Proceedings of the First Annual National Science Workshop, Department of Fisheries and Oceans

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PROCEEDINGS OF THE FIRST ANNUAL NATIONAL SCIENCE WORKSHOP, DEPATMENT OF FISHERIES AND OCEANS

by

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ABSTRACT

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DFO's first Annual National Science Workshop was held at the Institute of Ocean Sciences in Sidney, B.C. from November 14-16 2001. The purpose of the workshop was to build an awareness of the scientific research being conducted at DFOs ten laboratories and was organized following a recommendation of the Internal Science Advisory Committee. (For the full report see: http://intra.ncr.dfo.ca/science/Reports/ISAC-report_e.PDF). Over 130 Science and Oceans professionals came from across the country to hear fifty-five presentations and view 20 posters. Presentations were centered around three different research themes: New technology and methods for analysis and presentation of geographically referenced data; Climate change and its potential impacts on the Canadian aquatic ecosystems with special reference to the Arctic and the Labrador Sea; and Defining standards for marine and freshwater environmental quality (MEQ and FEQ) with special reference to contaminants and aquaculture. An evaluation completed by participants indicated that the workshop was a great success and should continue. One eminent marine scientist said it was the first time in his 30-year career that he had crossed paths with DFO's freshwater scientists. Michael Chadwick, Charles Gobeil, Fiona McLaughlin and Dave Monahan formed the workshop steering committee.

RÉSUMÉ

McLaughlin, F., C. Gobeil, D. Monahan and M. Chadwick. 2002 Proceedings of the First Annual National Science Workshop, Department of Fisheries and Oceans. Can. Tech. Rep. Fish Aquat. Sci.: 2403: ix + 191pp

Le premier Atelier national annuel sur les Sciences au MPO a eu lieu à l'Institut des Sciences de la Mer à Sidney en Colombie-Britannique, du 14 au 16 novembre 2001.Cet Atelier, qui visait à faire prendre conscience des recherches scientifiques en cours dans les dix laboratoires du MPO, a été organisé suite à une recommandation du Comité consultatif interne sur les Sciences. (Une version complète du rapport du Comité peut être consulté à l'adresse http://intra.ncr.dfo.ca/science/Reports/ISAC-report_f.PDF.) Plus de 130 professionnels des Directions des Sciences et des Océans de toutes les régions du pays sont venus assister à 55 présentations et voir 20 affiches. Les exposés portaient sur trois thèmes de recherches: les nouvelles technologies et méthodes pour l'analyse et la présentation de données géoréférencées, les changements climatiques et leurs effets possibles sur les écosystèmes aquatiques surtout dans l'Arctique et la mer du Labrador et la définition de normes de qualité pour les milieux marin et d'eau douce affectés par des contaminants ou des activités d'aquaculture. Une évaluation faite par les participants indiquait que l'Atelier a été un franc succès et qu'il devrait se poursuivre. Un scientifique réputé du milieu marin a même dit qu'il s'agissait de la première fois en 30 ans de carrière que sa route croisait celle des scientifiques des eaux douces au MPO. Michael Chadwick, Charles Gobeil, Fiona McLaughlin et Dave Monahan composaient le comité directeur de l'Atelier.

EXTENDED ABSTRACTS

DAY 1: NEW TECHNOLOGY AND METHODS FOR ANALYSIS AND PRESENTATION OF GEOGRAPHICALLY REFERENCED DATA.
CHAIR: DAVE MONAHAN

DAY 2 CLIMATE CHANGE AND ITS POTENTIAL IMPACTS ON CANADIAN AQUATIC ECOSYSTEMS WITH SPECIAL REFERENCE TO THE ARCTIC AND THE LABRADOR SEA.
CHAIR: FIONA MCLAUGHLIN

Day 3, Theme: Defining Standards for MEQ and FEQ with Special Reference to Contaminants and Aquaculture.
Chair: Charles Gobeil

DAY ONE
NEW TECHNOLOGY AND METHODS FOR ANALYSIS AND PRESENTATION OF GEOGRAPHICALLY REFERENCED-DATA

USE OF INDICATOR KRIGING TO CALCULATE AN INDEX OF THE OCCURRENCE AREA FOR THE GULF OF ST. LAWRENCE CAPELIN

Hugo Bourdages (InstitutMaurice-Lamontagne)
François Grégoire(InstitutMaurice-Lamontagne)

A relative index of the abundance of capelin (*Mallotus villosus* L.) in the Northern Gulf of St Lawrence was produced by a special geostatistical technique, called indicator kriging. This index was calculated using capelin catches (kg/set) from groundfish and shrimp surveys of the NGGC *Alfred Needler*. The catches were transformed to a binary indicator which was used to model annual variograms. Each kriged value gives the probability of finding capelin at a specific location. The index proposed was defined as the study area (km^2) associated to a minimal probability of 50 %. Between 1990 and 2000, the index showed an upward trend similar to another index based on the percentage of occurrence. However, great discrepancies were observed between these two indices and a third index based on a minimal probability of occurrence of 95 %. Unlike the previous indices, the indicator kriging takes into account the spatial structure of the variable of interest. Moreover, it gives a better delimitation of the occurrence zone of capelin.

REMOTE SENSING TECHNOLOGY, THE TOOLS THAT ARE AVAILABLE TO HYDROGRAPHY

Daniel Brousseau (Canadian Hydrographic Service)

The Canadian Hydrographic Service (CHS) was established in 1883 and is the only Canadian government agency responsible for the production, sale and maintenance of official Marine Navigation Charts in both paper and electronic versions. Consequently, CHS has a number of charts that are either on an unknown datum or have datum related issues. To correct some of these problems in a cost effective and timely manner, CHS has used remote sensing technology to obtain accurate and precise information. The data collected from these remote sensors includes detailed shoreline, man-made structures, shallow areas, etc. A number of major projects have already proven that these different datasets has impacted the updating and rectifying capability of their products. This presentation will show a brief account of some of the platforms and datasets available now or in the near future. These tools can also help scientists and management in their data acquisition, research, analysis and decision making.

BENTHIC HABITAT MAPPING IN SHALLOW WATER USING AIRBORNE HYPERSPECTRAL REMOTE SENSING

Gary Bugden (Coastal Ocean Science)
Ken Paul (Canadian Hydrographic Service)
Ed Horne (Biological Oceanography)
Tim Milligan (Marine Environmental Sciences)
Herb Ripley (Hyperspectral Data International)

Currently, efforts are being made in several locations to map the detailed characteristics of the sea floor using a combination of several techniques. These techniques include multibeam sonar, analysis of surficial geology and sea floor photography. Most of these programs have focussed on areas with depths greater than 50 meters, neglecting many ecologically sensitive and economically important areas that are often subject to environmental stress from anthropogenic activities. One of the major impediments to the extension of these programs into shallow water is the increasing inefficiency of multibeam sonar as the water depth decreases.

In the past, some success has been attained in tropical regions using airborne hyperspectral imagery to map bathymetry and bottom habitat type in optically shallow waters. This presents the possibility of using airborne remote sensing over shallow water to complement the use of multibeam sonar in deeper waters. We discuss the potential application of this technique in northern temperate regions. Preliminary results are presented from an area of intense mussel aquaculture in northern PEI and from an area of historical oyster harvesting in Cape Breton's Bras d'Or Lakes. Measurements of bottom sediment characteristics, the optical attributes of the water column and the characteristics and packaging of suspended particulate matter from an area of overlapping multibeam sonar and Compact Airborne Spectral Imagery (CASI) are presented along with underwater video. The application of the CASI imagery to the development of habitat basemaps of sensitive nearshore areas and the documentation of environmental impacts is discussed.

MULTIBEAM BACKSCATTER, THE "OTHER" HYDROGRAPHIC DATASET WHAT IS IT AND WHAT'S IT GOOD FOR?

Doug Cartwright (Canadian Hydrographic Service)

Backscatter data from multibeam surveys has been diligently recorded and archived by the Canadian Hydrographic Service ever since the start of the use multibeam echo sounders in 1996. With the exception of geological surveys, much of this data has not been utilized and is a potential wealth of information. In order for backscatter data to be useful, it is necessary to understand how the data is collected and what it actually represents. The basic principles of multibeam echo-sounding systems will be explained and in particular how this relates to the collection of backscatter data. The processing, mosaicing and interpretation of the resultant data will be detailed. For the benefit of those familiar with sidescan, traditional sidescan mosaics will be compared with multibeam backscatter mosaics. Backscatter data is a useful seabed-imaging tool which enhances the pure bathymetric dataset and which needs to be fully exploited by the ocean sciences community.

DEVELOPMENT OF A DIGITAL TERRAIN MODEL AS A SCIENTIFIC BASEMAP

Terry Curran, P.Eng.
Canadian Hydrographic Service

Increasingly there are requests by the scientific community for access to digital bathymetry collected by the Canadian Hydrographic Service (CHS). This can be combined with terrestrial data and formed into a digital terrain model (DTM). Other scientific or commercially strategic data such as cables, pipelines, and fish habitat can be layered on the DTM for interpretative or illustrative purposes. CHS has chart data, field (or fair) sheet data, and multibeam data. CHS is in the process of organizing some of this data into a seamless database, but much of the data is presently organized by separate files and is in non-digital form. The conversion to digital may take years. The creation of a moderate-density dataset and of a single coastline that may suit the needs of many users as an interim measure is described.

A SPATIALLY-EXPLICIT, HABITAT-BASED MODELLING APPROACH FOR FISH POPULATIONS

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Fish are affected by physical and biological factors that limit space and resources. This physical habitat is variable at different scales, therefore fish habitat use and availability through time and space is important to model. The limited supply of essential habitat can create a threshold that constrains population dynamics, range and abundance. By linking population parameters and rates with habitat supply and suitability estimates for specific life stages, we can help identify potential limits to productivity and thus define 'essential' habitat, which may differ for consecutive life stages. A pilot study of habitat characterization, suitability analysis, and linked population and spatially-explicit habitat models has been completed for Long Point Bay, Lake Erie (Minns et al. 1999a; Minns et al. 1999b). It is hypothesized that nearshore, vegetated and thermally suitable habitat is critical to the early life stages of yellow perch.

OBJECTIVES

Five objectives in constructing a habitat-based population model are:

1. How to characterize physical habitat?
2. How to define suitable habitat?
3. Can habitat be linked to fish population dynamics?
4. Does a particular habitat limit fish productivity?
5. Does suitable habitat predict fish distributions?

Once identified and quantified, the limiting habitat characteristics that determine the success of yellow perch can be used to guide conservation efforts. Also, the framework for the model can be applied to other fish species to test habitat-based species interactions.

HABITAT LINKAGES

A yellow perch (*Perca flavescens*) habitat model has been constructed for Long Point Bay in Lake Erie. This model builds upon several other habitat-based models in the Great Lakes basin for walleye (*Stizostedion vitreum;* Minns et al. 1999b) and northern pike (*Esox lucius;*(Minns et al. 1996). Temporal and spatial datasets for five habitat factors: bathymetry, vegetation, substrate, temperature, and exposure (calculated from fetch, wind direction and velocity) were compiled from field studies, existing databases, and remote sensing information. Table 1 indicates how these factors relate to the habitat requirements of yellow perch at different life stages. The life stages are defined as stages within the life cycle that have different habitat requirements. For yellow perch, these have been divided into adult spawning, egg, planktonic larva, demersal young-of-the-year (YOY), juvenile and non-spawning adult stages.

Habitat Suitability Index (HSI)

A habitat suitability index is a relative, qualitative measure of an area based on the habitat requirements of a fish. Habitat characteristics of a site are weighted and combined into a score between 0 and 1 (0 is poor habitat and 1 indicates prime or optimal habitat). In the yellow perch model, the HSI is a weighted combination of disturbance, macrophyte cover (vegetation), substrate type, and depth depending on the relative importance of that characteristic to the life stage. Temperature is not combined into an HSI because it can be used directly in preference-based or bioenergetic relationships in the population model.

Table 1: Habitat characteristics that are linked to yellow perch (*Perca flavescens*) life stage requirements.

Life Stage	Bathymetry	Exposure	Vegetation	Substrate	Temperature
Spawning Adult	X	X	X	X	X
Egg		X	X	X	X
Planktonic Larva	X	X			X
Demersal Larva	X	X	X	X	X
Juvenile	X		X	X	X
Non-spawning Adult	X		X	X	X

POPULATION MODEL

The basic components of the habitat-based population model for yellow perch are outline below (Figure 1). Long Point Bay was divided into a grid, based on AVHRR sea surface temperature maps, with a cell resolution of 1.4-km (See Figure 3b).

Spawning

Grid cells available for spawning are a function of degree-days. The largest adult size class spawns first. The cells are filled to capacity (based on the area needed for spawning) and in hierarchical order based on the HSI assignments (i.e. highest suitability to lowest).

Eggs

Egg mortality rate is a function of temperature and disturbance. Egg developmental state is a function of incubation days and temperature. At 100% development the eggs become planktonic larvae.

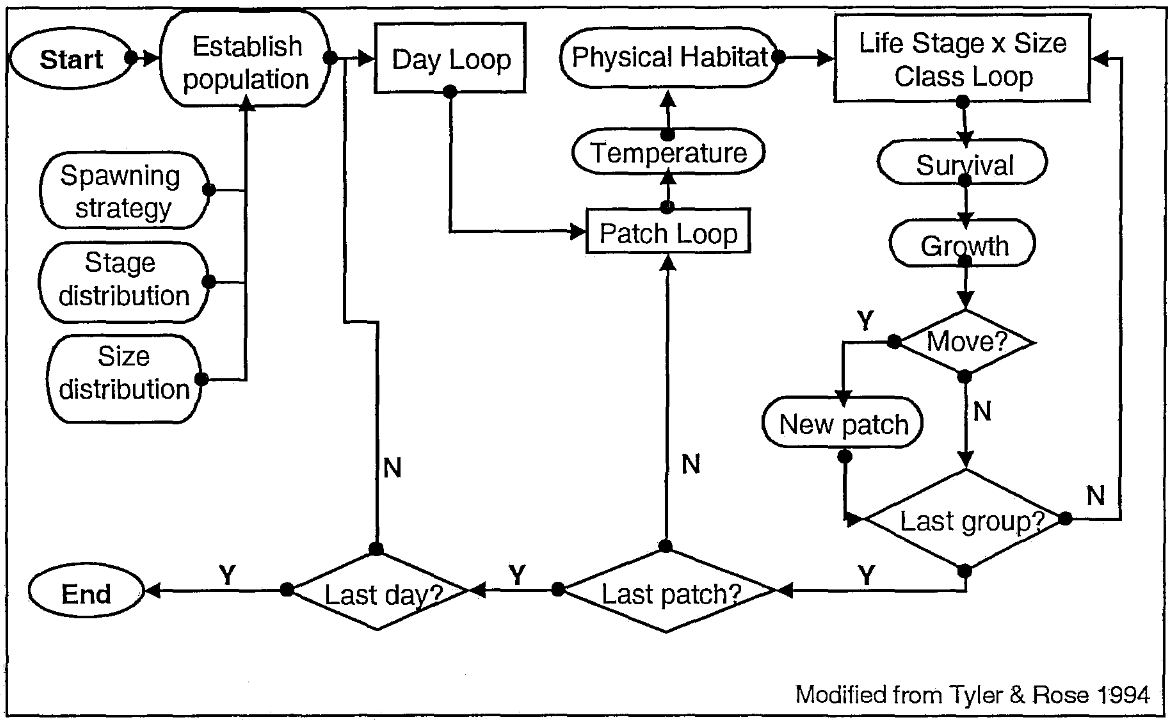

Figure 1: Schematic of programming logic for a spatially-explicit population model based on size class and age groups.

Habitat & Vital Rates

A cell's carrying capacity is a function of the cell area and the HSI. Carrying capacity is used in density-dependent calculations or to set the maximum occupancy of each cell by life stage.

Growth rates are a function of temperature and HSIs. Temperature defines the maximum growth rate & the HSI modifies growth due to relative food availability by habitat type.

Mortality rates are a function of temperature (Figure 2) and life-stage specific HSIs. Survival is low if the temperature is close to T_{max} and if there is a large daily temperature difference. The HSI is based on habitat-related predation pressure & physical disturbance (i.e. the presence of refugia) which differs in intensity for subsequent life stages.

Movement

Small individuals are passively moved based on an exposure field (fetch x wind). Larger individuals from one cell actively move to another based on improving their

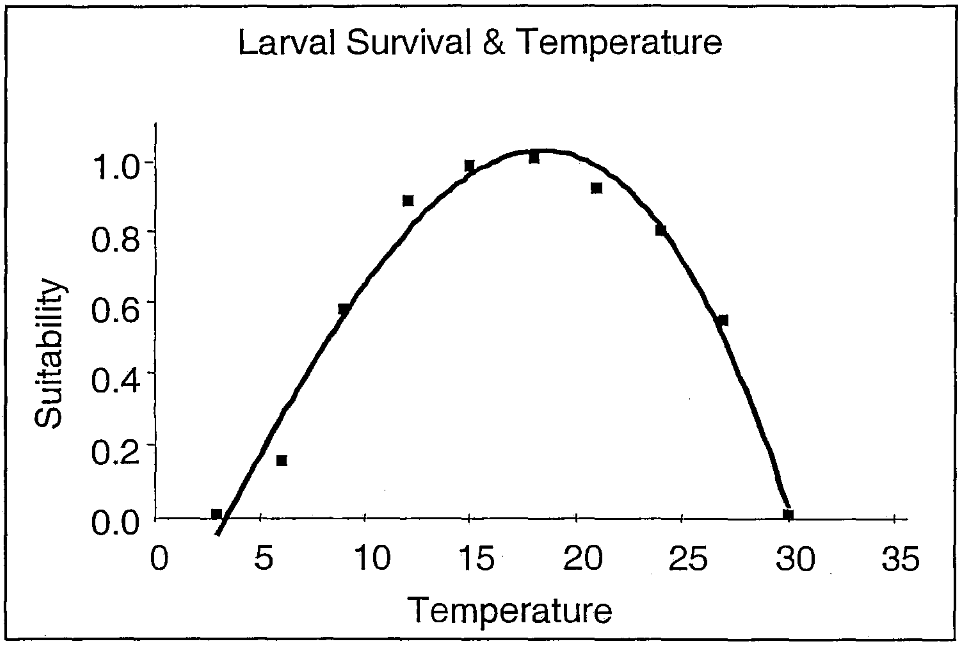

Figure 2: Larval yellow perch survival curve translated into suitabilities (1 = maximum survival rate) at different temperatures (Data from (Thorpe 1977)).

suitability, but the carrying capacity or density in neighbouring cells sets the limit on movement. Larger individuals move between cells based on maximizing the growth suitability and minimizing the mortality HSI. The area scanned for maximizing overall suitability depends on size-based swimming speed. (I.e. YOYs are able to swim 0.62 km/day based on average size and a 12-hr swim. Therefore, it would take 3 days to swim to the next cell once a 'decision' is made.)

INITIAL RESULTS

The contiguity of essential habitats is also important. If distances between consecutive, required habitats are too great than their mere existence is not solely important but also their relative accessibility. Spatially, optimal habitat for different factors may not overlap, which could limit the population potential at different times of the year. For example, Figure 3 illustrates that highly suitable vegetation, bathymetry and substrate (Figure 3a) does not overlap with highly suitable thermal habitat (Figure 3b) for juvenile pike.

Scenarios & Future Work

The models can be used to test climate change scenarios, like increases in air temperature & variability, as well as decreases in Great Lakes' water levels. Other scenarios include nearshore habitat loss and modification, like the loss of wetland area, shoreline development or hardening. The models can also be used for area management planning, habitat-based fisheries management, testing scenarios about productive capacity that are relevant to fish habitat management, and potentially, the selection of freshwater protected areas.

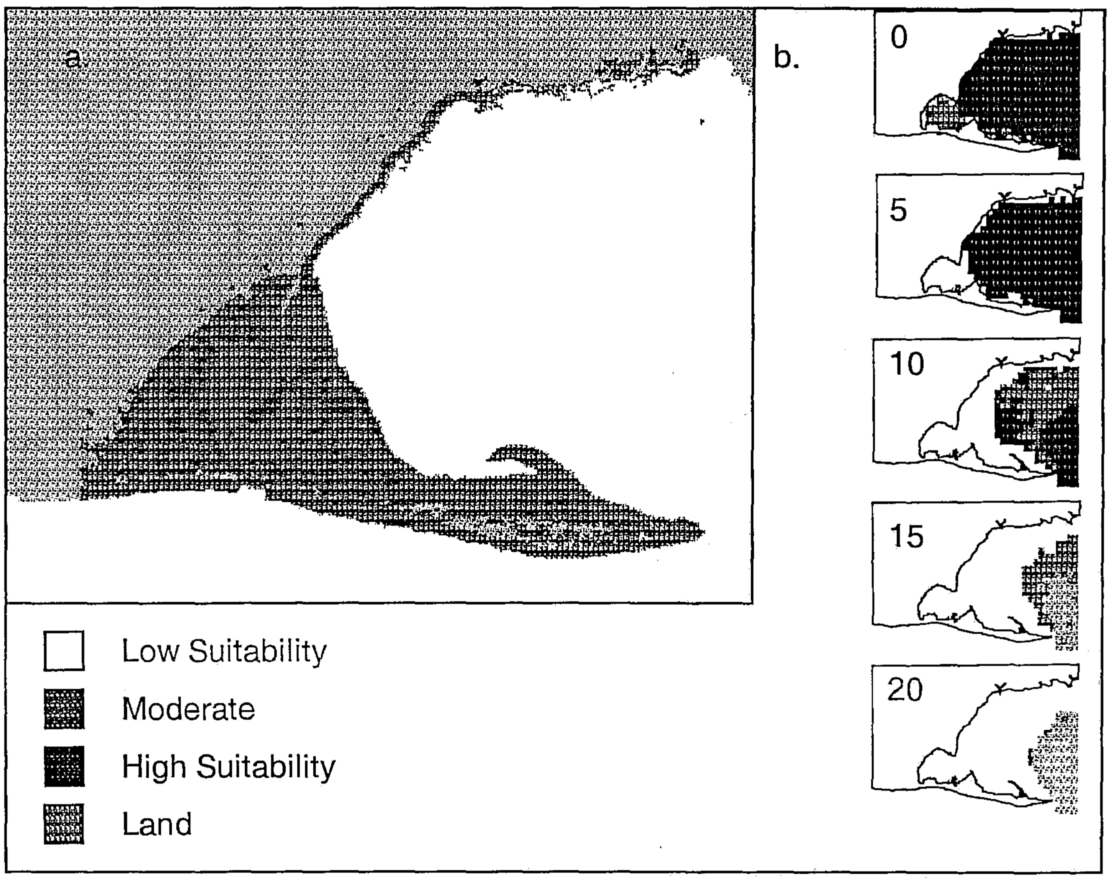

Figure 3: A map of Long Point Bay, Lake Erie a) showing the areas most suitable for northern pike (*Esox lucius*) juveniles based on vegetation, substrate and bathymetry only. b) the locations, by 5m depth intervals, that are most suitable thermally for pike juveniles.

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ACOUSTIC SEABED CLASSIFICATION: APPLICATIONS IN DFO

James L Galloway   P Eng
CHS Pacific

BACKGROUND

Acoustic seabed classification is rapidly gaining acceptance in the ocean community. Commercial products, such as those supplied by Quester Tangent Corp (QTC), measure acoustic diversity of the surficial seafloor zone and spawn thematic maps of the resulting acoustic classes. A research program into survey design, field operations, data visualization, and technology improvements for acoustic seabed classification has existed in CHS Pacific since 1997. A new initiative at QTC and the University of Victoria, School of Earth and Ocean Sciences, will help advance the development and application of seabed classification. The recently funded Canadian Marine Acoustic Remote Sensing (C-MARS) facility will bring the capability of academia to the measurement, modelling, and fundamental understanding of seabed acoustical diversity. Our focus has been to jointly work with QTC, which has developed the operational products necessary to conduct practical classification surveys, to work with C-MARS, which brings a very necessary academic component to the table, and to work with Knudsen Engineering Ltd (KEL), who have developed hydrographic sounders which output data in a form amenable to seabed classification extraction.

In excess of 15 surveys have been conducted to date in our quest to apply this technology to improve DFO program delivery. Much of this work was conducted in collaboration with the following organizations:

- Quester Tangent Inc (Industry partner): Products include IMPACT, QTCview, MultiView, SideView
- Knudsen Engineering Ltd (Industry partner): Products include 320M sounder, EchoControl data logging software.
- Univ. of Victoria C-MARS (Academic research partner)
- OGDs: Environment, NRCAN, Transport, DND (Great Lakes Contaminants, Georgia Basin, sponge reefs, Grand Banks fisheries, Harbour Contaminants, Q-route mapping)
- DFO divisions: CHS, Oceans, MEHS, Stock Assessment, Ecology Research

APPLIED ACOUSTIC SEABED CLASSIFICATION

Applications of the technology within DFO are diverse and include: Baseline MPA surveys, aquaculture debris field investigations, trawl impact studies, mapping shrimp, rockfish, & bivalve habitat, and hydrographic charting. Funding under SSF for the last two years has enabled development of infrastructure for acoustic seabed classification programs in Pacific region.

Studies of aquaculture debris fields, depicted in figure 1, reveals that the detritus below a pen can be mapped using a combination of backscatter from a multibeam sonar and from coincident acoustic seabed classification measurements. Overlaying seabed classification information on high resolution bathymetry clearly defines geological and ecological boundaries for MPA sites as in figure 2.

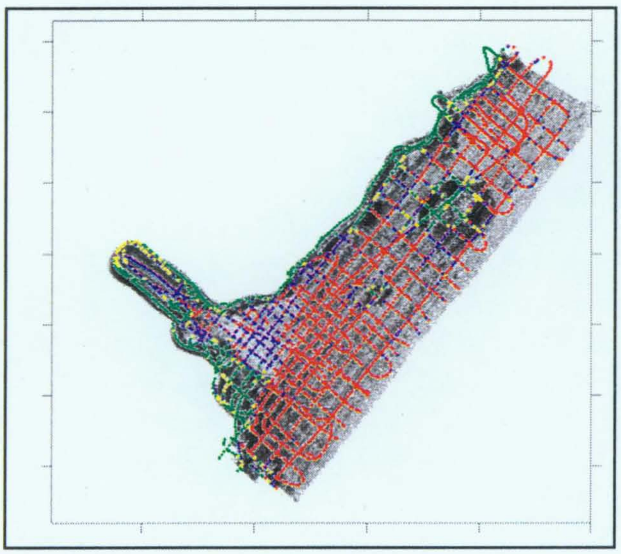

Figure 1: Acoustic seabed classification over backscatter from multibeam sonar

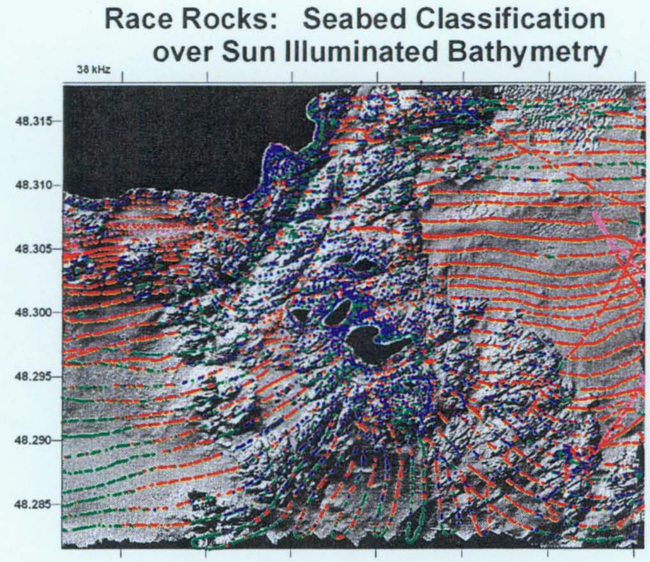

Figure 2: Seabed classification over high resolution multibeam bathymetry

PLANS AND CHALLENGES

The recently CHS funded (Program Integrity II) program to integrate seabed classification into routine hydrographic survey programs represents a significant step forward to establish acoustic seabed classification as a viable technology in DFO programs. This program has a number of components which are relevant to other programs such as habitat health and stock assessment within DFO:

- Acquisition of QTC IMPACT processing tools
- Acquisition of KEL EchoControl systems for use with CHS survey sounders
- Training in operation of tools

- Development of a CHS database infrastructure for acoustic seabed classification data. This database could be considered a regional/national resource as well.
- Development of a suite of visualization tools optimized for seabed classification applications
- Design of survey procedures for seabed classification operations. These procedures will conform to the ISO 9001 program recently adopted by CHS nationally.

The future is bright for this technology but some aspects require significant attention:

- Develop visualization techniques including optimal interpolation methods
- Develop objective data fusion techniques for ancillary information such as high resolution bathymetry, seafloor visual imagery, physical samples, sidescan data, benthic test fishery results, etc.
- Assemble "standard" classification catalogs which will enable a common basis for classification comparisons
- Model acoustic processes: method used by QTC is not scientifically defensible, need better numerical acoustic models for reflection and penetration.
- Improve classification algorithms: known deficiencies exist in QTC (and others') approach to classification.

These challenges are being addressed within Sonar Systems group (SSG) in CHS Pacific, at Quester Tangent Corp, and at the Canadian Marine Remote Sensing group at UVIC. Both SSF and Program Integrity II funding is being applied to improving the technology and to develop the infrastructure with which the region can conduct practical research into applications of acoustic seabed classification. SSG has started addressing the visualization task, data fusion will be investigated by all parties above, standard catalogs will be developed over time by CHS, C-MARS will deal with the modeling problems, and algorithm improvement will concern all three groups.

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A CASE FOR TARGETTED RESOLUTION IN GEOGRAPHICALLY REFERENCED MODELS

David Greenberg
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Modelling the ocean will always involve compromises of scale. Even with increases in the computation speed of present day CPUs and with the increasing size of available system memory and disk storage, ocean models are subject to practical limits on their resolution. Increasing resolution adds to computer storage space and computation time. The increase in computation time is not only due to more calculation points but also due to a decreased time step necessary to satisfy stability criteria.

Regional models (e.g. Figure 1) face the additional complications of the assumptions imposed on open ocean boundaries that are hopefully "far enough away" and "of small enough influence", not to impact on the solution in the area of interest. It has been shown that, depending on the process and time scale being modelled, solutions are influenced thousands of kilometers downstream of the open boundaries specified in areas of incoming shelf waves.

In practice, the scales important to an accurate solution of a problem are rarely uniform over the domain of a model (Figure 2). Changes in topography and coastline over small scales can have a critical influence over processes throughout a domain. Baroclinic and barotropic properties vary on many scales determined by many factors such as meteorology and the earths rotation. Among issues identified where resolution has been identified as affecting the solution, are: the Rossby radius, large depth gradients, coastlines, and the depth and cross section of critical sills and channels.

This examination looked at factors leading to varying physical scales and problems that might be better resolved with model spatial resolution that is targetted to the variation in these scales.

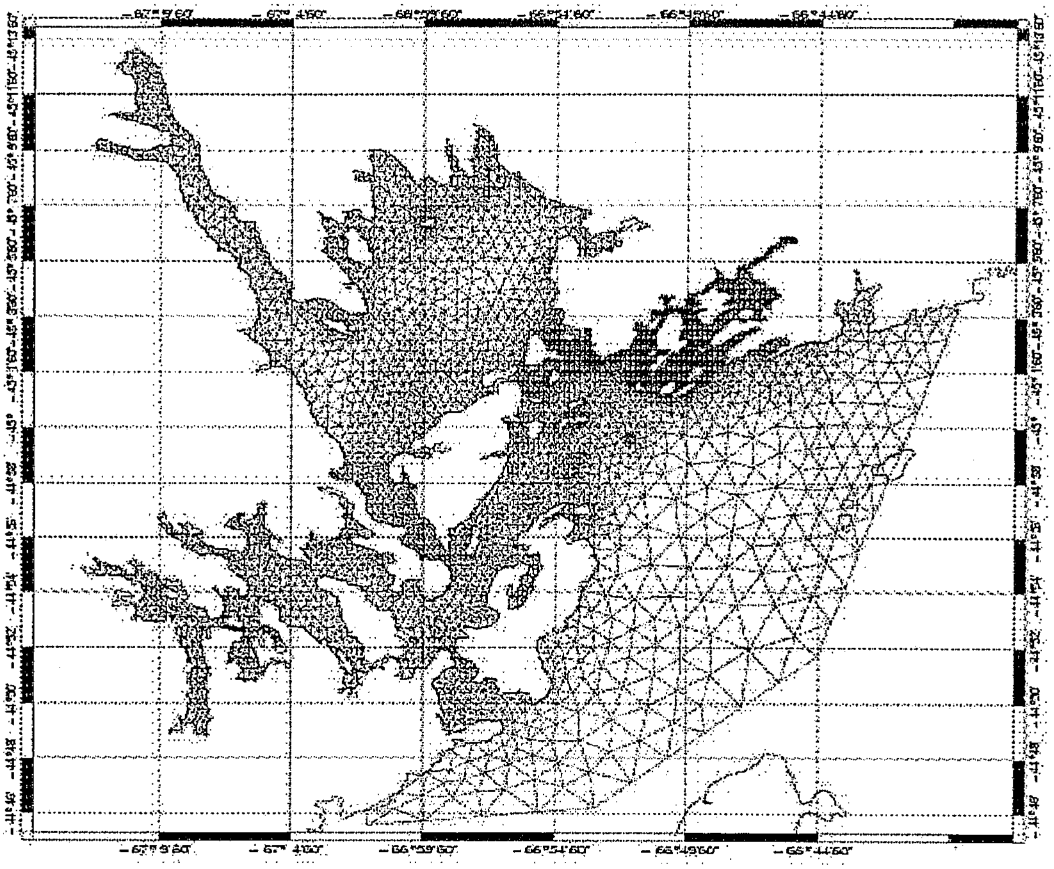

Figure 1: The finite-element model mesh used in the Quoddy Region (SW New Brunswick) model. This model, which had resolution varying from 3.5 kilometers to 30 metres, is being used to examine aquaculture issues such as flushing, oxygen utilization and the transport of parasites and disease between farms.

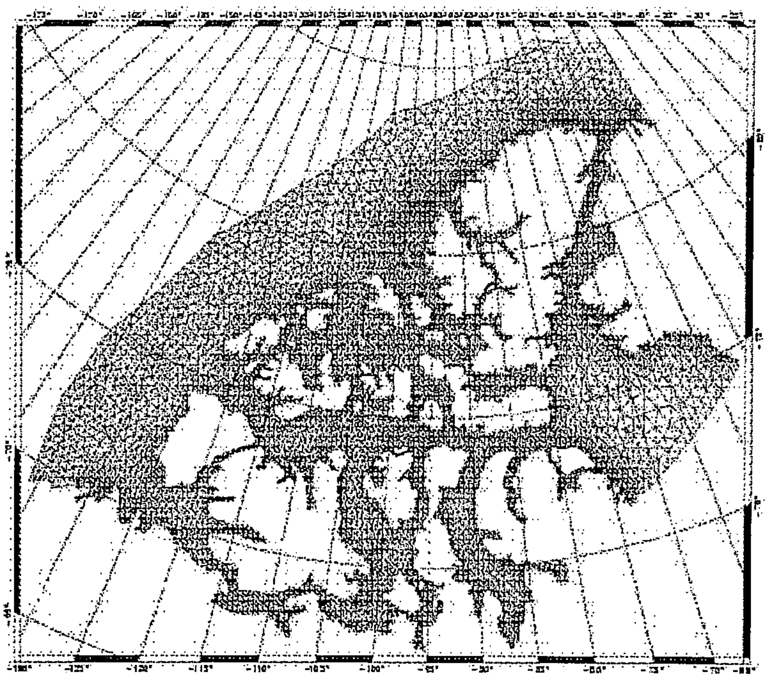

Figure 2: The finite-element mesh of the model being used in Arctic Archipelago studies to look at tides and transport through the area. The variable resolution capabilities of this model (here, 2.3 kilometers to 83 kilometers) are ideally suited to resolve the complex coastline. Studies to date have shown that although the major flows are through Lancaster Sound and Nares Strait, significant flows are seen through the narrow passages of Fury and Hecla Strait and leading into Jones Sound. The longitude and latitude lines show how geocentric coordinate finite-difference models using a square mesh at the equator would have such a regular mesh severely distorted in the polar regions.

ACCURACY OF SPATIAL DATA

Rob Hare
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ABSTRACT

Knowing the positional accuracy of your spatial data is important for effective integration and sound decision making within a geographic reference frame. GPS has taken much of the guesswork out of positioning spatial data today. But just how good is it and is it good enough? And is the GPS position you record really the true location of your spatial data?

Frequently confused terms will be clarified, some historical and future positioning methods will be discussed, errors from non-GPS sources will be identified and the importance of metadata will be highlighted.

GEORGES BANK
A SUCCESS STORY IN PRIVATE-PUBLIC PARTNERING

Mike Lamplugh (CHS-Atlantic Region)

While the use of HydroAccoustics has been the backbone of the Canadian Hydrographic Service's suit of tools for over 50 years, the ability to extract additional information from the data acquired during a standard hydrographic survey is reasonably recent. This derived data has applications in many other marine disciplines such as science, fisheries research & conservation and geology.

Over the last decade, the ability to conduct hydrographic surveys by insonifying 100% of the seafloor using (multi-beam technology) and the affordability of the computational power and the software required to render such data sets into imagery has created tremendous opportunities. For example, seafloor imagery of the offshore scallop fishing areas off Canada's East Coast (primarily outside the12 nautical mile limit) has brought the majority of the scallop companies into a partnering arrangement that recently completed surveying the entire 7600 square kms of the Canadian side of Georges Bank.

This presentation will give an overview of the project (fieldwork in 1999 & 2000 and all deliverables in 2001) and discuss the some of the potential that the success of this project has pointed us towards.

For example; the scallop industry and the DFO stock assessment personnel are exploring the use of this information to find, sample and harvest specific scallop beds rather than granting licenses for broad areas of the fishing banks. Also, the potential to use this data as the base maps to better understand the habitat, activities, spawning and other otherwise of the various species that coexist near the benthos are far reaching.

PLACING MARINE MAMMAL MOLECULAR GENETICS DATA IN A GEOGRAPHICALLY REFERENCED CONTEXT

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DFO, Central and Arctic Region
Freshwater Institute, Winnipeg, Manitoba

The application of molecular genetics has become widespread in many areas of wildlife management. Portions of DNA molecules can be used as markers to provide information about individuals, stocks and populations. The technology underpinning these types of studies has become increasingly more sensitive and efficient, allowing for large amounts of information to be gathered. The databases of mitochondrial DNA sequence information and nuclear DNA microsatellite alleles in many labs have grown to impressive proportions. The question then inevitably becomes, what does it all mean?

Finding meaning in molecular genetics data sets can be complicated. Sample sizes and the number of genetic "measurements" used have considerable impact on the statistical analyses. Interpreting data from animals sampled along migration routes can be clouded by factors such as mixed stock composition and inaccurate sampling location information. Most important, however, is the amount and quality of associated biological information about the animal(s) that can be used to provide a foundation for interpretation.

Most often, the primary question to be answered with genetics data is the identification of stocks. Usually, this is in a geographical context, centered around a community or fishery that is harvesting the species of interest. We are now exploring methods for referencing and retrieving genetic information that is linked to other forms of biological data (e.g. contaminants data, satellite tagging data, life history data) and organized in a geographical context. Hopefully, this will pull information together into a meaningful picture.

ESTABLISHMENT OF A SEAMLESS CHART DATUM ON THE ST. LAWRENCE RIVER

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Measuring depths and positions is the first thing that comes to mind when we talk about hydrographic surveying. But all those depth measurements have to refer to a vertical reference. The concept of chart datum has existed for many years will be there for many years to come. Chart datum is defined over benchmarks at specific locations on shore. The vertical reference is well defined on those benchmarks but vertical datum control is weakened when moving away from them. The latest GPS technologies make GPS tide detection possible, but it requires the introduction of new concepts to support it. Establishment of a seamless vertical reference is the main concern. This paper will explain how the seamless datum was established on the St-Lawrence River, how we will work with GPS tide detection and finally how that technology could be used elsewhere within the Department of Fisheries and Oceans.

AN ACOUSTIC STUDY OF 3-D FISH BEHAVIOUR: GEO-REFERENCING SINGLE FISH FROM A MOVING PLATFORM

Ian H. McQuinn(Institut Maurice-Lamontagne)
Paul D. Winger (Northwest Atlantic Fisheries Centre)

Horizontal orientation (tilt angle) is known to affect the target strength (TS) of insonified fish, and as such is a large component of the variability inherent in acoustic biomass estimates. Split-beam echosounders are able to measure the relative movement of single fish within the acoustic beam, however corrections for vessel motion are required to determine their absolute movement, i.e. relative to the ocean floor. Target data of individual Atlantic cod (Gadus morhua) were collected from a moving research vessel and subsequently tracked. GPS data were logged simultaneously to track vessel orientation and movement, and were used to geo-reference the fish tracks to determine the absolute 3-D displacement (speed and direction). The results revealed several patterns of swimming behaviour. These behavioural patterns and their affects on TS were analysed as a function of time of day. Regular diel orientation patterns were observed as cod rose from the ocean floor in the evening, increasing their tilt angle, which subsequently decreased at sunrise as the cod descended to the ocean floor. Mean target strength was found to be highly correlated with tilt angle and was predictable. This correlation allowed for the correction of the fish length-TS relationship and thus biomass estimates on these migrating cod as a function of time of day.

MITIGATION OF NATURAL HAZARDS: STORM SURGES, RISING SEA LEVELS AND COASTAL EROSION

C. T. O'Reilly, Glen King (Canadian Hydrographic Service-Atlantic)
Dr. John Shaw, Russ Parrott, Robert Taylor (Geological Survey of Canada-Atlantic)
George Parkes (Meterological Services Canada-(Atlantic)

Advances in Remote Sensing and GPS technology has made it possible to develop very high resolution digital elevation models of topographic landforms. Recent projects utilizing airbourne laser technology (LIDAR) have created 3-D maps of coastal shore and inter-tidal areas with horizontal footprints of less than 1 meter square, containing decimeter vertical precision. These data were reviewed by several partners which included hydrographers, geomorphologists, coastal engineers, academic researchers, Emergency Measures Organizations and the Transportation Safety Board. The coastline can no longer be considered as two dimensional lines on paper, but as a three dimensional land form which is undergoing very dynamic physical change. It has been proposed to utilize Remote Sensing to initiate high resolution 3-D baseline mapping in low-lying areas under threat of coastal flooding, rising sea level and tsnuami run-up. This presentation discusses several applications of merging land and sea data sets for coastal zone management and natural disaster mitigation. Stakeholders include all levels of governments, the insurance industry, National Defence as well as numerous environmental and marine interests affected by climate change.

ACOUSTIC SEABED CLASSIFICATION TECHNOLOGY APPLIED IN SHELLFISH PRODUCTIVITY RESEARCH.

Marc Ouellette and T. Landry,
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A good understanding of the relationship between shellfish population dynamics and their habitat is essential in order to conduct efficient and successful enhancement and/or restoration projects. The physical, chemical and biological characteristics of the seabed are key elements in shellfish productivity. This benthic assemblage has proven to be challenging to evaluate on a large scale.

With the development of new data acquisition and analysis tools, such as GPS, acoustic seabed classification technology, GIS software and geostatistics, it is now possible to map seabed areas within a reasonable accuracy, time and financial framework. Most importantly, these new technologies are capable of providing accurate and repeatable measurements. Acoustic seabed classification is the organisation of the seafloor and shallow subsurface sediment into seabed types or classes based on the characteristics of an acoustic response. This will provide us with the ability to measure spatial and temporal variation of the benthic assemblage in relationship to mollusc productivity.

A new shallow water seabed classification system, QTC View (Series V), is being used for the first time to survey sites in the Gulf of St. Lawrence and Bay of Fundy were research is presently being carried out on oyster bed restoration, quahaug population management and mussel farming.

APPLICATION OF RADIO AND ACOUSTIC TELEMETRY TO FISH HABITAT RESEARCH IN NEWFOUNDLAND

David A. Scruton (Newfoundland Region)

Biotelemetry is a very power tool in the study of animals in their natural environment and has been applied to a variety of freshwater, estuarine, and marine habitat research studies in Newfoundland. Initial studies looked at patterns of fish habitat use in relation to hydroelectric development over large spatial scales and in relation to seasonal variation. Radio transmitters have been used to study the upstream migration of anadromous salmonids, in both Newfoundland and Labrador, to identify critical spawning and over wintering habitats. Micro-scale radio transmitters have been used in the collection of microhabitat data for use in habitat hydraulic models, to assess fish response to hydro peaking, and to look at winter habitat use and activity levels. Digital Spectrum Processing (DSP) telemetry has been used to study burst swimming behaviour and speed of Atlantic salmon and to evaluate the effectiveness of a fish protection scheme at a hydroelectric development. CART (combined acoustic and radio transmitter) transmitters have been used to study estuarine migration and freshwater adaptation by anadromous salmon and to examine behaviour and dispersal patterns of experimentally released ('escaped') aquaculture fish. Physiological telemetry is a new and emerging tool with the ability of remotely relaying information on a fishes well being in relation to its environment (habitat) and potential stressors (e.g. effluents). Electromyogram (EMG) transmitters have been used to look at muscle response to swimming effort, including burst swimming, and to assess energy expenditure in relation to traversing fishways. Heart rate transmitters were used to study the effect of, and recovery from, 'hook and release' angling. Research is ongoing to develop a cardiac output transmitter to monitor fish response to effluents and other stressors, *in situ* (in the field). A new acoustic telemetry system has been employed in the study of habitat selection by juvenile cod in coastal areas. The resolution of this system has permitted detailed assessment of habitat use on fine spatial scales, has provided information on temporal (diel and seasonal) variation, and has allowed interpretation of cruising swimming speeds. Recently, work has been initiated into the integration of acoustic telemetry and hydroacoustic technologies. Many of these studies have been conducted in partnership with Lotek Wireless, a leading global manufacturer of telemetry products, and the Waterloo Biotelemetry Institute, an academic institute dedicated to biotelemetry research. The paper reviews some of the applications and results from studies conducted over the last decade.

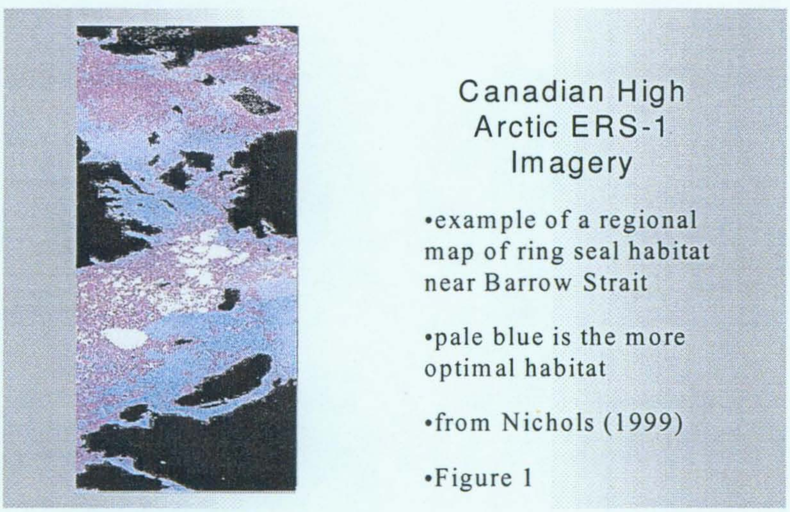
ASSESSMENT OF RINGED SEAL PUPPING HABITAT AND PRODUCTIVITY USING RADARSAT IMAGERY IN COASTAL LABRADOR

B. Sjare, DFO Newfoundland Region (lead investigator; ringed seal ecology)
J. Helbig, DFO Newfoundland Region (oceanography)
M. Hammill, DFO Laurentian (ringed seal ecology)
E. Simms, Memorial University, Newfoundland (remote sensing)
D. Barber, Centre for Earth Observations, University of Manitoba (remote sensing)

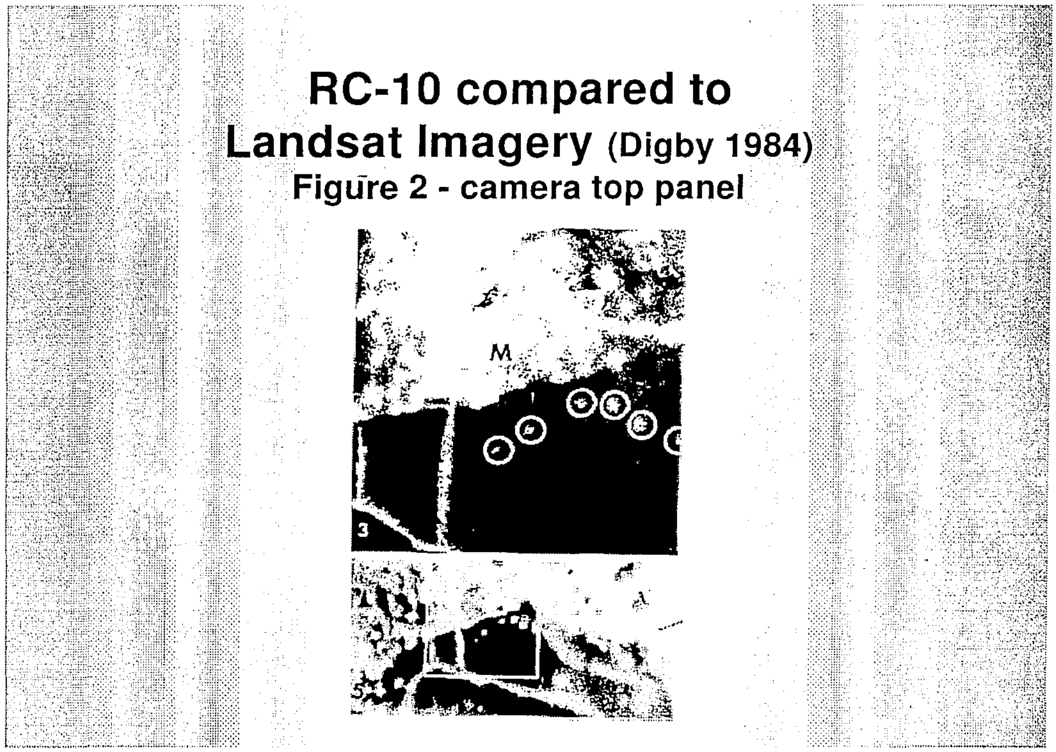
INTRODUCTION:

The distribution, abundance and productivity of ringed seals is influenced by sea ice and snow conditions (Furgal *et al.* 1996, Hammill and Smith 1988, Smith and Stirling 1975). Ringed seal pups are born in a snow cave (lair) constructed by the female near a well-drifted pressure ridge, ice hummock or the boundary between first-year and multi-year floes. The lair protects the pup from predation by polar bears as well as provides much needed shelter from the wind and cold temperatures. Adequate snow cover and appropriate ice roughness have been correlated with increased survival of ringed seal pups in the high Arctic (Furgal *et al.* 1996, Hammill and Smith 1988, Hammill and Smith 1991).

A recent study in the central Canadian High Arctic used synthetic aperture radar (SAR) imagery to develop a regional habitat suitability index based on sea ice conditions (Figure 1; Nichols 1999). It was possible to reliably separate ice types based on the different dielectrical properties. The index was then used to quantify the availability of winter habitat for ringed seals on a regional scale; it should be possible to develop a comparable index to describe the wintering distribution of seals in the region using RADARSAT imagery.



The effectiveness of RADARSAT imagery as a tool to assess ringed seal productivity is dependent on whether birth lairs and breathing holes can be reliably detected and quantified. A study conducted by Digby (1984) reported that seal holes could be detected on airborne SLAR imagery (side-looking aperture radar with 25m resolution) and on SAR (synthetic aperture radar with 3m resolution) as well as on LANDSAT satellite imagery (with 80m resolution). The actual holes were not detected on the imagery, but rather the well-drained area around the holes. These drier, more reflective areas of ice produced a strong contrast relative to the surrounding expanse of wet, flooded ice and showed up as bright white spots on the imagery (Figure 2).



Based on these results Digby (1984) concluded that, with proper quantification, remote detection of seal holes during the melt season could provide a method to monitor the wintering (i.e. breeding) distribution and relative abundance of ringed seals over large geographic areas. To date, the necessary ground-truthing research has never been conducted to support or refute Digby's (1984) conclusions.

Given the availability of RADARSAT imagery with approximately 8m and 25m resolution we have designed a field experiment to determine the effectiveness of this imagery as a tool to study the breeding habitat and productivity of ringed seals along the Coast of Labrador. This research will improve our understanding of the spatial and temporal distribution of breeding ringed seals relative to sea ice type and concentration, ice morphology and snow deposition/redistribution based on remote sensing. It will also provide the groundwork for the development of remote sensing analytical and modeling techniques required to predict the longer-term direction and magnitude of change in ringed seal breeding habitat and productivity relative to climate variability.

METHODS:

The study areas are located near the communities of Nain and Rigolet, Labrador. The Nain study site is located in landfast ice approximately 25km southeast of the community and the Rigolet site is located at the eastern end of Lake Melville.

A total of 23 standard and fine mode RADARSAT images for the two study areas were obtained during late March and mid May 2001. The March imagery will be used to document winter breeding habitat and the May imagery to follow the spring melt process and determine when birth lairs and breathing holes were most visible. RADARSAT imagery with 100m resolution (ScanSAR Wide) is available for the central and northern coast of Labrador and will be used to describe the general dynamics, extent of coverage and timing of landfast ice freeze/break-up.

To characterize the winter breeding habitat, on-ice teams collected data on ice and snow thickness as well as information on pressure ridges at approximately 15 stations in each study site during March (Furgal et al. 1996, Hammill and Smith 1988). In mid May, an on-ice team doing a systematic search on snowmobiles obtained GPS locations for approximately 53 birth lairs in a productive 3 X 5mi area at the Rigolet study site. A similar search was planned for the Nain site but ice conditions deteriorated and travel was not possible.

In addition to the on-ice searches, a low altitude, (150m) fixed-wing aircraft survey was conducted in both study areas. Full coverage was obtained and the locations of all birth lairs were logged in the GPS system of the aircraft. The area under the aircraft was videotaped using a camera system mounted in the belly of the aircraft. The study area near Nain was approximately 10 X 10mi and the Rigolet site was approximately 20 X 20mi (this included the area searched by snowmobile).

The raw images have been geo-referenced and are ready for processing and calibration to facilitate quantitative habitat mapping and detection of the distinctive drainage features associated with ringed seal structures in the ice. Unfortunately, due to funding pressures this project was abruptly terminated in June of 2001. We are currently applying for additional funds to proceed with the analysis of the imagery.

RATIONAL AND DISCUSSION:

Aerial and ship based surveys to assess marine mammal populations are expensive from both a human resources and a financial perspective. The use of satellite imagery and the development of an automated system of pattern recognition that links key habitat features to the distribution and relative abundance of a marine mammal population would be a valuable assessment tool. Given the strong link between ringed seal breeding distribution/productivity and sea ice condition, these seals are a good study species to evaluate the effectiveness of current remote sensing technology for habitat and assessment research.

Relatively little known is about the vulnerability and/or sensitivity of most Arctic marine mammal species to climate change; this is certainly the case for ringed seals. Without an improved understanding of the relationship between variable sea ice conditions and the adaptive capacity of ringed seals it will be difficult for the Department to adequately address these issues as well as other sea ice/climate change related concerns in Arctic regions.

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THE USE OF GEO-REFERENCED INFORMATION IN THE ASSESSMENT AND CONTROL OF THE SEA LAMPREY POPULATION IN THE ST.MARY'S RIVER

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Sault Ste. Marie, ON

The sea lamprey (*Petromyzon marinus*) is a non-indigenous, parasitic fish species in the Great Lakes. As parasites, the Great Lakes sea lamprey preferentially selects larger, cold-water species, such as lake trout and whitefish, as hosts. Over the course of its parasitic life stage, the sea lamprey consumes up to 20 kilograms of fish fluids and tissue, causing considerable mortality in these host species.

In the northern portion of Lake Huron more lake trout die from sea lamprey attacks than from natural and fishing mortality combined. The primary source of parasitic lampreys in Lake Huron is the St. Mary's River, the interconnecting waterway between Lakes Superior and Huron. Improved water quality and habitat restoration in the St. Mary's River in the mid-1970's created conditions that turned the river into the largest producer of parasitic-phase sea lampreys in the Great Lakes. This production of parasitic sea lampreys from the St. Mary's impacts the fish populations throughout all of Lake Huron as well as the northern part of Lake Michigan (Figure 1).

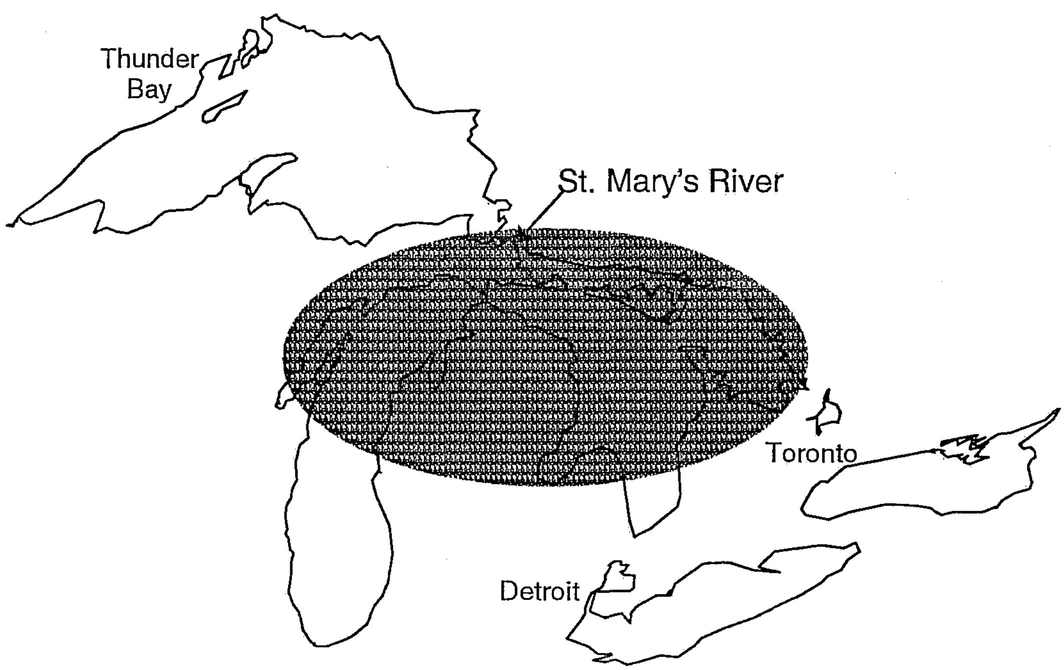

Figure 1. Impact area of parasitic sea lampreys produced by the St. Mary's River, including Lake Huron, Georgian Bay, and northern Lake Michigan.

The conventional method of controlling Great Lakes sea lampreys is through the application of a selective lampricide to nursery tributaries. The goal of the chemical application is to kill the sea lamprey larvae before they metamorphose to the parasitic stage and are recruited to the lake population. By adhering to strict application guidelines, virtually all of the sea lamprey larvae in the tributary are killed, with little to no impact on non-target organisms. However, with a mean annual discharge of 2140 $m^3 \cdot s^{-1}$, the St. Mary's River is 25 times larger than any tributary previously treated with conventional techniques. To evaluate the cost-effectiveness of available control methods, the sea lamprey control agents turned to some innovative assessment and control techniques.

To evaluate the effectiveness of control options a map of the distribution and abundance of lamprey larvae in the river was required. Beginning in 1993, a systematic sampling plan using a modified pontoon boat as a sampling platform was used to obtain samples of larval lamprey abundance from the river bottom. The samples of larval lampreys were taken by lowering an electrofishing bell to the river bottom through an opening in the deck of the boat. The electrodes in the bell were electrified, and any larvae that emerged under the bell were transported to the surface and deposited in a collection basket. The boat was equipped with a GPS unit, a receiver to correct the GPS position to allow real-time navigation, and a data-logging station to record the geodetic coordinates and lamprey catch data. Sampling was conducted along transects spaced every 70 metres in the river, and samples were taken every 70 metres along each transect (Figure 2). A total of 68.3 km^2 of the river was assessed between 1993 and 1996, resulting in 11,809 samples of larval sea lamprey abundance. The catch information was analyzed using proprietary software that used spline statistics to derive estimates of abundance using the georeferenced catch data as well as supplementary information such as water depth and substrate composition. The larval sea lamprey population in the St. Mary's River was estimated to be 5.2 million larvae.

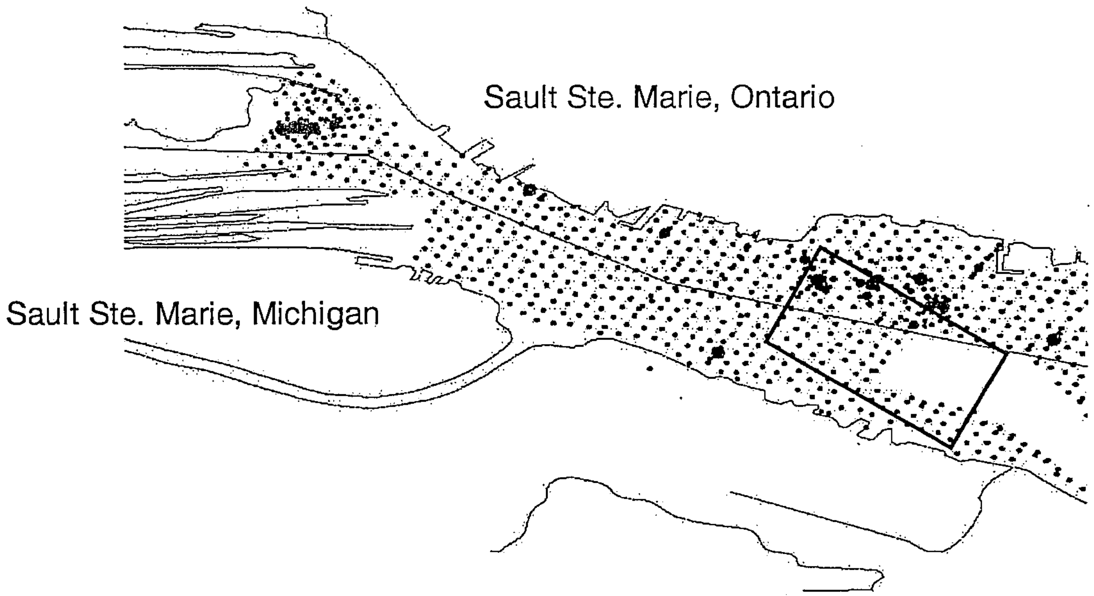

Figure 2. The 70m x 70m sampling grid for a portion of the St. Mary's River. Each circle represents a sample site; circle size is proportional to catch. The rectangle delimits an area of high lamprey abundance.

The first control option examined was a conventional lampricide treatment. A dye study to mimic the application of liquid lampricide was conducted in 1996 to determine the movement and mixing of the lampricide throughout the river. Georeferenced samples of the dye concentration were collected over a 48-hour period. The data from the dye study were used to calibrate a lampricide transport model developed by the Department of Engineering at Clarkson University. The calibrated model was used to determine where lethal concentrations of lampricide would be found within the river. We combined the transport model layer with the larval map to estimate that a conventional lampricide treatment would kill 35% of the estimated larval sea lamprey population. However, the cost of this control strategy in terms of manpower and lampricide costs was estimated to be 12.2 million dollars, and was not a cost-effective proposition.

The second control option considered spot treatments of areas of the river containing high densities of lamprey larvae with granular lampricide. To plan a granular lampricide treatment, we again turned to the map of lamprey density and distribution, and identified areas in the river containing the highest density of sea lamprey larvae. Using GIS software, we created polygons over the areas of the highest density, and calculated the area of each polygon to determine the amount of lampricide required for treatment. We targeted 58 high-density areas throughout the river, a total of 850 hectares that contained 75% of the lamprey population. Laboratory tests at the USGS center in Ashland, Wisconsin determined that granular lampricide is about 75% effective in killing lamprey larvae. The cost of applying granular lampricide to the 850 hectares was predicted to be about 4.4 million dollars, and would remove approximately 56% (75% of larvae x 75% effective x 100) of the total lamprey population, some 2.9 million larvae. Of great significance in implementing this control strategy was the one-time contribution of 3 million dollars by the state of Michigan as a supplement to the U.S. and Canadian federal contributions to the control program.

In 1998 and 1999 the targeted areas were treated by aerial application of granular lampricide. The treatment of the entire 850 hectares was completed in about 12 calendar days in total between the two years. Prior to the lampricide applications, 11 of the targeted areas were sampled using the deep-water electrofishing boat that was used to collect the original lamprey data. The sites were sampled again after the treatment was completed to verify the estimated mortality. To improve our ability to detect a change in abundance, sample spacing was reduced to a 25 metre grid. The observed change in lamprey abundance between the pre- and post-treatment sampling for one of the index sites is illustrated in Figure 3. In this specific site there are about 65% fewer lampreys collected during post-treatment sampling; the average reduction among the 11 index plots was 70%. Overall this equates to an estimated kill of 2.7 million lamprey larvae in the treatment area, or 52% of the stream population.

The true measure of success in controlling the St. Mary's River sea lamprey population will be in the lower wounding rates and increased survival of key teleost species, such as mature lake trout. Fish damage models were used to predict the benefits to lake trout survival and restoration from the control efforts (Figure 4). In general, the models showed that benefits to lake trout rehabilitation significantly increased approximately ten years after the start of control efforts. Fisheries monitoring programs should begin to detect these changes within the next 5 years.

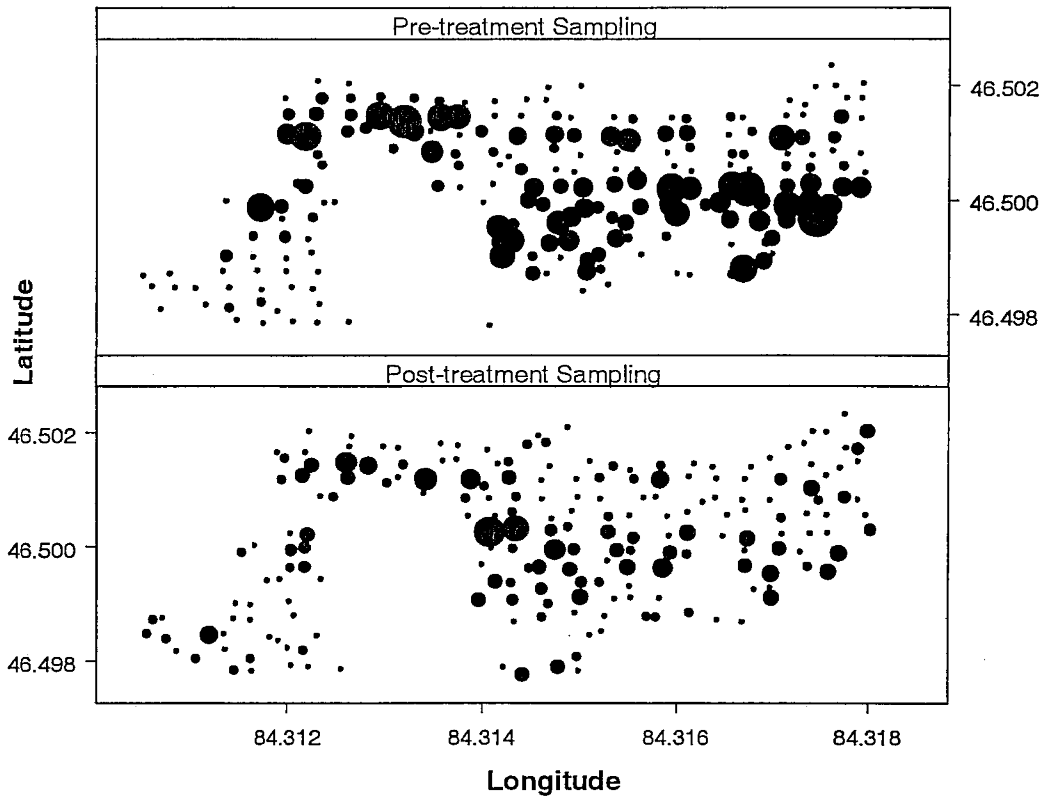

Figure 3. The reduction in lamprey abundance in an area of high lamprey density after treatment with granular lampricide. Each circle represents a sample site in the 25m grid; the size of the circle is proportional to catch.

Endnote: The control of the sea lamprey population in the St. Mary's River is a case study in cooperative, integrated resource management. The application of granular lampricide is one part of a three-part approach to controlling sea lampreys in the St. Mary's River. The production of geo-referenced maps of larval density and the application of granular lampricide to portions of the river were made possible through the joint resources of the Great Lakes Fishery Commission, Fisheries and Oceans Canada, the U.S. Fish and Wildlife Service, the U.S. Geological Survey, Michigan Department of Natural Resources, the State of Michigan, Chippewa-Ottawa Resource Authority, Great Lakes Power, and the U.S. Army Corps of Engineers.

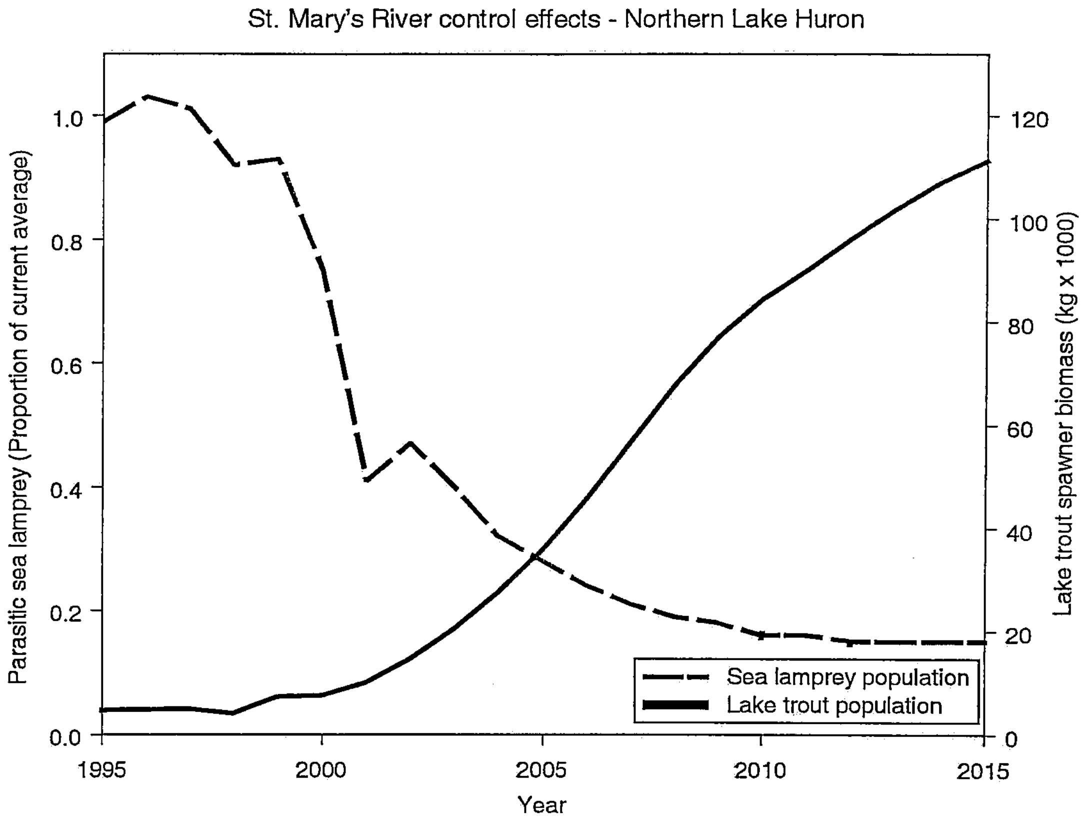

Figure 4. Output from a fish damage model that forecasts the benefits to northern Lake Huron lake trout populations from lamprey control efforts on the St. Mary's River.

Day Two

Climate Change and Its Potential Impacts on Canadian Aquatic Ecosystems with Special Reference to the Arctic and the Labrador Sea

ENDOTHERMY, ECTOTHERMY, AND THE EFFECT OF CLIMATE CHANGE ON BIOLOGICAL SYSTEMS OF THE NORTHWEST ATLANTIC

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The prospect of major shifts in marine temperature regimes due to global climate change has focussed attention on temperature-based limits to faunal distribution. However, the mechanisms by which temperature influences distribution have received relatively little attention. I propose that temperature-influenced predation susceptibility (TIPS) is the key mechanism by which temperature influences the distribution of marine fauna at upper trophic levels. The ability of a fish to escape a predatory attack depends on its reaction time and swimming speed. In aquatic ectotherms, performance of nervous and muscular systems is strongly influenced by ambient temperature (Lin and Regier 1995). Although cold-water fishes have biochemical adaptations that mitigate temperature effects on enzyme systems, burst speeds and reaction times decline steeply with temperature (Johnston et al. 1991). Ambient temperature has much less effect on swimming performance of marine endotherms. This means that susceptibility to capture depends on the difference between water temperature, which determines internal temperature in ectotherms, and body temperature of the endothermic predator. Where this difference is large, such as in polar waters, the endothermic predator will have a great advantage over ectothermic prey. Where the difference is small, such as in the tropics, endothermic predators will have little advantage over ectothermic prey.

The TIPS effect should be greatest where predators detect and pursue prey in open waters, because speed and reaction time should be the major determinants of attack success there. The effect should be less where predators search out prey that is hidden or immobile in vegetation or on the bottom (e.g. bottom-feeding cormorants). The effect should also be limited where predators use gravity to enter the water at great speed, thereby surprising surface-dwelling fish (e.g. plunge-diving seabirds). The species most likely to exhibit TIPS effects are seals and pursuit-diving seabirds. In the Northern Hemisphere most pursuit-diving seabirds are members of the Alcidae family, which includes murres and puffins. In the Southern Hemisphere penguins are the main group of pursuit-diving seabirds.

The structure of marine trophic webs changes dramatically with latitude (Lavigne et al. 1989). In polar and sub-polar systems, the dominant predators in the medium and large size range are seals and pursuit-diving seabirds. Pursuit-diving seabirds are largely confined to medium and high-latitudes (Fig. 1); seals have a similar world distribution. Seals and pursuit-diving seabirds are progressively replaced by fish at lower latitudes. In subtropical and tropical waters the role of large predators is chiefly filled by sharks and other large fish.

In the northwest Atlantic, numbers of locally-breeding pursuit-diving seabirds per km^2 of continental shelf are very high in Baffin Bay and Davis Strait, and much lower in Labrador, Newfoundland and the Gulf of St. Lawrence (Fig. 2). In summer, this group is virtually absent south of the 14° isotherm. Seals exist in high densities between Baffin Bay and the Gulf of St. Lawrence and in low densities in the Scotian Shelf (Fig. 3). Seal numbers are negligible south of the 15° isotherm in summer and the 5° isotherm in winter. Commercial fishery landings can be used as a rough proxy for potential food supplies for seals and pursuit-diving seabirds, because commercial fishes, or their juvenile stages, are a substantial part of the diet of these predators. Commercial fishery landings per km^2 of continental shelf peaks in the US mid-Atlantic coast (Fig. 4), an area devoid of seals and pursuit-diving seabirds. Hence the latitudinal distribution of these predators cannot be attributed to the distribution of their food supplies.

Water temperatures on the Newfoundland Shelf dropped sharply in the early 1990s. During this period there was a major influx of polar cod, a small fish which is the cornerstone of the Arctic marine food chain (Lawson and Stenson 1995, Drinkwater 2000). At the same time capelin, normally the dominant small fish in Newfoundland waters, shifted its distribution south and appeared in number on the Scotian Shelf (Frank et al. 1996). Also during the same period seal populations increased and numbers of medium-sized fish (groundfish) collapsed. Hence in the early 1990s the marine community on the Newfoundland Shelf shifted from a typical boreal structure (moderate abundances of both marine endotherms and medium-sized fish) in the direction of a typical Arctic structure (marine endotherms are abundant, medium-sized fish are uncommon).

Overfishing appears to have been the major cause of the groundfish collapse, and the increase in seals was part of a long-term trend. However, the increased susceptibility of fish to endothermic predators during the cold period may also have contributed to the shift in community structure on the Newfoundland Shelf. Predation susceptibility may depend on temperature characteristics more complex than simple means. In Atlantic salmon, which exhibit rapid vertical movements across the thermocline, the thickness of the warm surface layer may be a determinant of predation risk. Reliable projections of the effects of global climate change on marine organisms are unlikely without proper understanding of the mechanisms bby which temperature regimes influence biotic communities.

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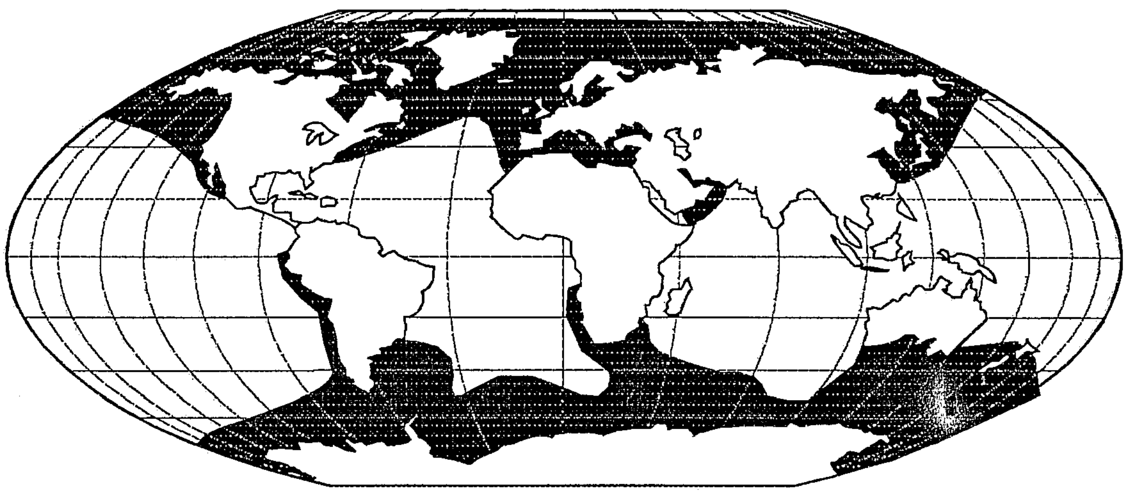

Figure 1 World distribution of pursuit-diving seabirds.

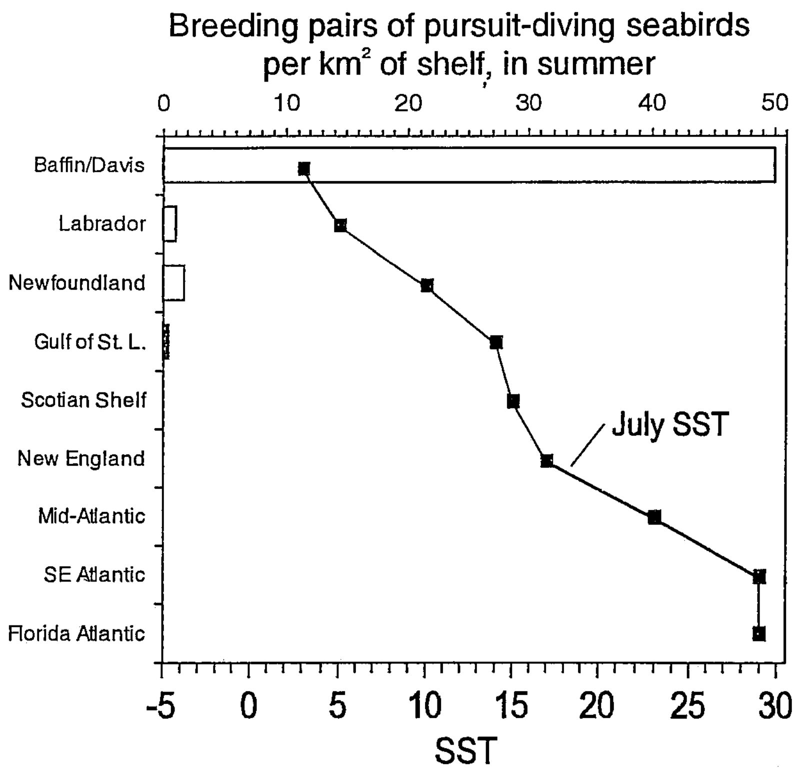

Figure 2 Density of pursuit-diving seabirds on the continental shelf of the northwest Atlantic, in relation to July sea surface temperature.

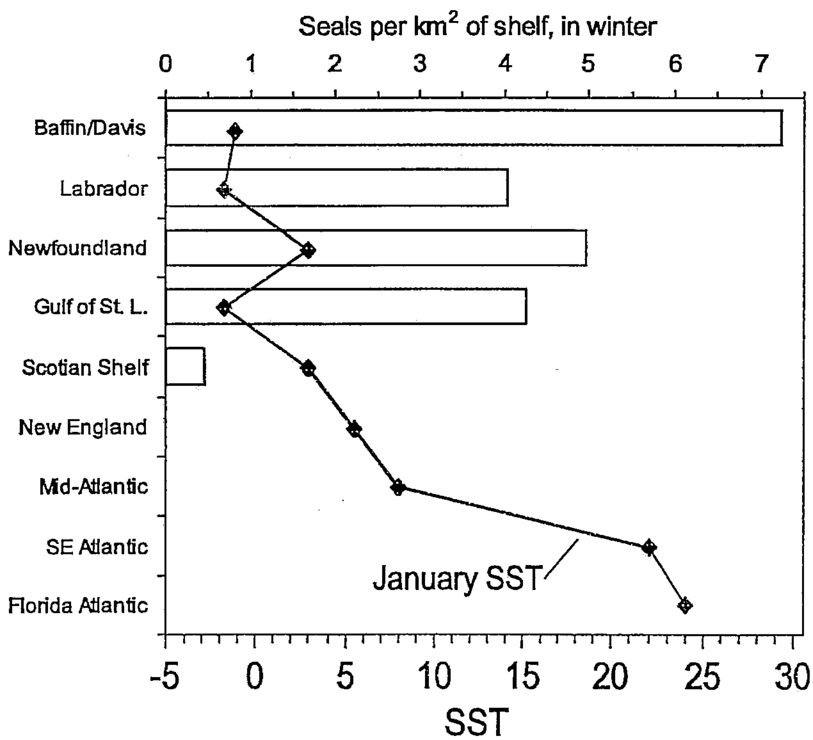

Figure 3 Density of seals in winter on the continental shelf of the northwest Atlantic, in relation to January sea surface temperature.

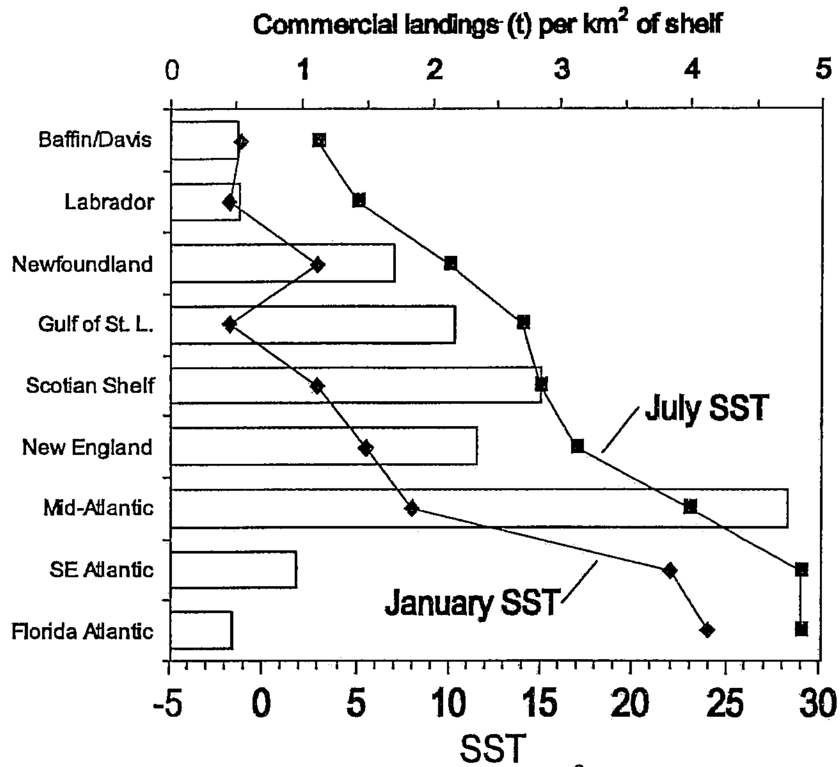

Figure 4 Commercial fisheries landings per km^2 of continental shelf in the northwest Atlantic, in relation to January and July sea surface temperatures.

A SIMPLE VIEW OF ARCTIC OCEAN CLIMATE VARIABILITY AND CONSEQUENCES TO ITS BIOTA

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1. INTRODUCTION

The classic view of a passive and steady-state Arctic Ocean changed in 1990's with the contrasting and almost sudden realization that global warming – if it occurs – will occur with greater impact in the high latitudes (compare, for example Carmack (1990) and SEARCH (2000)). First, models predicted that greenhouse gas warming would occur first and most intensely in high-latitudes (cf. Walsh and Crane, 1992). Observations followed with evidence of substantial variability in the Arctic's water column, atmosphere, ice cover, and export to the North Atlantic (e.g. Carmack et al., 1995; Walsh et al., 1996; Rothrock et al., 1999; Belkin et al., 1998). This variability spans temporal scales that include interannual fluctuations, interdecadal patterns, and long-term drift. One scientific challenge is to define the pertinent temporal scales of Arctic variability; that is, to distinguish recurrent modes from trends, and to separate natural from anthropogenic climate forcing. Another challenge is to predict the impact of climate variability on Arctic biota (Tynan and DeMaster, 1997; Carmack and McLaughlin, 2001).

It is here suggested that three main steps can be followed to understand the consequences of a changing physical environment on biota. The first is to examine how basic components of the physical system are linked to climate-scale forcing on seasonal and decadal time scales (time scales wherein which we at least have data); this is addressed in Section 2. The second step is to link the present physical environment (fluxes and habitats) to geochemical and biological distributions, processes and rates; an approach to this issue is discussed in Section 3. The third step is to predict, with scenarios and models, the likely response of key (habitat) domains to predicted future conditions and associated biological impacts; a framework identifying such domains is outlined in Section 4.

2. THE PHYSICAL SYSTEM AND OBSERVATIONS OF VARIABILITY

To start, the Arctic is an interconnected component of the global climate system. The primary 'task' of the latter is to even out a radiation imbalance resulting from excess heat income in the low latitudes and a deficit in the high latitudes (**Figure 1**). This is set in motion in the low latitudes where about half the

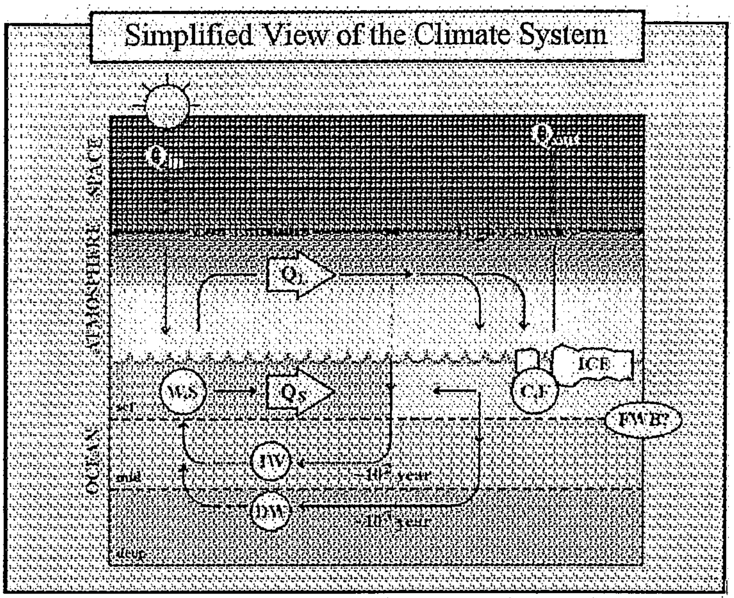

Figure 1 A simple model of the global climate system illustrating the importance of water-borne transport of heat poleward and the requirement to close the freshwater loop.

excesses heat is sent poleward as water vapour (latent heat) in the atmosphere (the fresh water branch), and the other half is sent poleward as warm water (sensible heat) in ocean currents (the salty branch). To keep the low latitudes from growing saltier (by evaporation) the high latitudes must complete the cycle by re-uniting the fresh and salty branches (after they dispose of their excess heat into space) and returning freshwater products to the low latitudes. Thus, in the low latitudes the subtropical gyres collect excess heat and provide water vapour, the western boundary currents carry this heat poleward and the eastern boundary (upwelling) currents bring low salinity waters back to the surface. Low latitude oceans are mainly stratified by temperature. In the high latitudes the return pipes include transport in buoyancy and thermohaline boundary currents, intermediate water sinking along the sub-polar fronts, deepwater sinking on shelves and in gyres and export by ice. High latitude oceans are stratified by their salinity distribution.

It is also important to accept that the Arctic is not a passive component in the global climate system, but rather an active player with potential strong feedbacks. A feedback can be negative or positive, depending on if it damps or amplifies a given mechanism. Consider the three examples shown in **Figure 2**:

- Albedo Feedback – Ice and snow reflect most solar radiation back into space. With initial warming and sea ice melting, more heat enters the ocean, thus melting more sea ice and increasing warming.
- Freshwater Feedback – If the export of freshwater from the Arctic (derived from runoff and ice melt) should increase, then the stratification of the

subarctic North Atlantic would likewise increase, and this would slow deep convection. Decreased overturning would then draw less Atlantic waters into the high-latitudes, leading, potentially, to a shutdown of the global overturning cell.

- Methane Gas Feedback – Vast amounts of methane and carbon dioxide are currently trapped in the permafrost and hydrate layers of the arctic margins. Semiletov, et al., (1996), estimate that ~ 10 X 10^3 Gt of organic carbon is currently stored in the upper 100m of sediments in Siberia alone, and this ignores deep hydrate deposits. As a greenhouse gas (GHG) methane is ~ 60X more active than carbon dioxide. With warming, coastal lakes will act as a thermal drill to tap this GHG source.

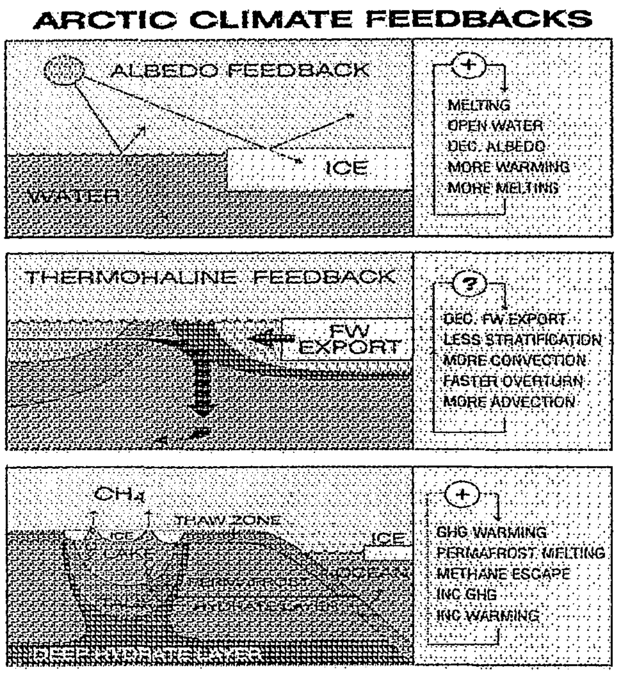

Figure 2 Schematic diagram showing three major feedback processes applicable to the Arctic climate system:

Existing data provides evidence of substantial variability on decadal time scales (**Figure 3**; adapted from McLaughlin et al., 2002). Walsh et al. (1996) drew attention to a downward trend in sea-level pressure over the Arctic in the late 1980's, which Wallace and Thompson (2002) relate to annular modes in the Northern Hemisphere wind field (also referred to as the Arctic Oscillation). Resulting changes in atmospheric forcing were subsequently argued to alter surface currents and ice trajectories (Proshutinsky and Johnson, 1997; Rigor et al., 2000). Observed changes in water column structure included a warming of the Atlantic layer (Carmack et al., 1995; Morison et al., 1998), a frontal shift of Pacific-origin waters (McLaughlin et al., 1996) and a relocation of the so-called cold halocline domain (Steele and Boyd, 1998). Variability in the extent, thickness, and export of sea ice has been argued by Parkinson et al. (1999),

Rothrock et al. (1999) and Kwok and Rothrock (1999). Changes in the pathways of freshwater
export to the North Atlantic via Fram Strait and the Canadian Archipelago are postulated by McLaughlin et al. (2002), and the effect on North Atlantic of such change are noted by Belkin et al. (1998) and Dickson et al. (2000). A comprehensive review of Arctic change is given by Morison et al. (2000).

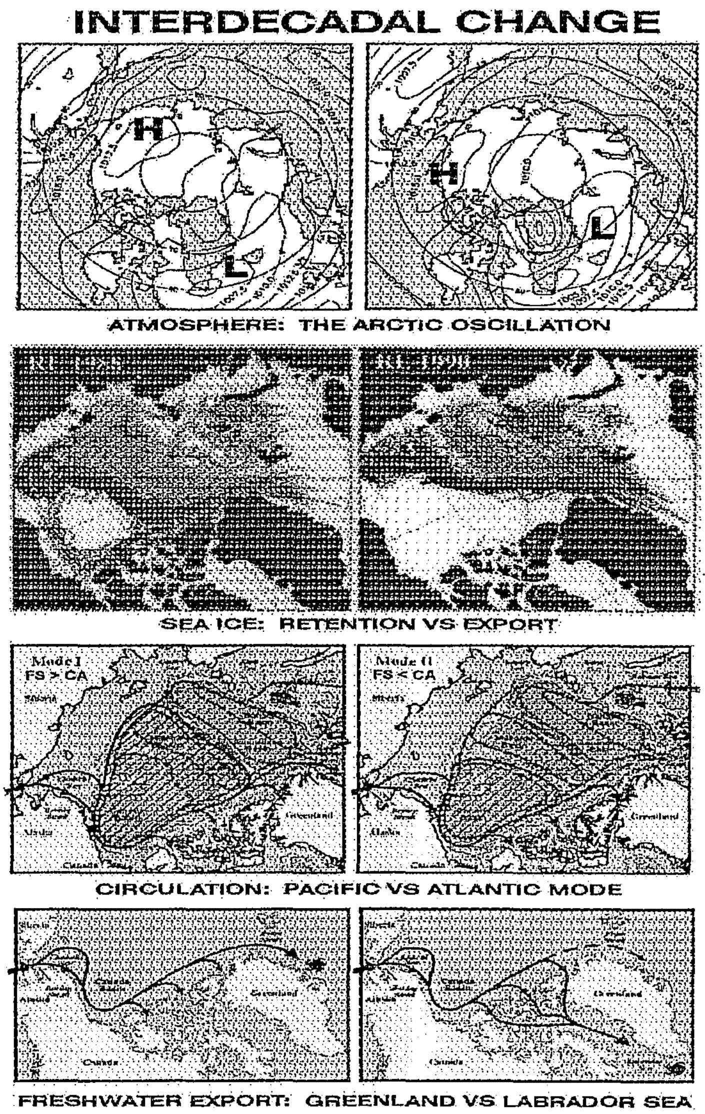

Figure 3 Diagrams summarizing observed, decadal-scale variability in the (a) atmosphere, (c) seaice drift, (c) ocean circulation and (d) export pathways to the northern North Atlantic (figure adopted from McLaughlin 2002).

3. Biological Consequences

Within the Arctic Ocean it is the ice climate, the water masses of the continental shelves and the structure of shelf-break and mid-ocean fronts that will likely be impacted most and first. Such changes will have both bottom-up (e.g. changes in light climate and nutrient availability) and top-down (e.g. changes in ice-based habitat, altered migration cues) ecological consequences. Bottom-up trophic dynamics holds that physics drives chemistry, which then drives primary production, and so on to the top predators. Because ecosystems are complex this approach – by itself - is flawed. The top-down perspective, on the other hand, sees predators as affecting the underlying food web. Consider two inverted triangles to show how bottom-up and top-down effects may work in Arctic ecosystems (**Figure 4a**). The bottom-up triangle posits that the base of the trophic pyramid depends on resource availability and is grounded on the primary producers. The top-down triangle, on the other hand, predicts that top predators can cascade across multiple trophic levels and on down the food chain to regulate producer populations at the base of the trophic pyramid. In the long (but simple) food chain of the arctic, both views are likely required. For example, a phytoplankton bloom in the ocean can result from either improved light and/or nutrient conditions (bottom-up) or from the removal of grazers.

In a simplified Arctic setting (**Figure 4b**) the ice cover, water column, lateral advection and shelf-basin exchange processes are all the traditional purveyance of the physical scientist, and all have critical bottom-up influence. But there are top down consequences too. Retreat of sea ice may remove the top predators such as seals from the food web, and this will reduce grazing pressure on Arctic cod. Advection may import hungry zooplankton or fish from far-field environments. This alone may determine if the upper water column retains and recycles resources, or if it export them to the benthos. Bottom stirring may engage the microbial loop. Wassmann (1998) gives a thoughtful discussion of this coupling.

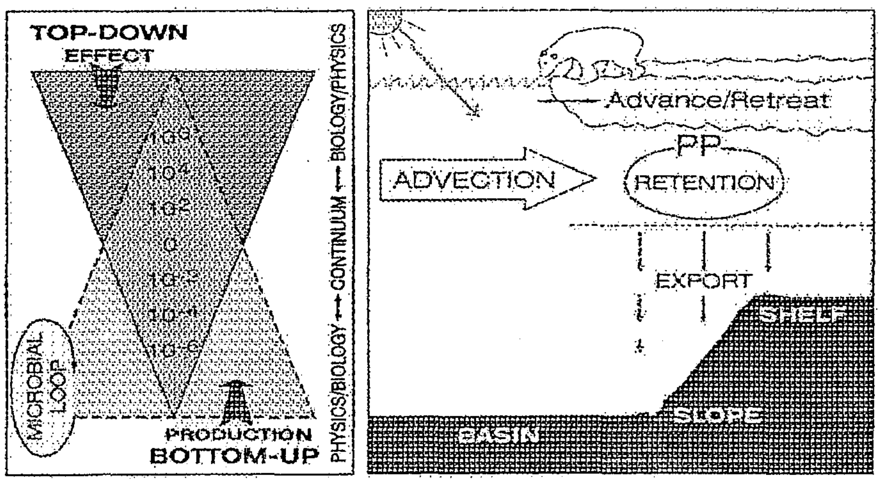

Figure 4 Schematic diagrams illustrating (a) the joint relationship of bottom-up and top-down trophic dynamics (from Mazumdar, pers. comm.), and (b) a simplified picture of factors affecting Arctic biota.

4. A Discussion of Scale

How do we attempt to predict the likely biological response to new environmental (physical) conditions? One approach is to be guided by scale (cf. Levin, 1992). Consider, for example, three hypothetical "climate scale" domains applicable to the Northern Hemisphere:

- The Seasonal Ice Zone (SIZ) of annually freezing and melting sea ice.
- The Riverine Coastal Domain (RCD) driven by freshwater runoff and ice melt.
- The Pacific Water Patch (PWP) of Pacific-origin water stored within the Arctic halocline.

Each of these domains is contiguous. Each is sufficiently large to link directly to and vary substantially with climate forcing. Each potentially carries both bottom-up and top-down impacts.

The Seasonal Ice Zone (SIZ): Each year over 7 X 10^6 km^2 of sea-ice freezes and melts in the Arctic. The top of this solid cover serves as floating platform for many large mammals, such as polar bears and seals, while the underside provides a rich habitat for plankton and fish. Shrinking and/or thinning this platform will thus impact the geographical range and survival of many Arctic species. As well, shorter duration of ice cover by earlier break-up and later freeze-up will impact on the timing of critical annual cycles. From a bottom-up perspective, retreat of the SIZ into the central Arctic basins will impact nutrient availability on shelves during summer and autumn through increased mixing and upwelling. Longer ice-free periods will increase underwater light (At present, ice lingers through May and June, months of high insolation.) A delayed freeze-up will expose more open water to forcing by autumn storms. Taking a top-down view climate change in the Arctic Ocean may pose a threat of extinction to seals that require snow and ice to birth their young and to polar bears that hunt only from sea ice. Removal and/or replacement of such predators from the adaptive ecosystem will clearly have top-down consequences.

Riverine Coastal Domain (RCD): A key process in the transport of fresh water through the Arctic is via buoyancy-boundary currents (BBCs; Arfeuille et al., 2002), which form when fresh, low-density river water enters the higher-density sea, and are deflected to the right by the Coriolis force. In the Northern Hemisphere, BBCs travel in a clockwise sense, with land to the right in the direction of flow. The Rossby radius $R_R = (g^*h)^{1/2}/f$ - where g^* is the reduced gravity, h is depth, and f the Coriolis term – roughly defines the width of BBCs; in the Arctic $R_R \sim 10$ km. The multiple sources of river input from North America, combined with ice melt, may effect a quasi-contiguous domain, here called the Riverine Coastal Domain (RCD), which extends around the northern part of the continent. The RCD concept is highly idealized in that it ignores wind and tidal forcing. However, it potentially provides an important migration and dispersal corridor for biota. Taking a bottom-up view, some consequences of climate variability on the RCD are evident. Climate models predict increased precipitation in high-latitudes under greenhouse gas warming (see CHAMP, 2001). This may result in altered runoff and export of terrestrial carbon (POC, DOC) to coastal ecosystems. Increased runoff may also alter erosion, suspended load transport, and thus the turbidity and light climate of coastal waters. Top-down impacts may be even more important, as such a pathways play a major role in plankton dispersal. Many anadromous fish species (salmon, cisco, char) use the RCD as a migration (and perhaps navigation) pathway.

The Pacific Water Patch (PWP): Pacific-origin waters flow north through Bering Strait and enter the Arctic basin north of the shallow Chukchi Sea at depths between ~ 80 and 220 m. Pacific-origin waters are distinguished by a shallow temperature maximum, a deeper temperature minimum and generally elevated nutrient levels. Historical data (e.g. prior to the 1990's) depict this water as spreading as far as the Lomonosov Ridge, thus covering the Canada and Makarov basins. In the 1990's, however, the lateral boundary or front separating Pacific- from Atlantic-origin waters was observed to retreat from the Makarov Basin (McLaughlin et al., 1996). Again, both bottom-up (associated with an alteration of the nutrient regime and stratification) and top-down (associated with grazer communities derived from the Pacific) might be expected, and require further inquiry.

5. Summary

The objective of this note has been to present a conceptual framework for study of Arctic climate variability and its impact on northern ecosystems. First, distinct components of the climate system (e.g. SIZ, RCD, PWP) are identified. Second, their relationship to biota (e.g. bottom-up and top-down dynamics) is established. Third, biological consequences of change are predicted in the context of expected and reasonable variability. Correlation with large-scale climate structures (e.g. the Polar Vortex) and associated indices (e.g. the Northern Hemisphere Annular Mode) offer promise of predictive capability of these domains on time scales ranging from seasonal to interannual (J. Overland, PMEL, pers. comm.; Wallace and Thompson, 2002).

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BIOPHYSICAL MODELING OF THE EARLY LIFE STAGES OF FISHES AND INVERTEBRATES IN THE GULF OF ST. LAWRENCE AND NORTH-EAST SCOTIAN SHELF

Joël Chassé (Bedford Institute of Oceanography)

Climate change may have potential effects on the stocks of marine fish and invertebrates in Eastern Canada. Using a model-based approach, the relative effects of circulation, temperature, salinity and trophodynamic processes on the populations of larval cod, lobster and crab are being studied in the Gulf of St. Lawrence and northeastern Scotian Shelf. A generic biophysical semi-lagrangian model is developed to study these processes. The initial developments focus on improving the biological-physical coupling by developing Individual-Based Models (IBM) of growth and mortality of eggs, larvae and post-larvae in relation to environmental conditions. These are incorporated into a full 3-D hydrodynamic model of the ocean. The physical component is a high-resolution prognostic model capable of long term advection-diffusion of the temperature and salinity fields. The main biological input to the model is the parameterisation of the distribution and abundance of the early stages of the life cycle as well as growth and mortality rates. Preliminary results, of a ten year long simulation, show large-scale drifts and exportation of snow crab larvae from the southern Gulf of St. Lawrence to the Scotian shelf before settlement at the bottom. This exportation from the Gulf is correlated with variations of the wind field. For the early life stages of cod, the retention in the Gulf is more important due mainly to a deeper vertical distribution of the larvae A sensitivity study to temperature shows that the survival of larvae is highly non-linear, i.e. increasing rapidly with temperature.

SEASONAL AND INTERANNUAL CHANGES IN THE UPPER WATERS OF THE LABRADOR SEA

Allyn Clarke, Ross Hendry and Igor Yashayaev (Bedford Institute of Oceanography)

The upper waters of the Labrador Sea consist of the cold low salinity shelf waters of Arctic origin carried to the Greenland and Labrador shelves by the East Greenland and Labrador currents, the warm salty waters carried from the Irminger Sea by the cyclonic circulation around the sub-polar gyre and the weakly stratified waters of the central Labrador Sea. The presence of the warm Irminger waters over the SW Greenland slope keeps this region largely ice free throughout the year. The Irminger waters also appear to form eddy structures, which move westward into the interior of the Labrador Sea. The waters of Davis Strait and the Labrador shelf are ice covered. Ice begins forming along the coasts in November and by the end of March of severe winters can extend out to the 2500 metre isobath. The ice retreats over May, June and early July.

Over the seasonal cycle, the central Labrador Sea loses heat (15 Wm^{-2}) and gains fresh water (0.2 m/yr.) through air-sea exchange although these estimates are poorly constrained. In terms of the buoyancy flux, cooling dominates over freshening driving convective renewal of intermediate waters. The thermohaline circulation associated with these intermediate waters transports the added freshwater out of the surface layers of the Labrador Sea so as to maintain the weakly stratified conditions that favour convection in the following years. Depending of the severity of the winter, convection by the end of March can extend to depths of a few hundred metres to 2400 metres. At the end of the cooling season, a shallow low salinity surface layer quickly forms across the entire Labrador Sea.

Strong interannual variability of the upper waters of the Labrador Sea is thought to arise through strong changes in the severity of winter conditions. This variation is linked to the North Atlantic Oscillation pattern. The Labrador Sea was well observed from the late 50s to the mid 70s and again in the 90s. We are fortunate to have captured a full range of strong and weakly convective winters through the last half century.

TOPEX/POSEIDON OBSERVATIONS OF INTERANNUAL SEA LEVEL VARIABILITY IN THE SCOTIA-MAINE REGION

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ABSTRACT

The TOPEX/Poseidon altimeter data over the period 1992-99 have been analyzed to examine interannual sea level variability in the Scotia-Maine region (defined as the outer Laurentian Channel, the Scotian Shelf, the Gulf of Maine and the Middle Atlantic Bight). Altimetric data reveal significant interannual sea level variability of magnitude of 5-10 cm in the 1990s, falling to the lowest in 1994, then rising to the highest in 1997-98 and falling again afterwards. The second sea level decrease shows an overall equatorward propagation. The altimetric results are generally consistent with those detected from coastal tide-gauge data. The interannual sea level variability is thought to be forced by fluctuations of the Gulf Stream position and of the baroclinic Labrador Current transport.

INTRODUCTION

The Scotia-Maine region from the Laurentian Channel in the north to the Middle Atlantic Bight in the south (Fig. 1) is subject to strong influences of the sub-polar gyre and the sub-tropic gyre (Loder et al., 1998). The shelf edge current, as an extension of the Labrador Current off Labrador and Newfoundland carrying colder and less saline water of Arctic origin, continues equatorward along the upper continental slope, and intrudes onto the shelf through cross-shelf channels (Petrie and Drinkwater, 1993; Drinkwater et al., 2000). It carries the mixed water derived from the Labrador Current Water and the warmer and more saline Slope Water offshore.

Recent ocean climate changes in this region have been studied in a number of aspects, and efforts have been made to explain mechanisms underlying these climatic events. Thompson (1986) by examining sea level data from the east coast of North America for the period 1950 to 1975 found that wind stresses and air pressure were only small contributors to the interannual changes of the coastal sea level. Petrie and Drinkwater (1993) reported high coherence in the decadal scale variation in the Scotian Shelf-Gulf of Maine region with the lowest temperature values in the mid-1960s. They suggested the changes in the offshore slope waters were the principal cause. Umoh (1995) showed that interannual temperature variability on the Scotian Shelf could not be accounted for by the atmospheric heat flux variability. Drinkwater et al. (2000) studied from the hydrographic data the interannual variability of the Slope Water properties and effects on the adjacent shelves. Petrie and Loucks (2000) using coastal tide gauge data along the eastern North America examined the sea level change in the past century. They found that post-glacier rebound accounted for most of the sea level trend over the century and the steric height contributed comparably for the period from 1971 to 1994.

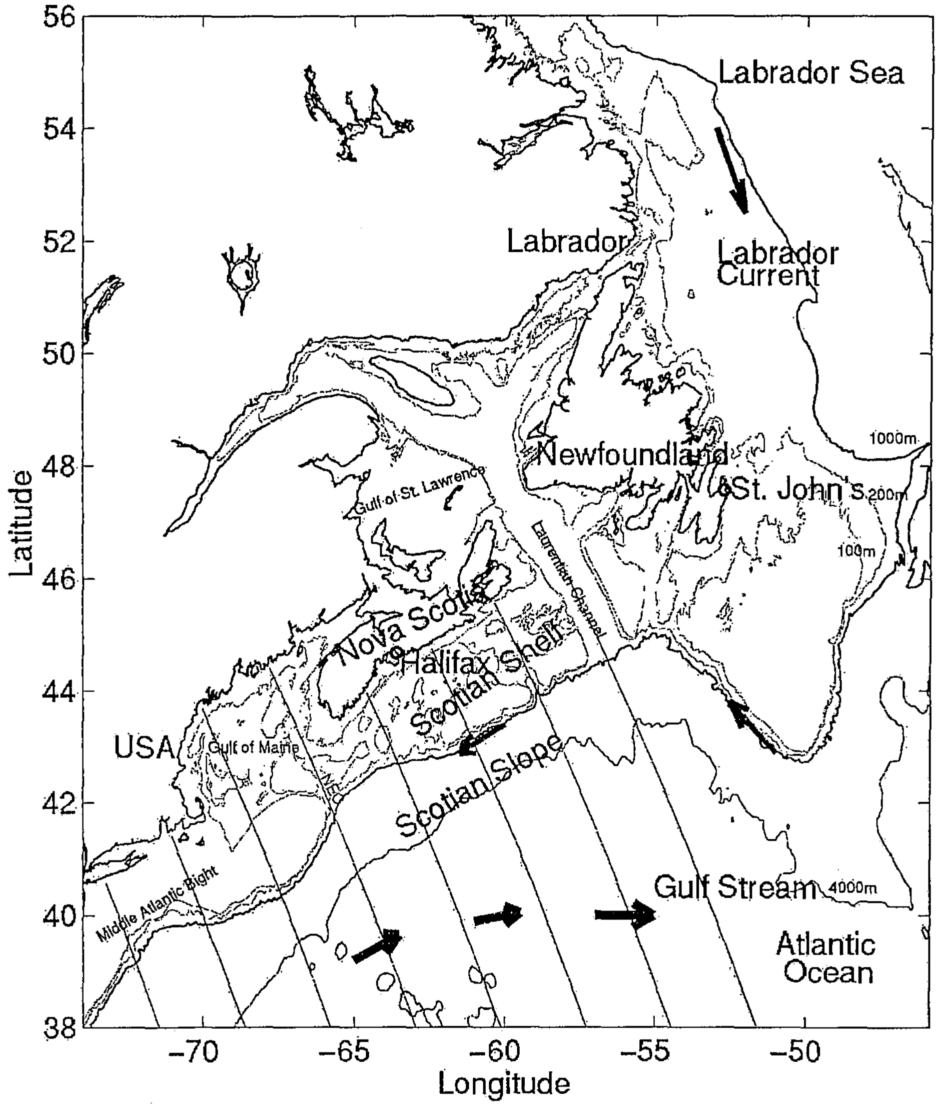

Figure 1: Map showing the study area. Open circles are the locations of coastal tide-gauge stations. The solid lines stand for the T/P descending ground tracks. The 100-, 200-, 1000-m and 4000-m isobaths are shown. NEC: Northeast Channel.

The primary purpose of this study is to examine interannual sea level change in the Scotia-Maine region for the period from 1992-99 using TOPEX/Poseidon (T/P) satellite altimetry and to explore mechanisms underlying the interannual variability. We first remove an annual cycle and residual tides from altimetric sea surface heights for each location on selected T/P ground tracks. The altimetric sea surface heights, together with tide-gauge data, are used to examine interannual sea level changes. The shelf climate changes are then discussed in the context of the large-scale shelf-edge currents associated with the sub-polar gyre and the position of the Gulf Stream. This study serves as a prelude to an integrated study of the Labrador Current variability off Labrador and Newfoundland and the shelf-edge current variability off the Scotia-Maine region, their impacts on the northwestern Atlantic shelf's physical environment and biological productivity, and their mechanisms in relation to large-scale atmospheric variability and oceanic circulation in the North Atlantic.

METHODOLOGY

Altimeter Data Processing:

The altimetric sea surface height data from the US-France T/P mission are the primary data for this study. The T/P satellite, launched in August 1992, has a repeat cycle of 10 days. In this study we have used the data on descending ground tracks (approximately aligned in the cross-shelf direction and perpendicular to the dominant shelf-scale flows) for the period from October 1992 to December 1999 (see Fig. 1).

Data are edited based on quality flags and parameter ranges as recommended and corrected for various instrumental and environmental effects as described in the user handbook [Benada, 1997] and in Han et al. (2001). A mean sea-surface height is computed at each grid point from all available data, and then the mean is removed from the individual height data, producing sea surface height anomalies. Both the marine geoid and mean dynamic topography are removed by this procedure. We apply a modified response analysis (Cartwright and Ray, 1990; Han et al., 2001) to the corrected T/P sea surface height anomalies to remove the annual cycle and the variability at the alias frequencies of major semidiurnal and diurnal tides. The residual time series after the removal are then analyzed to examine the interannual sea level variability.

Tide-Guage Data:

The tide-gauge data used in this study are 1-h sea level observations at Halifax, Nova Scotia and St. John's, Newfoundland obtained from Marine Environmental Data Service. Monthly-mean values are calculated from 1-h data for the period from 1992 to 1999. The monthly-mean sea levels are adjusted for the atmospheric effects using local atmospheric pressure data obtained from Environmental Canada. Then we calculated the monthly-mean sea level anomalies by removing means from the adjusted sea levels. A least squares regression is performed to eliminate annual and semi-annual cycles from the monthly anomalies. The monthly data are then used to generate seasonal sea level anomalies that are further smoothed with a temporal 5-point moving filter.

RESULTS

For each selected ground track, the T/P sea level anomalies are first averaged seasonally (Jan-Mar, Apr-Jun, Jul-Sep, and Oct-Dec for winter, spring, summer and fall respectively) at each location and then averaged spatially for the shelf segment inshore of the 1000-m isobath. The seasonal, spatially averaged anomalies and further smoothed using a temporal 5-point moving filter, as done for the tide-gauge data. For the Laurentian Channel track, the inshore limit is at Cabot Strait. The results are presented separately based on locations: the Laurentian Channel, the eastern Scotian Shelf, the central and western Scotian Shelf, the Gulf of Maine and the Middle Atlantic Bight.

A sea level fall before 1994, a rise after 1994 and a drop from 1997 with ranges of 5-10 cm were a general pattern from the Laurentian Channel to the Middle Atlantic Bight (Fig. 2). The lowest and highest sea level events seemingly propagate southwestward, while the precise timing depends on locations. The Laurentian Channel sea level (Fig. 2a) had a decline trend (a total fall of 2 cm or so) until 1994, then the sea level started to rise until 1996 (5 cm). It fell again in early 1997 and remained low afterwards (4 cm). The sea level variability over the eastern Scotian Shelf (Fig. 2b) was quite similar. The sea level on the central and western Scotian Shelf (Fig. 2c) exhibited a stronger fluctuation (a 5-cm decline, 7-cm rise and 4-cm fall again). A correlation analysis suggests a phase lag of nine months or so between the Laurentian Channel and the central and western Scotian Shelf. In the Gulf of Maine, the magnitude of the sea level variation around 1993-94 differed substantially for the two tracks: 7 cm on the west versus 4 cm on the east (Fig. 2d). Note that the eastern track goes right through the Northeast Channel to the east of the Scotian Shelf. The subsequent sea level changes were also quite different for the two tracks. The sea level on the eastern track started to fall gently in early 1997, while that on the western track did not fall until 1998. In the Middle Atlantic Bight, the initial sea level drop (6 cm) lasted until late 1994, and the sea level started to decline again in 1998 after a 7 cm increase between 1994 and 1997 (Fig. 2e). Correlation analyses suggest a less than three-month lag between the central and western Scotian Shelf and the Gulf of Maine and a three-month or longer lag between the Gulf of Maine and the Middle Atlantic Bight.

The sea level drop at the similar timeframe was also observed by tide-gauge data at Halifax (Fig. 3). Analyses indicate that the T/P sea level for the central and western Scotian Shelf is in nearly perfect correlation with the Halifax tide-gauge data, but with a notable discrepancy in their magnitudes. The range of the interannual variability amounts to 10 cm for the tide-gauge measurements, much greater than that from the T/P data. The discrepancy is not surprising since the tide-gauge data represent the condition at a specific coastal location, but the T/P data as calculated here are spatial means on the track segments over the nearby open shelf. On the other hand, the T/P altimeter measures a geocentric height, while tide gauge measures the sea level relative to the local seabed. Any interannual change of the bedrock elevation would affect the tide-gauge measurement of the sea level fluctuation (e.g. Petrie and Loucks, 2000), depending on scales of interest.

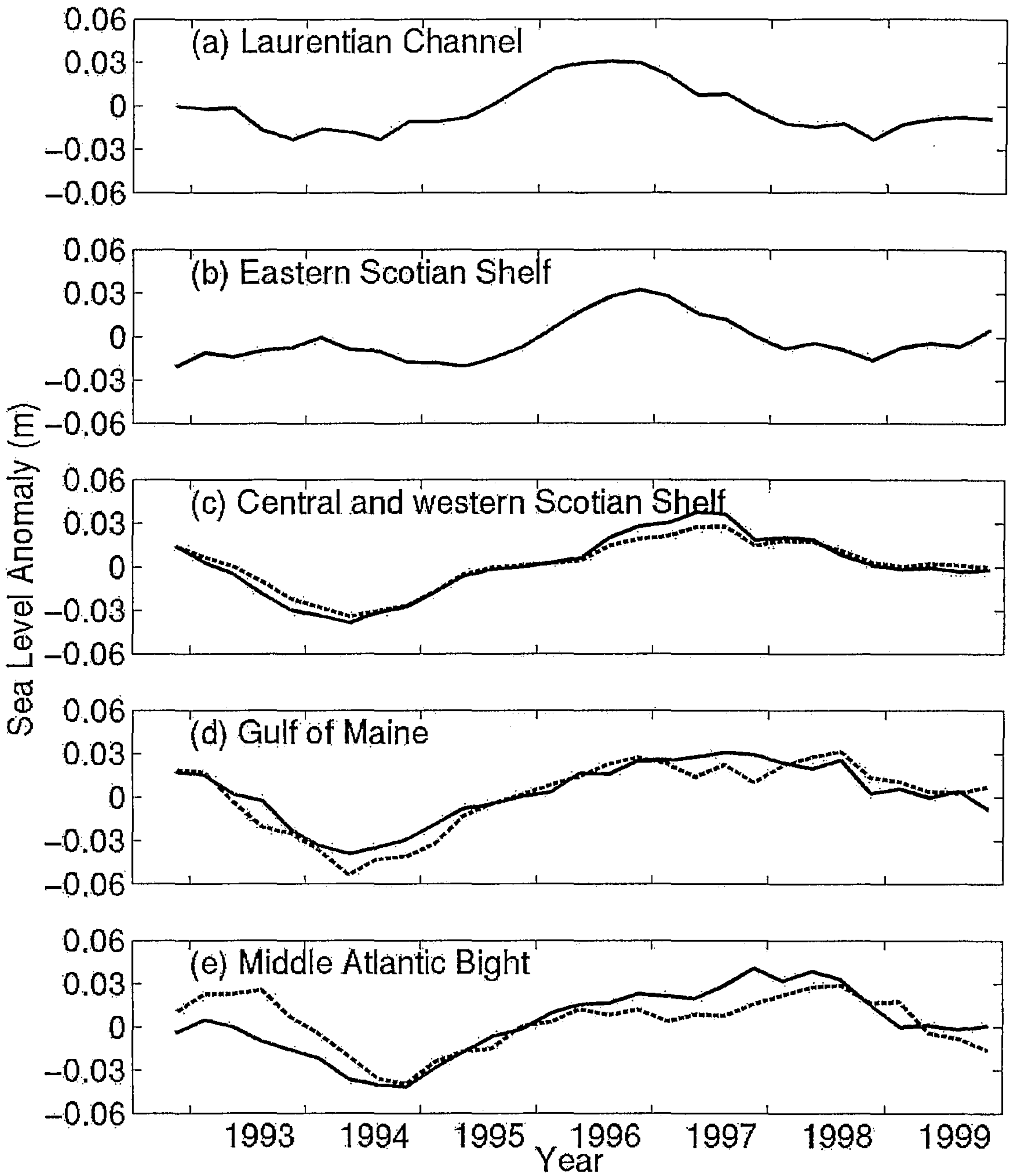

Figure 2: Seasonal-mean T/P sea level anomalies for the tracks over (a) the Laurentian Channel, (b) the eastern Scotian Shelf, (c) the central and western Scotian Shelf, (d) the Gulf of Maine, and (e) the Middle Atlantic Bight. In (c) – (e) the solid line is for the eastern track and the dashed line is for the western track.

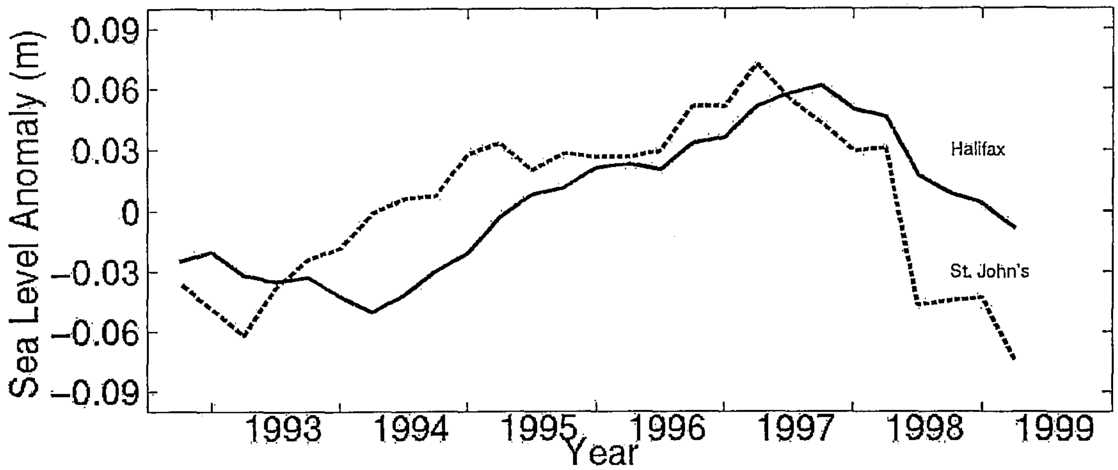

Figure 3: Seasonal-mean sea level anomalies derived from tide-gauge data at Halifax and St. John's.

The interannual sea level variability in the Scotia-Maine region can be caused by a number of factors, of both oceanographic and atmospheric origins. The regional circulation variability is in part a response to the fluctuations of the Labrador Current and the Gulf of St. Lawrence outflow and to shelf-ocean exchange associated with the fluctuation of the Gulf Stream. Local air temperature, wind and precipitation over the Scotian Shelf and in the Gulf of Maine and the Middle Atlantic Bight are also factors impacting heat and water fluxes across the sea surface. They affect water properties and steric heights directly and dynamic sea level indirectly. Earlier studies indicated that the contributions of the wind stresses and air pressure to the interannual sea level variability were small (Thompson, 1986) and atmospheric heat fluxes could not account for the interannual temperature variability over the Scotian Shelf (Umoh and Thompson, 1994).

We conjecture that the interannual sea level variability is related to fluctuations of the Labrador Current and the Gulf Stream position. The sea level change in the Scotia-Maine region appears initially to be associated with the change of the position of the Gulf Stream. In 1993-94, the Gulf Stream was in its most northern position off Nova Scotia and the eastern United States (Fig. 4b), with the sea level in the Scotian-Maine region being the lowest. After that, the Gulf Stream retreated southward, and the sea level over the shelf started to rise. The onshore slope also started to increase, resulting in a larger southwestward shelf-edge/slope current. The offshore retreat of the Gulf Stream also provides a favorable environment for a further penetration of the Labrador Current equatorward along the shelf-edge and slope and shoreward onto the shelf along the cross-shelf channel. Han and Tang (2001) by combining the satellite altimetry and hydrographic data calculated spring/summer transport anomalies of the Labrador Current. They found significant interannual transport variation in the 1990s. The baroclinic Labrador Current in 1995-96 was strongest off central

Labrador (Fig. 4a). Hereafter, we call this Labrador Current intensification the cold Labrador Current pulse.

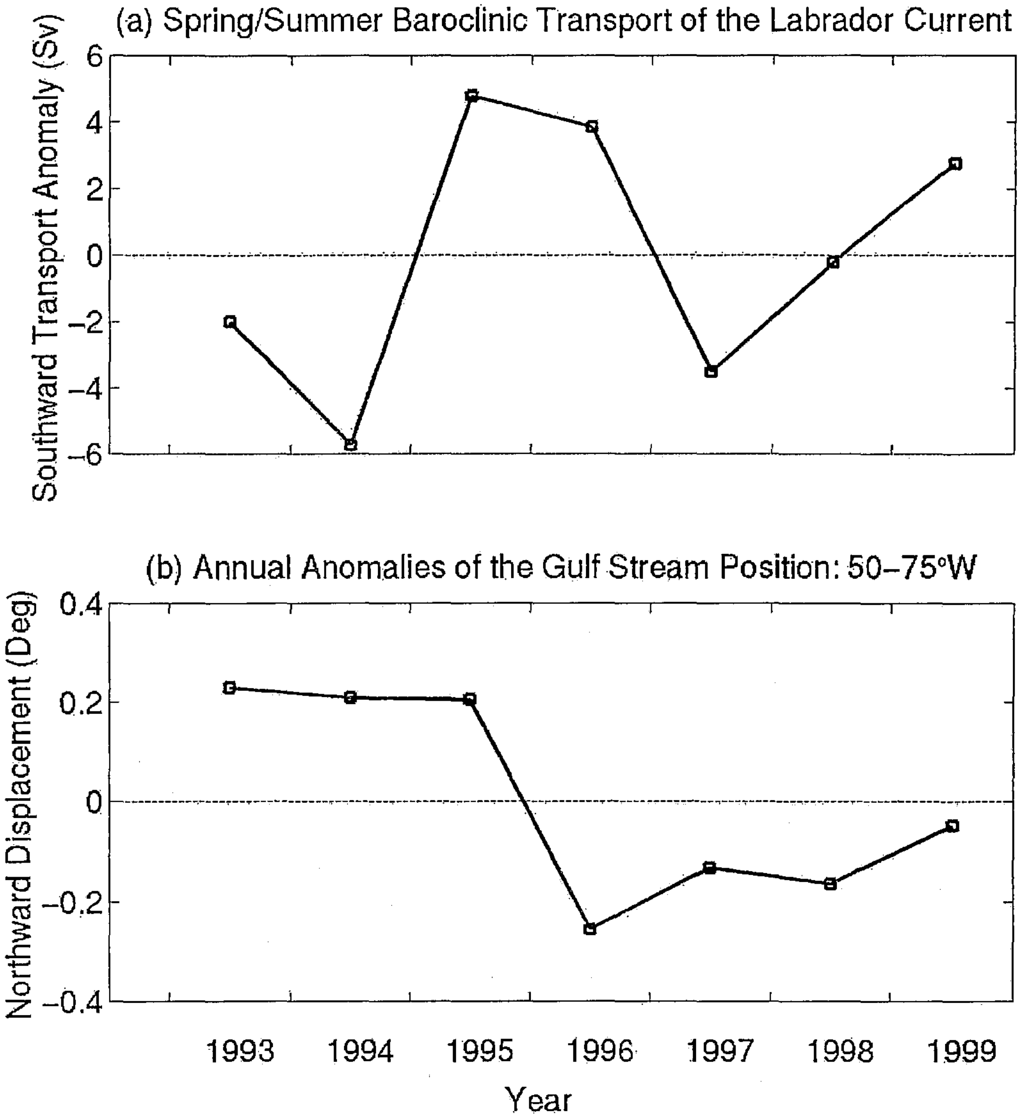

Figure 4 (a) Variation of the spring/summer baroclinic transport of the Labrador Current, adapted from Fig. 8a of Han and Tang (2001), and (b) annual anomalies of the Gulf Stream position: 50-75W (K. Drinkwater and R. Pettipas, personal communication, 2000).

The cold Labrador Current pulse did not arrive at the Newfoundland Shelf until early 1997, as suggested in tide gauge data at St. John's, Newfoundland (Fig. 3) and indicated in the hydrographic data off the Southwestern Newfoundland Shelf (P.C. Smith, personal communication, 2000). The tide-gauge data showed a sea level drop at St. John's in early 1997. The sea level variations at St. John's and Halifax had a nine-month lag, similar to that of altimetric observations from the Laurentian Channel to the central and western Scotian Shelf. Smith observed the anomalously cold water off the southwestern Newfoundland Shelf in early 1997, and the event lasted about a year. The occupation of the cold Labrador Current water reduces the steric height (P.C. Smith, personal communication, 2000). The further penetration onto the Scotian Shelf may be more complicated due to the presence of the deeper Laurentian Channel and direct interactions with offshore warm slope water. The arrival of the cold Labrador Current pulse off the eastern Scotian Shelf was indeed indicated in the hydrographic data (Drinkwater et al., 2000). They found the cold Labrador Slope Water intruded into Emerald Basin and western Scotian Shelf in late 1997 and the Gulf of Maine in Feb. 1998 and the Middle Atlantic Bight in April 1998. The timing of the cold water arrival corresponds well with that of altimetric sea level falls at respective locations. After the passage of the cold water pulse, sea level in the entire Scotia-Maine region remained low because the Gulf Stream repositioned back northward.

SUMMARY

We have examined the seasonal-mean sea level anomalies in the Scotia-Maine region for the period from 1992-1999 using T/P altimeter measurements and tide-gauge data. The study revealed a substantial Interannual variation of coastal sea level off Nova Scotia and northeastern United States in the 1990s. After falling to the lowest point in 1994, the sea level rose until late 1997 and fell again afterwards. The magnitude of the interannual variability amounts to 10 cm, comparable to the range of the annual cycle. The phase change shows equatorward progression of the second sea level drop. We conjecture that the sea level drop in/after 1997 is attributed to the arrival of the baroclinic Labrador Current pulse and the sea level rise before 1997 may be related to the southward retreat of the Gulf Stream northern wall. Likewise, the maintenance of the low water level after the passage of the Labrador Current pulse may be related to the northward repositioning of the Gulf Stream. An extensive analysis of altimetry, hydrographic and meteorological data is warranted for an in-depth understanding of the northwestern Atlantic shelf's sea level and transport variability, its forcing mechanisms and impacts on physical environment and biological productivity.

ACKNOWLEDGMENTS

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DISTRIBUTION AND ECOLOGY OF *CALANUS SPP.* IN THE LABRADOR SEA

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ABSTRACT

Three species of copepod of the genus *Calanus* generally make up 80% of the zooplankton biomass in the Labrador Sea in spring and early summer. *Calanus finmarchicus* is abundant everywhere, but is especially dominant in central regions. *C. hyperboreus* is generally more important on the Labrador and Greenland shelves than in deep water and *C. glacialis* only occurs over the shelves. Patterns of abundance of *C. finmarchicus* result from the interaction of its reproductive cycle and variations in the dynamics of the phytoplankton spring bloom in different areas and different years. In areas where the bloom occurs early, the onset and termination of reproduction are early and large numbers of young stage copepodites develop to form the new generation. In areas where the bloom is late, or of low intensity, the onset of reproduction occurs in May. In such cases it appears that cannibalism of eggs and nauplii by the very abundant egg-laying females leads to very low survival rates.

ENVIRONMENTAL CONDITIONS IN SPRING AND EARLY SUMMER ALONG THE L3 LINE

Since 1995, mesozooplankton abundance and biomass have been assessed for samples collected in the surface layers (0-100 m) of the Labrador Sea. Cruises were in either spring or early summer. Along the L3 section between Hamilton Bank (Labrador Shelf) and Cape Desolation (Greenland) average temperatures (0-50 m) over the central basin were more-or-less constant (*ca.* 3°C) in spring (May 1996, May/Jun 1997, 2000). In early summer (July 1995, June/July 1998,1999) they were also more-or-less constant but *ca.* 2 °C higher. Temperatures over the shelves and along the margins were lower. Integrated nitrate concentrations over much of the central basin in the 0-50 m layer were close to their potential maximum (700 mM/m2) in spring and substantially lower in early summer in 1995 and 1999 (with too little data to say much in 1998) (Fig. 1). Silicate concentrations were also similar and relatively high in spring and much lower in early summer in the central basin. Nitrate and silicate concentrations were generally low over the shelves, in both spring and early summer.

DISTRIBUTION OF CALANUS SPP. IN SPRING AND EARLY SUMMER

Three species of *Calanus* (*Calanus finmarchicus*, *C. hyperboreus* and *C. glacialis*) generally accounted for *ca.* 80 % of the zooplankton biomass, with

Calanus finmarchicus being dominant, especially in deep waters and *C. hyperboreus* being next more important, especially in spring and especially over the Labrador Shelf. *C. finmarchicus* abundance was also generally higher over deep than shallow waters, except in early summer of 1999 when concentrations were high over the Labrador Shelf (Fig. 2). Highest concentrations occurred in early summer in 1995 (off the Newfoundland Shelf and at the eastern end of the L3 line) and 1999 (at the eastern end of the L3 line), and in the spring of 1997 (in the central northern region). *C. hyperboreus*, the next most important species in terms of biomass, was less abundant and also, it was not as ubiquitously distributed as *C. finmarchicus* (Fig. 3). It was more abundant over the Labrador and Greenland shelves and at the shelf margins than in deep water. Over deep water concentrations were higher in the north than farther south (May/Jun 1997). *C. glacialis* was more-or-less confined to the shelves and more abundant in early summer than in spring (Fig. 4). These patterns support the view that *C. finmarchicus* is associated with North Atlantic waters, while *C. hyperboreus* and *C. glacialis* are derived from Arctic waters: *C. hyperboreus* from Baffin Bay (via the Baffin Island Current) and *C. glacialis* from Hudson Bay, via the outflow from Hudson Strait.

CALANUS FINMARCHICUS LIFE HISTORY AND POPULATION DYNAMICS

C. finmarchicus often makes up 70% of the biomass of zooplankton in the study area and various of its life history stages are important food sources to many higher predators, including mackerel, herring, larval groundfish, salmon and baleen whales. These factors render it a species of special interest. *C. finmarchicus* has life history that involves diapause, a resting period spent as a pre-adult "stage 5" at depth during the winter. In spring, it returns to the surface layers to mature to adulthood, to mate and to start laying eggs. The eggs develop into the new generation of immature young stages that feed, grow and develop over the algal growth season. The patterns of total abundance of *C. finmarchicus* are related to the state of development of the population, manifested in the stage structure.

There were variable, but generally high numbers of overwintered pre-adult and adult *C. finmarchicus* in the near-surface waters (0-100m) along the L3 line at deep water stations in spring (Fig. 5). These had probably migrated up from their overwintering depths within the previous 1-2 months. Concentrations of females were lower in early summer than in spring in 1995 and 1999, but not in 1998. Egg production rates of isolated female *C. finmarchicus*, measured during spring (1997, 2000) and early summer (1999), were high (60-70 eggs/female/day) over the central basin, but lower (10-30 eggs/females/day) over the shelves. Rates appeared to be higher in spring than summer, but not significantly so.

Concentrations of young stage copepodites were generally low over the central basin, except in the eastern Labrador Sea in early summer in 1995 and 1999 (Fig. 6), despite the fact that several thousands of females were producing 60-70 eggs per day more-or-less everywhere. By contrast, moderately high concentrations were observed intermittently over the shelves in spring and early summer and in the eastern Labrador Sea in spring of 2000. One reason why young stages might have been absent at many stations may be the timing of sampling *versus* the timing of the onset of reproduction. The first young stage which is sampled efficiently with a 200 micron mesh net is the stage 1 copepodite. At 3°C (spring conditions) it takes an egg about 30 days to hatch and develop to a stage 1 copepodite. At 5°C (early summer conditions) it takes *ca*. 23 days. Thus, if egg-laying had started less than *ca*. 30 or 23 days before a given station was sampled, no stage 1 copepodites would have been present. If this was the cause for the observed distribution patterns, then it implies variability in the timing of the onset of egg-laying between areas and/or years. It is well known that the timing of the onset of reproduction does vary throughout the geographic range of *C. finmarchicus* and it has been suggested that this is caused (in part) by differences in the timing of the spring bloom, since females need to feed to lay eggs. In the Labrador Sea, however, nitrate and silicate showed little depletion in spring (Fig. 1), suggesting the bloom had not occurred by that time. In spring, however, egg production rates were very high. Thus, in the Labrador Sea, egg production apparently starts before the spring bloom. If egg-laying is not dependent on the occurrence of the spring bloom, then it is reasonable to expect that in the years sampling was in early summer (June/July), *C. finmarchicus* females would have been laying eggs in May. This being the case, young stages should have been present more-or-less everywhere in the years when sampling was in early summer. The fact that they were only observed in few areas, suggests that eggs laid in May survived and developed in these areas, while elsewhere they did not.

There are three suggestions that can be made (and have been made in the literature) as to why eggs might not survive and develop. The first is that the eggs do not hatch. It has been suggested that this may happen because of a poor, or toxic, maternal diet, or because of release of toxins by phytoplankton into the water, which act on the eggs. This does not appear to be the case in the Labrador Sea, however, since it was determined that eggs collected during egg production rate experiments showed high hatching success, in the presence or absence of phytoplankton. The second suggestion is that when the hatched eggs have developed through to the first feeding (naupliar stages), there is not enough food or no suitable food in the water, so they starve to death. This is possible, but seems unlikely, because significant algal growth apparently did occur between the time when most eggs were bring laid (spring) and early summer, as evidenced by an appreciable depletion of nutrients during the interim (Fig. 1). The third suggestion is that eggs and nauplii are eaten by predators. Several researchers have observed that female *C. finmarchicus* consume their own eggs in laboratory experiments and they are by far the most abundant potential predators. Extensive cannibalism by females on their own eggs, has recently been put forward to account for observations of *Calanus finmarchicus* abundance in the Norwegian Sea, an area somewhat analogous to the Labrador

Sea. In the Norwegian Sea there were time series measurements at a fixed station. Concentrations of females and areal egg production rates were highest before the spring bloom (as in the Labrador Sea). The new generation, on the other hand, seemed to have been produced from eggs laid during or after the spring bloom. The authors of this paper claim that this is evidence of "self-regulation of population size in *C. finmarchicus*". This ecological interpretation can be questioned, but it does seem plausible that female *C. finmarchicus* may consume significant numbers of their own eggs *in situ*.

In the Labrador Sea data, consistent with the cannibalism idea, very low concentrations of young stages occurred where concentrations of females were high (>10K m-2) (Fig. 7). Very high abundances occurred only where concentrations of females were very low (<2.5K m-2), which was generally in early summer, when numbers of females tended to be lower relative to spring. This is consistent with the seasonal picture in the Norwegian Sea data. Even in early summer, however, young stages were not always abundant where numbers of females were low, and in spring there were four instances where there were moderate numbers of young stages (>19K m-2) where concentrations of females were relatively high (>6K m-2). Each of these latter instances occurred in the eastern Labrador Sea, and each was in a region where nutrients were depleted in spring, relative to most of the central basin, *i.e.* they were areas where the bloom had occurred early relative to most of the basin. These apparently "early bloom" events suggest an explanation as to why *Calanus finmarchicus* females in the Labrador Sea usually produce eggs in advance of the bloom, and why they might consume these eggs in large numbers.

The suggested explanation for this apparently "precocious" egg-laying behaviour, is that sometimes, the bloom may occur early, and when it does, it is essential that female *C. finmarchicus* be ready to respond to it. Sea WiFS colour satellite data from a swath of pixels along the L3 line (1997-2000) show that in some areas and some years, there does not seem to be a pronounced spring bloom, but that when there is one, it may start anytime between April and June (Fig. 8). Thus, *C. finmarchicus* females should be to ready to respond to a spring bloom by April. A scheme that would allow successful reproduction under any circumstances (early bloom, optimally timed bloom, late or no bloom) is presented in Fig. 9. In this scheme overwintered immature females and stage 5 copepodites start to appear in the surface layers in March or early April. If there is an early bloom then the high concentrations of food (phytoplankton) accelerate female maturation leading to the onset of egg-laying very quickly (within *ca.* 1 week). In such circumstances young stages will appear in May. If there is no early bloom maturation will still proceed, but at a slower pace, so that egg-laying will start in May. If the bloom starts in May, the eggs will hatch and the new generation will develop. If the bloom has not started by May, however, the high concentrations of females will eat large numbers, sometimes all, of the eggs that are being laid. After May, if no bloom has occurred, some of the females will start to die off (due to predation or "old-age") and some of the eggs still being laid will be able to survive and develop a new, perhaps small, generation. In this interpretation, cannibalism is not a mechanism for "self-regulation of population size" but a way of sustaining a reproductively actively population over an extended period. It allows *C. finmarchicus*: (1) to fully exploit early and/or timely blooms; (2) to allow the female population to "wait" for late blooms; and, (3) to allow a small new generation to survive even in the absence of any real bloom.

Early blooms appear to be fairly rare on the L3 line, but there is a region where they occur regularly (Fig. 10). In each of the last 4 years there were high surface chlorophyll concentrations in late April in the northeast Labrador Sea. Farther south (in the region of the L3 line) there were traces of chlorophyll in 2000, in the east, which is consistent with our observation that nutrient levels were depleted there in May (Fig. 1). The most likely reason for this regular early blooming in the north is that there is ice across much of Davis Strait each year, which begins to melt in late March. As it does so, the surface layer of melt water is advected to the south east by the prevailing winds, leading to water column stratification throughout the area, and hence to the bloom. Farther south stratification generally is set up by the warming of the surface layers, which occurs later.

The northern region of the Labrador Sea was sampled during the spring cruise of 1997. At that time and in that area, near surface nitrate concentrations, which can be used as an index of the state of the spring bloom, were very low (< 1μM), indicating that the bloom has already occurred (Fig. 11). Farther south and around the basin margin nitrate concentrations were between 1 and 6 μM, indicating a moderate degree of depletion, whereas in the main body of the central Labrador Sea and to the southeast, concentrations were > 6 μM, indicating less nitrate utilisation. These nitrate concentrations suggest areas of "late-bloom", "ongoing-bloom" and "early-bloom" conditions, respectively. In "late bloom" areas, concentrations of *C. finmarchicus* females were intermediate and numbers of young stages were high. In areas where the bloom was "ongoing", concentrations of females were high and those of young stages were either high or low. Finally, in the southeast, where the bloom was in its early stages, concentrations of young stages were low and numbers of females were high. These observations lend further support to the hypothesis illustrated in Fig. 9 as to how *C. finmarchicus* reproduction responds to variations in the annual cycle of phytoplankton growth.

FUTURE RESEARCH QUESTIONS

To this point the population dynamics of *C. finmarchicus* in the Labrador Sea have been considered as an essentially one-dimensional problem. It is evident that over an annual time-scale (the life cycle of *C. finmarchicus*), however, patterns of spatial distribution will be affected, not only by biological processes (phytoplankton dynamics, reproduction, development and mortality rates), but also by hydrodynamics. The Labrador Sea and adjacent slopes are part of the sub-polar gyre. Transport rates between areas (*e.g.* Irminger Sea, Labrador Sea) are high enough to allow for significant advective transport of *C. finmarchicus* in the surface layers within the annual growth period, especially in the basin margins, and at depth during the *ca.* 6 month overwintering period. The extensive sampling needed to observe the spatial/temporal patterns of events year-round throughout the Labrador Sea, let alone the entire sub-polar gyre, is obviously not practical. An approach which incorporates observations, and life-history and hydrodynamics modelling seems more realistic. An opportunity for such a study is presenting itself in the 2002 field season, when a group from the UK will be sampling spring-summer and fall over a grid in the Irminger Sea. The Ocean Sciences Division at BIO are hoping to collect data on the spatial and vertical distribution of *Calanus finmarchicus* in the Labrador Sea in early summer and early winter. This information will be used in the development of a life-history/hydrodynamics model for *C. finmarchicus* for the entire sub-polar gyre that is one of the objectives of the UK team. The overall aim is to be able to predict how changes in climate (including hyrodynamics, hydrography and spring bloom dynamics) will affect the overall abundance and space-time dynamics of *C. finmarchicus* in the sub-polar gyre, and the potential implications for processes on the fringing continental shelves (*e.g.* fisheries).

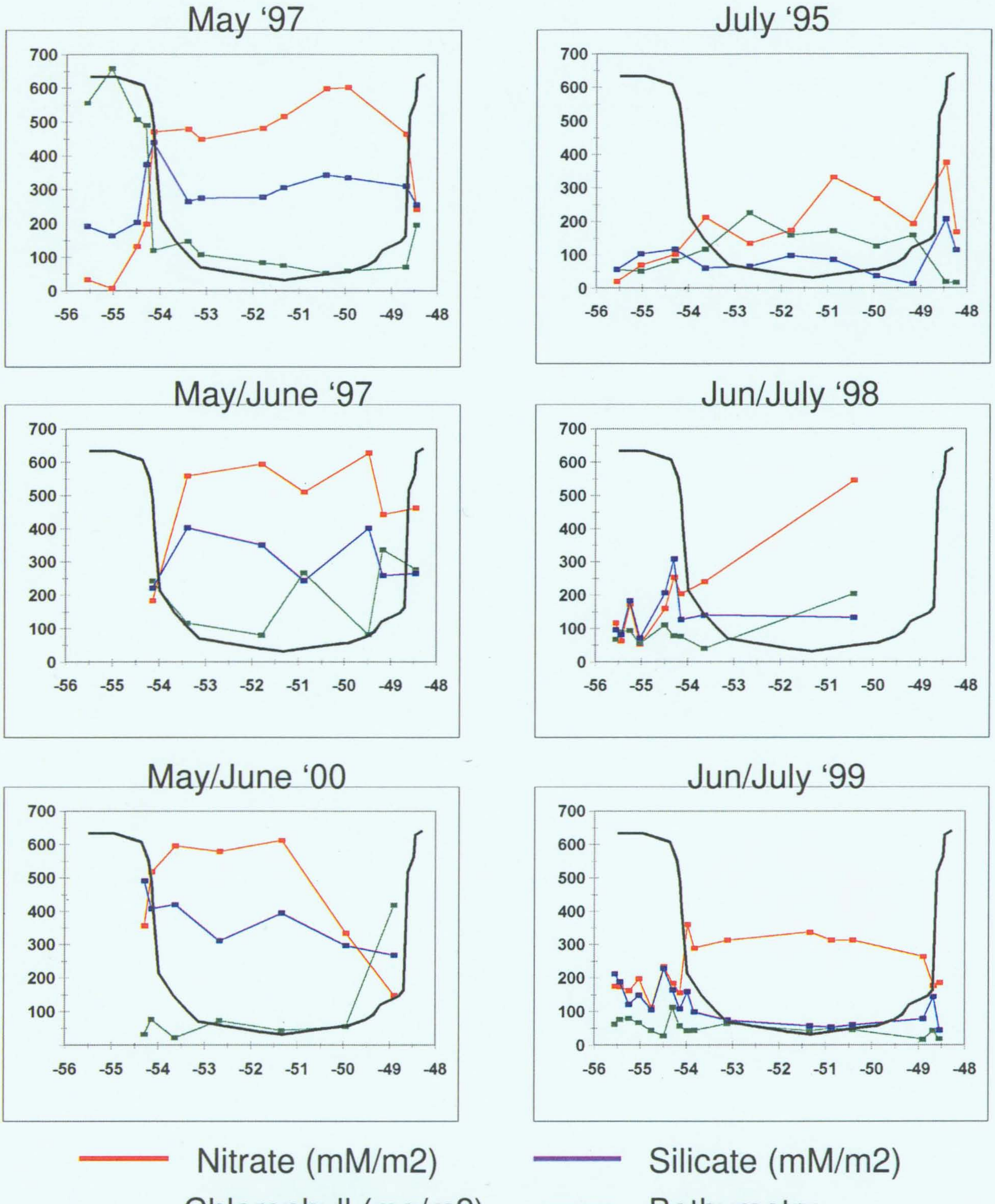

Figure 1: Nitrate, silicate and chlorophyll concentrations along the L3 section

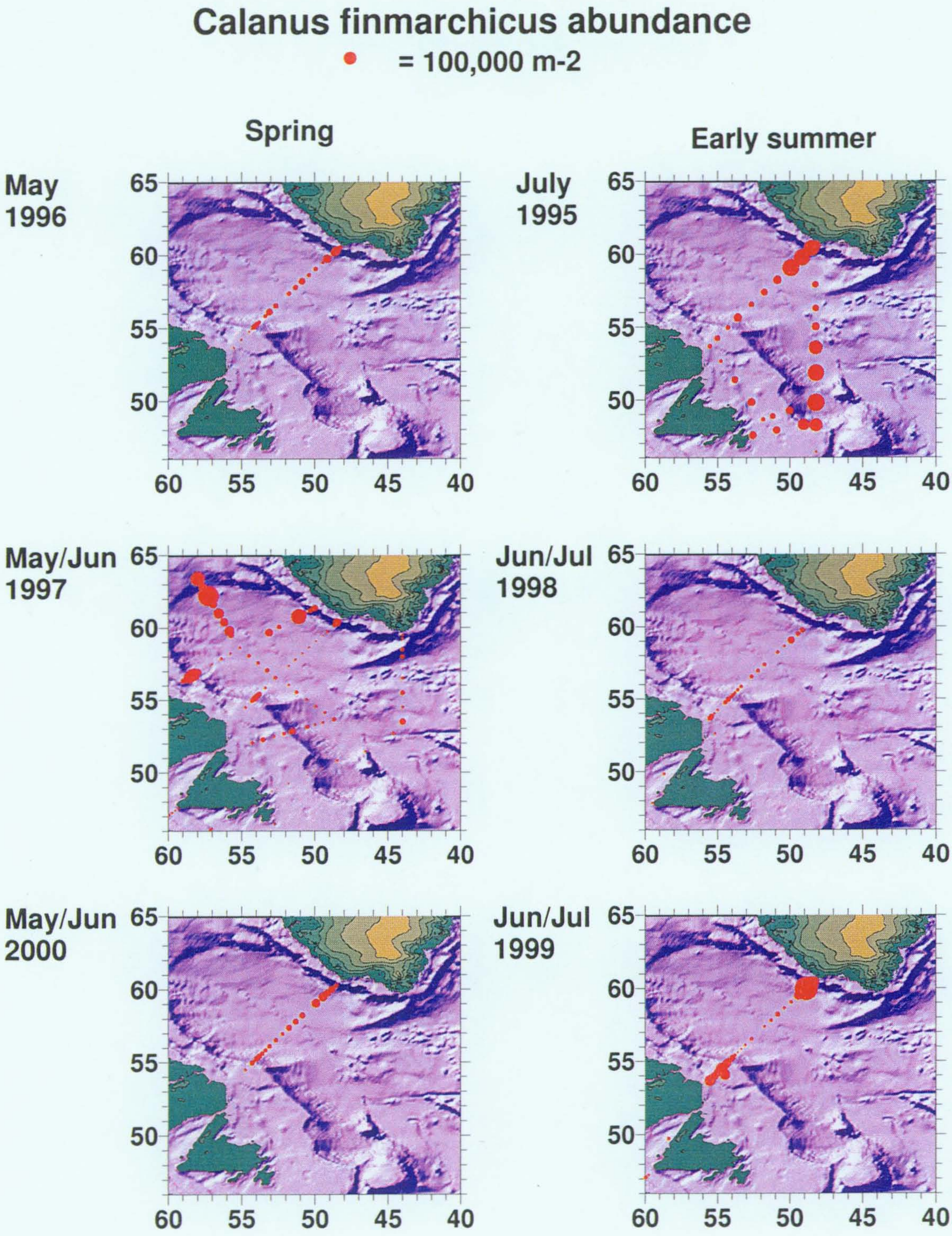

Figure 2. *Calanus finmarchicus* abundance in the Labrador Sea 1995-2000

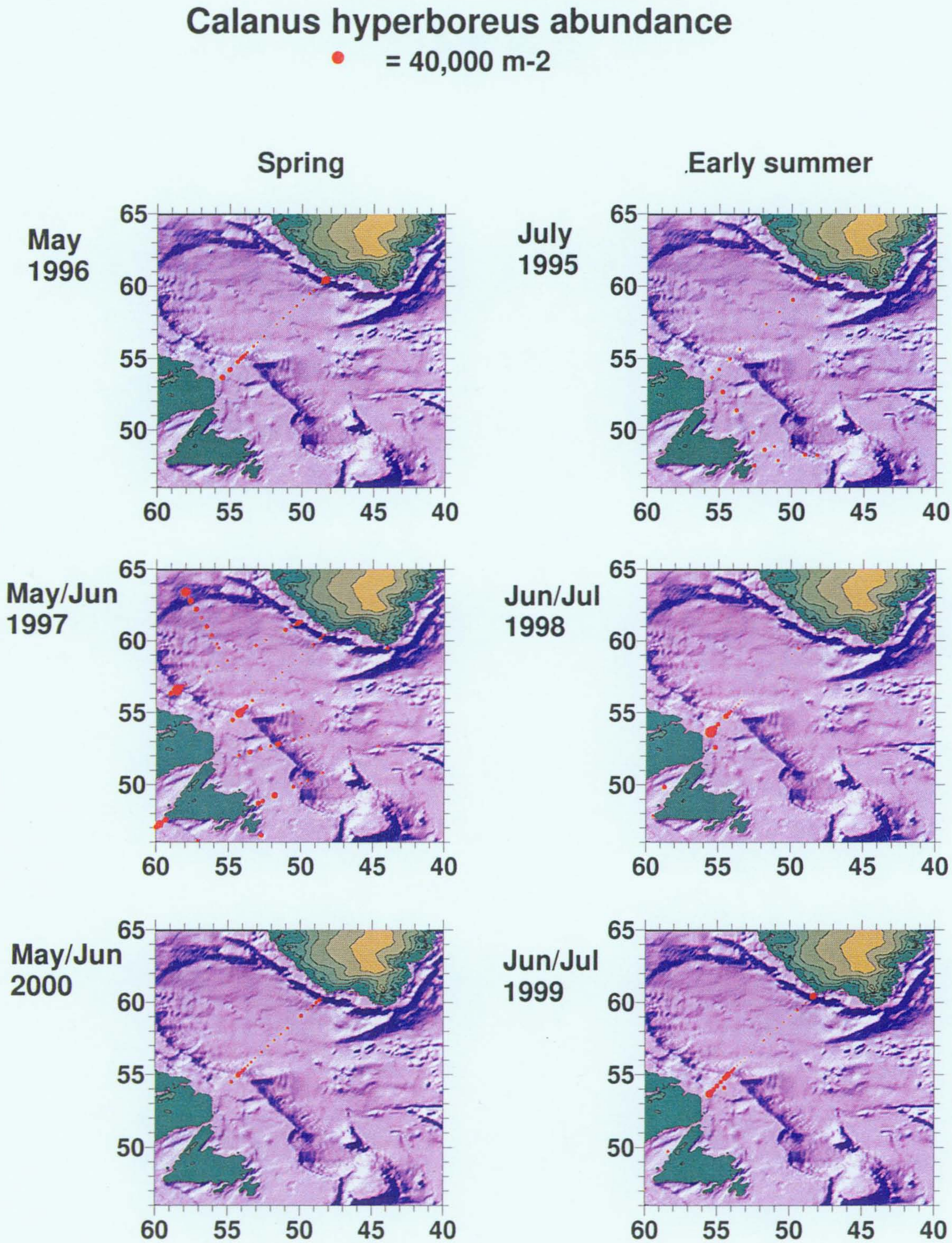

Figure 3. *Calanus hyperboreus* abundance in the Labrador Sea

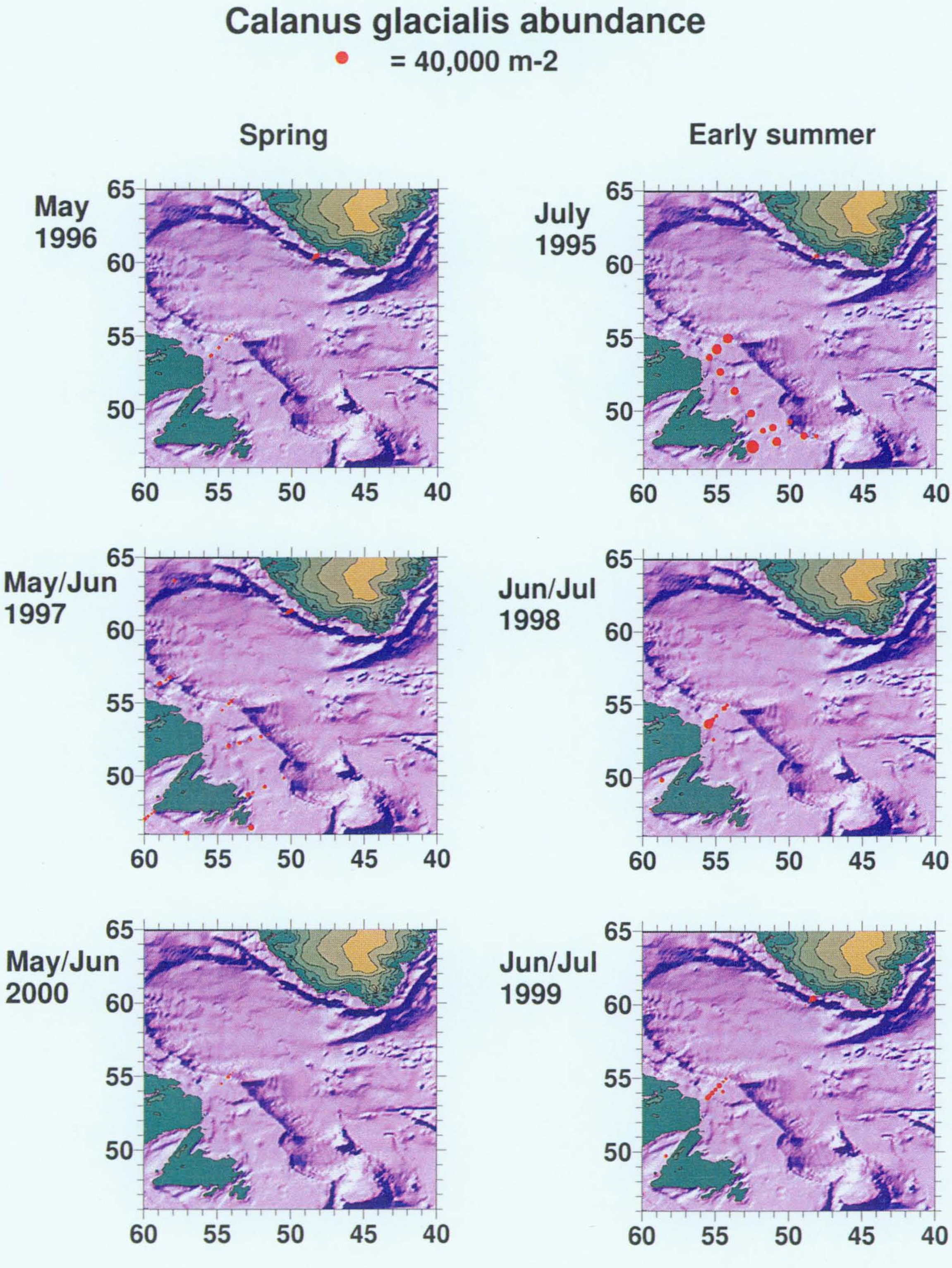

Figure 4. *Calanus glacialis* abundance in the Labrador Sea

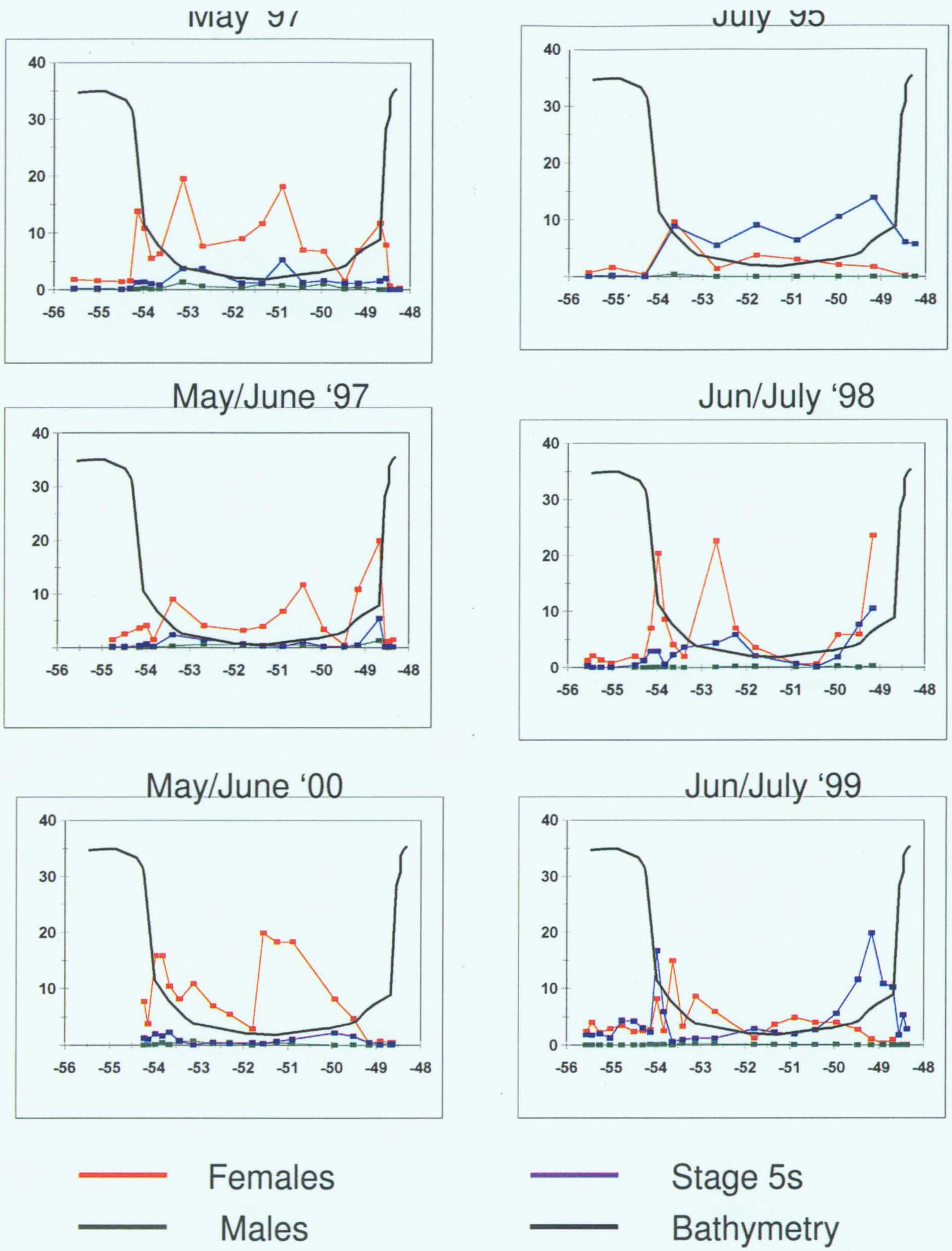

Figure 5. Abundance of female, male and stage 5 *Calanus finmarchicus* along the L3 section (1000s per sq. m.)

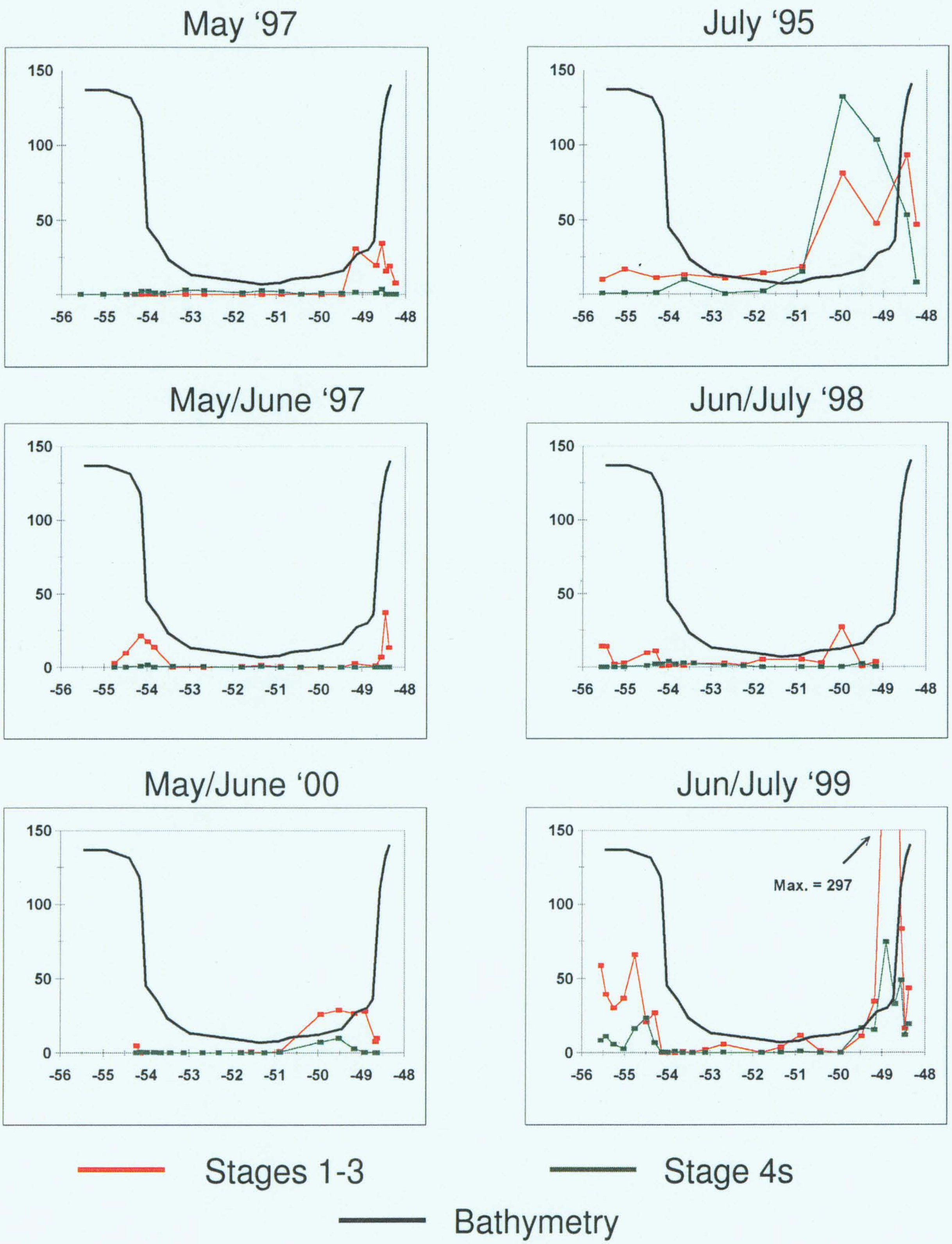

Figure 6. Abundance of stages 1-3 and stage 4 *Calanus finmarchicus* along the L3 line (1000s per sq. m.)

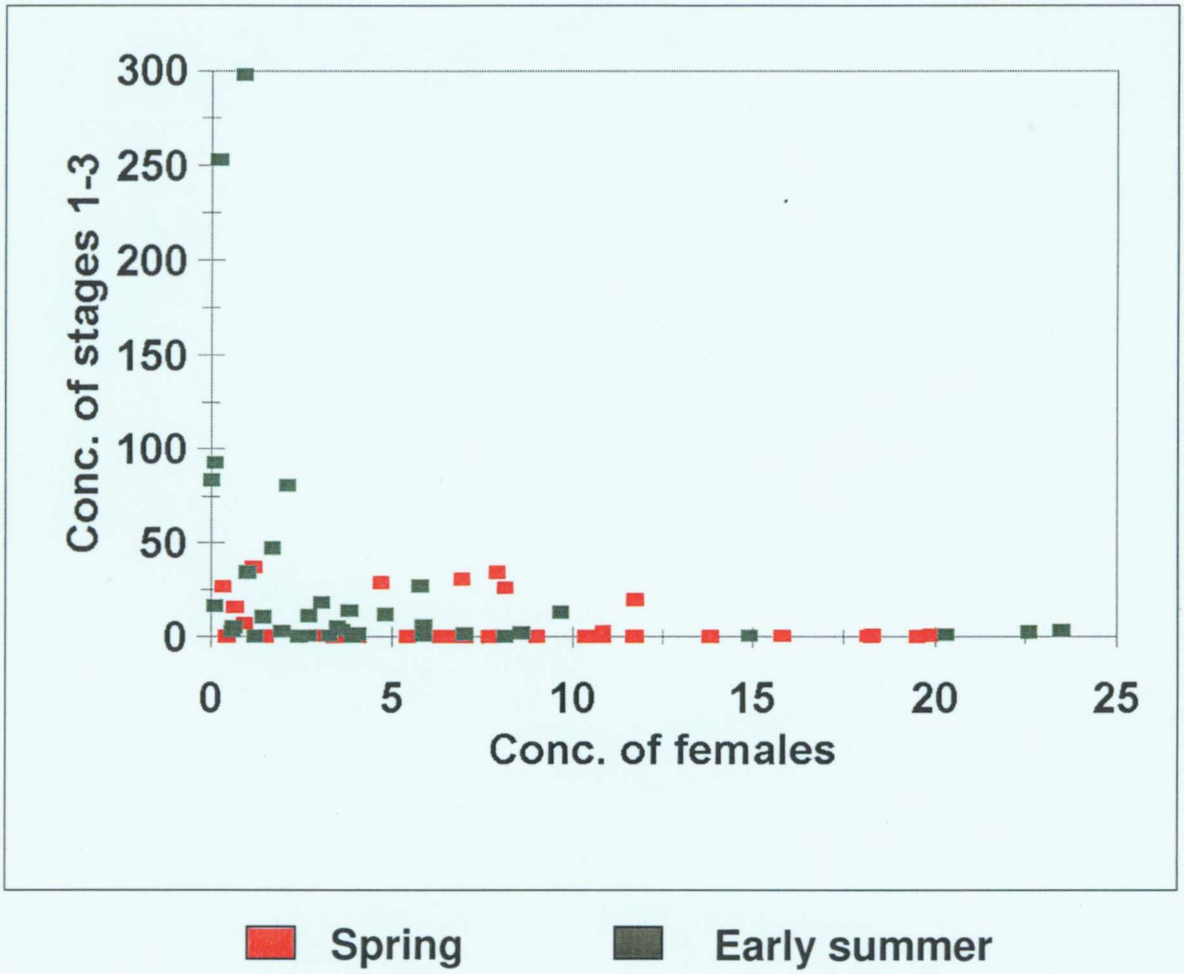

Figure 7. Relationship between concentrations (1000s per sq. m.) of *Calanus finmarchicus* copepodite stages 1-3 and females at central basin stations along the L3 line

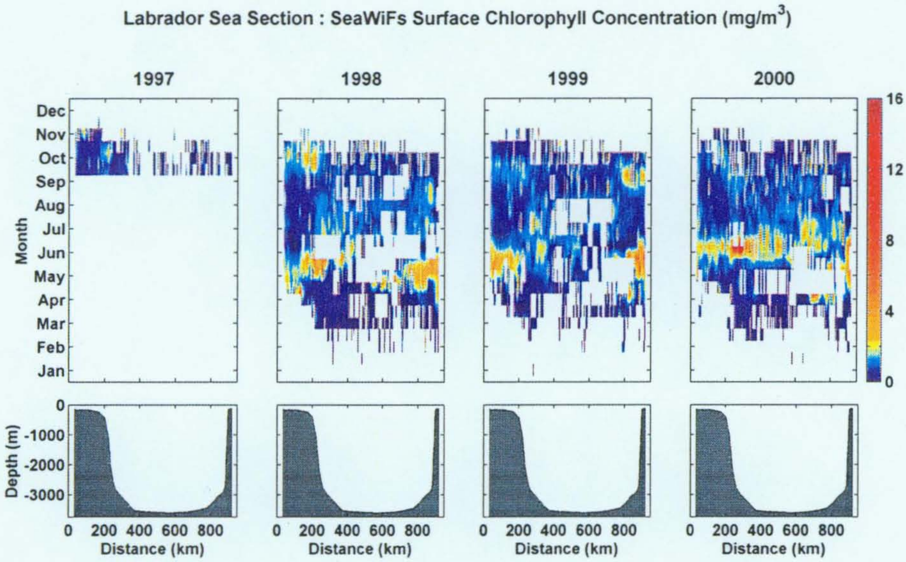

Figure 8. Annual cycles of SeaWiFS surface chlorophyll concentration (mg m^{-3}) along the L3 section.

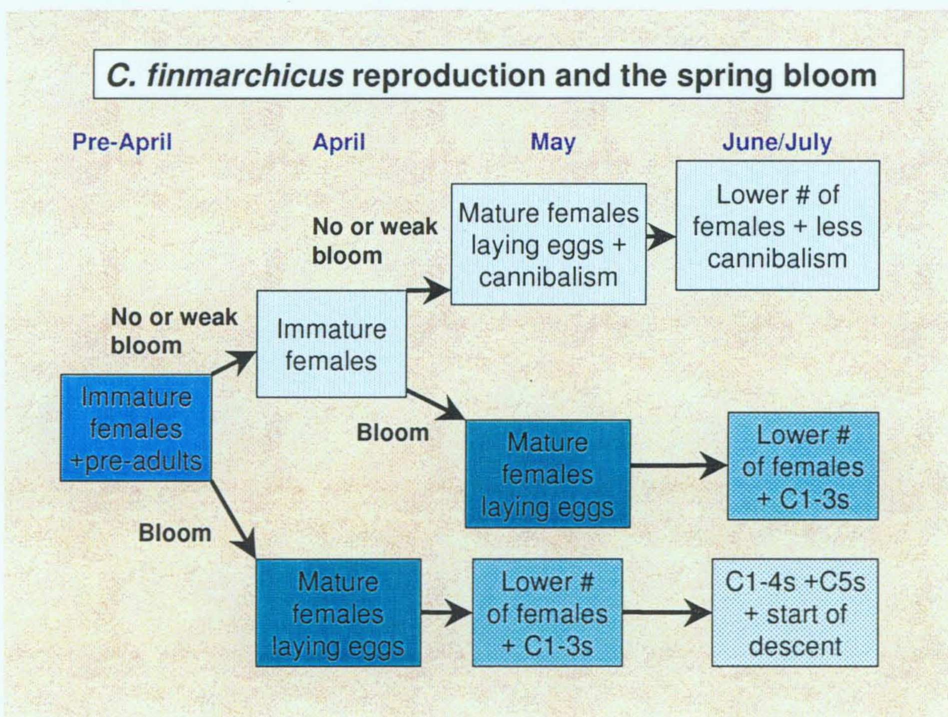

Figure 9. Hypothesised scheme describing the timing of reproduction of *C. finmarchicus* in relation to the timing of the spring bloom.

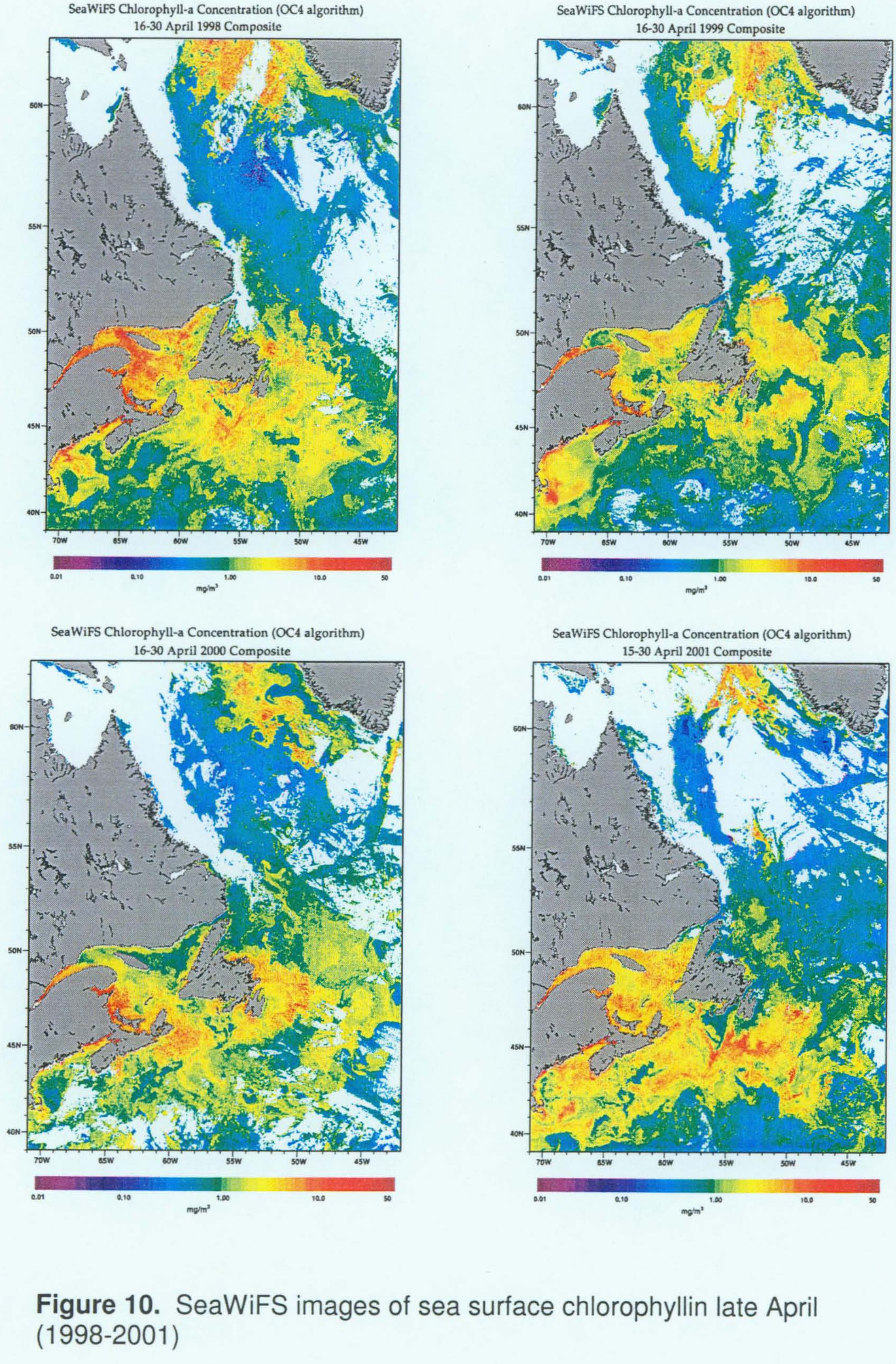

Figure 10. SeaWiFS images of sea surface chlorophyllin late April (1998-2001)

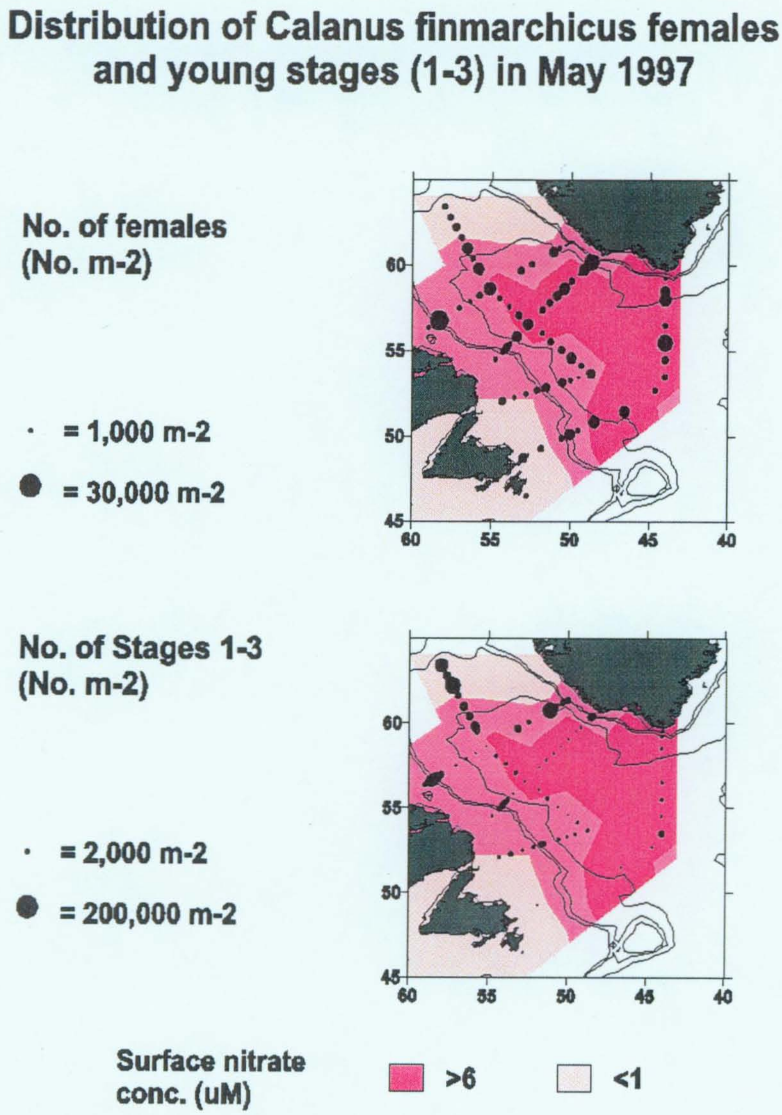

Figure 11. Distribution of *Calanus finmarchicus* females and stages 1-3 in relation to surface nitrate concentrations in spring1997.

ARTIC SEA ICE FROM 1950 TO 2050

Greg Holloway, Tessa Sou and Nadja Steiner (Institute of Ocean Sciences)

From estimates of atmospheric forcing, ocean forcing and rivers discharges, we model the evolution of Arctic Ocean, sea ice and snow from 1950 to 2000. Changes in total ice extent and volume are compared with results from satellite and submarine surveys to form a comprehensive view. Working with G. Flato and O. Saenko, Canada Centre for Climate Modeling and Analysis, we impose atmospheric climate projections from 1950 to 2050 after correcting model climate to observed climate over 1950 to 2000. This yields detailed projections for possible response of the Arctic Ocean/ice/snow system to impending changes through 2050.

PRODUCTION , RESPIRATION AND BIOGENIC CARBON INVENTORIES IN THE LABRADOR SEA

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A NEED TO DEFINE ECOSYSTEM PRODUCTIVITY - TOTAL VERSUS NET PRODUCTION

The primary (light-driven) production of biogenic carbon by the phytoplankton is the basic driving element of any marine ecosystem. The carbon is food for zooplankton in the water column and for animals in and on the sediment. Most estimates of phytoplankton production are based on measurements of something close to total or gross production.

Total production is not an accurate measure of the carbon made available for the ecosystem or (eventually) for deep storage. Another process - microplankton respiration - has to be taken into account because it drastically reduces the available carbon. Respiration is accounted for in the calculation of net production (as production minus respiration). Net production is the most useful expression of plankton productivity because it is the simplest definition of carbon made available rather than total carbon produced.

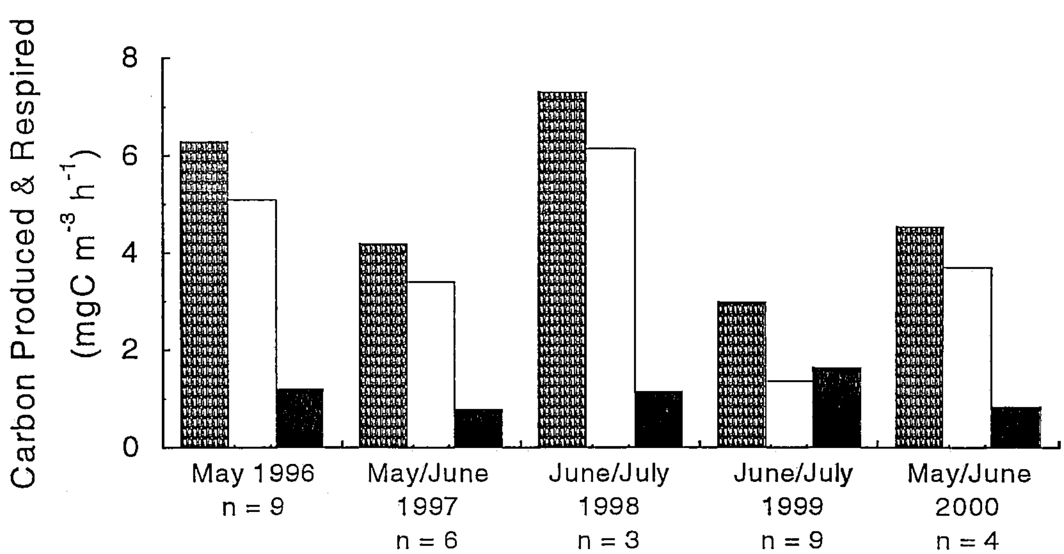

Figure 1. Total production (grey) net production (white) and respiration (black) in surface waters (from 10 m) on the AR7W Section in the Labrador Sea; n signifies the number of stations utilized to calculate mean values. Note the low respiration (less than 25% of production) and the tracking of year-to-year variations in production by net production.

When year-to-year variations in total production, respiration and net production on the Section are compared from 1996 - 2000 (Fig. 1), respiration is low and net production follows production early during each growing season (from May to July).

SEASONAL PRODUCTION AND RESPIRATION

However, production and respiration in this climate-sensitive region of the world's ocean also follow a seasonal succession. High productivity during May (at the beginning of the growing season) gives way to respiration by October (Fig. 2). A five-fold decrease in total production is accompanied by a three-fold increase in respiration during the transition. This means that an environment dominated by net production has given way to an environment dominated by the net consumption of carbon.

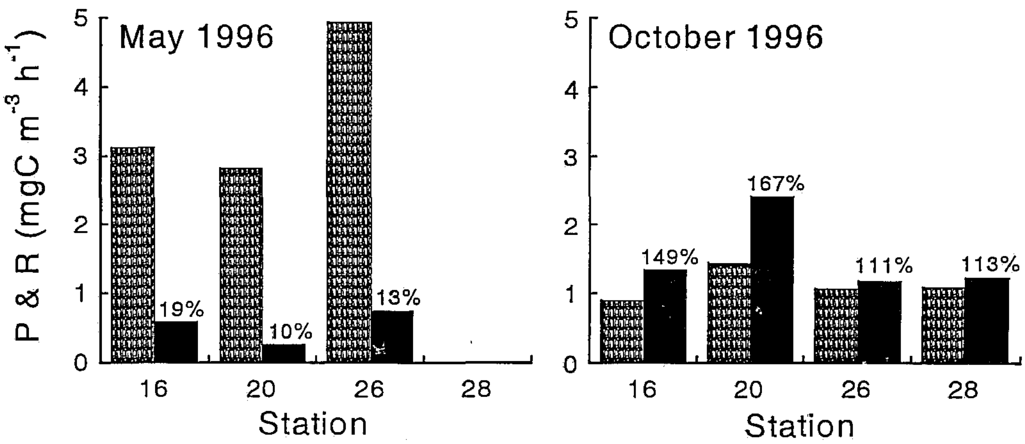

Figure 2. Production (grey) and respiration (black) at 4 stations in surface waters (from 10 m) on the eastern end of the Section. Note the seasonal transition from an environment of net production during May (when respiration is 10-19% of production) to an environment of net consumption during October (when respiration is 111-167% of production).

Production and respiration are not always (if ever) "in balance". This notion is especially evident in the fact that seasonal changes in total production, net production and respiration (Fig. 2) are a good deal larger than the year-to-year variations measured at approximately the same time of year (Fig. 1). Seasonal variations in production and respiration must be taken into account if we are to understand the Labrador Sea as the seasonally-intense system that it is.

SURFACE CARBON INVENTORIES ON THE SECTION

During a short growing season, biogenic carbon is thought to accumulate as dissolved organic carbon (DOC) and increase the near-surface inventory of carbon available for deep transport by winter mixing. This concept has been confirmed by our measurements (Fig. 3) of an increase of total organic carbon (TOC) as net production gives way to net consumption between May and October (Fig. 2).

The increase in TOC is driven primarily by an increase in dissolved organic carbon (DOC). In turn, the increase in DOC is driven by the accumulation of colloidal organic carbon (COC) - generally regarded as the most biologically-reactive fraction of DOC. The fact that both COC and DOC are higher (Fig. 3) when respiration is predominant during October (Fig. 2) suggests that the biogenic carbon accumulated at the end of the growing season is indeed biologically-reactive. However, the combination of physical and biological processes that regulate this seasonal carbon accumulation remains unknown.

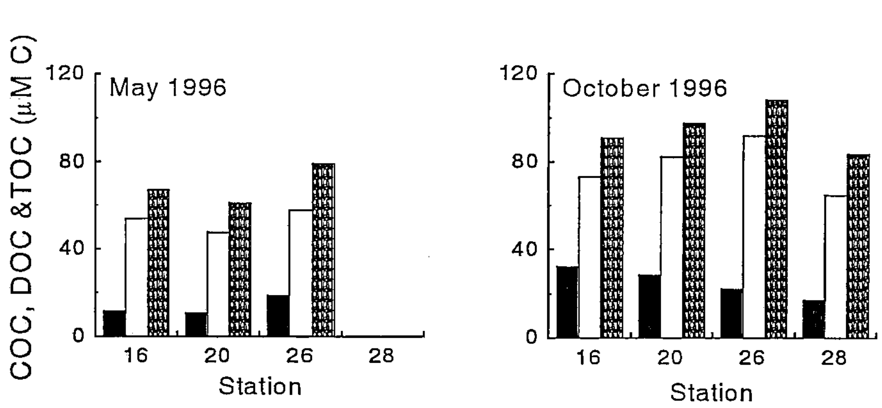

Figure 3. Total organic carbon (grey) dissolved organic carbon (white) and colloidal organic carbon (black) at 4 stations in surface waters (from 10 m) on the eastern end of the Section. Note the increase in TOC, DOC and COC during the seasonal transition from net production in May to net consumption of carbon in October.

In addition to seasonal changes in the near-surface carbon inventory, there are well-defined positive correlations of year-to-year variations in mean biogenic carbon with mean net production (Fig. 4).

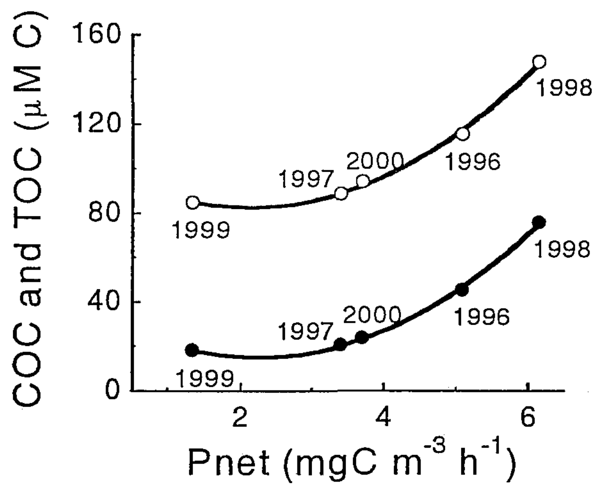

Figure 4. Curves fitted to plots of mean colloidal organic carbon (COC) concentration (closed circles) and mean total organic carbon (TOC) concentration (open circles) versus mean net production (Pnet) in surface waters (from 10 m) on the Section.

To our knowledge, these are the first data delineating a relationship between net production and independent measurements of the total biogenic carbon pool (TOC). These data are also the first suggesting that net production can be related to a bioreactive form of biogenic carbon (COC) that is not phytoplankton biomass. Given that particulate organic carbon (POC) - the traditional measure of phytoplankton and associated microbial biomass - is not associated in any simple manner with measured productions and respirations (or the net productions calculated from the two measurements), this second observation becomes especially important.

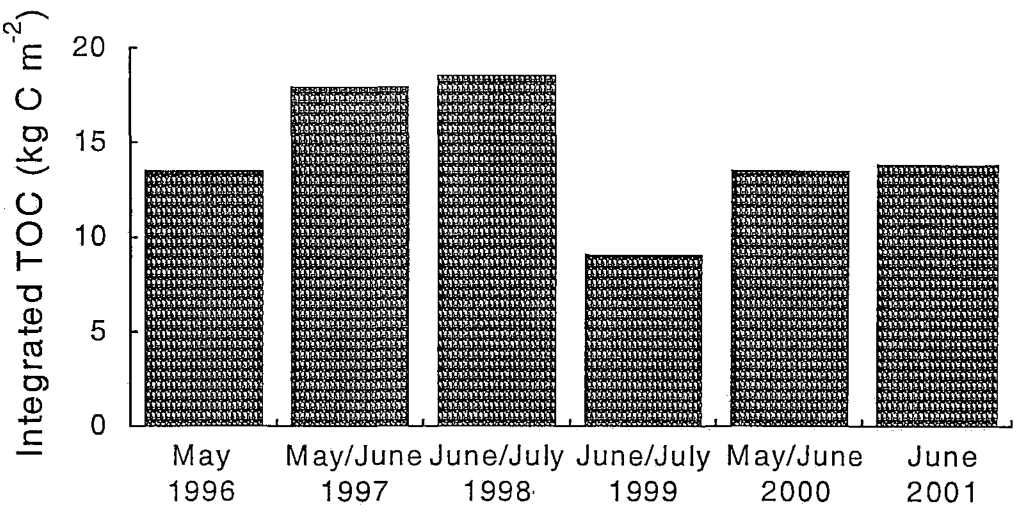

Figure 5. Average integrated total organic carbon (TOC) over all depths calculated for stations located in the central basin region (stations 7 - 21) of the Section. Note that the year-to-year variations in integrated carbon can be large, ranging from about 5 to 10 kgC m^{-2}.

Integrated Deep Carbon Inventories on the Section

Integrated over all depths, the biogenic carbon in samples taken from deep CTD casts in the central basin on the Section yielded suprising results (Fig. 5): Large year-to-year variations in deep and shallow water carbon were apparent from 1996 to 2001, resulting in similar large year-to-year variations of integrated total organic carbon (TOC).

These results are distinctly at odds with a widely-held view that biogenic carbon (measured as TOC or DOC) is more-or-less uniform and low in the deep ocean.

THE STRUCTURE AND FUNCTION OF PLANKTON COMMUNITIES IN THE LABRADOR SEA

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The Labrador Sea is the region of the North Atlantic bounded in the north by Davis Strait, in the west by Baffin Island and Labrador, and in the east by Greenland. A defining characteristic of this region, which belongs to the polar biome, is the presence of a brackish surface layer that induces enough stability to permit a rapid algal bloom in the spring as soon as irradiance is sufficient. Secondarily, an important distinction can be made between the continental shelf areas and the central basin. Biogeographically, the shelves belong to the boreal polar province (BPLR). The water is cold, of low salinity and seasonally covered by ice. The central basin belongs to the Atlantic arctic province (ARCT). The water circulates in a cyclonic gyre, entraining some Atlantic water of higher temperature and salinity, and undergoes deep convective mixing in winter.

The biological pump for carbon in the ocean takes in CO_2 by photosynthesis, gives much of it back by respiration, and exports the remainder as particles or organic solutes [Figure 1]. The amount of biogenic carbon sequestered in the deep ocean depends on the food web: who its members are, how the web is put together, and the strength of its links and sinks. Although historical studies at ocean weather stations delineated the seasonal progression of net phytoplankton and mesozooplankton in some detail, an assessment of the biological pump cannot be made without data on the microbial members of the food web. Here, we present our measurements of the components important in the metazoan food chain (large phytoplankton and mesozooplankton) together with those in the microbial loop (small phytoplankton, bacteria, dissolved organic carbon) [Figures 2-4].

There is much inter-annual and seasonal variability in biomass and productivity; nevertheless, a clear distinction can be made between the photic zone communities in the adjacent BPLR and ARCT provinces [Figure 5]. In BPLR, diatoms contribute significantly to the high biomass of phytoplankton. By contrast, the phytoplankton of ARCT are smaller and comprise a lower biomass, but richer in both numerical abundance and diversity. The bacteria of ARCT are exceedingly abundant (up to 4.6 million cells per mL), perhaps indicative of the recent claim that a given concentration of dissolved organic carbon will yield more bacterial biomass at low than at high temperatures. Therefore, there are many small cells which presumably do not contribute directly to the sinking flux of carbon in ARCT. The factors influencing the export of carbon in the Labrador Sea are constrained by in situ measurements from ships, resolved in space and time by remote sensing from satellites and moored instruments, and deduced by simulation models.

Figure 1. A conceptual model of the cycles of physical and biological processes in the Labrador Sea, and the consequence for timing of carbon export by the physical pump (i.e. in the form of CO_2; shown in blue), the biophysical pump (i.e. in the form of DOC; shown in red) during periods of deep convective mixing in winter and the biological pump (i.e. in the form particulate biogenic carbon as phytodetritus, fecal pellets and the soma of pelagic grazers; shown in green) during periods of high biological activity in summer. Microheterotrophs (MiH) include bacteria, heterotrophic flagellates, dinoflagellates and ciliates.

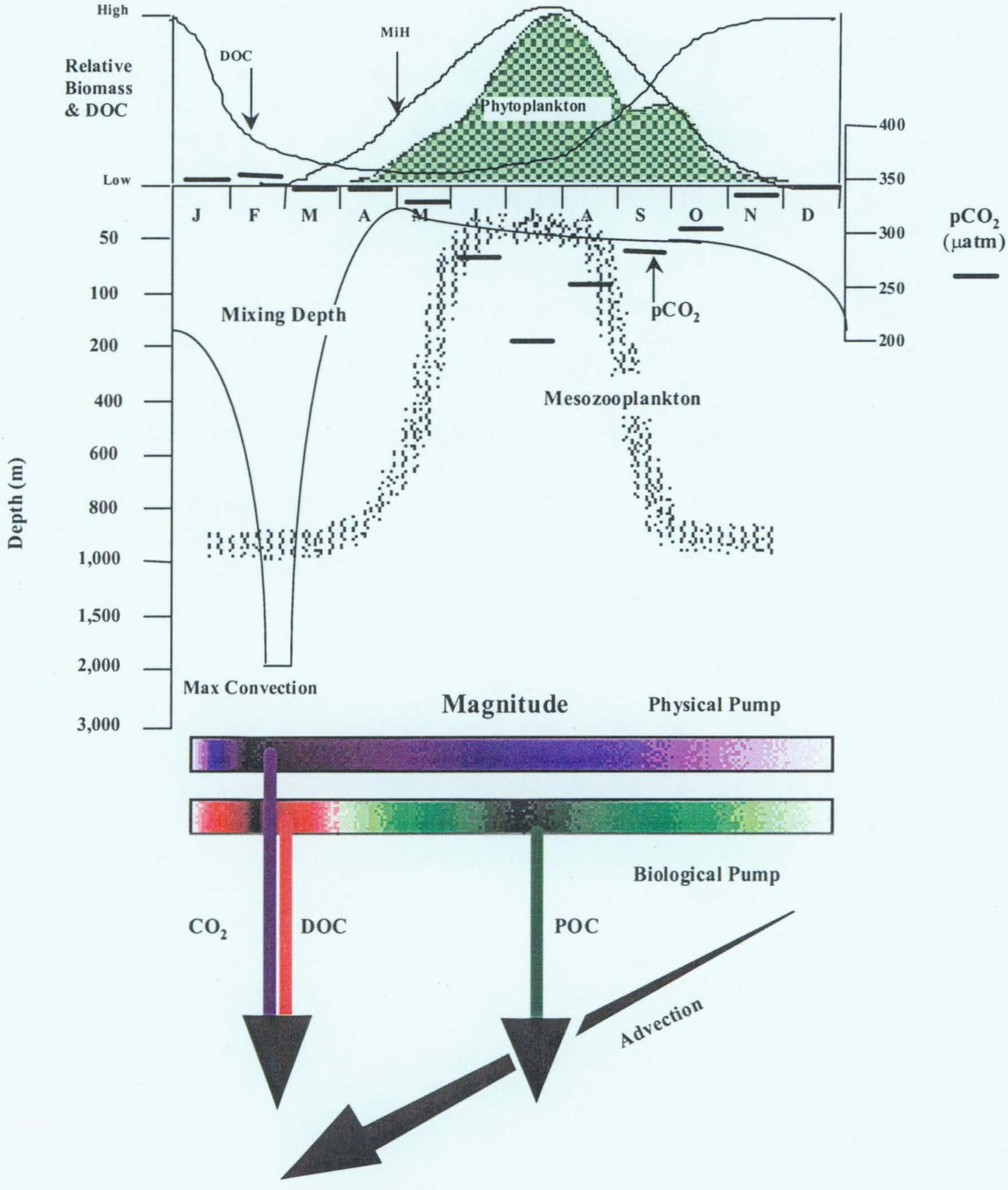


Figure 2A. Spatial distribution of chlorophyll on AR7W section of the Labrador Sea in spring (May), summer (Jun-Jul) and autumn (Oct).

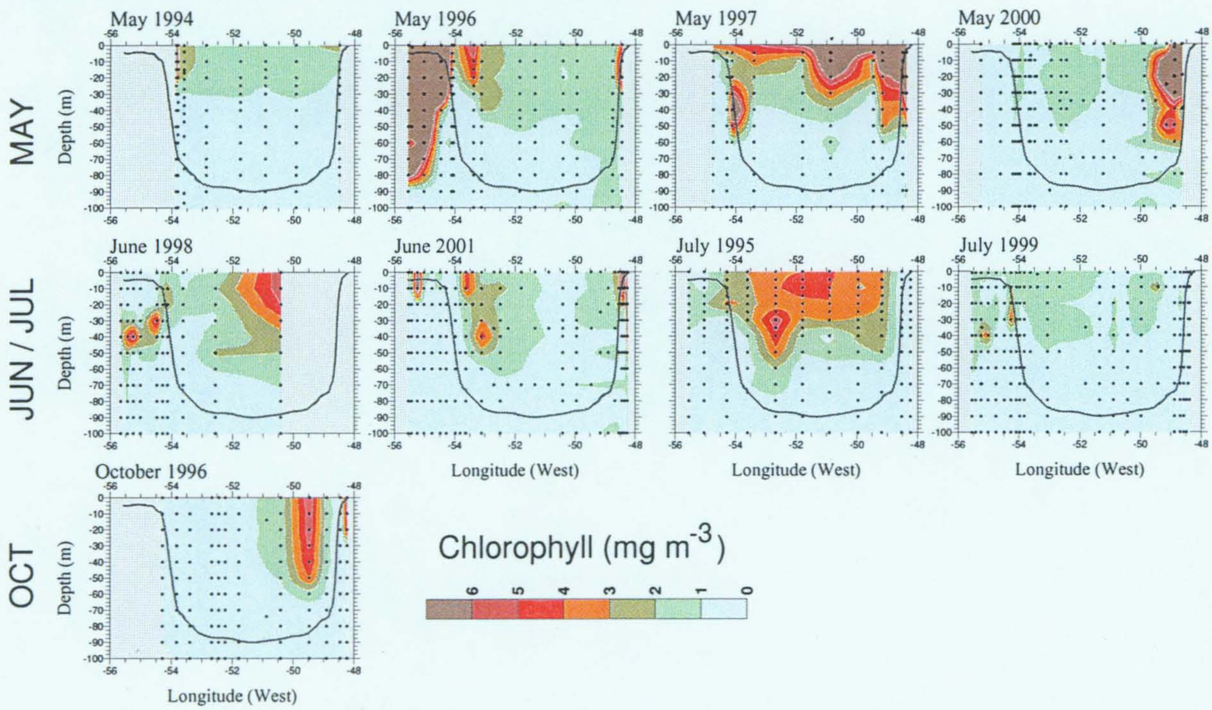


Figure 2B. Chlorophyll areal standing stocks on AR7W section of the Labrador Sea in spring (May), summer (Jun-Jul) and autumn (Oct).

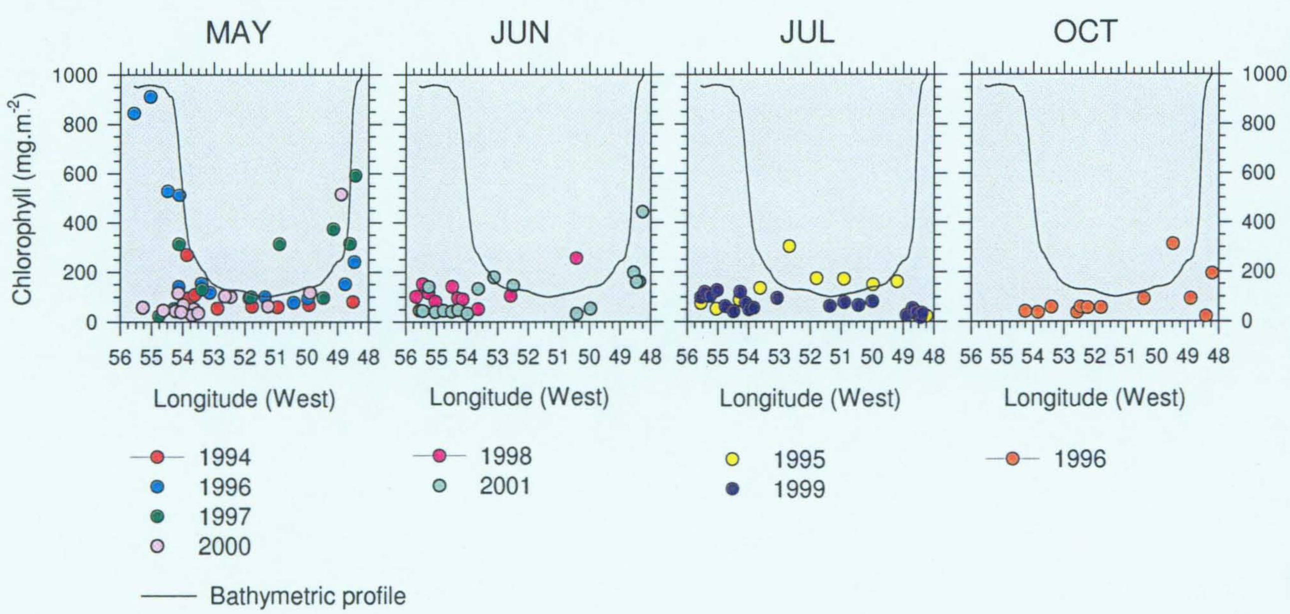


Figure 3A. Spatial distribution of phytoplankton on AR7W section of the Labrador Sea in spring (May), summer (Jun-Jul) and autumn (Oct).

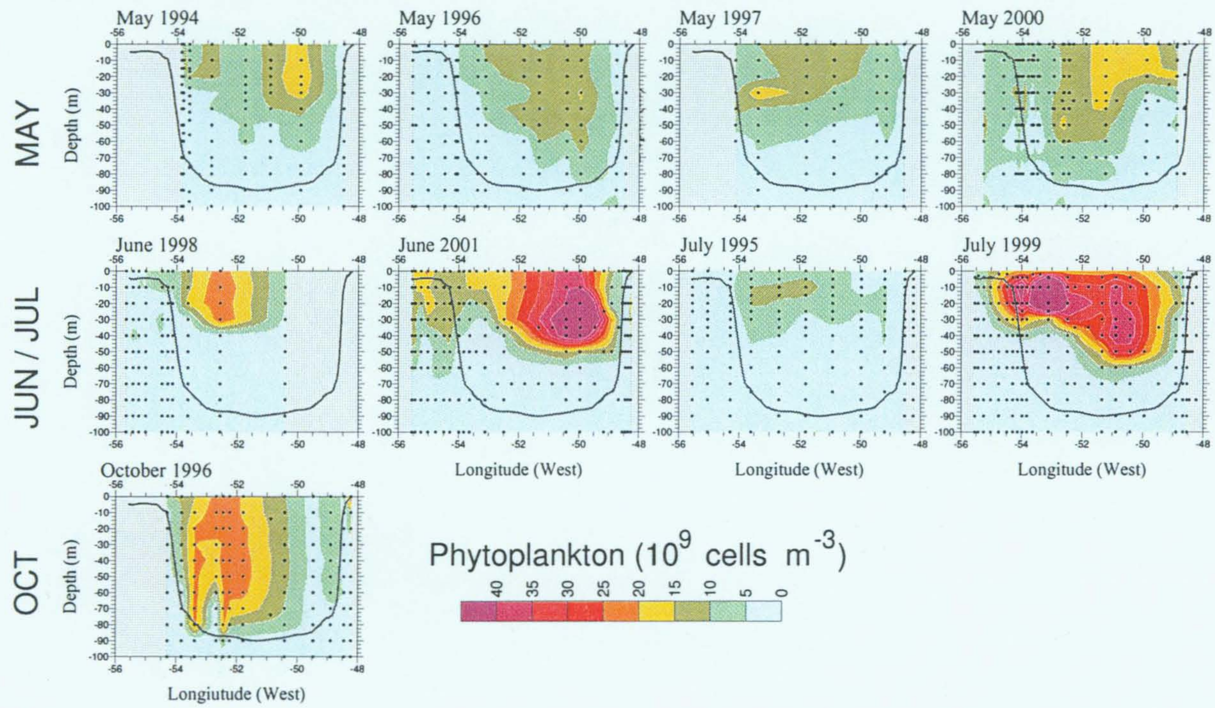


Figure 3B. Phytoplankton areal standing stocks on AR7W section of the Labrador Sea in spring (May), summer (Jun-Jul) and autumn (Oct).

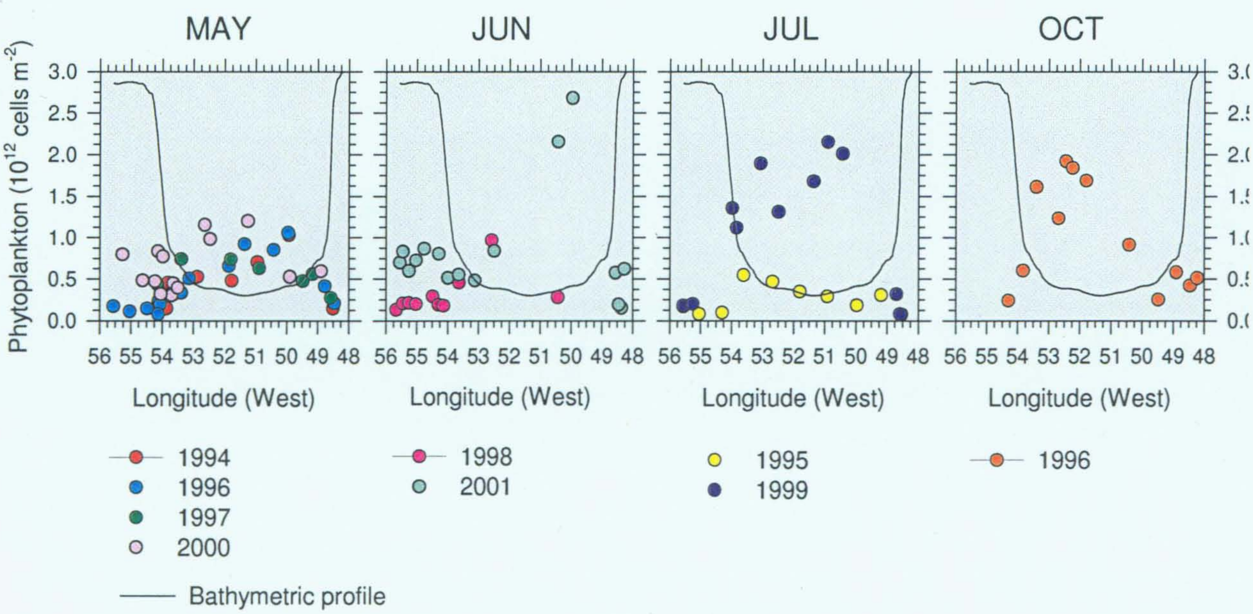


Figure 4A. Spatial distribution of bacterioplankton on AR7W section of the Labrador Sea in spring (May), summer (Jun-Jul) and autumn (Oct).

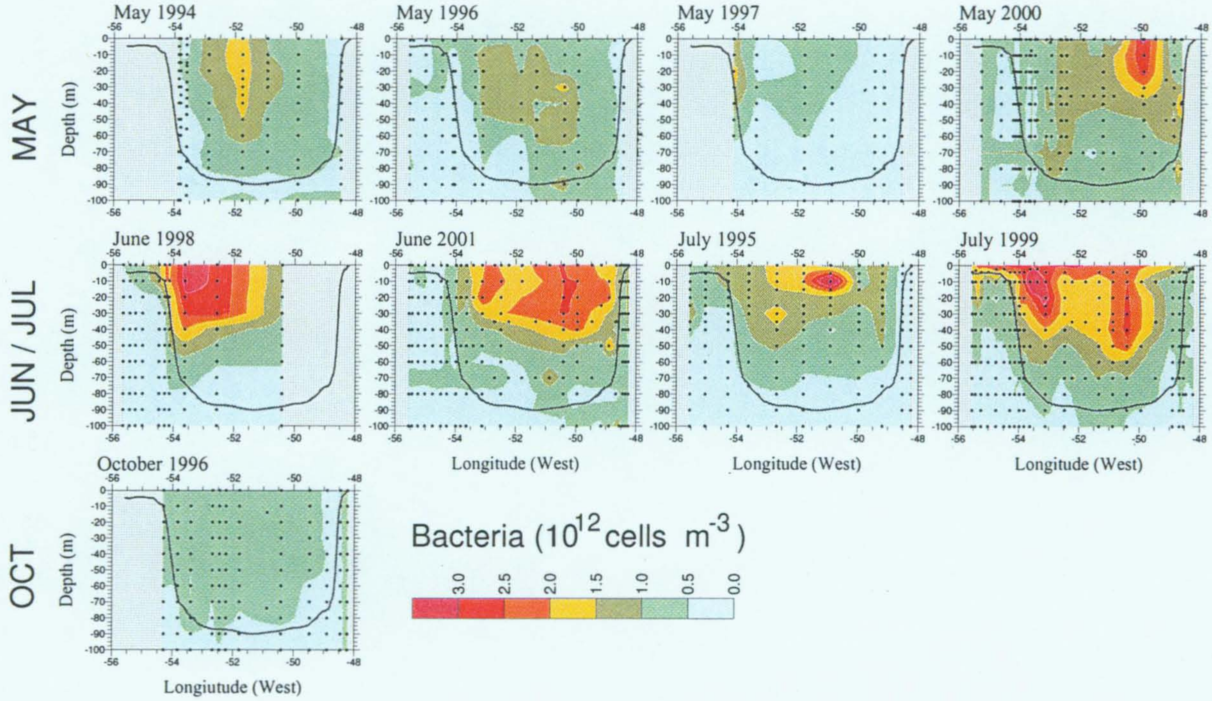


Figure 4B. Bacterioplankton areal standing stocks on AR7W section of the Labrador Sea in spring (May), summer (Jun-Jul) and autumn (Oct).

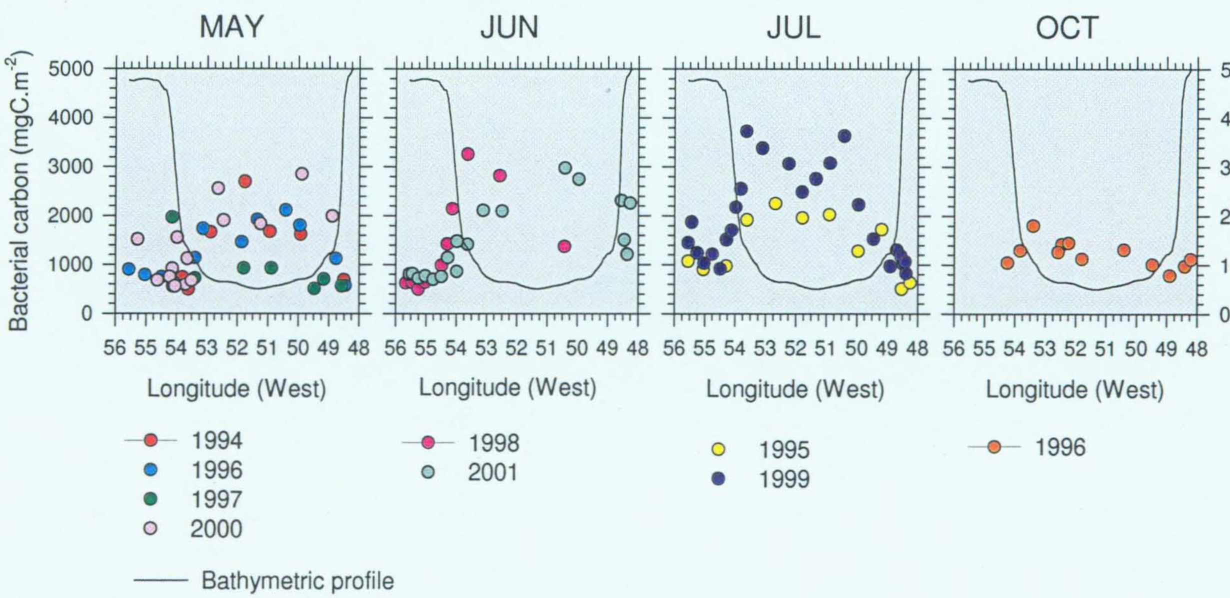
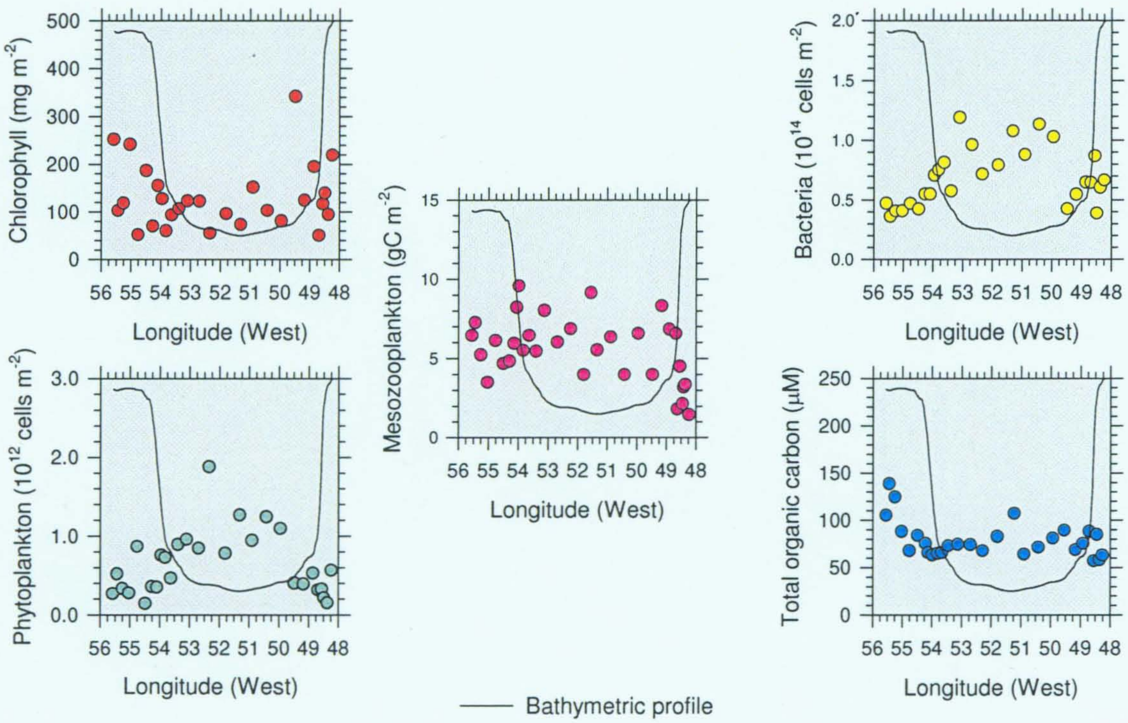


Figure 5. Seasonally-averaged areal standing stocks of chlorophyll, phytoplankton, bacterioplankton, mesozooplankton and total organic carbon on AR7W section of the Labrador Sea.



ON THE JUXTAPOSITION OF ATLANTIC AND PACIFIC-ORIGIN WATERS ACROSS THE CANADA BASIN

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Institute of Ocean Sciences,
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Physical and geochemical data collected weekly during the year-long 2800 km drift of the *CCGS des Groseilliers* together with data collected on the *CCGS Louis S. St-Laurent* in 1997 and 1998 provide a quasi-synoptic picture of the water mass properties found across the southern Canada Basin (Figure 1).

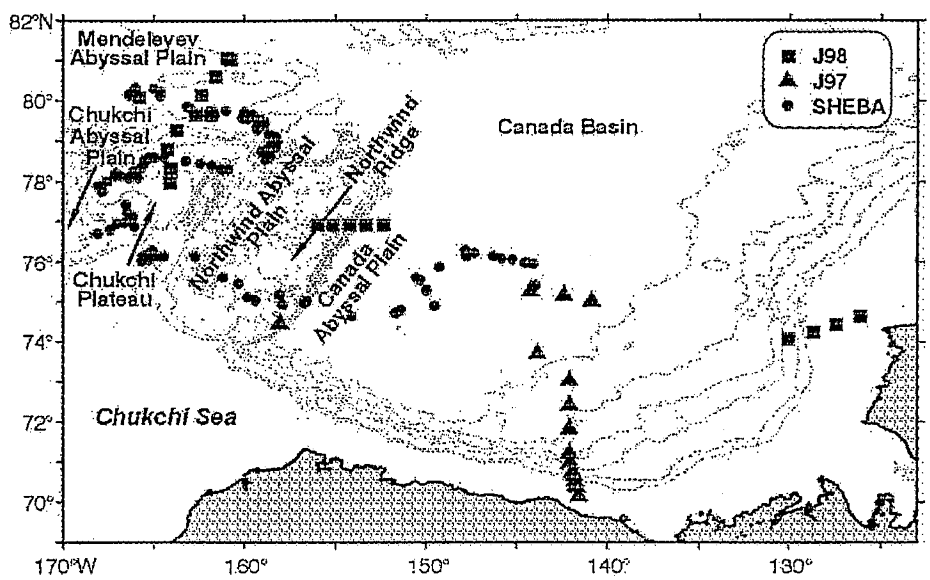

Figure 1. Station locations in the Canada Basin, 1997-1998

The water column in the Canada Basin consists of three main layers: a low-salinity upper layer which includes a mixed layer and halocline; a warm Atlantic layer; and a cold, more saline deep layer. A strong inverse thermocline, where temperature increases rapidly with depth, denotes the boundary between upper and Atlantic layers.

Pacific-origin waters occupy much of the halocline and overlie denser Atlantic-origin waters. They enter the Canada Basin via Bering Strait, are seasonally modified in the Chukchi Sea and contribute summer and winter water to the upper and middle halocline (Coachman and Barnes, 1961). Upper halocline water is characterized by a shallow local temperature maximum found between S=31 and S=32, low nutrient concentrations and high oxygen concentrations. Middle halocline water is characterized by a shallow temperature minimum found near S=33.1, high nutrient concentrations, and lower oxygen concentrations

(Kinney et al., 1979). High nutrient concentrations reflect advection of nutrient-rich waters transported through the Bering/Chukchi seas during winter when biological production (uptake) is very low (Coachman and Barnes, 1961, Cooper et al., 1997).

The boundary between Pacific and Atlantic-origin water lies between the middle and lower halocline of the upper layer. Atlantic-origin waters enter the Canada Basin from the Makarov Basin via Fram Strait and the Barents Sea and the Nansen and Amundsen basins. The shallowest component of Atlantic-origin water is the lower halocline, which is characterised by low nutrient and oxygen concentrations and a minimum in NO ($NO=9*NO_3 +O_2$; Jones and Anderson, 1986). Below lies the Atlantic layer which is comprised of warm Fram Strait Branch (FSB) water that overlies colder, fresher Barents Sea Branch (BSB) water (Schauer et al., 1997).

During the 1990s there have been significant changes observed in both the Arctic atmosphere and ocean circulation (for overview see Dickson, 1999). Atlantic Layer temperatures almost $1^{\circ}C$ warmer than the historical record were observed in three of the Arctic Ocean's four sub-basins by 1993 (Quadfasel et al., 1991, Carmack et al., 1995, Morison et al., 1998). Sub-basin circulation and the distribution of Atlantic-origin and Pacific-origin waters within the Arctic Ocean also differed from the past due to the relocation of the Atlantic/Pacific water mass boundary eastward from the Lomonosov to the Mendeleyev Ridge (McLaughlin et al., 1996). The Canada Basin itself has also undergone change. Between 1979 and 1996, temperatures of the upper and lower halocline layers increased and decreased respectively (Melling, 1998). By 1995, the thickness of Pacific-origin water had decreased in the southern Canada Basin water column, replaced by Atlantic-origin water whose composition included 20% more water from the Barents Sea than was present in 1992 (McLaughlin et al., in press). All of these oceanic changes occurred after an increase in the atmospheric Arctic Oscillation (Walsh et al., 1996) and an atmospheric regime shift toward increased cyclonic circulation (Proshutinsky and Johnson 1997; Johnson et al., 1999).

SHEBA data are examined within this context of change. In 1997-98, three different water mass structures are observed across the Canada Basin, each reflecting varying quantities of Pacific- and Atlantic-origin waters. The

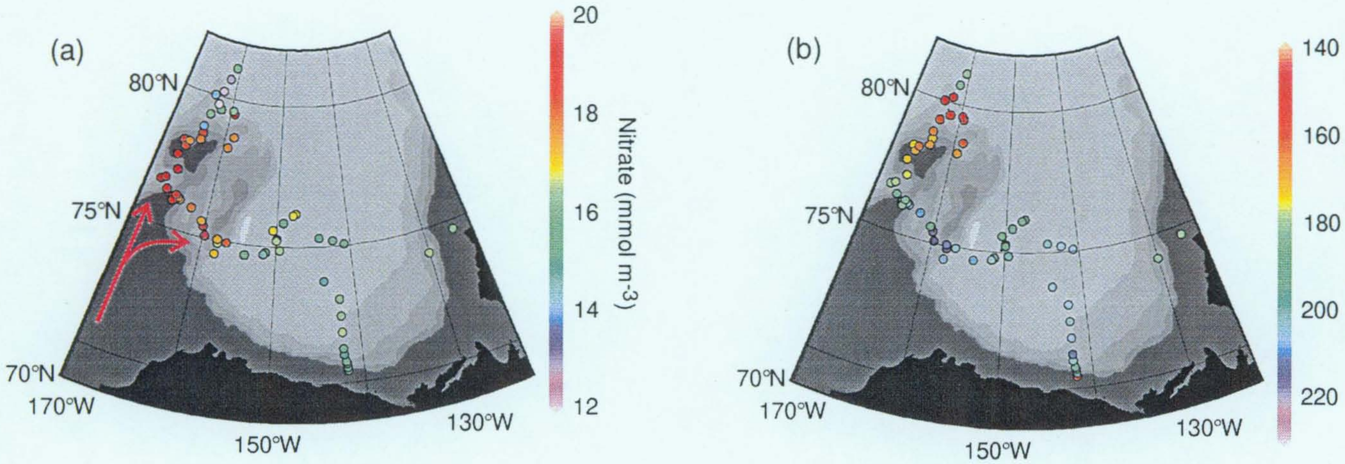

Figure 2 Pacific-origin water distribution

intensity of Pacific-origin water, identified by a nutrient maximum, is strongest over the Chukchi Abyssal Plain and Northwind Abyssal Plain. Stations where nitrate concentrations are highest identify two winter water inflow pathways, one via Herald Canyon and the other located between Herald Canyon and Hanna Shoal (Figure 2a). In contrast the quantity of Pacific-origin water, in terms of equivalent thickness, is lowest over the northern Chukchi Plateau and increases progressively from the Northwind Ridge eastward across the southern Canada Basin (Figure 2b). A cross-basin section of nitrate concentration clearly illustrates that there is less Pacific-origin water found over the Chukchi Plateau than in the southern Canada Basin (Figure 3).

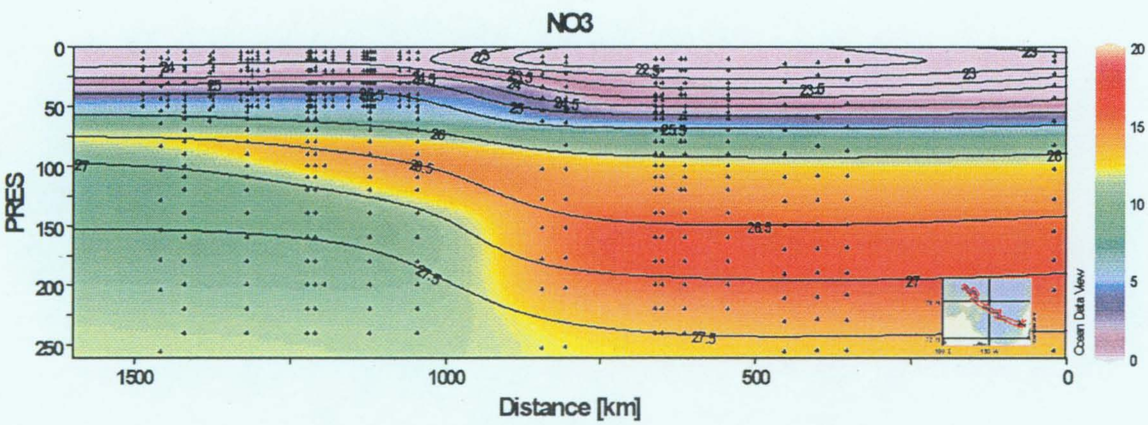

Figure 3 Nitrate concentrations across the Canada Basin

Atlantic-origin waters about 0.5 °C warmer than the historical record finally arrived in the Canada Basin, some nine years after entering the Arctic Ocean upstream. The warmest waters are found over the Chukchi Abyssal Plain and the northern flank of the Chukchi Plateau and identify two pathways by which Fram Strait Branch waters enter the southern Canada Basin: one located

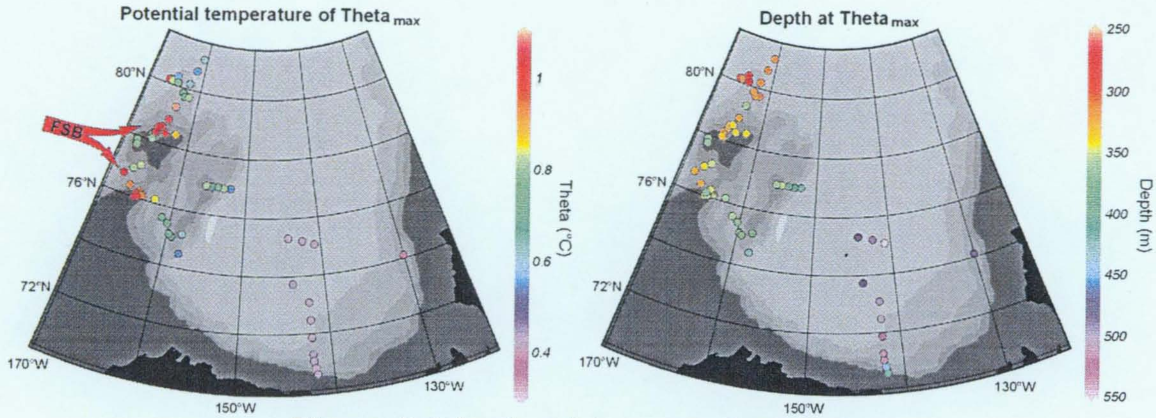

Figure 3 Atlantic-origin water distribution

between the Chukchi Shelf and Plateau; and the other following topography around the Chukchi Plateau.

Comparison with data collected in 1968 at T-3, north of JOIS98 station 8 in the Mendeleyev Abyssal Plain, and with data collected in 1985 at AIWEX near JOIS97 Station 12 clearly show that Canada Basin waters are in transition.

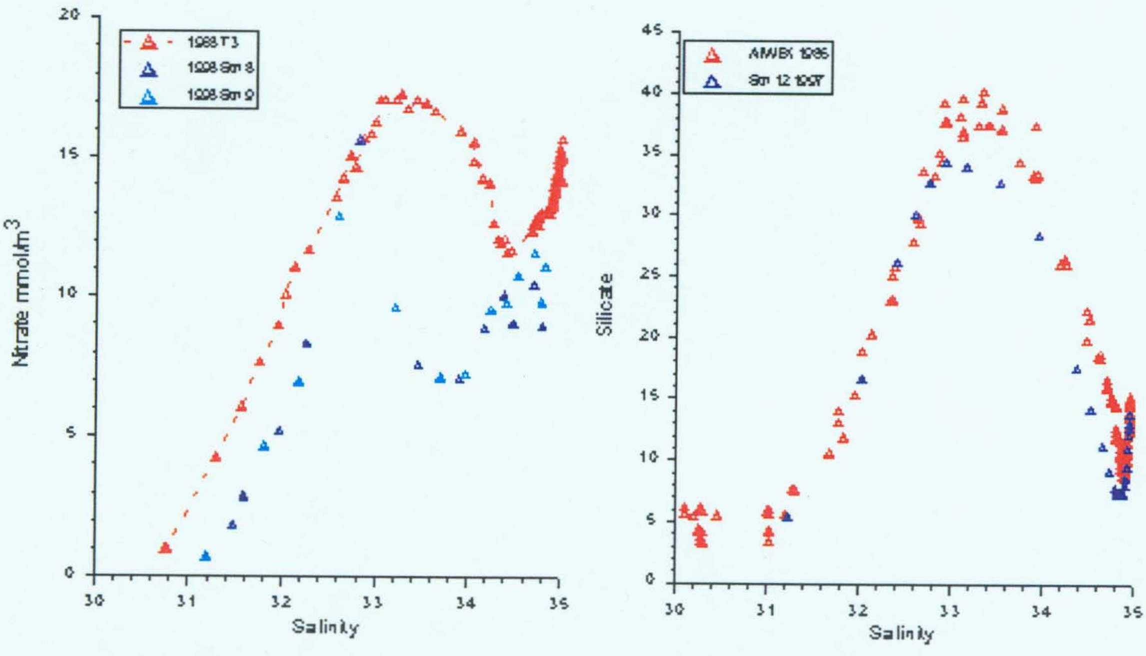

Figure 4 Change in Canada Basin water mass composition over time

Nutrient concentrations have decreased at salinities S>32.6 in waters north of the Chukchi Plateau and at S>32.8 in the southern Canada Basin. These data show that the presence of Pacific-origin waters in the Canada Basin water column is diminished. Although the largest difference is found over the Chukchi Plateau, changes are also evident in the southern Canada Basin.

diminished. Although the largest difference is found over the Chukchi Plateau, changes are also evident in the southern Canada Basin.

In summary, Canada Basin waters are responding to events that occurred upstream in the early 1990s. SHEBA/JOIS observations reveal the pathways that deliver upstream changes in Atlantic-origin water properties to the Canada Basin. They also show the amount of Pacific-origin water varies across the Canada Basin, a change likely due to the recent freshening of Atlantic-origin water.

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ARCTIC PACK ICE AND CLIMATE CHANGE: IS GLOBAL WARMING IMPORTANT?

Humfrey Melling (Institute of Ocean Sciences)

It is commonly assumed that polar pack ice will melt in response to warming climate. Indeed, we all know that snows of winter melt in summer. Indeed, Arctic measurements during the 1990s have revealed reductions in the extent and thickness of Arctic pack ice. The case is proved...

In this talk I review the physical factors that act collectively to determine the amount of pack ice in the Arctic. I argue that a direct connection between climate warming and ice loss is too simplistic in a climatic zone where average annual temperature will remain below freezing even in a greenhouse-changed climate. The causes, significance and future of change in Arctic pack ice remain an active area of research.

CARBON SINKS IN SEASONALLY ICE-COVERED SEAS AND CLIMATE CHANGE FEEDBACKS

Lisa A. Miller (Institute of Ocean Sciences)

Speculation has run rampant that polar waters, particularly those which are covered by ice during only part of the year, absorb more atmospheric CO_2 than they release. Studies in a limited number of such areas support these speculations, but the mechanisms of their carbon sinks are vastly different. Therefore, it is unlikely that climate variations will produce uniform changes in the carbon cycle throughout the Arctic, making it extremely difficult to predict what feedbacks polar waters will contribute to global climate change.

ENVIRONMENTALLY INDUCED VARIATION IN SIZE-AT-AGE IN JUVENILE ATLANTIC SALMON (*SALMO SALAR*)

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Juvenile Atlantic salmon have been surveyed in the Miramichi River (Figure 1), North America's most productive Atlantic salmon river,, for over 30 years. Surveys were initiated to validate spawning escapements, distribution of spawners within the watershed, detect environmental problems, and provide predictions of adult recruitment. Attempts to link juvenile abundance with subsequent adult recruitment have not been successful.

Recent DFO studies have shown that, in the Miramichi River basin, size-at-age of juveniles have varied but generally decreased between 1971 and 1999 while mean annual air temperatures increased at the rate of 0.2-0.4 degrees C per decade. Size-at-age was found to be negatively correlated with spring air and water temperatures.

Juvenile growth was monitored at 4 sites within the watershed during 2000 and 2001 to better understand the role of environmental conditions on fish. Environmental conditions were favorable in 2000 with temperatures rarely exceeding 23 degrees Celsius whereas 2001 was characterized by low flows and higher water temperatures. At 2 sites where average water temperatures often exceeded 23°C in 2001, growth of age 0+ parr relative to 2000, was decreased by 16 to 26% in length and 25 to 38% in weight. At the 2 sites where water temperatures rarely exceeded 23 degrees in either year, growth in 2001 was similar to growth in 2000. Growth of age 1+ parr, in 2001 relative to 2000, was decreased by similar amounts in both temperature regimes. Age 0+ parr inhabit nursery areas which encompass only the immediate area of the redd they emerged from, and changes in their growth should correlate well with water conditions at that site in a stream or river. Older parr are capable of migrating upstream and downstream several kilometers and changes in their growth relate more to overall changes in water conditions for the area.

These data validate climate change models, which have predicted that increased air and water temperatures would reduce growth of juvenile Atlantic salmon and reduce the overall productivity of Atlantic salmon populations in the Miramichi River.

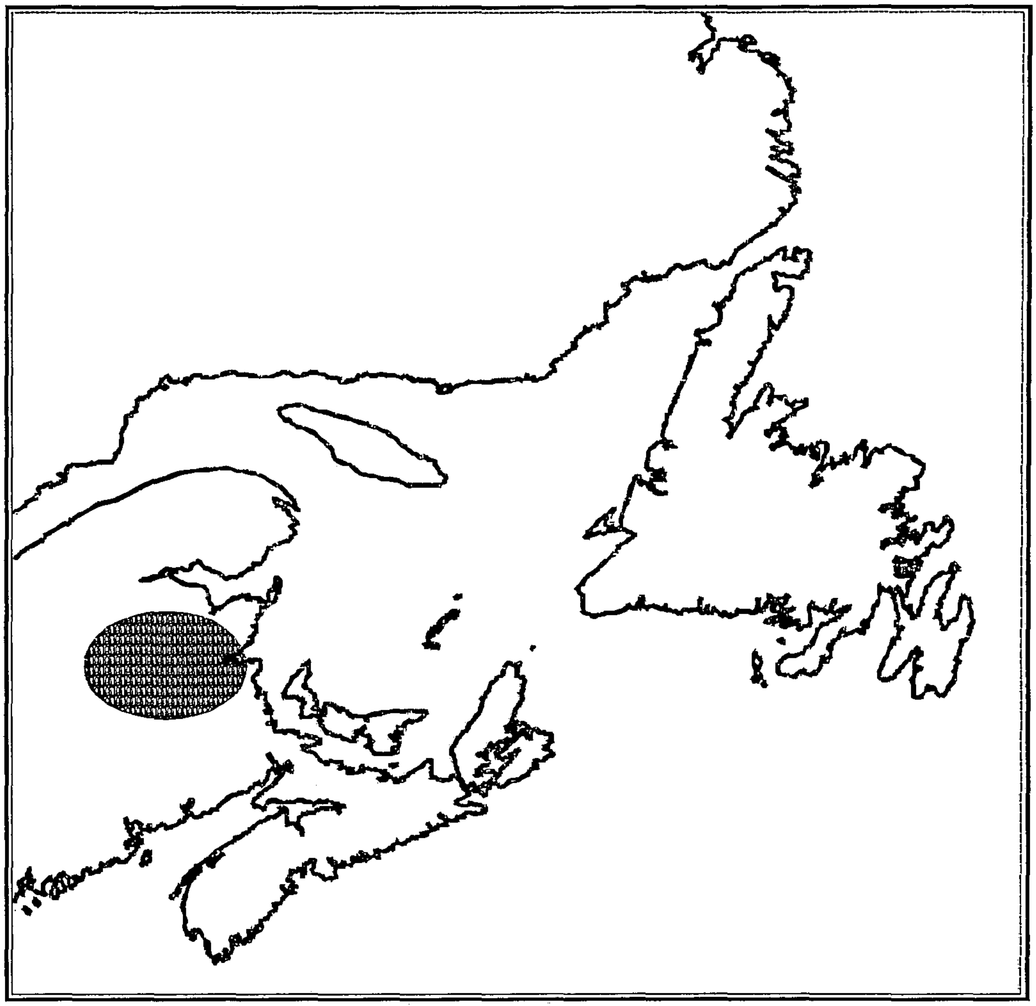

Figure 1. The Atlantic provinces of Canada showing the Miramichi River Watershed on the Gulf of St. Lawrence coast of the province of New Brunswick.

^{129}I VENTILATION AGES IN THE LABRADOR SEA

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INTRODUCTION

Numerous advances in our understanding of oceanic processes, such as patterns and rates of circulation, air-sea gas exchange and surface nutrient uptake and deep regeneration, have resulted from the use of chemical tracers of these processes. The 20th century invasion of anthropogenic substances, such as fallout from nuclear weapons tests in the atmospheric and chlorofluorocarbons, into the ocean has provided especially valuable insights into the rates and pathways of ocean ventilation. ^{129}I is a relatively long-lived ($t_{1/2}$ = 16 million years) anthropogenic tracer that has been released to the ocean in large quantities (10 times the pre-existing natural inventory) from European nuclear fuel reprocessing facilities since the late 1960s (Raisbeck et al., 1995). Recent analytical innovations in accelerator mass spectrometry (AMS) mean that ^{129}I can now be measured on 1 liter water samples practically anywhere in the Arctic and North Atlantic Oceans, thereby positioning ^{129}I as a new and very useful oceanographic tracer for circulation studies (Kilius et al., 1992; Edmonds et al., 1998). The present study was designed to measure an ^{129}I time series in the Labrador Sea in order to constrain ventilation ages for the deep waters of the North Atlantic Ocean.

DISCUSSION

Iodine-129 discharges into the Irish Sea and English Channel from nuclear fuel reprocessing facilities at Sellafield (UK) and La Hague (France), respectively (Figure 1) are transported into the North Sea and Norwegian Coastal Current and from there they pass into the Norwegian/Greenland Seas on a time scale of 1-2 years. The subsequent transport of ^{129}I into the Arctic Ocean and its utility as a tracer for the circulation of Atlantic water has been outlined in Smith et al. (1998; 1999). However, deep mixing and convection in the Greenland and Norwegian Seas (Rudels, 1995) also injects tracer ^{129}I into intermediate waters that overflow the sills between Greenland and Iceland (Denmark Strait Overflow Water; DSOW) and between Iceland and Scotland (Iceland Scotland Overflow Water; ISOW). DSOW flows directly over the sill into the bottom of the Irminger Sea Basin while ISOW follows a more circuitous pathway, flowing across the Mid-Atlantic Ridge through the Gibbs Fracture Zone before over-riding DSOW in the Irminger Sea. The two water masses undergo some degree of mixing as they flow into the Labrador Sea and eventually form the Deep Western Boundary Current (DWBC) that effectively ventilates the deep North Atlantic. ^{129}I should be easily traced in DSOW, ISOW and the Deep Western Boundary Current because it is released into the ocean essentially as a point source rather than being globally distributed as is the case for fallout tritium and chlorofluorocarbons and therefore encounters much lower "interferences" from signals in water masses not directly labelled by a reprocessing signal. The potential of ^{129}I as a circulation tracer in the North Atlantic is also favoured by the nature of its input function. Until 1990 its input function was similar to that of CFCs, but between 1991 and 1999, its annual input to the Greenland/Norwegian Sea increased by 600% as a result of sharply increasing releases (3 years earlier) from La Hague. Since the CFC concentration in the atmosphere has remained relatively constant over the same period (Walker et al., 2000), the ^{129}I/CFC ratio in surface waters of the Greenland Sea has presumably undergone a similar 600% increase in the past 6 years. Measurements of this ratio in "downstream" water masses should be usable as a chronometer to determine ventilation ages with a resolution of approximately 1 year over this time period, depending on the degree to which mixing occurs with water labelled by tracer signals from previous years.

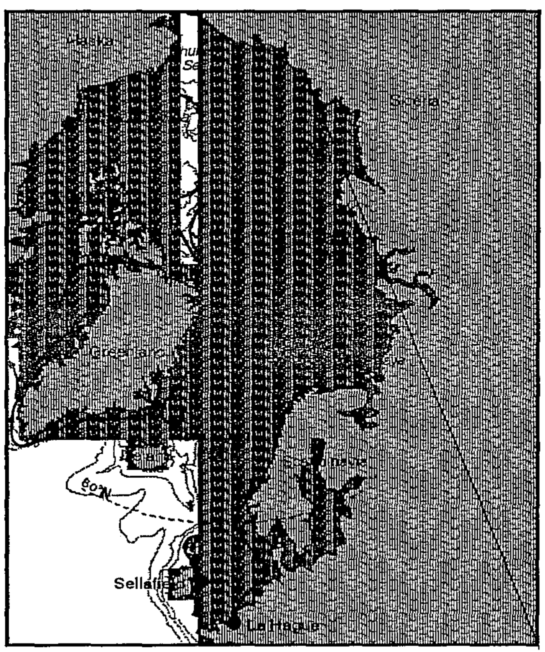

Figure 1. The ^{129}I tracer plumes from Sellafield and La Hague are transported into the Arctic Ocean and Greenland-Norwegian Seas (Nordic Seas) via the Norwegian Coastal Current. Convection in the Nordic Seas results in the incorporation of the tracer signal into the various overflow waters, including Denmark Strait Overflow Water (DSOW) that flows over the sill between Greenland and Iceland, followed by the subsequent transport of ^{129}I into the deep waters of the North Atlantic Ocean.

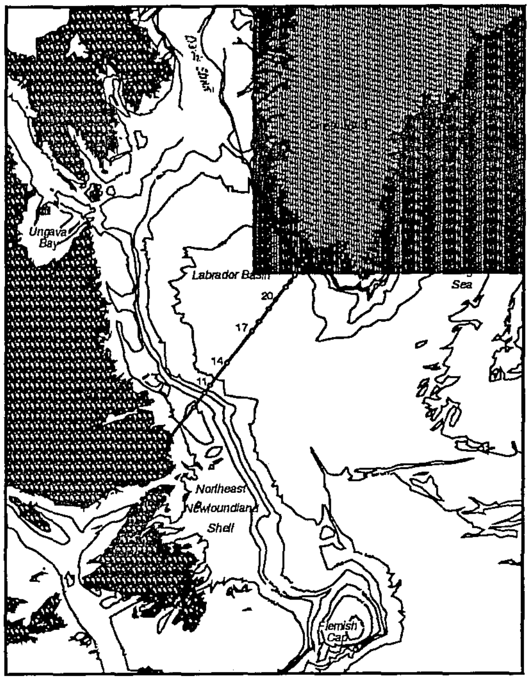

Figure 2. Stations on the Labrador Sea line that were sampled for ^{129}I in 1997, 1999 and 2001.

^{129}I enters the surface waters of the Labrador Sea via the West Greenland and East Greenland Currents with a much smaller component arriving from the north, probably as a consequence of the recirculation of Atlantic water through Nares Strait. Pacific-origin water passing southerly through the Canadian Archipelago carries only a small, fallout ^{129}I signal ($\cong 2 \times 10^7$ at/l). The ^{129}I concentration in underlying Labrador Sea water (LSW) is governed mainly by convection of the surface signal supplied via the East Greenland Current. Inputs of ^{129}I to LSW by mixing with North Atlantic Central Water (NACW) are presumably small owing to the absence of direct injection of ^{129}I into the thermocline of the North Atlantic. The ^{129}I/CFC ratio in LSW is much lower than that typical of surface water in the Greenland Sea, owing to the historically limited supply of ^{129}I to the Labrador Sea. However, the ^{129}I/CFC ratio in LSW will steadily increase as a function of time in future years as the recent large ^{129}I pulse from European reprocessing plants passes through the Nordic and Labrador Seas and is gradually "titrated" into LSW via surface flow with the East and West Greenland Currents. The ^{129}I/CFC ratio should provide a well-defined chronological marker for following LSW water as it flows through the North Atlantic and it can probably be used to test the validity of the various ventilation ages proposed by Sy et al. (1997) for North Atlantic intermediate waters. ISOW lies immediately below LSW and is labelled by the ^{129}I concentrations that reflect the time of formation of this water mass in the Greenland-Norwegian Sea. These ^{129}I levels are lower than those of

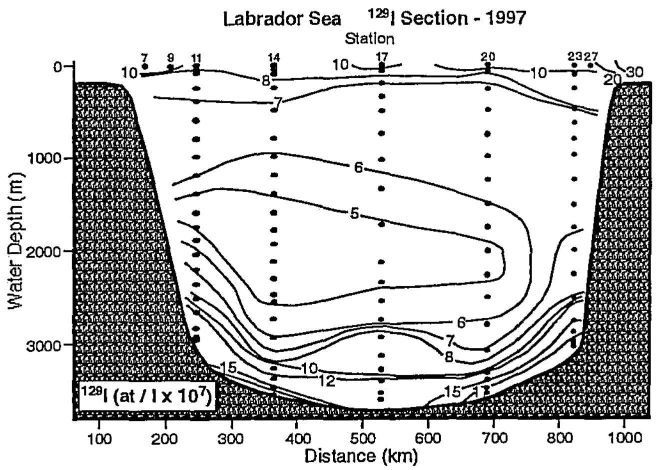

Figure 3. ^{129}I section for 1997 shows elevated ^{129}I levels (> 15 x 10^7 at/l) in Denmark Strait Overflow Water (> 3000 m) compared to overlying water masses owing to rapid ventilation of the deep waters of the Labrador Sea.

the underlying DSOW owing to the comparatively longer pathway and consequently greater transit time for the passage of ISOW into the Labrador Sea. The densest water in the Labrador Sea is DSOW, formed primarily from Arctic Intermediate water in winter in the Greenland and Iceland Seas and is labelled by comparatively high levels of both ^{129}I and CFCs.

Approximately 220 ^{129}I measurements were made on water samples collected in each of 1997 and 1999 on the Labrador Sea line (Figure 2) and measurements on samples collected in 2001 are underway. The ^{129}I sections (Figure 3, 4) show that the entire Labrador Sea water column was labelled by a European nuclear fuel reprocessing signal superimposed on a small, residual fallout background signal. Surface water concentrations were highest in the eastern Labrador Sea, proximal to the surface water source in the West Greenland Current. ^{129}I levels decreased with increasing water depth in LSW, with the lowest values (3-5 x 10^7 at/l) measured in each year at about 1800 m, close to the deepest historical extent of convection. The highest ^{129}I levels (> 30 x 10^7 at/l) were measured in DSOW, below depths of 3000 m. The most significant finding was that the ^{129}I concentration in core DSOW increased by 50-100% between 1997 and 1999. These results indicate that the leading edge of the 1992-1999 ramp in the ^{129}I

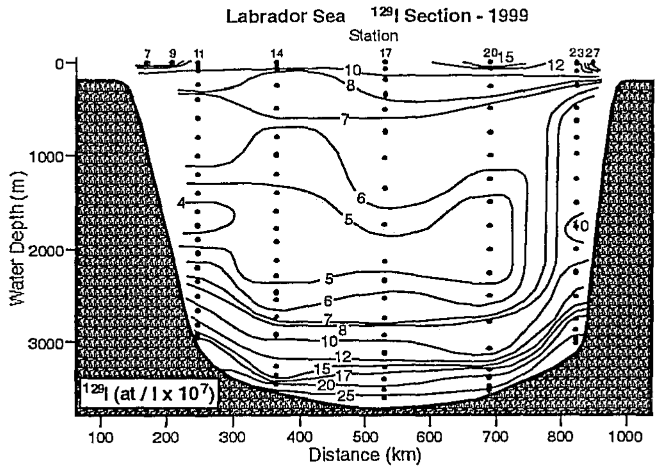

Figure 4. ^{129}I section shows an increase of 50-100 % in the ^{129}I concentration in Denmark Strait Overflow Water (> 3000 m) between 1997 and 1999. This inscrease is consistent with a proportionally similar increase in the ^{129}I input function in surface source waters in the Greenland Sea, approximately 3 years earlier, thereby indicating a ventilation age for DSOW of 3 years.

input function was evident in DSOW transiting the Labrador Sea during 1997-99. From a comparison of ^{129}I/CFC ratios measured in DSOW with the historical input function estimated for surface waters in the Greenland Sea (Smethie et al., 2000; Smethie and Fine, 2001), it was estimated that the ventilation age of DSOW was 2-3 y in the Eastern Labrador Sea and 3-4 y in DSOW in the Western Labrador Sea. The large 1997-99 increase measured in ^{129}I concentrations in DSOW will be similarly propagated through the DWBC in future years and should permit the annual resolution of transit times as the leading edge of this signal passes southwards through the North and South Atlantic Oceans. Future programs will involve the collection of samples on sections across the DWBC from tropic to sub-arctic latitudes. The intent of this work will to be to accurately determine transit times for both the DSOW and ISOW components of the overflow waters throughout the Atlantic Ocean.

Although the focus of the program so far has been on the deep overflow waters, it is interesting to note that ^{129}I levels will increase comparatively rapidly in surface waters of the Labrador Sea (via the East and West Greenland Currents) in response to the large reprocessing plant discharges during the 1990s and it is important to continue to document this time series begun in 1997. In the absence of recent convection in the Labrador Sea, ^{129}I levels will not have changed much by 2001 in LSW (100-2200 m), because the only significant ^{129}I source available to LSW is from the surface currents noted above. Nevertheless, the documentation of the slow increase in ^{129}I concentrations will provide an important chronology for determining the future flow of LSW through the North Atlantic. As the ^{129}I/CFC ratio increases with time, it can used to evaluate the hypotheses of Sy et al. (1997) that LSW spreads across the Mid-Atlantic Ridge and into the West European basins on a time scale of 4-5.5 years. It may also be possible to track the leading edge of the ^{129}I signal after injection into the Labrador Current and use it to follow the flow of northern waters southwards through the North Atlantic Ocean.

CONCLUSIONS

1. A 50% increase in the ^{129}I concentration in DSOW in the Labrador Sea between 1997 and 1999 is consistent with a 2-4 year transit time from surface water, source regions in the Greenland Sea.

2. Additional increases of the order of 100% will occur in the ^{129}I concentration in DSOW during the next few years as the leading edge of a large pulse of ^{129}I discharged from European nuclear fuel reprocessing plants during the 1990s passes through the Nordic and Labrador Seas and enters the North Atlantic Deep waters.

3. The excellent resolution of the reprocessing tracer ^{129}I signal, compared to background ^{129}I indicates that this will be a useful tracer for Nordic Sea Overflow waters and Labrador Sea Water and should be easily followed throughout the North and South Atlantic Oceans for many future decades.

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UNDERSTANDING LONG-TERM OCEAN CLIMATE VARIABILITY: DO FISH LISTEN TO GOSSIP?

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ABSTRACT

The climate system is non-linear and highly complex. Various analytical approaches have attempted to reduce this complexity to simpler forms. For example, using indices such as the North Atlantic Oscillation (NAO) have produced some interesting enviro-climate relationships. This study works with the system's non-linearity thus taking a new approach to climate indices. As the ocean is considered to be the long-term memory for the land/atmosphere system, we can regard any "memory" in land signals as a "reminder or feedback" from the oceans. This enables us to associate repeated or persistent signals in seasonal air temperatures with long-term, bulk, ocean processes. These feedback signals represent part of the internal communications within the climate system, the "gossip". To index such communications a new filtering technique, called MONACLE, has been derived that emphasises the non-linearity in a time series as well as allowing noise to be an integral part of the feedback process. The resulting time series can be shown to match bio-system responses to bulk ocean climate-processes. This text demonstrates such a climate-indexing approach for historical fish catch for locations from Lake Winnipeg to the Labrador Sea, from within the Arctic Circle and the Atlantic and Pacific Oceans.

INTRODUCTION

"Do fish listen to gossip"? With such a phrase in the title, the reader can anticipate that this study has taken a slightly different approach to climate and so asks us to use scientific creativity to tackle an old problem. Marine fisheries studies have a long history of debate on the relative importance of climate and population dynamics. Scores of studies have noted apparent climatic and even cyclic behaviour in some fish populations (covered in books and reports such as Cushing (1982) and Beamish (1995)). None of these climate studies lessens the importance of over-fishing and fisheries management practices.

This climate study has explored the importance of internal communications and the associated ideas of repetition, persistence, memory and feedback within the climate system. A new filter called MONACLE[#] has been developed and the above concepts and ideas behind MONACLE, as well as the use of simple sine-wave simulations to examine how the filter behaves with both non-linearity and with system-noise, have been outlined in Topliss (2001). In this text we will compare the MONACLE index with other climatic and ocean "indices" and

[#] MONACLE - Using the concept of communications internal to the climate system the acronym stands for MOther Nature's Aquatic Chat LinE.

identify regions where, in the absence of other information, MONACLE indicates possible climatic influences on long term catch records.

ECOSYSTEM TIME SERIES

Just as the NAO is associated with the greatest spatial coherence in the winter season, MONACLE produces a consistent set of matches when using regional autumn air temperatures. The new index can be "tuned" to take account of regional-seasonality and even over how long we might detect such a feedback signal. Most MONACLE analyses can be fully optimised by allowing minor regionally based variations in the filter's season (autumn) start time (months 8 to 10) and season length (2 to 4 months) and in the correlation window (7, 9 or 11 years). Good comparisons between MONACLE and historic fish catch can be repeated around the North Atlantic with cod off Northern Norway, off Western Greenland, off Eastern Canada, with Mackerel off New England and with the Sardine catch off Portugal (Topliss, 2001; 2002).

INDICES

Socio-economic influences on catch data are a concern and may dominate many recent records. Notwithstanding the factors involved in historic catch data, such series have shown marked cyclic and globally synchronistic behaviour (Klyashtorin, 1998) indicative of climatic influences.

ATLANTIC

Where MONACLE indicates a match with an ecosystem times series, similar varying time series do not imply cause and effect. Rather MONACLE records the passing of information internal to the climate system. For example, in Eastern Canada, larger-scale climate events in the 1970s resulted in cold water being transported off Labrador. This process has been qualitatively described via the LSW and along with potential over-fishing helped identify the consequences for eastern-Atlantic cod (Fig. 1a). Such eco-climate studies are less interested in the level of any correlation than in an understanding of the underlying process. A MONACLE index match, Fig. 1b, implies that the same cold-water transport process has provided "feedback" from the oceans to

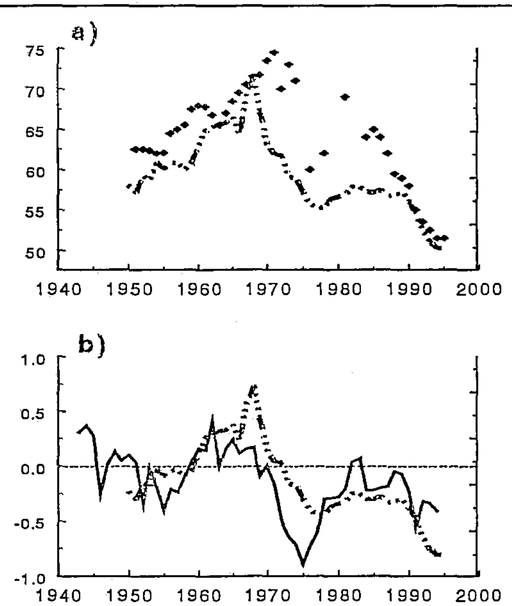

Figure 1 a) Diamonds are potential temperature of Labrador slope water [LSW], dashed line East Atlantic Cod catch; b) solid line MONACLE, 3 month season; dashed line Cod, r=0.59, n=45. [From Topliss (2002)]

the land and can be detected in regional air temperatures.
Further north in the Atlantic within the Arctic Circle, a match in time-scales of 60 years can be observed, Figure 2, for the regional MONACLE index and Norwegian cod (in the Vestfjorden). Again the match is good enough to raise the question of a regional ocean-climate mechanism associated with these long-term changes.

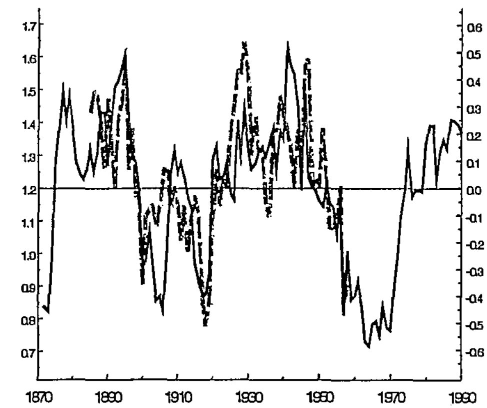

Figure 2: Dashed line, Cod series in the Vestfjorden; solid line local MONACLE index, earlier-shorter 2 month arctic season derived from atmospheric station at Bodo.

A literature search for this ocean region has provided no information on any known, specific climate process or mechanism. One study (see in Cushing, 1982) was able to "fit" the observed Cod catch variations via a combination of sine waves with periods taken from an analysis of regional tree-ring data. So here MONACLE confirms such possible climatic links plus indicates an associated, potential ocean process requiring further study.

PACIFIC and WESTERN CANADA

Variations in Alaskan Salmon catch have been related to the Pacific Decadal Oscillation, PDO, showing comparisons over 70 years, Figure 3a. The PDO is an ocean index related to sea surface temperature and to circulation processes within the Alaskan gyre system. Salmon are a diadromous species spending part of their life cycle in rivers and part in the open ocean. The issue of which of these ecosystems, oceanic or freshwater, has the greatest impact is expected to change with species, species behaviour and with environment (Pacific or Atlantic). Understanding the relative contribution should aid in understanding the long-term changes currently observed for many Salmon species.

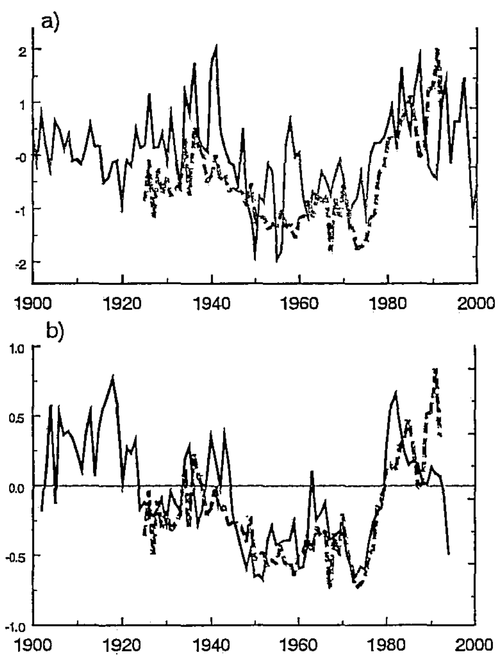

Figure 3. a) Solid line Pacific Decadel Oscillation, PDO, dashed line Total Alaskan Salmon Catch; b) solid line MONACLE, 3 month season; dashed line Salmon, r=0.70, n=68. [From Topliss (2002)]

The regional MONACLE index, Figure 3b, supports an oceanic-climatic influence on the long-term variations in Alaskan salmon.

In the North Sea the long term catch level maintained its value after the cessation in fishing activities during both world wars (Cushing, 1985). This apparent continuity, across the gaps, was used in early fisheries studies to support the (old) idea of a "steady state" ecosystem.

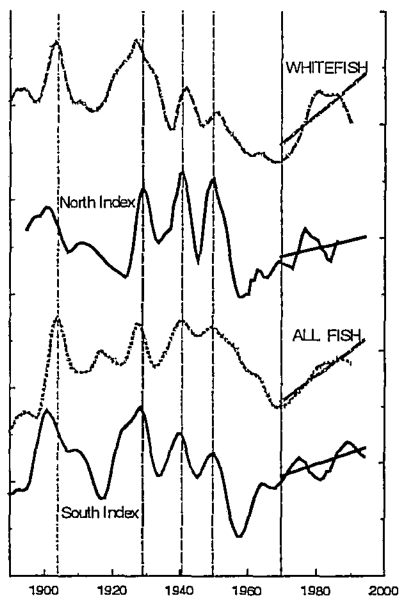

Figure 4: Top dashed line historic Whitefish catch; 2nd, solid line MONACLE index for north of lake; 3rd, dashed line total fish catch; bottom solid line index for south of lake.

In 1970 (see 5th vertical bar in Figure 4) all activity in Lake Winnipeg was closed due to a problem with mercury contamination. This shutdown also corresponded to a low point in fish catch. After the closure improved fisheries management practises were implemented and catch levels rose over the following 20 years.

The issue raised by a match, Figure 4, with any climate index, here with MONACLE, would be; was the catch recovery also related to long term climatic conditions?

SUMMARY

This study has raised questions about abrupt changes or regime shifts in both the climate and the ecosystem. The socio-economic importance of understanding such ecosystem regime shifts [FAO, 1997] warrants examining indexing schemes capable of tracking such potential climatic influences.

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ARE SALMON STARVING IN THE OCEAN?

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ABSTRACT

We conducted a study to assess the effects of ocean conditions and climate change on salmon growth. Juvenile coho salmon (*Oncorhynchus kisutch*) were collected off the west coast of British Columbia and Alaska in 1998-2000. Sea surface temperature was higher in 1998 by about 2-3°C due to a warm El Niño that was followed by a cool La Niña. Coho salmon were two-fold smaller in southern British Columbia than in Alaska in 1998. Lipid and energy contents were also lower in coho from southern British Columbia in 1998. These differences disappeared in 1999-2000. Coho salmon consumed on average about 10% of their body weight per day. These feeding rates did not vary significantly between regions or years. Simulations performed using a bioenergetic model showed that summer growth was reduced by only 10 grams when temperature increased by 3°C, but could easily vary by a factor of two with small differences in prey caloric contents. Our analyses suggest that an increase in sea surface temperature affects salmon growth through changes in prey community structure rather than by a diminution in feeding rates or an increase in metabolic rates.

RÉSUMÉ

Nous avons réalisé une étude pour déterminer les effets des conditions océaniques et des changements climatiques sur la croissance des saumons. Nous avons récolté des saumons coho (*Oncorhynchus kisutch*) juveniles le long de la côte ouest de la Colombie-Britannique et de l'Alaska en 1998-2000. La température de l'eau était 2-3°C plus élevée en 1998 due à un El Niño chaud qui a été suivi d'un La Niña froid. Les saumons coho étaient deux fois plus petits au sud de la Colombie-Britannique qu'en Alaska en 1998. Les réserves énergétiques étaient aussi plus faibles au sud de la Colombie-Britannique en 1998. Ces différences n'étaient pas apparentes en 1999-2000. Les saumons coho consommaient en moyenne 10% de leur masse corporelle par jour. Ces taux de consommation ne variaient pas de façon significative entre les régions et les années. Des simulations réalisées à l'aide d'un modèle bioénergétique ont démontré que la croissance estivale des saumons était seulement réduite de 10 grammes lorsque la température de l'eau augmentait de 3°C, mais qu'elle pouvait facilement variée par un facteur de deux avec des petites différences associées à la densité calorique des proies. Nos analyses suggèrent qu'une augmentation de la température de l'eau influence la croissance des saumons

par des changements au niveaux de la communauté de proies plutôt que par une diminution des taux de consommation ou une augmentation des taux métaboliques.

INTRODUCTION

The marine survival and production of several stocks of Pacific salmon and steelhead trout (*Oncorhynchus spp.*) located in Central and Southern British Columbia, Washington, Oregon, and California have decreased tremendously during the last decade (Hare et al. 1999; Beamish et al. 2000; Welch et al. 2000). Fisheries have been closed, and a number of those stocks have been added to the species endangered list in the United States. This period was also the warmest on record. However, it is unclear how warmer sea surface temperature (SST) should influence the survival of salmon.

Higher temperature may increase the metabolic rates of salmon, and hence, reduce the energy available for growth (Pyper and Peterman 1999). As mortality rates tend to be larger in small fish (Lorenzen 1996), a reduction in growth rate may thus reduce the survival of salmon. Warmer SST may also produce poorer ocean conditions for salmon growth through bottom-up processes. As warm water tends to be lighter, an increase in SST may increase the stability of the water column in the mixed layer and may prevent or reduce the upwelling of deep nutrient-rich water, and consequently, may decrease both primary and secondary productivity (Gargett 1997). Thus, in warmer years, salmon may have less food and reduced growth.

The objectives of this study were to assess how the growth rates of juvenile coho salmon (*Oncorhynchus kisutch*) were influenced by oceanographic and climatic conditions. We examined the effects of SST on plankton community structure and food consumption rates of salmon. We also assessed the effects of prey quality and SST on salmon growth.

METHODS

We collected juvenile coho salmon off the west coast of British Columbia using a rope trawl mounted on the *W.E. Ricker* in the spring (May-June), summer (July-August), and fall (October-November) of 1998, 1999, and 2000 (Fig. 1). For the purpose of this study, the area north of latitude 52°N was defined as Northern BC, while the area west of Vancouver Island (47-51°N) was defined as Southern BC (Fig. 1). These areas correspond to the coastal downwelling and coastal upwelling domains, respectively (Ware and McFarlane 1989).
Each net tow consisted of hauling the net at the surface (0-20 m) for 30 minutes at 5 knots. Up to 30 juvenile coho salmon were randomly selected from each net tow. Fork length and mass of coho were determined on board the research vessel using a ruler and an electronic scale equipped with a counterweight to

correct for ship motion, respectively. Otoliths and scales were removed for age determination. A skin sample was also taken from the operculum using a hole punch and preserved in 70% ethanol for stock identification. Whole fish were then frozen individually at –20ºC in pre-identified plastic bags for subsequent analyses. Water temperature profiles were usually obtained before the net was deployed using a CTD recorder connected to a computer. Zooplankton samples were collected with a bongo net (mesh size: 250 μm) towed to a maximum depth of 150 m. One side of the net was used to estimate plankton biomass, while the other side was used for species identification and enumeration. All the plankton identifications were performed by Moira Galbraith at the Institute of Ocean Science.

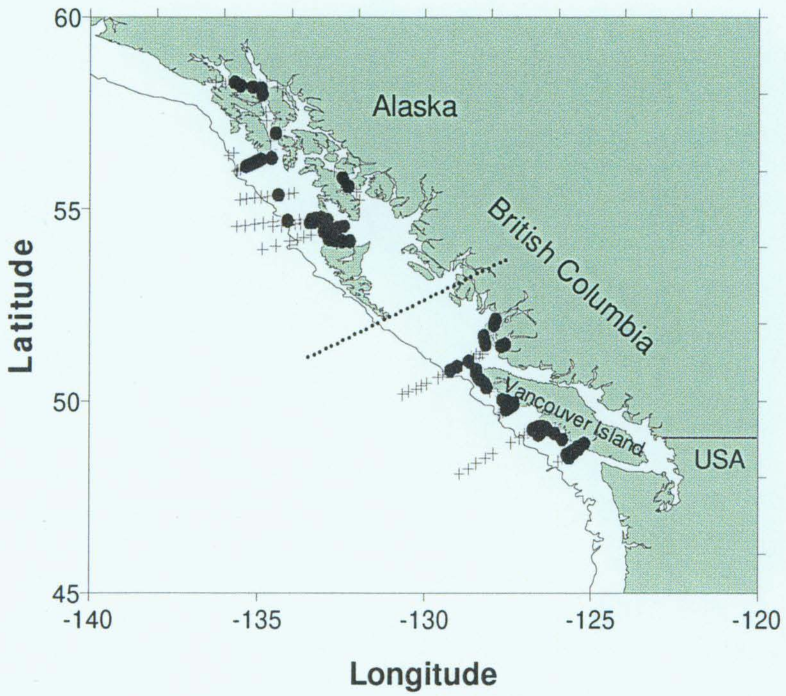

Figure 1. Sampling locations during the month of October 1998, 1999, and 2000. The closed circles represent stations where juvenile coho salmon were caught, while no coho salmon were caught at the stations indicated with the plus sign.

Food consumption rates of juvenile coho salmon were estimated using a mass balance model of stable cesium (^{133}Cs) following the procedures presented in Rowan and Rasmussen (1996). This model was initially developed for radioactive cesium (^{137}Cs) and gives similar results to those obtained using a mercury mass balance model that has been recently validated (Trudel et al. 2000). It should also be applicable to other cesium isotopes, as fish are not expected to be capable of discriminating between different cesium isotopes (Forseth et al. 1999).

^{133}Cs concentration in salmon and their food was determined by ICPMS (ERI Environmental Research Inc., North Vancouver, British Columbia). About 1-2 g wet weight of skinless dorsal muscle was removed below the dorsal fin. Whole fish ^{133}Cs concentration were obtained by multiplying muscle ^{133}Cs concentration by 0.76. This correction factor was empirically determined using 30 pairs of muscle and whole coho samples. All the samples were dried at 60ºC for a week and ground into a fine powder before they were analyzed. About one out of every eight samples were analyzed in duplicate. Differences between duplicates was usually below 8% (mean difference = 3.3±0.9%). Food consumption rates of juvenile coho salmon in northern and southern British Columbia were estimated using the average ^{133}Cs concentration of the fish caught in the spring and fall and their stomachs collected from these regions.

RESULTS AND DISCUSSION

SST was higher in 1998 than 1999 and 2000 by about 2-3°C due to a warm El Niño event that occurred in 1997 and lasted until the end of 1998 followed by a cold La Niña. This El Niño corresponded to one of the strongest ever recorded. Surface nutrient concentrations were also much lower in 1998 than 1999 (Whitney and Welch, *in press*). Nitrates were actually depleted at the surface during the summer of 1998 (Whitney and Welch, *in press*), suggesting that primary productivity was greatly reduced during that period.

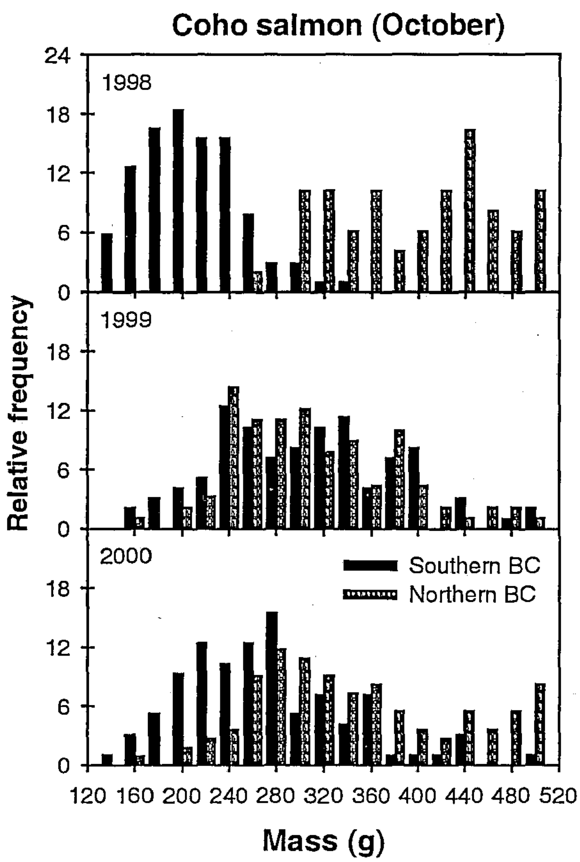

Figure 2. Size frequency distribution of coho salmon caught in Southern BC (gray bars) and Northern BC (black bars) in 1998, 1999, 2000. Here, frequency is expressed as a percent of the total catch in a given area.

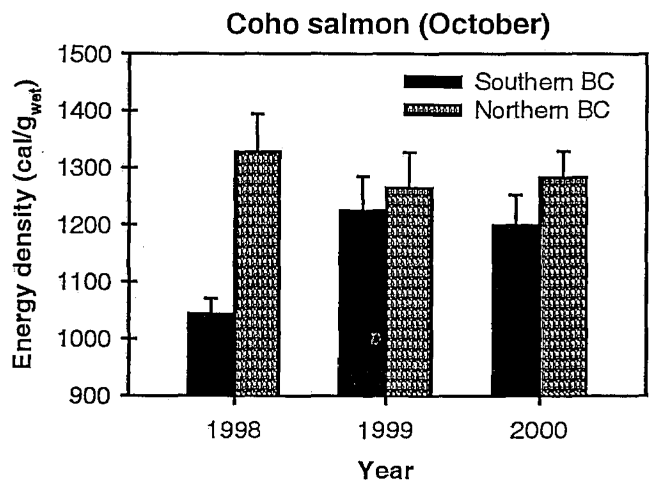

Figure 3. Caloric contents in coho salmon collected Southern BC (gray bars) and Northern BC (black bars) in 1998, 1999, 2000. The error bars represent the 95% CI.

Coho salmon caught at the end of the growing season were about two-fold smaller in Southern BC (~200g) than in Northern BC (~400g) in 1998 (Fig. 2). These differences disappeared in 1999-2000, with fish mass averaging around 300 g. Energy contents were also lower in coho caught in Southern BC in 1998, but not in 1999-2000 (Fig. 3). Thus, coho salmon collected in Southern BC in 1998 were in poorer condition, and had lower growth rates than those from Northern BC, but were similar in both regions after the 1997-98 El Niño.

Food consumption rates of juvenile coho salmon averaged about 10% of their body weight per day and did not vary significantly between regions or years (Fig. 4). These estimates represent about 75% of their maximum physiological capacity, and are among the highest values reported in the literature for any wild fish (M. Trudel, *unpublished*). Thus, there are no indications that coho salmon were starving, despite that ocean conditions were less favourable for salmon growth in Southern BC in 1998. These results also indicates that the growth differences observed in this study were not related to feeding rate differences.

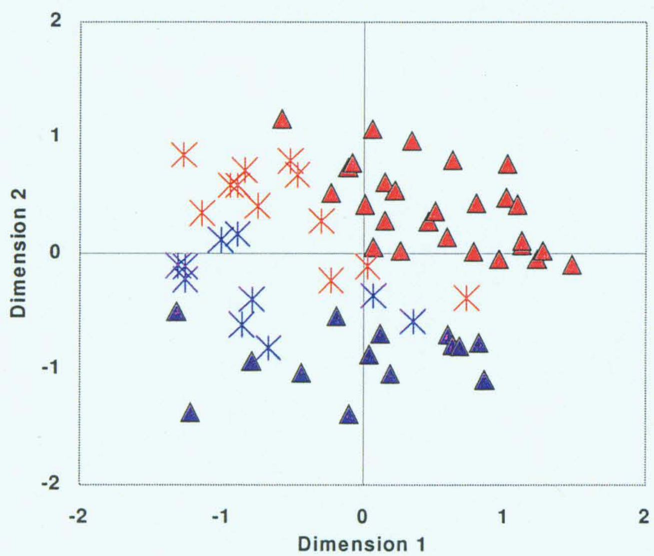

Figure 5. Non-metric multidimensional scaling performed on the log(x+1) transformed abundance data. ▲: Southern BC 1998; ▲: Southern BC 1999; ✳: Northern BC 1998; ✳: Northern BC 1999.

Zooplankton community structure varied between regions and years. In 1998, California shelf copepods occurred in significant numbers in the zooplankton community of Southern BC, and were also present in Northern BC, albeit in much lower quantities. In 1999, boreal shelf copepods dominated the zooplankton community in both regions. In addition, California shelf copepods disappeared from the west coast of British Columbia in 1999. Samples collected in 2000 have yet to be analysed. The changes in zooplankton community structure were much more pronounced in Southern BC than in Northern BC (Fig. 5). This suggests that differences in prey quality mediated by a change in zooplankton community structure rather then changes in food consumption rates may be responsible for the differences in the growth rates of coho salmon observed in 1998. Unfortunately, we do not have the stomachs of the fish caught in 1998 to directly test this hypothesis.

To assess the potential effects of prey quality and SST on the growth of juvenile coho salmon, we used a bioenergetic model in conjunction with the feeding rates derived in this study. We used prey with low (700 cal/g) and high (900 cal/g) quality. These values are within the range of published values for zooplankton (Davis et al. 1998). SST was modelled using the temperature cycle provided in Brett (1983). These simulations were also performed by increasing the daily temperature by 3°C to simulate the effects of increased SST observed in this study. We assumed that coho smolts entered the ocean weighing 10 g on May 15, and monitored their growth until October 15 of the same year (Sandercock 1991).

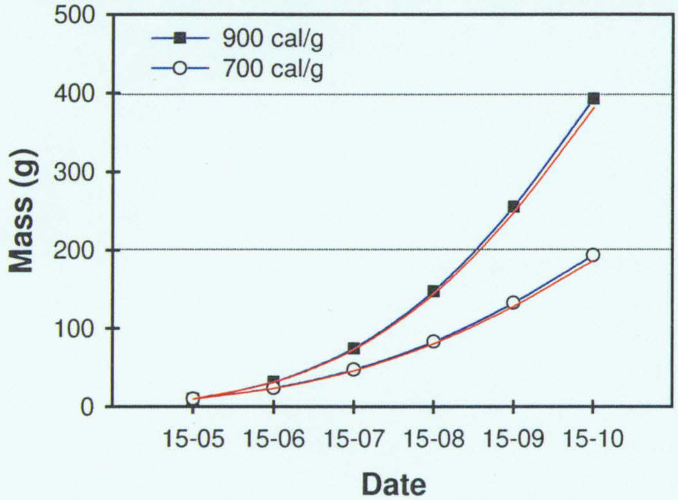

Figure 6. Growth rates of coho salmon predicted using prey of low (700 cal/g_{wet}) and high quality (900 cal/g_{wet}).

Coho salmon reached a size of about 200 g and 400 g when they were feeding on prey of low and high quality, respectively (Fig. 6). These differences are similar to those observed in this study. Increasing SST by 3°C decreased the final size by about 10 g, suggesting that the observed differences in growth rate were unlikely due to an increase in SST associated with the El Niño. Taken together, these analyses strongly suggest that changes in prey community structure can have large impacts on top predators.

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SENSITIVITY OF CARBON EXPORT TO OCEAN CLIMATE: PERSPECTIVES FROM ECOSYSTEM MODELLING

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THE LABRADOR SEA AND THE GLOBAL CARBON CYCLE

The Labrador Sea is one of the few relatively small ocean regions where there is a direct connection between the atmosphere and the deep ocean through deep winter convection. As such it is known to play a critical role in the long-term sequestration of anthropogenic carbon dioxide (CO_2) in the ocean. Recent calculations indicate that the Labrador Sea alone accounts for 8-19% of the global ocean uptake of anthropogenic CO_2 (Tait et al. 2000). Less well known however is the role of deep convective areas such as the Labrador Sea in the sequestration of CO_2 through the biological pump.

THE BIOLOGICAL PUMP

The biological pump (Figure 1) begins with the production of organic carbon from dissolved CO2 through photosynthesis. A fraction of that organic material escapes the surface ocean, effectively removing CO2 from the atmosphere-ocean system. In most of the ocean, this export of organic carbon is due mostly to the settling of detritus (sinking flux) and to a lesser extent to the vertical motions of some members of the marine biota (vertical migration flux). Thus, in most of the ocean, organic carbon moves through the water column to reach the depths. However, in convective areas such as the Labrador Sea, organic carbon in dissolved form (DOC) can be transported with the water to the depths where it can be sequestered. Our work aims at exploring the relative strength of this DOC flux and its regulation by physical and biological processes using ecosystem models combined with physical information on the climate of the Labrador Sea.

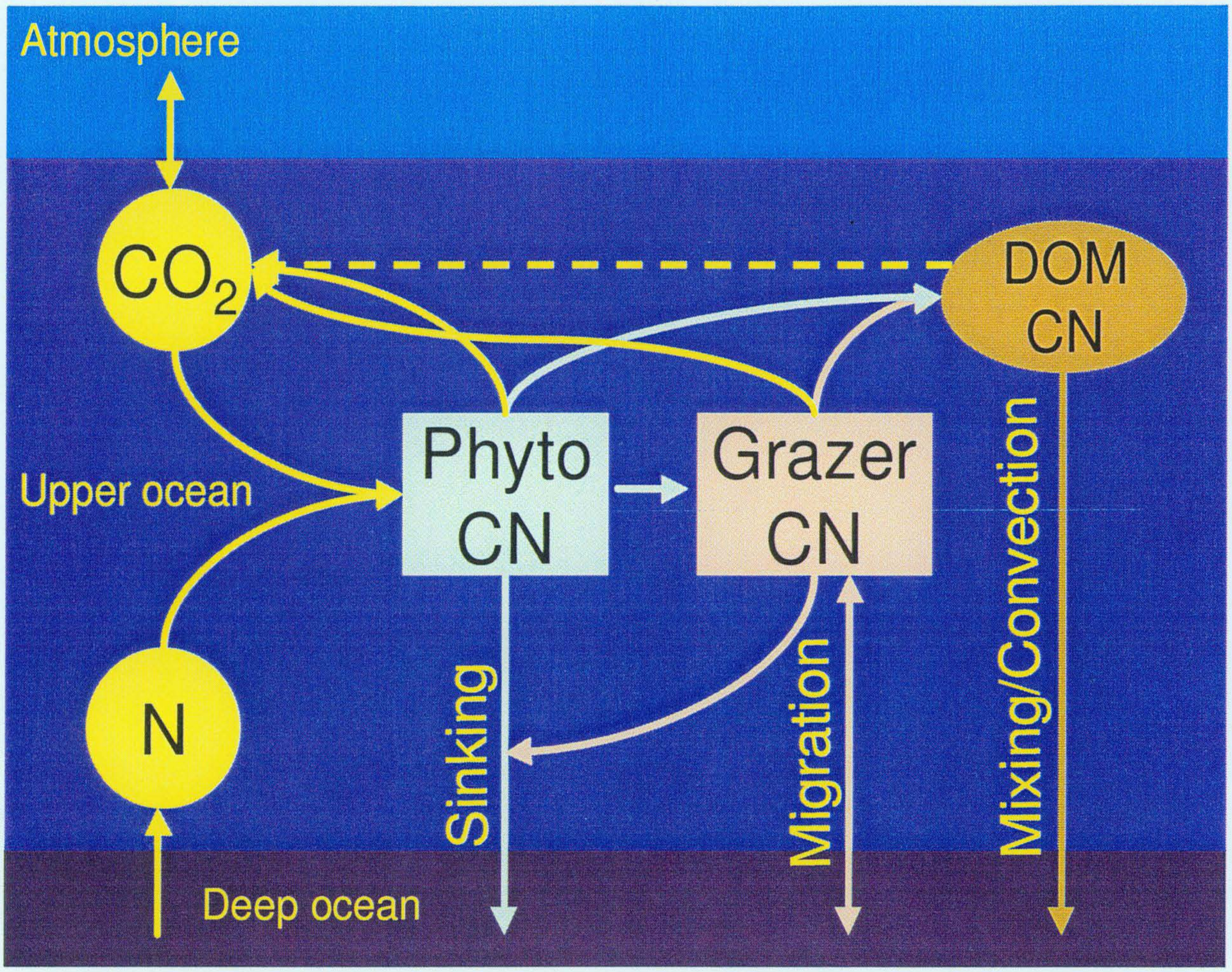

Figure 1 - Schematic representaiton of the biological pump in the ocean. N is Nitrogen and CO_2 is carbon dioxide, inorganic compounds that are combined into phytoplankton (Phyto) biomass (CN) though photosynthesis. DOM is Dissolved Organic Matter generated by metabolic processes in the water column. The down vertical arrows depict the routes by which organic matter can be lost from th eopen ocean. An ecosystem model forced by ocean-atmosphere exchanges of heat and momentum (i.e. ocean climate) simulates these processes.

AN ECOSYSTEM MODEL TO INVESTIGATE THE BIOLOGICAL PUMP

We use an ecosystem model that simulates the flows of nitrogen among various ecosystem compartments and that also tracks the vertical motions of organic nitrogen (Figure 1). Nitrogen is used because it is assumed to limit biological activity in the ocean. The associated carbon flows are calculated using mostly fixed ratios. In some cases, we introduce simple rules that essentially say that organisms prefer to retain nitrogen in their bodies (because it is in short supply) and expel carbon. This model has been tested extensively in a subarctic semi-enclosed sea (the Gulf of St. Lawrence) (Tian et al. 2000, 2001).

THE BIOLOGICAL PUMP IN THE LABRADOR SEA

When applied to the Labrador Sea, the model suggests that the DOC flux is as large as the sinking flux and is substantially larger than the vertical migration flux (Figure 2). The model also suggests that the DOC flux is particularly efficient in moving organic carbon to depth, while retaining nitrogen in the surface ocean. This decoupling of carbon and nitrogen fluxes enhances the biological pump when nutrients are limiting.

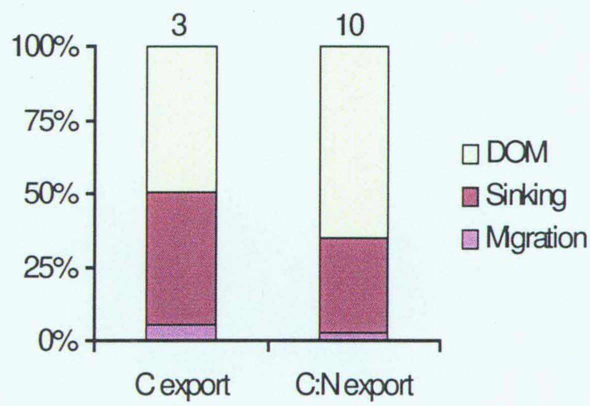

Figure 2. Relative importance of export fluxes in the Labrador Sea simulated by a physical-ecosystem model. C export is the total downward organic carbon flux across the 200 m isobath (moles C/yr). C:N export is the carbon-to-nitrogen ratio of the exported organic matter (moles C/moles N); a C:N higher than 6.6, the average C:N of organic matter, indicates that C is preferentially exported. C export and C:N export averaged across a number of simulations are given at the top of each bar and are broken down into contributions from dissolved organic matter (DOM), particle sinking, and vertical migration.

OCEAN CLIMATE AND THE BIOLOGICAL PUMP IN THE LABRADOR SEA

We also examined the impact of variations in the strength of winter convection on carbon export. To study this effect, the ecosystem model was forced with data on the physical structure and climate of the Labrador Sea from periods when convection was weak (the late 1960s and early 1970s) and when it was strong (early to mid-1990s) (Figure 3). The results indicate that the sinking flux is relatively insensitive to the variations in ocean climate (Figure 4). In contrast, the DOC flux is very sensitive and is the main contributor to climate-related variations in total export. This goes against prevailing views that the sinking flux is the main driver behind export variability. More to the point, this gives clues as to the

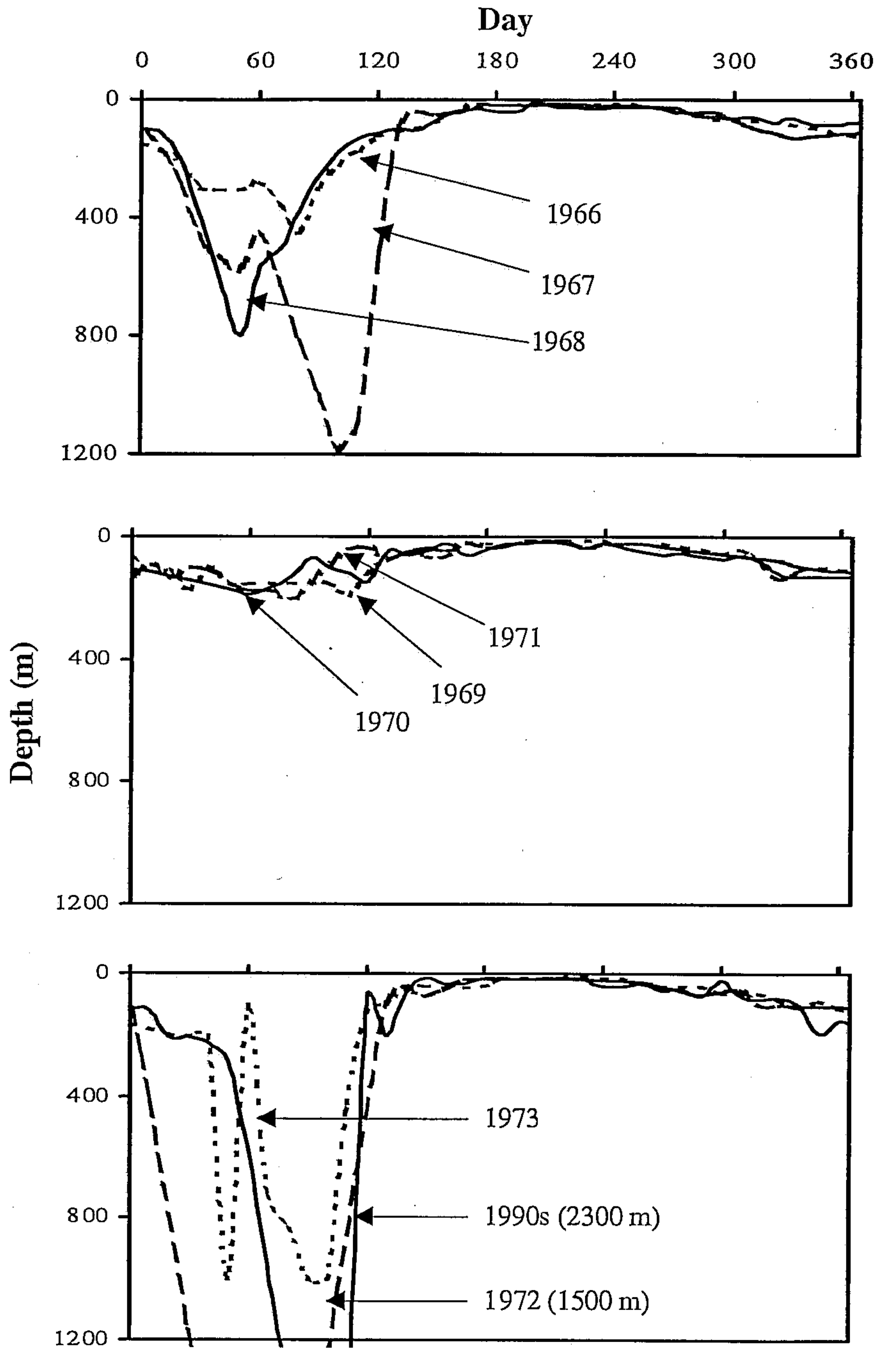

Figure 3 - Annual evolution of the surface mixed-layer diagnosed from temperature-salinity records acquired in the Labrador Sea for these specific years.

potential impact of climate change on organic carbon cycling in the Labrador Sea if climate warming does result in a reduction of winter convection. Lower organic carbon export would leave more CO_2 in surface waters and lower the ocean's uptake of CO_2.

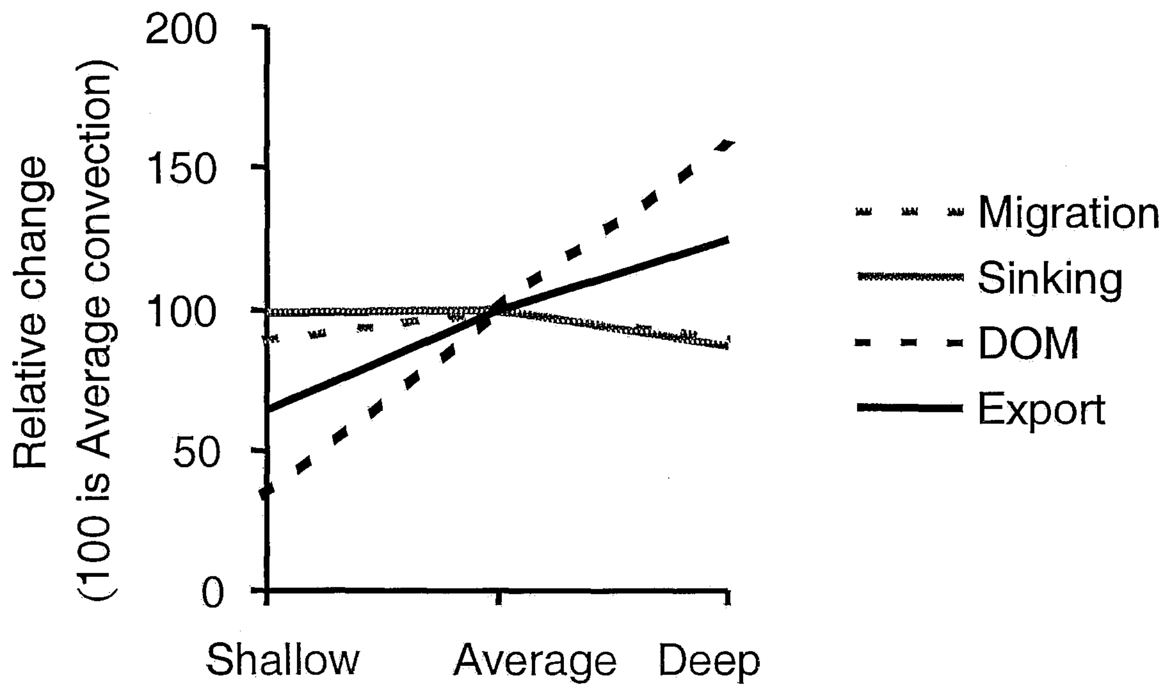

Figure 4 Relative changes in export fluxes simulated by the physical-ecosystem model under shallow (< 200 m), average (300-1000 m) and deep (> 1500 m) maximum depth of winter convection in the central Labrador Sea.

CONCLUSIONS AND FUTURE DIRECTIONS

These results are preliminary and subject to change as the work evolves. Nevertheless, they are stimulating further research. One ongoing effort is to develop and refine an ecosystem model that couples carbon and nitrogen flows across all compartments, as opposed to only some of the compartments in this model (see Pahlow and Vezina, this volume). A related effort is to investigate the implications of the DOC flux for climate variations at a global scale by coupling the improved ecosystem model to an atmosphere-ocean climate model. This work will be part of a new international research initiative (SOLAS or Surface Ocean Lower Atmosphere Study) that DFO has joined along with a network of

Canadian universities and other government laboratories. As part of a team working to understand the future of the ocean's carbon sink, our goal is to learn more about potential interactions between DOC flux and climate.

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DAY THREE
DEFINING STANDARDS FOR MEQ AND FEQ WITH SPECIAL REFERENCE TO CONTAMINANTS AND AQUACULTURE

APPLYING ENVIRONMENTAL EFFECTS MONITORING STRATEGIES AND MITIGATION APPROACHES TO GOLD MINES IN NORTHWESTERN ONTARIO

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Freshwater Institute

There are 900 present or former mining sites for base metals, gold, potash, coal and iron ore across Canada and most sites are adjacent to freshwater systems in remote areas. Guidance statements for the implementation of Environmental Effects Monitoring (EEM) Program for metal mining in Canada include determination of the magnitude and extent of contaminant discharges into receiving waters and the bio-availability of contaminants to fishes. Analyses of arsenic in surficial sediments from waters receiving gold mining effluents in the Red Lake region of northwestern Ontario reveal concentrations up to 67 times greater than from reference sites, upstream of effluent inputs. Concentrations of arsenic found in liver, kidney, gill and muscle tissues of white suckers (*Catostomus commersoni*) captured downstream of gold milling and mining operations were up 48 times greater than those in fish tissues collected from reference sites. Results from experiments employing limnocorrals deployed in Balmer Lake, a tertiary discharge location for effluents from two gold mines, indicate that arsenic is principally associated with iron oxyhydroxides in those sediments and that the release of arsenic from sediments to the overlying water is regulated by the redox status of iron. Mitigation options are evaluated.

ANTI-SEA LICE PESTICIDE EFFECTS ON NON-TARGET ORGANISMS: A SUMMARY OF STUDIES CONDUCTED WITH AMERICAN LOBSTERS AND SALMOSAN® (AZAMETHIPHOS)

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In 1994 the salmonid aquaculture industry in Eastern Canada experienced its first widespread infestation of ectoparasitic copepods commonly called sea lice. Since that time the use of chemical to combat these infestations is a normal part of salmon aquaculture operations in Eastern Canada. The widespread use of anti-lice compounds has given rise to a number of concerns regarding the effect of these chemicals on "non-target" organisms, particularly lobsters.

American lobsters (*Homarus americanus*) represent an important part of the commercial fishery in southern New Brunswick. The value of landed catches is in excess of $7 million (Canadian) annually. Lobsters are often found (and fished) in close proximity of salmon aquaculture operations.

Currently in Canada only one pesticide formulation, Salmosan® (47.5% w/w azamethiphos), is fully registered for use against sea lice infestations of farmed salmon. The recommended treatment regime is a 30- or 60-minute bath treatment at 100 µg/L. Although the 48-h LC50 of azamethiphos to larval and adult lobster ranges from 1.03 to 3.57µg/L, the estimates are not significantly different from each other ($p<0.05$) (Table 1) (Burridge et al. 1999). In addition, we have reported that repeated short-term exposure (15 or 30 minute) to high concentrations (25 and 10 µg/L) of this formulation will result in significant mortality (Burridge et al. 2000). Repeated exposures to lower concentrations (0.5 and 1 µg/L) do not result in any mortality.

Table 1. Estimates of the 48-h LC50 for Salmosan® (reported as measured azamethiphos) and the larval stages, first post-larval stage, and adults of the American lobster. (n = number of replicate tests).

Larval Stage	48-h LC 50	95 % CI	n
Stage I	3.57 µg/L	1.76 - 5.37	6
Stage II	1.03 µg/L	0 - 4.28	7
Stage III	2.29 µg/L	0.72 - 3.88	8
Stage IV	2.12 µg/L	1.06 - 3.18	5
Adults	*1.39 µg/L*	*0.78 - 2.02*	*6*

Lethality tests were conducted with adult females over a two-year period. This spans the normal biennial spawning/molting cycle. The 48-h LC50 was found to range from 0.61 µg/L (in August) during late premolt and early postmolt to 3.24 µg/L (in April) during the prolonged intermolt period (Figure 1). At no time during this study was an LC50 estimate found to be statistically different from the estimated LC50 for the test immediately before or after ($p<0.05$). ANOVA showed significant differences and multiple comparisons (t test) show lobsters were statistically less sensitive to azamethiphos during February and April compared to August ($p<0.05$). These data strongly suggest that time of year when exposure occurs may play an important role in assessing the risk of the use of this pesticide.

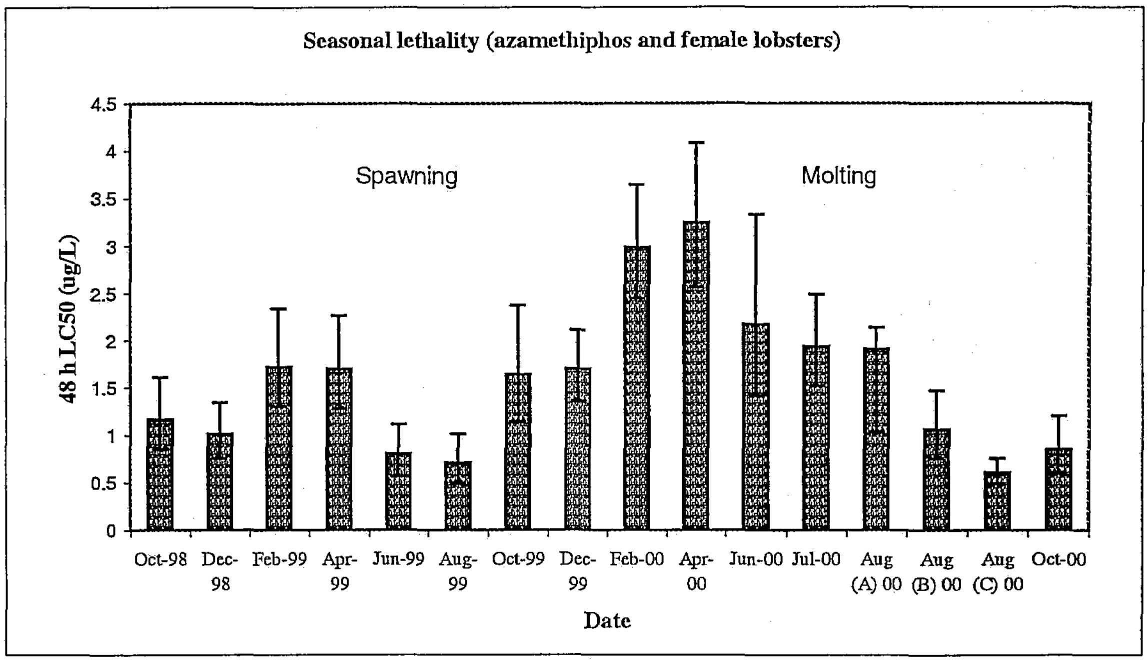

Figure 1 Calculated 48-h LC50 for azamethiphos and adult female lobsters. Bars represent the 95% confidence interval about the mean.

The effect of timing of exposure is further demonstrated by data from experiments conducted to determine the effects of biweekly, one-hour exposures of azamethiphos on spawning of preovigerous female lobsters. Results shown in Table 2 show that when female lobsters are induced to spawn in the fall (using photo-thermal manipulation) and exposed to azamethiphos several weeks prior to spawning there is no effect on survival of the maternal female or spawning success. When the induction and exposure took place in the spring azamethiphos affected survival and spawning. Exposure to 10 µg/L resulted in significant mortality after as few as 3 biweekly exposures. In addition, spawning was affected by repeated (4) exposures to this concentration in 1998 (Table 2). In 1999, four of 25 surviving lobsters failed to spawn compared to 0 of the controls. This difference was not significantly significant (Table 2).

In 1998 and 2001 a smaller percentage of lobsters died after repeated exposures to 5 µg/L than to 10 µg/L (Table 2). Instances of preovigerous females failing to spawn and of lobsters resorbing oocyte vitellin were also observed in some lobsters exposed to azamethiphos at and 5 µg/L. In 2001 only 67% (6 of 9) surviving lobsters spawned successfully compared to 100% of the controls. This difference was not significantly significant (Table 2). The risk of azamethiphos affecting wild lobster populations in the vicinity of aquaculture operations has yet to be determined.

Table 2. Effects of azamethiphos on spawning in American lobsters. * indicates statistically significant difference compared to controls

Treatment	N	% Mortality	Days to Spawn	% Spawning	% Survivors spawning
1997 Fall					
Control (n=4 x 1h)	24	0	95	96	96
10µg/L (n=4 x 1h)	24	13	102*	79	90
0.06 µg/L (1x 14d)	24	8	93	100	100
1998 Spring					
Control (n=4 x 1h)	21	0	74	95	95
5 µg/L (n=4 x 1h)	24	8	71	83	90
10 µg/L (n=4 x 1h)	23	43	79	26*	46*
1999 Spring					
Control (n=3 x 1h)	24	0	67	100	100
10 µg/L (n=3 x 1h)	48	48	74*	44*	84
2001 Spring					
Control (n=4 x 1h)	10	0	79	100	100
10 µg/L (n=4 x 1h)	10	100		0*	0*
5 µg/L (n=4 x 1h)	10	10	82	60*	67
2.5 µg/L (n=4 x 1h)	10	0	78	100	100
1.25 µg/L (n=4 x 1h)	10	0	77	90	90

The data reported here are the result of collaboration between lobster physiologists and ecotoxicologists and clearly show the benefit of such an interdisciplinary approach. Techniques for manipulating lobster molting and reproduction are providing new endpoints for ecotoxicological studies. Pertinent questions about the effects of sea lice pesticides on non-target organisms have led to the development of the novel and ecologically meaningful bioassays described here. While many of the major questions about effects of azamethiphos on lobster survival have been answered, there are a number of sublethal endpoints yet to be addressed in a significant manner.

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INSTREAM FLOW REQUIREMENT FOR THE PROTECTION OF FISH HABITAT: AN OVERVIEW OF APPROACHES

Daniel Caissie (Gulf Fisheries Centre)

The Competition between water abstraction from river (e.g. irrigation, hydroelectric, drinking waters, etc.) and instream flow needs (e.g. minimum flow for the protection of fish habitat) is a recurring problem in water resources management. Habitat mangers need effective tools during impact assessment to determine the amount of water that is required for river instream use. Different methods have been developed to address instream flow issues in rivers, and these methods are generally classified in three main categories: 1) historical streamflow, 2) river hydraulics and 3) habitat preference methods. Historical streamflow methods are the simplest methods because they make use of hydrometric data in the analysis. These methods, also called office methods, can be applied on regional basis. River hydraulics methods require field data in their application and the most commonly applied methods is the wetted perimeter method. Habitat preference methods also require field data collection, as well as biological considerations of the studied river. This method is currently identified as being the most popular method in North American for instream flow issues. However, this approach to instream flow assessment has also been the most critiqued method and it remains very controversial in its application. The different instream flow methods will be described and implication of their applications will be presented.

INORGANIC CHEMICALS IN SEDIMENTS, WILD LOBSTERS, AND SEA URCHINS NEAR AQUACULTURE SITES AS INDICATORS OF MARINE ENVIRONMENTAL QUALITY

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INTRODUCTION

Environmental impacts of salmon aquaculture have been studied including interactions between cultured and wild species (Hindar, 2001), nutrient enrichment (McClelland and Valiella, 1998), dissolved oxygen (USEPA, 1999), and effects of antibiotics (Weston, 1996). Many chemicals including additives in artificial feeds such as immunostimulants and carotenoid pigments (Torrissen, 1989) are used in aquaculture operations. Other sources of chemical input include residual contaminant content (metals and organics) in salmon diet constituents, and Cu, which is commonly used in antifouling chemicals for the treatment of net-pen cages, both of which have drawn little attention regarding impacts to the marine environment (Burridge *et al.*, 1999). In New Brunswick, Canada, however, there have been attempts to determine acceptable levels of aquaculture chemical impact and factors that should be considered and incorporated in the implementation of environmental monitoring programs. The Department of the Environment and the Local Government have regulatory authority over net-pen fish farms (DELG, 2000) and consider performance standards based on redox potential, sulfide and ammonia as standard parameters to indicate sediment conditions. Unacceptable impacts are considered to have been reached when sediments become anoxic. The purpose of this study is to quantify the marine environmental impacts of produced chemicals from feed and wastes associated with aquaculture activities. Chemical components in feed, sediments, and non-target species (sea urchin and lobster) from around the cages were investigated. Sediment chemical components were compared to environmental monitoring program (EMP) ratings (i.e., A-normal; B-hypoxic; C-anoxic), and were used to evaluate the extent of detectable effects at 0m (under the cage) to 100m distance from cage sites.

MATERIALS AND METHODS

In the summer of 1998, sediment samples were collected by divers at 14 sites in southwestern New Brunswick. The site locations remain unknown to the authors.

Sediments were collected from under the cages (0m) at 14 aquaculture operation sites. Sediments were rated on site as A (Normal), B (Hypoxic), or C (Anoxic), based on the analysis of sulfide, redox potential, and ammonia (Hargrave *et al.*, 1995).

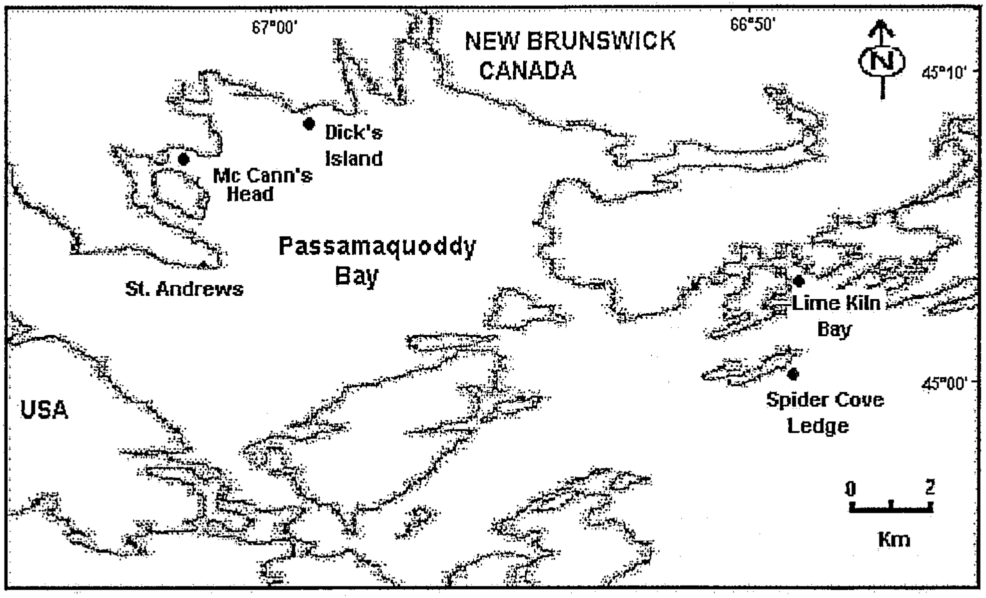

Figure 1. Lobster sampling locations at aquaculture, remediation and control sites in southwestern New Brunswick, Canada.

Market size lobsters were collected by divers at 4 sites in southwestern New Brunswick, Canada. McCann's Head and Dick's Island are salmon aquaculture operational sites. McCann's Head is located in a sheltered location and Dick's Island is in a slightly more exposed area. Lime Kiln Bay is a remediation site, abandoned for a year, and Spider Cove Ledge is a control site (Figure 1). For A-, B-, and C-rated sediments, eighty sea urchins per site rating were collected with twenty per distance at each of 0-25m, 25-50m, 50-75m and 75-100m distance from cage sites.

Sediments, lobster digestive glands, sea urchin intestinal tissues, and commercially available Amino Balance© diet, were digested in acid, and chemical analysis (Cu, Fe, Mn, Zn) was carried out using a Perkin-Elmer Model 403 flame atomic absorption spectrophotometer following the procedure of Chou *et al.* (2000). Total organic carbon analyses on the sediments were determined based on the Walkey-Black method (Walkey, 1947).

RESULTS AND DISCUSSION

SEDIMENT CHEMISTRY UNDER CAGE

There are two general trends, shown in Table 1, in the chemical composition of sediments from under the cages at 0m, associated with the environmental monitoring program ratings (EMP): 1) Cu, Zn, and organic carbon increase when the environmental conditions become more degraded from the Normal (A) to Hypoxic (B), and to Anoxic (C) sites (Fig.2). 2) Fe and Mn remain high in Normal (A), and decrease
to Hypoxic (B), and to Anoxic (C) sites (Fig.3). Diet Amino-10 contained 15 μg Cu/g, 232 μg Zn/g, 52 μg Mn/g and 392 μg Fe/g, which contributes to the waste under the

Table 1. Metal concentrations (μg/g dry weight) and % organic carbon in sediments from EMP rated A, B, and C sites from salmon aquaculture sites in southwestern New Brunswick.

EMP Rating	Cu	Zn	Fe	Mn	%Org. Carbon
A (Normal)	21.0±1.96	71.5±8.73	3.45±0.58	462±70.0	1.76±0.61
B (Hypoxic)	33.5±12.8	161±56.6	3.01±0.39	311±48.0	5.36±2.62
C (Anoxic)	54.5±5.11	253±85.7	3.01±0.34	337±69.0	9.07±3.95

cage. The fecal and metabolic waste metals and organic carbon from the diet fed at the cage, contribute some interesting changes to the marine environment. For example, at the degraded B- and C-rated sites, sediment Cu was surprisingly 2 and 3.5 times the dietary values (Fig. 2). The occurrence of more concentrated Cu in hypoxic and anoxic sediments may be attributed to: 1) excretion of more concentrated Cu in the fish faeces 2) the use of anti-fouling paint 3) accumulation and breakdown of the feed that loses organic material, without dispersing metals into the water column. Cu is known to bind tightly with organic material (Chapman and Stevens, 1978) and thus a high concentration factor for Cu is expected, especially in the presence of high organic

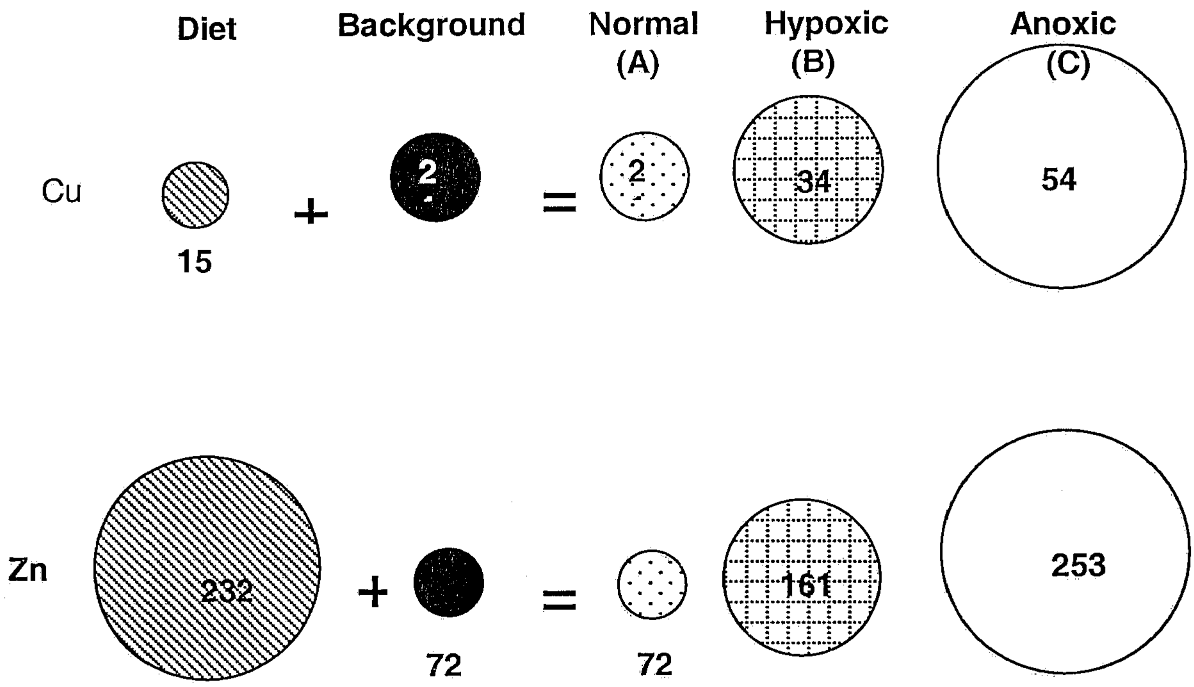

Figure 2. Fecal and waste metabolic form of Cu and Zn (μg/g dry wt.) in salmon diets, background sediments, and normal, hypoxic and anoxic sediments under cages.

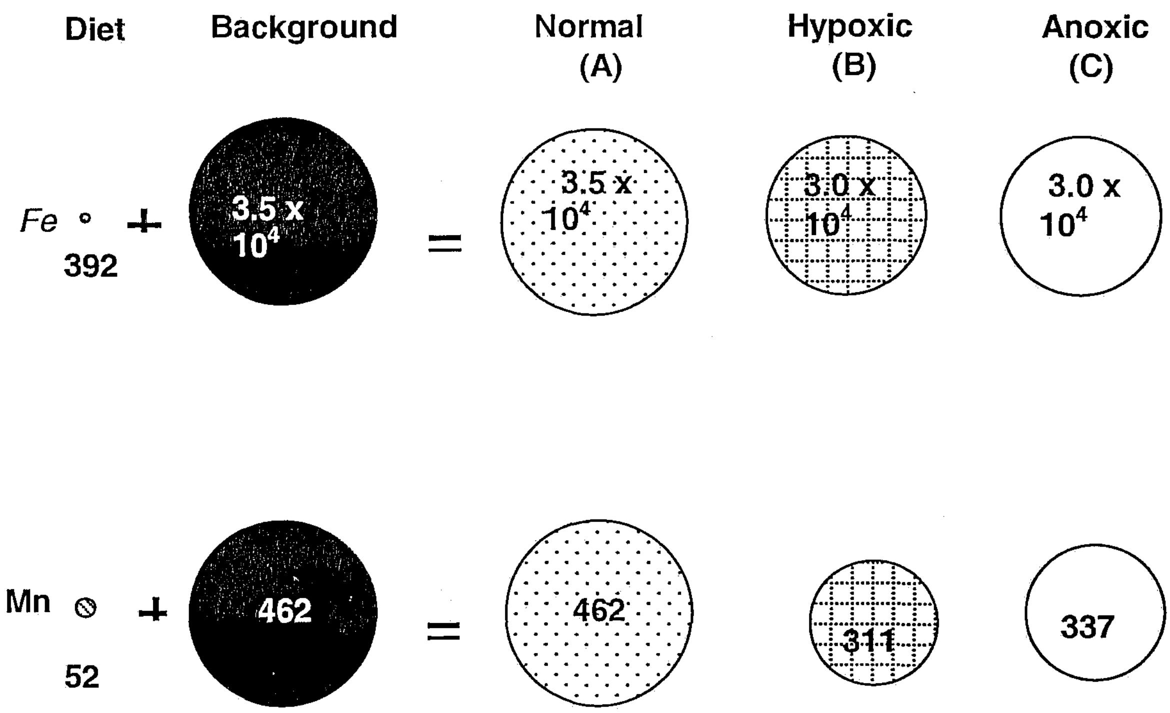

Figure 3. Fecal and waste metabolic form of Fe and Mn (μg/g dry wt.) in salmon diets, background sediments, and normal, hypoxic and anoxic sediments under the cages.

carbon. There is some slight elevation of Cu at A-rated sites compared to the diet. In the case of Zn, the accumulation to 253 μg Zn g^{-1} in the sediments at the most degraded C-sites possibly indicates that the seafloor was saturated with Zn, equivalent to the diet concentrations (Fig. 2), and that it had slowly built up to anoxic levels. Elevated organic carbon levels at B- and C-rated sites originates mostly from the feed and waste (Table 1). The increase in organic carbon accompanies the decrease in Mn at B- and C-rated sites (Fig. 3) suggesting dilutions of the background sediment Mn levels as a result of the accumulation of feed, which contains much lower Mn concentrations (~50 μg g^{-1}). Although there is a slight decrease in Fe from Normal to Anoxic sites, there are no apparent relationships between Fe in sediments and organic carbon at all sites. This may be a result of very high compositions of Fe in the natural background sediments (Loring, 1979), to concentrations which are more than a thousand times the diet levels (Fig. 3).

METALS IN NON-TARGET SPECIES

Heinig (2001) reported that shifts in benthic community structure as a result of aquaculture activity offer greater feeding opportunities for foraging epibenthic species, and that, at certain sites, the population of lobsters has increased significantly following installation and operation of net-pens in the area. Given the presence of lobster, which are known to accumulate extremely elevated levels of metals, especially in the digestive gland (Chou *et al.*, 2000) and other species nearby the cages, the input of chemicals, in particular Cu which is used in antifouling paints, is of concern. In this study, higher Cu was detected in McCann's Head lobster than at the other three sites (Fig. 4). The site is heavily farmed and is more localised and sheltered, and traps cage waste, compared to the active farming site, Dick's Island which is located in an open area of Passamaquoddy Bay. As copper is toxic to some marine species (Chapman and Stevens, 1978), environmental monitoring is needed to detect instances of uncontrolled use of chemicals containing copper, such as antifoulants, and growers should be cautioned regarding their use of these chemicals and the potential effects on non-target organisms. In our results, Zn, Mn, and Fe were all within the range for "normal" levels in lobsters from Atlantic Canada (Chou and Uthe, 1978), suggesting there is no mass accumulation of these three metals in lobsters as a result of aquaculture operations for these lobster study sites.

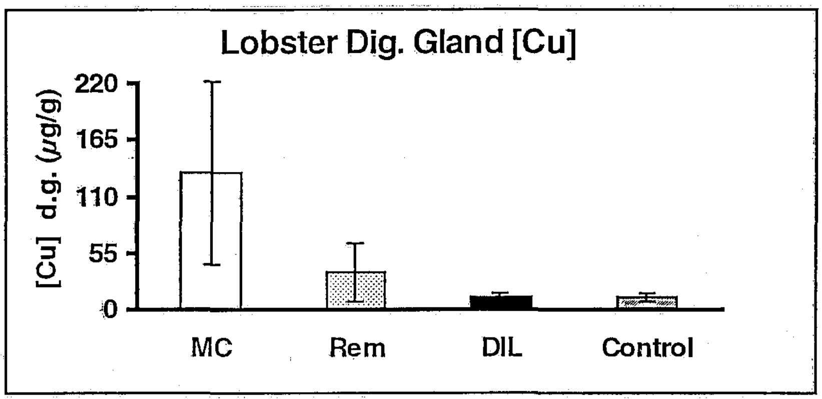

Figure 4. Copper concentrations in lobster digestive glands at McCann's Head (MC), remediation site (Rem), Dick's Island (DIL), and the control site.

Sea urchins, which are a non-migratory species, were also selected at three cage sites, with locations unknown to the authors. In sea urchins, the Ca, Cu, Fe, and Mn concentrations remain relatively constant at the normal, A-rated sites regardless of distance from cages. At B-rated sites, Ca increases with increased distance from the cage sites; Cu and Fe increases, reaching a peak at 75m for Cu, and peaking at 50m for Fe, then both drop to lows at 100m; Mn decreases with increasing distance from the cages. At C-rated sites, Ca increases with increased distance from the cages to 100m; Cu increases to a peak at 75m, then drops at 100m; Fe and Mn peak at 50m for C-rated sites, then drop to very low levels at 100m. Metal uptake in sea urchins shows that the impact of aquaculture waste could reach at least 75m distance away from the cage sites (Fig. 5).

CONCLUSION

In conclusion, degraded sediment sites showed elevated levels of Cu, Zn, organic carbon, and low Mn and Fe under the cages. Bioindicator species such as lobsters under cages were elevated in Cu compared to control sites. In sea urchins, Ca, Cu, Fe, and Mn were elevated at least to the 75m distance away from cage site.

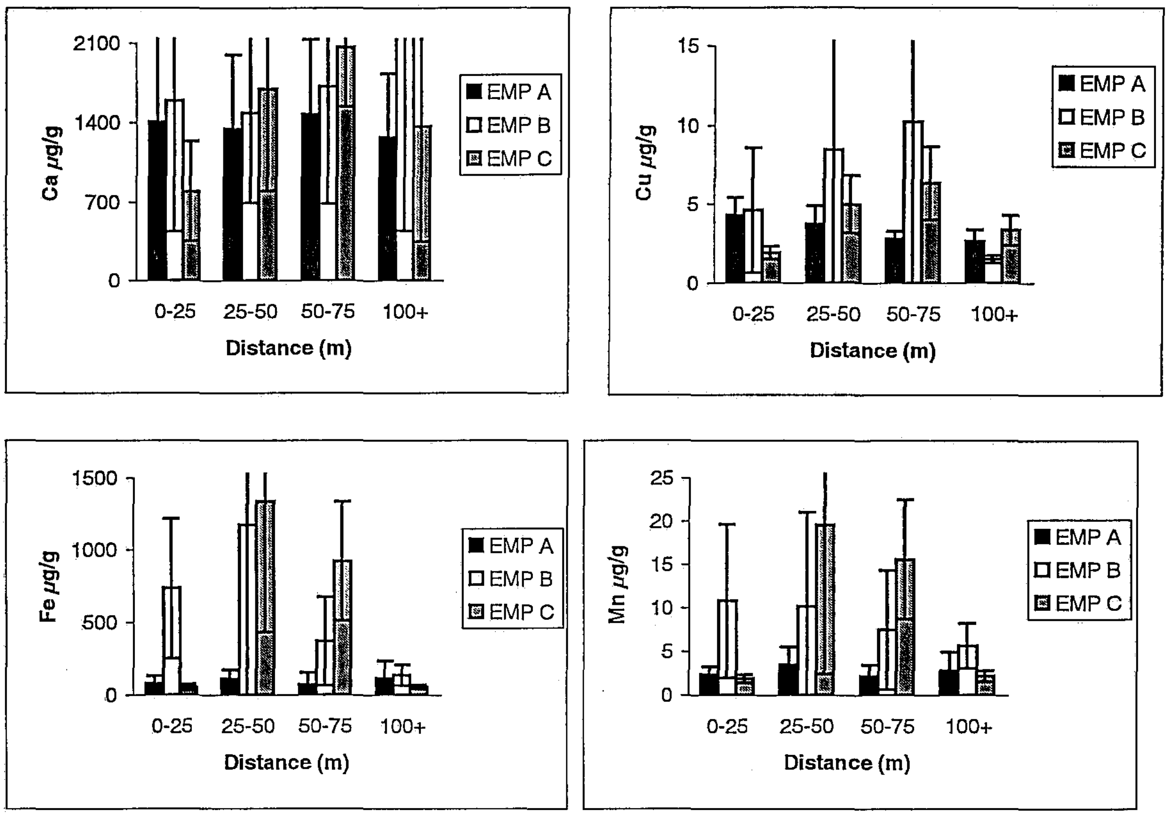

Figure 5. Metal concentrations in intestines of sea urchins at 0-100m from salmon cage sites.

Principal components analysis (PCA) on selected variables (Cu, Zn, Fe, Mn, organic carbon, and particles <63 µm) was successful for differentiating normal, hypoxic and anoxic sediment conditions (Chou *et al.* 2002). The groupings based on two components with >90% explainable variance, and cluster analysis identified a similar EMP classification with the exception of mis-identification of some sites by EMP. The sediment chemistry components were shown to be valid indicators for evaluating marine environmental conditions and for assessing aquaculture operating sites. The developed techniques, using chemical variables in combination with EMP and the statistical approach should be useful to predict the impacts of aquaculture practices and the suitability of aquaculture operations, further to the establishment of marine environmental quality guidelines. Research should be directed toward the establishment of guidelines for contaminants in sediments and bioindicator species at aquaculture sites. For environmental monitoring, EMP alone cannot detect inputs of toxic trace metals from food and wastes and anti-fouling compounds used in the treatment of net-pens. The developed techniques, using chemical variables in combination with EMP and the statistical approach should be useful to predict the near-field impacts of aquaculture practices and to evaluate the suitability of the aquaculture operations. This work will improve the complement of tools available for the assessment of near-field impacts of aquaculture, and aid in the understanding and knowledge of the requirements for marine environmental quality.

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IMPORTANCE OF SOURCE TO THE BIOAVAILABILITY OF PAHs

Walter J. Cretney, Neil Dangerfield and Remi Odense
(Institute of Ocean Sciences)

Up to 10,000-fold differences are observed in Biota-Sediments Accumulation Factors (BSAFs) for some PAHs of similar chemical properties in Kitimat Arm, B.C. The lowest BSAFs are observed for PAHs whose predominant source is the aluminum smelter at the head of the arm. Biogenic PAHs from a local pulp mill or the surrounding conifer forest have the highest BSAFs. The association of the smelter PAHs with soot carbon can account for their low BSAFs, because the partition coefficients for PAHs in smelter soot are about 100 times greater than those for PAHs in organic carbon. In the main study area, the soot-carbon content exceeds the organic-carbon content in most of the sediment samples. Hence, the partitioning of the smelter PAHs is controlled by the partition coefficient for soot carbon. Nevertheless, the BSAF results show that PAHs in clams and their contiguous sediments are not in thermodynamic equilibrium, regardless of PAH source. Possible reasons for the disequilibrium will be discussed.

TRACKING CONTAMINANTS IN THE MARINE ENVIRONMENT

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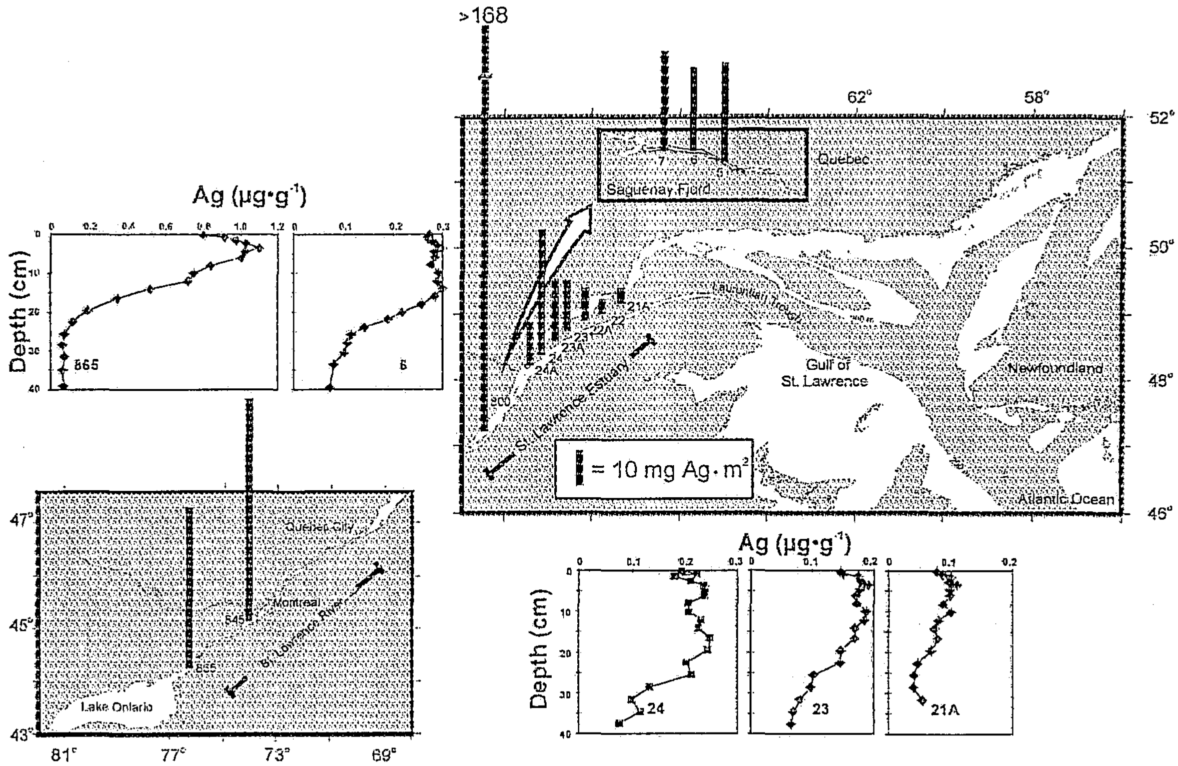
Canada borders three oceans and has the longest coastline and, consequently, the largest sediment regime of any nation in the world. Large quantities of industrial and urban wastes are discharged into the marine environments of both the Atlantic and Pacific Oceans and most of the anthropogenic contaminants are deposited in coastal sediment regimes. The sediments are the single most important sink for particle-reactive contaminants and, as a result, they provide the best environmental phase to evaluate contaminant transport through the coastal zone. The responsibility for environmental quality and health in marine systems resides with DFO and it is therefore important to maintain research and monitoring activities within this department which address contaminants uptake and cycling through coastal sediments.

Scientists from several DFO regions are currently combining their expertise to analyze a wide range of contaminants in sediment cores collected in the following three types of locations from the Canadian coastal environment: 1) municipal effluent impact zones, 2) industrial effluent impact zones and 3) far-field zones. The municipal effluent impact zone locations are used to study sediment uptake of contaminants associated with municipal wastes and general urban runoff. Examples of this type of location include the head of the Laurentian Trough, Halifax Harbour and Vancouver Harbour. Measurements conducted in industrial effluent zones focus on contaminants associated with a particular source. Typical locations include heavily industrialized regions from which representative sediment cores can be collected such as the Saguenay Fjord, Que., Port Mellon, B.C. and Sydney Harbour, N.S. Measurements in far-field zones provide both a contaminant baseline and can also be used to establish background signals and evaluate analytical and sampling protocols. Examples include Cabot Strait (Gulf of St. Lawrence), Emerald Basin (Scotian Shelf) and the Strait of Georgia (BC).

Sediment box-cores collected for this program are sectioned horizontally using rigorous sampling protocol. Sediment subsample are then distributed to the various national laboratories for contaminant analyses. Inter-regional collaborations are important to optimise the usage of limited scientific resources. Further, they provide a mechanism for standardising contaminant data results by insuring that identical laboratory protocols are employed for all samples, regardless of the sampling locations. All cores are analyzed for the radionuclides,

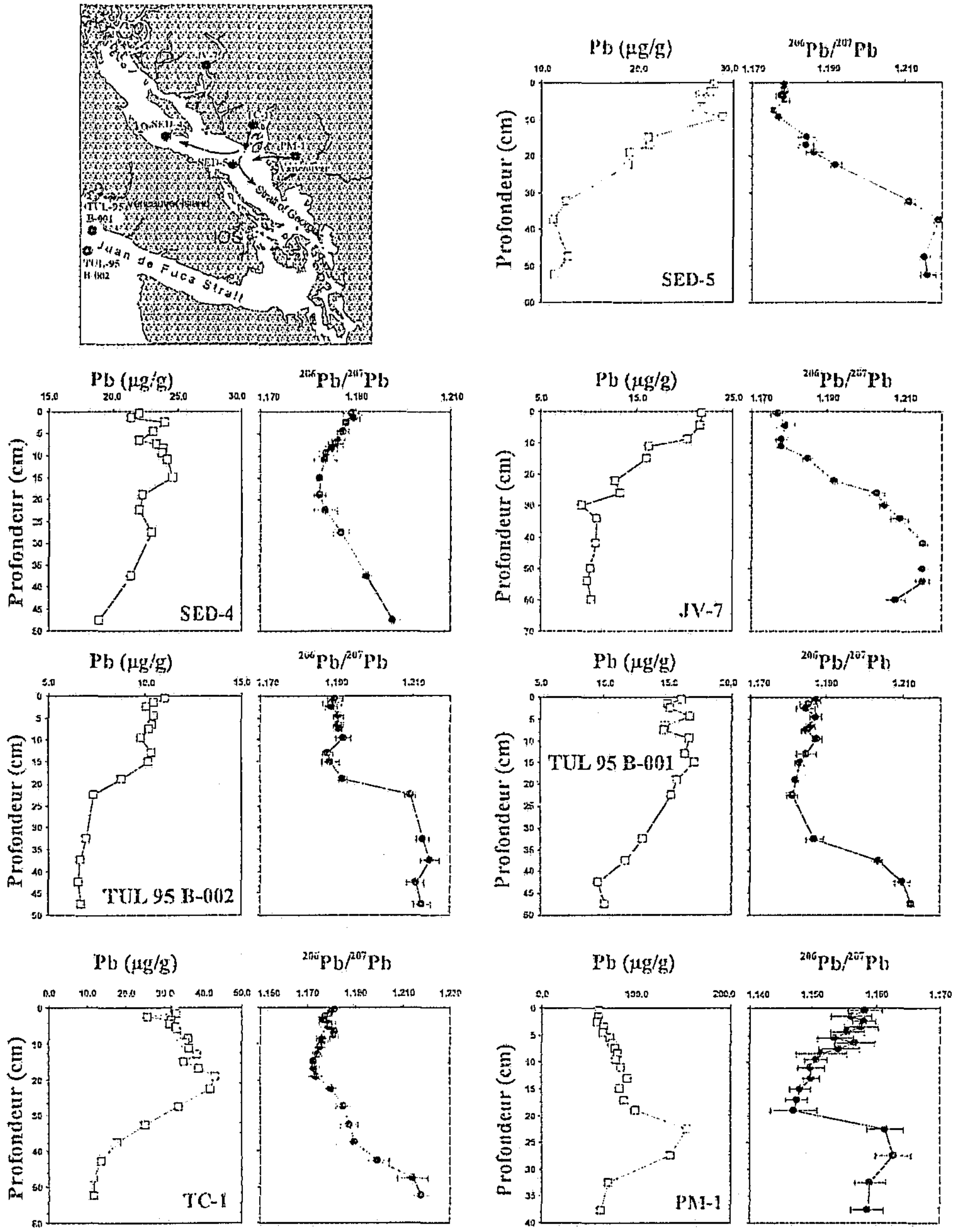
^{210}Pb and ^{137}Cs, a number of metals (Hg, Pb, Cd, Ag, Cu, Zn Mn), stable Pb isotope ratios, total carbon and organic carbon, acid volatile sulfide, PCBs (50 congeners including highly toxic coplanars), several pesticides (mirex, DDT, DDE, HCB etc.), dioxins and furans as well as PAHs and aliphatic hydrocarbon. Examples of results are reported below.

Example 1: Silver as a tracer to delineate impacted zones of sewage discharges in the coastal marine environment.



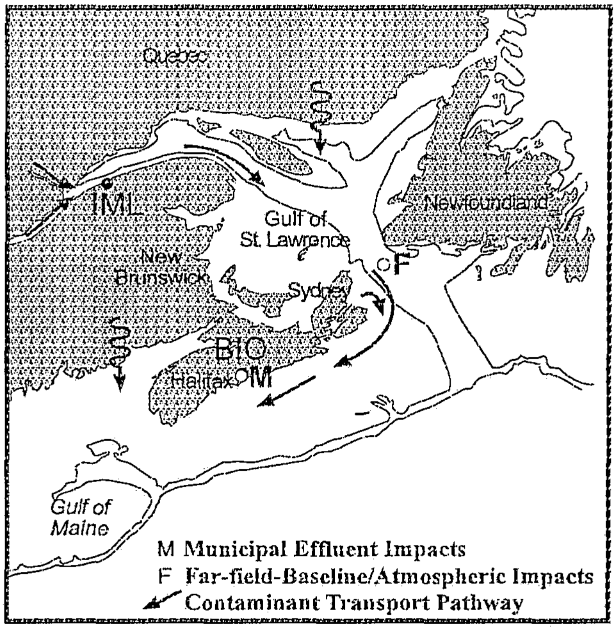
The concentration of Ag in sediment cores from the St. Lawrence River and Estuary and the Saguenay Fjord reaches values 2-15 times higher than its crustal abundance (0.7 µg/g), indicative of widespread dispersion of anthropogenic Ag. The direct discharge of wastewaters is likely the most important pathway for the introduction of anthropogenic Ag into these environments, but the input from the Great Lakes can also be important as suggested by very high Ag concentrations in a core collected in the river near Lake Ontario. Estimates of the total burden of anthropogenic Ag deposited in the sediments are on the order of 43 t in the St. Lawrence Estuary, 12 t in the St. Lawrence River, and 2.7 t in the Saguenay Fjord.

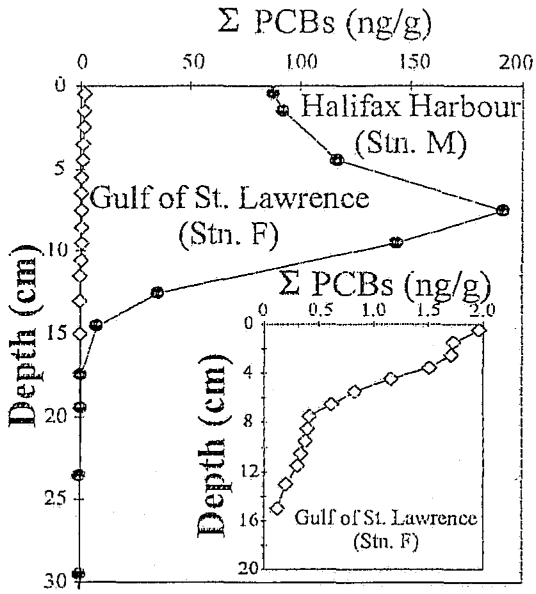
Example 2: Stable Pb isotopes as indicators of Pb sources in Strait of Georgia.



The isotopic composition of the excess Pb in surface sediments of the Strait of Georgia suggests that the main source of this Pb was past combustion of Canadian gasoline containing Pb from Bathurst, New Brunswick, which has a $^{206}Pb/^{207}Pb$ of ~1.16.

Example 3: Contrast in PCBs deposition in Canadian coastal sediments.





Concentrations of PCBs in Halifax Harbour sediments and in a core sample collected at a depth of 500-m in the Cabot Strait, at the seaward end of the Laurentian Trough. Levels of PCBs in Halifax Harbour sediments are two orders of magnitude higher than those in the Cabot Strait and are comparable to concentrations found in severely impacted environments. Nevertheless, levels of PCBs in Cabot Strait sediments are well above detection limit and the trend with depth indicates that the entire Gulf of St. Lawrence has been contaminated by PCBs and that this contamination is increasing.

SEDIMENT GEOCHEMISTRY: VARIABLES FOR SCALING ORGANIC ENRICHMENT

B. T. Hargrave (Bedford Institute of Oceanography)

Research in the Maritimes Region over the past decade has shown that organic enrichment of marine sediments at finfish and mussel aqauculture sites can be determined using sediment geochemical variables. As organic matter loading increases, oxygen supply by advective and diffusive processes becomes limiting and anoxic conditions develop progressively closer to the sediment surface. Aerobic (oxygen-based) respiration decreases and anaerobic (sulfate reduction) metabolism becomes the predominant for pathway organic matter consumption. Under high rates of organic matter supply (>1 g C m^{-2} d^{-1}), white sulfur bacterial mats form on the surface of anoxic sediments. This is only usually observed when organic matter addition exceeds the natural range of input rates (e.g. at discharge points for sewage and fish processing plant wastes, under finfish cages in shallow water with high rates of food addition) but it may also occur with high detrital (macroalgal) input. The transition from oxidized to reduced sediments at aquaculture sites can be measured using inter-relationships between sediment organic matter, total sulfide and Eh potential. A scale of benthic enrichment based on thresholds of these variables is proposed that can be used as a guide for aquaculture site evaluation and environmental monitoring.

INTRODUCTION AND APPROACH TO DETERMINING THE EFFECTS OF SALMON AQUACULTURE ON THE MARINE ECOSYSTEM

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INTRODUCTION

Salmon aquaculture is an important renewable resource industry in New Brunswick. The industry has developed rapidly from a few farms in 1982(Chang, 2001). In 1999 and 2000 there were 87 Canadian and 33 American salmon aquaculture sites concentrated in relatively small area of Southwestern Bay of Fundy. Production of cultured Atlantic salmon reached 25,000 tonnes ($190M) in New Brunswick in 2000. This area provides sheltered inlets and bays for cage culture, is relatively free of strong storm wave effects and has compatible water temperatures during winter. Most of the best, well-protected sites are occupied. Last year the New Brunswick Department of Fisheries and Aquaculture instituted a fallowing strategy (most sites were without fish for periods of up to 6 months) to combat disease. This strategy has increased the pressure to license alternative sites and applications for nine new sites were approved in 2001.

The salmon aquaculture industry is a major anthropogenic source of waste in southwestern Bay of Fundy. The wastes may be classified as organic or chemical. Organic wastes result from excess feed and faeces that may accumulate in the sediment and lead to eutrophication in the water column and anaerobic conditions in the sediment. Poor water quality and crowded conditions induce stress in caged fish and contribute to impaired growth and predispose them to disease. This, in turn, necessitates increased use of chemical therapeutants. For example, this area recently experienced sea lice infestations and infectious salmon anemia, a viral infection. Pesticides are being used to combat sea lice infestations and disinfectants help to prevent the spread of the virus. These substances contribute to the input of chemical wastes to the environment, which may have a negative impact on human health, health of the cultured species, habitat and indigenous organisms (Ervik *et. al.*, 1994, Rosenthal *et. al.*, 1993)

Little is known about the quantities, and often, the identity of the chemicals released into the environment from the aquaculture industry. With the rapid expansion of the industry in the last decade, the chemical wastes produced may now be a significant factor in its environmental impact. There has been considerable concern, suspicion and uncertainty among fishermen and environmentalists in Southwestern New Brunswick regarding the effects of these chemical wastes on local fisheries resources, indigenous species and fish habitat, but these are difficult to determine. Because of the need to develop methods and criteria to assess the environmental impact of the salmon aquaculture industry, our objective is the identification of the hazard and assessment of the risk of chemical wastes produced.

This paper summarises an ESSRF funded project in progress on the effect of chemical wastes on non-target animals and habitat near salmon cage sites. The study is carried out in the southwestern Bay of Fundy. The information generated will find application in coastal zone management strategies and regulations related to the salmon aquaculture industry. This project is an integrated and co-ordinated multi-disciplinary approach to assessing the impacts on the ecosystem of chemicals used in the Atlantic salmon aquaculture industry. The objectives are: identification of chemicals, their sources, and the quantities released; their distribution, environmental fate and concentrations; and their effect on the ecosystem and important harvest fisheries resources. In addition, it is hoped that potential conflicts with other users may be addressed to provide a basis for improved protection of cultured and wild fisheries resources and their habitat.

SOURCES

Chemicals used in aquaculture may be introduced intentionally or unintentionally and fall into three general categories: food components, medicinals and construction materials (Zitko, 1994). Fish oils (herring, shark), meals (fish, wheat, blood, poultry, canola, corn gluten), essential minerals, dyes and antioxidants are added to fish feed. Pesticides, disinfectants, antibiotics, chemotherapeutants and anesthetics are among medicinals commonly used. Construction materials include wood, plastics, paints, metal, antifoulants and preservatives. The user usually knows the identity of intentionally added chemicals, but the identity and source(s) of unintentionally added chemicals are difficult to trace. The latter includes organochlorine pesticides, PCB's, dioxanes and other persistent chemicals in feed, chemicals in construction materials, and metabolites and degradation products of intentionally added chemicals. As a first priority, this project focussed on the identification and measurement of inorganic and organic chemicals in feed.

DISTRIBUTION AND FATE

The distribution and fate of the chemical wastes is largely unknown. Persistent chemicals may accumulate in sediment, as part of the excess feed or faeces sinking to the bottom. Recent improvements in feeding technology have significantly decreased the amount of excess feed that falls through the cages. Less feed per kilogram of fish is required as new feed formulations and real-time video monitoring of feeding behaviour improve feed utilisation. Consequently the major waste under feces has changed from excess feed to feces. Sediment samples were collected in the depositional zone near and under cages in use and at fallowed sites. The samples were analyzed for the chemicals that were found in fish feed. The results will be used to deduce the source and the significance of the concentrations observed.

BIOLOGICAL EFFECTS

Recently, epidemic sea lice infestations (parasitic copepods: *Lepeophtheirus salmonis* and *Caligus elongatus*) have caused significant losses to the industry. Infested fish have been treated with baths of hydrogen peroxide, pyrethrins, cypremethrin, dichlorvos or azamethiphos. Also medicated feed containing ivermectin, emamectin benzoate, diflubenzuron or teflubenzuron have been used, or are being considered for use. These pesticides and anti-parasitic drugs were developed and approved for land based use at levels considered safe for mammals. Also, the efficacy and therapeutic indices for the treatment of sea lice infestations of Atlantic salmon have been determined. However, many of these chemicals were used with no, or limited, information on their lethal and sublethal effects on other marine organisms, and information on their effects on the marine ecosystem is extremely limited. Our laboratory studies obtained some of the information that is needed in identifying the hazard and assessing the risk of these chemicals to other animals.

Studies in Progress (Collaborator)

1. Source, distribution and fate
   - Inorganic chemicals in feed, sediment and marine organisms (Dr. C. Chou, BIO, Chou et al, see these proceedings).
   - PCBs, DDTs and PAHs in feed and sediment (Dr. J. Hellou, BIO, see below).
   - Dioxans, fruans and PCBs in sediment(Dr. M. Ikonomou, IOS).
2. Biological Effects
   - Aquatic toxicology of chemicals used for the treatment of sea lice infestations of caged Atlantic salmon (Dr. L. E. Burridge, SABS, see these proceedings).
   - Biodiversity of bentic macrofauna (Mr. G. Pohle, Huntsman Marine Sciences Center, St. Andrews, NB).
   - Antibiotic resistant aerobic bacteria in sediment (Dr. B. Hargrave, BIO, and Dr. S. Armstrong, Dalhousie University, Halifax, NS).

Future ESSRF Projects

1. Endocrine disruption in invertebrates: Impact of emamectin benzoate on molting and egg production in the American lobster (L. E, Burridge, ongoing).
2. Antibiotic residues and microbial resistance in marine sediments associated with salmon farms in Southwest New Brunswick (B. Hargrave, new proposal).
3. Accumulation by wild fisheries resources of chemical wastes produced by the salmon aquaculture industry (M. Ikonomou, new proposal).

A summary of the source, fate and distribution of organic chemicals in sediment from salmon aquaculture sites sampled in 1998 and 1999

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

Table 1: PAHs in Sediment

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

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

PCBs in Sediment

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

ACKNOWLEDGEMENTS

We thank the following for valuable contributions and participation in the research projects presented: S. Armstrong, B. Best, B. Chang, N. Hamilton, B. Hargrave, B. Hatt, M. Ikonomou, T. King, M. Lyons, K. Mckeigan, S. Mercer, T. Moffatt, L. Paon, D. Sephton, S. Stellar, S. Waddy, J. Wade, W. Young-Lai, and V. Zitko.

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ADDRESSING ENVIRONMENTAL QUALITY: EXAMPLE OF A MULTI-FACETED ORGANIC APPROACH.

J. Hellou and T. King, J. Leonard, S. Steller, P. Yeats, V. Zitko et al.
Fisheries and Oceans, Marine Environmental Sciences Division, Maritimes Region.

A stepwise approach including chemical and biological variables was devised to assess the state of Halifax Harbour. Marine environmental quality (MEQ) and coastal zone management (CZM) issues aiming for the long-term protection and conservation of marine habitat and resources are being addressed. Parental and alkylated polycyclic aromatic compounds (PACs) and mono- to deca-chlorinated biphenyls (PCBs) were measured in blue mussels, Mytilus edulis, and in the corresponding surficial sediments, to determine their levels, distribution, bioavailability, weathering, and potential sources. Summed PACs ranged from 1.27 to 51.37 ug/g, dry, and summed PCBs from 14 to 718 ng/g, dry, in sediments (Figure 1). PACs and PCBs were highest in sediments at a downtown Halifax location, in proximity to numerous raw sewage effluents (Figure 1, site 7).

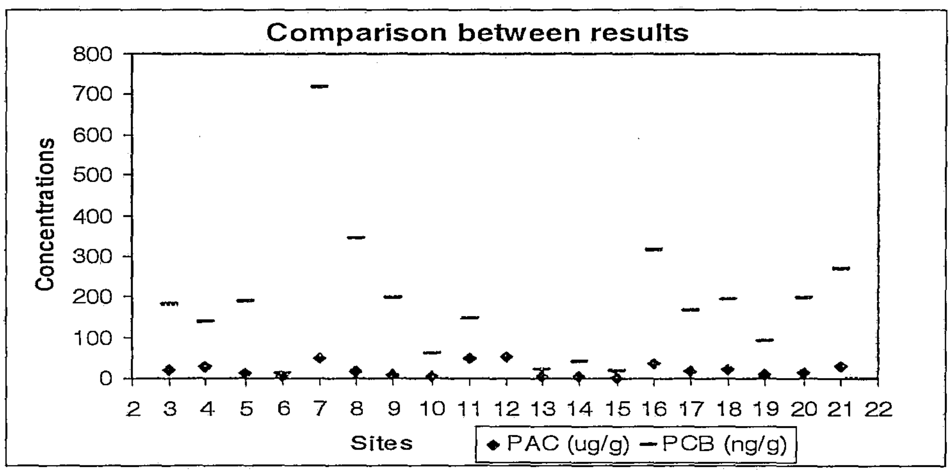

Figure 1: Sum of PAC and PCB concentrations observed in sediments

Sediment characteristics such as floc, sulfur and organic carbon content, and other hydrocarbon classes were also examined in these samples and correlated to the organic contaminants results (Hellou et al, 2002a, b and c). All groups of hydrocarbons were lower in sediments collected at the entrance to the harbour. Sources of hydrocarbons associated to observed PACs, alkanes and terpanes included diesel oil, lubricating oil, plant waxes, car soot and coal (Hellou et al 2002c). The proportions of PCB congeners demonstrate the weathering of older Aroclor mixtures in collected sediments (Hellou et al 2002b). Levels of PACs and PCBs observed in sediments of Halifax Harbour were compared to those observed at other sites in the US and Europe and interpreted in terms of published sediment quality criteria (Hellou et al 2002b and c).

Mussels collected inter-tidally at that downtown location also displayed the highest concentrations of PACs (Hellou et al, 2000). Levels were generally lower in inter-tidal mussels collected in April 1999, July or November 1997, with more variable fingerprints than in sediments. Of the 159 PCB congeners analysed, only 10-16 were detected in more than 60% of the April or November mussels, with IUPAC #11 generally present at higher levels (Hellou et al 2002b). This dichloro-biphenyl congener was not detected in our sediments and has not been detected in substantial amounts in Aroclor mixtures. However, it has also been detected in the hepatopancreas of lobsters collected from Halifax Harbour and is known as a minor dye product associated with yellow and orange pigments (King et al, 2002).

Biota-sediment accumulation factors (BSAF= concentration in animals divided by concentration in sediments, both in dry weight) of 0.006 to 1.26 and from 0.3 to 33 were displayed for individual abundant PACs and PCB congeners, respectively (Hellou et al 2002b and c). For the two groups of contaminants, BSAF were highest at the entrance to the harbour, as illustrated for the two most predominant PCB IUPAC congeners 153 and 138 (Figure 2).

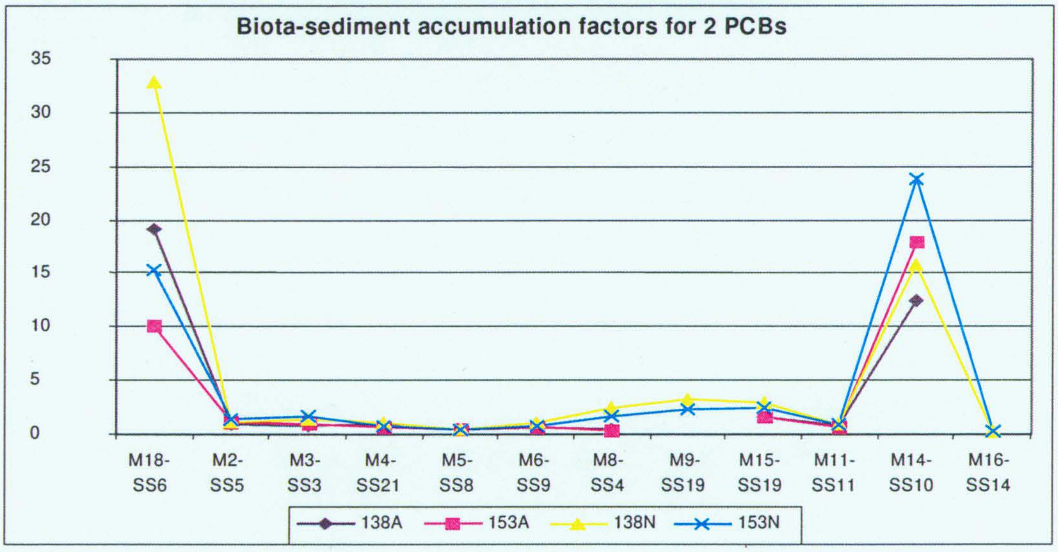

Figure 2: BSAFs determined in mussels collected in April (A) and November (N).

Cumulative biological effects determined in mussels included changes in lipid content and condition indices, and were interpreted by correlating results with chemical analyses (Hellou et al 2000). Biomarker results showed pronounced and different temporal variability at each site. Ongoing research at three sites, including the analysis of metals and other biological effects in mussels, as well as the bioavailability and effect of contaminants to local benthic amphipods, i.e. Corophium volutator, will be presented.

The presented work covers a small section of data needed for the assessment of environmental quality. Additional chemicals, particularly PAC derivatives, surfactants, prescription drug residues, have to be measured and their fates and effects assessed in laboratory experiments, while other ecosystem components need examination.

ACKNOWLEDGEMENTS:
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CONTAMINANTS OF FUTURE CONCERN IN THE AQUATIC ENVIRONMENT

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In the past several years a substantial body of research has pointed out the hazards posed to wildlife and human health by endocrine-disrupting chemicals (EDCs). A number of industrial, municipal, agricultural, and natural compounds have been shown or are suspected to be estrogenic. Such compounds include polychlorinated dioxins, furans (PCDD/F) and biphenyls (PCBs); selected pesticides (DDT, methoxychlor, kepone); brominated flame retardants (PBDEs); non-ionic surfactants such as nonylphenol (NP) and biodegradation products of alkylphenol ethoxylates (APEOs); other industrial chemicals such as phthalate esters and bisphenol-A, as well as natural and synthetic estrogens (17b-estradiol, diethylstilbesterol, b-sitosterol and flavones).

Although there is a large body of scientific literature associated with the fate, distribution, toxicity and endocrine effects of classical organic contaminants such as PCDD/Fs, PCBs, DDT etc. there is limited information on the fate and distribution of "new era" environmental contaminants of industrial origin such as the PBDEs, APEOs and the phthalate esters. These chemicals are produced in mega-ton quantities each year and they are found in all environmental compartments. However, in order to accurately determine their environmental concentrations novel non-conventional analytical methodologies are required. Over the past few years our focus has been to: a) to develop analytical methods that would deal with the challenges associated in measuring comprehensively these three classes of contaminants in environmental samples and b) to examine the spatial and temporal distribution and inter-species patterns of these contaminants in the marine and freshwater environment.

BROMINATED FLAME RETARDANTS, PBDEs.

PBDEs are persistent, lipophilic and bioaccumulating contaminants and they have been found in all environmental matrices and even in samples from remote areas which suggests a world-wide distribution. However, data in Canada is lacking and, therefore, our work focused on: a) developing comprehensive analytical methods for the determination of PBDES in all environmental matrices (1, 2) and b) examining PBDE levels and congener distributions in tissue and blubber samples of several marine organisms collected off the Canadian west coast and Holman Island in the Northwest Territories.

In all the marine samples we have analyzed today detectable levels of PBDEs have been measured. PBDE levels were measured in Ringed seal blubber from remote locations (Holman Island, NWT) collected in 1981, 1991, 1996 and 2000. In 1981 the levels were low (0.6 ppb total PBDE), close to that of the procedure blank. However, a large increase has occurred in the later years, reaching 6 ppb total PBDE in 2000 (3,4). The females showed lower levels than the males of the corresponding collection year which is consistent with the marine-mammal trend of females unloading lipophilic contaminants to their young via lactation. As this area is remote from urban/industrial sites and thus PBDE sources, these low PBDE levels are attributed to atmospheric deposition. The major contributing congeners constituting ca. 90% of the total were PBDE-47, 100, 99, 28/33, 153, and 154). A PBDE total of ca. 400 ppb has been reported in Ringed seals from the more contaminated Baltic Sea with a ca. 70% contribution of congener 47. A recent study on Harbour seal blubber from San Francisco Bay revealed a 1 ppm mean (congeners 47, 99 and 153) with congener 47 as the main contributor. The exponential increases of ΣPBDE we observe in ringed seals from the Canadian arctic correlate well with production of the commercial penta-BDE mixture (e.g. Bromkal 70-5DE) over the same time period (Figure 1). It is evident that both commercial penta-BDE production and ΣPBDE levels have increased exponentially since 1981. Conversely, while ΣPBDE levels in human milk from Sweden increased sharply from 1981 to 1997, levels have since decreased. This reduction in human milk ΣPBDE burdens may reflect regulatory measures in Europe.

The PBDE levels detected in British Columbia biota were much higher than in the Ringed seals from remote Holman Island (Figure 2). Dungeness crab hepatopancreas (199-478 ppb), English sole liver (22-339 ppb), and Harbour porpoise blubber (652-2269 ppb) were analysed including SPMD that had been placed in the Fraser River. The congeners 47, 49, 99, 100, 153, 154 and 28/33 comprised 97-99% of the total PBDE detected. For all samples, congener 47 was the major contributor and congener patterns were distinct from those found in the commercial mixtures Bromkal 70-5DE and Bromkal 79-8DE which suggests selective uptake and/or biological/physical debromination of higher brominated congeners. Attributed to differences in contaminant uptake, metabolism and excretion, the congener pattern differed between the Dungeness crab and sole – the former was enriched in tri/tetra and the latter in penta/hexa (5). In comparison to other contaminants, Dungeness crab samples contained a total PBDE at 1-27% of the total PCBs, 18-49% of the total organochlorine pesticides and at levels almost 200 fold more than those of PCDD/Fs (Figure 3).

Our work (1 to 5) on PBDEs today has shown: a) Multiresidue analysis is essential to identify patterns/fate of PBDEs in the environment; b) PBDEs are present in all environmental compartments; c) ppb to ppm levels are measured in biota from BC; d) congener patterns detected in biota reveal metabolism of commercial mixture profiles; e) distinct intra-species congener patterns from the same ecosystem; f) 4 years doubling rates in Arctic marine mammals; g) PBDEs are the major organohalogen contaminant in biota from certain locations.

NON-IONIC SURFACTANTS

Alkylphenol polyethoxylates (APEOs) are the second largest class of nonionic surfactants in commercial production in North America. In use for over 40 yr, APEO production has been estimated at >0.3 Mt yr^{-1} worldwide and about 0.2 Mt in the United States. In Canada, about 6.0 kt of nonylphenol polyethoxylates were used in 1989 with this figure expected to rise to 7.0 kt by 1993. The degradation of APEOs in the environment has been the subject of disagreement, contradiction, and controversy for many years. Recent concern has focused on APEOs as potential endocrine disrupters. Considering toxicity, the large production volumes and likely persistence, APEOs - especially NP*n*EOs - have emerged as a leading issue in Europe where a phased withdrawal for many uses is being implemented.

Recently we also became interested on the fate and distribution of NP*n*EO in the marine environment. We developed a novel analytical method based on LC/ESI-MS for the quantitative determination of NP*n*EO in environmental matrices (6). We applied the method to determine individual oligomers (n = 1 to 19) of NP*n*EO in marine sediment cores and surface grabs collected from the Strait of Georgia, British Columbia, Canada, near the Iona municipal outfall (7). Our data showed that over half the NP*n*EO inventory in marine sediments resides in ethoxylates of chain length greater than $n = 2$ (Figure 4) suggesting that analyses limited to short-chain ethoxylates (n = 2) are under-reporting total NP*n*EO by a factor of two. The NP*n*EO vertical profiles and oligomer distributions in dated sediment cores suggest that little degradation occurs once these compounds enter the sediments. The lack of change in NP*n*EO oligomer distribution with age suggests that degradation by chain shortening does not occur significantly. A rough inventory shows that over 30 t of NP*n*EO resides in Fraser River delta sediments near the Iona municipal outfall and that the entire Strait of Georgia sediments contain over 170 t of Np*n*EO.

PLASTISIZERS (PHTALATE ESTERS)

Di-alkyl phthalate esters (PEs) are widely used as non-reactive plasticizers in vinyl plastics and in a broad range of industrial and consumer products. The broad range in the alkyl moiety of the compounds results in a broad range of physical, chemical, toxicological and environmental properties. Because of the extensive use, high rate of global production of approximately 3.2 million tones per year, and categorization as EPA priority pollutants the environmental fate of PEs have been extensively studied in the laboratory and the field. Concentrations (in the ppm range) of certain phthalate esters, in particular DEHP, have been detected in sediments in North America and Europe. Information about sediment and biota concentrations of other phthalate esters such as DBP, diisononyl phthalate (DINP) and diisodecyl phthalate (DIDP), which are some of most widely used plasticizers in the plastics industry, are relatively rare and often in doubt due to difficulties associated with their measurement. This has precluded an analysis of the distribution, persistence, food-chain bioaccumulation and potential ecological impacts of these global pollutants.

One of the problems in the analysis of phthalate esters is that commercial formulations predominantly consist of phthalate esters with a specific molecular weight, but include many isomers within each molecular weight class. At the time we started this work there were no analytical methods or required standards to fully separate phthalate esters in different molecular weight classes corresponding to the formulations from which they originate. To examine the environmental fate of PEs we developed a new method based on reversed phase liquid chromatography/ electrospray ionization mass spectrometry (LC/ESI-MS) for the quantitative determination of individual phthalate esters, including six congeners on the USEPA Priority pollutant list and several commercial PEs isomeric mixtures, in marine sediments and biota in an urbanized coastal inlet (8).

All the major single isomer phthalates and the isomeric mixtures were detected in all the sediment and biota samples collected from the inner Vancouver harbour, False Creek area, Figure 5. The total combined (single isomers and isomeric mixtures) phthalate ester concentrations in sediments ranged between 2.0 and 3.6 ppm and predominantly consisted of high molecular weight phthalate esters. The total combined phthalate concentrations in fish (striped seaperch) ranged between 4 to 54 ppb and consisted predominantly of low molecular weight phthalate esters. In contrast to the PE concentration in the sediments, which comprised mainly (i.e. 95%) of higher molecular weight PEs, the fish tissue samples were mainly (i.e. 67%) comprised of the lower molecular weight PEs. The results indicate that while concentrations of DEHP and some of the other high molecular weight PEs can be relatively high (i.e. the ppm range) in sediments, the concentrations in fish can be substantially (i.e. 100 to 1,000 fold) lower. The results suggest that the higher molecular weight PEs may be less bioavailable than the lower molecular weight PEs or that metabolic transformation of PEs in sea perch is more prevalent for the higher than the lower molecular weight PEs.

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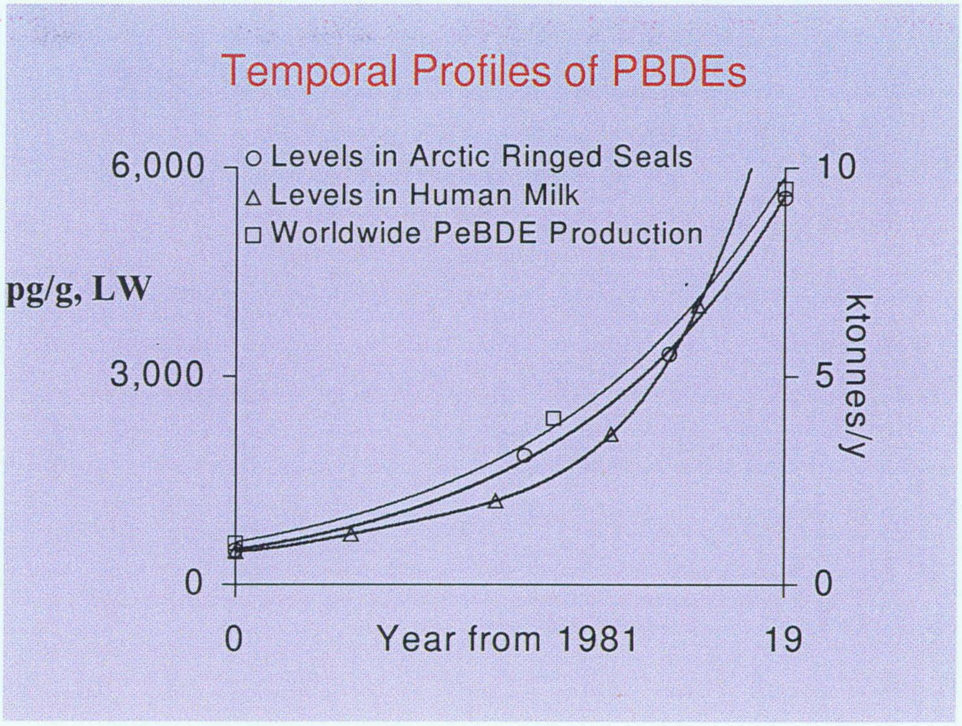

Figure 1. Comparison of PBDE levels in ringed seals from the Canadian arctic, PBDE levels in human milk from Sweden and worldwide commercial penta-BDE (PeBDE) production.

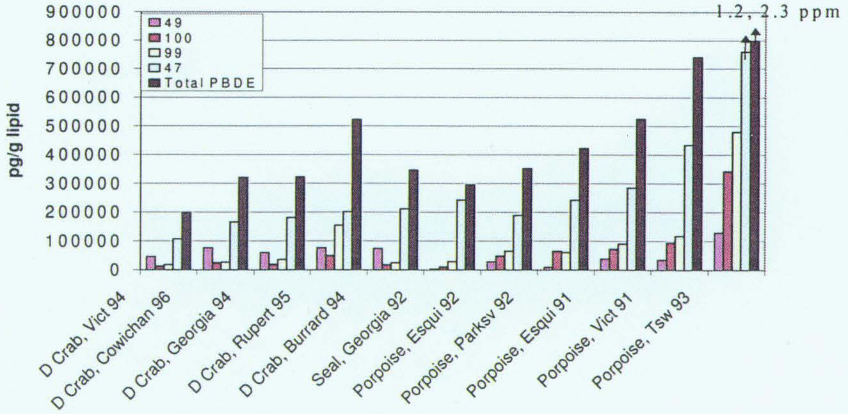

Figure 2. Levels of total PBDE and the major congeners in BC marine biota. (For the porpoise from Tsawassan, BDE47 and the total PBDE are offscale – the values are given above.)

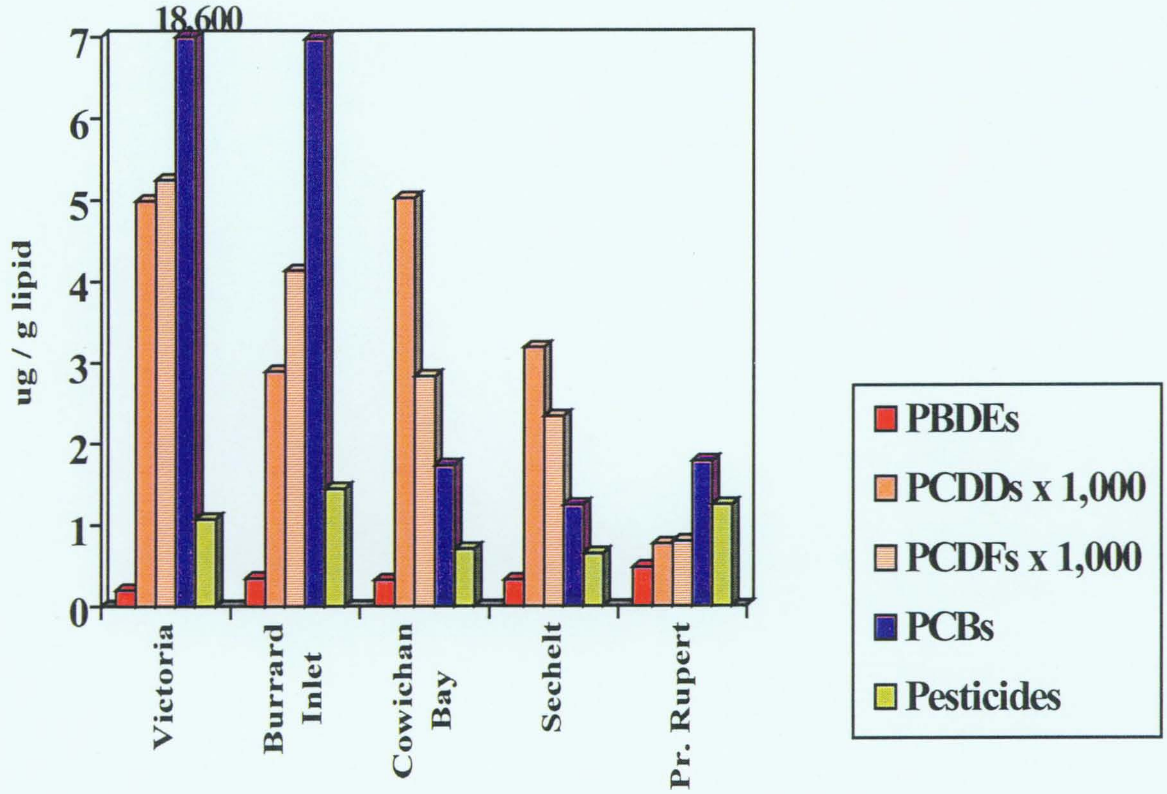

Figure 3. Total PBDE and important co-occurring contaminants for five Dungeness crab samples from Canada's West Coast. Pesticides included in total were 1,3-dichlorobenzene, 1,4-dichlorobenzene, 1,2-dichlorobenzene, 1,3,5-trichlorobenzene, 1,2,4-trichlorobenzene, 1,2,3-trichlorobenzene, 1,2,3,5/1,2,4,5-tetrachlorobenzene, 1,2,3,4-tetrachlorobenzene, pentachlorobenzene, hexachlorobenzene, α-HCH, β-HCH, δ-HCH, heptachlor, aldrin, oxychlordane, *trans*-chlordane, *cis*-chlordane, *o,p'*-DDE, *p,p'*-DDE, trans-nonachlor, cis-nonachlor, *o,p'*-DDD, *p,p'*-DDD, *o,p'*-DDT, *p,p'*-DDT, mirex, heptachlor epoxide, alpha-endosulphan (I), dieldrin, endrin, and methoxychlor.

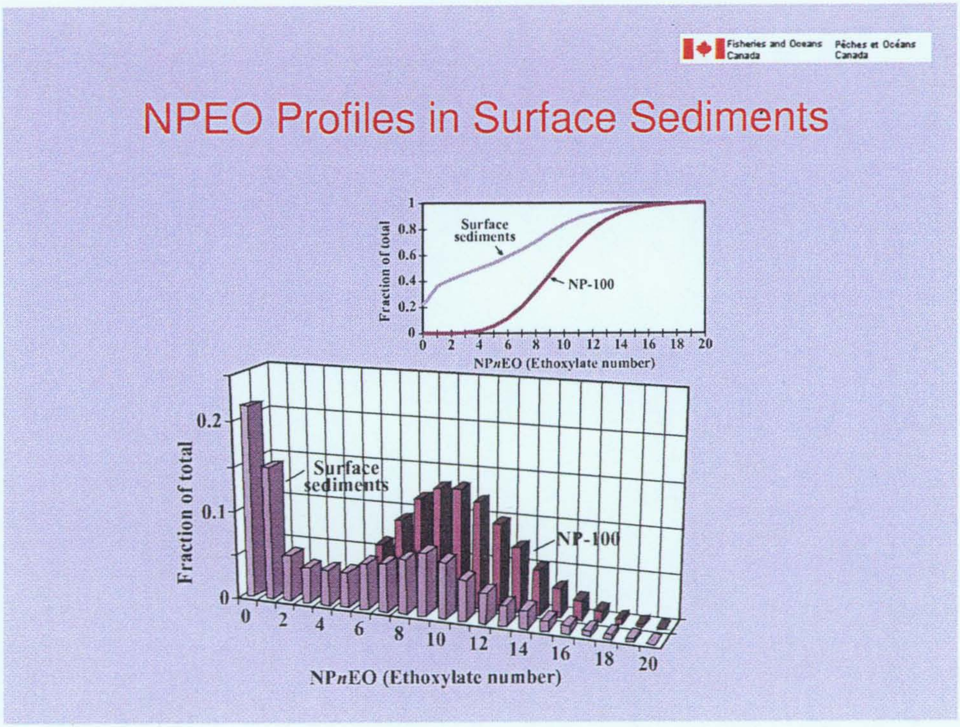

Figure 4. The bottom panel shows histograms of average composition of NPEO in surface sediments (n = 25) and the composition of a commonly used commercial product, NP-100. The top inset panel shows cumulative contribution for the two histograms presented in the bottom panel.

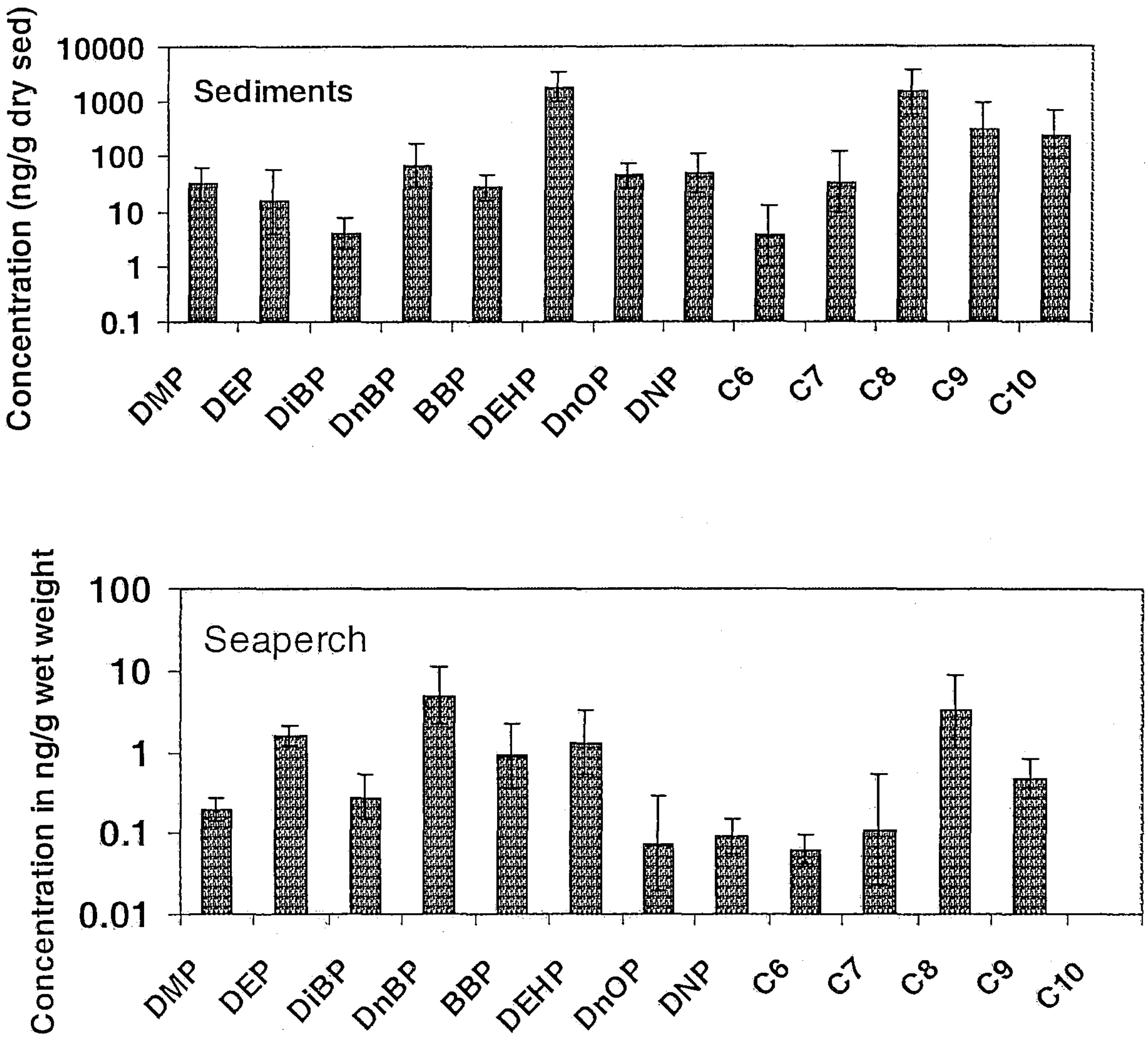

Figure 5. Concentrations of several individual phthalate ester congeners (DMP, DEP, DiBP, DnBP, BBP, DEHP, DnOP, DNP) and isomeric phthalate ester mixtures (C6, C7, C8, C9, C10) in sediment and seaperch from several locations in False Creek, Vancouver, BC.

HABITAT IMPACTS OF SHELLFISH AQUACULTURE IN BAYNES SOUND, B.C.: ISSUES OF SCALE AND SPATIAL LOCATION

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Shellfish aquaculture has taken place in coastal British Columbia since the early 1900s, and Baynes Sound has developed into one of the major production areas of cultured shellfish in the province. There have been very few scientific studies of the environmental impact of shellfish aquaculture to date, and the most notable management issues have centred around land use conflicts with adjacent upland owners, recreational harvesters, wild harvesters, other recreational activities, and navigation. Recently, ecosystem concerns have been published regarding intertidal bivalve bottom culture practices (e.g. Simenstad and Fresh 1995), and the existing and planned expanded scale of this aquaculture in BC has raised concerns among DFO, CWS and WLAP resource managers, particularly in Baynes Sound.

Here, we: 1) review the existing scientific literature on the potential environmental impacts of intertidal bottom culture aquaculture on coastal ecosystem processes, specifically relating to fish and fish habitat; 2) describe the current practices of intertidal bottom culture operations and their potential impacts in Baynes Sound; 3) assess the need for monitoring and/or a cumulative effects study related to the planned increase in the total amount of leased area in the intertidal zone of Baynes Sound; and 4) identify gaps in the understanding of ecosystem impacts of extensive, intensive intertidal bottom bivalve aquaculture. A summary of possible short term and long term management options around the issues of scale and the spatial location of intertidal bivalve aquaculture is presented.

PATHOGEN POLLUTION IN THE GULF OF ST. LAWRENCE AND ESTUARY

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ABSTRACT

Over the past 20 years there has been intense interest in viruses, bacteria, fungi, parasites and the diseases they cause in marine mammals. Some of these pathogenic agents are new to science or at least were unknown in marine mammals due to lack of study [phocine and cetacean distemper viruses (*Morbillivirus*), *Brucella pinnipediae, Brucella cetaceae*] (Osterhaus and Vedder 1988; Ross et al. 1994). However, some well known terrestrial pathogens are also now found in marine mammals, some with an anthropogenic source (*Giardia duodenalis, Cryptosporidium, Toxoplasma gondii*) (see Buergelt and Bonde 1983; Hill et al. 1987; Olsen et al. 1997; Deng et al. 2000; Cole et al. 2000). On the east coast of Canada using a monoclonal antibody technique on rectal faeces, upto 50% of adult female harp seals (*Phoca groenlandica*) and 25% of adult or juvenile harbour (*Phoca vitulina*) and grey (*Halichoerus grypus*) seals were infected with *Giardia* sp. cysts (Table 1) (Measures and Olsen 1999).

Table 1. Prevalence of Giardia sp. cysts in rectal faeces of phocids from the east coast of Canada using a monoclonal antibody technique.

Seal species	N examined	N positive (prevalence)
harp seal	85	31 (36%)*
hooded seal	11	0 (0%)
harbour seals	14	1 (7%)**
grey seals	19	4 (21%)**

*50% of adult female harp seals positive (excluding adult males and pups which were negative).
** 25% of grouped adult and juvenile harbour and grey seals were positive (excluding pups which were negative).

Giardia infections are acquired by the fecal-oral route or by ingestion of contaminated food or water containing cysts. Recently, using a sequence of the amplified fragment of the 16s-rRNA gene and the polymerase chain (PCR) technique on duodenal contents, the species of *Giardia* in seals was determined - *Giardia duodenalis*, human genotype. Furthermore, the PCR technique was found to be more sensitive in detecting seal infections such that the prevalences indicated in Table 1 are, at best, underestimates (Table 2) (A. Appelbee, M. Olsen and L. Measures, unpublished data).

Table 2. Prevalence of *Giardia duodenalis* in duodenal contents of phocids from the east coast of Canada using a PCR technique.

Seal species	N examined	N positive (prevalence)
harp seal	38	16 (42%)
hooded seal*	11	7 (64%)

*same seals as tested in Table 1.

While this data indicates that the source of infection for seals is human waste or that of their domestic animals, it is unknown whether seals were infected in the recent past or perhaps many hundreds or thousands of years ago.

In another study involving a serologic test (MAT) of sera from seals on the east coast of Canada, 2% of hooded seals and 9% of harbour and grey seals were seropositive to *Toxoplasma gondii* (Table 3) (Measures, unpublished data).

Table 3. Seroprevalence of *Toxoplasma gondii* in phocids from the east coast of Canada using a modified agglutination technique.

Seal species	N examined	N positive (prevalence)
harp seal	112	0 (0%)
hooded seal	60	1 (1.7%)
harbour seals	34	3 (8.8%)
grey seals	122	11 (9.0%)

The only known final host for *T. gondii* is cats, domestic or wild. Transmission occurs by ingestion of contaminated food or water containing infective oocysts passed with faeces of cats or ingestion of meat containing mature cysts. Mature cysts are found primarily in infected intermediate hosts, which could be any mammal, including seals or humans, or birds. It has been postulated that oocysts of *T. gondii* are getting into the marine environment when cat faeces are washed into marine coastal areas by storm run-off or by humans disposing of cat faeces into municipal wastewaters that are inadequately treated. In laboratory experiments small doses of infective oocysts of *Toxoplasma gondii* from cats were infective to grey seals (Measures, unpublished data).

The point source of these pathogens in the marine environment has yet to be determined but may include municipal wastewaters, agricultural runoff, ship ballast or septic reservoirs (see Measures and Olsen 1999). A number of studies show that some of these pathogens are present in marine shellfish, suggesting that infective stages are in the water column (Fayer et al. 1997; Graczyk et al. 1998). It is unknown how marine mammals become infected - either directly through contamination of seawater or indirectly through the food chain. Such findings are perhaps not surprising given that anthropogenic chemical contamination of the marine environment, particularly of marine mammals, has been going on for many years. However, it illustrates that human activities are more wide-reaching than previously believed in the marine environment (see Daszak et al. 2000) and are highly significant in terms of animal (anthroponotic) and human (zoonotic)health.

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POPs AND MERCURY IN AQUATIC FOODWEBS OF SUBSISTENCE LAKES IN LABRADOR

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Results of studies carried out under the Toxic Chemicals Program, other supplemental studies carried out by the Newfoundland Region and studies being carried out under a TSRI project examining levels of priority POPs and mercury in top predator fish from lakes with important subsistence fisheries in a broad range of systems from northern Alberta to Labrador, will be discussed. The TSRI foodweb project is led by Environment Canada with a number of partners from DFO and Universities. We had previously found high levels of mercury in fish in some lakes in Labrador and the TSRI project has established that these lakes have some of the most highly contaminated fish of all the lakes examined to date. With respect to POPs, PCBs and DDT related compounds have been observed to be the major POPs found in lake trout from all locations to date, with the exception of a large lake in Labrador, Wabush Lake, where fish are contaminated with quite high levels of DDT. Assessing levels of chemicals in fish is important in relation to fish and environmental as well as human health. Difficulties in tying ecotoxicological effects to chemical class, in the absence of tandem long-term chronic toxicity studies will be briefly discussed, in related to novel ecotoxicological observations in Wabush Lake.

IMMUNOLOGICAL BIOMARKERS OF MARINE ENVIRONMENTAL QUALITY

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In recent years a number of studies have shown the importance of an integrated approach to evaluate Marine Environmental Health (MEH). Our work over the past five years has focused on the development of a suite of biomarkers, using the immune system, which can be related to indicators of MEH at higher levels of organisation such as growth and reproduction. This presentation outlines the progress of our work and is divided into three sections: 1) *In vivo* development of immune assays using bivalves; 2) *In situ* adaptation of assays, development of complementary assays and transfer of technology to fish and 3) application and validation of the bioindicators to an investigation of impacts of bivalve aquaculture in Richibucto Harbour, NB.

1- *In vivo* development of immune assays

Tributyltin (TBT) is a biocide used in antifouling marine paints which was shown to alter reproduction and growth in invertebrates resulting in the loss of populations from some coastal areas worldwide (Gibbs and Bryan, 1996; Oehlmann et al, 1996). Because of these effects, Canada and many other countries instituted a partial ban on use of TBT in boat paints in the 1980s. TBT was also known as a powerful immunotoxin for vertebrates. While the distribution of TBT along the Canadian west coast was reasonably well described, the incidence and effects of TBT in Maritime waters was identified as an important data gap during the 1994 mid-program review of DFO's Green Plan Toxic Chemicals Program. In response to this gap, we initiated a program designed to determine if TBT and its degradation product dibutyltin (DBT) were present in the Maritimes and to assess their effects on wild and cultured bivalves. Since little was know about the immunotoxicity of the butyltins for bivalves, we investigated the effects of TBT and DBT on the immune function of the blue mussel (*Mytilus edulis*).

Profiles of TBT and DBT in sediments were obtained in 1996 from four sites in the southern Gulf of St. Lawrence (Fig. 1): Summerside (Prince Edward Island, PEI), Pictou (Nova Scotia, NS), Miramichi (New Brunswick, NB), Shediac (NB) and one reference site: Cardigan (PEI) (St-Jean et al. 1999). All samples were contaminated with both TBT and DBT reaching a maximum of 83.4 ng Sn/g (d.w.) in Shediac. Seasonal monitoring of levels of TBT and DBT in wild blue mussels, *Mytilus edulis,* was also conducted at these same sites in 1995 and 1996 with the addition of a second reference site in 1996 - Richibucto (NB). Mussels from all sites, except Richibucto, were contaminated by TBT at levels ranging from 7 ng Sn/g (d.w.) in Cardigan to 426 ng (d.w.) (1995) and 671 ng Sn/g (d.w.) (1996) in Summerside. DBT was also present in most samples but at lower concentrations reaching 378 ng Sn/g (d.w.) in 1996 samples from

Summerside. These results suggested that inputs of TBT from June to September, at least in the southern Gulf of St. Lawrence, were still well above expected levels after 8 years of TBT-paint regulation. The next step was to elaborate bioassays that would assess the potential immunotoxicity of TBT and DBT in bivalves.

A laboratory experiment was designed in which blue mussels were exposed to water-borne TBT or DBT (0, 5, 10, 20, 40,or 80 ng Sn/l) under flow-through conditions (St-Jean et al. 2002a). In addition to standard immune responses including membrane injury (MI), phagocytic activity (PA), lysosome retention (LR), and haemocyte count (HC) we developed a bacterial challenge test in an effort to link exposure to butyltins, immunomodulations and potential impacts on disease resistance. For this test, mussels were subjected to the same concentrations of TBT or DBT described above and were then injected with the common bacteria *Listonella* (=*Vibrio*) *anguillarum* (14 X 10^6/ml) and monitored for subsequent bacterial clearance. A second experiment was carried out with the highest doses of TBT/DBT (40 and 80 ng Sn/l) under the same experimental design and PA, LR, HC and bacterial clearance were monitored. Both TBT and DBT significantly affected all immunological parameters in both experiments. TBT produced greater and more rapid MI than did equivalent doses of DBT and MI was dose-related, as early as day 1, for doses > 10ng/l TBT and >20ng/l DBT. Similarly, PA was reduced by all doses of TBT and DBT in a time- and dose-responsive manner. LR was significantly elevated by 80 ng/l DBT between days 1 and 11 but not thereafter. Significant elevations and depressions in HC were observed in mussels exposed to both butyltins though effects were highly variable and not clearly related to either dose or time of exposure. A significant dose-related impairment in clearing *Vibrio* from the haemolymph was observed for all doses of both butyltins in both experiments (Fig. 2). Although butyltins were not bioaccumulated in the mussels exposed to doses lower than 40 ng/l, this study established the strong and sustained response of the immune system of mussels exposed to environmentally relevant, low, water-borne concentrations of TBT or DBT. In addition, a follow up experiment tested these end points with nominal butyltin concentrations (1-6 ng Sn/l) comparable to those triggering imposex and growth impairment (Gibbs et al, 1987; Chagot et al, 1990). As observed previously, all doses modulated the biomarkers, HC, PA and LR within 11 days (St-Jean et al. 2002b) (Fig. 3).

The conclusions of this phase of our research were that: 1) TBT and DBT alter immune function in mussels, which in turn; 2) alters the ability to clear foreign substances; and 3) these alterations appear at very low concentrations of butyltins - < 1 ng/l (part per trillion) - concentrations which routinely occur in Canadian aquatic environments. Beyond the issue of TBT contamination though, these results also suggested that immunological biomarkers show potential for measuring Marine Environmental Health and for use in Environmental Effects Monitoring more generally.

2) *In situ* adaptation of assays, development of complementary assays and transfer of technology to fish

In this phase, we hypothesized that we could generalize immunological biomarkers from TBT-exposure to marine environmental health more generally, and from mussels to other coastal marine organisms including fish. From 1999 to 2001 we have been addressing this hypothesis in Pictou Harbour, Nova Scotia, through a community-led project involving industry (a pulp and paper mill), municipalities (a sewage treatment plant), Environment Canada and the local Atlantic Coastal Action Plan (ACAP) group – the Pictou Harbour Environmental Protection Project (PHEPP). In the first two years, we successfully transferred the biomarkers developed in the laboratory and introduced new immune biomarkers to an *in situ* situation for the mussel and in the last 2 years, we transferred the bioassays to fish. The intent of this project was to quantify normal variation in immune function over space and time in order that anthropogenically induced changes in the immune system, or immunomodulation, could be discerned.

Monthly measurements of up to 8 immunological biomarkers plus an annual bacterial challenge have been taken from mussels caged throughout the ice-free season at 14 sites including receiving environments of a pulp and paper mill, a coal-fired electrical power generating station, a sewage treatment plant, untreated sewage discharge and agricultural runoff (Fig. 4). In addition, similar measures have been collected monthly from wild mummichogs (*Fundulus heteroclitus*, a small, common Atlantic coastal fish) living in 6 different sites. The immunological biomarkers were related to condition indices: relative weights of whole bodies, livers and gonads for fish, glycogen content and growth for mussels. All biomarkers from each site were analyzed concomitantly using a multivariate statistical approach, which enabled us, among other things, to discern differences among sites and seasons. This approach also enabled us to rank sites in comparison with reference sites of minimal anthropogenic impact (Caribou for fish and Malagash for mussels) and ultimately to infer degree of environmental stress. Results of this analysis are still being analyzed, but trends are beginning to emerge for both mussels and fish which suggest the following:

- immunological biomarkers differ between sites
- at least some of these differences are consistent over years
- there is seasonal variation within sites which suggests that sites to be compared must first be characterized over time
- preliminary analysis show a correlation between the immunological biomarkers and what we perceive to be relative degree of human impact on the environment
- immunological biomarkers correlate with indices of growth and survival – important aspects in assessing the health of the animals and their environments.

3) Application and validation of immunological biomarkers to an investigation of impacts of bivalve aquaculture in Richibucto Harbour, NB.

This next phase in our research is designed to test the *in situ* immunological biomarkers developed during the Pictou Project for their utility in quantifying interactions between the commercial bivalve aquaculture industry and the environment in Richibucto Harbour, NB. In addition to responding to growing concern from the public over the impacts of bivalve aquaculture, this research addresses DFO aquaculture priorities of:

- broadening the present "down stream" effects beyond the immediate vicinity of

aquaculture sites;

- providing advice for the development of scientifically defensible farm siting guidelines
- developing tools for the measurement of cumulative impacts of chemical contaminants.

We propose to take the caging techniques and immunological biomarkers developed in Pictou Harbour, and apply them to MEH monitoring in Richibucto Harbour where a major use of the waters is bivalve aquaculture. The two oyster farms in Richibucto Harbour – one established and the other just beginning - provide an ideal opportunity to monitor potential impacts on, and of, the environment. Potential environmental impacts of bivalve culture include reduction of water quality through excreted ammonia and substrate quality by deposition of faeces and pseudofaeces. Localized depletion of phytoplankton might have negative impacts on zooplankton, including commercially important fish and invertebrate larvae. However, it has also been suggested that cultured bivalves might improve water quality through removal of anthropogenic nutrification and contaminants which would otherwise eutrophy or degrade coastal waters. Much of Richibucto Harbour is closed to harvesting of wild shellfish because of bacterial contamination, which is thought to be the result of effluents from sewage, fish processing plants and agricultural runoff.

The objectives of this project will be met through two distinct but complimentary experiments conducted over a three-year period. The first experiment is designed to assess the relationship, if any, between stocking densities and stress in cultured oysters and in wild and caged bivalves sharing the immediate environment. The second is designed to assess the impact of anthropogenic effluents, such as sewage from the town of Richibucto, on caged bivalves.

This is an opportunity to try to understand the interactions between the environment and bivalve aquaculture. In this project we are involved in a partnership involving physical oceanographers from the University of Québec, biologists and economists from the Université de Moncton and Dalhousie

University and chemists from Environment Canada. Our part of this larger project will be to try to quantify MEH using the immunological biomarkers developed through our earlier work with TBT and in Pictou Harbour.

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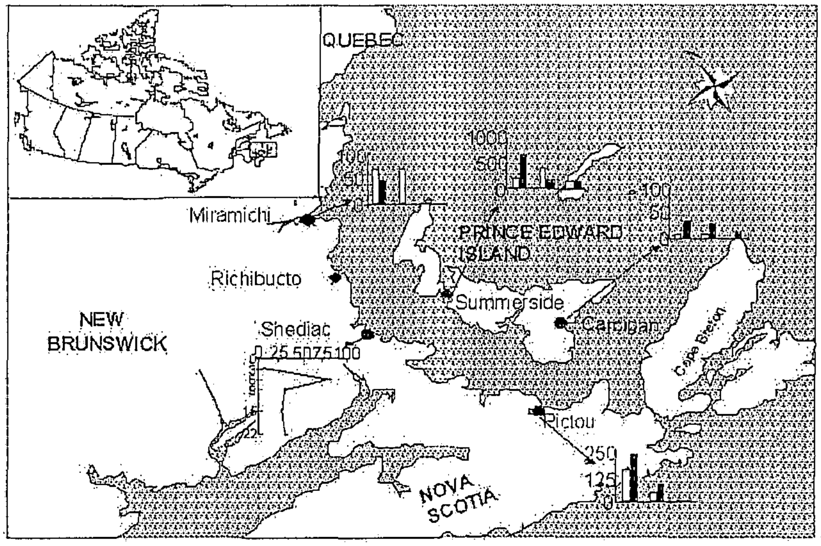

Figure 1: Sites in the southern Gulf of St. Lawrence sampled for butyltins in sediments and blue mussels 1995-1996. Bars represent TBT concentrations (ng Sn/ g dw) in mussels during 1995 (black) and 1996 (white). TBT concentration (ng Sn /g dw) profile is shown for sediments (cm depth) of Shediac in 1996 (adapted from St-Jean et al. 1999).

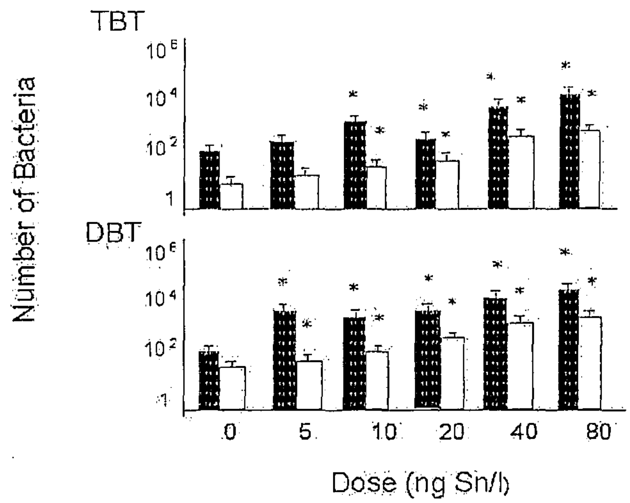

Figure 2: Reduced bacterial clearance in blue mussels exposed for 32d to TBT and DBT. Bacteria *Vibrio anguillarum* were counted 4d (black bars) and 14d (white bars) after inoculation. Bars are mean (+ 1SD) responses of 10 animals. Asterisks indicate significantly higher bacterial counts than found in mussels not exposed to butyltins (0 dose) and measured on the same day. Adapted from St-Jean et al. 2002a.

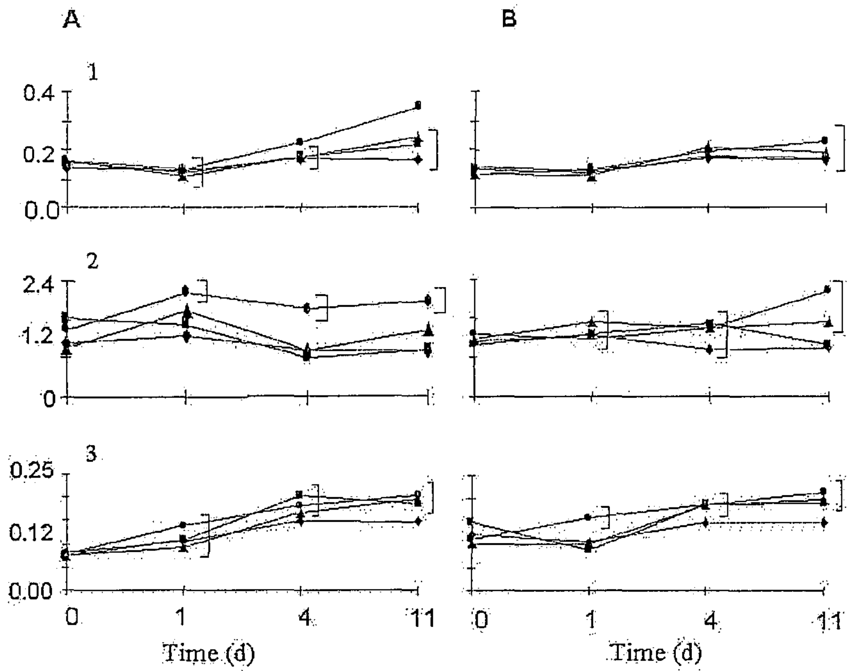

Figure 3: Immunomodulations measured in 10 blue mussels exposed continuously to water-borne (A) DBT and (B) TBT. 1- Mean optical densities for Phagocytic Activity (PA); 2- Mean Haemocyte Counts (HC in millions); 3- Mean optical densities for Lysosome Retention (LR). diamonds: control, squares: 1 ng/l, triangles: 3 ng/l, circles: 6ng/l. Brackets indicate significant differences from control. Adapted from St-Jean et al. 2002b.

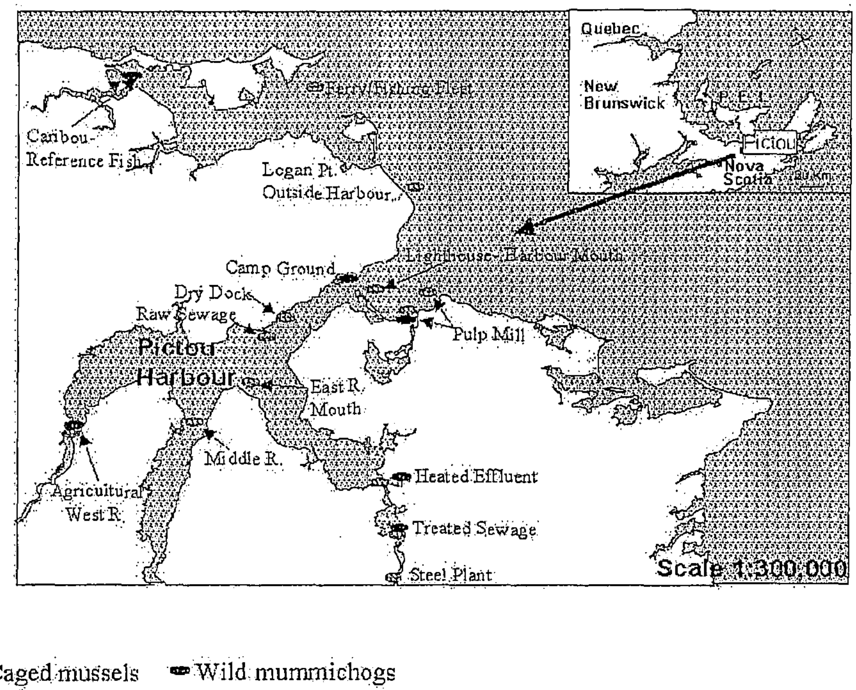

Figure 4: Sites in and around Pictou Harbour, Nova Scotia, from which wild mummichogs and caged blue mussels were sampled for immune parameters during the ice-free seasons of 1999-2001.

METAL CONCENTRATIONS IN MARINE BIOTA LIVING IN AND AROUND COPPER MINE TAILINGS AT TWO SITES IN NEWFOUNDLAND

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Paul Sylvester and Dewan Gani, Dept. of Earth Sciences, Memorial University of Newfoundland, St. John's, NF.

Metal concentrations in near shore marine biota living in and around tailings from two abandoned copper mines in Newfoundland, Canada are presented. Despite the elevated metal concentrations in the biota and the sediment, there is little evidence that the ecosystem has suffered any long term damage. The question of whether these environments would be considered "healthy" is raised.

The two sites are located on the north east coast of the island of Newfoundland. Little Bay (49^0 36' N, 55^0 56' W) is a well protected, low energy environment whereas Tilt Cove (49^0 53' N 55^0 38' W) is a high energy site open to the ocean (Fig. 1). At Little Bay the mine closed in 1969 and a freshwater tailings pond was abandoned. The tailings pond dam ruptured in the 1990's and tailings spilled and continue to spill into

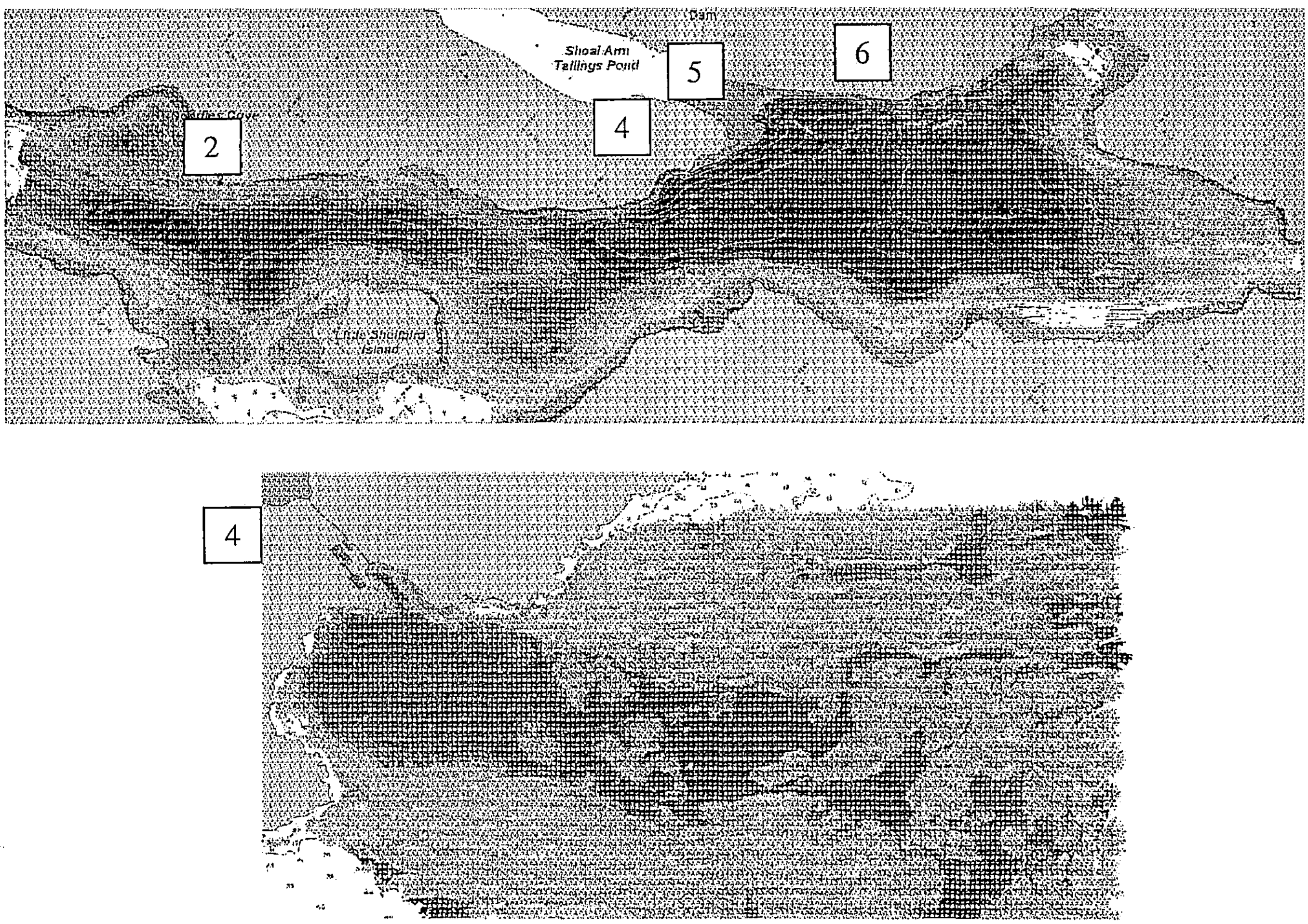

Figure 1. Backscatter images of the seafloor at Little Bay (top) and Tilt Cove (bottom). Darker shades represent softer sediment. Numbers indicate sampling sites.

Little Bay Arm. In March 2000 there was an estimated 500,000 m^3 of tailings in Little Bay Arm (Stirling and Roy 2000). At Tilt Cove the mine operated for almost 100 years. Shortly after its opening, tailings were deposited directly into the marine environment. There is an estimated 2.6 million m^3 of tailings in the marine environment off Tilt Cove.

An examination of the composition of the tailings that remain on-land (Table 1) clearly demonstrates that they are elevated in Cu, Mn, Ni, Zn, As, and Pb relative to non-contaminated marine sediment from this area. There are some site specific differences but in general the marine

Table 1. Comparison of metal concentrations in the tailings and ma sediment.

Element	On-Land Little Bay	Tilt Cove	Marine Control
Cu	450	3500	10
Mn	1500	500	900
Ni	80	200	30
Zn	140	2300	60
As	50	180	5
Pb	3	115	30

sediments from the two study sites have a similar composition as the on-land tailings (Paul Sylvester, Memorial University of Newfoundland, unpublished data). Similarly the biota at the two sites have elevated concentrations of certain metals. However, the Cu concentrtions found in the biota appear to be determined, in large part, to on-land activities and their proximity to the tailings source. For example, in Little Bay the highest concentrations of Cu in the two species of seaweed that were sampled, occur at the old copper concentrate loading dock and near an abandoned slag heap (site 2 and 6 Fig. 2). The bivalves that were collected record the highest concentrations of Cu at the tailings dam breach (site 4 and 5 Fig. 2). At Tilt Cove the highest concentrations of Cu occur at the tailings outfall pipe (site 4 Fig. 3).

Despite the elevated concentrations of various metals in bivalves from Little Bay, Veinott et al. (2001) concluded that it was unlikely that the local population would consume enough mussels to exceed the US FDA's levels of concern. As well, unpublished work by Jerry Payne and others (DFO Newfoundland) has shown that the tailings at Little Bay are not acutely toxic, there is no evidence of avoidance of the tailings by flounder, and the tailings are not devoid of life. However there is evidence of chronic effects. Specimens exposed to tailings exhibit an immune response, suggesting that the tailings are perceived as a threat. Also, there is evidence of oxidative damage, and endocrine system disruption.

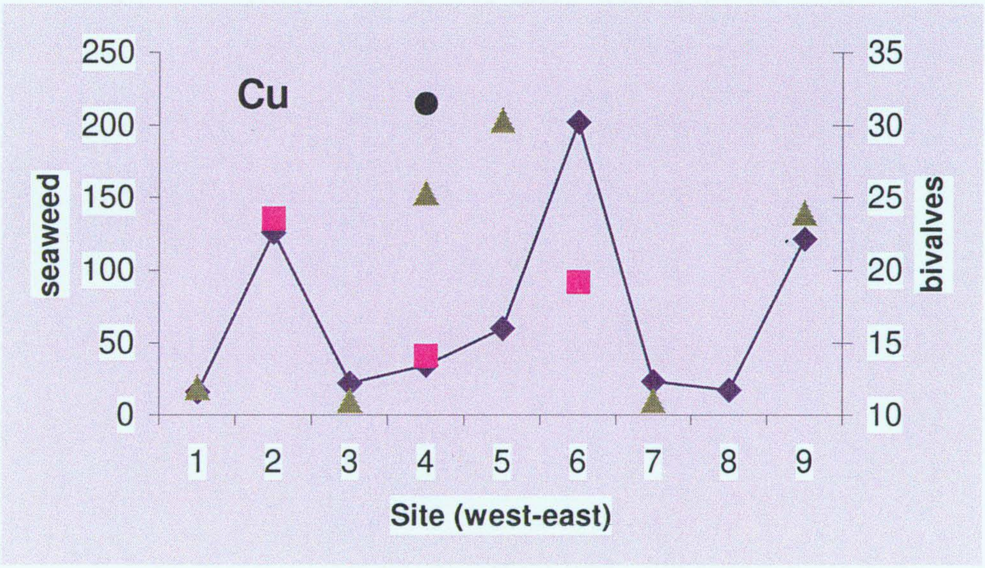

Figure 2. Copper concentrations in biota from Little Bay. Concentrations are in ppm. Squares and diamonds represent seaweed samples. Circle and triangles represent bivalve

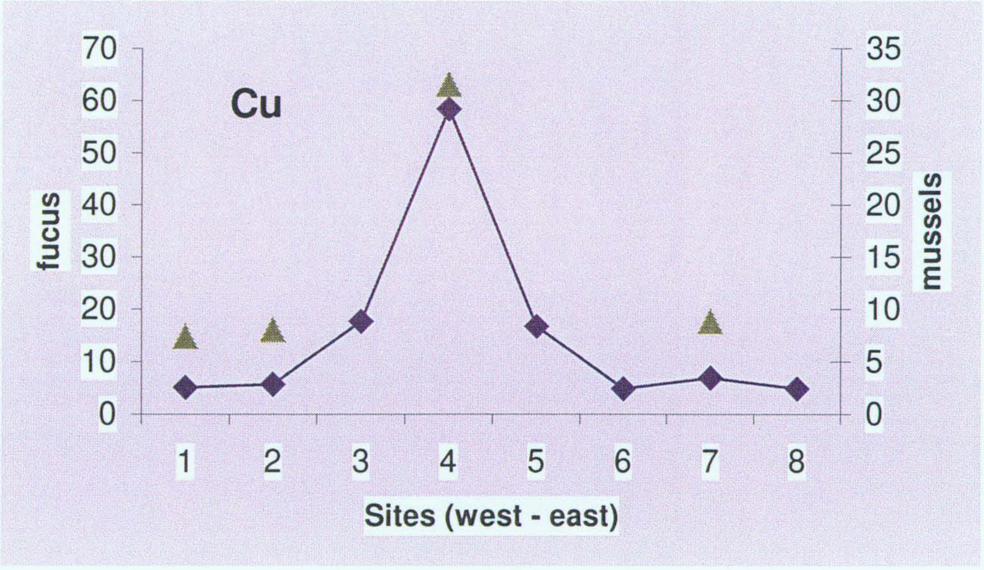

Figure 3. Copper concentrations in biota from Tilt Cove. Concentrations are in ppm. Diamonds represent seaweed samples (fucus). Triangles represent bivalve concentrations (mussels)

The conflicting data make classifying systems like Little Bay's, as a healthy or unhealthy ecosystem, difficult. A sediment quality triad assessment would find contaminated sediment but no evidence of acute toxicity. The triad would also conclude that there is an abundant and diverse benthic infaunal community. In all likelihood Little Bay would be given a healthy rating by such an evaluation system. Given the conclusions of Veinott et al. (2001), it would appear that consumption of a moderate number of mussels is also not a concern for the local population. Again Little Bay would not raise any concerns. However, little is know of the chronic effects of the consumption of mixtures of metals and consumption guidelines are not designed to address metal mixtures. Furthermore, long term studies have not been carried out to monitor, for example, chronic effects trans-generationally. Taking these factors into consideration, Little Bay is not so easily categorized as healthy.

DFO has identified a need for indicators that allow the monitoring of ecosystem health. Little Bay is a good example of the challenges facing anyone attempting to select specific criteria to use in a classification scheme. Results from Tilt Cove are forthcoming but it is presumed that similar conflicts will arise.

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ASSESSING STATUS AND TRENDS OF PERSISTENT TOXIC SUBSTANCES IN FRESH WATER FOOD WEBS

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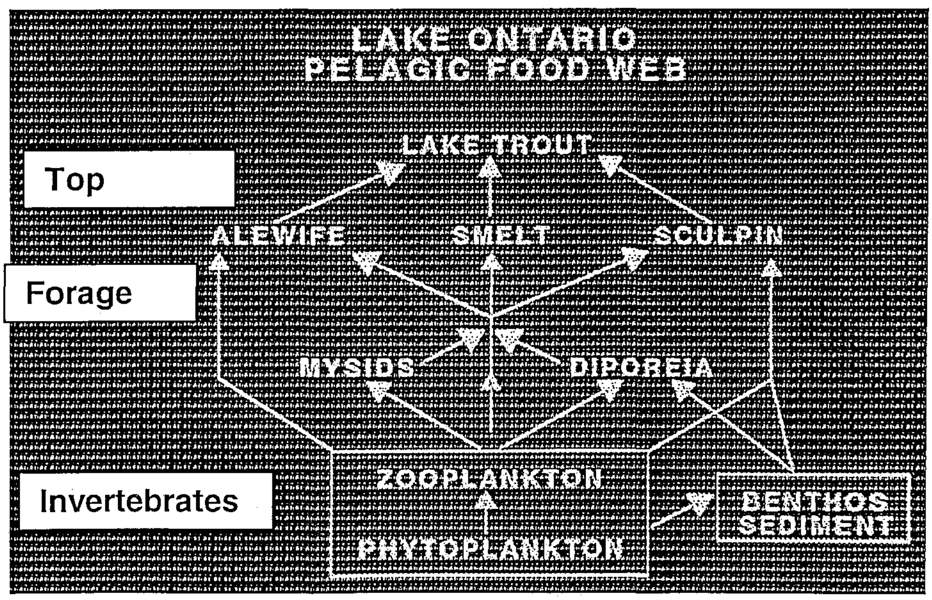
BACKGROUND

- An International Great Lakes Fisheries Based Contaminants Surveillance Program Was Initiated In the 1970's to Address the Effectiveness of Pollution Abatement Legislation.
- The Focus Was on the Identification and Control of Point Source Emissions.
- There Was No Recognition of the Biological Factors Controlling Contaminant Cycling and Accumulation.
- In Order to Evaluate the Ecosystem Level Impact of Environmental Contaminants a Food Web Based Assessment Program is Required (See Figure 1).
- Factors Influencing Spatial & Temporal Contaminant Trends Must Be Incorporated Into the Study Design.
- This Includes Factors Influencing Fate & Pathways of Contaminants.

Fig.1: TYPICAL FRESHWATER FOOD WEB STRUCTURE AND CONTAMINANT PATHWAYS



PROGRAM DESIGN: In Order to Establish a Monitoring Program to Track Changes in Environmental Contaminant Conditions Using the Biological Community as the Indicator of Conditions the following principles must be applied:

- Develop and Implement a Food Web Based Sampling Program That Will Provide Samples Plus Data Which Accurately Describe the Current Site-Specific Status of Ecosystem Level Contamination.

- Develop and Implement a Continuing Program That Will Provide Appropriate Samples Plus Data Which Permit Valid Year to Year Comparisons of Ecosystem Level Contaminant Conditions.

PROGRAM IMPLEMENTATION: This requires knowledge of the composition and the function of the particular biological community selected as the indicator.

- Factors Influencing Contaminant Accumulation Patterns Include:

- For Fish Species: Age (Duration of Exposure) (See Figure 2), Diet (See Figure 3 & 4), Migration Patterns, Trophic Level, Lipid Content, Sex, Spawning Cycle, Collection Period, Tissue Type, Growth Rate.

- For Invertebrates Factors Include: Benthic, Pelagic, Inshore/Offshore Habitat, Reproductive State, Migration Patterns, Tissue Type Analysed etc.

Fig. 2: Influence of Fish Age on Levels of Contaminant Accumulation

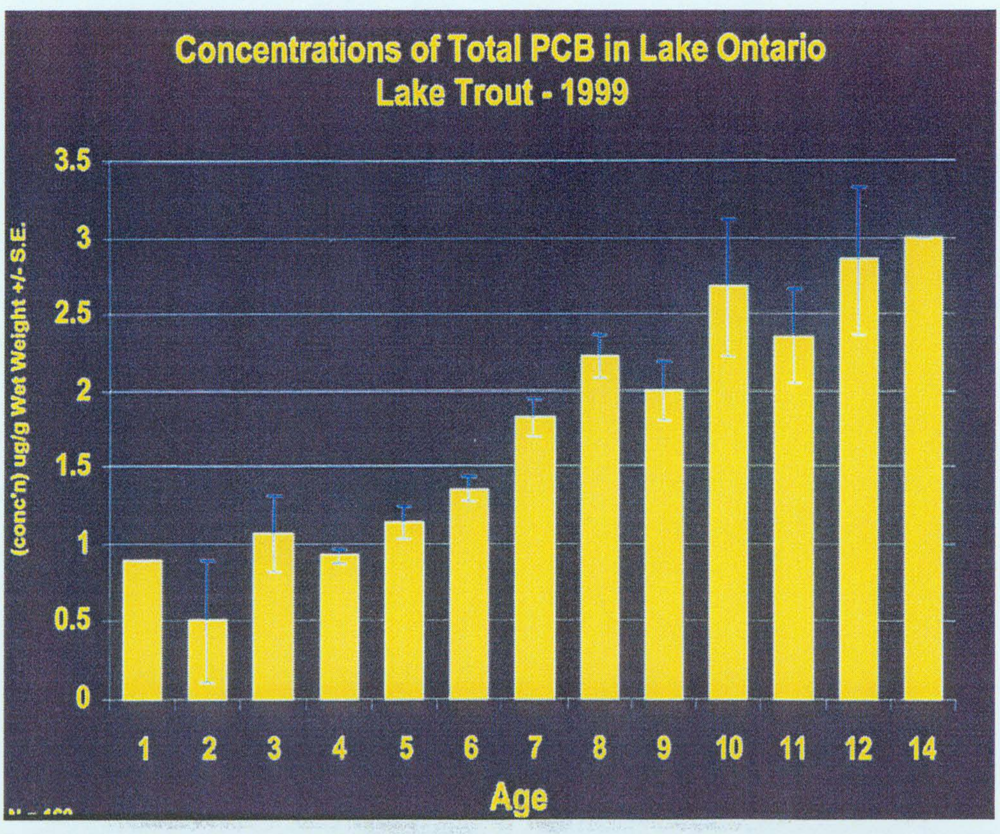


Fig. 3: Contaminant Levels in Major Prey Species (Forage Fish) Influence Predator Contaminant Burdens

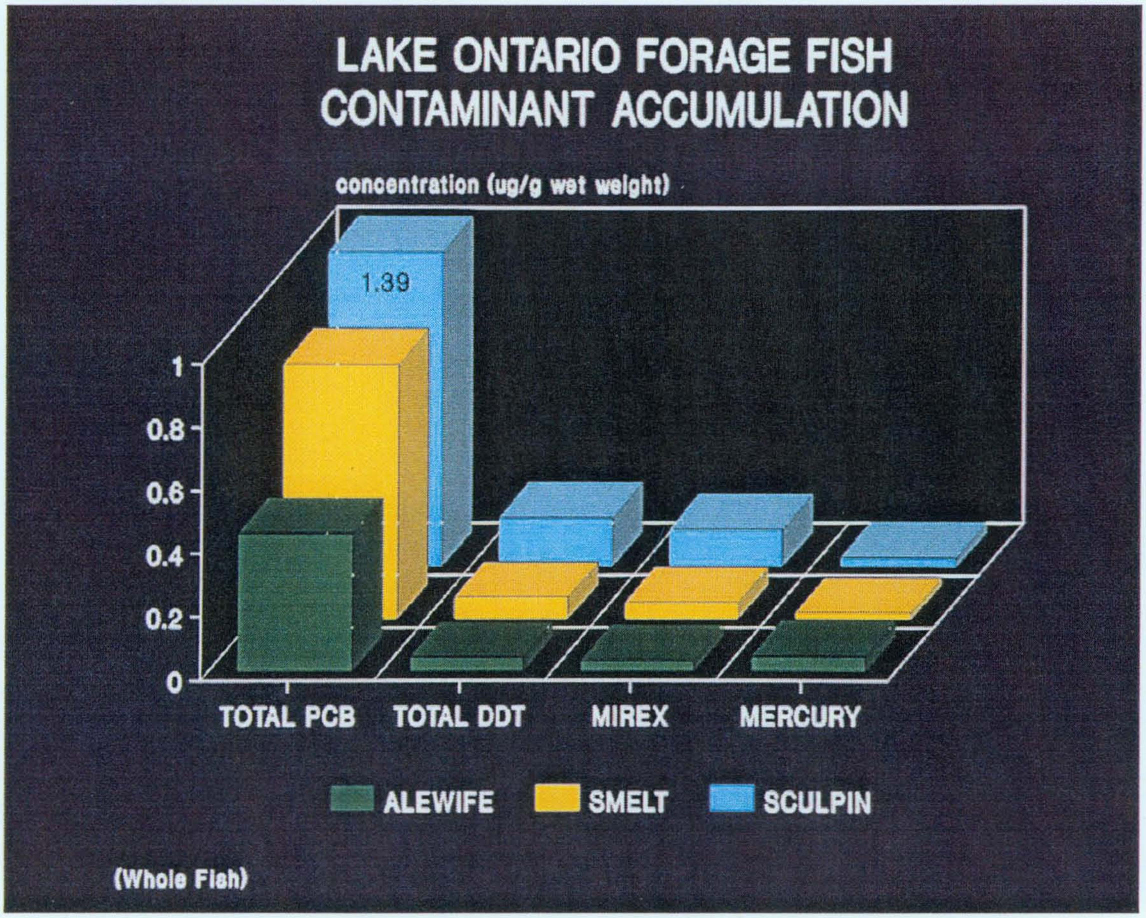
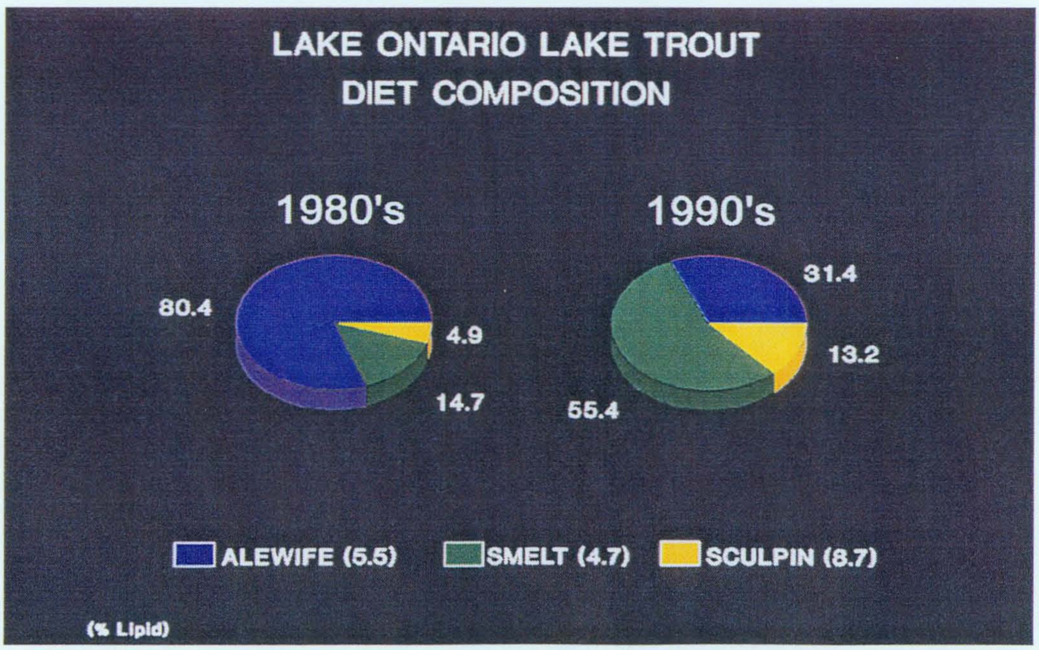


Fig. 4: Diet Composition Changes May Occur Over Time Due To Changes in Fish Community Composition



Changes in Fish Community Composition Are Caused By:

- Harvest Rate Shifts
- Recruitment Rate Changes
- Habitat Loss
- Climate Patterns
- Exotic Species Invasions

PROGRAM IMPLEMENTATION:

First Determine Specific Objectives:

1. Assessment of Spatial &/or Temporal Trends *or*
2. Measurement of Environmental Conditions *or*
3. Provision of Human Health/Consumption Advice Risk Assessment

A Food Web Based Study Provides:

- The Ability to Assess Contaminant Burden Changes Based on Ecosystem Changes Vs Changes in Loadings.
- The Ability to Identify Emerging Problems at the Base of the Food Chain.
- The Ability to Develop Comprehensive Predictive Models on Contaminant Accumulation Patterns.
- The Potential to Develop Alternate Harvest Strategies When Contaminant Levels are Projected to Reach Actionable Levels.

CONCLUSIONS:

- Determine the Primary Objective of the Program
- Implement a Food Web Based Contaminants Assessment Program

- Understand the Significance of the Biological Variables Influencing the Chemical Data.

- Be Consistent in the Implementation Phase.

- Compare Similar Data Sets for Valid Trend (Temporal/Spatial) Assessment.

THE TRAFFIC LIGHT APPROACH TO ASSESSMENT OF HEAVY METAL DATA FOR MARINE SEDIMENTS

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Assessment of contaminant data for marine sediments is, and will continue to be, an important component of marine environmental quality (MEQ) assessments. Practical use of heavy metal data depends on (1) assessment of natural background concentrations of potential contaminants, and (2) development of realistic reference points for management action.

In contaminated sediments, heavy metal concentrations increase with decreasing grain size of the sediments. When assessing contaminant levels it is critical to account for this variability. For the east coast of Canada lithium has been found to be a good normalizer for the grain size variability. Figure 1 shows a plot of the copper:lithium relationship illustrating both the natural relationship and the augmentation of copper concentrations in two contaminated harbours.

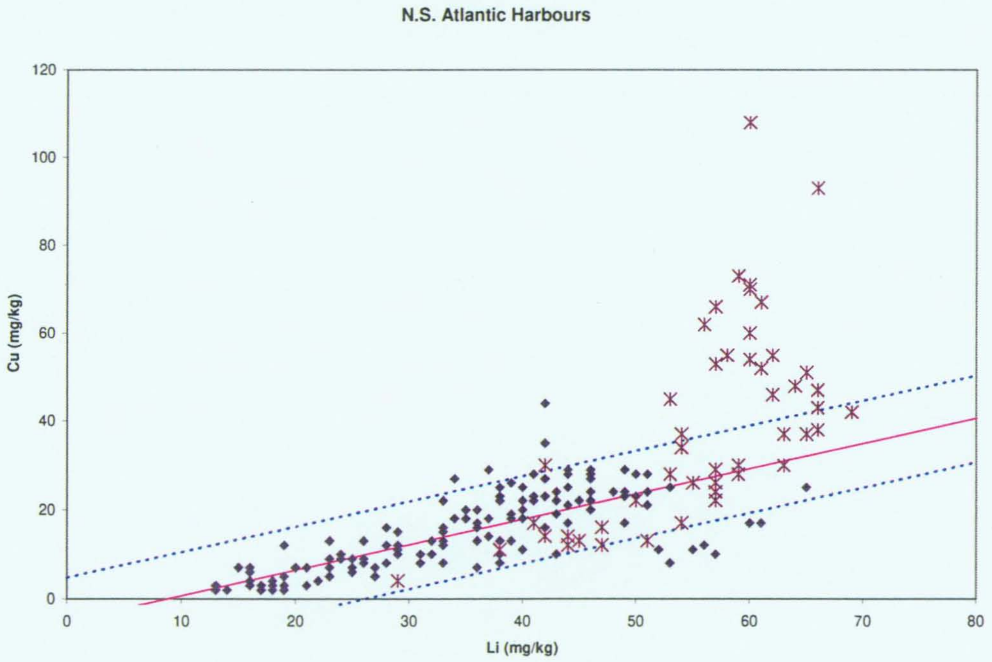

Figure 1. Cu vs Li relationship for N.S. harbours.

The traffic light approach to MEQ establishes reference points for indicators based on a three point scale, green (good), yellow (intermediate) and red (bad). Pointential reference points based on contaminant levels in sediments include ones based on toxicity and ones based on background concentrations. Some potential reference points are illustrated in Figure 2, which shows potential reference levels supperimposed on the Cu:Li relationship.

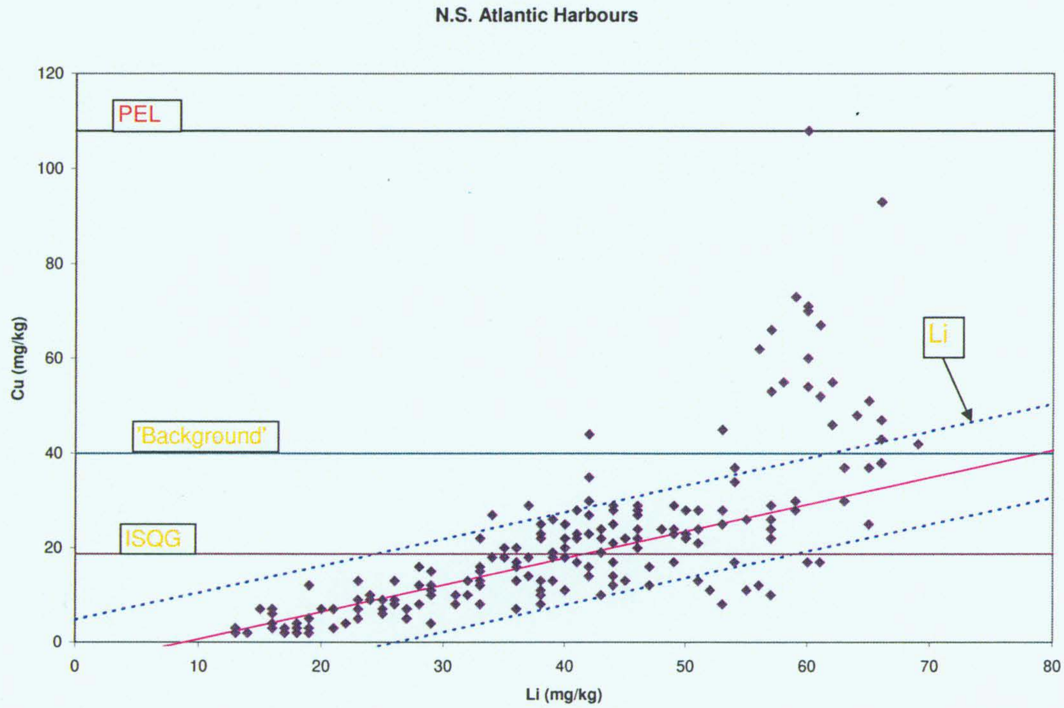

Figure 2. Potential Reference levels.

The highest level shown is the Canadian Council of Ministers of the Environment (CCME) probably effects level (PEL). This is the concentration above which most toxicity tests show some harmful effects and it provides a potential red light indicator. The other toxicity based level shown is the CCME interim sediment quality guideline (ISQG) which shows the level above which the most sensitive toxicity tests show some effects. This is a potential yellow light indicator, however, the fact that approximately half the natural concentration sediments have higher levels that the ISQG seriously limits its usefulness. Two other potential yellow lights based on assessments of natural background levels are also indicated. The sloped line that describes the upper bound of the confidence interval around the Cu:Li regression line does the better job of describing the true background concentration and thus is the better choice of a yellow light that indicates concentrations above background.

A similar approach to assessing background concentrations has been taken in an investigation of the far field effects of wastes from finfish aquaculture. We have used the locations where elevated concentrations of zinc and copper were found in Quoddy region sediments as a tracer of wastes from the farms. Zinc is an important component of the fish food and copper has been used extensively as an antifoulant. Background distributions of these metals were established using the metal:Li relationships as described above, and locations of samples with elevated concentrations were plotted on a map of the area. Figure 3 shows the Cu:Li relationship with the elevated samples highlighted. A similar plot can be produced for Zn. Although the anomalous samples do not show large concentrations increases, they can be clearly distinguished from the natural distributions using the Li relationships. Locations for the elevated concentrations are shown in Figure 4. The two areas with the bulk of the anomalous concentrations, Back Bay and Lime Kiln Bay, are both inlets with a high density of fish farms and restricted water circulation. Another nearby area with a similar density of farms but better water circulation (Bliss Harbour), has very few anomalies.

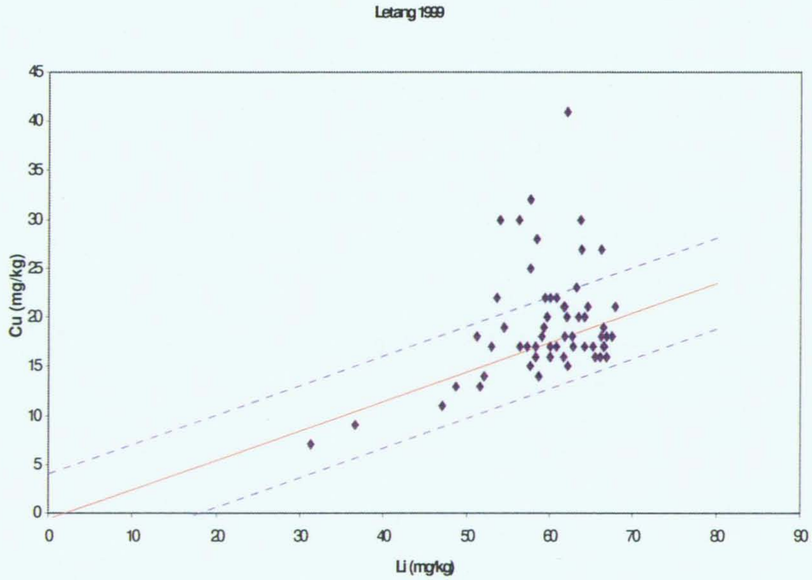

Figure 3. Cu:Li relationship for the Quoddy region.

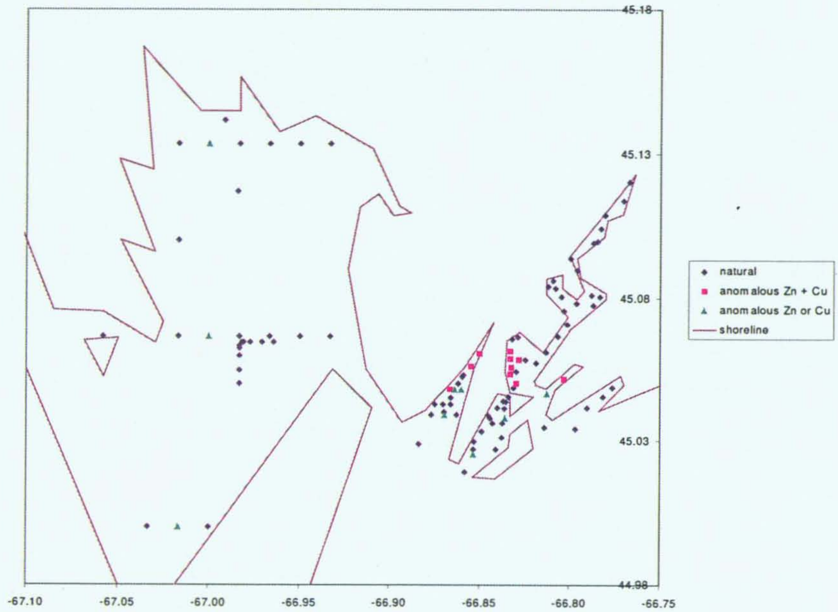

Figure 4. Map of anomalous concentration locations.

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