, dyes and antioxidants are added to fish feed. Pesticides, disinfectants, antibiotics, chemotherapeutants and anesthetics are among medicinals commonly used. Construction sources include wood, plastics, paints, metal, antifoulants and preservatives. The identity of intentionally added chemicals is usually known, but the identity and sources of unintentionally added chemicals need to be determined. Such unintentionally added chemicals may include organochlorine and other persistent chemicals in feed, chemicals in construction materials, and metabolites and degradation products of intentionally added chemicals. The objectives are:

(a) To detect, identify and quantify the source of chemical wastes from the aquaculture industry.
(b) To determine the fate, distribution and persistence of chemical wastes in sediment and biota.
(c) To determine lethal and sublethal effects of chemical wastes on fisheries resources.
(d) To advise management and industry on the nature and dimensions of problems and appropriate counter measures and alternatives for the management of salmon aquaculture.

The following summarizes the progress:

**Metals: Dr. Chiu Chou (Leader)**

The determination of Cu, Fe, Mn and Zn in the diet, sediments, and lobsters, and organic carbon in the sediments for samples collected in 1998 were completed. Results have been compared to the Environmental Monitoring Program Ratings (EMP). Organic carbon results for all survey sites, show an increase related to sediment condition, as follows: low to high in normal to anoxic sediments. In general, Cu and Zn from under the cages, relate to EMP Ratings: Cu and Zn are lower in normal sediments and increase in hypoxic and anoxic sediments. At some sample sites, the EMP Ratings do not match the sediment Cu and Zn concentrations. Mn sediment concentrations decrease from normal to anoxic conditions. Fe does not appear to relate to EMP Ratings for sediments. However, the ratio of Fe/Organic carbon improves the relationship to the EMP Ratings, suggesting that the form of Fe present in the hypoxic and anoxic sediments may differ from the normal sites. Metal analyses of sediment samples collected in 1999 are in progress. Lobster samples were collected at 4 sites in 1999 (McCann's Head, Dick's Island, Lime Kiln Bay and Spider Cove Ledge) and have been analysed for Cu, Fe, Mn, and Zn. Results indicate that lobsters collected under cages at McCann's Head are elevated in Cu compared to control site. In 2000, 25 lobsters were collected from Beaver Harbour, and analyses are in progress.

**Organics: Dr. Jocyelne Hellou**

During the summer of 1998, small and large food pellets, fish oil, used as an ingredient to prepare feed, as well as 15 sediments were collected around aquaculture sites. The samples were analysed for 159 PCB congeners, 31 parental and alkylated polycyclic aromatic hydrocarbons (PAHs) and 12 organochlorine pesticides. These chemicals would represent compounds that are unintentionally used by the industry. Combustion derived PAHs were most abundant in sediments, with alkylated PAHs representing between 3 and 27% of the sum of PAHs. Naphthalenes were detected in sediments, food pellets and fish oil, while alkylated phenanthrenes were only detected in sediments. Trace levels of resolved or co-eluting PCB congeners were detected in some of the sediments ($<4$ ng $g^{-1}$, dry), with IUPAC congener numbers 153/132/168 and 138/160/163/158 were the most abundant group. As expected, the DDTs predominated within the pesticides series. Concentrations of organochlorine compounds tended to be higher where organic carbon content was more elevated, but PAHs did not follow this trend. Analyses are in progress for sediment samples collected in 1999.

**Macro Fauna: Dr. Gerhard Pohle (Leader)**

Three salmon farm sites were sampled (Demo farm, Kelly Cove and Ministers Island), each with four replicates at 0, 50 and 100 m from cages (at Kelly Cove it was actually not possible to take samples at 100 m due to high gravel content). Macrofauna analyses are in progress (technical assistance provided by S&T Youth Internship Program)

**Toxicology: Dr. Les Burridge (Leader)**

Under laboratory conditions, the response of lobsters to azamethiphos and cypermethrin (pesticides used in the treatment of sea lice infestations of cultured salmon) was uniform between the three larval stages, the first post-larval stage and adults although there tended to be considerable variation in the response of the larval animals. In general these compounds were lethal (48 h LC50) at concentrations equal to approximately 1-3% of the recommended treatment concentration. The results of each study suggested that it was unlikely that there would be any adverse effects of a single bath treatment on wild populations of American lobster. However, multiple treatments may be taking place in a single bay at the same time. The consequences of multiple inputs of chemicals over short time was investigated.

Preovigerous female American lobsters (N=72) were divided into two treatment and one control groups. Ovarian maturation and spawning was induced using elevated water temperature and short day length. Lobsters were exposed four times for one hour to either 10 or 5 µg $L^{-1}$ of azamethiphos. These concentrations represent 10 and 5 % of the recommended treatment concentration. Treatments were separated by two weeks and three experiments were conducted over three spawning seasons. Survival and success of spawning were monitored. Similar results were observed in the three experiments. For example, in the second experiment, only one lobster was dead after the third exposure to10 µg $L^{-1}$ azamethiphos, but after the fourth exposure, 43% (10) of the lobsters died. In contrast, only 8% (2) of those exposed to 5 µg $L^{-1}$ died after the final exposure and there were no deaths amongst the controls. In a separate experiment the activity of acetylcholinesterase (AChE) in the muscle of exposed lobsters was measured. These data suggested a possible cumulative inhibition of this enzyme. Alternatively, increased sensitivity of the lobsters during the fourth exposure compared to earlier exposures may be related to seasonal differences in physiology or to the endocrine state of preovigerous and spawning females. Two months after the last exposure, spawning success, as assessed by the presence of extruded eggs, was also affected by exposure to the highest concentration of azamethiphos. Seven (54%) of the surviving lobsters exposed to 10 µg $L^{-1}$ failed to spawn, while 2 (9%) of the surviving lobsters exposed to 5 µg $L^{-1}$ of azamethiphos and only 1 (5%) of the control lobsters failed to spawn. Oocyte vittelin was resorbed by some of the lobsters in the azamethiphos treated groups.

Studies on the effect of season and moulting stage on the lethality of azamethiphos to lobster, the lethality of emamectin benzoate in feed to adult lobster and lobster larvae, and the effect of emamectin benzoate medicated feed on the reproductive success of lobsters are in progress.

# Flocculation and Sediment in Letang Inlet, N.B.

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The disaggregated inorganic grain size (DIGS) of bottom sediment is being used to

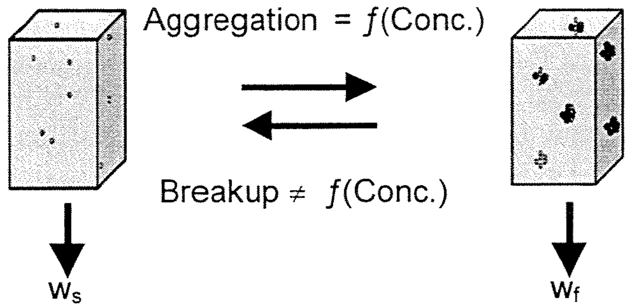


**Fig. 1**

understand the sediment dynamics of the Letang inlet region and its relationship to aquaculture activities. Theoretical, laboratory and field studies all suggest that fine grained particles in suspension exist in one of two forms: as single grains or as part of flocs. A simple box model (Fig. 1) describes the exchange of material between these two states as a result of aggregation and floc break up where $w_s$ and $w_f$ are respectively the single grain (Stokes) and floc settling velocities of a grain in a size class. Aggregation is primarily dependent on concentration and adhesion efficiency, the probability of two particles sticking together on contact.Turbulence initially favours aggregation by increasing the encounter rate of particles but above some level causes floc break-up. Aggregation rate is a function of concentration but break up is not. Changes to the balance between these two modes of deposition as a result for example of increased particle load, can be determined by calculating from the DIGS the fraction of material deposited as flocs. If aggregation increases, the floc fraction will increase. The model of Kranck et al. (1996a,b) is fitted to the data to determine floc fraction, the amount of material deposited as flocs, and floc limit, the intersection between the 'floc tail' of fine grained sediment and the modal peak of single grain settled material (Milligan and Loring, 1997).

The DIGS for subsamples of a core collected in Back Bay, an area adjacent to Letang Inlet, shows a distinct increase in floc limit up core (Fig. 2). The disappearance of the

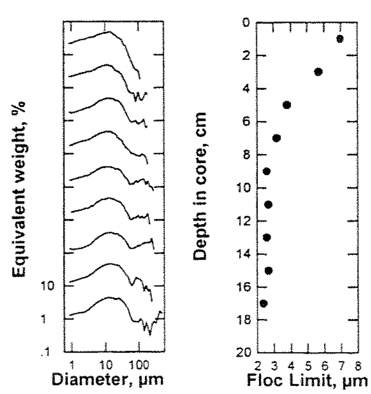


**Fig. 2:** Vertical profile of disaggregated inorganic grain size (DIGS) spectra for a sediment core from Back Bay, SWNB.

sharp increase in slope from ~0.1 to 2 above 9 cm indicates that the amount of material deposited as flocs has increased at this location, conceivable as a result of adding fine grained, 'sticky' particles from anthropogenic sources. Through excess feed and faeces, aquaculture introduces additional fine-grained particulate material to the environment. Sedimentation rate for this core is unknown so the change in sediment dynamics can not be attributed to any known change in ambient conditions.

Surficial sediments were collected in Letang Inlet in 1990. Stations were re-sampled for DIGS in 1999 to examine changes in sediment dynamics. Results show no significant increase in floc settled material, however, sedimentation rates in Letang Inlet determined by pore water analysis (see Cranston, this volume) are of the order 0.1 cm $y^{-1}$. At this rate, the ~1 cm deep subsamples taken from the grab could mask any alteration to the DIGS. Under aquaculture MC funding, a new coring device is being constructed to allow more precise sampling of the sediment water interface. Samples collected in both years are being used to map the depositional and erosional areas and to identify regions where accumulations of fine-grained sediment are located. Data can be used in site selection under the present assumption that accumulation of wastes below cages is to be avoided.

During field work in the Letang area in September 2000, particulate matter exchange between the water column and sediment was examined with a new instrument designed to take multiple water samples in the benthic boundary layer (within 1 m of the bottom). Suspended sediment samples from both the water column and benthic boundary layer were collected at selected stations at The Wolves and in Letang Inlet for DIGS analysis. Samples were also collected hourly over a 13-hr tidal station in Lime Kiln Bay. *In situ* floc size at the station was measured using a digital silhouette camera (Milligan, 1996). Simultaneous current measurements were made at the anchor station using an ADCP. Data will be analyzed to determine the role of aggregation in the vertical flux of fine-grained sediment in this region of intense salmon aquaculture.

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# Effects of Green Macroalgal Mats on the Population Dynamics of Soft-shell Clams (*Mya arenaria*) in Southwestern New Brunswick

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Coastal eutrophication, the over-enrichment of coastal zones with inorganic and organic nutrients, is becoming a global phenomenon. Increases in anthrophogenic activities near coastal zones (e.g. housing developments, aquaculture, agriculture) increase nutrient levels, such as nitrogen and phosphorus, in coastal waters (Rosenberg 1985, Strain & Yeats 1999). The impact of enrichment depends on the capacity of the environment to receive and absorb these inorganic nutrients (Strain & Yeats 1999). A common feature of additional nutrient loading in many locations is an increase in occurrence of dense green macroalgal mats composed of mainly *Enteromorpha* sp. and *Ulva* sp. (Reise et al 1989, Lavery & McComb 1991, Kolbe et al. 1995). Since, nitrogen and phosphorus are thought to be limiting nutrients with respect to algal growth, the surplus of nutrients in the ecosystem could cause the proliferation of these species. Green macroalgal mats have been documented to have negative effects to the molluscan fauna in impacted regions (Soulsby et al. 1982, Vadas & Beal 1987, Everett 1994, Norko & Bonsdorff 1996, Raffaelli et al. 1998, Thiel et al. 1998). The impact to shellfish has been attributed to changes in sediment chemistry, water chemistry at the sediment-water interface, and the physical environment caused by macroalgal mats (Hull 1987, Everett 1994, Raffaelli et al. 1998).

Soft-shell clams (*Mya arenaria* L.) are filter-feeding bivalves distributed along the North American Atlantic coast from Labrador to South Carolina. They can be found in muddy to gravel substrates from the intertidal zone down to 200 m, but are more abundant in intertidal and subtidal areas (Strasser 1999). The dioecious soft-shell clams are mass spawners, and have a planktotrophic larval development stage (Strasser 1999).

The goal of this study is to determine the impact of green macroalgal mats on the population dynamics of soft-shell clams in southwestern New Brunswick. Two experimental sites (Clam Cove, Deer Island and Hinds Bay) were selected where macroalgal beds are present. Macroalgal mats do not occur at two control sites (Pocologan and Mascarene). Within these sites, the following will be examined: (1) survival, growth and recruitment of soft-shell clams, (2) quantify and qualify the macroalgal cover, and (3) describe the physical environment.

During my 2000 field season we accomplished: 1) aerial survey for macroalgal cover, 2) collected historical photographs of macroalgal cover of my sites, 3) collected algal samples for nutrient analysis 4) performed reciprocal transplant experiment of soft-shell clams, 5) conducted preliminary burial depth experiment, and 6) collected water samples for dissolved nutrient analysis.

Findings from these experiments and observations were that:

1) a temporal algal cover difference exists between sites proximate to salmon aquaculture facilities;
2) there are length- dry weight differences in wild clams collected from under algae and from adjacent areas of sediment without algal cover;
3) burial depth differences exist between clams found under algae and from sediment without algal cover;
4) density differences do not exist between plots under algae and clear of algae.
5) water and algal nutrient analysis are in progress.

We plan to continue to analyze my data from 2000 and to prepare the sampling plans for the 2001 field season. Further, we plan to repeat my growth experiment, document condition indices for clams under and adjacent to algal mats, document clam recruitment, measure algal biomass, cover and nutrient concentration. We will also continue to sample water from inflowing streams and sea water for dissolved inorganic nutrients and DOC. Finally, we will describe the physical environment with respect to oxygen levels, Eh and particle grain size at the algal-sediment interface.

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# Near Field Impacts and Recovery of Sensitive Habitats Underlying Fish Farms in the Broughton Archipelago, B.C.

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Stolt Seafarm Ltd

The objectives of this project are to:

1) determine the zone of influence underlying fish farms using changes in taxonomic composition of benthic invertebrate communities (macrofauna and meiofauna);
2) assess two proposed monitoring methods designed to detect organic enrichment and classify the level of impact;
3) determine the recovery or fallowing period of impacted sediments underlying a fish farm;
4) verify recommended fallowing periods in support of HADD determinations.

In general, abandoned fish farm sites in the Broughton Archipelago, south-central coast of British Columbia, will be surveyed over time to determine recovery rates of underlying sensitive habitats as certain farms in B.C. go through a relocation process. Cost-effective sediment monitoring tools (total sediment sulfide and redox (Eh) potentials) developed in the Maritimes region (Wildish et al. 1999) have been incorporated into this study (Barry Hargrave) to determine their ability to detect a HADD (habitat, alteration, disruption, and destruction) in Pacific region coastal ecosystems. In addition, the sampling protocols of the Performance Base Standards monitoring program initiated by the B.C. government will be assessed within the context of HADD determinations.

The Canadian Hydrographic Service (Jim Galloway, Rob Hare) has carried out multibeam (EM3000) and QTC (substrate habitat classification system) surveys of the seafloor surrounding an abandoned farm site at Carrie Bay. An overlay of the two mapping surveys shows a strong relationship between the reflectivity (backscatter) results and the QTC classification of sediment type. These tools appear to be able to detect the depositional field of natural and farm waste material. OSAP (Dario Stucchi) is deploying current metres at each abandoned farm site to determine water column physical properties and current activity. This information can be used to explain the depositional characteristics of farm-derived material (verify impact footprint) and also to determine the contribution of bottom currents to the recovery process of impacted sediments.

Grab and core samples are being collected in a grid pattern at each abandoned farm site under the co-ordination of MEHSD (Terri Sutherland, Colin Levings). These samples are analyzed for a variety of geochemical (size, bulk density, sulfide/Eh, oxygen, carbon/nitrogen, trace metals) and biological properties (macro- and meiofaunal diversity). This data will be analyzed by an MSc. student, Nara Mehlenbacher, in collaboration with Royann Petrell of UBC. Research for the dissertation will relate changes in the diversity of fauna taking place during the recovery process to associated changes in geochemical variables.

The integration of the physical and biological data collected during this study will provide information useful for predicting optimum fallowing times at fish farm sites in the future. These findings will allow habitat managers (Wayne Knapp) to recommend potential rotational policies for fish farm operations for integrated management purposes to ensure the long-term success of the aquaculture industry.

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## Environmental Studies for Sustainable Aquaculture-Pacific Region

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The objectives of this project are to 1) determine the assimilative capacity of the upper water column (productivity and respiration); 2) determine sedimentation rates with enhanced organic loading; 3) determine transport pathways of waste particulates; and 4) link findings in support of HADD determinations. The research focus of the pacific region for the 00/01 fiscal year has been to determine benthic impacts, sedimentation fluxes, and circulation patterns surrounding a low-energy and a high-energy fish farm site. These measurements will lend information required to determine enhanced sedimentation rates and transport pathways of farm-derived particulates. Knowledge of dispersal distances of waste particulates is required in order to verify the regional siting criteria used to assess fish farm licences. A secondary focus of this research is to determine a cost-effective tracer of waste feed and fecal material.

This study took place in the Broughton Archipelago, which is located in the southcentral coast of British Columbia. Van-Veen Grab and Gravity Core samples were collected at various distances from two farm sites in order to determine the extent of the depositional fields and potential benthic impacts. The grab samples were processed for both macro-and meiofaunal analysis, while the core samples were analyzed for oxygen, Eh, sulphide, and carbon/nitrogen content. The sampling stations were located along two transects in the dominant upstream and downstream current direction. However, due to the coarse nature of the seafloor and logistical problems that occurred, the number of cores and grabs collected were limited. In addition, benthic chambers were deployed in the far-field region (300 m from farm site) to determine the respiration rate of the benthic environment. Five replicate grabs were collected at the chamber stations to typify the fauna responsible for the observed respiration rates.

Sediment traps were also deployed at various distances (0, 5, 30, 300 m) away from the two farm sites in the dominant upstream and downstream current direction. The sediment traps were deployed to gain information regarding the dispersal characteristics of water-born waste particulates. The material collected will be analyzed for total suspended solids, chlorophyll, and carbon/nitrogen content. Isotope analysis and a metal scan will be carried out on the sedimented material to determine a potential tracer of waste particulates. A tracer of feed pellets and faeces is required in order to determine cumulative far-field effects of aquaculture waste.

Current meters were deployed at a distance of 300 metres from each farm site in the dominant upstream and downstream current directions. These deployments will be carried out for a month to capture a full neap/spring cycle. Time-series of water property profiles were carried out in the downstream direction at each site to determine the circulation and physical/chemical properties of the water column. Additional water column profiles were carried out in surrounding channels to determine background measurements of water column properties. Models of circulation are currently being developed to predict the transport pathways of waste particulates in order to validate the existing regional siting criteria.

# Remote Acoustic Characterisation of Mariculture Site Sediments

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A multibeam bathymetric and backscatter survey of Letang and Bliss Harbour Estuaries was recently performed by the Canadian Hydrographic Service using a Simrad EM3000S sonar integrated with a Applanix POS/MV inertial navigation system. The system provides a view of the seabed relief and bottom backscatter strength at resolutions as low as ~2m spatially. The survey launch draws only 70 cm and has a flush-mounted transducer so it can operate around mariculture hardware with little likelihood of hookup (a problem for towed or pole-mounted systems). The system was capable of imaging under active mariculture sites to examine the impact of the industry on the seabed.

The survey clearly delineated regional sediment distribution and the presence or absence of seafloor bedrock outcrop and pockmarks. Of particular interest, however, was the imaging of the anthropogenic signature resulting from intense mariculture activity in the area. Three main observations were noted:

1) In areas of regional low backscatter sediments (presumably fine grained material) a distinct signature ~ 17 dB above the surrounding sediment was seen as a series of ring-like targets centred under each active farm site. Physical sampling has yet to be conducted to determine if the material deposited in these ring-like areas is rich in organic matter and not in itself of high impedance contrast. Increased backscatter strength could be due to the in-situ development of bubbles in sediment caused by high deposition and accumulation of organically rich sediments at these sites.

2) In those same low backscatter areas, a circular positive bathymetric anomaly about 20 cm high could clearly be distinguished indicating accretion of material under the pens.

3) The concrete moorings blocks, the record of them being dragged through the soft surficial sediments, and the effect of abrasion of the mooring cables on the bottom was very distinct in the topography.

For areas of high regional bottom backscatter (presumably coarse sands and gravel pavements), the first two observations were absent. That the backscatter signature is less visible is not surprising given the reduced contrast (the background sediment has a similar mean backscatter signature). However, the fact that no topographic anomaly was noted suggests that deposition is not so significant at these sites. This would make sense given that these coarser sediments closely correlate with areas of higher currents and thus higher bottom shear stress. In the low backscatter areas, locations where salmon farms used to be located could be distinguished by a faint residual signature in the sediment (and the relict marks of the mooring hardware). This would indicate that the 1st and 2nd observations are ephemeral features that gradually disappear after a site is abandoned. The hope is that future repetitive surveys can be conducted to monitor the time variability of this anthropogenic signature.

# Temporal Studies (1971-2001) of Benthic Macrofauna in Letang Inlet, N.B.

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During the last 30 years the Letang Inlet, N.B., has become significantly more industrialized with the establishment of a pulp and paper mill releasing discharges into the upper Letang starting in 1971, and the establishment of a salmon mariculture industry in the lower Letang beginning in the early 1980's. Both of these industries release organic wastes which if present in excessive amounts lead to "organic enrichment" effects as characterized by Poole et al. (1978) and Pearson and Rosenberg (1978). Prior to 1971 the only sources that contributed to organic enrichment included two fish processing plants in Black's Harbour and Back Bay and small amounts of municipal sewage.

During this period many benthic macrofaunal samples have been collected in the Letang inet. For example, see:

- Fisheries Research Board MS Rep. No.1295 (for 1970-71,72)
- Fisheries and Marine Science Tech. Rep. No. 718 (for 1975)
- Can. Fish. Aquat. Sci. Tech. Rep. No. 770 (for 1973)
- Can. Fish. Aquat.Tech. Rep. No. 1473 (REMOTS® sediment-interface photography in 1985)
- partly published in data reports by the Atlantic Reference Center (for 1994-1999)
- Unpublished data (D.Wildish): 7 stations, 3 replicates, by grab and with 1 $mm^2$ mesh (for 1997).

Our aim was to see if these historical samples could be used to determine whether increased organic enrichment in the Letang inlet had resulted in the classical macrofaunal responses to organic enrichment.

## Methods

Some difficulties were anticipated in comparing data from studies conducted at different times. For example, for studies in 1970-1971 macrofauna were separated from sediment using a 2.5 to 3 $mm^2$ mesh, whereas later studies used a 1$mm^2$ mesh. Prior to 1976 all taxonomic identifications were confirmed at the Canadian Oceanographic Centre (Dr. Dan Faber). After 1976, taxonomic determinations for macrofauna were carried out at the Atlantic Reference Centre, Huntsman Marine

Science Center (Dr. G. Pohle). There were also minor variations in types of grabs and methods for combining replicates.

To account for these inconsistencies, we repeated sampling at Letang stations previously visited in the early 1970's. During the summer of 2000, we re-sampled at 5 stations taking 3 replicate grabs at each location and keeping samples seived through 3 and 1 $mm^2$ mesh separate. At the same time we re-occupied 3 stations (3 replicates each) in the St. Croix estuary which were also sampled in the early 1970's as a reference or control site not subject to potential organic enrichment from any industrial source.

**Results**

All samples collected in 2000 for benthic macrofauna have been processed for taxonomic identification and Species x Number matrices have been prepared. The next step is the digitization of the historical data from Letang and St.Croix estuaries, which we hope to accomplish this winter. We feel that it is important to repeat the 2000 sampling effort in 2001 to obtain precisely geo-referenced samples using an accurate Trackpoint positioning system. This will confirm that we obtain statistically reliable and comparable data when we re-occupy stations in successive years.

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# Seasonal Monitoring of Sedimentary Variables in Lime Kiln Bay, Letang Inlet, N.B.

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The purpose of a seasonal survey of sediments in the Letang Inlet is to determine if the natural changes in benthic macrofauna communities and sediment geochemical variables associated with organic enrichment (e.g. following phytoplankton die-off and deposition) are of sufficient magnitude at specific times of the year to be measurable. Such changes in pelagic and benthic inputs of organic matter may have a practical significance for determining the optimal time of year for sampling being undertaken to monitor under-cage sediment variables by the New Brunswick Department of Fisheries and Aquaculture as part of the Environmental Monitoring Program. The current practice is to use a main fall sample collection to monitor all mariculture sites in SWNB using two geochemical measures (total sulfide and redox (Eh) potentials) in surface sediments. A second period of sample collection is undertaken in the spring at the most impacted (C) sites. The practical question of concern is does this timing introduce a seasonal bias in the results?

## Sampling

Sample collection was initially by separate grab and diver-held core tubes. This has been streamlined using a wedge corer (described in Hargrave 1969), modified to subsample sediments with core depth (max.depth=25cm). Five replicate cores are taken at each of two sites within Lime Kiln Bay. The location inside the bar (site E) is more depositional than the one outside (site R) which is more subject to tidal and wind driven currents. Diving services and a diving tender are currently provided by Luke Aymar (Advanced Net Cleaning, 506-754-0148). Positioning for re-occupation of the same site for monthly sample collection is guided by anchor chains and blocks with actual bottom sampling sites located using an aluminum stake. All samples on a given date are taken within one $m^2$. Subsequent samples are taken in the next adjacent one metre plot.

Sampling was initiated on the 20$^{th}$ September with subsequent trips on the 31$^{th}$ October, 30$^{th}$ November, 2000 and 4$^{th}$ January 2001. Trips are planned for the 28$^{th}$ February and 30$^{th}$ March 2001.

## Sedimentary variables measured

Two of the least disturbed wedge cores (minimum turbidity of water overlying the intact sediment-water interface) are used for sediment-interface photography (35 mm digital camera). Surface (0-2 cm) samples are removed for Eh and sulfide determinations (Wildish et al. 1999). Sediment samples are then withdrawn from predrilled holes (4 cm intervals) for determination of Eh (NHE,mV), sulfide (uM), chlorophyll *a* (µg $g^{-1}$ dry sediment), organic carbon and nitrogen and inorganic grain size (methods described by T. Milligan in this volume). Plans have been developed to use freeze-dried sediment for analysis of enzymatic hydrolyzable amino acids (EHAA) following the method described by Mayer et al. (1989). All five cores are then sieved using a 1mm mesh to remove macrofauna for taxonomic analysis and biomass determination.

## Results

Preliminary data for redox, sulfide and sedimentary chlorophyll *a* were presented. Attempts to place TidBit temperature sensors have been frustrated, possibly by chain or rope movements at both sites that chafe the devices. Analyses which have not yet been completed include macrofauna sample processing and analysis, sediment interface photographs (stored as digital files), carbon, nitrogen and EHAA analysis on dried sediment samples.

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# Holding Capacity for Salmonid Aquaculture in Bay d'Espoir, NF

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Newfoundland is one of few areas in the world where salmonid aquaculture must contend with a four-to-five month interval of winter ice cover. Background to the Newfoundland industry's unusual environmental challenges is provided by Tlusty et al. (2000a). In response to these industry challenges, and to the industry's development aspirations, emphasis for the present study was placed on salmonid over-wintering areas as this is considered by industry to be the limiting factor relative to their development planning.

Biological, oceanographic and aquaculture production data were obtained to assess the assimilative capacity of Bay d'Espoir for salmonid aquaculture. Biological data were obtained by on-site monitoring and sample (water column and benthos) analyses. Oceanographic data collection focused on deployments of moored curent meter arrays and drifter-drogue studies while bathymetric mapping (Furuno EM3000) was conducted by arrangement with the Canadian Hydrographic Service and with the Geological Survey of Canada (Atlantic).

This work identified seasonal levels of dissolved oxygen, biochemical oxygen demand, ortho-phosphate, nitrate-nitrogen, nitrite-nitrogen, and chlorophyll-a in the water column in the immediate vicinity of and >50m away from net pen sites (Tlusty et al. 1999). Effort was directed also to examination of energy utilization of salmonid feed at low temperatures (Tlusty et al. 2000b) to address questions of seasonal carbon loading in the vicinity of aquaculture cages. Extensive sediment samples were analyzed for percent organic matter (weight loss on ignition, 500°C), and profiles of ammonia and sulfate in pore water (see Cranston, this volume). Geomorphological features of the Bay d'Espoir estuarine fjord that are pertinent to aquaculture industry development and design of field activities also were examined (Tlusty et al. 2000c).

This holding-capacity research program was designed as a four-year endeavour. Unfortunately, work had to be discontinued after only two years due to lack of funding. Environmental monitoring of over-wintering sites revealed no significant impact on water quality. Some benthic impacts were detected but were localized under the aquaculture cages and were highly variable with time and between sites (Power et al. 1999, Tlusty et al. 2000b).

Tlusty et al. (1999) calculated a preliminary assimilative capacity based on the allowable change in nutrients ($\Delta C$), the rate of nutrient release by fish (R), inlet flushing time and volume (Silvert 1994). There is considerable uncertainty about this estimate. We stress that our preliminary estimate of assimilative capacity is just an approximation and needs to be followed up with further monitoring and testing. We consider that a meaningful hydrographic model of the circulation dynamics of the estuarine fjord is an essential prerequisite to refinement of our preliminary estimates and explanation of our observations relative to unifying principles (Cranston 1994) regarding alternative approaches to evaluating fjord assimilative capacity for aquaculture.

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# Organic Carbon Burial Rates: Letang Inlet, N.B.; Bay d'Espoir, NF; Georgia Strait, B.C.

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A project to aid in the development and implementation of effective management strategies for sustainable development of salmonid aquaculture in Canada began in 2000. Over a 3 year period, the purpose of the research is to study processes and impacts in aquaculture study areas in Letang Inlet, N.B., Bay d'Espoir, NF and Broughton Archipelago, B.C..

This report is a summary of organic carbon burial rates measured in Letang and Bay d'Espoir. Similar methods were used in another project to collect this data in Georgia Strait, which is 200 km away from the site in B.C., but is presented to show similarities between the three areas. The method involves collecting gravity cores, recovering pore water samples at selected intervals, and measuring the increase in ammonium with depth in the core. The increase is due to deposition and degradation of organic matter in the cores. A calibration curve has been assembled to relate the ammonium concentration gradient with organic carbon burial rates, based on cores from a variety of sites where ammonium in pore water was measured along with organic carbon burial rates.

In September 2000, seven cores from the Letang area were collected and processed. In Passamaquoddy Bay, an organic carbon burial rate of 10 mg C $m^{-2}$ $d^{-1}$ was measured. Burial rates of 20 to 30 mg C $m^{-2}$ $d^{-1}$ were measured in Back Bay and at The Wolves. Rates of 30 to 50 mg C $m^{-2}$ $d^{-1}$ were found for cores collected in Bliss Harbour and Lime Kiln Bay.

In 1991 and 1992, Letang cores were processed using the same methodology. Carbon burial rates were 20 to 40 mg C $m^{-2}$ $d^{-1}$ for Scotch Bay, Lime Kiln Bay and Bliss Harbour cores. Significantly higher rates were found for cores from near the fish plant in Black's Harbour (100 mg C $m^{-2}$ $d^{-1}$); at the edge of a salmon net-pen (100 mg C $m^{-2}$ $d^{-1}$); and underneath a salmon net-pen (2000 mg C $m^{-2}$ $d^{-1}$).

Seven core sites were studied in Bay d'Espoir in 1999. Carbon burial rates ranged from 20 to 40 mg C $m^{-2}$ $d^{-1}$ for six sites. The highest rate was 60 mg C $m^{-2}$ $d^{-1}$, measured at the upper end of Little Passage.

During 3 sampling programs in Georgia Strait, 40 gravity cores were processed using the carbon burial method. Directly off the Fraser River, carbon burial rates averaged 100 mg C $m^{-2}$ $d^{-1}$ due to the high amount of suspended matter provided by the river. Off the mouth of Vancouver Harbour and Howe Sound, carbon burial averaged 40 mg C $m^{-2}$ $d^{-1}$ , while in the deep water basin 30 to 50 km northwest of the city, carbon burial rates averaged 20 mg C $m^{-2}$ $d^{-1}$ .

Carbon burial rates in these three rather different environments are very similar, ranging from 20 to 40 mg C $m^{-2}$ $d^{-1}$. Higher values are observed in areas where enrichment is due to natural and anthropogenic sources related to rivers, cities, fish processing and fin-fish aquaculture. A comparative summary of carbon burial results from 40 field studies is low (Fig. 1).

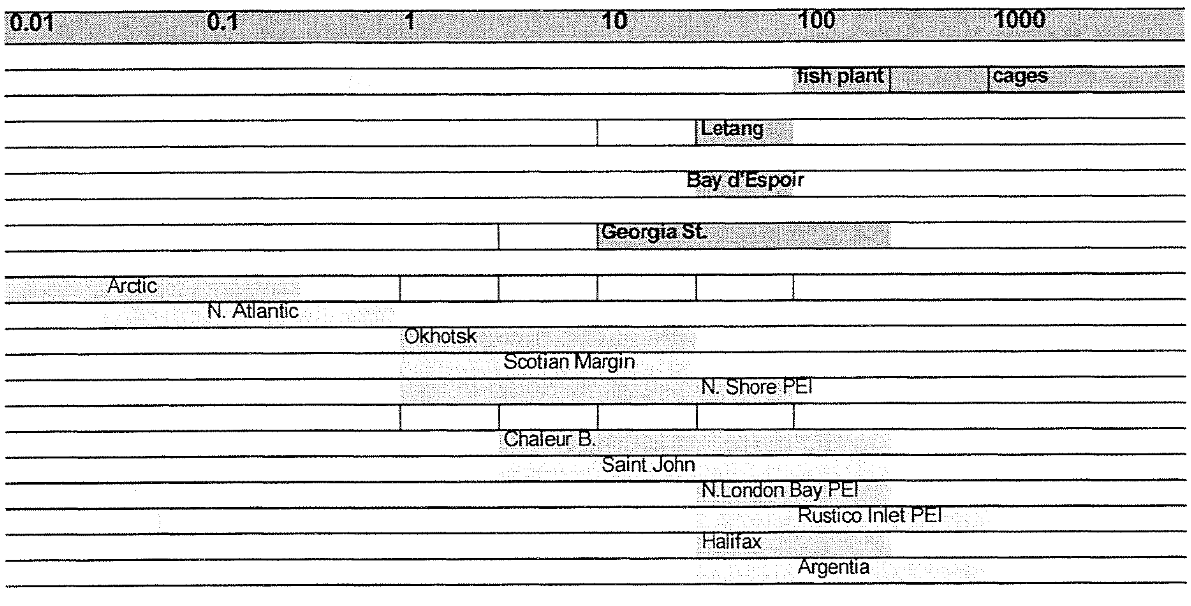


**Fig. 1:** Organic carbon burial rates in various marine study sites using the ammonium gradient method (units are mg C $m^{-2}$ $d^{-1}$).

# The Pockmarks of Passamaquoddy Bay

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The most unexpected discovery in Passamaquoddy Bay during a geological survey in 1988 was a large population of pockmarks (gas or water escape craters) on the seabed. These features cover large areas of the seabed of Pasamaquoddy Bay. A preliminary analyses of the pockmark distribution shows that they occurred in two large clusters, one south of Navy Island at the mouth of the St. Croix river, and the other in the central to western part of the Bay Bay. The deepest pockmark was 29 m in depth, making it one of the largest in the world. The density of the pockmarks ranges from less than 100 $km^{-2}$ to >400 $km^{-2}$. In some places 20% of the seabed is covered with pockmarks with the average being 7%. Over 3 $km^3$ of sediment was calculated to have been eroded and removed through the process of pockmark formation.

Is the formation of the pockmarks due to venting of gas or water? It has been suggested that the pre-Holocene, glaciomarine sediments, which underlie the Holocene muds in which the pockmarks are formed, may have de-watered and produced the pockmarks.
However, widespread shallow, gas-charged sediments associated with the areas where pockmarks occur, suggest that gas, not water is responsible for their formation. In addition, what is the source for the gas? Is it petrogenic originating from deep bedrock sources, or is it biogenic from the degradation of organic material within the surficial sediments? The large volume of material eroded during (3 $km^3$) suggests a larger source than could be provided by the surficial sediments alone. This suggests a potential bedrock source. The bedrock beneath the Bay is interpreted as sandstone of the Perry formation which outcrops at the coast in many areas around Passamaquoddy Bay. Seismic profiles penetrate the Perry formation and allow the extent of the bedrock beneath the Bay to be determined as well as bedrock structure to be delineated. If the Perry formation is the source for the gas, venting has occurred from the oldest rocks in eastern Canada.

Many of the pockmarks are eyed, that is, they have intense areas at the bottom with high acoustic backscatter. In the North Sea such eyes are dense benthic communities that appear to be clustered at the base of the pockmarks because of the presence of chemosynthetic bacteria living on the venting hydrocarbon gases. The eyed pockmarks occur mainly in the area south of Navy Island. This leads to another interesting correlation between venting gas and faulting. The eyed pockmarks align with the major fault of the area called the Oak Bay Fault. It trends along the St. Croix River and continues beneath the area of eyed pockmarks. Either the fault is active and gas escapes along its trace, or the fault is inactive and gas seeps out along the relict fault.

More recently, multibeam bathymetry has been collected in the Bay and it clearly shows the distribution and depth of the pockmarks. The venting of gas from the sediments represents a major process of sediment erosion and redeposition in the Bay. It is not clear if the pockmarks are relict or are presently active.

# Knowledge Gaps in Aquaculture-Evironment Interactions with Respect to Cumulative Impacts and the Determination of "HADD"

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Although cumulative impacts are identified as one of the weak areas of environmental assessments with respect to aquaculture, it is one of many issues of interest to habitat managers where additional research is required. Effects due to cumulative impacts must be considered at both site (project) and regional (area-wide) levels.

Consideration of cumulative impacts at the project level is a requirement of the Canadian Environmental Assessment Act (CEAA 16(1)(a)). Proponents are required to determine the significance of the effects of the cumulative impacts of their project. From an area perspective, impacts should be apportioned on an industry basis with determination of the level of 'significance' of potential effects.

The portion of the total cumulative load attributed to the aquaculture industry should then be further apportioned. Considering cumulative impacts either as non-point or point source pollution can accomplish this. Treating cumulative impacts as non-point posses difficulties in determining share responsibilities. Management structures must be developed to deal with any remediation necessary to reduce excessive loads on a collective basis. Currently, only New Brunswick is introducing such a regulatory structure through the creation of Bay Management Agreements. Enforcement may be an issue, as the load share is not individually attributed.

A more manageable option would be to treat cumulative impacts as point source pollution. This would require more work for Science, but if the industry load could be attributed on a site-by-site basis according to site outputs, it may be more easily enforced, especially as decisions would be based on sound scientific rationale.

**What tools are required?**

At the project level, Habitat Management requires tools that will enable proponents to make valid evaluations of the effects of the cumulative impacts of their projects at the assessment stage. Determinations of cumulative impacts at the area level requires models that attribute share responsibility and significance on both an industry and a site basis. In addition, models are required that provide usable advice on share reduction. The most important characteristics of any models that are made available for either proponents or Habitat Managers is that they be cost-effective and easy-to-use. As public concerns must be considered in CEAA reviews, it would be useful if any model could also be visual and easily interpretable to the public.

**Several questions are introduced for consideration:**

- What role could integrated management play? What uses should be made of the coastal zones?
- Siting aquaculture operations on erosional sites has implications for the far-field. With due consideration of the Fisheries Act, could benefits be realized in both the far-field and near-field by modifying this practice?

## DISCUSSION

Discussion during the second and third days of the workshop focused on four topics:

1. Tracking Dispersion
2. Oxygen Mass Balance Modeling
3. Identification of New Tools

### *Tracking Dispersion*

Backscatter images produced from EM3000 multibeam surveys are now available from all three study locations and may be used to identify depositional and erosional bottom types. The geo-referenced data will be of great interest to DFO Habitat Management. It clearly shows spatial differences in greyscale values associated with differences in acoustic reflection. The images indicate areas of high reflectivity for highly enriched organic sediments under existing net pens at some locations (NF and N.B.) and at a fallowed site (B.C.). QTC data from the Broughton Island site appears consistent with inferred differences in bottom type with rock and soft mud sediments accurately differentiated. However, more ground-truthing is needed where fine-grained sediments accumulate to quantify exactly what variables are responsible for large differences in reflectivity. Confusion may be created if greyscale values produced by the EM3000 system are inverted during processing.

The inter-relationship between near and far field studies, where observations under and adjacent to active farms sites are compared to similar measurements at a distance, is demonstrated in work underway in N.B. and B.C.. The study of resuspension and sediment transport in the Broughton Island archipelago focus on identifying the zone of influence of near field observations at increasing distance from a farm. Carbon, nitrogen (elemental and stable isotope analyses) and particle size anomalies in surface bottom deposits are correlated with local bathymetry as shown in detail using EM3000 data. Combining bathymetric and backscatter data has been used to identify the spatial area of benthic impact at one site.

### *Oxygen Mass Balance Modeling*

There is a clear need and opportunity in the ESSA project to connect observations of concentrations and processes controlling oxygen distribution to 3-D physical circulation models. Published values for mass balance calculations of biological oxygen demand (BOD) in the Letang system are very general without spatial resolution. For example, the previous calculations cannot be used to answer questions on the scale of the Bay Management approach proposed by N.B.. The opinion was expressed that we need to evolve a more sophisticated approach.

The natural seasonal cycle of dissolved oxygen in most coastal waters shows a depression in late summer or fall months. In Bay d'Espoir NF, where fish pens are positioned under the ice during winter, oxygen deficits develop in basins. On the west coast of B.C. this is related to upwelling of deep oxygen-depleted offshore water which is advected through the coastal archipelago. In inshore areas of the Bay of Fundy, stratification and warming of surface waters depress oxygen concentrations during August. This is also the time when the rate of heterotrophic respiration (oxygen consumption in water and sediments) is at a seasonal maximum due to high temperature and microbial degradation of organic matter produced during preceding months. The high temperatures also increase salmon respiration rates at the time of year when fish are reaching maturity. Maximum oxygen demand is therefore reached at the time of year when oxygen saturation is lowest. Stress limits for salmon are reached when dissolved oxygen concentrations fall to below 5-6 mg $L^{-1}$.

There was a suggestion during and following the workshop that interested ESSA participants could form a mass balance oxygen modeling working group to combine new results from studies of primary production, respiration, nutrient and oxygen distributions. New observations/calculations are needed to quantify oxygen fluxes in intertidal and offshore areas, advective exchanges, and for oxygen consumption of resuspended material. We are currently able to model sources (inputs) of oxygen more accurately than losses, but we must begin to understand (at least to order-of-magnitude estimates) all sinks for oxygen in the ecosystems being modeled to place BOD due to salmon in a broad context.

The ESSA proposal describes an aim to construct mass balance source models of carbon, nitrogen and phosphorus, but it is also necessary, especially for management of expansion of finfish aquaculture, to have predictive knowledge of sinks for these elements associated with organic matter enrichment. It was emphasized that the question asked determines what observations are required to provide an answer. A focus of research on questions and predictions of oxygen demand would allow the development of general models for evaluating the potential stress of oxygen depletion on salmon. Industry and DFO Habitat Management in all regions would be interested in predictions of where and when oxygen stress might occur.

### *Identification of New Tools*

*Backscatter* Data from the EM3000 multibeam system may be useful for identifying bottom areas with different acoustic reflectivity, but more ground-truthing is required. It is a new tool with a potential to provide inlet-wide observations to map bottom features with detailed bathymetry and other variables (such as backscatter) that can be extracted from the geo-referenced data. The accurate location of bottom features represents a significant advancement in our ability to target sampling for future studies of sediment physical/chemical variables as well as benthic community analysis. It remains to be determined, however, if the localized changes in bottom acoustic reflectivity shown in backscatter images can be used to demonstrate broadscale changes throughout an inlet system. Chemical and biological changes in sediments and benthic communities in the far field are far more subtle than occur at a farm site and the changes may not be detectable with the multibeam approach.

*Benthos® in situ camera* Observations of suspended flocculated material in aggregates of varying sizes (>5 mm) using an *in situ* camera provides a new approach to investigate factors controlling the natural dynamics of disperson and sedimentation of particulate matter. Data exists from Back Bay, N.B. (samples in 1990 and 1999) from analysis of core profiles of disaggregated inorganic particle size that inlet-wide changes have occurred in the nature and rates of fine particle deposition over the past decade. The nature of suspended and settled particles in inshore and offshore deep water areas in N.B. was similar implying that there is linkage between the water column and surface sediments where shear stress is sufficient to cause resuspension.

Exchange of particulate matter between the sediment surface and the water column may be critical in determining the fate of recently settled organically rich particles produced at salmon aquaculture sites. However, it is not clear if results from areas of relatively high suspended matter concentration, such as the Bay of Fundy, apply to locations in NF and B.C. where turbidity is lower. There is also a need to better define optical properties of the water column in all locations if we wish to understand the origin and possibly predict the fate of suspended matter. Secchi disc depth observations only provide a crude optical measure. More accurate profiles of underwater light quantity and quality are needed along with CTD and chlorophyll profiles to provide an improved description of optical properties in the water column.

Suggestions for new tracers of suspended matter included the following:
1. Pigments used in fish feed pellets,
2. ICP mass spectrometry and stable isotope analyses to compare the composition of feed, material collected in sediment traps and bottom sediments,
3. Specific organic compounds (e.g. fatty acids)
4. Enyme hydrolyzable amino acid (EHAA) analysis of sediment.

Sediment geochemical variables such as redox (Eh) potentials and total sediment sulfide ($S^{=}$) appear to be sensitive indicators of near field changes in sediment geochemical processes in response to increased organic matter supply. However, these variables may not be useful in the far field where natural variations occur due to sediment grain size and seasonal differences in input and metabolism of organic matter from natural processes. Further observations, both seasonal and between regions, are needed to determine the generality of the inverse relationship between Eh and $S^{=}$. Further observations are also needed to provide data to compare sediment accumulation (burial) rate and variables such as sediment pore water $SO_4^{=}$ and $NH_4^{+}$ gradients to determine if variations within an inlet system define local or regional changes within a study area.

Discussion of techniques/variables potentially useful for identifying far field changes in environmental factors attributable to finfish aquaculture led to the identification of a list of 'core' variables needed to compare and model results between regions. These included:
- dissolved oxygen
- water column optical properties (pigments, total SPM)

- dissolved nutrients
- dissolved organic carbon
- inorganic SPM
- particulate organic carbon, nitrogen and stable isotopes.

These variables, all measurable in preserved or chemically fixed samples, were considered to be "transportable". That is, samples could be collected, fixed or preserved in various ways and analyzed in a laboratory at a later date. In contrast rate measurements such as primary production, pelagic and benthic respiration, observations of suspended aggregates in the water column and sediment geochemical variables such as Eh potentials and total sulfide concentrations cannot be determined using preserved samples. These were termed to be "non-transportable" variables.

One aim of the ESSA project is to link mass balance and physical circulation models to predict potential far field effects of aquaculture. This requires measurements of both "transportable" and "non-transportable" variables at locations/regions of the study sites where models might be constructed. It was agreed that as far as possible all these variables would be measured at all study sites. Whenever possible observations will be made on a seasonal basis, at a minimum at least two times during the year, to determine the range between winter and late summer conditions.

## EXTERNAL REVIEWER'S COMMENTS

# Scientific Overview of the ESSA Project

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### *General Overview*

The presentations were very good, and the workshop was an interesting and valuable contribution to our understanding of aquaculture impacts. My main comments deal with a lack of focus and coherence in the context of the stated objective of the project, namely to understand the far-field effects of aquaculture.

Given that the project started only recently, this is not surprising. Much of the work reported started before the ESSA project with funding from other sources, and in some cases DFO A-based funding was used. This obviously affected both the objectives and the amount of research effort applied, and it is fortunate that so many of these earlier projects fit in so well with the ESSA project. It is necessary to determine whether such studies should be continued and expanded, and if so what changes are needed to meet the objectives of the project and to incorporate previous studies.

As many people noted during the workshop, many of the studies did not actually deal with far-field effects. Given that in many cases the work was not carried out originally as part of ESSA, this is not surprising, but there will have to be an effort to focus on far-field effects in the future. In fact, given that so much previous research focussed on near-field benthic impacts directly under farm pens, it is surprising that so much of the work discussed was on-topic.

Now that ESSA is underway, it should be possible to focus more effectively on far-field effects and design experiments that will provide conclusive answers to at least some of the major questions. Having a national research program with adequate funding is a necessary, but not sufficient, condition for resolving questions about the far-field effects of aquaculture. However, the work will have to be well co-ordinated for the answers to have value in the national, rather than strictly regional, context, and it will be difficult to focus on the far-field rather than the interesting, and easier to study, local impacts.

### *Summary of the Key Topics*

The four objectives of the project, which were the four main questions addressed during the workshop, were as follows:

- How can assimilative capacity be determined for wastes produced by marine finfish aquaculture?
- What measurements can be made to document changing patterns and rates of sedimentation?
- How can material released from aquaculture sites be tracked within a coastal system?
- 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?

It was not always clear how to interpret these questions in the context of the workshop. For example, it is relatively easy to define the assimilative capacity of the seabed under a fish farm, but not as easy to deal with the far-field impacts if they are less dramatic or qualitatively different in nature. In general one expects far-field effects to be significantly less than local impacts, but they are important because they cover a much larger area.

There can also be far-field effects that are larger than near-field effects because the causative agents operate over different ranges, a point which received little discussion during the workshop. For example, primary production is generally enhanced because of nutrification, but turbidity at a farm site may inhibit it. As one moves away from the site, the turbidity is decreased by settling, but the soluble nutrients remain in the water column and can promote algal growth.

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 characterise 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.

There was also little attention paid to the difference between near-field and far-field monitoring. The use of redox and sulfide measurements as primary indicators of benthic impact using metholodology described by Wildish et al. (1999) has been well accepted. The clearest characteristic of the regression lines supporting its use is a change in slope of regressions of benthic respiration (measured as oxygen uptake or carbon dioxide release) and total sulfides in surface sediments (Hargrave et al. 1997) indicating the dividing line demarcating reference and heavily impacted sites. However, its effectiveness in identifying carbon loading at a distance from the farm sites is not as clear. Cranston's method of looking at ammonium and sulfide gradients (see Ray Cranston this volume) has been tested at much lower loading levels and may be a more sensitive probe of far-field effects.

The work that was presented on tracking aquaculture effluents seemed promising but preliminary. For example, the work that Phil Yeats' group has carried out looking at metals was originally a small-scale A-base project. Fatty acid signatures offer another approach, but all of these methods require a degree of knowledge of what is being fed to the fish. It was commented that feed producers are reasonably co-operative, and much of the information is available from them (or is even printed on the labels), but some fish farmers are less willing to share information about their feeding strategies, which may limit the usefulness of these approaches.

Very little was said about mitigation, and perhaps it is premature to talk about the cure before we better understand the problems. I had the sense that the habitat managers present were hoping for more progress in this direction than was forthcoming (this was most evident in the Friday morning wrap-up). Fallowing was mentioned, which is a passive form of mitigation that makes sense, but may not be the most effective measure for heavily impacted sites. More aggressive forms of remediation, such as farrowing, are widely believed to have a more immediate effect on the recovery of the seabed under fish pen. However, the release of buried sediments (possibly including dinoflagellate cysts) might have deleterious long-range effects is not well known. I do not recall anyone addressing the problem of assessing the far-field effects of various remediation measures. Site selection was also referred to as a mitigation measure, and in principle this is the ideal approach, once we know enough about far-field effects to implement it.

### *Near-Field vs. Far-Field Effects*

The conflict between looking at far-field effects, which is the focus of the ESSA project, and concentrating on the much more visible and usually more interesting near-field effects was evident throughout the workshop. This was most evident in the discussion of multibeam acoustic methods for seabed mapping which produce absolutely amazing results in areas of high deposition, but which, as discussion later in the workshop revealed, cannot identify the smaller effects of far-field deposition.

It was not always clear what causes far-field effects. Paul Kepkay presented interesting data on DOC concentrations both inshore and near The Wolves. He suggested that DOC pulses and the associated BOD could be important far-field agents. Other nutrients were of course considered, but whether they really have a significant effect was not resolved so far as I could tell. One problem was that most of the data presently available to address these questions within the ESSA project come from the Bay of Fundy, where high turbidity means that algal growth is likely to be limited by light and not nutrients. There are of course macroalgae in the intertidal zone, sea grasses and benthic diatoms, but at present there does not seem to be any evidence of aquaculture enhancing these primary producers.

One point that came up during Kats Haya's talk was the possibility that some of the constituents of fish feed might have an undesirable impact on the environment. Phil Yeats pointed out that there was a surprising amount of metal in fish feed, some of it added for pharmaceutical purposes. The recent question of whether airborne dioxin could be concentrated in some of the fish species used for fish meal and then transmitted through farmed fish to the environment was raised but not answered. Kats said that his group does not yet have the necessary analytical equipment, but plans to look into this point in the near future.

***Time Scales***

For most effects in biological oceanography there is a correlation between time and space scales, which suggests that the time-scale for far-field effects should be longer than that for local impacts. This is not always true of course, and in fact the effects of deposition in the footprint of a pen can persist for many years even though the spatial scale is only a few tens of metres. However, the possibility that some effects of fish farms on distant parts of the environment can take a long time to appear should not be discounted without evidence to the contrary.

This has clear inferences for the time scale of experiments, and suggests a need for long-term research in at least some areas. Ecological changes do not always occur continuously, and changes in ecosystem structure may occur abruptly some time after the initial change in physical and chemical characteristics of the environment. Furthermore, one of the issues singled out by several speakers was the importance of identifying cumulative effects, which includes both the combined effects of many different types of effluent input and the long-term accumulation of wastes.

***Physical Oceanography***

Physical oceanography is one of the areas where the greatest progress has been made. However, although recent work is much more closely related to issues of aquaculture impacts than has generally been the case in the past, better co-ordination between physical and biological oceanographers is called for to meet the objectives of this project. The focus of estuarine modelling has moved from current calculations to analysis of the transport properties of water masses. The recent simulations of drogue movement provides valuable information on the transport of fish farm effluents in a way that can easily be understood both by scientists and by other stakeholders. What is needed is to determine which biological questions the existing studies answer, and what further investigations are called for.

The simulations shown during the workshop covered just a few tidal cycles and showed the degree of mixing between different water bodies and the short-term flushing rates, which is important for the resolution of questions about disease transmission between farm sites such as determination of a minimal spacing between leases. The work presented has already had a significant practical impact by showing that the amount of short-term mixing in inlets in SWNB is so great that it makes no sense to treat the farms separately, and this has led to the adoption of large-scale Bay Management Units. It is however essential to recognise that there are many different time scales involved for aquaculture impacts and that for the far-field effects in particular it is necessary to calculate long-term transport and retention.

One of the most important results of the recent improvements in fine-scale hydrodynamic modelling is the demonstration that some of the water flushed by tidal action can re-enter an estuary on the next flood tide. This has major potential to increase the flushing time of aquaculture sites and lead to retention of waste products, increase of BOD, and nutrification which can either enhance primary productivity or produce harmful algal blooms (HABs). The simulations shown at the workshop were based on a number of simplifying assumptions regarding residual currents, runoff, and other factors which could affect the amount of water which re-enters the estuary. It will be important to incorporate these factors into more realistic models, and to devise experiments to test and validate them.

Fred Page presented a number of experimental studies that confirmed some, but by no means all, of the theoretical models. His dye experiments confirmed the well established Okubo relationship, but the results of drogue experiments was less clear, and they do not yet strongly support theoretical calculations of retention time. This is a critical issue in predicting nutrient dynamics, and the determination of retention times will require extensive experimental and theoretical research. A related issue is whether effluents can be trapped in regions of inlets that are not as well flushed as the rest of the inlet, leading to high nutrient and BOD concentrations which could have deleterious effects.

### *Sedimentology and Geochemistry*

Since sedimentology deals mainly with particulate matter that originates within fish pens, it is difficult to divide it into near-field and far-field studies. Far-field effects can of course arise through resuspension, bed-load transport, and the break-up of flocs. Unfortunately flocculation is much more interesting than deflocculation, and some of the most interesting material presented at the workshop dealt with properties of sediments under or in the immediate vicinity of fish pens

The same must be said about many of the geochemical studies presented, such as the work on sulfide and redox values under impacted sites, and the remarkable relationship between geochemical gradients and carbon loading that Ray Cranston presented. It is necessary to sort through this work to identify techniques that can be used in areas where the depositional rates are low but significant.

### *Holding Capacity*

There was some discussion of holding capacity calculations, mainly in the context of Vern Pepper's presentation on the work conducted in Newfoundland. Of course in the long run this is the sort of information that a research project like ESSA should be able to provide to habitat managers. There was some discussion of criteria for limiting holding capacity, with surprisingly little agreement on what sort of criteria should be used. Barry Hargrave referred to relative criteria such as doubling of the nutrient levels or of the benthic carbon loading, but there are two other criteria that could be used: one is an absolute increase, such as the 0.5 μmol-N/L proposed in Silvert (1994). Another is an absolute limit on the total permissible level. In the long run this point will need to be resolved. Benthic carbon loading has also been used to calculate site capacity (Cranston 1994), but up to the present this has been based on local effects under the pens without reference to far-field effects. Vern Pepper spoke of a colonizer-persister scale of benthic impact which might serve as an ecological indicator suitable for looking at ecosystem changes in the far-field, where more traditional measures like diversity indices are not very reliable.

### *Event-Driven Effects*

There was little discussion of the effects of events, such as storms and exceptional forcing due to high winds and extreme tides, although Tim Milligan and others acknowledged their importance. Gordon Fader even pointed out that storms can disturb the seabed enough to cause eruptions of methane and other toxic gases. Violent events are of course difficult to study, since there is an understandable reluctance to do field work in bad weather, but these occurrences should probably receive more attention than they do. Some far-field effects are probably dominated by such events – for example, it is likely that some of the macrophyte detritus that appears on the shoreline in areas where fish farms are located could be due to epiphytes on the pens that are removed and distributed by occasional high current events. Similarly, the role of storm events in resuspending and transporting sediment needs to be quantified.

### *Modelling*

Modelling can be a very effective way to explore different possible scenarios, to generate hypotheses, and to devise effective experiments. Models seem to have been used almost exclusively by the physical oceanographers at this workshop. In fact, practically all of the physical oceanography presented was theoretical modelling with very few mentions of current meters or real drogues, while the biologists and chemists made very little mention of models. The main exception was Peter Strain's calculation of nutrient budgets.

A related experimental issue is the division of effort between descriptive studies and process-oriented investigations. Process-oriented studies are likely to play a key role in far-field research because the effects can occur through an indirect pathway involving several intermediate steps. For example, far-field sedimentation involves a primary sedimentation process (particulates falling to the seabed, sometimes after a previous process of flocculation), and then resuspension, followed by transport to a depositional zone. Ecological impacts, especially those involving food chain linkages or migration, are also multi-step, and we can understand – and model – them much more effectively if we understand the sequence of processes involved.

An important application of modelling is in setting criteria for site selection, since this implicitly involves prediction of both the commercial potential and environmental impacts of the proposed site. At some point it will be necessary to produce models that can be used by habitat managers to assess the acceptability of lease requests, and these models will have to incorporate estimation of the far-field effects.

There was some discussion of whether the physical models could be run in different locations with different input scenarios on a production basis, and it appears that this might be feasible. At present the simulations require a lot of scientific input, and the fine scales required in both space and time are very demanding on computer power. Mike Dowd is working on box models which are much simpler than the finite element ones that Dave Greenberg has been developing, but these require a lot of calibration and testing because of the tentative nature of the transfer parameters used. The inclusion of events like storms was also discussed, although it was not clear whether these should be dealt with by stochastic modelling or by inputting different scenarios – the latter approach to some people is less rigorous, but can be more useful as a means of providing risk assessments.

***Inter-Regional Aspects***

One of the key aspects of ESSA is that it involves three different DFO regions with study sites that differ in several key environmental variables. This offers an excellent opportunity to carry out comparative studies leading to general conclusions, but it isn't clear that this potential will be achieved as fully as possible. Some of the reasons have to do with the very different resources available for research in the three regions. It is clear that the Maritimes region, with both BIO and Saint Andrew's to rely on, is in the best situation. The study sites in Bay d'Espoir, NF and Broughton Islands, B.C. are remote and field work is expensive. Given that the environmental conditions in NF and B.C. are very different from the macro-tidal situation in the Bay of Fundy, it may be very difficult to obtain a balanced picture that adequately reflects conditions across Canada.

Many of the studies presented were clearly site-specific, and while it is difficult to avoid this in a field where there are so many different environments to be investigated, closer attention to the site-specific factors and limitations could be paid. For example, I find that Norwegian researchers tend to be more careful about identifying the types of locations where they consider their results to be valid – such as fjords with and without sills – than was the case here. Questions about sites in SW New Brunswick were referred to research conducted two decades ago in the Cumberland Basin, and no clear distinction was made between the effects of nutrification in New Brunswick and British Columbia.

It is difficult for researchers who have been working in one area to be sensitive to the very different nature of other sites, but one of the strengths of the ESSA project is that it brings together scientists from different regions. They will be in a position to review each others' work critically from the viewpoint of generality and to identify which results are likely to be generic and which site-specific. More co-ordination focussed on implementing this kind of interaction could greatly improve the generality of the results. Some of the research, such as the sedimentology work that Tim Milligan is co-ordinating, addresses this problem by having one researcher responsible for investigations in his area in all three regions. This is a valuable approach, and although there are practical (to say nothing of financial) reasons why this cannot always be followed, there is a definite benefit to having individual scientists involved in the research in more than one region.

### *Co-ordination with Other Programs*

There was little discussion of how ESSA might tie in with other programs in the field, except for those that preceded it in the three regions involved. This is understandable in terms of the DFO political situation, but from a scientific point of view it might be more efficient and effective to establish co-operative relationships with some foreign programs that more closely parallel situations in parts of Canada. This is especially true in British Columbia, where the factors affecting the impacts of fish farms are closer to those found in countries like Norway and Chile than those in the Bay of Fundy. The situation in Newfoundland seems to be unique, although there may be similar conditions in Scandinavia. It may be that initiatives like the joint workshop between Canada and Norway that was held in Bergen in 1993 could be useful.

### *Advice to Management*

As our scientific understanding of the nature of environmental impacts of aquaculture develops, so does the degree of sophistication required to understand the science and to apply it for advice to DFO Habitat Management staff. There was only brief discussion of this at the end of the workshop. It was pointed out that this was not in the terms of reference of the project and that there were no funds allocated for this purpose. However, I think that it is important to consider ways of incorporating this research into a practical management scheme. To do so may require a supplemental project at the end of ESSA. Planning for this eventuality at an early stage would have several benefits:

- Better planning for implementation of the science-management link
- Increased awareness of the ultimate management needs
- Encouragement for habitat managers to maintain involvement with ESSA and to support it.

It should be noted that this latter point has immediate benefits. For example, one of the questions which came up regularly during the discussions was the definition of a Harmful Alteration, Disruption and Distruction (HADD) as described in the Fisheries Act, which is a point for which the input of habitat managers is highly desirable, if not essential.

Jim Ross raised a point that emphasised the importance of the ESSA project, namely that it is harder to manage pollution from non-point sources than from point sources. So far aquaculture has been treated as a point source, and the emphasis has been on dealing with impacts such as those predicted with Estimated Site Potential (ESP) models. Recent work, like Fred Page's study showing that from the point of view of water circulation and mixing, Letang is basically one site, emphasises the importance of looking at inlet-wide, namely far-field, effects.

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# Regional Considerations of the ESSA Project

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As a representative for the B.C. Salmon Farmers Association, and a member of the ESSA Steering Committee, I provide the following comments regarding the current progress of the ESSA research initiatives and the proposed direction of the research for the upcoming year. As a research/consulting marine ecologist I also offer insight into current, and historical industry initiatives which should be considered in future ESSA information meetings and in finalizing results of the multi-year program in assisting DFO habitat managers in decision-making processes regarding HADD's.

Comments on 2001 ESSA Meeting:

I appreciate that the individual ESSA research programs are intended as complementary efforts to document (and model) regional system effects of finfish aquaculture, and as such I fully support the research which was presented during the workshop. However, in wearing my west-coast industry hat, my primary concerns related to the research, the intended direction, and my perception of the overall ESSA objectives relate to: (i) the ability of the research to differentiate farm wastes from natural and other anthropogenic sources, and thus an approach which will adequately represent the "contribution" of farm wastes to the structure and function of a regional coastal ecosystem model; and (ii) the approach by which the approaches and final outcomes of these regional initiatives will be consolidated into a national DFO management approach given the regional differences.

- Differentiation of wastes is being addressed by a number of the ESSA research participants, and effort in establishing waste "tracers" was discussed extensively at the meeting. I would caution that much of the presented research is dependent upon the ability to differentiate these impacts from background and/or other waste streams entering the marine system under investigation. Interpretation of results from this broad array of research initiatives, in the context of farm impacts, will be extremely limited without this aspect of the overall program being completed. I would encourage a concerted effort to identify an appropriate tracer(s) before any of the specific programs continue down an incorrect path; inclusion of the appropriate dependent variable(s) at the onset will only strengthen each component of the ESSA project.

- Specific to the New Brunswick research initiatives, I remain unconvinced (albeit from an outsiders perspective) that The Wolves represents an appropriate reference area for all of the farms being studied within the "inshore" SWNB area. It would appear that physiographically and oceanographically the areas are distinctly different, and most importantly that the inshore study areas are being influenced by a suite of upland inputs (streams, rivers, point and non-point source pollution inputs, etc.) which are not necessarily present in the signal being measured well outside the influence of this protected region of the coast. This concern further complicates the ability of the various research designs to differentiate farm-derived organic waste inputs from the background, particularly if the "reference" is not measuring all (or any) of these other waste inputs. It may not be possible to acquire a reference station(s) which exactly mirrors that of the area in which the farms are operating, but the I would suspect that many of these differences could be eliminated through careful consideration of reference station siting.

- Specific to the British Columbia research initiatives, I am concerned again that far-field research of "farm" impacts is being initiated in the absence of a clear farm waste tracer. Although west coast research is examining a variety of potential "tracers", this needs to be completed first, and most effectively ground-truthed with near-field studies and/or historical data. The complicated, and diverse nature of sites in B.C. makes the development of a single approach to habitat impacts modelling unlikely. Secondly, the use of abandoned farm site to examine fallowing rates may lead to misleading information for future DFO habitat management. Many of the sites which are currently being abandoned in this province have been identified as poor sites (in terms of documented environmental impact), and thus have been required to move to more appropriate locations in terms of assimilative capacity, etc. These sites, specifically, are not representative of current industry siting on this coast and may not provide data of particular benefit to the discussion of HADDs.

- I recognize that the consolidation of these ESSA projects in to a common, synthesis report will not necessarily lead to development of National standards for fish farm HADD's or for common sampling/survey protocols. It should be stated clearly that the dramatic difference between the regions clearly necessitates independent approaches in regulatory protocols and decision-making processes. I fully endorse the cross-regional aspects to some of the research (e.g., B. Hargrave sampling with T. Sutherland in B.C.), and I would hope that the results of these efforts be formally evaluated, and strongly conveyed, in future publications resulting from the ESSA initiative.

Current, Complementary Research in B.C.

<u>Industry-Government Initiatives</u>:

- I trust that you are aware of directed research which is currently being conducted on our coast. Of interest are our efforts to establish benthic sampling protocols appropriate to soft-bottom environments and to areas characterized by rock sublittoral formations. These directed efforts are intended to provide data important to the development of Performance-Based regulations for the west coast industry.

- Industry has also collected sediment samples and ROV imagery at all operating sites on this coast over the past 6 months. These data are also being analyzed in support of the above goal. I would suggest that results of such extensive surveys would be of use in evaluating program designs for the ESSA initiative, particularly as they relate to west coast endeavours.

Graduate Research:

- I have recently started a Ph.D. program involving shellfish-finfish interactions. I will be looking at water-born contaminants which originate from salmon farms, and how they impact adjacent shellfish stocks. The goal of the research is to determine safe distances for shellfish operations (implications to DFO siting criteria), and to explore the potential for finfish-shellfish polyculture in temperate waters.

  My research program is establishing "downstream" longlines at two finfish farms (one Chinook and the other Atlantic salmon) which will be stocked with commercial shellfish (scallops, oysters and mussels). It is my intent to conduct regular (and frequent) sampling of tissue burden levels, examining potential bioaccumulation of any water-born farm contaminant, i.e., trace metals from antifoulants or feed derivatives, antibiotic residues, hydrocarbons, pesticides, etc. As my shellfish (depth stratified by species) will extend from the farm perimeter to in excess of 200 metres from the farm, I will have the capability of documenting dispersion of contaminants (including re-suspension) and potential environmental persistence through this design.

  My proposed research fits into the goals of the ESSA initiative. If industry agrees, I would like to stay on the ESSA Steering Committee, but to further my role as a contributing member through the research I am about to undertake. I would appreciate your views on such participation.

Again, I fully endorse the research programs that DFO scientists have initiated through the ESSA program. I trust that the concerns related above will be taken constructively, and that industry can continue to provide input (as appropriate) to the research which will undoubtedly be used in developing new or revised regulations and/or guidelines for DFO Habitat Managers on both coasts. I look forward to future meetings, and perhaps in collaboration on this coast.

## RESEARCH PLANS 2001-2002

Field work planned for the next fiscal year was not discussed in detail. In the Maritimes Region the intention is to use one sampling site in Lime Kiln Bay for continuous time series observations of current velocity and direction (moored ADCP) with time series measurements of dissolved nitrate and phosphate at the same location. Monthly sampling at two locations in Lime Kiln Bay to examine seasonality in sediment geochemistry and macrofauna community structure and abundance will also continue. It is hoped that measurements of chlorophyll and primary production and water column and benthic respiration can be made during late spring, early summer or winter months to provide some seasonal coverage for rate measurements.

Studies in the Broughton Island area of B.C. will continue with field work in February and late September 2001. Far field observations of water column and sediment variables with current meter and sediment trap mooring deployments will be carried out as part of a combine field program to make near field observations at operating farm sites and at more distant (reference) locations. Collaboration between DFO staff from Maritimes and Pacific DFO regions is planned for both periods of field work.

The next annual ESSA Science Workshop will be held jointly with the Aquaculture Working Group, DFO National Habitat Management Committee in Halifax and Dartmouth (21-25 January, 2002). The combined meeting will allow DFO science and habitat management staff to discuss broad questions associated with both finfish and shellfish aquaculture development in Canada. Results from the ESSA project will be presented and progress for work reviewed along with plans for the coming year.

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