Science Review 1994 &'95

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Bedford Institute of Oceanography

Gulf Fisheries Centre

Halifax Fisheries Research Laboratory

St. Andrews Biological Station

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Science Review 1994 & '95

of the

Bedford Institute of Oceanography

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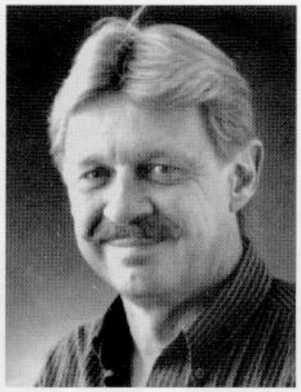
1994 and '95 in Review

J.A. Elliott, J.S. Loch, K.D. McAlpine[1], and H.B. Nicholls

J.A. Elliott

J.S. Loch



K.D. McAlpine

H.B. Nicholls

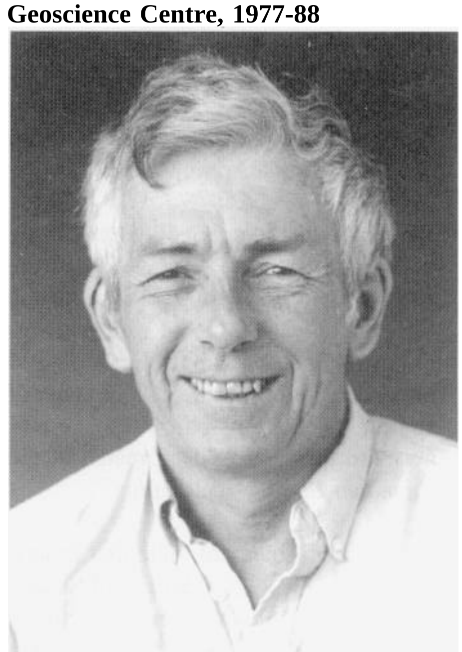
The years 1994 and '95 were ones in which significant changes occurred in the organization and funding of the research and survey programs carried out at the Bedford Institute of Oceanography (BIO), the Halifax Fisheries Research Laboratory (HFRL), and the St. Andrews Biological Station (SABS). These changes were mainly driven by a major "Program Review" of federal programs in Canada. In addition, a merger of the Canadian Coast Guard with the Department of Fisheries and Oceans (DFO) on April 1, 1995, resulted in other changes, one of which was a decision to combine DFO's Scotia-Fundy and Gulf Regions into a single organization, the Maritimes Region. In the Department of Natural Resources, a major re-focusing of programs occurred and the Atlantic Geoscience Centre was renamed Geological Survey of Canada (Atlantic). In Environment Canada, the decision was taken to transfer both the Marine Wildlife Conservation Division and the Environmental Quality Laboratory from BIO to other locations.

Note that in the case of the coverage of DFO programs and achievements in this Science Review, the activities of staff at the Gulf Fisheries Centre, Moncton, New Brunswick are only partially included because the new DFO Maritimes Region was not established until the latter part of the review period.

Staff

A number of key staff changes occurred within the laboratories during the 1994-95 biennium. In January 1995, Mr. Stephen B. MacPhee, Regional Science Director, DFO, Scotia-Fundy Region, was transferred to DFO Headquarters, Ottawa to assume the position of Director-General, Canadian Hydrographic Service. He was replaced on an acting basis by Dr. James A. Elliott, Director, Physical and Chemical Sciences Branch. During 1995, John S. Loch, Regional Science Director, DFO, Gulf Region, was named as the new Regional Science Director for Scotia-Fundy Region, to take up the position as of 1 April, 1996. Subsequently he was named Regional Science Director of the new Maritimes Region. Within DFO the situation as at the end of this reporting period, i.e., December 31, 1995, was one of transition; the reader is referred to the Appendix, "Organization and Staff," which provides the situation as at December 1996, by which time the new organization had become established. Among the changes that will be noted in DFO is the disappearance of the organizational units Biological Sciences Branch and Physical and Chemical Sciences Branch as a result of a process of "delayering."

Michael Keen, Director, Atlantic Geoscience Centre, 1977-88



Family, friends and former colleagues gathered on Tuesday, January 11, 1994, for a brief ceremony at the Bedford Institute of Oceanography to pay tribute to Dr. Keen's lifetime of achievements, and to mark the formal naming of Michael Keen Canyon in his memory. (Dr. Keen died in 1991). This undersea feature cuts the edge of the continental shelf east of the Grand Banks of Newfoundland, at the south end of the Flemish pass between Beothuk Knoll

[1] Note that Dr. D.B. Prior was the Director of the Geological Survey of Canada (Atlantic) during the review period. but he resigned in 1996 to take up an appointment with Texas A & M University, and was replaced on an acting basis by Dr. K.D. McAlpine.

and Flemish Cap. Ranging in depth from 1000 metres in the north to 3200 metres in the south, it is about 50 kilometres long and features a cross section comparable to that of the Grand Canyon at its deepest point.

Awards and Presentations

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

- Dr. Ken Mann, Scientist Emeritus of the Habitat Ecology Division of DFO at BIO, received the American Society of Limnology and Oceanography (ASLO) "Lifetime Achievement Award" in 1994. He was the first recipient of this award that is to be presented annually to a scientist who has demonstrated long-term commitment to the field of aquatic sciences.

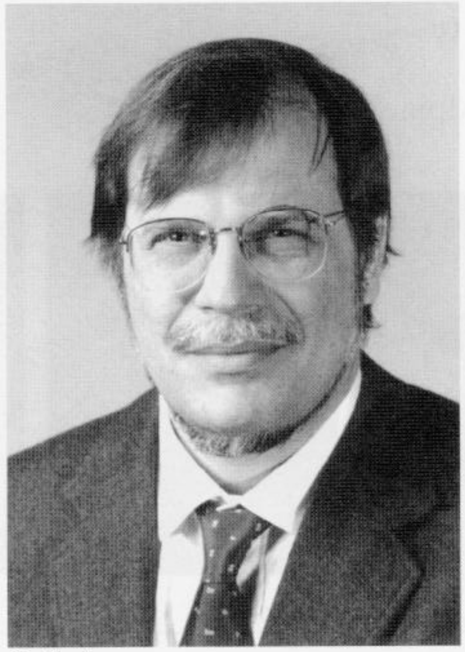
- Dr. Peter Jones, a marine chemist with DFO at BIO, was awarded an honourary doctorate degree of the University of Goteberg, Sweden in October 1994 in recognition of his work on the chemical conditions of the Arctic Ocean.

- Dr. Charlotte Keen, Geological Survey of Canada (Atlantic), was awarded the 1994 George P. Woolard award of the Geological Society of America in recognition of her outstanding contributions to the understanding of the development of continental margins. In 1995 she was awarded the Tuzo Wilson medal of the Canadian Geophysical Union.

- Dr. Peter Hacquebard, Scientist Emeritus with the Geological Survey of Canada (Atlantic) at BIO, was the first recipient of the Walter Bell Silver Medal, which was awarded at the Walter Bell Memorial Symposium on Paleobotany and Coal Science held May 28 - June 1, 1995, in Sydney, Nova Scotia.

Huntsman Award

The A.G. Huntsman Award for excellence in the marine sciences is administered by a private foundation based at BIO. It was first awarded in 1980, and up to the end of 1995, 17 persons had received the Huntsman Medal. One award was made during the period covered by this Review, for 1994. The presentation and distin-



Dr. Boyle

guished lecture took place on Wednesday, January 18, 1995, at the Bedford Institute of Oceanography. Dr. Edward A. Boyle, Massachusetts Institute of Technology, Cambridge, Massachusetts was the recipient in the category of physical/chemical oceanography. He was selected for his fundamental work and leadership in developing an important discipline in marine geochemistry (paleo-oceanographic chemistry) that uses trace metal contents of foraminiferal shells to retrieve historical data on nutrients, productivity, and deep-water circulation of the oceans. The title of Dr. Boyle's distinguished lecture was, "The Ice Age Ocean Conveyor Belt: on, off, or somewhere in between."

Research and Survey Highlights

Examples of the research undertaken, together with some of the major events that occurred during the 1994-95 biennium, are outlined below by broad geographic region.

Gulf of Maine, Georges Bank, Bay of Fundy

Ascophyllum nodosum (rockweed), a fucoid alga, is the dominant intertidal seaweed of Atlantic Canada. It has been harvested for the past 33 years in southwestern Nova Scotia and southeastern New Brunswick. Halifax Fisheries Research Laboratory personnel undertook investigations to understand the relationship between *Ascophyllum* canopy and associated macro-invertebrates. This study examined the abundance and diversity of invertebrates with respect to tide level and weave exposure, degree of canopy cover and underlying substratum. A 3D imaging technique was developed to provide a detailed, quantitative description of the habitat space created by the seaweed canopy. The effects of commercial harvesting on associated invertebrates, due to alteration of the canopy structure and density, were evaluated by comparative studies in commercially harvested beds as well as through manipulations of the canopy. The results are being used to develop rockweed management strategies to reduce or prevent negative impacts on the invertebrate community.

Research examining benthic changes around salmon mariculture sites in the Fundy Isles area of New Brunswick was undertaken during the review period. The aim of the project was to compare three different techniques for measuring benthic changes: organic carbon burial rates; benthic enrichment indices; and conventional grab sampling. Comparisons were made based on the results obtained and on the costs for each method. This project was a collaborative effort between the St. Andrews Biological Station and the Bedford Institute of Oceanography.

Among biological factors considered in fish stock evaluations, length-at-age is a useful indicator of how well individual fish are doing because it reflects the conditions the fish has experienced for feeding and growth, and can be obtained from many sources. For example, the new "sentinel" fisheries surveys conducted by the fishing industry may make contributions in this area soon, whereas several years may be needed before trends can be identified in catch rates. In most recent years, there are indications in a few stocks that biological factors may be improving. Compared to the early 1990s since 1993 increases in length-at-age have been seen for eastern Georges Bank (5Z) haddock and some components of Northern cod. Traditional models used to predict abundance often do not take account of changes in important biological characteristics of fish stocks. such as length-at-age. As biologists expand their studies and analyses, more of these biological factors are being included in the evaluation of stock status. This leads to evaluations which are more complex, but more biologically realistic.

Acollaborative investigation was undertaken with scientists from the Woods Hole Oceanographic Institution and the University of Rhode Island to study vertical mixing and stratification, and their effect on the life history parameters of target species. The work was part of a joint Canada/US (GLOBEC) Global Ocean Ecosystem Dynamics program of the Northwest Atlantic and Georges Bank to examine the biological and physical processes affecting recruitment of important species.

One important source of new environmental information to be examined by the Georges Bank Environmental Review Panel (established to reconsider the issue of exploratory drilling on the bank), is a multidisciplinary research program on the fate and effects of drilling wastes that is being carried out at the Bedford Institute of Oceanography. With funding support from the federal Program on Energy Research and Development (PERD), DFO and contract scientists have been carrying out a number of closely coordinated field, laboratory, and modeling studies. These are addressing the physical oceanography and sedimentology of Georges Bank, the flocculation behaviour of drilling wastes, and the sublethal effects of drilling wastes on the sea scallop *Placopecten magellanicus*, which is the most important commercial species on Georges Bank.

Through collaborative research (DFO, Dalhousie University and Institute for Marine Biosciences), a set of molecular DNA markers has been developed with which to examine the population genetics of sea scallops. Each of the three types of markers, cDNA probes, single-locus microsatellites, and RAPD markers, reveal a high level of genetic variability among individuals. Among the features of these markers, the microsatellites require only a small amount of DNA to produce a reaction: a protocol was developed which will allow individual scallop larvae (less than 0.02mm) to be genotyped. Local scallop hatcheries are currently using this technology for such applications as determining the parental contribution of different spawning sets, the level of inbreeding in their stock and tracking the yield and growth performance of selected pedigrees.

St. Andrews Biological Station has been sampling phytoplankton populations in the Southwest Bay of Fundy since 1987. All algal species are monitored, with the main focus being those species that produce toxins or cause harmful effects. During 1988, domoic acid was detected in shellfish and plankton, the algal species implicated being the diatom, *Pseudo-nitzschia pseudodelicatissima*. Although *P. pseudodelicatissima* has been an annual occurrence, concentrations were considerably higher during 1988. Analysis of 1995 samples, however, showed similar densities. *P. pseudodelicatissima* numbers in excess of one million chains of cells/litre were observed on August 22 and August 29, 1995. The DFO Fish Inspection Branch was notified and sampling of soft-shell clams and blue mussels from the New Brunswick coast of the Bay of Fundy for domoic acid was initiated. Domoic acid was detected from shellfish extracts and, on September 1, the regulatory level of 20 ppm was exceeded. This resulted in the suspension of shellfish harvesting in the southwest Bay of Fundy.

The evolution toward co-management of fisheries will have considerable, and as yet unknown, impacts on science programs of DFO, In a novel project during the summer of 1995, staff from the herring team at the St. Andrews Biological Station gained experience in responding to the challenge of in-season management. While DFO staff have a long history of close cooperation with the Scotia-Fundy herring industry, this new experiment during the summer of 1995 involved working with the industry to respond to biological signals from the fishery in real time. The experiment resulted from concern and uncertainty regarding the status of the major 4WX herring stocks. The move improved the record of information from the fishery, e.g., a series of surveys of major spawning areas using commercial vessels documented the number, location and size of herring schools. Resulting in improved protection of components of the fishery, a similar management system was recommended for future years.

Scotian Shelf

A research project of BIO physical oceanographers completed the task of compiling geographic parameters such as average depth, width, length, volume and surface area for 104 inlets along the Atlantic coast of Nova Scotia and elsewhere. These parameters were used to sort inlets with similar characteristics into groups where the circulation and climatology may be similar. This will enable investigators to infer the circulation and stratification for inlets that have not yet been sampled but that are part of a group for which some studies exist; and also to help focus future field work on inlets for which more detailed information is needed.

In 1994, the Geological Survey of Canada (Atlantic), in the first year of a three-year program funded under the joint Nova Scotia Mineral Development Program, surveyed part of the Scotian Shelf to assess offshore sand and gravel deposits. The resource potential was confirmed using investigations with high resolution seismic and side scan sonar data. In addition, bulk samples were collected for material strength testing.

Ecosystem considerations of the eastern Scotian Shelf cod stock include reviews of grey seal predation. This was first done in 1993 using information on the composition of grey seal diets collected between 1989 and early 1993. The proportion of cod (mostly less than 4 years old) in these samples did not indicate a trend over the sampling period. Given the low and declining biomass of cod, it was considered likely that grey seals would reduce their predation on cod in favour of more abundant prey. However, samples collected from Sable Island between the summer of 1993 and January, 1996 show that the proportion of cod in the diet, although variable among samples, has shown no trend over the five years of sampling on the Island. The mean percentage of cod in the grey seal diet has remained at about 15%. Given that the grey seal population has continued to increase at the same rate as previously measured, the average estimate of consumption of 4VsW cod by grey seal is 17,700t in 1995; an increase of 12% over 1994. This increase in a significant cod predator is coincidental with an apparent period of low production and reproduction for cod, thus increasing the ecological pressure on the cod population.

For the past several years, DFO scientists have collected detailed temperature data from selected inlets along the Atlantic coast of Nova Scotia in support of aquaculture. The data are used in two ways. The first is to define the climate of the inlets to determine which species could be cultured; the second is to determine the flushing of the inlets by the waters of the adjacent continental shelf. The temperature recording instruments are tended on a six-month schedule, usually in May and November.

A project to transfer the Canadian Shelf Climate Database to a more formal relational database management system was completed in 1994. The database, consisting of over 425,000 profiles and 9 million observations, is the most comprehensive assembly of temperature and salinity observations available for the Canadian east coast. The conversion has made it much easier for scientists to extract and analyze the data and has reduced the effort required to maintain and update the database.

BIO marine chemists completed a mission to the Scotian Shelf in the fall of 1994, the purpose of which was: (1) to study processes controlling the transport of organic carbon and particle-associated chemicals (which include most contaminants) in the ocean; (2) to further investigate the environmental effect of drill waste dispersion around the Rowan Gorilla III oil rig (Cohasset Field, Sable Island Bank); and (3) to collect samples for a monitoring program aimed at predicting the influence of environmental conditions on fish stocks on the Scotian Shelf.

Scientists from the St.Andrews Biological Station, together with colleagues from Australia and the United States, worked with fishermen from the St. Margarets Bay Tuna Association in Nova Scotia in a field study during mid-August 1995. This study examined the use of external archival tags (miniature data loggers) on bluefin tuna.

The Canadian Hydrographic Service at BIO, together with other partners, has carried out high resolution multi-beam surveys for projects in the Atlantic coastal zone area. Using the vessels FCG *Creed* and *DOLPHIN*, the work included mapping corridors for underwater communications cables from Nova Scotia to Newfoundland, and from Nova Scotia to the edge of the Scotian Shelf for transmission overseas. Another survey was performed for the Sable Island Offshore Energy Project to provide data in support of undersea pipeline routes.


FCG *Creed*

The Arctic surfclam, *Mactromeris polynyma*, is a large clam (75-125 mm), similar in appearance to the more common Atlantic surfclam. The main distinguishing feature is that most specimens have a purple color in the foot and mantle that turns red upon cooking, similar to lobster and shrimp. It is found in both the Atlantic and Pacific oceans in medium to coarse sand bottom. In the Atlantic there are commercial fisheries on Banquereau Bank and the Grand Banks. The fishery on Banquereau Bank started with developmental surveys conducted by DFO scientists in 1980-83. After a three-month test fishery, a commercial fishery was managed with a TAC/EA program and limited entry. It is now conducted by 3 large (60 m) freezer processors using hydraulic dredges. The fishery targets clams in the 10-15 year old age range for the sushi and surimi market in Japan. The value of this fishery increased from zero in 1985 to approximately $35 million in 1993, and created jobs for 480 persons.

Biological and physical oceanographers from BIO collaborated in a research program directed at assessing effects of changes in climate (past, present and future) on physical and ecological processes on the Scotian Shelf. Studies included a field program to identify and characterize supply sources of zooplankton to the Scotian Shelf (e.g. Gulf of St. Lawrence, Labrador Current and The Shelf Basins) and the development of a model based on newly collected and historical data.

In early 1994 a new group was established comprising fishermen and scientists with the objectives of improving communication between members of the two professions, sharing information and ideas, and jointly launching research projects on problems of mutual interest. Known as the "Fishermen Scientists Research Society." it initially covered the Eastern Shore area of Nova Scotia. In the August 10, 1994 issue of the *Globe and Mail,* an article under the heading "Conservation: fishermen are gathering valuable data about cod and haddock stocks for a former antagonist - federal scientists," the federal Fisheries Minister, Brian Tobin, was quoted as saying: "It has looked to me many times that the fishermen were on one team and DFO was on the other; and each team spent a great deal of its time trying to figure out how to outwit the other.....Now we have fishermen and scientists working on the same team."

Gulf of St. Lawrence

In July 1994, GSC (Atlantic) participated in an expedition on the *Edwin Link* in the Saguenay Fjord. Quebec. One purpose of the mission was to use a submersible to investigate the age of several turbidite channels discovered about a year previously near the mouth of the North Arm of the fjord. The observations indicate that the channels were not formed as a result of the 1988 Chicoutimi earthquake, but may be related to a major collapse of fjord basin sediments that is believed to be associated with a large earthquake that occurred in this area in 1663. A second purpose of the expedition focused on observations of sea floor communities in the North Arm and their recovery in response to the cessation of industrial waste discharge (pulp mill organic waste) in the early 1970s. Visual observations did not detect any anoxic bottom areas in the middle part of the arm or any indications of sulphur bacteria colonies.

In 1994 and 1995, Halifax Fisheries Research Laboratory staff worked with the *Chondrus* buyers and harvesters to design an experimental harvest for *Furcellaria fastigata* off western Prince Edward Island, "The World's Capital of Irish Moss". The purpose of the study was to determine the impact of drag raking on *Furcellaria* regrowth and recruitment.

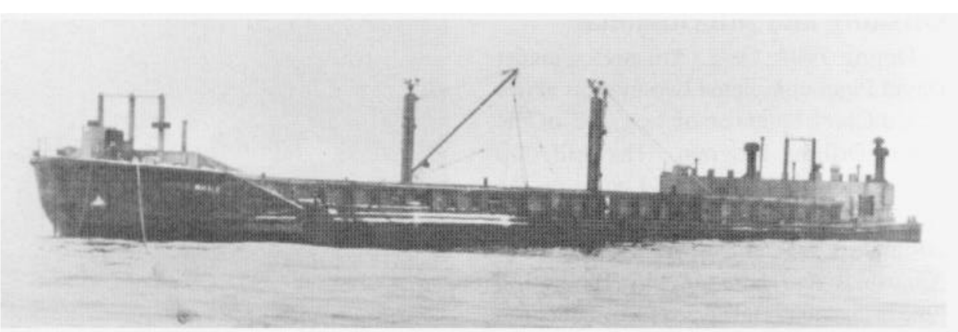
Towards the end of the review period there was increasing scientific activity by DFO staff in association with the submerged wreck of the *Irving Whale* oil barge off the north coast of Prince Edward Island, and its planned recovery. Among projects undertaken, snow crabs collected in the vicinity of the wreck of the *Irving Whale* and at a control site were analyzed for polychlorinated biphenyls (PCBs). The results were used to develop a baseline for assessing the consequences of recovering the submerged wreck, which contained PCBs in the oil heating system.

Grand Banks, Labrador Sea

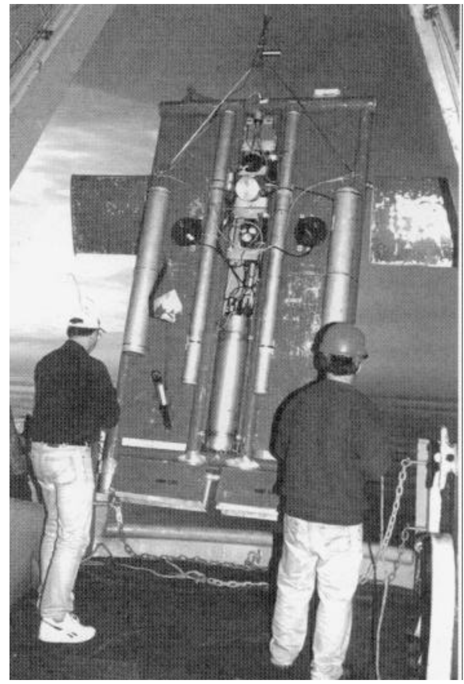
A team of DFO scientists undertook field observations of the Labrador ice pack off Cartwright, Labrador. Poor weather conditions made helicopter operations difficult and although ice conditions were heavy, swells moving through the ice pack broke up the large floes making it difficult to locate safe landing sites. Despite these difficulties, data on ice thickness and type were collected both on the ice and through an airborne electromagnetic ice thickness sensor during three different overpasses of the ERS-1 satellite from which SAR imagery was obtained. These data have allowed the development and validation of algorithms to estimate ice thickness and type from the satellite SAR missions. In addition, beacons were set at various locations across the ice pack and temperature and salinity profiles of the water column obtained at each location. These data were used to test and validate ice-ocean models that predict the movement, and formation and decay, of the ice pack off Labrador.

During the summer of 1994 CSS *Hudson* completed the occupation of the World Ocean Circulation Experiment (WOCE) repeat section across the Labrador Sea. This year, the eastern end of the section was free of ice so that stations could be occupied right onto the east Greenland shelf. On the Labrador side, ice was encountered as the vessel crossed the 400 metre isobath, thus terminating the transect at the inshore edge of the offshore branch of the Labrador Current. This section measures the amount and characteristics of oceanic convection that has taken place in the Labrador Sea during the previous winter. The Labrador Sea is the source region of one of the components of the thermohaline overturning cell of the North Atlantic and may be responsible for observed interdecadal variability in North Atlantic waters and climate.

The Geological Survey of Canada (GSC) Atlantic has recently designed and put into operation a coastal information system to manage and distribute coastal geomorphologic data. This project, using commercial GIS software, was initiated through in-kind cooperation with the Government of Newfoundland and Labrador, and is now continuing via in-kind and financial support from Environment Canada and the Province of Nova Scotia. GSC scientists have mapped the coastline for 22 national topographic series map sheets (at a scale of 150,000) and plan to continue mapping throughout the Atlantic Provinces in collaboration with provincial and federal departments.



Irving Whale



BRUTIV Vehicle

During June 24 to July 3, 1995, the CSS *Hudson,* working together with the CSS *Wilfred Templeman,* carried out the fourth and final mission in the trawling impact experiment being conducted on the Grand Banks of Newfoundland. This year's program included a further sampling, by the *Parizeau,* of the experimental corridors trawled in 1994, in order to again evaluate what effects could still be discerned one year after the second trawling event. After the *Parizeau* completed this sampling, the *Wilfred Templeman* retrawled the experimental corridors in the same manner as in 1993 and 1994. The *Parizeau* then carried out post-trawl sampling in the same manner as before. Successful modifications to the BRUTIV vehicle permitted its first use since 1993 in providing video imaging of trawled and untrawled corridors. The data from this and earlier missions in the series will provide quantitative information on the immediate, short-term, and longer-term effects of otter trawling in benthic marine environments.

Arctic

Geological and geophysical investigations in Hudson Strait and Ungava Bay were carried out in October and November, 1993 by GSC (Atlantic) in collaboration with researchers from Centre Géoscientifique du Quebec, Université de

CCGS Louis S. St. Laurent *at the North Pole*

Montreal, and University of Colorado. Cruise objectives were: delineation of the late Quaternary geology and history of the region, and acquisition of data relating to global climate change; and collection of gravity and magnetic field data in Ungava Bay.

BIO marine chemists participated in an expedition aboard the Russian research vessel *Geolog Fersman* in the Barents and Kara Seas. During this cruise, the vessel discovered a sunken vessel believed to hold radioactive waste containing in excess of 200 Curies of ‘Strontium-90 equivalent’ according to the so-called “White paper” released by the Russian Federation in early 1993. DFO scientists participated in this cruise as part of a series of survey activities being carried out in cooperation with Russian, Norwegian and US agencies. Sediment samples were collected over a wide area and returned to BIO for analysis for radionuclides.

The CCGS *Louis S. St. Laurent*, with five scientific staff from Scotia-Fundy Science on board, reached the North Pole at 1200 hours Atlantic time on 22 August, 1994. It battled through heavy ice over the Lomonosov Ridge at 88°51‘N, but finally made it to the pole. The *Louis S. St. Laurent* is the first Canadian ship to reach the North Pole and the event was celebrated with a High Arctic barbecue in addition to other ceremonies. DFO staff collected samples at the North Pole for the radionuclides Cesium-137, Plutonium, Iodine-129, Americium, and Strontium-90. Also at the North Pole they found Eurasian Basin water with a maximum temperature of 15°C which is 0.7° higher than in the Makarov Basin. A scientist collecting conductivity, temperature and depth (CTD) profiles several miles from the ship and traveling by helicopter discovered an uncharted Seamount near the Lomonosov Ridge.

BIO scientists completed a 1994 study on the summer distribution of sea ice meltwater and river run-off, and surface circulation, in Foxe Basin, Hudson Bay and Hudson Strait using the oxygen isotope method. It was found that the reduction of surface salinity in summer in Foxe Basin is predominately due to sea ice meltwater and that river run-off and sea ice meltwater contribute equally to the surface layer in northern Hudson Bay. Oxygen isotope data provided new information on the surface circulation in northern Hudson Bay and Foxe Basin.

Offshore and International

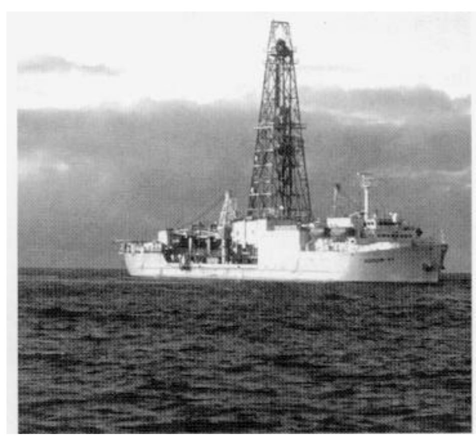
During 1994, GSC (Atlantic) scientist David Piper completed two months at sea as Co-Chief Scientist of Leg 155 of the Ocean Drilling Program. The drill ship *Joides Resolution* drilled 34 holes on the rapidly accumulating sediments 300-500 kilometres seaward of the mouth of the Amazon River. These provided, for the first time in an equatorial area, a record of ocean and continental climate change over the past 60,000 years with a resolution of about ten years. Until now, the only proxy climatic records of similar resolution have come from the Greenland ice sheet. Such records allow an assessment of the processes leading to rapid climatic change and will eventually improve our predictive capabilities for changes in climate on the scale of decades.

DFO scientists participated on a five-week autumn 1994 cruise to the Labrador Sea and the Irminger Sea on the German Research Vessel *Meteor. Meteor* was carrying out a fall occupation of WOCE repeat sections AR7W and AR7E across the Labrador and Irminger Seas from Labrador to Greenland to Ireland. BIO staff have been involved in occupying AR7W each spring since 1990; this fall occupation contributed to the better documentation of the winter transformations of water masses in this region.

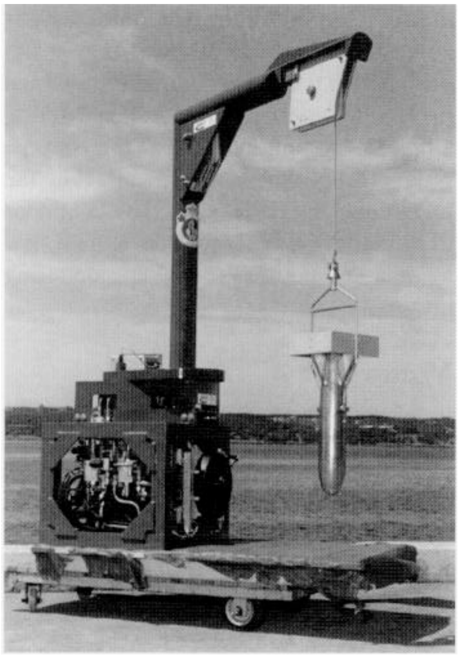
Biological oceanographers from BIO completed a three-week mission aboard CSS *Hudson* to the northwestern Atlantic during the summer of 1995. The mission’s primary objective was to map the broad-scale distribution of phytoplankton and zooplankton (and their physical-chemical environment): (1) on the Nova Scotian, Newfoundland and southern Labrador shelves; (2) in the Labrador Sea; and (3) in the open North Atlantic between Greenland and the Sargasso Sea.

Non-Site Specific

Software developed by the Canadian Hydrographic Service (CHS) is putting



The drill ship Joides Resolution



MV-CTD probe

Canada on the map in the field of information technology. CHS's Spatial Data Option (SDO), an extension of the Oracle database software, enables scientists to access and manage huge volumes of multi-dimensional data about a wide range of geographical subjects. Herman Varma, a CHS hydrographer at BIO, developed the ground-breaking technology. The software was then evaluated and implemented by a team at CHS in Ottawa. For the past several years the group has monitored the technology in a specialized testing laboratory set up by the Oracle Corporation in Hull, Quebec. The technology has gained international attention. CHS has met with interested hydrographic agencies, spatial data producers and users in related fields, such as genetics and the environment, from several countries. At least four leading GIS and desktop mapping suppliers have announced new products based on a close integration of SDO technology.

A further step in the development of a moving vessel conductivity/temperature/depth (MV-CTD) probe, was accomplished during the review period. The stability of the MV-CTD fish was tested from the swath *vessel, Frederick* G. *Creed,* for the high towing speeds expected on container ships. It was towed in the wake of the vessel at a speed of 22 knots without any signs of instability. This is a joint development project with a Dartmouth, NS company, Brooke Ocean Technology Ltd.

An experiment was undertaken to determine the effects of ambient temperature on cod egg development, hatching and larval yolk utilization. Temperatures ranged from 1°C to 8°C. A similar experiment was performed on haddock. The experiments were conducted at the St. Andrews Biological Station to investigate the potential aquaculture of these species, as well as for understanding their biology in the wild.

Tests were conducted by members of the St.Andrews Biological Station to determine the lethality of a pyrethrum formulation to larval stages of the American lobster. Pyrethrum is a group of naturally occurring compounds with high insecticidal activity, commonly referred to as pyrethrins. They are extracted from certain species of *chrysanthemum.* The formulation under investigation had been proposed as a treatment for sea lice infestations of farmed salmon.

The development of a moored instrumented platform for monitoring the concentration of particulate material around offshore petrochemical rigs continued during the review period. The platform includes sensors to monitor the concentration of bulk suspended particulates, a digital camera system to photograph flocculated material, as well as a current meter capable of measuring turbulence. The final platform will include a telemetry system to transmit its data either to a nearby rig or to shore via a satellite transmitter in a surface buoy.

In 1995, BIO scientists released an ocean data inventory system. This is an integrated software and database package that contains information on the current meter, thermograph and thermosalinograph holdings of Maritimes Region, DFO, from the waters of eastern Canada. The inventory contains information from over 4000 current meters and 2200 thermograph deployments. The package allows users to identify when and where moored time series information was collected and to display each record, as well as providing monthly statistics from these records.

Appointments

Staff were appointed to a variety of national and international memberships and positions during the review period, including the following:

- Mike Bewers, DFO at BIO, was appointed a member of the Joint Scientific and Technical Committee for the Global Ocean Observing System (GOOS).
- Allyn Clarke, DFO at BIO, was elected Vice-Chairman of the Joint Scientific Committee for the World Climate Research Programme (WCRP). He was also appointed a member of the Joint Scientific and Technical Committee for the Global Ocean Observing System (GOOS).
- Brian Nicholls, DFO at BIO, was appointed Chairperson of the Coastal Zone Canada Association at the first meeting of this new non-governmental organization.
- Mike Sinclair, DFO at BIO, was appointed Chairperson of the Scientific committee on Oceanic Research (SCOR) Working Group on the Impact of World Fisheries Harvests on the Stability and Diversity of Marine Ecosystems.
- Rob Stephenson, DFO at the St.Andrews Biological Station, was appointed Chairperson of the ICES Pelagic Fish Committee.

Conferences and Workshops

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

- Symposium on cod and environmental change-This special event was held at BIO in February, 1994 to review the situation of groundfish (with an emphasis on cod) in the waters of the east coast of Canada. The event was open to the public.
- Annual Meeting of the American Fisheries Society-The 124th Annual Meeting was held in Halifax in August, 1994. The Local Arrangements Chairperson was Peter Amiro of DFO's Diadromous

Minister of Fisheries Brian Tobin attending CZC'94

Fisheries Division. Over 1000 delegates attended this international event.

- Coastal Zone Canada '94 - This international conference was held in Halifax in September, 1994. The conference was co-chaired by Brian Nicholls, DFO at BIO, and Larry Hildebrand of Environment Canada. 750 delegates attended from over fifty countries.

- Workshop on Modeling the Environmental Interactions of Mariculture-This workshop, organized under the auspices of the ICES Working Group on Environmental Interactions of Mariculture, was held at BIO in 1995. Over 30 researchers from eight countries participated.

- Aquatic Toxicity Workshop - This annual national workshop, the 22nd in the series, was held in St. Andrews in October 1995, and was hosted by the St. Andrews Biological Station.

Partnering and Technology Transfer

Partnering and technology transfer events and highlights during the review period included the following:

- In June, 1995, the Canadian Hydrographic Service at BIO, along with several local agencies and businesses, participated in an "Ocean Information Technology Showcase." This event was held at the same time as the Halifax G-7 Summit meetings to promote Canada's competence in oceans-related technologies.

- The Geological Survey of Canada's marine program has improved its ocean and sea-floor mapping capability using digital techniques. A key factor has been the development of a new digital data logging system in collaboration with the private sector. GSC Atlantic contracted MUSE Research, an electronics company in Ontario, to build a shipboard acquisition and laboratory processing system which would serve GSC mapping missions for coastal and offshore resource and environmental applications. This project is one example of successful GSC technology partnering with the Canadian marine industry, which has resulted in commercial competitive systems such as AGCNAV (Xon Digital Communications Ltd.); ocean vibracorer (Brooke Ocean Technology Ltd.); Arktos coastal survey vehicles (Watercraft Offshore Canada Ltd.); and swath mapping data correction (Applied Analytics Ltd.).

- In 1995, Focal Technologies Inc., Dartmouth, NS announced that sales of its optical plankton counter (OPC) surpassed the $1 million mark. The OPC, an instrument used to monitor and assess zooplankton in east coast waters, was developed by DFO at BIO during 1985-89 and the technology transferred to Focal during 1989-90. Among other optical-electronic products, Focal currently manufacture the OPC under DFO license. BIO continues to partner with Focal on co-developing new technology required for DFO monitoring program needs.

Visitors

As in previous years, the regional establishments received many special visitors from Canada and abroad. Of particular interest were the visits by the following:

- April 28, 1994 - Vice-Admiral Jose Sarmento Gouveia, Portuguese Hydrographer, visited BIO.

- August 12, 1994 - Joint Government/Industry fish disease delegation from Australia visited the Halifax Fisheries Research Laboratory.

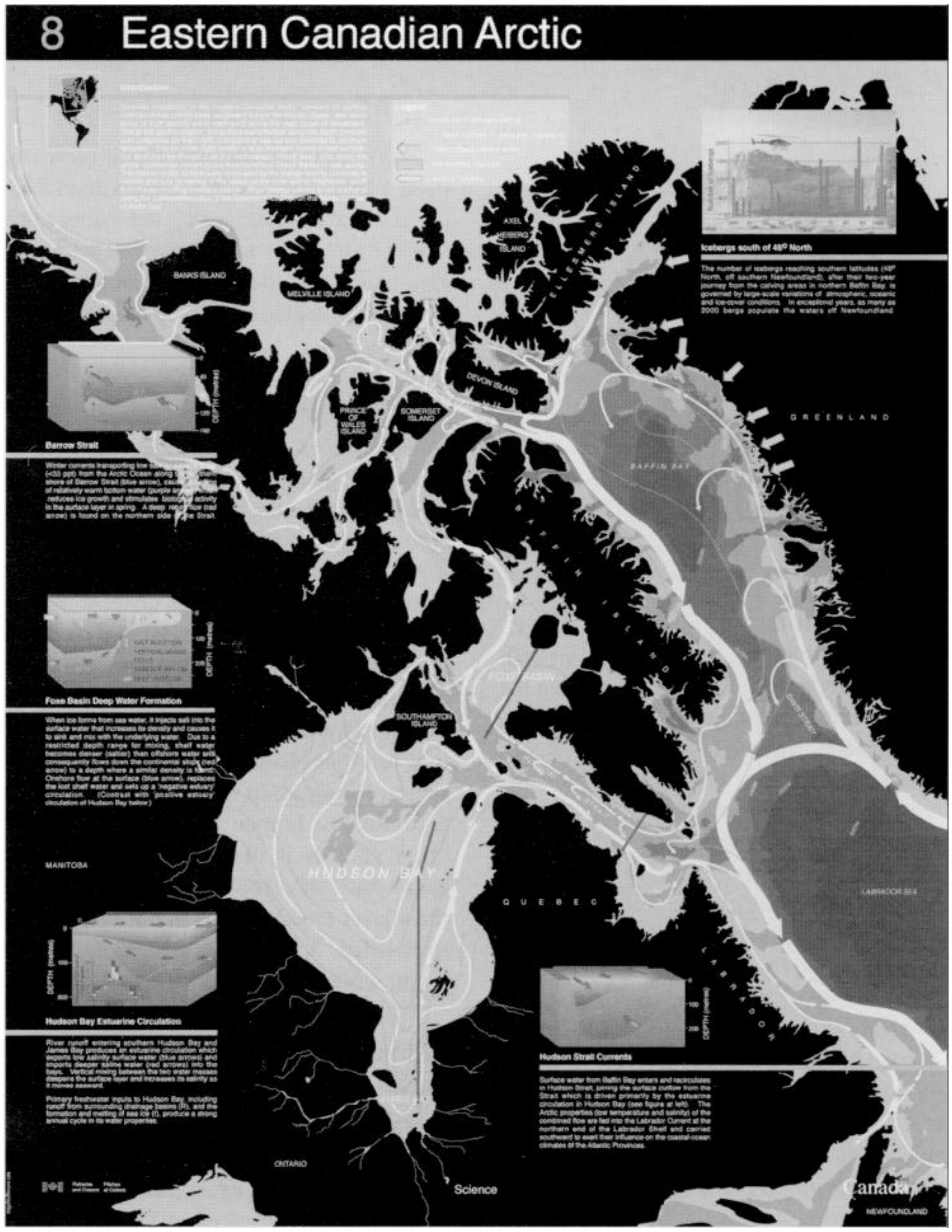
- August 15, 1994 -Delegation of Cuban fisheries scientists visited the St. Andrews Biological Station.

- August 22, 1994 - Dr. Stan Dromisky, M.P., visited BIO for discussions on the Canadian Environmental Protection Act (CEPA).

- October 24, 1994 - Dr. Max M. Tilzer, Director, Alfred Wegener Institute for Polar and Northern Research, Bremerhaven, Germany, visited BIO.

- November 15, 1994 - Rear-Admiral Gamett, Commander of Maritime Forces Atlantic, visited BIO.

Ocean Information Technology Showcase



- May 19, 1995 - A party of 13 fisheries scientists from Indonesian universities and other institutes visited BIO.

- June 17, 1995 - Mrs.Yeltsin (wife of the President of Russia) paid a private visit to BIO during the G7 Summit Meetings in Halifax, June 14-17.

- October 4, 1995 - Mr. Arnoldo Macaya, former president of the Chilean Salmon and Trout Growers' Association, visited the St. Andrews Biological Station

- November 3, 1995 - Prof. T.J. Lam, Department of Zoology, National University of Singapore, visited BIO.

Facilities and Support Services

The decision was taken during the reporting period to close down the Halifax Fisheries Research Laboratory facilities and to transfer the staff to the Bedford Institute of Oceanography, the Gulf Fisheries Centre, and the St. Andrews Biological Station. As at December 31, 1995, planning was actively proceeding towards this end. This decision was taken in order to consolidate Regional research programs at a smaller number of sites and because the facilities at the Halifax Fisheries Research Laboratory are in need of urgent and major renovation. As a cost-cutting measure, the decision was taken to work towards the gradual devolution of DFO's salmon hatcheries to external organizations and private industry. These hatcheries are part of the DFO Maritimes Region Science organization.

Publications

The establishments reach their respective clients and customers through a variety of means, including journal articles, reports and nautical charts. During 1994 and 1995, the published output of the establishments continued at a high level. Full details are provided in the Appendix of this Review entitled "Charts and Publications." Selected highlights are noted below:

Oceanographic Wall Chart #8 covering the Eastern Canadian Arctic, was published in March 1994. The chart illustrates both the surface circulation and salinity fields, as well as regions of permanent ice cover and iceberg calving areas along the west coast of Greenland. Inset schematic diagrams depict important physical processes of the region. The chart was produced in English, French and three native dialects (Cree, Northern Quebec and Eastern Arctic Inuktitut).

A monograph on dinoflagellates coauthored by a team of geologists and biologists from government, industry and academia, led by Dr. Robert Fensome of GSC Atlantic at BIO, was awarded the Paleontological Society's 1995 Golden Trilobite Award in recognition of excellence in a paleontological publication.

Histology of the Atlantic Cod: The Atlas Series

C.M. Morrison

C. M. Morrison

Introduction

A series of four atlases has been produced. Originally atlases on supporting tissues (muscle, cartilage and bone), the urinary system, the brain and sensory organs and the circulatory system were planned, but these were not completed because of lack of funding and change in priorities. The first atlas was published in 1987, when cod was one of the most economically important fish in Canada (in 1985 the landed volume of cod for the east coast of Canada was 478,000 metric tonnes, having a value of $187,000,000). Much effort had been expended on assessment of stocks of eggs, larval, juvenile and adult cod; but few histological studies had been done. The atlas series was started to provide a basic histology of the cod, so that the effects of factors such as disease, parasites, and pollutants could be properly evaluated. Given the slow return of the cod stocks, this baseline knowledge is also important to determine factors affecting the remaining cod. It was expected that the atlases could be used as a point of reference for similar tissues in other finfish species, and these atlases were aimed at scientists and veterinarians, technicians, hatchery managers and students specializing in finfish. Requests for the atlases have been received from veterinarians and scientists working on fish in this country and abroad; permission has been requested to photocopy parts of the atlases for teaching purposes at veterinary colleges; they have been used in presentations to fishermen on the reproductive stages of fish.

Work done for the cod larval atlas has been a basis for research on larvae of species of marine finfish that are being considered for use in aquaculture. These species include haddock, which is similar in its development to cod, winter flounder and halibut.

The Atlases

The atlases are illustrated with figures showing gross morphology and light microscopy in both color and black and white, and ultrastructural features are illustrated using both scanning and transmission electron micrographs. This enables microscopic structure to be correlated with gross structure and function. Common parasites are illustrated. Existing atlases of fish histology use mainly light microscopy, but it was felt that electron microscopy was essential for an up-to-date description, as in textbooks of human histology. Work by other authors is discussed, and in many cases study of complete organ systems for the atlases enabled gaps in our knowledge to be filled. A detailed bibliography of pertinent work is included with each atlas.

Atlas 1: Digestive Tract (Morrison 1987)

The first atlas describes the digestive tract and the organs associated with it; the gallbladder, liver, pancreas and swimbladder. During research for both this atlas and the second, "spines" were found

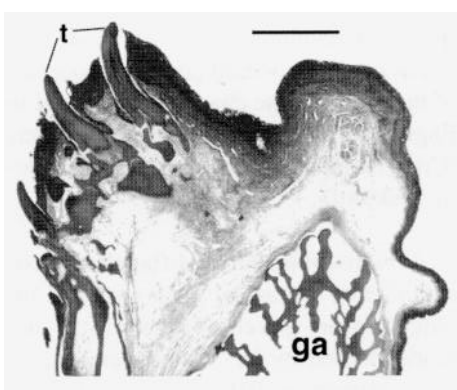


Figure I: Projections on gill arch (ga), with teeth (t). Light micrograph of paraffin section stained with haematoxylin and eosin. Bar = 500, µm.

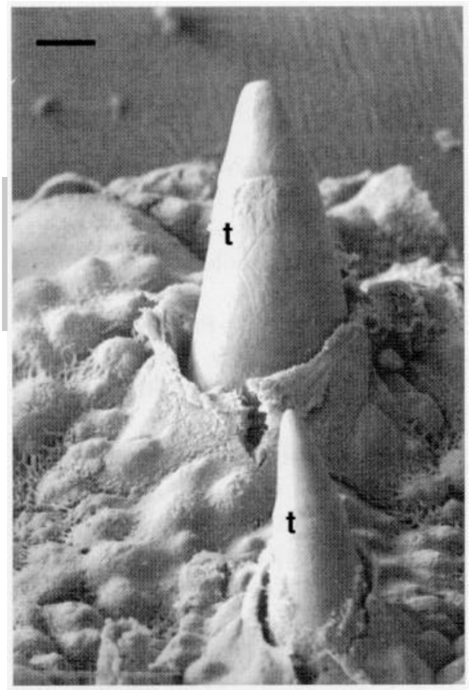


Figure 2: Teeth (t) on lower pharyngeal tooth plate. Scanning electron micrograph. Bar = 200 µm.

on the gill arches. These have been described in several species of fish using scanning electron microscopy. After sectioning it was realized that these are in fact teeth (Fig. l), which form a complete circle with those on the pharyngeal tooth plates (Fig. 2). This is of functional significance when it is considered that cod ingest live prey, which must be restrained until swallowed. In the rectum we found small parasites - probably amoebas- and bacteria attached to the epithelial surface. We also discovered flagellates (Fig. 3), found on further study to be a new species, *Spironucleus torosus* (Poynton and Morrison 1990). This species has a parasitic phase in which it is attached to the surface of the epithelial cells. The cod differs from salmonids since it is normal for the liver to contain a great deal of lipid except in the spring, when spawning. The cod is also unusual because most of the endocrine tissue of the pancreas is concentrated in a "principal islet" on the gallbladder. Attempts have been made to use this islet as a source of insulin. The coccidian protozoan parasite *Goussia gadi,* which had been reported in cod

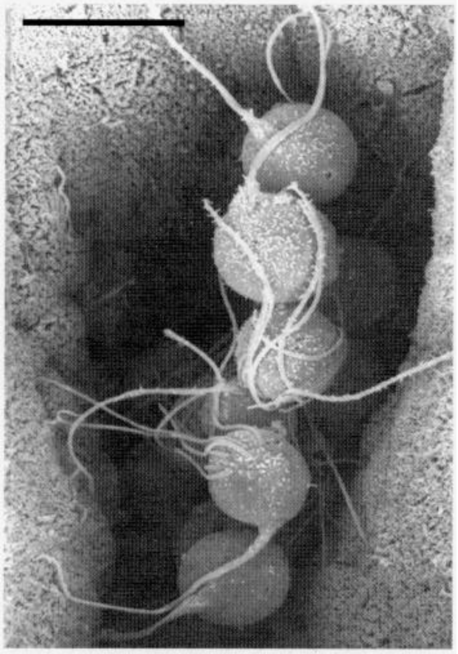


Figure 3: *Flagellates in the rectum. Scanning electron micrograph. Bar = 5 µm.*

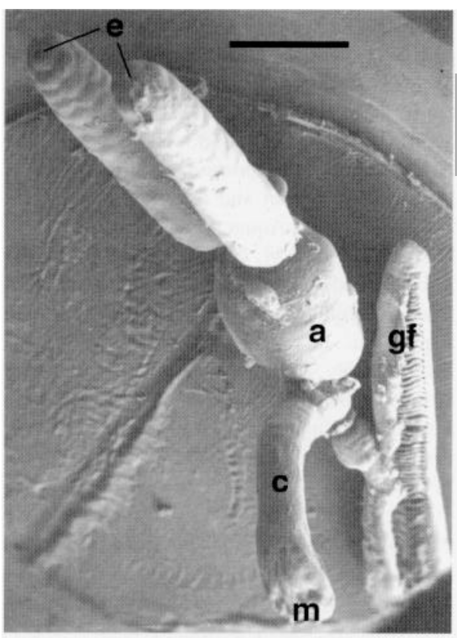


Figure 4: The copepod Clavella adunca *on a gill filament (gf). Scanning electron micrograph. Mouth, m; cephalothorax, c; abdomen, a; egg sacs, e. Bar = 1mm.*

swimbladders in Europe (Fiebiger 1913) was not present in the cod studied for the atlas, but has been found in further studies (Morrison and Marryatt 1990). This parasite can cause the swimbladder to be filled with pus, and may affect the ability of the host to control its buoyancy (Odense and Logan 1976).

Atlas 2: Respiratory System (Morrison 1988)

The second atlas shows the structure of the gills and also the pseudobranch. Dr. R. Boutilier of Dalhousie University injected a cod with methyl methacrylate for this atlas. This resin polymerised in the blood vessels of the gills and the tissues were then removed, leaving a "corrosion cast" of the blood vessels (Fig. 5). Cysts of the microsporidian parasite *Loma branchialis* (Morrison and Sprague 1981) and the copepods *Lernaeocera branchialis* and *Clavella adunca* (Fig. 4) were commonly found on the gills. *L. branchialis* is usually near the base of the gills, and in many cases penetrates the blood system and sometimes the heart, producing loss in body weight (Khan *et al.* 1986). The enigmatic "nodule of unknown etiology" (MacLean *et al.* 1986) was also found in many gill filaments. This has been described in other species of fish, but its etiology is unknown.

The pseudobranch possesses lamellae like the gills, but they are fused and covered by connective tissue. The pseudobranch receives oxygenated blood and has no respiratory function. It consists of specialised cells with closely packed mitochondria and numerous smooth tubules, and it has been suggested that it may have an endocrine function. Removal of the pseudobranch causes darkening of the fish, so it appears to control the chromatophores; removal also reduces the ability of the swimbladder to secrete gas. Nodules of *Loma branchialis* were found in some pseudobranchs, and "pseudobranch tumors" were found in some cod (Morrison *et al.* 1982). The tumors consisted of rounded cells with a round nucleus and prominent nucleolus, which are believed to be protozoan parasites.

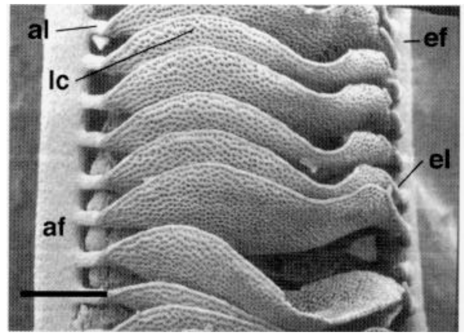


Figure 5: Corrosion cast of blood vessels of gill filament. Scanning electron micrograph. Afferent filament artery, af; efferent filament artery, ef; afferent lamellar arteriole, al; lamellar capillary sheet, lc; efferent lamellar arteriole, el. Bar = 100 µm.

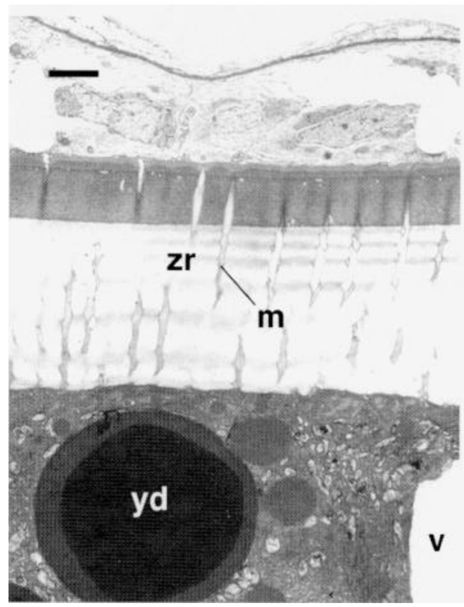


Figure 6: Periphery of developing oöcyte. Transmission electron micrograph. Zona radiata, zr; microvilli in pores in the zona radiata, m; vesicle, v; yolk droplet, yd. Bar = 2 µm.

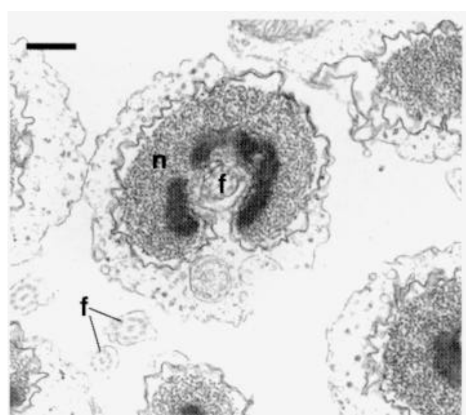


Figure 7: Maturing spermatozoa. Transmission electron micrograph. Nucleus, n; cross-section of flagellum, f. Bar = 500 nm.

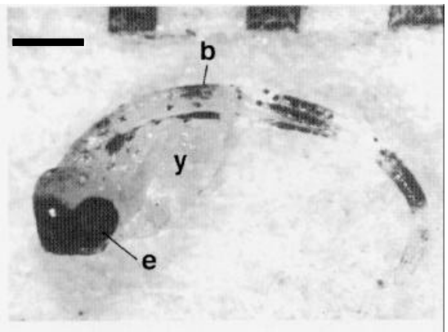


Figure 8: Peak-hatch cod larva. Bar of pigment on body, b; eye, e; yolk-sac, y. Bar = 0.5mm.

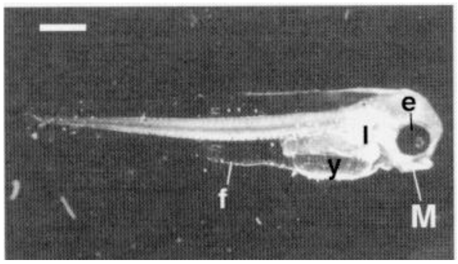


Figure 9. Three day post-hatch cod larva, dark-field. Eye, e; Meckel's cartilage, M; liver, l; yolk-sac, y; fin-fold, f. Bar = 500 µm.

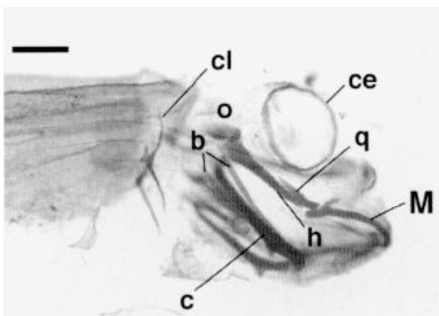


Figure 10: Nine day post-hatch larva stained for cartilage and bone. Cartilage around eye, ce; otic capsule, o; Meckel's cartilage, M; hyosymplecticum, h; quadrate, q; ceratohyal, c; branchial arch, b; cleithrum of pectoral girdle, cl. Bar = 500 µm.

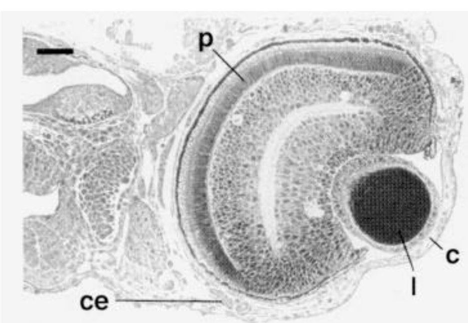


Figure 11: Section through the eye of a peak-hatch larva. Larva embedded in JB4 resin, sectioned at 1mm and stained with toluidine blue. Lens of eye, l; photoreceptors of retina, p; cornea, c; ring of cartilage around eye, ce. Bar = 50 µm.

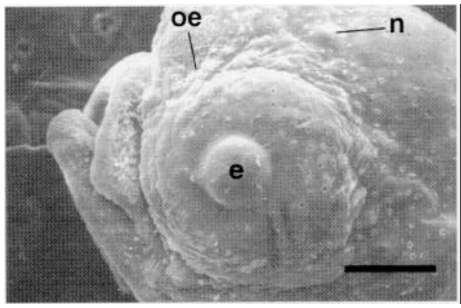


Figure 12: Head of 2 day port-hatch larva. Scanning electron micrograph. Eye, e; neuromast, n; olfactory epithelium, oe. Bar = 100 µm.

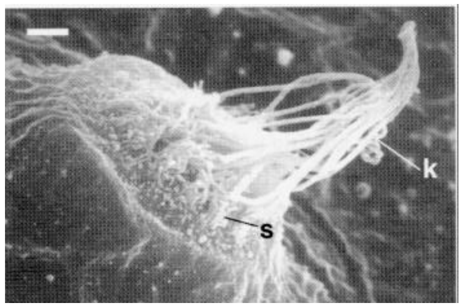


Figure 13: Neurormast on head of 44 day. post-hatch larva. Scanning electron micrograph. Kinocilium, k; stereovillus, s. Bar = 2 µm.

Atlas 3: Reproductive System (Morrison 1990)

The gross appearance and histology of the various stages of maturity are illustrated in color and black and white, and the ultrastructure of the development of the oöcytes and spermatozoa is also illustrated (Fig. 6 and 7). Problems of staging, such as differentiating between a virgin and resting fish, are discussed, and a Table describing the stages is presented. The only abnormalities found in studies for the atlas were cysts of *Loma branchialis,* which spreads throughout the organs of some cod (Morrison 1983). We have since found *Ichthyophonus hoferi,* which is believed to be a fungus, in some cod gonads.

Atlas 4: Histology of the Cod Larva (Morrison 1993)

The last atlas, on the histology of the cod larva is the largest and most ambitious. The organ systems are described at several stages of development, in as much detail as possible. Larvae grown at St. Andrews Biological Station by Dr. Neilson provided the samples for this atlas. The pigmentation (Fig. 8) and gross morphology (Fig. 9) are shown, and a cartilage and bone stain modified from that used on larger animals was employed to reveal the developing skeleton (Fig. 10). Histological techniques were used to show the structure of the organs (Fig. 11). The surface of the larva was studied using scanning electron microscopy at both low magnifications (Fig. 12), and at higher magnifications to show details of such features as the neuromasts (Fig. 13). Transmission electron microscopy was used to study internal ultrastructure (Fig. 14).

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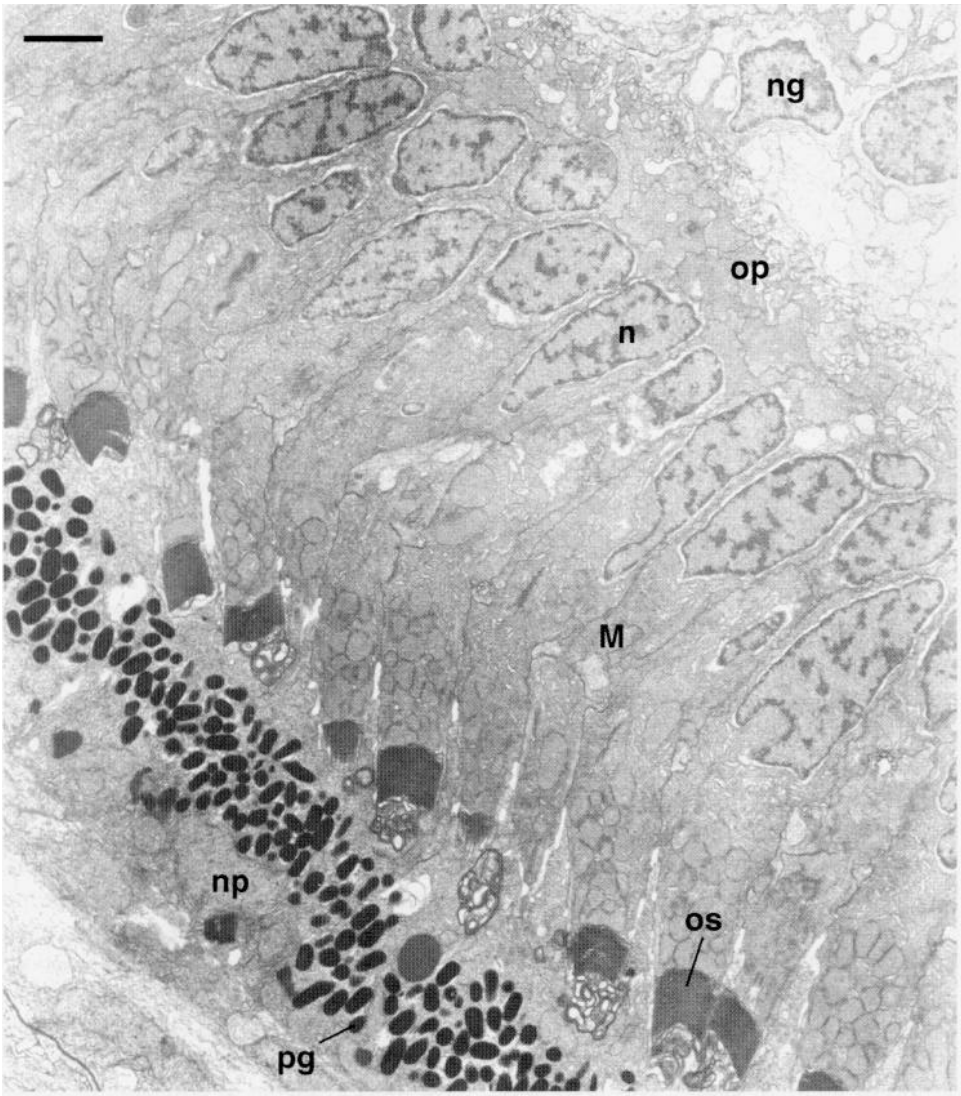

Figure 14: Photoreceptors of eye of 1 day post-hatch larva. Transmission electron micrograph. Nucleus of photoreceptor, n; outer segment of photoreceptor, os; nucleus of pigment cell, np; pigment granule, pg; cell of Müller, M; outer plexiform layer, op; nucleus of ganglion cell, ng. Bar = 2 µm.

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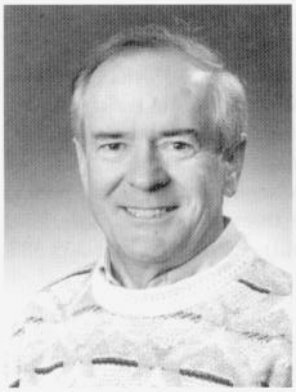
Upper Ocean Profiling from Vessels While Underway

J.-G. Dessureault and R.A. Clarke



J.-G. Dessureault

R.A. Clarke

Background

For more than a century. sub-surface information has been collected using oceanographic vessels. These vessels steam somewhat slower than a commuter on a bicycle, and when they also occupy oceanographic stations their average speed is reduced to that of a pedestrian. It is little wonder that oceanographers can be said to have never conducted a program in which they have oversampled the phenomena being studied.

Oceanographers have recognized the limitations of their vessels and tools for a number of years. In 1937, Spilhaus developed the bathythermograph which could provide a temperature profile to 275 m. Naval vessels are said to have taken bathythermograph casts at speeds exceeding 25 knots, but probably at some risk. In the late 50's and early 60's, engineers began to design and build electronic instrumentation for oceanographic observations. Instruments to measure the upper ocean temperature field were among the first to be useful. Three different classes of instruments were developed.

The towed thermistor chain consisted of a large number of thermistors spaced along a cable towed astern of a vessel at speeds of a few knots. The bottom of the cable was held at some fixed depth by a weight or depressor and the instrument provided Temperature (T) versus time (distance) data at a number of fixed depths. These temperature chains were used to study internal waves in the upper 100 m but soon fell out of use. Because each thermistor was connected to a separate conductor leading back to the ship and the recording equipment, these systems were difficult to maintain and calibrate. However, they provided the high horizontal spatial resolution needed for investigations of internal wave phenomena.

The Bedford Institute of Oceanography (BIO) developed one of the first towed profiling bodies to be marketed, BATFISH (Dessureault, 1976). This is capable of profiling the upper 400 m of the water column at speeds up to 10 knots. This body was first equipped with a Conductivity, Temperature, Depth (CTD) package but the sensor suite has expanded over the years to include fluorometer, particle counter, light meter and dissolved oxygen meter. These bodies are towed using hard faired cables to minimize cable drag; this requires large specialized winches and sheave blocks and restricts their use to research vessels. The slope of the profiles are generally less than one to four; hence these systems can observe horizontal scales down to a few kilometres and are most useful in studies of fronts, jets and eddies as well as biological patchiness and interactions between the physical environment, phytoplanktons and zooplanktons.

Finally there are the expendable probes which can be deployed from both ships and aircrafts. Probes are now available to measure temperature, temperature and conductivity, sound speed and velocity profiles to depths of 1500 m. Millions of Expendable Bathy Thermograph (XBT) profiles have provided the basis for what we know about the global climatology of the heat content of the upper ocean. XBT's deployed from merchant vessels remain one of the principal tools available to designers of ocean

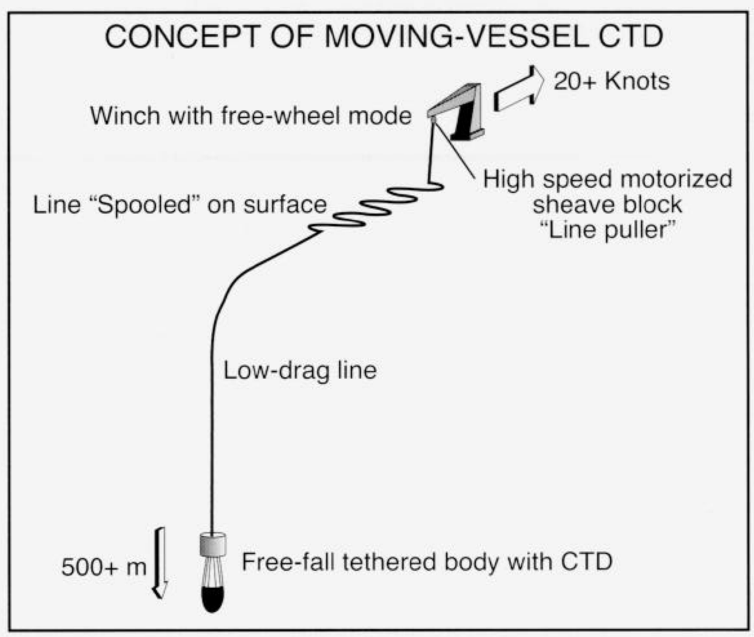


Figure I: Concept of the Moving Vessel CTD system climate observing programs such as Tropical Ocean Global Atmosphere (TOGA), World Ocean Circulation Experiment (WOCE) and their successor Climate Variability and Predictability (CLIVAR).

Temperature data alone are not always sufficient to describe variability in the upper and intermediate layers of the ocean. Density is a function of both temperature and salinity. Changes in the fresh water budget in the northern parts of the North Atlantic are thought to modulate the strength of late winter convection and hence the vertical circulation of the Atlantic and even of the global ocean. The delays in the development of accurate, affordable and reliable expendable CTD (XCTD) probes frustrated WOCE and TOGA planners who had written such probes into their planning documents.

Development at BIO

The development at BIO of an underway profiling system was prompted by the desire to provide an alternative to XCTD technology. Conceptually, this new system is like a bathythermograph (Fig. 1). The differences are that the body is heavier and tear-drop shaped, the mechanical sensing and recording elements are replaced by a modern small, robust and self contained CTD unit and the line is paid out fast enough to be loose on the water. It is being called Moving Vessel CTD (MV-CTD).

The bathythermograph was restricted to depths of 215 m or less. We wished to develop a system that could obtain profiles to depths of up to 1500 m or deeper and that could be deployed from vessels with cruising speeds up to 22-25 knots. The system is being designed for unattended operation on merchant vessels. It will be a computer controlled system where the deployment and recovery of the probe will be initiated by a single command issued by the officer-of-the-watch on the bridge.

The present prototype system consists of a tethered free-fall underwater body with a drogue, a CTD, a tether line, a line puller, a docking chute, a winch and a computer with control software.

The underwater body (Fig. 2) is a tear-drop shaped brass casting with a stabiliz-

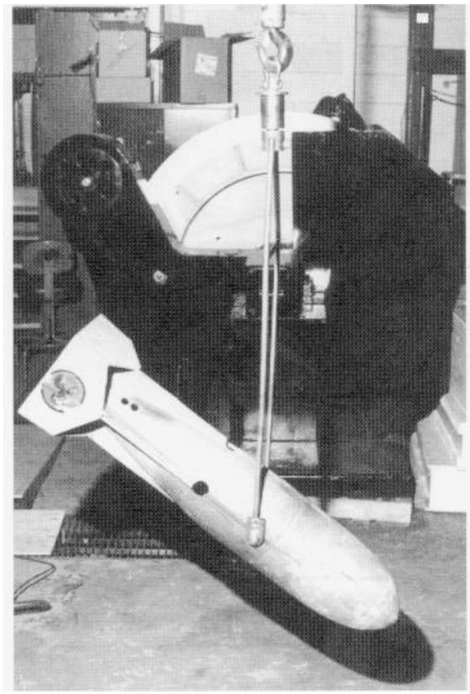


Figure 2: The underwater body and the winch in the background.

ing tail shroud. It is one metre long, weighs 80 kg and is suspended by a bridle pivoted slightly behind its centre of gravity. The bridle is designed so that the body both descends and ascends through the water column nose first. The body towed in this fashion is very stable; even as it approaches the vessel through the turbulence of the propellers. The stabilizing tail shroud serves the additional function of protecting the CTD sensors on recovery of the body. In order to stop the fish from swinging into the stem of the vessel as it is lifted out of water, a drogue line is attached to the bridle. On the prototype system, the drogue line is deployed and recovered by hand. During underway operations, it is hoped that the ship's master will consent to leaving the drogue line in the water between casts. The drogue would be deployed by the crew on reaching the open sea and recovered at the end of the voyage as the vessel approaches its final destination.

A Falmouth Scientific, Inc. Micro-CTD was selected as the sensor package because of its size, accuracy and robustness. Its inductive conductivity sensor should be more stable than a four electrode sensor in an operational environment in which the sensor is neither cleaned nor kept filled with distilled water between profiles. The CTD is controlled by aTattletale- computer that, together with a battery pack and radio modem, is contained in a separate pressure case within the underwater unit. The Tattletale computer communicates with a computer on board the vessel through a radio modem when the fish is in its cradle. At the beginning of a cast, the Tattletale turns on the CTD for an eight minute period and receives and stores the CTD data. On recovery, and in response to a command via the radio modem, the Tattletale downloads the data to the shipboard computer and then goes into a sleep mode. The Tattletale computer's sleep mode allows the battery pack to supply sufficient power for nearly one thousand profiles over periods of weeks. This means that the pressure case does not need to be opened to replace the batteries during a normal field expedition.

The line puller "pulls" the line from the free-wheeling drum at a controlled speed and feeds it onto the water. It consists of two 30-cm diameter pinch rollers, one of which is hydraulically powered. The line puller is mounted on an axis which runs athwart ship, thus it is able to pivot so that the plane of the unit remains parallel to the line as it leads aft of the vessel during recovery. The line puller needs to be capable of paying out line at high speed. Deployments from a 22 knot vessel require pay-out rates of more than 17 m s-l.

Because the line is "pushed" onto the turbulent water by the high speed line puller, it must be supple so that it does not kink easily. The highest tension in the line arise when the recovery operation begins. The momentum of the body and of the line have to be absorbed and then the recovery winch speed added to the vessel speed produce a tangential drag on the line which can easily reach its working strength. Therefore, the line needs to have a high strength versus diameter ratio and a low tangential drag coefficient. The low tangential drag minimizes the slowing of the descent speed of the body and reduces the tension during recovery.

The tangential drag on a cable is much less than its transverse drag, hence, a streamline body with a high terminal velocity will tend to pull its cable along the surface of the ocean and then vertically behind it as it falls. The water acts as a

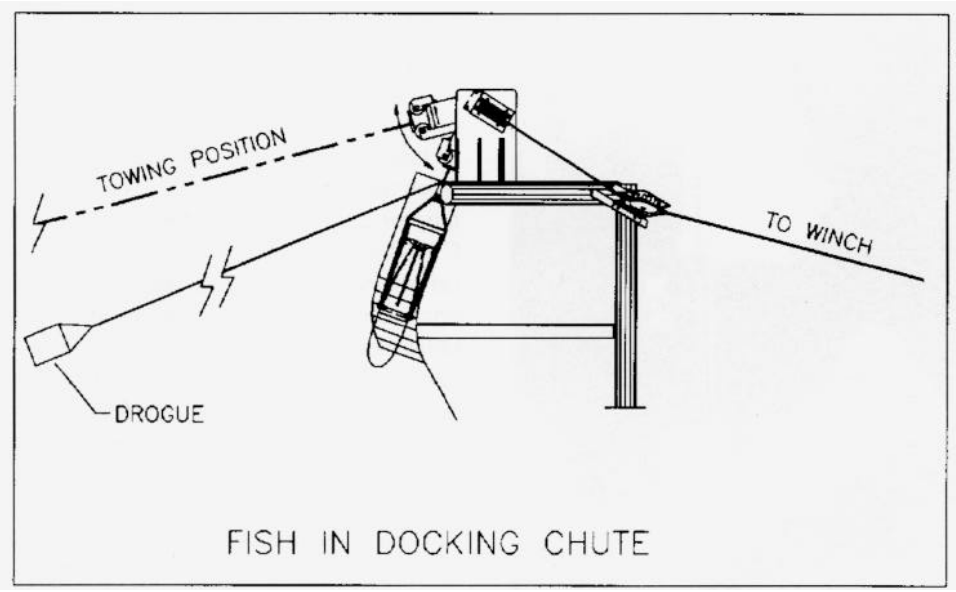


Figure 3: Side view of the davit, line puller and docking chute.

virtual sheave at the point of entry in the water of the body. This process is helped if the winch and cable handling system is able to pay the cable onto the sea surface at a speed greater or equal to the sum of the ship's speed plus the fish's drop rate. The same phenomena means that when the system stops paying out and starts winching in the cable, the fish will rise vertically towards the sea surface with a vertical velocity that is nearly equal to the ship's speed plus the winch's speed. Hence such a system will provide both down and up profiles close to the location at which the probe was released.

Early in the design of this system, we decided not to use electromechanical cable because we were concerned about its reliability in unattended operations. We saw three possible areas of concern. First was the area where the cable enters the fish since the fish needs to rotate at least 180 degrees about its pivot point. Second was the reliability of the electrical conductors in a cable that was being deployed under no tension and then suddenly recovered at its full working load. Third was the potential requirement for an electromechanical swivel at the fish. In the series of tests to date, we have used 8-mm diameter braided aramid fibre cable with a rated breaking strength of 36 kN. For higher speed operations and a greater safety margin, we will change to a larger (11 mm) diameter line and eventually will require a smooth urethane jacket which has a lower tangential drag coefficient.

An electromechanical cable is necessary in operations which require the data in real time. Brooke Ocean Technology Ltd. is currently designing a modified system using electromechanical cable to obtain sound velocity profiles for use with multi-beam sounding systems. This system is being designed for use to a depth of 100 m at a speed of 10 knots.

The davit and docking chute (Fig. 3) was an integrated unit that had been designed to simplify installation on various vessels. The davit is attached to the vessel through a single base plate with some braces to the rail. Attached to the davit are two sheaves which route the cable from the winch to the line puller mounted directly above the docking chute. These sheaves allow the winch to be placed in a variety of different positions relative to the docking chute and hence permit the system to be adapted to different vessel layouts. The chute is a metal cradle whose curved and flared outboard end extends beyond and below the top of the ship's after bulwark. Between profiles, the underwater body lays in the chute without the necessity of lashing or clamping.

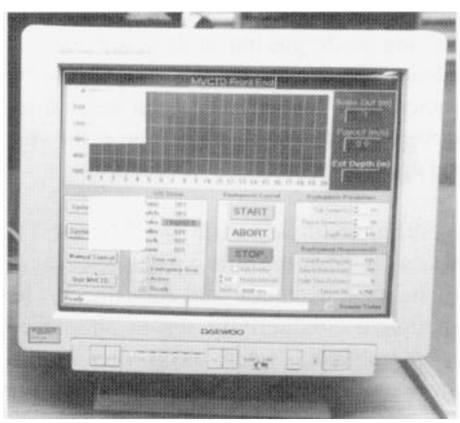


Figure 4: Control computer screen.

The winch drum diameter is large (1 m) to reduce the number of layers of cable, hence reducing the crushing pressure and simplifying the spooling. The winch can hold 3000 m of line and can recover the fish at 1.4 m s^{-1} with a pull of 14 kN. The present winch is driven by an electric motor; the next model will be driven by an hydraulic motor, sharing the hydraulic power unit with the line puller. This modification will permit faster recovery speeds. Presently the fish reaches 600 m in 160 s; the recovery of the line and fish then takes 15 min.

The shipboard computer turns on the CTD through the modem radio link, controls the winch and line puller for the deployment and recovery operation, recovers the CTD data and puts the underwater unit into sleep mode between profiles. The software runs on an Intel 486, 33 MHz computer under Windows 3.1.

The computer program evaluates a mathematical model that describes the forces on the underwater body and the line during all stages of deployment and start of recovery. A typical screen is shown in Figure 4. The user enters the vessel speed, the winch speed and the target profile depth. The program computes the length of line that needs to be paid out to achieve the target depth. At higher vessel speeds, the length of line will be limited by the maximum tension that occurs when recovery of the fish begins. The program computes this tension based on the drag coefficient. the diameter and the length of the line paid out and the ship speed.

With the current version of the software, the operator needs to enter a separate program in order to wake up the computer in

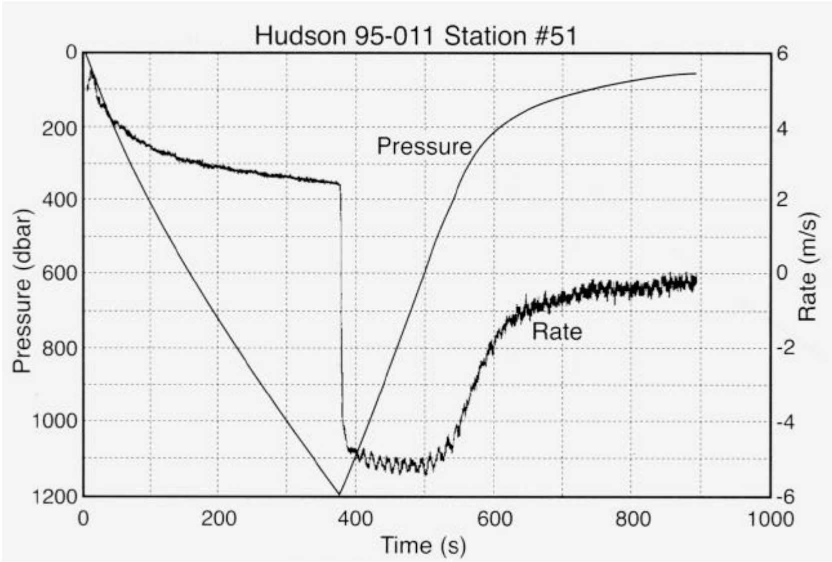


Figure 5: Depth and Rate versus Time for a cast to 1200 m at 10 knots (CSS Hudson, *June 1995).*

the sea unit and start the CTD. Then, returning to the winch control program, a single start switch starts the entire deployment and recovery cycle of the winch and line puller. The operator can terminate a profile at any time by activating an emergency stop button on the computer screen. This stops the line puller or the winch and applies the brake to the winch. An emergency stop switch mounted on the hydraulic power unit by the winch accomplishes the same action.

Ultimately, we see a software package that would reside in a computer on the bridge of a volunteer-observing-vessel. This computer would be interfaced into the vessel navigation system and hence know the vessel speed through the water. It might even know when profiles are to be taken and simply ask the officer of the watch whether it is okay to take a profile at this particular time. The shipboard computer would then carry out the entire operation including the creation and transmission of a Temperature/Salinity Code (TESAC) message describing the temperature/salinity profile.

At Sea Results

The prototype system was used on two WOCE cruises (Oct./Nov. 1994, Jun./Jul. 1995) in the Newfoundland Basin of the Northwest Atlantic on CSS *Hudson.* The system had undergone engineering trials on two previous cruises on CSS *Parizeau.* During the course of the October cruise, seventeen CTD profiles were obtained using the system at ship speeds ranging from 7.8 to 13 knots (Fig. 5). The system performed well; however, it was not sufficiently mature to allow the regular watchkeeper access to its control software. We were pleased that neither the chief officer and the bosun expressed concern about the stem plates of CSS *Hudson* and in fact admired both the design and the execution.

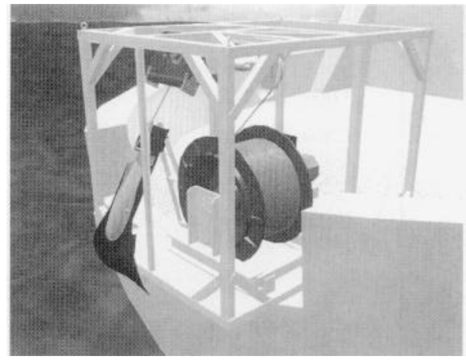


Figure 7: Computer-rendered view of the second generation MV-CTD deck unit.

We had concerns that the conductivity sensor would be affected by being mounted within a fish constructed of brass and in close proximity to the aluminum tail shroud protector. This was tested by suspending the fish containing the CTD and its associated electronics 1.3 m beneath our Seabird deep sea CTD system and taking two profiles to 600 m. The salinity profiles obtained by the fish with the FSI CTD where only different by an offset of 0.06 Practical Salinity Unit (PSU).

During tests in November 1994, it was discovered that under reduced vessel speed (and rough sea) conditions. it was necessary to reduce the line pay-out rate to avoid line tangles. As a result, speed control will be built into future versions of the control software. This is an important feature because we observed that we could continue to collect profiles with this system when the vessel was hove to due to weather conditions.

In June 1995. a longer cable (3000 m) was used and three casts at ten knots reached 1100-1200 m (Fig. 6). On the forth cast, the line parted and the fish was lost early in the cruise. A stronger line and a shock absorber will be used to prevent reoccurrence.

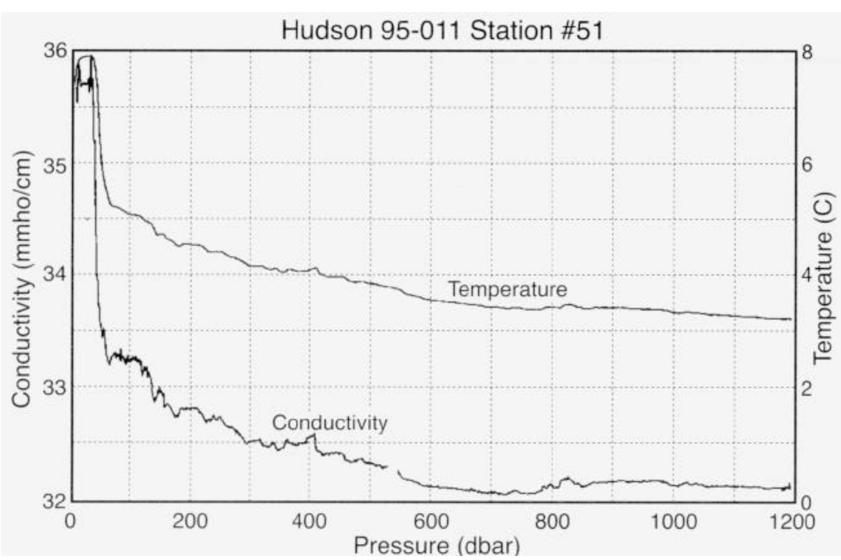


Figure 6: MV-CTD cast to 1200 m obtained at vessel speed of 10 knots shouing Temperature and Conductivity versus Pressure.

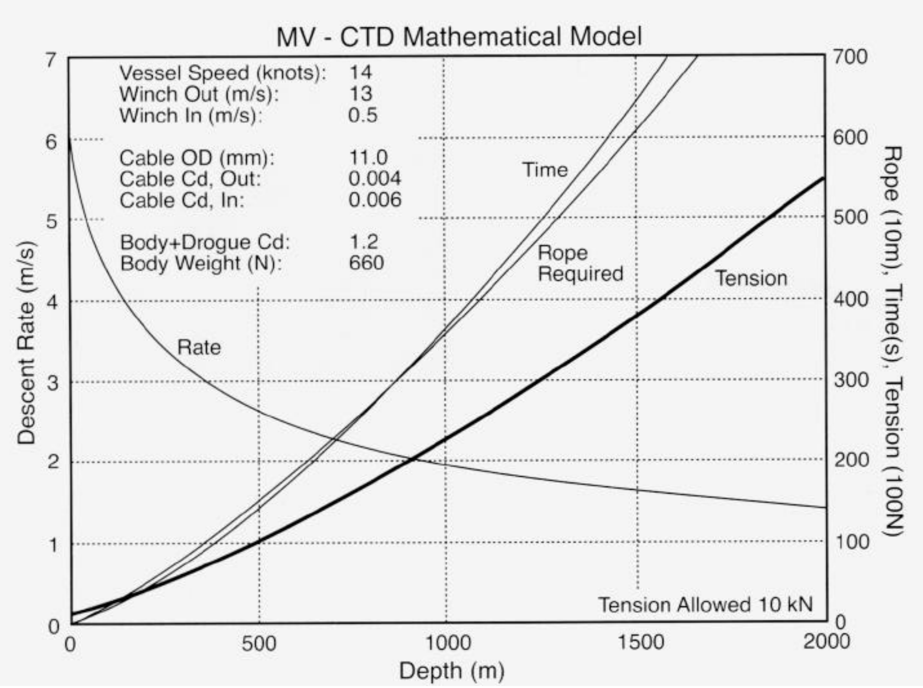


Figure 8: Predicted perforrnance at 14 knots. A cast to 500 m will require 1600 m of line which will result in a line tension of 10.5 kN at the beginning of the recovery.

Second Generation

The design of the second generation system is underway. A computer generated representation is shown in Figure 8. All the components are integrated in a single frame which will simplify the transportation and installation on all ships. The width and height are such that it will fit inside a standard container for shipping. In order to accommodate the short distance between the winch and the line puller, the winch is moved back and forth on tracks in synchronism with the line being spooled on the drum.

The new line will be an electromechanical cable capable of transmitting the data from the CTD as it is being collected. This benefit and the elimination of the radio modem and batteries justify the extra cost of the cable. A mathematical model shows (Fig. 7) that at 14 knots, a cast to 500 m is possible with a maximum tension in the line of 10 kN.

In future years, this system will be used on our vessels to obtain upper ocean data as they travel to and from working areas in the course of a wide variety of research programs.

Acknowledgments

This project was funded through Canada's Green Plan climate change project. B. D. Beanlands, E. F. Phillips and N. Rice have been responsible for the design and development of the computer control and data handling aspects of the system. Brooke Ocean Technology Ltd. was contracted for the detail design and construction of the winch and line puller. Omnitech Electronics Inc. has contributed to the design of the controller. The enthusiasm and support of our colleagues, particularly during some of the initial discarded attempts, is greatly appreciated.

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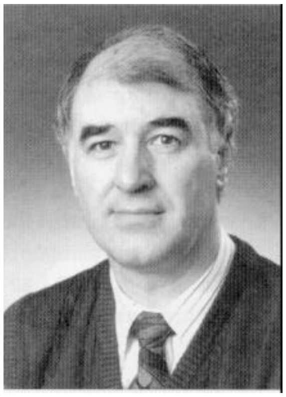
Engineering the Tools for Science

D.F. Dinn, M.B.Chin-Yee, G.D. Steeves



D.F. Dinn

M.B. Chin-Yee

G.D. Steeves

Introduction

Engineering is often described as the application of science for the benefit of society. Today, fisheries and oceanographic science, like most modern sciences, relies on sophisticated equipment engineered to address specific research goals. In the Scotia Fundy-Region (now the Maritimes Region), it can be convincingly demonstrated that the science program itself depends strongly on engineering technology to fully develop and test the many hypotheses about the ocean and the renewable resources that it contains. Many research and operational programs of the Region look to the engineering and technical staff to design, develop, construct, install, test and maintain unique equipment that cover a broad spectrum of applications for measurement and data collection. For decades, research involving the physics of the ocean and the seafloor has relied heavily on electronic and mechanical engineering. In the past decade, biological research has made increasing demands on these disciplines to address issues related to habitat, to primary production in the ocean and to the fisheries.

The Working Climate

Researchers in fields as diverse as ocean physics and chemistry, hydrography, marine biology, aquaculture, and marine geophysics, all depend on a cadre of engineers and technicians -both in-house and in the private sector-for support essential to their programs. Over the years, technical support personnel have played key roles in creating and mobilizing an array of instruments and devices that have been used successfully to collect, measure, observe, and record all manner of information at the air/sea interface, in the water column, on the seafloor, and in the sediments and strata of the sub-bottom.

The crucible of progress is a collegial approach where engineers come to understand the scientific requirements and scientists come to appreciate the engineering trade-offs; together they face the realities of funding and scheduling. Successful ventures have demonstrated the need for the science and the engineering staff to establish a very interactive, symbiotic relationship in their search for solutions. The relationships that result in the successful development and application of special tools for science tend to be long term. This is an important point, because in the current reality where fisheries and oceanographic research often depend on data collected over many annual cycles, and where the windows of opportunity for at-sea data collection each year are limited, progress tends to be evolutionary more than revolutionary. Thus, the long view is the only realistic one.

The Needs

Scientists are looking for answers to a myriad of questions to help them understand ocean processes. The contributions to this Review outline a number of current studies being undertaken. The impact of human activity on global climate change, the effect of large scale ocean circulation and micro-scale mixing on fish abundance, the effect of deleterious substances in the water and sediments, and the mapping of sub-sea resources are some of the areas where answers are needed. To answer these questions, scientists must have the tools to gather information and make the necessary measurements. Some of these tools, like the conductivity-temperature-depth (CTD) probe - a staple instrument of the physical oceanographer for characterizing water masses - are available commercially. However, many of the unique instruments needed by the science program are not. It is in the latter case that scientists join forces with engineers and technicians to devise the tools for collecting vital data.

Engineers and technicians are an integral part of the scientific investigation. They look for answers to technical issues that, poorly resolved, could jeopardize a scientific program. Often the issues are conceptually, but deceptively, simple: how to keep a moored instrument operating in a mid-water location for a year. In some research programs the technical issues are complex: how to assess the impact of trawling activities in an area like the Grand Banks. Sometimes the issue is measuring a scientific parameter without disturbing the environment: how to measure the average growth rate of fish in aquaculture pens without handling the fish or preventing them from swimming freely.

The oceans remain essentially underexplored, and given Canada's vast coastal zone, its offshore fishing banks, and its Arctic domain, the need for scientific exploration and engineering will continue into the foreseeable future.

The Approach

When researching the answer to a question, the scientist must analyze the relevant information collected either from existing sources, or by known methods, or by means yet to be devised. In the latter case, technology often plays a key role in finding a. solution to the data collection problem. The ideal solution will be efficient and cost-effective. Often, the engineering and technical effort will be provided by a team assigned from Management and Technical Services (now Technical Support Services, CCG) and from the client organization - the Region has fostered the concept of a "knowledgeable client" for many years. This team works directly with the personnel dedicated to a particular scientific program to design and develop the necessary equipment. Engineering consultants and contractors play an important role here, as well.

The team often remains on assignment to a project from conception, through the design, construction, and testing phases, and into the sea trials and commissioning. Generally. after it is commissioned, the equipment is operated by the client. It is common for engineering members on the team to take part in some of the scientific expeditions in order to remain aware of scientific findings and the adaptations to their designs that might be required in order to satisfy new needs driven by the findings. This approach underscores the iterative and incremental nature of science and scientific support: new knowledge generally leads to new questions.

Technology Transfer

The need to develop solutions to scientific measurement and data collection problems has naturally led to some interesting and innovative applications of technology. Some of these applications have sparked the interest of companies in the private sector, a fact that has given rise to a number of joint ventures (DOLPHIN Submersible handling system, Tidal Telemetry System) and technology transfers (Pop-Up Float, Moving Vessel CTD, BIONESS towed net system). This arrangement has provided opportunities for Canadian companies to take advantage of the results of research and development by Department of Fisheries and Oceans (DFO) scientists and engineers, and go on to successfully compete on the international scene. In return for the right to use DFO-developed technology, companies return an annual royalty or licensing fee (based on sales) to the federal government. Of course, the companies expect to generate revenue from marketing the licensed product; this creates employment and national wealth, and successful companies broaden the tax base for the government. For these reasons, employees are encouraged to actively pursue patents and licenses under the Public Service Inventions Act.

Some New Tools Developed

Benthic Video Grab System: In order to understand the impact of trawl fishing on the fish habitat, biologists needed sampling equipment that could provide clear images of the sea floor in 300 m of water and retrieve 200 kg benthic samples for quantative analysis. Existing devices sampled blindly and had no means of preselecting interesting or particular areas for sampling. Overcoming this deficiency was of major importance to the proposed study.

The Benthic Video Grab (Fig. 1), together with its deployment winch, was designed to meet the challenge. The grab differs from other similar devices in three important aspects: a) the assembly is landed on the seafloor with the open sampling bucket poised 20 cm above the bottom. By keeping the umbilical cable slack, the grab rests on the bottom, decoupled from ship motion so that the sample area remains undisturbed: b) a high-resolution color video camera above the open bucket gives the operator a real-time view of the seafloor that is about to be sampled; c) the grab can be closed or opened on command from the ship, giving the operator the ability to retain or discard samples. To reduce the disturbance produced by the "bow wave" ahead of the decending unit, the design minimizes the frontal area of the sampler when the bucket is fully open.

Figure 1: The Benthic Video-Grab being deployed from CSS Hudson.

To take a sample, a hydraulic ram slowly drives the grab bucket into the benthic layer using a force of up to 1 tonne, more than sufficient even in relatively hard bottoms. The volume of the sample with full penetration of the bucket is 0.06 m^3 (2.4 ft^3). Essential to the proper operation of the bucket is a lid that closes as the sample is taken. This prevents the fine-grained fraction of the sample washing away as it is hoisted to the surface.

A black-and-white, low-light camera looks down and ahead of the grab as it hangs from the ship on a 30-conductor, kevlar-reinforced cable. This gives the operator a better view as the grab is maneuvered over the seafloor. Lighting is supplied by two 500 watt quartz-halogen lamps. The color camera looks down through the open bucket at the sample area. With focus. zoom and macro remote-control capabilities, the color camera can show remarkable seabed detail. The video information, together with time, latitude and longitude from the differential global positioning system (DGPS), are recorded on Super VHS tape. The sea floor images can be monitored from the shipboard lab. While controlling the grab and the winch. the scientist can direct the maneuvering of the ship as the grab "flies" over the seafloor, look for an appropriate site on which to land the grab, take the sample. and hoist the sample to the surface.

A site on the Grand Banks off Newfoundland has been studied periodically over the past three years by DFO staff from Habitat Ecology, Ocean Physics, and Engineering and Technical Services. Adding pieces to the puzzle of what has happened to the fish on Canada's East coast demands the intensive effort of people and technology. Assessing the extent of damage to the habitat and organisms caused by trawling, and determining the period required for the area to recover to untrawled conditions may be one key to this puzzle. The final expedition of the Trawling Impact Study took place in July of 1995. The task of analyzing the huge quantity of samples is underway and early results are as yet inconclusive.

Salmon Sizing Video System: The Finfish Aquaculture Section at the St. Andrews Biological Station, in concert with the New Brunswick Salmon Growers Association, were looking for a means of periodically assessing statistical growth rates by measuring the length of fish in aquaculture cages. Researchers and growers have a common interest in the growth of fish as a function of feeding and temperature regimes, genetics, and many other factors. Previous studies that involved the removal of the fish for measuring, placed an unacceptable stress on them and led to dubious conclusions.

Stereoscopic photography combined with geometric calculation (i.e., photogrammetry) has long been used to make accurate spatial measurements. The images produced by two separated. parallel cameras oriented perpendicular to the plane of interest can be analyzed to give point-to-point distances. Photographic film cameras are impractical for this live-specimen application. The operator of the apparatus needs real-time viewing for fish target acquisition and camera orientation. Most importantly, only a few image-pairs of the moving fish will be geometrically useful for analysis. Video cameras provide a promising alternative. With scan rates of thirty frames per second, two cameras can be synchronized for simultaneous imaging.

Figure 2: The underwater portion of the Salmon Sizing System showing the video cameras, with flotation device at the top.

By merging the two images using a split screen technique with the "left eye" image on one half of the screen and the "right eye" image on the other, a double image results that is ideal for geometrical analysis.

The operator of the apparatus (Fig. 2) uses a video monitor to ensure that an adequate quantity of good images (same fish in both halves of the image) are acquired at the cage site. VHS recordings of split-screen images are then viewed in a laboratory. Those stereo-pairs that seem promising for measuring are "frame-grabbed" for image analysis using commercially available image-analysis hardware and software (similar to that used in estimating fish age from otoliths). The system is easily transported and deployed, and provides an economical method for the measurement of large numbers of fish.

Sound Velocity Profiler for Multi-beam Ocean Mapping: The Canadian Hydrographic Service is using state-of-the-art multi-beam (MB) sonar technology for mapping coastal waters. (See "New Technologies for Ocean Mapping" in this Review) With the use of multiple oblique beams for measuring depth comes, among other things, the unequivocal need to know the sound velocity profile (SVP) in the water column so that the effects of sound-ray refraction can be removed from the derived vertical depths and from the computed horizontal offsets of the rays. Currently, the survey vessel must stop and deploy a sensor on a wire to measure the SVP. The hydrographer must make an operational compromise between time spent running survey lines and that used for measuring SVPs. Profiles might need to be taken more often than once per hour in those areas where the SVP is changing rapidly with time or tide, or with position in the survey area. It is not until the depth data are partially processed, however, that the full impact of errors due to refraction is apparent. In the end, the error (from all sources) in the charted depths must be less than 0.3 m in water up to 30 m deep, and 1% for deeper water.

The challenge given to a team composed of engineers, technicians, hydrographers and scientists was to improve the efficiency of MB surveys while at the same time decreasing the error from refraction. Due consideration was given to issues such as mathematically modeling the errors and collecting independent, redundant depth data to help identify and resolve the refraction-induced errors.

In the end, an efficient way to obtain SVPs while underway was seen as a common denominator of the solution. An existing science project, the Moving Vessel CTD (MVCTD) system for large ships operating in deep water, provided a starting point for solving the MB problem. However, it was important that the SVP profiler operate from a 10 m-hydrographic launch; three of these boats are now fitted with the Simrad EM3000 MB sonar for bottom mapping in water to 75 m deep.

A design study for a compact, semi-autonomous SVP profiler was coordinated by the team with input from a local consulting company. Finding no existing system that would meet the requirements, a specification was prepared and a contract placed to build a profiler. The design is such that while the launch is underway at 10 knots, the profiler will be able to take SVPs on command or periodically (e.g., every 5 minutes) and transfer the data to the EM3000 sonar for processing and archiving with the hydrographic data (Fig. 3). The construction contract is being managed by an engineer, and the team has a technologist from the MVCTD project as one of its members.

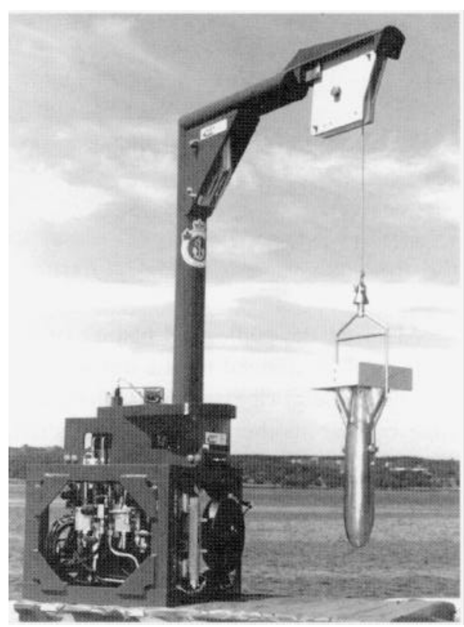


Figure 3: The Moving vessel Sound Velocity Profiling Winch.

At the time of this printing, the SV profiler is expected to be an operational tool on inshore surveys. Commercial licensing arrangements are already in progress with a local manufacturer, and the company has prospects for sales in several countries.

Opportunities and Challenges: CCG-DFO Amalgamation

The creation of one marine fleet and the imminent decommissioning of older but, nevertheless, capable and important ships servicing the science and CCG programs will create a demand for engineering expertise to reconfigure the remaining ships for tasks new to them. Adding capabilities for oceanographic winching and instrument handling, water and bottom sampling, chemistry, biology and geophysics laboratories, and scientific computing and networking to new classes of ships will need the input from specialists in diverse fields. Fortunately, much of the expertise needed to plan and implement these tasks already exists in the newly re-engineered Department of Fisheries and Oceans and in the commercial ocean sector in the region.

Conclusions

The Department of Fisheries and Oceans intends to remain a world leader in the management and protection of marine resources. Remaining on the cutting edge demands a vigorous application of new technologies in order to meet the challenges that will arise from Canada's consolidated ocean responsibilities. The partnership of science, engineering, and technical support will be essential to maintaining excellence in such an endeavour.

Diverging Plates: The Underlying Story

R.R. Boutilier and C.E. Keen

R.R. Boutilier

C.E. Keen

Much of the geological history of the Earth is characterized by the dynamic interaction of semi-rigid plates which collide, slide by one another, or are pulled apart. The plates, or lithosphere, overlie an asthenosphere that responds like a viscous fluid to the plate motions. As a result of the intensive focus on plate tectonics over the past few decades, we have a relatively good understanding of the structure and interactions of the plates, particularly within the upper 30 to 50 km. However, we are only beginning to address important questions concerning the nature of the lowermost lithosphere and the relationship between the lithosphere and asthenosphere. Simple concepts of a sharp boundary, for example, between the lithosphere and the asthenosphere have been useful in making first-order predictions from plate tectonic theory. However, we have now advanced past the stage where such simple ideas are sufficient, and we need to employ more realistic models.

One of the areas of study where our current simple concepts limit our ability to correctly predict observed geological structures is at divergent plate boundaries (Keen and Beaumont, 1990; Keen, 198.5). Divergence starts with rupture of a lithospheric plate during continental rifting.This allows hot mantle material (asthenosphere) to well up into the space created. As the mantle rises, the confining pressure is reduced; part of it melts, yielding a relatively low viscosity fluid. This can seep relatively quickly upwards into the crust where it solidifies as igneous rock. As rifting proceeds, seafloor spreading occurs and an up-welling melt creates the oceanic crust. The centre of up-welling and divergence is termed a mid-ocean ridge. This is illustrated in Fig. 1.

Igneous crust formed at the mid-ocean ridge is typically 8 km thick, although the thickness depends on the spreading rate (White, 1992).At very slow spreading rates. for example less than 10 mm/yr, time is available for significant cooling of the rising mantle which results in the formation

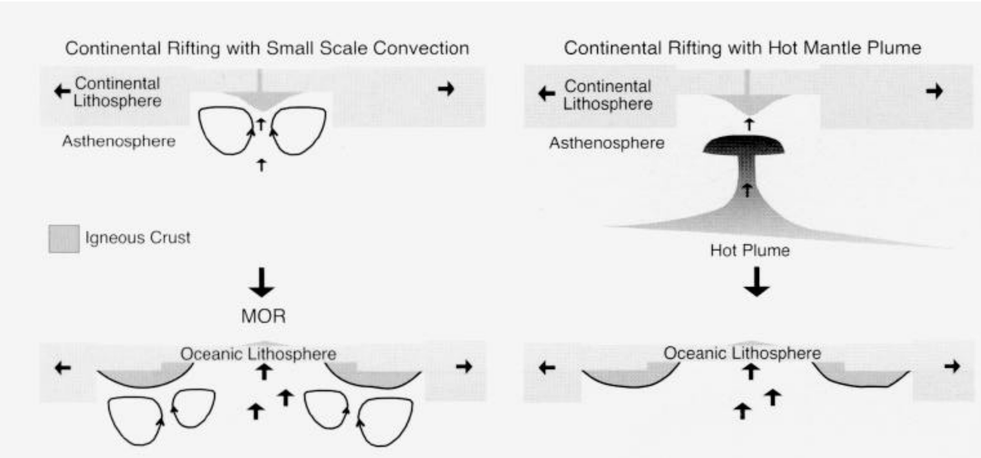


Figure 1: A cartoon showing two proposed explanations for the existence of large volcanic features associated with rifted continental margins. On the left, small scale convection, driven by the thermal perturbation created by continental rifting, delivers melt that forms igneous crust to the rifting centre. This is followed by a seafloor spreading stage (lower left) where convection and melt delivery can continue under the old continental margin, and new oceanic crust is created by upwelling at the mid ocean ridge (MOR). On the right is the hot spot explanation. The high temperature of the hot spot, arriving daring the continental rifting stage, induces the large volume of melt that creates the thick igneous crust. In the seafloor spreading stage (lower right) the mantle has been cooled somewhat, or the hot spot material has been displaced, and normal temperature mantle wells up to create ordinary oceanic crust.

of a thinner oceanic crust (ca. 4 km). These low spreading rates are relatively uncommon in the world's oceans. More common is oceanic crust which is relatively uniform in thickness, varying between 6 and 8 km (White, 1992).

Along much of the divergent continental margin of eastern North America, as far north as Nova Scotia, anomalously large thicknesses of igneous crust (as much as 20 km) are observed (e.g. Holbrook and Kelemen, 1993; Holbrook *et al.* 1994). This extreme thickness has been associated with a major magnetic feature called the East Coast Magnetic Anomaly (ECMA), although the exact relationship between the anomaly and the thick crust is a matter of considerable debate (e.g. Hutchinson et *al.* 1990; McBride and Nelson, 1990; Holbrook and Keleman, 1993; Keen and Potter, 1995). Figure 2 illustrates the position of the ECMA and shows observations of crustal thickness in several sections across this margin. These cross-sections are typical of observations from around the world at divergent plate margins.

The Baltimore Canyon and Carolina Trough cross sections (Fig. 2) show the thick igneous crust. Such margins are termed volcanic margins. Seaward of the large igneous structure the oceanic crust returns to a normal, uniform thickness (about 6 km). The volcanic margins of Figure 1 contrast sharply with the Nova Scotian Margin cross section, which represents an "avolcanic" margin, where the transition from continental to oceanic crust does not show evidence of large igneous crustal thicknesses.

There is currently a debate on the origin of the thick igneous crust, which forms a welt about 70 km wide and can be traced along the ECMA southward for ca. 2000 km along the axis of the ancient rift (Keen, 1969; Emery *et al.* 1970). One possibility is that the mantle source was excessively hot (hotter by 150 to 200°C) during rifting and thus created a much larger volume of melt during upwelling. However, there is little evidence to indicate the former presence of such a long, thin strip of hot mantle. An alternative explanation is that small scale convection in the asthenosphere under the rift acted as a "conveyor belt" to enhance the supply of melted mantle to the lithosphere (e.g. Mutter *et al.* 1988). This suggestion is supported by the work of Anderson (1994, 1995) who proposes that the source of large igneous provinces may be the relatively shallow, low-viscosity sub-lithospheric mantle, which may undergo convection as a consequence of rift processes within the overlying plate. These two possible explanations are shown in cartoon form in Figure 1.

The thick igneous crust at volcanic margins is thought to have been created during and shortly after rifting (Austin et *al.,* 1990; Sheridan et *al.,* 1993). If thick igneous crust can be explained by the activation of small scale convection during the rift stage, it is evident that melt-producing convection must have been spatially limited and confined to a relatively short interval of the margin's history.

Our work involves the use of numerical models to test in a quantitative way the physical circumstances under which small scale convection would occur below a rift zone. The numerical models provide predictions of the timing and amount of melting in the mantle. This in turn predicts variations in crustal thickness that can be compared with observations. A major challenge in our modelling is to demonstrate process-driven factors which can explain both volcanic and avolcanic divergent plate margins.

Tools and Methods

The methods used build on those described in Keen and Boutilier, 1995. The models are two dimensional and solve for the temperature structure and flow velocities in the asthenosphere that result from rifting. The mantle is assumed to be a viscous fluid. The viscosity depends in part on temperature. The solid-like lithosphere is thus simulated simply as a cold region within which viscosity is so large that flow is imperceptible during the model evolution. The viscosity depends as well on pressure, increasing slowly with depth. The viscosity also depends on strain rate (i.e. rate of change of flow). This results in a highly nonlinear behavior, where by flow reduces viscosity, leading to more and more localized flow. This in turn affects cooling rates. and creates other time dependent behavior. We must consider all of these factors in determining how realistic each model might be. These material properties are based on laboratory measurements on ultrabasic rocks and wet dunite (e.g. Kirby and Kronenberg. 1987; Chopra and Patterson, 1981).

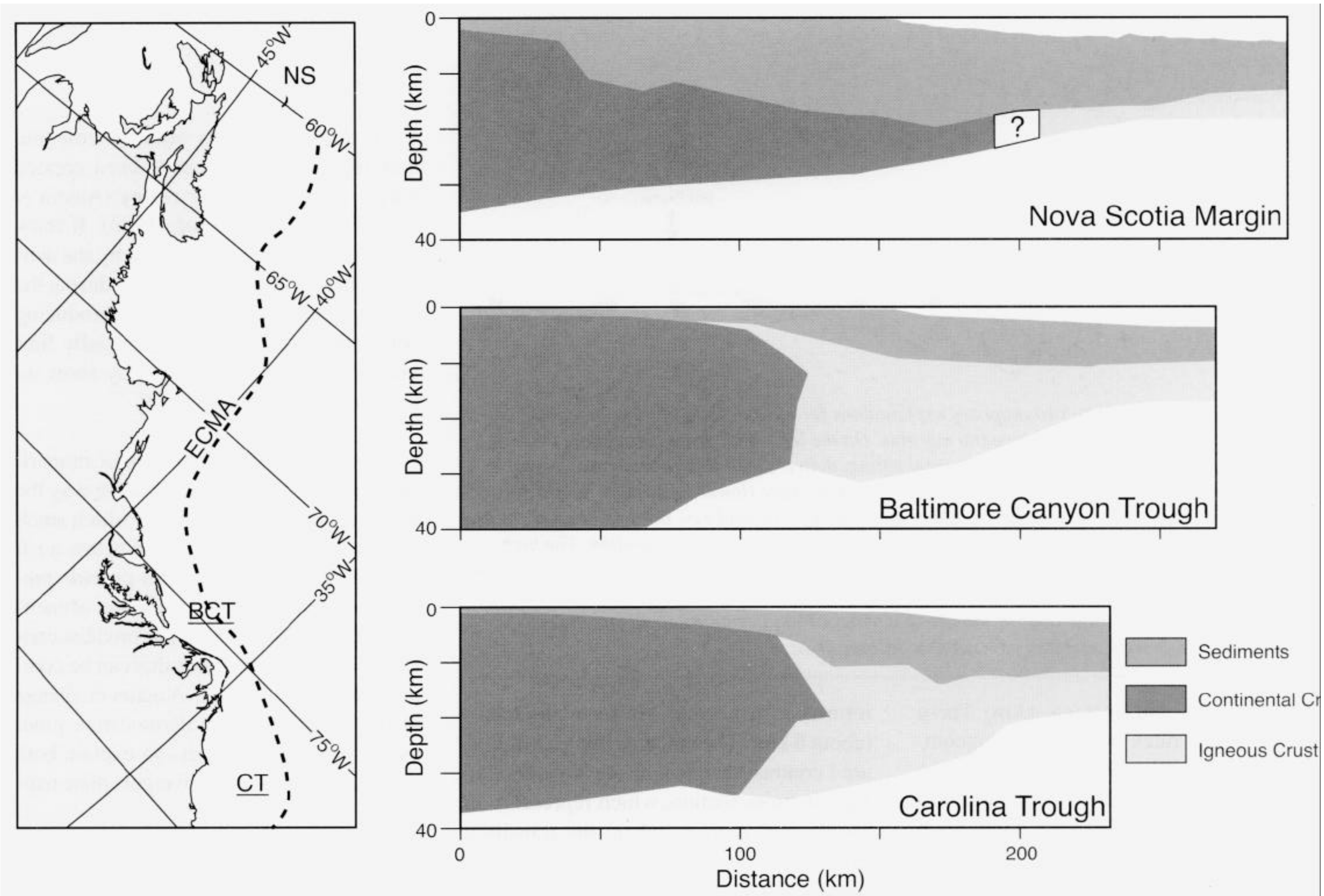


Figure 2: Position of the East Coast Magnetic Anomaly and cross sections of crustal structure at three locations: NS - Nova Scotia margin (Kay et al., 1991); BCT - Baltimore Canyon trough (Holbrook and Kelemen, 1993); CT - Carolina Trough (Holbrook et al., 1994). The ECMA is shown as a dashed line (Holbrook and Keleman, 1993) and marks the position of the 70 km wide welt of thick igneous crust below the margins. Simplified from Keen and Potter (1995).

Model calculations are performed at time steps, stepping forward in time through the continental rifting stage (see Fig.l).An upwelling zone analogous to a widening oceanic rift system is created. with the ridge axis at the upwelling centre. As the mantle rises at the rift axis, pressure is reduced. At about 80 km depth, which we call the base of the melt window, the reduced pressure allows decompression melting to occur. Part (10-20%) of the relatively solid mantle rock melts and a very low viscosity fluid is released. The melt may migrate upwards underplating or intruding the crust, or emerging on the surface through volcanism. As mantle material continues to rise, a larger fraction is able to melt. We used a compilation of laboratory measurements to determine the solidus for this decompression melting process (McKenzie and Bickle, 1988) and from this are able to calculate the volume of melt which would be produced by our models. Mantle material that flows upwards through the base of the melt window, provided it is sufficiently hot, can deliver melt. Increasing the flow rate increases the melt delivered, as does increasing the temperature of the mantle flowing upwards. Cooling of the uprising material by conduction tends to reduce melt delivery.

Evolution of a Model

Figure 3 shows the evolution of one model at four different times and illustrates most of the physical characteristics of our models. The extension and spreading rate (VO) are held constant in this model. The flow in the mantle throughout the evolution is highly time dependent; the frames were chosen at times when the velocities in the asthenosphere reached maximum values.

In Figure 3a, almost 7 Ma after the initiation of rifting, the flow in the asthenosphere is well behaved and directed into the developing rift. A thermal anomaly with a half-width of about 100 km has developed. Since the upward velocities are relatively high, and there is little concurrent cooling, the melt which is delivered to the surface is approximately equal to that needed to form normal oceanic crust (6 to 8 km).

To increase the melt delivered to levels approaching those observed at volcanic margins (about 20 km), the upward flow through the base of the melt window would have to be increased. Convection at this stage might provide that increase. but the strongly focused upward flow does not allow enough room at this stage for convection to develop. Were the viscosity to be

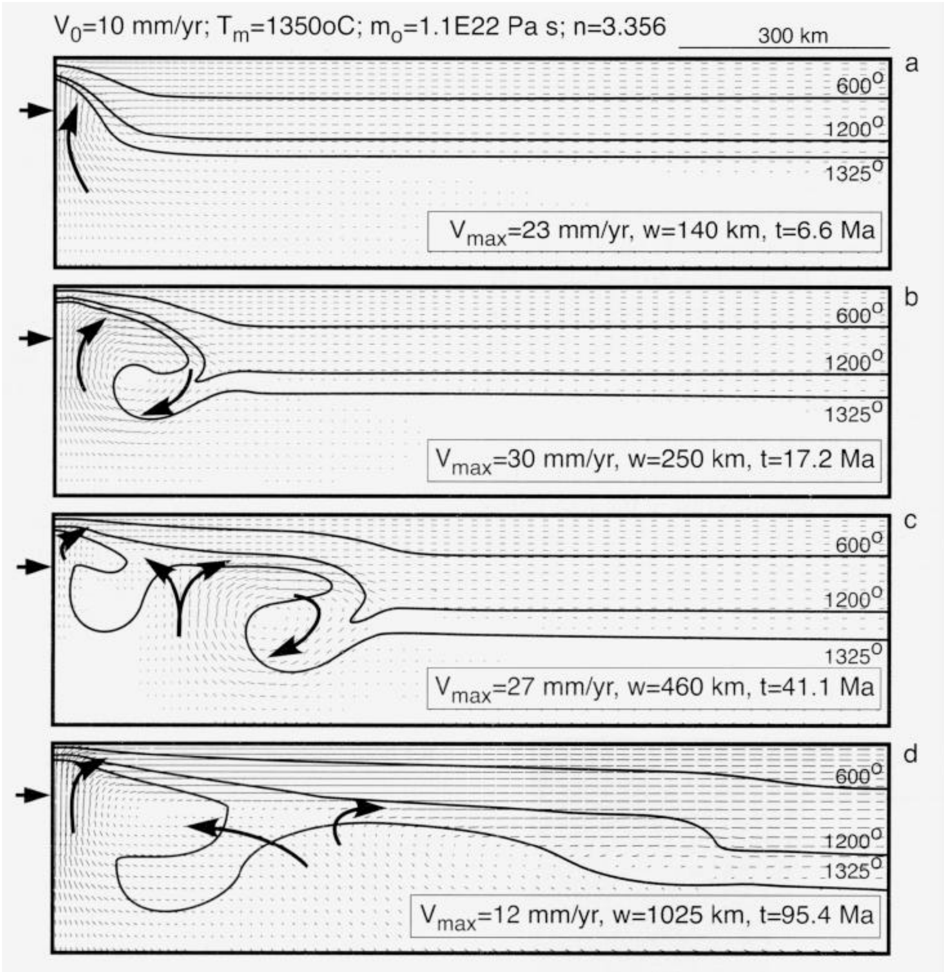


Figure 3: The evolution of one model shown at four times. The initial half-width of the rift zone for this model is about 70 km. In each frame bold arrows indicate the general direction of asthenospheric flow, with the short lines being the instantaneous direction of flow calculated by the numerical program. Selected temperature isotherms showing the perturbed thermal structure are indicated. At the top of the figure the extensional velocity, or spreading rate, the mantle temperature, a characteristic viscosity and degree of non-linearity are indicated. In each frame are indicated the maximum velocity of flow in the asthenosphere, the distance from the ridge axis to the continental margin, and the time since the beginning of rifting. Flow line vectors are scaled relative to the maximum velocity value. On each frame, a small arrow on the left edge indicates the base of the melt window (corresponding to about 80 km depth). Only flow penetrating upwards through this depth can contribute the melt which forms the crust.

lower or the thermal anomaly sharper, there might be a convective response.

Figure 3b shows the configuration at 17.2 Ma after the initiation of rifting. Here, convection has begun adjacent to the widening margin. A mass of colder material under the margin is falling, but this relatively cold material is also being entrained in the flow of the convection cell; the strong entraining flow is due in part to convection but is also driven by the need for mass to flow into the ridge axis. Thus, the two phenomena are linked by geometry.

The maximum flow velocity Vmax at t = 17.2 Ma is 30 mm/yr, which is 30% higher than that at t = 6.6 Ma. The flow impinges on the base of the melt window. Thus we expect more melt to be delivered at this time. However, if the colder material from the convection cell under the old margin were to get entrained into the upwelling at the ridge axis, the drop in temperature alone would decrease the melt delivered. Additional reduction in melt delivery can occur if material that had already experienced partial melting were re-circulated in like manner. The melt delivery calculations presented here include the first effect, but not the second.

Figure 3c and 3d show the continued evolution of the model. The convective response continues under the old margin but at a reduced intensity (the thermal gradient under the old margin is fading away), and the convective flow is now far enough away from the ridge axis to be relatively independent. Some interaction is still visible, however. Note that the convection is occurring just below the base of the melt window, so that no additional igneous activity will result. Additionally, cold structures resulting from convection are still present in the model and are clearly interacting with the ridge axis flow. However, it can be seen that at the ridge axis the flow evolves to a laminar form; this model will thus generate uniform oceanic crust.

We have run many other models with different parameters. They allow us to verify the following general statements. (1) The driving force for convection is the lateral thermal gradients near the base of the lithosphere, generated by rifting in the plate. Stronger gradients will produce more vigorous convection. (2) When the viscosity is relatively higher (or asthenospheric temperature lower), the convective response is lessened or suppressed. In the opposite case, more vigorous convection occurs, the time dependence of the system increases. and more complex interactions result. (3) Possible flow behaviors that are more nonlinear (i.e. have a stronger relationship between viscosity and strain rate) provide models that are less stable and more time dependent. Highly nonlinear models can convect vigorously for an interval of time and then stop, allowing the system to revert to a stable form. This might explain volcanic margins. However, there is a tendency for these highly nonlinear models to be unstable. thus preventing the generation of uniformly thick oceanic crust.

Figure 4 shows two typical crustal cross sections from our model calculations. Figure 4a shows the results from the model shown in Figure 3. At the old margin (900 km in the figure) the Moho has been thinned by extension at the early stages of the model. The melt that is first delivered is deposited there, and subsequent delivery of melt continues to build the oceanic crust.

The initial delivery of melt is irregular and time dependent, reflecting the convection that began in the early stages of the model. There is then a stage of relatively thin oceanic crust (the middle third) that reflects the presence of colder material rising to the ridge axis through time, resulting from the convection. This effect is seen in many models that were run, often consisting of a period of enhanced melt delivery followed by a period of relative melt starvation. In most cases this was used as a criterion to reject the model.

The long-term oceanic crust created in the model Figure 4a appears stable and of approximately the required thickness for oceanic crust (although somewhat more variable in thickness than desirable). We tentatively find this model acceptable, and suggest that it may approximate processes at an avolcanic divergent margin.

The bottom frame depicts our most successful model thus far for a volcanic margin. The model has the same extension rate as the model in Figure 4a but the rift geometry was localized to a 40 km half-width, creating a sharp break in the lithosphere and a strong thermal gradient in the early rift stage. The model successfully provided a narrow wedge of melt over 20 km thick adjacent to the margin, and provides more or less uniform oceanic crust thereafter. The blip in the oceanic crust at the mid-left is problematic and suggests that a slightly more stable model is required.

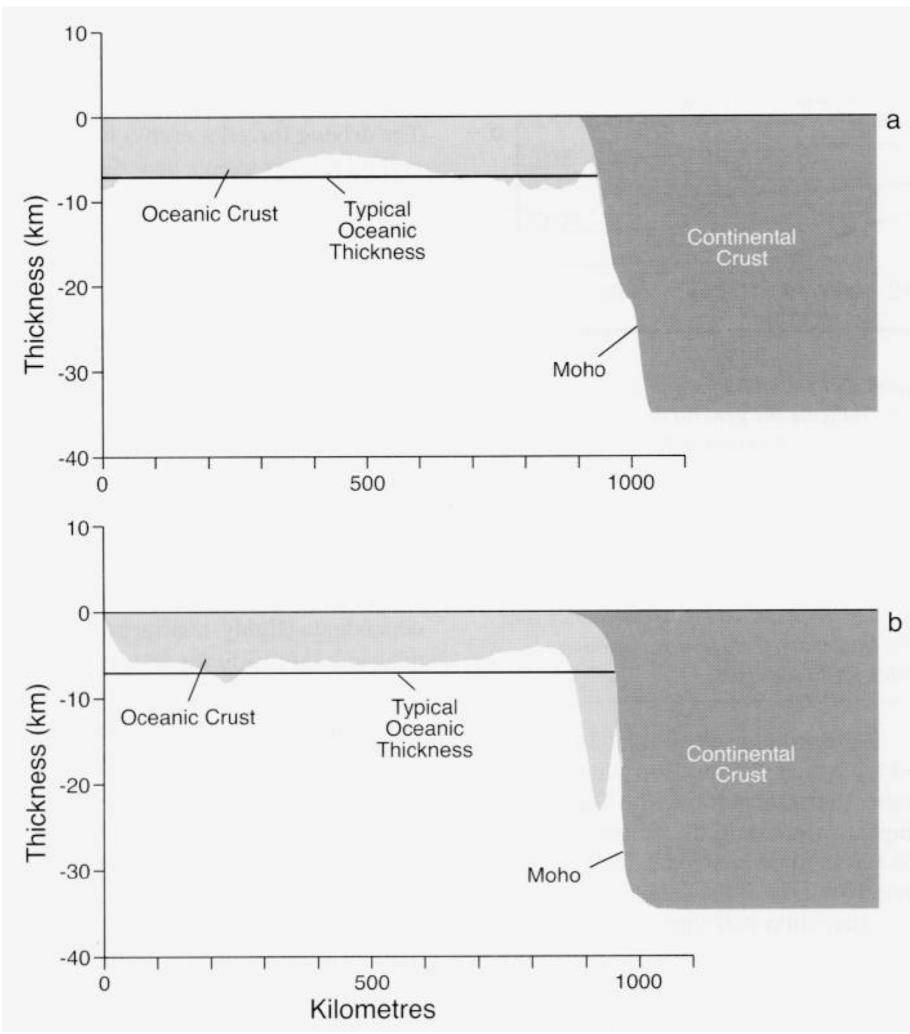


Figure 4: Predictions of oceanic crustal thickness for two models. Note the Moho near 1000 km in each frame, which was thinned by extension prior to the onset of sea-floor spreading. (a) is the melt delivery from the model shown at Figure 3 which had a relatively wide rift zone within the lithosphere. (b) is the melt delivery from a model with a sharp rift zone. At the top of each frame the mantle temperature, a characteristic viscosity and degree of non-linearity used for the model are indicated. Vertical exaggeration is approximately 16:l.

There remain significant problems with this otherwise encouraging result. The main problem is that the mantle physical properties of the two models shown in Figure 4 are too dissimilar (in background temperature, and in degree of nonlinearity). We are searching for a physical model that has just one viscosity relationship (i.e. dependence on pressure, temperature and strain rate, and characteristic viscosity), where natural variations in spreading rate and mantle temperatures produce acceptable results. The volcanic margin result, for example, does not provide this; slowing the spreading rate by a factor of two produces a model (not shown) whose melt delivery was unacceptably irregular. Changing the initial asthenospheric temperature by 25°C also produced an unacceptable result. Since such variations obviously occur in the Earth, we conclude that we need to search further for an acceptable model. That model will work for both volcanic and avolcanic margins.

Discussion

These results are the first to quantitatively test the hypothesis that small scale convection in the asthenosphere can arise from plate divergence in the overlying lithosphere. They thus hold the promise for a viable alternative to explanations which require high temperature asthenosphere as a source of large volumes of igneous rocks in some continental rifts and rifted continental margins. We hope that the difficulties presented by the results of these models can be overcome with additional work.

One likely consequence of melting is that the creation and extraction of melt from the mantle will alter the viscosity and density of the residual mantle matrix. The viscosity is likely to be reduced, creating more vigorous flow. In contrast the density of residual mantle is decreased, and the pooling of lighter mantle material near the edges of the rift zone will tend to stabilize the system and impede convective flow (Su and Buck, 1993). These are properties that have not been incorporated into our models but that may be important in enhancing up-flow and melting, while concurrently providing the necessary stability. We are currently investigating this aspect of the problem.

Small scale convection in the asthenosphere could predict other important aspects of rifted margins which are otherwise difficult to explain. One of these is the history of vertical motions, recorded in the sedimentary record. The sediments show that after formation the margin undergoes a long term subsidence due mainly to cooling of the lithosphere. Superimposed on the long term cooling are shorter period oscillations (ca 10 to 40 Ma cycle time) with amplitudes of several hundred metres. These relatively short term variations may be linked with the time dependence of convective flow, as seen, for example, in Figure 3. Acceleration or deceleration in flow will change the vertical stress field acting on the base of the plate and thereby cause a change in the elevation of the plate.

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Environmental Interactions with Sea Cage Culture of Atlantic Salmon

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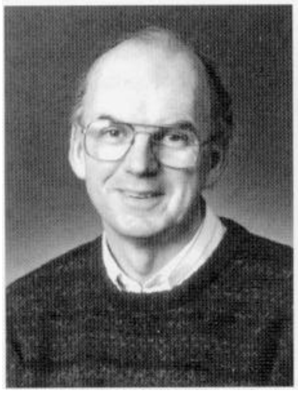

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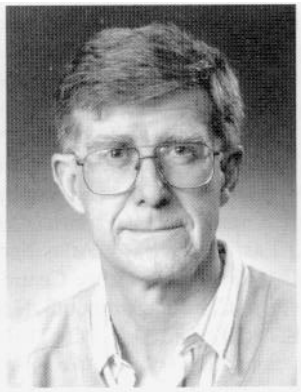

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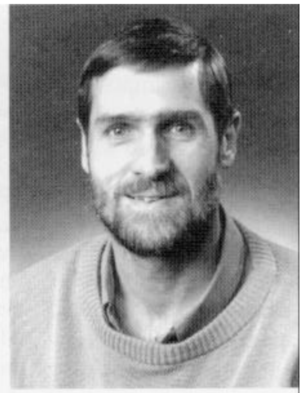

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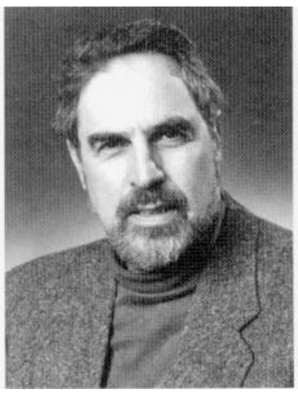

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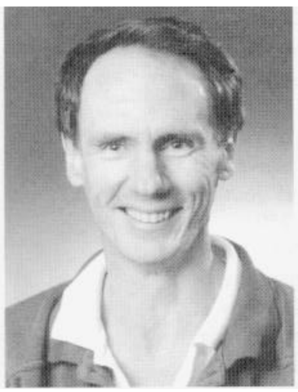

P. Strain

D. Wildish

Background

Mariculture of fish such as Atlantic salmon offers the promise of increasing supplies of food from marine ecosystems, but scientific studies and industrial experience have shown that coastal areas have only a finite ability to support sustained aquaculture yield. There is a risk of excessive nutrient enrichment through release of uneaten food and fish wastes when this occurs in enclosed coastal embayments. Optimal siting of aquaculture operations and decisions concerning industry expansion require environmental information. Physical conditions such as maximum and minimum water temperature, water depth and current speed, and biological factors such as potential for the spread of pathogens, impacts of escapees on wild stocks, and occurrence of toxic plankton blooms, are now recognized as important factors that can limit aquaculture activities in coastal waters.

For the past five years, Department of Fisheries and Oceans (DFO) staff at the Bedford Institute of Oceanography (BIO), the St. Andrews Biological Station, and in the Newfoundland Region have conducted research to evaluate environmental interactions of salmon aquaculture (Wildish et al., 1990). Field observations and modelling studies in the Bay of Fundy and Baie d'Espoir, Newfoundland, have been combined to determine environmental and operational factors that could limit site selection and expansion of finfish cage aquaculture in coastal regions. The overall aim is to develop sampling methods, modelling tools, data bases and knowledge useful for management advice on cumulative impacts of finfish cage aquaculture in the context of coastal zone management. Advice has been provided to DFO Habitat Management concerning methods for surveillance, calculation of site holding capacity, and data requirements for modelling environmental interactions. Draft guidelines have been prepared for assessment of benthic carbon loading and spatial scales of mariculture impacts.

Field and Modelling Studies - Water Column

A project was initiated in Newfoundland at a salmon aquaculture site in Baie d'Espoir to obtain data on water column variables to test empirical models that predict carrying capacity for finfish production based on nutrient loading and oxygen demand. The availability of sheltered sites to avoid ice rafting in the spring was identified as an overall limiting factor in coastal fjord systems. Symptoms of oxygen stress observed during summer months indicated that models predicting oxygen availability and demand from currents, depth and water column structure are important for predicting carrying capacity of suitable sites.

Studies have also been carried out in the Western Isles Region in the Bay of Fundy where salmon aquaculture has grown rapidly over the last ten years. A hydrodynamic finite difference model was developed by ASA Consultants Ltd. to predict principal oceanographic features, including tidal currents, circulation, distribution of temperature and salinity in space and time, and diffusion characteristics (Trites and

Petrie, 1995). Output from the model illustrates where impacts of increased nitrogen release and biological oxygen demand (BOD) from both fish farms and fish processing plants in the area might occur. Fish pens have to be located in areas of sufficient water exchange to avoid oxygen depletion and possible ammonia accumulation associated with large numbers of fish held in enclosures. Water column observations of dissolved oxygen and nutrients and flushing experiments at selected cage sites carried out over short (tidal) time periods have shown that variable flushing rates occur under different hydrographic conditions (Wildish *et al.* 1993).

Descriptions of physical processes that dominate water exchange were used to predict the impact of nutrient inputs on inlet-wide scales and to develop a carrying capacity model based on the potential for nutrient enrichment from estimated numbers and sizes of salmon held in cages in the Western Isles Region (Strain et al. 1995). The input from the aquaculture industry could then be evaluated in the context of other man-made and natural inputs. When making a comparison between inputs from different sources, it is important to consider both the nature of the inputs and their interaction with water movements. Figure I compares the magnitudes of inputs of nitrogen and BOD from various sources to the Letang Inlet.

Although organic enrichment of coastal embayments through discharges of domestic sewage, agriculture and industrial wastes is generally more wide-spread than the release of waste products from aquaculture facilities, the latter may be a significant source in small less-populated areas. The largest single input to the Letang region is from aquaculture (Fig. 1). Despite this, the local impact from the fish plant is as severe (or much more severe, for pre-1991 conditions) as the worst impact from aquaculture. To restate this comparison, aquaculture changes existing nutrient concentrations by moderate amounts over a large area; the fish plant causes larger changes over a smaller area.

Field and Modelling Studies - Sediments

Of several possible negative effects, deposition of particulate matter as unconsumed food and faecal matter from finfish aquaculture has been identified as one having potential long-term negative environmental impacts (Hargrave 1994). Studies have shown that sediments and the organisms in them (the benthos) change in response to organic enrichment. However, enhanced sedimentation from salmon net-pen aquaculture is site specific, spatially limited, and highly dependent on physical factors such as water current speed and seasonal storm-related resuspension. Organic matter accumulated under fish pens can lead to localized anoxic conditions which result in depletion of macrofauna and increased fluxes of oxygen and dissolved inorganic nutrients between sediments and overlying water (Hargrave *et al.* 1993). A survey of 11 farm and 11 reference sites in the Western Isles Region in 1994 showed that benthic variables which are correlated with organic matter sedimentation (gas and nutrient fluxes, sulfide, organic carbon and oxidation-reduction potentials) can be used to scale the degree of organic enrichment (Hargrave et al. 1995). However, biological processes are not always sufficient to limit organic matter accumulation especially in areas where hydrographic conditions and/or low current speeds result in low rates of oxygen supply to the sediment surface.

Model Development and Application

Although effects of organic enrichment in the water column and sediments arising from aquaculture activities have been identified in these site specific studies, there have been few attempts to derive general models linking numerous physical, chemical and biological factors that are altered by increased organic matter supply. Silvert (1992, 1994a) formulated a general approach of this type and Sowles *et al.* (1994) used data from different finfish aquaculture sites to calibrate these conceptual models. These models describe and predict impacts of organic loading under various operating and environmental conditions and provide a basis for decisions concerning the suitability of a coastal site for new or expanded aquaculture development.

The modelling approach used to assess environmental impacts of salmon aquaculture in the Western Isles Region is based on a nested set of hierarchical submodels as shown in Figure 2 and described by Silvert (1994b). The central submodel is FISH, which is an input-output representation of the feeding physiology of farmed fish. Using environmental variables such as water temperature and photoperiod, this submodel calculates the amount of feed consumed and the resulting growth and excretion rates as a function of the size and age of the fish. The POINT submodel integrates the FISH submodel over the size and age distribution of all the fish in the farm, calculating a total point source strength for loadings from the site.

The POINT submodel can be used to derive several different models dealing with various types of environmental impact. The one that has received the greatest emphasis so far is SETTLE, which describes the deposition of waste feed and faecal pellets on the seabed under and near the site (Silvert, l994a, Gowen *et al.* 1994). Another is the Water Quality Model (WQM), which describes the transport of dissolved and suspended material. This is being integrated with the ASA hydrodynamic model described earlier. The FARM model is used to calculate near-field effects, such as the tidal variation of benthic oxygen levels at a site.

A major problem in the analysis of data relating to the environmental impacts of fish farms is the difficulty of making complete sets of quantitative observations. The nets and mooring systems often preclude the use of traditional benthic sampling equipment, and observations may be made by divers using only video equipment and simple sampling devices. Because of this, there is concern about how to use qualitative descriptive data to characterize benthic conditions without compromising scientific objectivity. Fuzzy logic is ideally suited to the processing of this kind of data. Results from observations in diver logs taken under a net pen fish farm have been analyzed using this new technique. Preliminary results show a strong correspondence between highly enriched sedimentary conditions and high levels of sediment organic

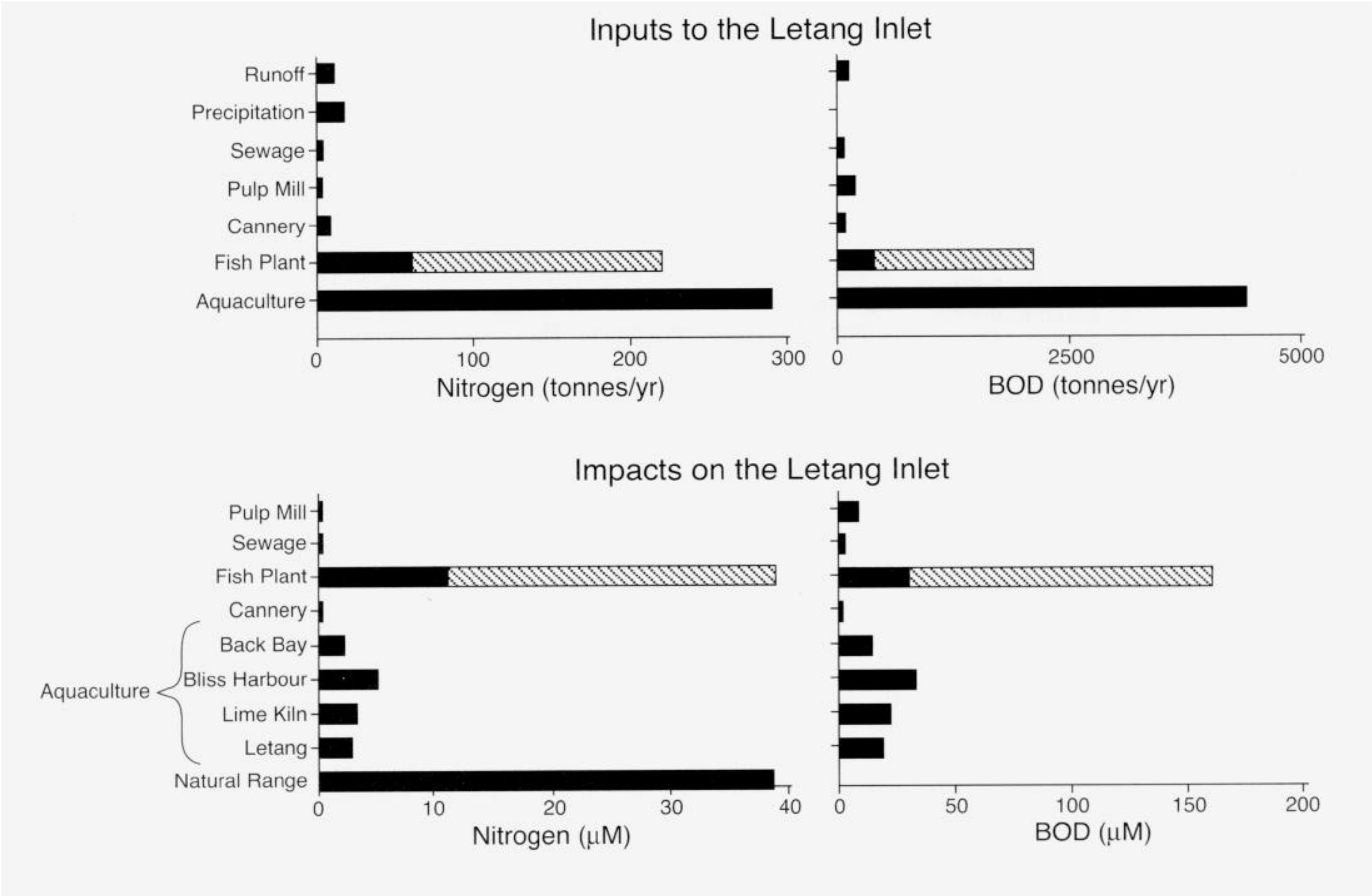

Figure 1: Inputs and impacts of discharges of nitrogen and biochemical oxygen demand (BOD) to the Letang Inlet. Inputs are the total discharge per year; impacts are the changes in ambient concentration caused by these inputs in the waters they affect. The solid bars for the fish plant are for discharges after 1991, when improvements to the plant's waste management were made. The total length of these bars are discharges prior to 1991.

matter, porewater nutrients and organic matter decay rates.

The next step in the utilization of these models is the development of a computer application to combine data, models and expert advice for input to the decision-making process (Silvert, 1994c,d). Work is currently underway to develop a Decision Support System (DSS) that will incorporate simplified versions of several models along with geo-referenced hydrographic and environmental information (Silvert 1994e). Model predictions of fish growth (farm yield) and environmental impacts will be made based on user-provided information about a specific site (such as area, depth, maximum-minimum current speeds, number of fish).

The different approaches used for modelling environmental interactions of finfish aquaculture were discussed at an international workshop held at BIO in September 1995. It was concluded that for model development an integrated approach is needed which must occur simultaneously with the implementation of advisory tools. Participants in the workshop felt that models are essential tools for practical management purposes to ensure that the future of finfish aquaculture in coastal regions is sustainable.

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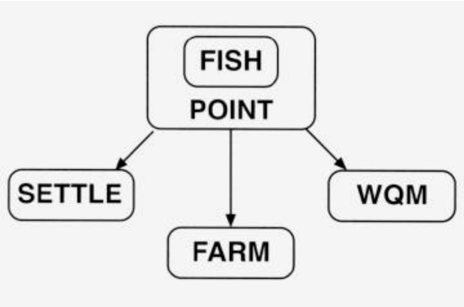

Figure 2: Configuration of hierarchical submodels used in simulation models of point source loadings from fish farms.

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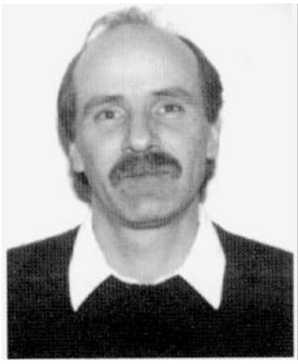
Status of Maritime Atlantic Salmon Stocks

G.J. Chaput



G.J. Chaput

Introduction

Of the more than 550 rivers with Atlantic salmon populations in eastern Canada more than one-third are located in the Maritimes. The two largest Atlantic salmon rivers in eastern North America are located in New Brunswick. The Saint John River is the largest river, draining an estimated 55,000 km^2 of watershed area (in Canada and the U.S.A.). The Miramichi River, draining approximately 14.000 km^2 into the southern Gulf of St. Lawrence, contains the largest Atlantic salmon population with an average of 111,000 fish returned annually between 1984 and 1994 (Chaput *et al.* MS1995).

The Atlantic salmon possesses a highly refined homing ability and each river is considered to possess a unique spawning population. Atlantic salmon returns to its natal river to spawn after feeding at sea for one year (1 SW = one sea-winter) or two years (2SW). Feeding occurs as far afield as the Labrador Sea, off Greenland and even the North Sea (Europe). In contrast to the Pacific salmon species,Atlantic salmon does not immediately die after spawning. Repeat spawning events are always accompanied by return migrations to sea for reconditioning and additional growth although kelts (post-spawning salmon) have been artificially reconditioned in captivity, exclusively in freshwater.

Atlantic salmon is further defined by geographic differences in biological characteristics. Salmon stocks from the inner Bay of Fundy mature predominantly as 1SW fish, have a high incidence of repeat spawning and are not known to migrate to the Labrador Sea. In contrast, stocks from the outer Bay of Fundy, Atlantic coast of Nova Scotia and the southern Gulf of St. Lawrence have both 1SW (which tend to be mostly male fish) and 2SW (which tend to be mostly females) components, a lower incidence of repeat spawning and undertake extensive marine feeding migrations. Because of significant variations in the life history characteristics of the salmon stocks in the Maritimes Region, assessments are undertaken on finer spatial scales, often to the level of individual river. Over the past decade there has been a steady increase in our knowledge. In 1983, assessments were done for only the three main rivers in the Maritimes (Saint John, Miramichi, and Restigouche rivers). Assessments were produced for 26 rivers in 1994 (Science Branch 1995).

The assessment of Atlantic salmon consists of 6 parts:

- accounting of harvests,
- definition of the target spawning requirement,
- estimation of returns
- estimation of escapement and egg depositions,
- conclusions on status of the stock and prospects, and
- provision of advice for fisheries management.

The following summarizes the status of the salmon stocks in the Maritimes for 1994. I also show how divergent trends in abundance have occurred within the stocks and that the prospects are stock dependent. In one geographic area, the abundance of the freshwater stages is sufficient to sustain the spawning recruitment. In another area, the salmon stocks are in a depressed state and the potential for recovery is limited by reduced recruitment in both the freshwater and marine environments.

Harvests

The commercial fisheries in the Maritimes were permanently closed in 1984. The Maritime commercial landings peaked in 1967 at more than 800 tons but averaged only 6% of the total Canadian landings between 1970 and 1985 (Marshall 1988). Recreational catches prior to 1984 averaged just over 20.000 fish, of which 85% originated in the rivers of the southern Gulf of St. Lawrence. Beginning in 1984, all salmon of fork length greater than or equal to 63 cm had to be released alive back to the river. The objective of this management measure, in concert with the closure of the commercial fisheries, was to augment the spawning escapement of the large salmon spawners which in recent years had been below the escapement targets. Currently, First Nations food fisheries account for 100% of the directed large salmon harvests but only 15% of the small salmon harvests, recreational fisheries accounting for the remaining 85% (Anon. 1995a).

Targets

The formal definition of conservation for Atlantic salmon, adopted in 1991, is based on the World Conservation Strategy. It intends to ensure that the "fullest sustainable advantage" is derived from the resource (CAFSAC 1991). The practical application of that definition is based on the potential production of salmon stocks. An interim level of 2.4 eggs per m^2 of fluvial rearing habitat is being used. It is an interim value because river-specific refined values can be used in its place as they become available. As an example, there are about 55 million m^2 of habitat area in the Miramichi River which translates to an egg deposition target of 132 million eggs. Generally, these egg targets are converted to number of spawners required using average fecundity values for the stock, which, for the Miramichi River translates to 23,600 large salmon.

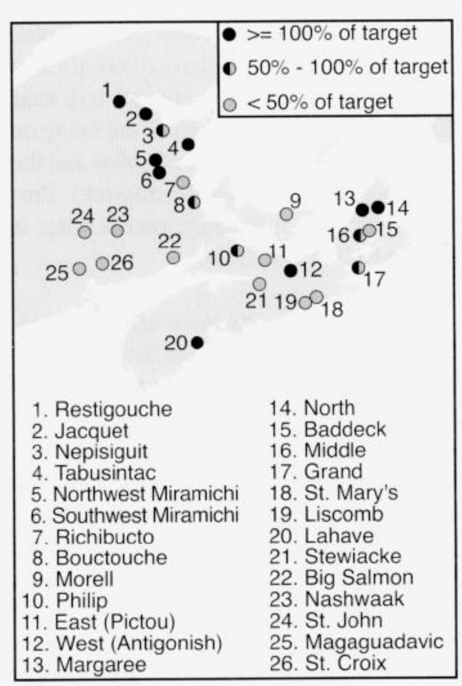


Figure 1: Egg depositions in 1994 relative to targets for 26 rivers in the Maritime provinces. Figure and data are extracted from Anon. (1995a).

Estimation of Returns and Escapements

Estimates of total returns are obtained using various techniques. In 1994, 26 rivers were assessed using counts at fishways and counting fences (11 rivers), mark and recapture experiments (7 rivers), visual count surveys such as snorkeling (4 rivers) and angling catches (4 rivers). The returns represent the size of the population before any in-river removals. Spawning escapement is simply the returns minus all known in-river removals.

Status of Stocks in 1994

There are geographical differences in the health of the wild salmon stocks in the Maritimes. Returns and spawning escapement of salmon to the rivers of the Bay of Fundy and to most rivers of the Atlantic coast of Nova Scotia were deficient (less than 50% of target) (Fig. 1). This contrasts with the higher escapement levels observed in the rivers of the Gulf of St. Lawrence where half of the assessed rivers received egg depositions which equaled or exceeded the targets.

Severe deficiencies in egg depositions in the Bay of Fundy and Atlantic coast rivers occurred in spite of intensive smolt stocking programs. To give an idea of how extensive these stocking programs are, the 681,000 smolts were stocked to the following areas: 250.000 smolts for the Saint John River, 232,000 smolts to ten rivers of southwestern Nova Scotia (Salmon Fishing Area 21), 112,000 smolts to six rivers of the Eastern Shore (SFA 20) and 87,000 smolts to six rivers of eastern Cape Breton (SFA 19) (Fig. 2). The objectives of the stocking program are to mitigate losses to acid rain (SFA 20 and 21) and hydroelectric development, as well as for enhancement of wild stocks. Salmon returning to rivers affected by acidification or obstructions are comprised of high proportions of hatchery-reared fish. Hatchery-reared fish comprise negligible proportions of the salmon returns to the rivers of the southern Gulf of St. Lawrence, with the exception of the Morel1 River in P.E.I. (Fig. 2).

Aquaculture escapees are a potential threat to the survival of the wild salmon stocks of the Bay of Fundy. Escapees of salmon from the Passamaquoddy Bay industry were sampled from several New Brunswick rivers of the Bay of Fundy and these escapees dominated the returns to the St. Croix and Magaguadavic rivers (Fig. 2). Escapees from the aquaculture cages in a single storm in 1994 were estimated to have been in the order of 20,000 to 40,000 fish, greater than the entire nm of wild and hatchery-reared Atlantic salmon returning to all the rivers of the Bay of Fundy in 1994.

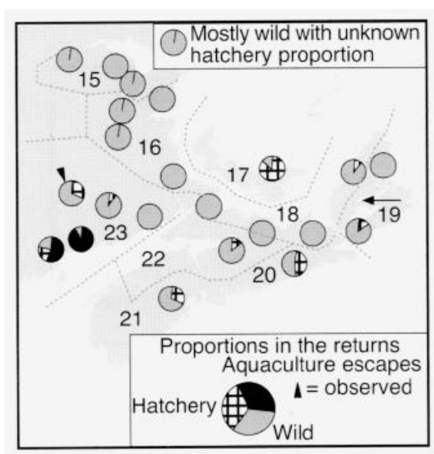


Figure 2: Wild, hatchery-origin, and aquaculture escapee proportions in the total returns of salmon in 1994 to selected rivers of the Maritime provinces. Numbers in text refer to Salmon Fishing Areas (SFA) 15 to 23. Figure and data are extractedfrom (Anon. 1995a).

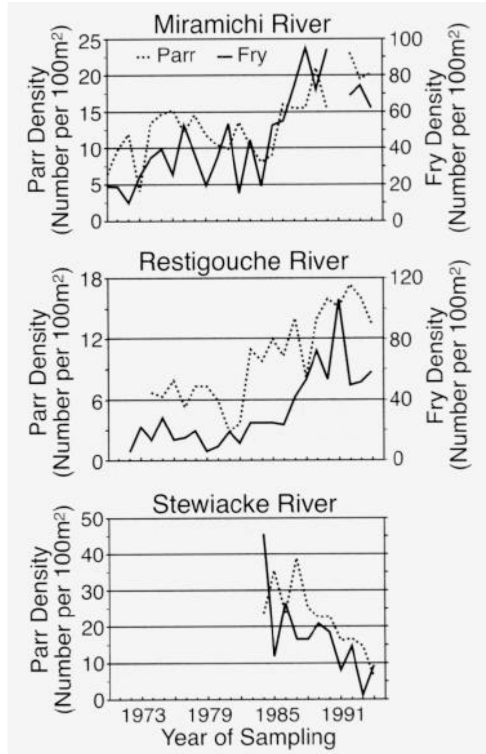


Figure 3: Trends in juvenile densities from three rivers in the Maritimes Region. Data sources are: Restigouche River (Locke et al. *MS1995) Miramichi River (Chaput* et al. *MS1995) and Stewiacke River for 1984 to 1991 (Amiro MS1992) and for 1992 to 1994 (Anon. 1995a).*

Status Over the Last Two Decades

The commercial fisheries were closed and recreational fisheries for large salmon were converted to hook-and-release in 1984 in response to the declining escapement of Atlantic salmon throughout the Maritime Provinces. The expectation of this management action was that escapement would increase with increased recruitment in future generations. The expectations have been borne out in the southern Gulf of St. Lawrence stocks but not in the Bay of Fundy and Atlantic coast rivers.

Juvenile surveys have been conducted annually since 1970 at index sites in both the Miramichi and Restigouche rivers. The increased escapement of adult salmon in these rivers was followed by the increased abundance of fry (hatch of the current year) and parr (juveniles of one year old or more) (Fig. 3). Juvenile salmon densities have remained high since 1985 at about twice the levels observed in the 1970's. A shorter time series of juvenile data from the Stewiacke River (inner Bay of Fundy) shows the opposite trend with both fry and parr densities declining since 1984 and being at the lowest level ever in 1994 (Fig. 3).

Spawning escapement and total returns of 2SW salmon also show opposite trends in the two geographic areas. Where returns and escapements to the southern Gulf of St. Lawrence rivers generally improved since the 1970's, escapements to the Bay of Fundy and Atlantic coast rivers peaked in 1985 and returns as well as spawner abundance have continued their downward trend to the lowest level ever in 1994 (Fig. 4). The escapement of 2SW salmon to Canadian rivers in 1994 was estimated to have been fewer than 82,000 fish, 50% of which spawned in the southern Gulf of St. Lawrence rivers (Anon. 1995b). With healthy salmon stocks throughout Canada, the southern Gulf stocks would be expected to contribute about 28% of the total Canadian 2SW spawning escapement.

Why are There Differences Between Areas?

In terms of habitat perturbations, the southern Gulf of St. Lawrence rivers are comparatively pristine. Many of the Atlantic coast rivers have been impacted by acid rain depositions. Five Bay of Fundy rivers have been developed for hydro-electric generation, the most notable being the Saint John River. More recently a tidal power generating station was constructed at the mouth of the Annapolis River, Nova Scotia. Several of the Bay of Fundy rivers are also impacted by causeways situated at or near their mouths, the most significant being on the Annapolis River (Nova Scotia) and the Petitcodiac River (New Brunswick). Provision for salmon passage on the latter is known to be ineffective.

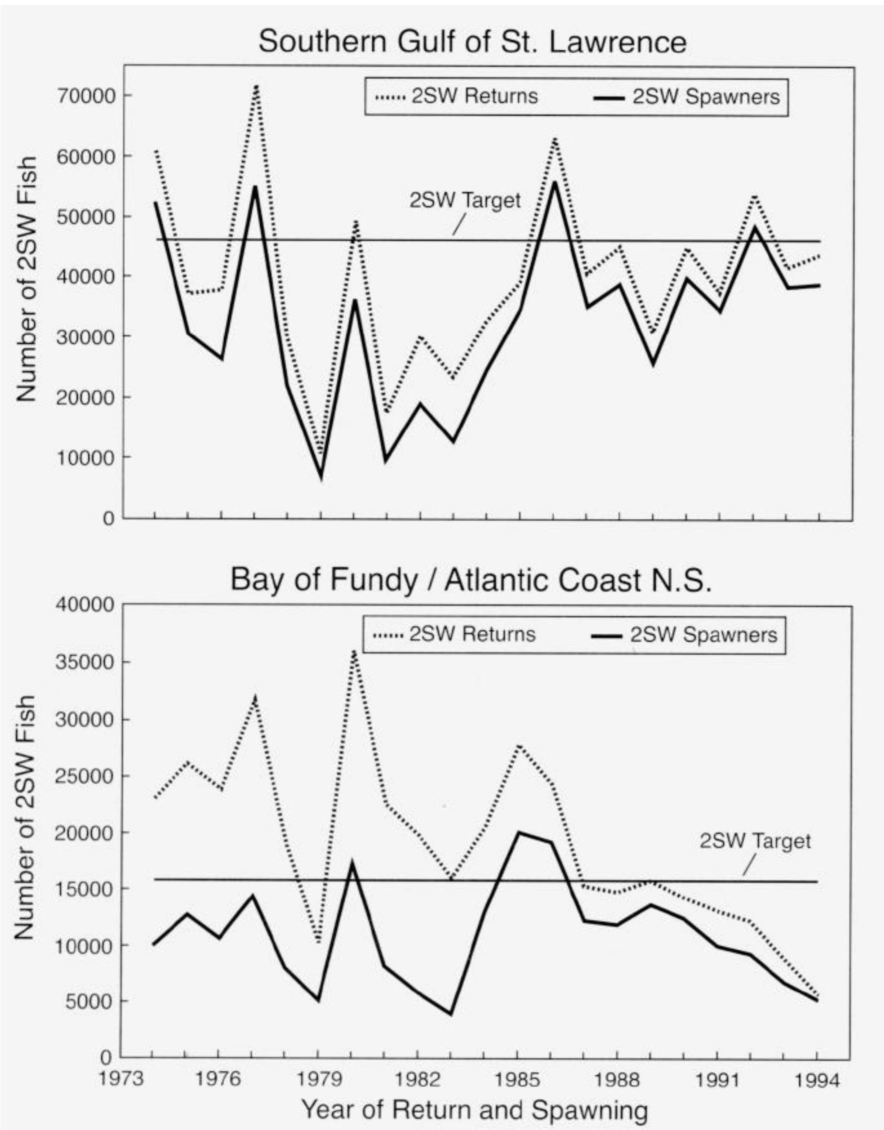


Figure 4: Trends in returns and escapements of 2SW salmon to two areas of the Maritimes, 1974 to 1994. Data are from Anon. (1995b).

Marine conditions have also changed. The winter marine habitat in the Northwest Atlantic, based on sea surface temperatures and corresponding probability functions of salmon abundance at temperature (Reddin *et al.* 1993), has decreased since 1983 and has remained low compared to the 1970's (Fig. 5). The marine habitat area during January to March is highly correlated with the abundance of 2SW salmon in North America (Anon. 1995b). There is also a strong correlation between the marine habitat area and the sea survivals of hatchery reared smolts to the Saint John River (Fig. 5), suggesting that a marine environmental factor may be contributing to the depressed stock levels. Although the correlation with the southern Gulf of St. Lawrence 2SW returns is not evident, higher returns of salmon were observed in the 1970's when the Greenland high seas fishery was harvesting as many as 200,000 salmon of North American origin annually (Anon. 1990). This occurred at a time when juvenile densities in the Miramichi and Restigouche were about half the current levels. The returns in recent years of 2SW salmon to the southern Gulf of St. Lawrence rivers are stable in spite of the depressed marine survival observed in other stocks. Stable returns could be the result of high smolt production from these rivers as inferred from the increased juvenile densities.

Long-term Prospects

For the southern Gulf of St. Lawrence stocks, the returns are expected to remain the same or increase, especially if marine survival remains the same or improves. For the stocks of the Bay of Fundy and Atlantic Coast of Nova Scotia, there is very little basis for optimism. Freshwater production, even when not impacted by habitat perturbations as in the case of the Stewiacke River. is depressed. Even if sea survival were to improve substantially, less smolt production is expected from these rivers

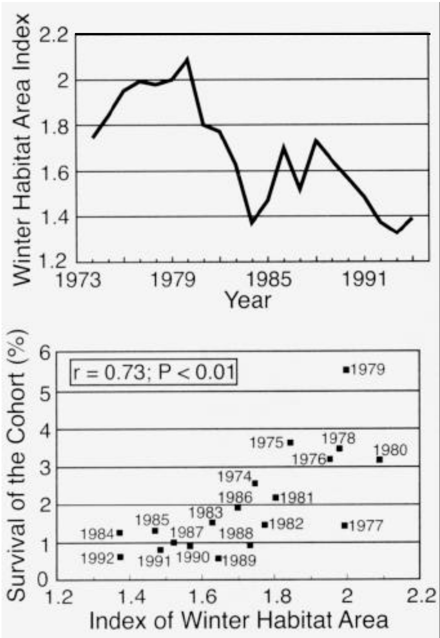


Figure 5: Trends in the winter marine habitat index of the Northwest Atlantic (upper) and relationship between the marine habitat index and sea survival of the cohort of the hatchery-reared smolts from the Saint John River (lower). Habitat index data are from Anon. (1995b) and molt survival data are from Marshall and Cameron (MS1995).

and recovery to the levels of the 1970's will be further delayed.

There is little opportunity to improve sea survival by regulating fisheries because fisheries-induced mortality has been essentially eliminated. The only large salmon harvests are in First Nations food fisheries and these represent a negligible proportion (<1%) of the total returns. Remnants of marine commercial fisheries exist off the Labrador coast and the Quebec north shore. The Greenland fishery is greatly reduced from its peak harvest of almost 2,700 t in 1971 (Jensen 1988).

Chadwick (1995) proposed index rivers as the most useful way to manage anadromous fish stocks. It is not possible to pick a single river in the Maritimes which would be representative of the status of the Atlantic salmon stocks but stock status is more similar within two main geographic areas: the southern Gulf of St. Lawrence rivers and the Bay of Fundy/Atlantic coast rivers. The Atlantic salmon species in the Maritimes is defined by its stock complexity. Reliable indicators of stock abundance are required to properly manage the resource. The key to ensuring its sound management lies in recognizing this diversity and in monitoring the largest number of stocks possible.

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Ocean Climate Variability on the Scotian Shelf and in the Gulf of Maine

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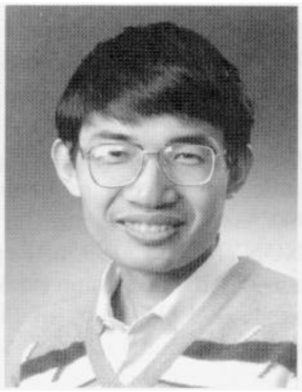
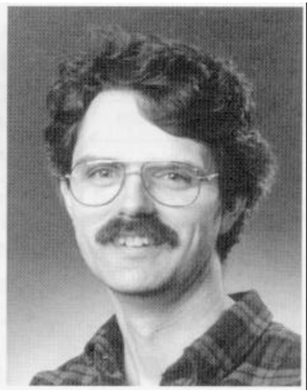


G. Han



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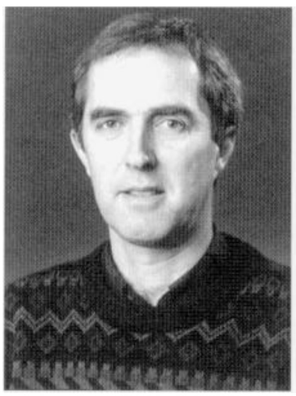

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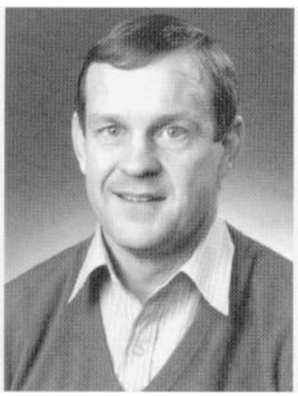

P. Smith

Introduction

Thirty-two years ago in Rome at the International Commission for the Northwest Atlantic Fisheries (ICNAF) Environmental Symposium, Louis Lauzier of the St. Andrews Biological Station reported on the long-term water and air temperature variations in the Scotian Shelf-Gulf of Maine area (Lauzier 1964, see Figure 1 for locations mentioned in text). Using sea surface temperature time series from coastal sites and lightship vessels, and deeper data from a small number of offshore banks and channels, he was able to describe the year-to-year fluctuations and the longer-term trends of the ocean climate from Cabot Strait to the central Gulf of Maine. In his closing discussion Lauzier stated: "We cannot explain the long-term variations of temperatures described previously. ... More information on the circulation, water mass production and heat budget is essential. Little is known about the first two and less about the last one."

Since Lauzier's presentation, the ocean climate of the Scotian Shelf-Gulf of Maine area has continued to experience short and long-term variations. There also has been a dramatic increase in the amount of temperature and salinity data collected in the region. Extensive databases of oceanographic observations along with tools for rapid recovery and analysis of these data have allowed us to describe the climate fluctuations in more detail than in the past. Meteorological and sea surface temperature data have been combined to permit calculations of the transfer of heat between the atmosphere and ocean. Moreover, models have been developed that can examine the effects of climate changes on ocean currents on the continental shelf. All of these factors have contributed to the progress that has been made in addressing the issues raised by Lauzier.

Average Conditions

Before discussing the climate variations that occur in Scotian Shelf-Gulf of Maine waters, we shall briefly describe the average conditions. As an example, the wintertime surface temperature and salinity for the northwestern Atlantic shelf are shown in Figure 2. The Scotian Shelf-Gulf of Maine region features surface water temperatures from about - 1 to 6°C and surface salinities of 32-33. The region is part of a larger oceanographic area that includes the Gulf of St. Lawrence, Newfoundland and Labrador Shelves. The shelf waters tend to move through the region in an overall southwesterly direction. from the Labrador Shelf to the Newfoundland Shelf and the Gulf of St. Lawrence, and finally onto the Scotian Shelf and into the Gulf of Maine. The northern component of the region's waters contributes to their lower temperatures and salinities relative to the offshore oceanic waters. River discharge and land runoff also tend to reduce salinity. Over the continental slope offshore of the Scotian

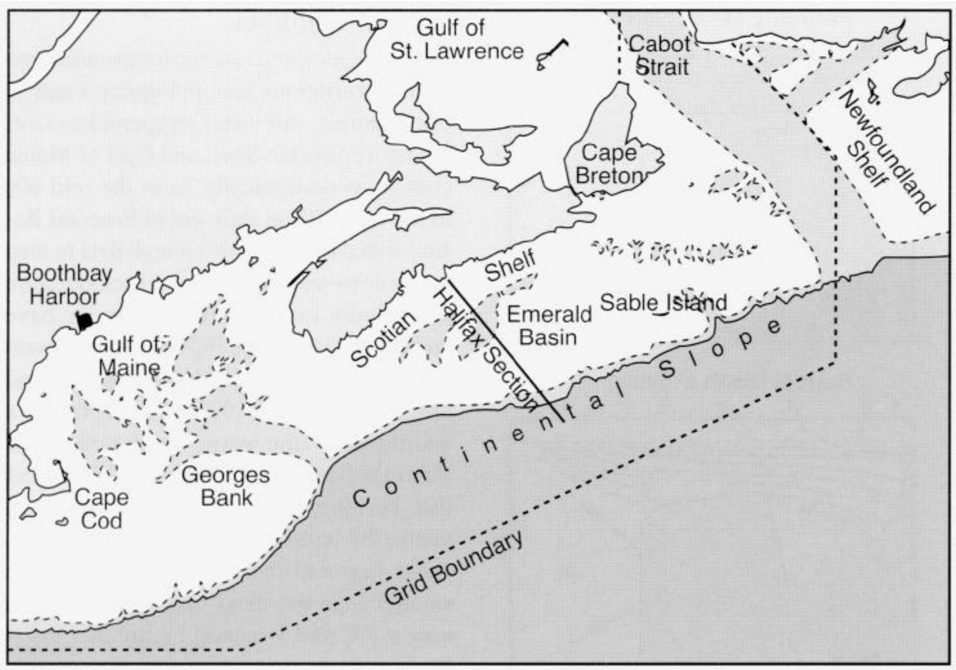

Figure 1: Area map with place names used in the text.

Shelf, the temperature and salinity increase to values characteristic of the Gulf Stream and the Sargasso Sea. We are left with the impression of a distinct shelf regime adjacent to the deep ocean. A similar general picture holds throughout the year.

The temperature and salinity also change with depth and season. During winter on the Halifax Section (see Figure 1 for location), the ocean has a two-layer structure with cooler, fresher waters near the surface overlaying warmer, saltier waters (Fig. 3). In summer, the temperature of the near-surface waters increases substantially giving rise to a three layer structure with a warm surface layer, a cold intermediate-depth layer and a warm bottom layer. The bottom layer in Emerald Basin, the deep shelf basin in Figure 3. is caused by relatively dense water from the continental slope moving onto the shelf and flooding the inner basins. Through mixing, these waters gradually influence the shallower waters over the shelf. The deep inner basin waters generally remain there until they are displaced by another onshelf flow of slope water.

The water over the upper continental slope is typically made up of two types: Labrador Slope Water, derived principally from the Labrador Current, with temperatures of 4-8°C and salinities of 34-35; and Warm Slope Water, with a major component from the Gulf Stream, with higher temperatures and salinities of 8-13°C of 34.5-35.5 respectively. The changing proportions of these two types of slope water, one time the cooler, fresher Labrador Slope Water dominant, another time the warmer, saltier Warm Slope Water, causes variations in the temperature and salinity of the shelf waters.

Temperature and Salinity Variability

Temporal Changes

One of the data series Lauzier used to illustrate ocean climate variability was the sea surface temperature record from Boothbay Harbor, Maine. Started in 1906, this record is one of the longest for the east coast of North America. The annual mean temperatures show that large fluctuations can occur from year to year (Fig. 4); in addition, there have been extended periods when temperatures were well above normal, particularly from the late 1940s to the late 1950s, and well below normal, for several years centred around 1915, 1940 and 1965. To determine if these temperature variations also occurred offshore, we examined data collected from oceanographic ships. However, in this instance, we are restricted to the last 50 years because there were only a limited number of surveys prior to 1950. Even since 1950, there are areas of the shelf that have substantially more data than others.

One such area is Emerald Basin where observations were taken frequently for three decades as part of the standard oceanographic Halifax Section. In addition, as we saw above, data from the Basin cover essentially the full range of temperature and salinity properties on the shelf, including offshore waters from the upper continental slope.

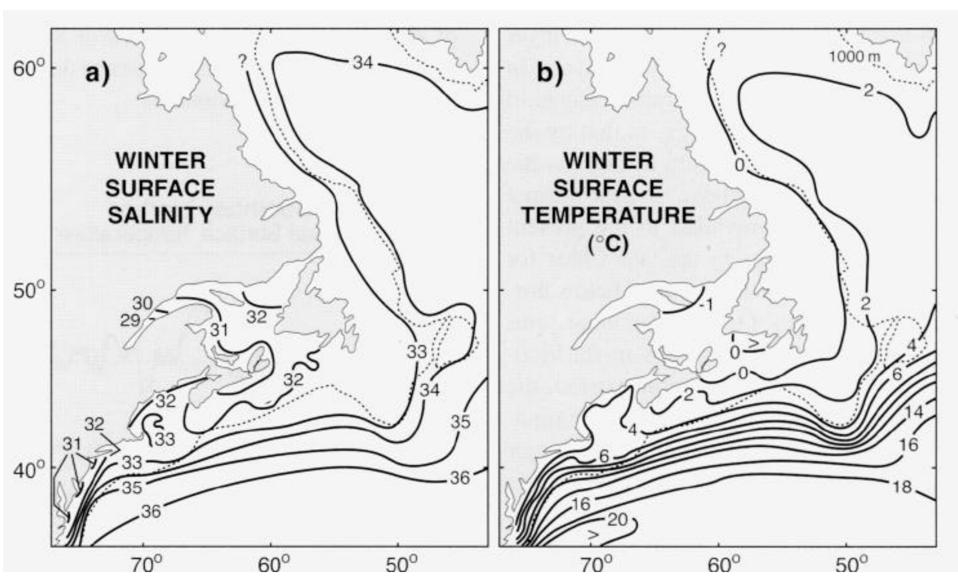

Figure 2: Winter surface temperature and salinity for the northwestern Atlantic shelf region.

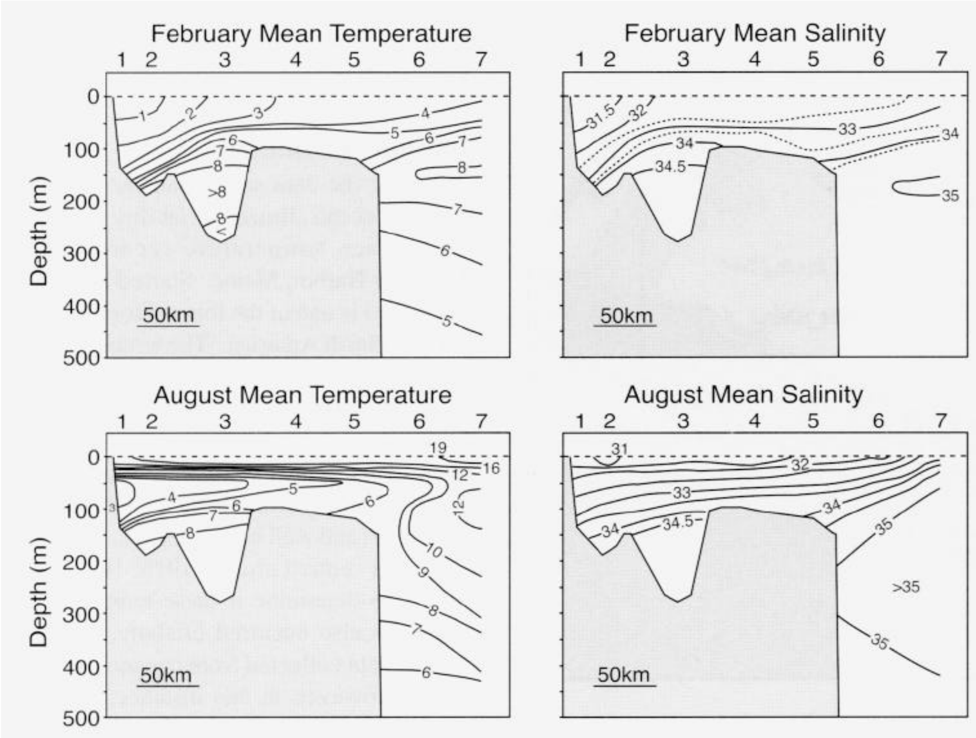

Figure 3: Average February and August temperature and salinity on the Halifax Section across the Scotian Shelf.

The variability of the annual temperature anomaly (the difference of the average temperature for any given year from the mean value calculated for all years combined) is quite similar to the temperature at Boothbay Harbor for the same period (Fig. 5). From the early 1950s to the mid 1960s, the temperatures in Emerald Basin decreased steadily from about 1°C above normal (positive anomalies) to about 3°C below normal (negative anomalies) in the 0-200 m layer. Over this period the decrease was greater for the deeper 100-200 m layer than for the shallower 0-100 m layer. In the late 1960s there was a rapid change to above normal temperatures, so that by the mid 1970s the values were as high as the earlier maximum. Above or near normal conditions have prevailed to the present time. Occasionally, in the late 1980s for example, the 0-100 m layer had below normal temperatures. On the other hand, temperatures in 1994-95 were among the highest recorded. Over the entire period, the lower layer generally had greater anomalies than the shallower one. The larger magnitude of the anomalies in the deeper layer was one of the factors that led Petrie and Drinkwater (1993) to conclude that the long-term changes were caused by subsurface waters from the upper continental slope moving onto the shelf and flooding the deep inner basins. These waters would then spread into the upper layers with their influence diminishing as they mixed with the shallower waters.

The variations of salinity are not as systematic as those for temperature. However, the periods of below normal temperatures generally have below normal salinities and vice versa. This is consistent with Labrador Slope Water dominating during times of negative anomalies, and Warm Slope Water having the greatest influence during periods of positive anomalies.

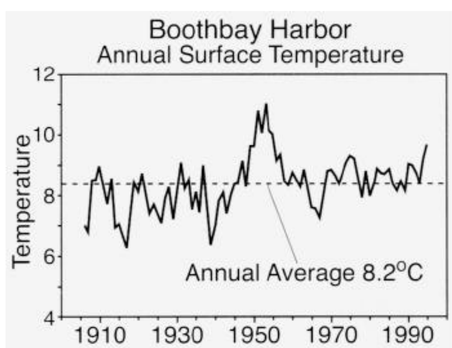

Figure 4: Time series of the annual surface temperature for Boothbay Harbor, Maine from 1906-1995.

Spatial Changes

How widespread are the temperature and salinity variations seen in Figures 4 and 5? For example, did water temperatures over the entire Scotian Shelf and Gulf of Maine change as dramatically from the mid 60s to the early 70s as they did in Emerald Basin? Since there are not enough data to map the year-to-year variations of temperature and salinity for the entire region, we have combined data from 1959-67 to represent a cold period (henceforth the cold 60s) and observations from 1972-81 to represent a warm period (the warm 70s) based on the Emerald Basin record (Fig. 5). We expect that, because we averaged data from many years, the temperature and salinity differences between these two periods will be smaller than the maximum differences of nearly 5°C and 1 seen in Figure 5.

For each of the two combined datasets. we calculated the temperature and salinities for each season for the shelf area from Cabot Strait to Cape Cod as well as for a limited region over the continental slope (indicated by the grid boundary in Figure 1). The differences between the warm and cold years for the summer for the sea surface and the bottom (or 300 m, whichever is shallower) are shown in Figures 6 and 7. Positive values mean that the temperatures in the warm 70s were greater than in the cold 60s. whereas, negative values mean the opposite.

At the surface the differences range from about -1°C to about 3°C (Fig. 6). Negative values are found on the eastern Scotian Shelf, particularly east of Cape Breton, and in an area over most of Emerald Basin and extending southward to the continental slope. Over most of the region, differences of 1-2°C prevail. In the Gulf of Maine. there is a small patch with temperature differences of about 3°C.

At the bottom the temperature differences range from just below zero to about 3°C and are generally greater than at the surface (Fig. 7). Negative differences are limited to the eastern Scotian Shelf and around Sable Island; otherwise, the differences are positive. In particular, the region over and west of Emerald Basin has a value of 3°C. Temperature differences in the Gulf of Maine and Georges Bank are 1-2°C.

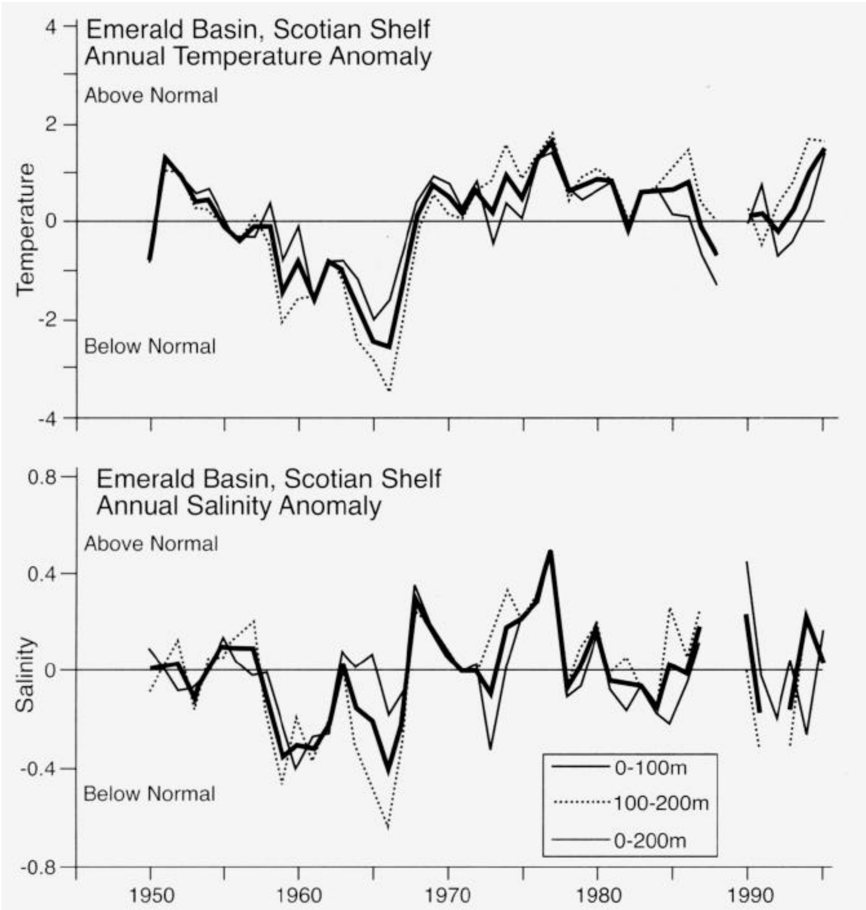

Figure 5: Time series of the annual temperature and salinity anomalies for Emerald Basin for the 0-200, 0-100 and 100-200 m layers. Gaps in the record indicate years when data were not collected.

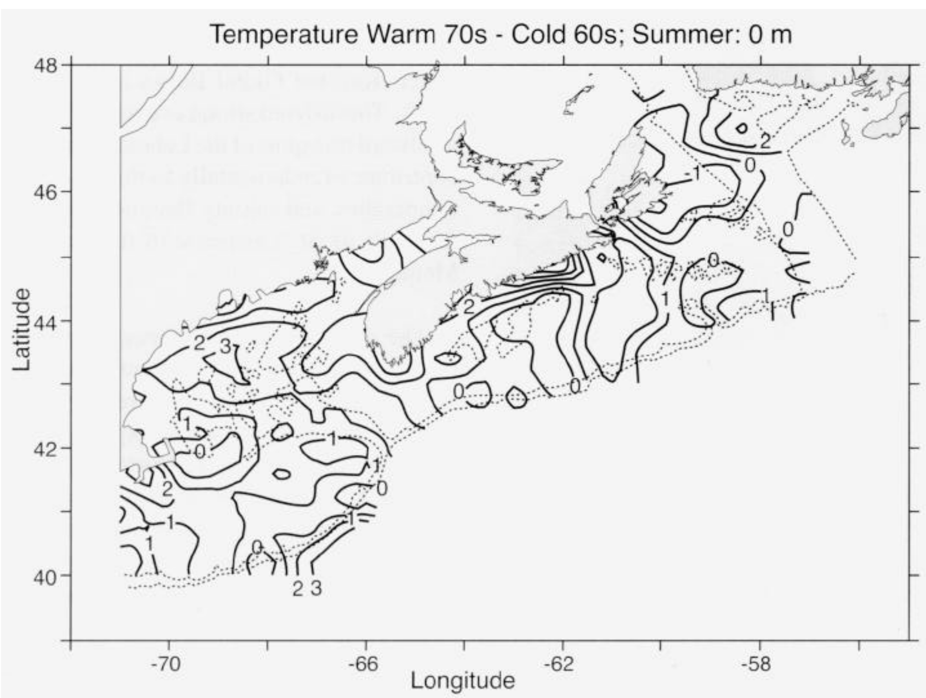

Figure 6: The summer, surface temperature differences (Warm 70s-Cold 60s). A positive difference means that the temperature in the warm 70s was higher than during the cold 60s and vice versa.

Similar analyses show that there were higher salinities during the 1970s associated with higher temperatures over most of the Scotian Shelf and the Gulf of Maine. The eastern Scotian Shelf was the exception with lower surface salinities in the 1970s corresponding to the lower temperatures found there.

We conclude that the shift to higher temperatures and salinities between the 1960s and 1970s was widespread across the Scotian Shelf and the Gulf of Maine but the magnitude varied with location. Thus the time series of Emerald Basin temperatures and salinities (Fig. 5) capture the general flavour of the climate variations in the region but the exact nature of the changes depends on the site.

Circulation Variability

We have seen how temperature and salinity changed over a wide area in the last section. Did these changes affect the currents as well? Or, on the other hand, did changes to the currents cause the variations of temperature and salinity? To address these questions, we have examined the vertical temperature, salinity and density structure for the cold 60s and the warm 70s for the Halifax Section. The winter values are shown in Figure 8 where the temperature, salinity and along-shelf current (derived from the density structure) for the cold 60s are shown in the left hand panels; the differences between the warm 70s and the cold 60s are shown on the right. The deep temperatures and salinities were higher over the continental shelf and slope during the warm 70s, consistent with a greater contribution of Warm Slope Water. On the other hand, salinities and (to a lesser extent) temperatures were lower at shallower depths, particularly over the continental slope. apparently related to increased St. Lawrence River runoff during the warm 70s. A key result is the indication of significant changes in the current structure especially evident as reduced southwestward flow over the slope during the warm 70s, which is consistent with a reduced Labrador Slope Water influence on slope water properties. The sense of this picture for the currents over the slope does not change from season to season and demonstrates that important long-term circulation changes on the Scotian Shelf are associated with variations

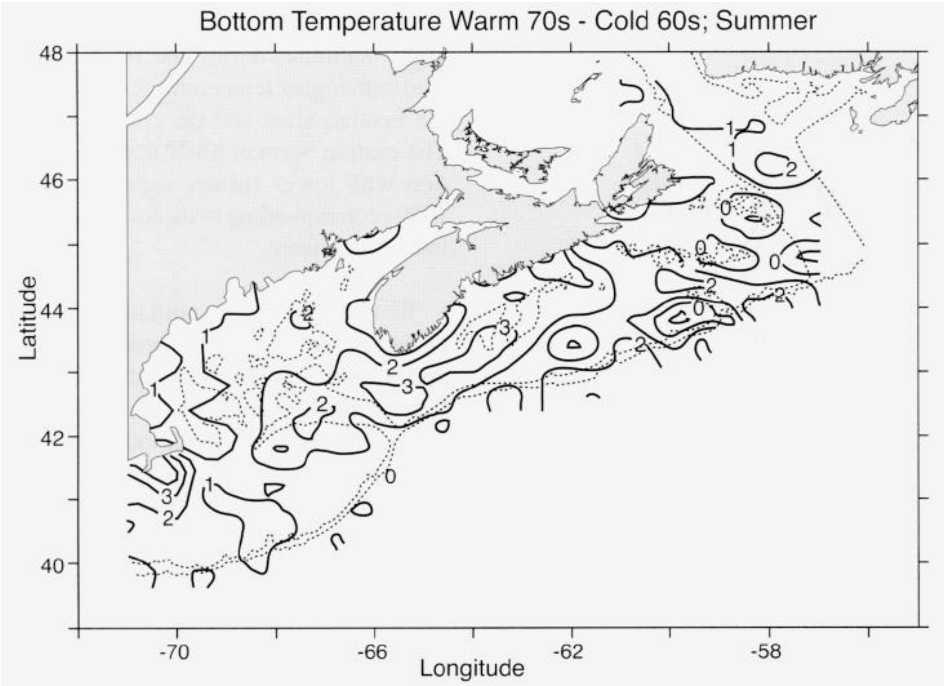

Figure 7: The summer bottom (or 300 m, whichever is shallower) temperature differences (Warm 70s-Cold 60s). A positive difference means that the temperature in the warm 70s was greater than during the cold 60s and vice versa. Note that the bottom depths vary from about 10 to over 1000 m in the region.

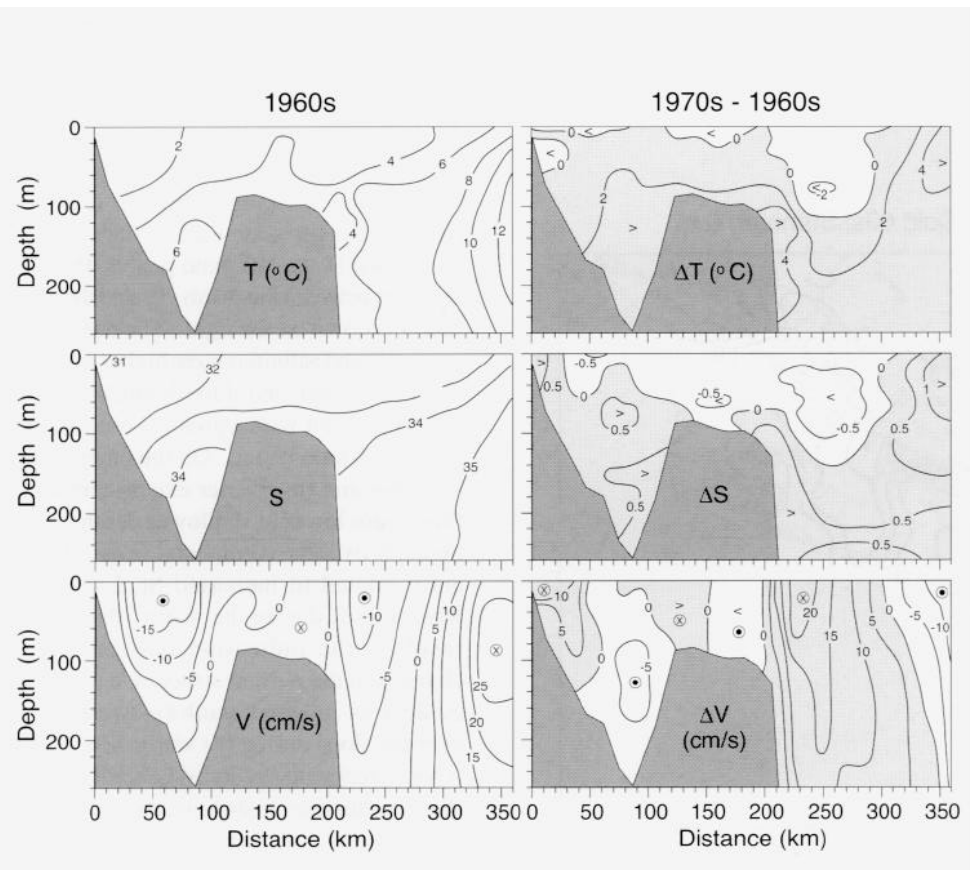

Figure 8: Wintertime estimates of temperature, salinity and along-shelf current (positive northeastward) for the Halifax Section. The left panels are the values for the cold 60s, the right hand panels are the differences between the warm 70s and the cold 60s.

in the temperature and salinity fields that in turn are strongly influenced by the upstream supply of both shelf (from the Gulf of St. Lawrence) and slope (Labrador Current) waters.

Causes of the Temperature and Salinity Variations

Thompson *et al.* (1988) suggested that year-to-year variations in the magnitude of the local heat exchange between the atmosphere and the ocean might account for the longer-term variability characterized by the temperature in Figure 5. However, a quantitative investigation by Umoh (1992) indicated that this was not true for the central Scotian Shelf. In addition, estimates of the atmosphere-ocean heat exchange indicate that there was slightly more heat transferred to the ocean during the cold 60s than during the warm 70s, contrary to expectations. Thus it is unlikely that local atmosphere-ocean exchange was the cause of the long-term temperature variability.

On the other hand, Petrie and Drinkwater (1993) found that during the cold 60s the westward flow of the Labrador Current along the upper slope from the Newfoundland to the Scotian Shelf was about four times greater than during the warm 70s. They used this observation in a simple model to predict successfully the temperature and salinity properties of the slope water from the Grand Banks to Georges Bank. This offered strong evidence that the westward transport of the Labrador Current contributes fundamentally to the observed temperature and salinity fluctuations from the Gulf of St. Lawrence to the Gulf of Maine.

The question of what causes the variations of the Labrador Current naturally arises. At present we must respond, as Lauzier did, that we cannot explain these long-term variations of the Current. On the other hand, significant progress has been made addressing the issues he raised: characterizing the changes in water mass structure, determining their effects on the circulation over the continental shelf and slope, evaluating the heat exchange between the atmosphere and ocean, and defining the role of the Labrador Current in the production of slope water.

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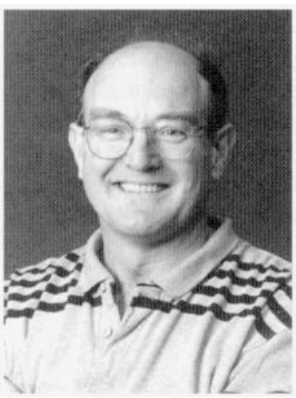
Organochlorine Levels in the Marine Food Web of the Southern Gulf of St. Lawrence

G. Harding, P. Vass and B. Hargrave



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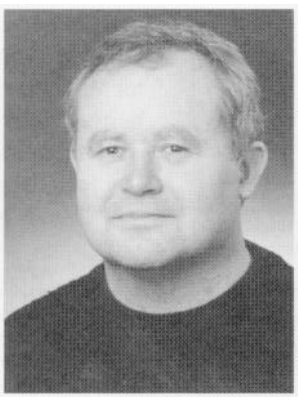

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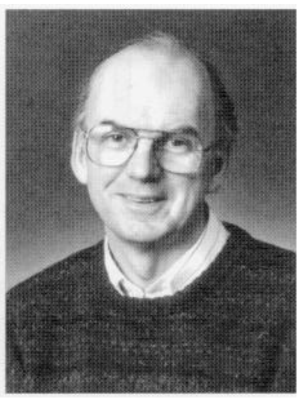

B. Hargrave

The southern Gulf of St. Lawrence accounts for approximately one-quarter of the commercial fishery landings off the east coast of Canada. This large body of water receives substantial quantities of organochlorines from the more populated and industrialized regions of the continent, mainly from atmospheric transport and subsequent precipitation and from river flow. The total freshwater drainage area of the Gulf is 1.35 X 10^6 km^2, of which the highly urbanized and industrialized (about 45 million people; Environment Canada figures for 1991) St. Lawrence River-Great Lakes region makes up 1.18 X 10^6 km^2 (Canadian Government 1973) with an average annual outflow of 10,730 m^3. s^{-1} (1959-1989; K. Drinkwater pers. Comm.) Moreover, the Gulf of St. Lawrence is located on the lee side of the continental atmospheric circulation and thereby receives atmospheric fallout from the major industrial centres of the Great Lakes region and the eastern seaboard of the United States (Bryson *et al.* 1974).

Organochlorines are a chemical class of compounds, not known to exist naturally in the environment, which were produced in large quantities in N. America for their toxic properties for agriculture [eg DDT family, lindane, toxaphene, etc] and their heat resistent qualities for industry [eg. polychlorinated biphenyls (PCBs)] Although pesticides such as DDT were all but banned from North America in the early 1970s, considerable quantities still escape to the global atmosphere from Central and

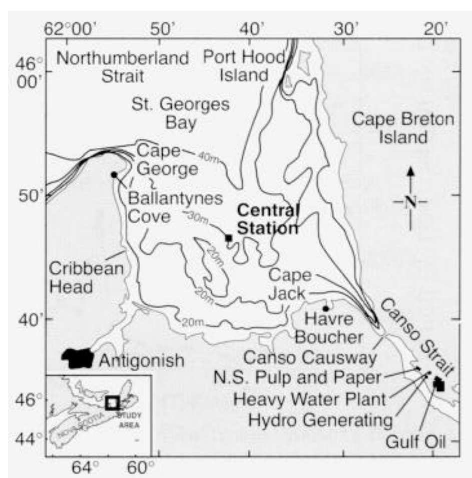

Figure 1: Study area showing the collection sites in St. Georges Bay, N.S.. and the urban and industrial centres of the region.

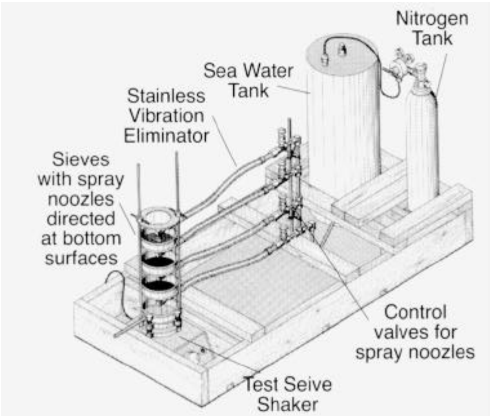

Figure 2: The vibrating sieve apparatus developed and used to sort plankton into size categories from 1977 to 1993.

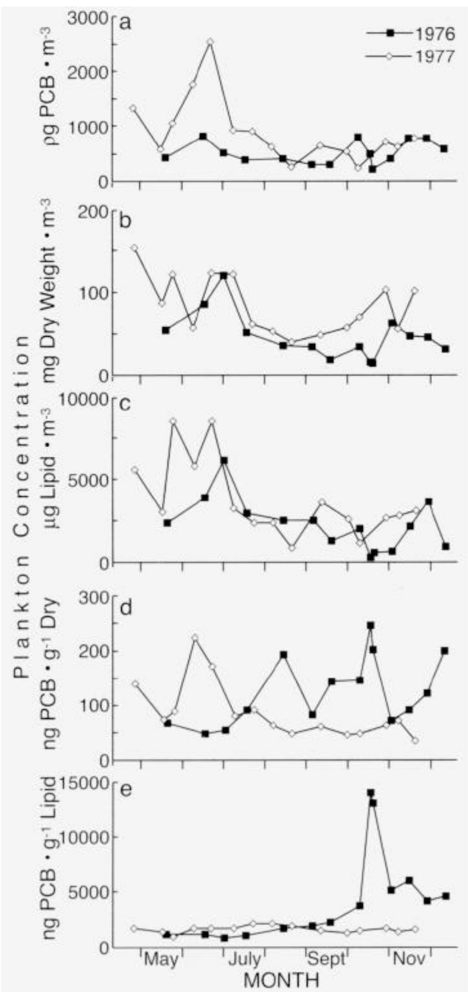

Figure 3: Seasonal distribution of PCB, dry and lipid content of plankton per m^3 and PCB concentrations on a dry and lipid weight basis in the combined 66-2035um size fiactions from St. Georges Bay. 1976 and 1977.

South America where its use continues as an inexpensive method for malaria control. Similarly, PCBs continue to escape from dump sites in spite of the near-global ban on their manufacture since the 1980s. Organochlorines have a high lipid but low water solubility and are highly resistent to degradation (Hutzinger *et* al. 1974) which results in their bioaccumulation in marine food chains (Hargrave et al. 1992). The toxic properties of organochlorines are of concern to human health because of our own position in the trophic chain (Feely 1995, Hansen 1996). It is important to the fisherman, the fish plant worker, the consumer and government regulators that we understand more fully the dynamics of these contaminants in the marine environment.

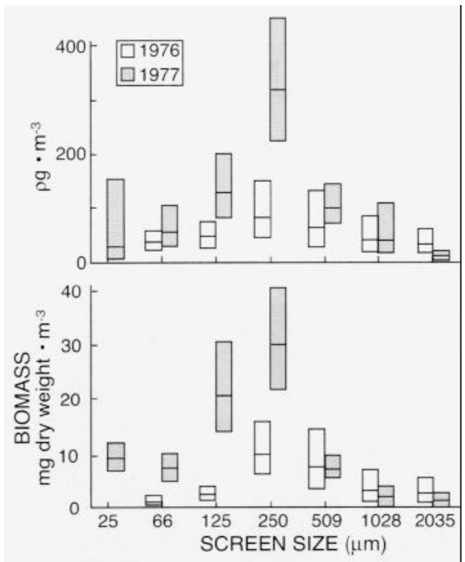

Figure 4: Size-frequency distributions of PCB content arid dry weight of plankton per m^3 in St. Georges Bay in 1976 and 1977 (G.M. and 95% CI shown).

In the present account we report results of research which provided measurements of organochlorine levels in the pelagic marine food web of southern Gulf of St. Lawrence from the mid 1970's through to the 1990's. St. Georges Bay, Nova Scotia, was chosen as a representative embayment within the southern Gulf of St. Lawrence to study organochlorine pollution because it is relatively remote from local sources of industrial and domestic effluents (Fig. 1). To understand bioaccumulation of organochlorines in an ecological entity such as the Gulf, organisms were studied as components of a food chain. Simplistically, or-

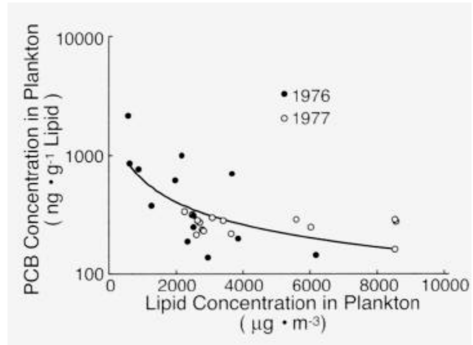

Figure 5: The relationship between planktonic PCB concentration normalized to lipid content and lipid content of plankton per unit volume seawater filtered for combined size fractions for individual sampling trips in 1976 and 1977. The solid line represents the best least squares fit to log-transformed data: $Y = 57764X^{-0.655}$, $r = 0.73$, $N = 28$.

ganisms can be grouped within trophic levels, such that all plants are the primary producers, herbivores are the primary consumers, carnivores are secondary. tertiary, etc. consumers. Plankton was collected with three to four nets with different mesh sizes and sorted to seven to nine size categories (logarithmic) with a specially designed and constructed vibrating sieve apparatus (Fig. 2) Silversides and smelt were collected at night under the glare of spotlights with a dip net. White hake were collected by otter trawling in the bay. Capelin, gaspereau, herring and mackerel were obtained free of contamination from boat paint, grease etc. from a local gillnet and a trap fishermen.

PCBs, as Aroclor 1254, were quantified

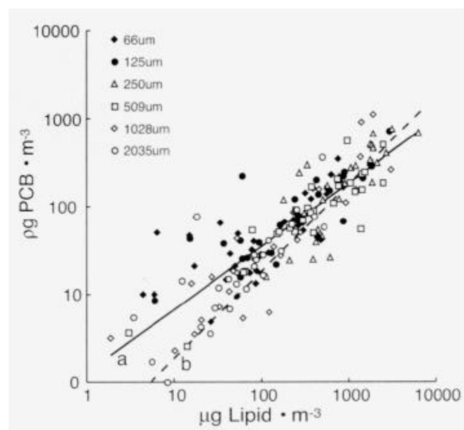

Figure 6: The relationship between PCB and lipid content in plankton in the water column, plotting individual sieve size fractions collected in 1976 and 1977. The solid line represents the least squares fit to log-transformed data: $Y = 1.26x^{0.72}$, $r = 0.86$, $N = 176$; whereas the dashed line represents a best fit to a linear equation passing through the origin; $Y = 0.187X$.

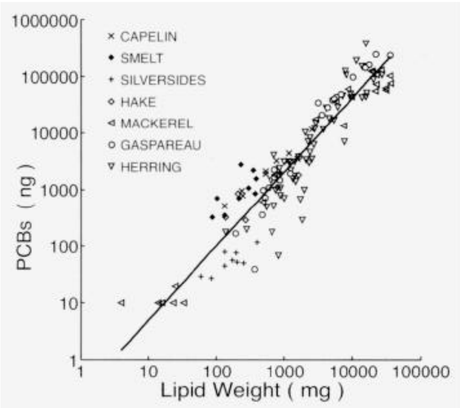

Figure 7: The relationship between PCB content (ng) arid lipid weight (mg) of seven fish species collected in St. Georges Bay, N.S., during 1977. The fitted line represents a least squares fit to log-transformed data: Y = $0.236X^{1.313}$ r = 0.94, N =135.

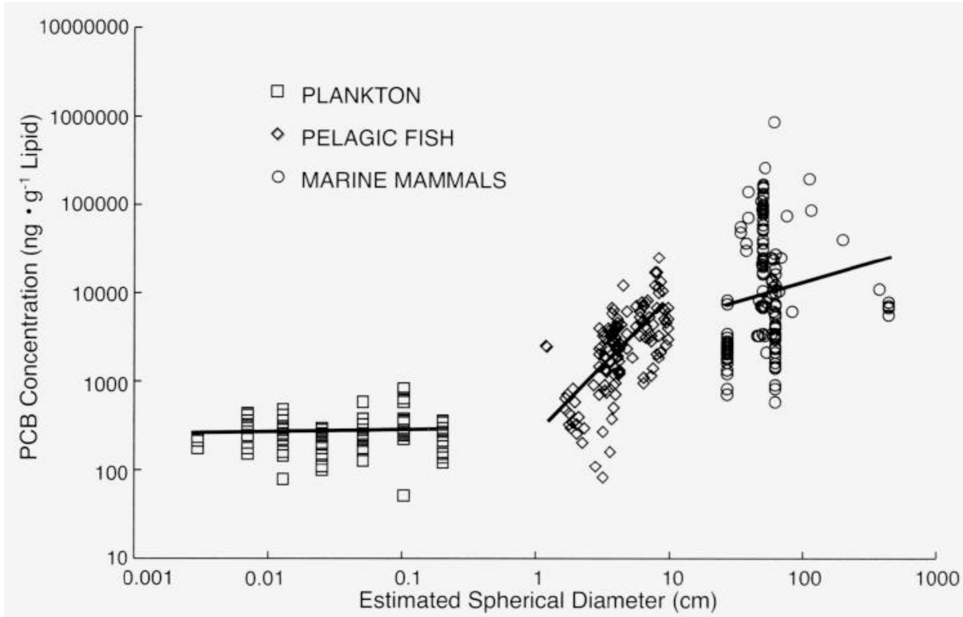

Figure 9: PCB levels in plankton, pelagic fish and marine mammals normalized to lipid content a&plotted against body size (Equivalent Spherical Diameter). The plankton and fish were collected in 1977 from St. Georges Bay, N.S. Information on marine mammals was collected in the 1970s and published in the literature (see Harding et al. *in press).*
Plankton are fitted by: Y = $254x^{0.01}$, r = 0.03, n = 88.
Fish are fitted by: Y = $216X^{1.58}$, r = 0.68, N = 135.
Marine mammals are fitted by: Y = $1337X^{0.51}$, r = 0.18. N = 131.

in bulk seawater from St. Georges Bay in the late 1970s at 3.1±1.0 $ng.L^{-1}$ (X±SD; parts per trillion), whereas the contamination measured in plankton was three orders-of-magnitude greater at 2.9±3.3 $ng.g^{-1}$ wet weight (parts per billion). However on an ecosystem basis, it is necessary to express PCB contamination of plankton on a habitat volume basis. The PCB levels in plankton of 25um to >2.0mm ESD (nominal equivalent spherical diameter) in the water column was 62±49 $pg.m^{-3}$, which is four orders-of magnitude less than that measured in seawater. Seasonal concentrations of PCBs in the plankton component of the ecosystem tended to be highest in the spring and lowest in the summer, followed by slightly elevated but variable levels in the late fall (Fig. 3a). A similar pattern was evident in the seasonal distribution of plankton standing stock (Fig. 3 b&c) but not in the PCB concentration per unit biomass (Fig. 3 d&e). The seasonal decline noted in total planktonic PCBs (pg $PCB.m^3$) of the southern Gulf of St. Lawrence is mainly due to the reduced summer biomass present in the 509 and 1028um seive fractions between mid-july through to the beginning of October (Fig. 4), because the relative PCB concentration present in terms of dry or lipid weight did not change consistently during this period (Fig. 3 d&e).

This dependence of planktonic PCB concentrations on standing stock also is evident from a plot of PCB concentration versus lipid concentration in the plankton (Fig. 5). The lower the planktonic lipid content of the St. Georges Bay ecosystem, the more concentrated the PCBs are in the remaining lipid pool. Planktonic PCB concentrations, expressed on a lipid basis, were found to be correlated with cumulative rainfall 21 days before sampling for the two years analysed to date. Ware and Addison (1973) found a similar correlation between planktonic PCB concentrations and rainfall 10 to 20 days prior to collection. This suggests that the shorter-term pulses of PCB input into the southern Gulf, reflected in the plankton, are most likely due to atmospheric input washed out with the rain. The 1976 and 1977 time series of planktonic PCB and lipid content per m^3 were analysed for each size fraction by cross-correlation techniques after the common trends were

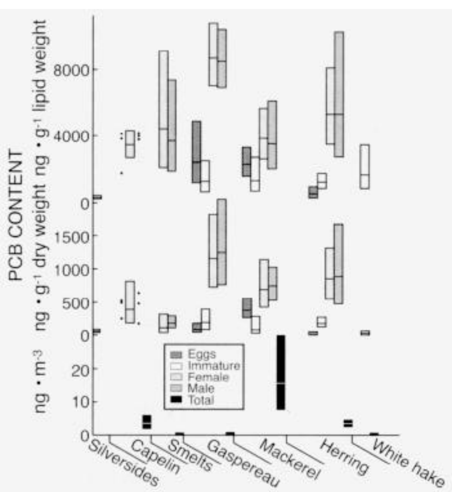

Figure 8: PCB concentrations, based on a lipid weight, dry weight and per m^3 basis, present in eggs, immatures, adult female and male individuals of seven fish species collected in St. Georges Bay, N.S., during 1977 (GM and 95% C.I.).

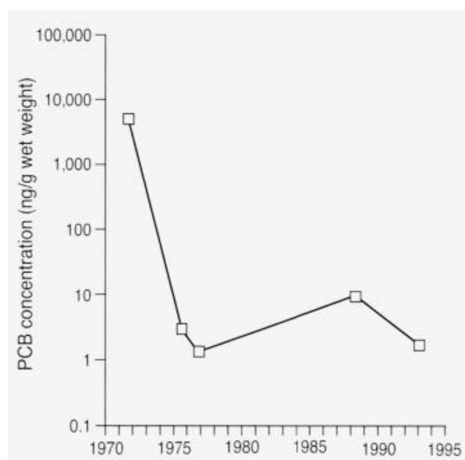

Figure 10: Mean PCB content in plankton in the size range 125 to 509um collected in the southern Gulf of St. Lawrence between 1972 and 1993.

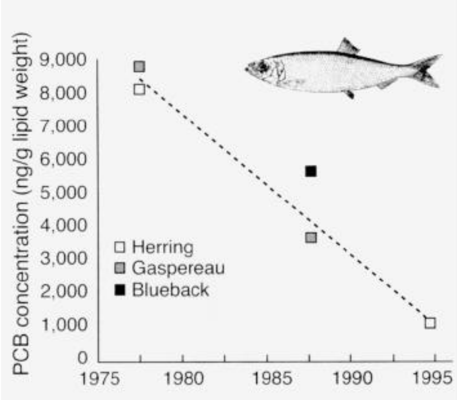

Figure 11: Mean PCB content of clupeid fish in the southern Gulf of St. Lawrence between 1977 and 1994.

removed from the data (Wilkinson *et al.* 1992). In the majority of cases, a significant positive correlation was obtained between PCBs and lipid content of the planktonic community with no time lag. One conclusion is that the plankton sampling interval chosen of three to four weeks was too long to be able to detect an increased uptake of PCBs as a result of atmospheric input or an expanded 'lipid pool' in a prolific feeding population.

PCB concentrations in both plankton and fishes are very dependent on the lipid concentration of the organism (Fig. 6 & 7), which follows from their lipophilic nature. Adult fish were found to be more contaminated by PCBs than either their eggs or juveniles (Fig. 8). PCBs were transferred from mother to offspring in fish, but at lower levels than that present in the parent, and the maximum accumulation from the environment occurred between immature and adult fish. Highest concentrations of PCBs in fish in the mid-1970s were found in gaspereau, herring and smelt in contrast to mackerel, capelin, white hake and silversides. However, the bulk of the PCBs in the southern Gulf of St. Lawrence was present in the mackerel population and this was due to the overwhelming abundance of mackerel during this period (Fig. 8). No difference was found between PCB contamination of the sexes of fish species analysed.

	Year	$pg.m^{-3}$	%
Bulk seawater	1976	3.1×10^6	97.96
Plankton	1976/77	6.0×10^2	0.02
Fish	1977	2.3×10^4	0.73
Mammals	1970s	4.1×10^4	1.30

Table 1. Tabulation of PCB levels in the Pelagic Ecosystem of the Southern Gulf of St. Lawrence

Biomagnification of polychlorinated biphenyls occurs between the larger categories of plankton to fish to marine mammals but not within the lower planktonic trophic levels (Fig. 9). PCB concentrations in fish increased with size and on average were ten times the levels found in plankton. Marine mammals collected by other researchers in the region during the 1970's had accumulated up to several orders-of-magnitude higher concentrations than those found in fish, with an apparently more gradual increase in concentration with size of organism. Lipid content and age, or exposure period, appear to be the main factors which determine PCB concentrations in the marine food web of the southern Gulf of St. Lawrence (Harding *et al.* in press).

PCB levels in plankton have dropped exponentially from the early 1970s to the 1980s, but thereafter the decline has levelled out (Fig. 10). There is the possibility that the high values measured by Ware & Addison (1973) in plankton collected north of Prince Edward Island in 1972 might be a result of PCBs escaping from the sunken oil barge *Irving Whale,* however PCB were matched with Aroclor 1254 and not Aroclor 1242 which is the PCB signature of the barge (Gilbert *et al.* 1996). PCB concentrations of clupeid fish (herring family) species collected in the Gulf have consistently declined over the decades between the mid 1970's and 1990's (Fig. 11). The presence of discontinued pesticides, such as DDT, in the undegraded form in our local plankton and fishes indicates recent atmospheric transport of pesticides from Central America or further south. We are presently attempting to evaluate the transport of organochlorines to the Canadian east coast marine environment. A preliminary PCB tabulation for the pelagic realm of the Gulf of St. Lawrence, based on information collected in the 1970's, demonstrates that most of the contamination in the pelagic ecosystem was present in the water column but that the marine mammals had by far accumulated most of the organochlorines present in the biosphere (Table 1). The present studies form a very fortuitous data time series to evaluate any further damage caused by the recovery of the *Irving Whale* oil barge which originally had 7,600 L of Aroclor 1242 (PCBs) on board when it sank between PET and the Magdallen Islands in 1970.

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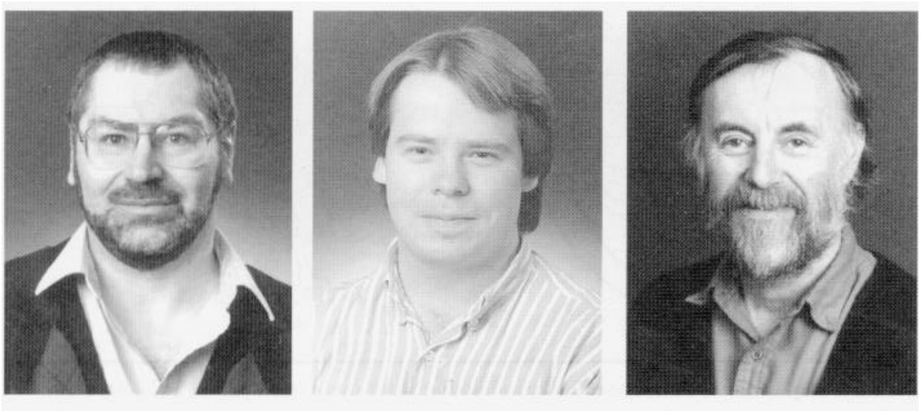
Dinoflagellate Evolution and Diversity Through Time

R.A. Fensome, R.A. MacRae and G.L. Williams



R.A. Fensome *R.A. MacRae* *G.L. Williams*

Introduction

Unlike most other groups of protists, dinoflagellates have left an extensive fossil record. This record is restricted essentially to the last 245 million years (Mesozoic and Cenozoic), though comparative anatomical and molecular phylogenetic studies of modern dinoflagellates indicate a probable Precambrian (greater than 570 million years) origin for the group. This Paleozoic (245-570 million years) gap in the dinoflagellate fossil record has been used to suggest that this record is seriously flawed and therefore cannot be used to deduce the evolutionary history of the group (Evitt 1981). However, recent studies using large datasets (Fensome *et al.* in press; MacRae *et al.* in press) and informal cladistic analyses (Fensome *et al.* 1993) demonstrate that the fossil record can indeed be used to meaningfully examine the past diversity and evolution of this major planktonic group of organisms. This work also has broader implications in helping understand the development of modern plankton biodiversity and its vital role in modern ecosystems. Aspects of this ongoing research are reviewed in the present paper.

Dinoflagellates

Dinoflagellates are primarily single-celled organisms that possess, firstly, a nucleus lacking histones and having chromosomes that remain condensed throughout the cell division cycle and, secondly, at least one life-cycle stage involving cells with two characteristic flagella (Fig. 1). As in related protists, such as ciliates, dinoflagellates possess a layer of vesicles towards the periphery of the cell. In dinoflagellates, these vesicles commonly contain cellulosic plates arranged in consistent patterns (tabulation patterns). These patterns provide the primary basis for determining evolutionary relationships within the group.

About half of living dinoflagellate species are photosynthetic, others are heterotrophic; and some species have both nutritional modes, underlining the futility of attempting to classify these relatively simple organisms as plants or animals. Dinoflagellates are today most diverse in continental shelf environments, but also occur in oceanic and freshwater habitats. Some are parasitic and one group, popularly known as zooxanthellae, live symbiotically in the soft tissue of invertebrates such as corals, giving these animals

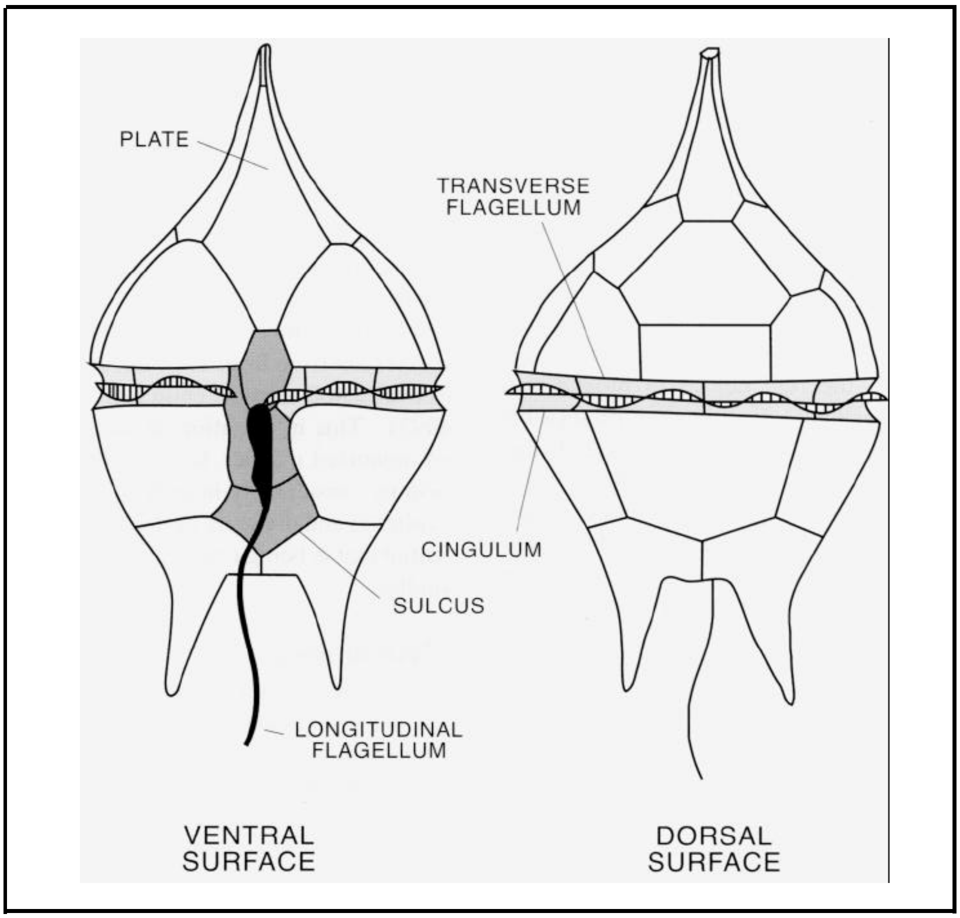


Figure 1: The principal morphological features of a typical modern dinoflagellate - motile stage.

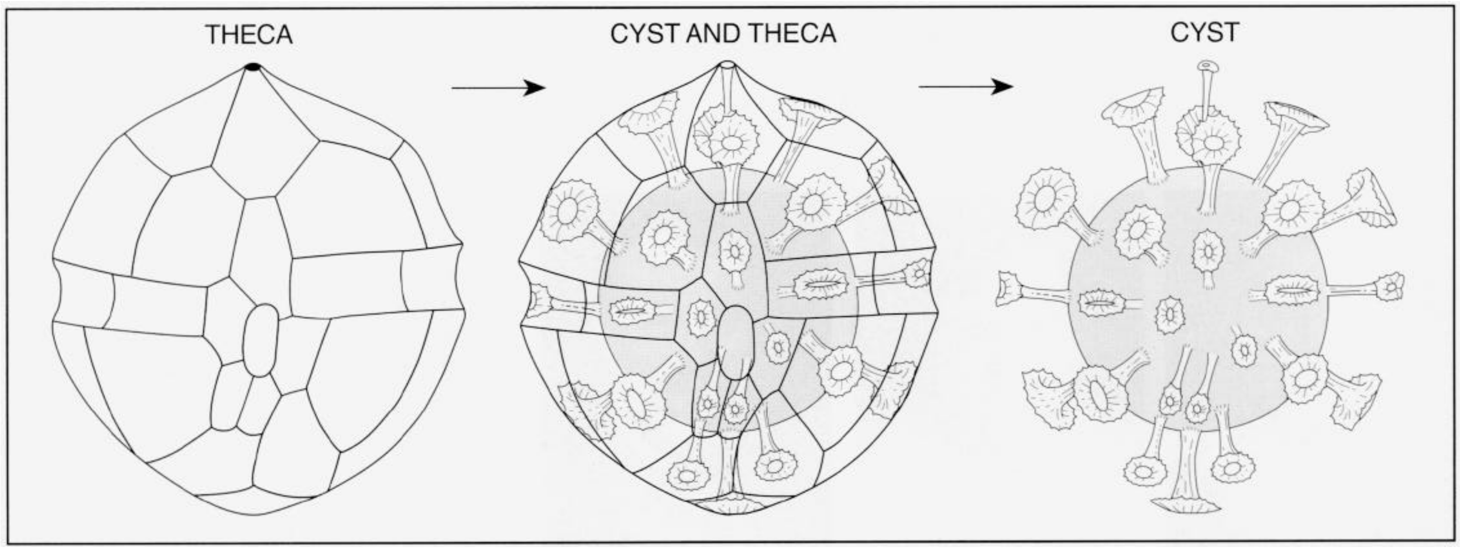


Figure 2: The relationship between a dinoflagellate motile stage (left) and the corresponding dinoflagellate cyst stage (right). Not all cysts show such a clear one process per plate relationship, but cyst affinity to the "parent" theca is usually determinable, at least to family level. Practically all dinoflagellate fossils represent the cyst stage. Figure adapted from Evitt (1985)

their bright colours. Dinoflagellates are of major economic importance, being at or near the base of the marine food-chain; they are also primary causal agents of paralytic shellfish poisoning and related toxic phenomena (red tides).

History of Study

The German microscopist, Ehrenberg (1838), was the first to recognize fossil dinoflagellates, which he observed in thin sections of Cretaceous flint. Such fossils were recognized as being organic-walled as early as the mid-nineteenth century, but extraction techniques to release them from the rock matrix did not become standard procedures until the mid-twentieth century. Indeed, the real nature of most fossil dinoflagellates - that they are preservable organic-walled resting cysts - was only discovered 35 years ago (Evitt 1961). Fossil cysts can be recognized as dinoflagellates if they show direct "reflection" of the tabulation pattern on the cyst wall, or by the position and shape of processes (Fig. 2) or a type of excystment opening termed an archeopyle; archeopyles correspond to particular plates or groups of plates of the tabulation and therefore demonstrate dinoflagellate affinity, even in the absence of other diagnostic features. The presence of tabulation evidence on fossils has allowed us to develop the first detailed, integrated phylogenetic classification of fossil and living dinoflagellates (Fensome *et al.* 1993.

Fossil dinoflagellates evolved into a great diversity of morphologies from the Late Triassic to Recent. This feature and their occurrence in marine sedimentary rocks, commonly in great abundance, makes them ideal biostratigraphic index fossils, and they have been used extensively for this purpose in petroleum exploration. This has culminated, for example, in their key usage in the sequence stratigraphic methodology developed by EXXON Oil Company (Haq *et al.* 1987). One spinoff of this stratigraphic application has been an exponential increase in the amount of information on fossil dinoflagellates: for example, the number of formally described species has risen from a few dozen in 1960 to over 3,400 today (Lentin and Williams 1993). This information, if harnessed in an organized manner, has the potential to help us considerably in understanding the evolution and diversity of the group, a potential that is being realized in our present studies.

Methodology

Our investigation of dinoflagellate diversity has been made possible by the organized nature of dinoflagellate taxonomy (Lentin and Williams 1993; Fensome *et al.* 1993) and by access to a major database, PALYNODATA, compiled over the last 25 years under the auspices of several major oil companies and the Geological Survey of Canada. The PALYNODATA program stores taxonomic, bibliographic, geographic and biostratigraphic information from all known pre-Quaternary palynological publications (palynology being the study of organic-walled microfossils such as dinoflagellates and vascular plant pollen and spores). PALYNODATA has enabled us to examine diversity patterns at the species level; the majority of previous studies for all biological groups have been restricted to analysis of diversity at higher taxonomic ranks.

From a dataset extracted from PALYNODATA, species diversity of dinoflagellates was assessed for each Mesozoic and Tertiary stage using the timescale of Harland *et al.* (1990), with slight modification. (We use the term "stage" here to refer to the time intervals sampled; they essentially correspond to geological "ages" in the Mesozoic and "subepochs" in the Tertiary.) The dataset was filtered extensively, the following data being excluded: 1) range records at greater than stage precision (e.g. those ranges recorded simply as Early Cretaceous or Jurassic rather than, say, as the Jurassic stages Bajocian-Bathonian), because such coarse records usually represent uncertainty; 2) records from catalogs and indices that do not provide original range data; 3) records with identified sampling problems, such as those involving resedimentation or other forms of contamination.

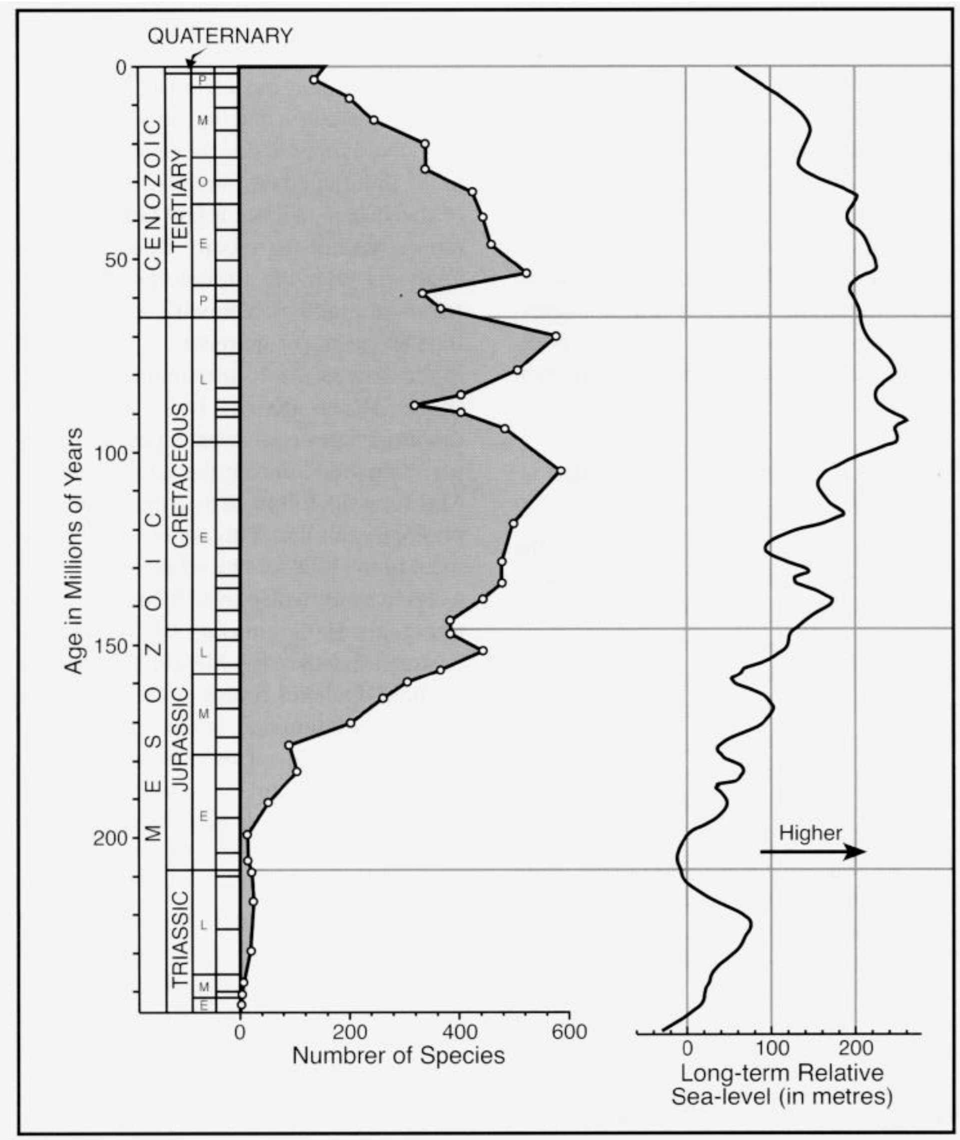


Figure 3: Left: fossil dinoflagellate species diversity (from MacRae et al. *in press). Right: relative changes in long-term sea level, after Haq* et al. *(1987). The time scale is based on that of Harland* et al. *(1990): geological periods and epochs are labelled (P at base of Tertiary = Paleocene, E = Eocene, O = Oligocene, M = Miocene, P at top of Tertiary T = Pliocene), stages, epochs are indicated but not labelled. Q = Quaternary; Tertiary and Quaternary together comprise the Cenozoic. Triassic, Jurassic and Cretaceous together comprise the Mesozoic.*

The filtered dataset comprises 38,000 age records from 2,129 publications. Species names are recorded in PALYNODATA directly from the literature - i.e. without regard for current taxonomy. Hence, a dictionary listing correct names and synonyms was developed and employed to convert the names in the dataset to a meaningful taxonomy. Thus, about 6,000 unique database “species” names were reduced to 2,507 names, regarded as species in the ensuing diversity analyses.

The total stratigraphic range of each species was calculated as a composite of the individual range records for each species in the filtered dataset. Diversity for each stage was then calculated by adding the number of species whose ranges pass through, begin in or terminate in each stage. A count of the number of ranges beginning in or terminating in a given stage provides data for origination and extinction plots (though the data are too coarse to make meaningful analysis of individual time horizons such as the Cretaceous-Tertiary boundary). Percentage extinction and percentage origination plots are more meaningful than simple counts, since they emphasize relative rates on a per-taxon basis (Sepkoski 1986); these were calculated by dividing the number of extinctions or originations by the total diversity for the interval under consideration and dividing by 100.

Dinoflagellate Diversity Patterns

The species diversity plot (Fig. 3) developed for dinoflagellates shows that the group first appeared in the fossil record in the Late Triassic (apart from two questionable Paleozoic species not shown). Latest Triassic extinctions caused a decline in the earliest Jurassic, but subsequently dinoflagellates generally underwent exponential growth over the next 50 million years from a low of 13 to a Late Jurassic high of 420 species. The group then maintained more or less high diversities until the Eocene, with peaks in the late Early Cretaceous (584 species), latest Cretaceous (568 species) and Early Eocene (518 species). These three peaks are punctuated by significant lows in the early Late Cretaceous (315 species) and earliest Tertiary (325 species). The early Late Cretaceous low may be in part a sampling artifact due to the presence of two short stages. The earliest Tertiary low is clearly due to the large number of extinctions (207 species) in the last Cretaceous stage, though as already noted the dataset cannot differentiate between extinctions during the stage and at the end of it.

From the Late Eocene, dinoflagellate evolutionary patterns changed dramatically. Origination rate generally declined and extinction rate generally increased. resulting in a diversity drop to a Pliocene low of 136 species.

A variety of biases can affect diversity patterns, including rock area/volume, research interests, rock type and preservational differences (see Raup 1976a, b; Sheehan 1977). For example, increased diversity commonly observed among many marine animals in younger rocks is mainly due to an increasing proportion of rock available for study (Sepkoski 1986). From our own work, it is clear that there is generally a greater number of publications from intervals with greater diversity. However, the significance of this correlation may be deceptive since, as pointed out by Raup

(1977), “systematists follow the fossils”.

A potential problem in the analysis of dinoflagellate evolution and diversity patterns is the cyst-based nature of the fossil record. Since most fossil dinoflagellates are organic-walled cysts and only about 13 16 percent of modern species produce fossilizable cysts (Head 1996), the question arises as to how representative the dinoflagellate record is. The vast majority of fossil dinoflagellates belong to relatively few families and there appears to be significant continuity within cyst-forming lineages. We therefore consider that, although it may not be appropriate to view fossil dinoflagellate assemblages as close proxies for past total dinoflagellate communities, the patterns observed in this and similar studies are real and their analysis will yield meaningful explanations.

What, then, are the main influences on the diversity of fossil dinoflagellates? Several hypotheses can be formulated: for example the Tertiary decline may have been the result of a cooling climate, greater seasonality, and major reorganization of ocean currents resulting from plate tectonics and the onset of glaciation. Such changes may have adversely affected lineages that developed under warmer, more uniform environments. Sea level fluctuations may also have had an effect. Indeed, there is a broad correlation between the dinoflagellate species diversity plot and the long-term sea level curve. Modern dinoflagellates are most diverse in marine shelf areas and organic-walled cyst production is also greatest in these areas (Stover *et al.* 1996). Hence, the Late Tertiary lowering of sea level and concomitant closing of continental seaways, thus decreasing shelf area, may have contributed to the dinoflagellate diversity decline. Sea levels were relatively high during the Cretaceous and continental shelves were correspondingly broad; perhaps not surprisingly dinoflagellate diversity was also generally high throughout this period.

Haq (1973) published species diversity plots for Mesozoic-Cenozoic calcareous nannoplankton, and these show some striking parallels with the dinoflagellate data. For example, maximum Mesozoic-Cenozoic levels occurred in the latest Cretaceous stage. corresponding with the second highest peak in dinoflagellates. Perhaps most significantly, the nannofossil diversity plot resembles the dinoflagellate diversity plot for the Cenozoic, peaking in the Early Eocene, then declining steadily to the present day. Knoll (1989) also found a post-Eocene decline in calcareous nannoplankton. Haq related maximum diversity to periods of maximum transgression, when more equable climatic conditions resulted in greater nannoplankton productivity.

The Early Mesozoic Radiation of Dinoflagellates

The appearance of dinoflagellates in the early Mesozoic is intriguing: is this appearance a real evolutionary event; or is it an artifact of the fossil record, as implied by Evitt (1981)? To determine this, it was necessary to compare the evolutionary patterns shown by dinoflagellates with those of other groups undergoing evolutionary radiations. We displayed the dinoflagellate diversity data in a series of spindle plots (Fig. 4), one for each family with fossil species, the breadth of each spindle representing the number of species within the family during a given geologic stage.

The spindle plots show that by the end of the Triassic, four families were present - a small number, but including those with among the fewest and the most plates. The Early-Mid Jurassic saw the first appearance of 11 dinoflagellate families. By the end of the Jurassic all but a few families were represented in the record: those that first appeared after the Jurassic are based on minor morphological modifications in contrast to the major innovations represented in the Triassic-Mid Jurassic record. From these observations, it is clear that dinoflagellates underwent a period of “experimentation” during the late Triassic to Mid Jurassic, followed by a period of morphologic stability. This pattern of “experimentation” followed by relative stability is a classic pattern displayed by many groups of organisms (Gould *et al.* 1987) and demonstrates that the early Mesozoic expansion of dinoflagellates represents a real evolutionary radiation and is not an artifact of the fossil record. This interpretation has been independently corroborated by biogeochemical evidence (Moldowan *et al.* 1996).

Some interesting questions arise. What stimulated the early Mesozoic radiation of dinoflagellates? Assuming that the biologi-

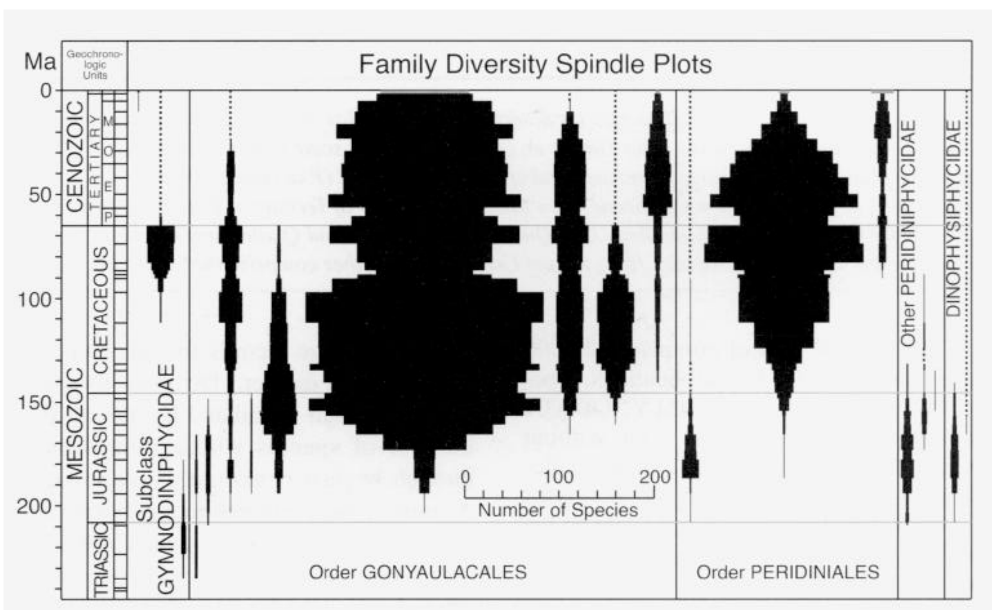


Figure 4: Spindle plots showing the number of species per family per geological stage. Timescale and geochronologic units as in Figure 3. The Quaternary is represented by the small unlabelled area above the Tertiary. Quaternary inforrnation is incomplete in PALYNODATA and therefore plots in this interval are tentative and consequently indicated in grey rather than black. Adapted frorn Fensome et al. *(in press).*

cal and biochemical evidence is correct in indicating a Precambrian origin for the dinoflagellate lineage, what happened to this lineage during the Paleozoic, between 245 and 570 million years ago?

The radiation was possibly stimulated by the break-up of the supercontinent Pangaea and the consequent increased number of continental shelf habitats for cyst producing organisms. Stimulation probably also came from the large amounts of ecospace available after the devastating end Permian extinctions, biotic recovery from which was gradual. Paleozoic corals, for example, were totally eradicated by the end of the Permian and their Mesozoic (probably unrelated) counterparts, the scleractinian corals, did not appear until the Mid Triassic. Geochemical evidence shows that some of these early scleractinian corals were zooxanthellate (Stanley et al. 1995), leading to the tantalizing possibility that corals and dinoflagellates may have co-evolved. This possibility is supported by similarities between the modern zooxanthellate dinoflagellate, *Symbiodinium*, and the Triassic fossil dinoflagellate, *Suessia*.

Moldowan et al. (1996) reported that triaromatic dinosteroids, which are derived almost exclusively from dinoflagellates, have not been detected in samples from the Carboniferous and Permian (362.5 to 245 million years ago), but occur sporadically in pre-Carboniferous rocks enriched in acritarchs (organic-walled microfossils of undetermined affinity). Thus at least some Paleozoic acritarchs may represent organisms from the dinoflagellate lineage. Pre-Mesozoic dinoflagellates need not have closely resembled later, known forms. For example, probably their now well-established arrangement of flagella, furrows (cingulum and sulcus) and plate patterns was an innovation of the Mesozoic radiation. If so, this would explain why Paleozoic acritarchs are not morphologically identifiable as dinoflagellates.

Future Directions

Diversity studies of fossils are critical in assessing the nature and historical development of modern biodiversity. Studies of fossils and modern organisms is firmly linked through Quaternary research. Our work with fossil dinoflagellate diversities has so far lacked a detailed Quaternary component, since PALYNODATA lacks a complete inventory of Quaternary data. Hence, with the aid of colleague Peta Mudie at Geological Survey of Canada (Atlantic) (GSC Atlantic), we are currently developing a database of Quaternary dinoflagellate occurrences that we can analyze for diversity patterns, thus effectively linking the past and the present.

PALYNODATA has also enabled us to make initial analyses of acritarch diversity patterns. Acritarchs are significant in that they will provide information about Paleozoic trends in organic-walled microplankton fossils and data thus developed can be added to our dinoflagellate information to give Paleozoic to Cenozoic (and even Precambrian) plots. This work has been initiated with the collaboration of Aubrey Fricker, formerly of GSC Atlantic, and Paul Strother of Boston College, Massachusetts.

The family spindle plots have provided a pilot study for another methodology that we plan to pursue. For example, spindle plots for morphological groupings may provide insights into ecological or evolutionary patterns. Finally, our data are also appropriate for analysis of diversity for particular time intervals plotted geographically - i.e. on palinospastic reconstructions, revealing clues to ancient seaways and paleoceanographic currents. And all this can be learned from fossils millions of years old and no bigger than a fraction of a millimetre.

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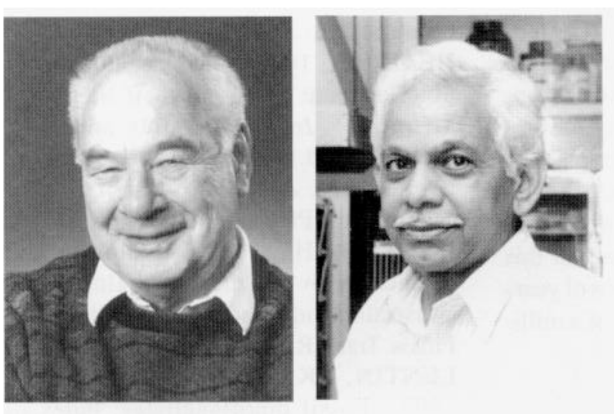
Phycotoxins: Physiology and Production

J.E. Stewart and D.V. Subba Rao



J.E. Stewart *D.V. Subba Rao*

Introduction

Phycotoxins ([phyco = seaweeds and algae] plus toxins) are a diverse group of poisonous substances produced by various aquatic plants in marine and fresh waters throughout the world. Not all aquatic plants produce toxins; and among those that do. not all, even from the same genera and species, produce toxins at all times and under all circumstances. In addition, problems with toxins occurring in shellfish are experienced commonly when no algal blooms have been noted, e.g. much of the chronic Paralytic Shellfish Poisoning in the Bay of Fundy, the recorded instances of Diarrhetic Shellfish Poisoning on the Nova Scotian south shore, and the domoic acid in scallops from Georges Bank in 1995 to name a few. The problems caused by phycotoxins in freshwater are often the result of blooms of cyanobacteria (formerly known as blue-green algae) which make the waters toxic, resulting in large losses among wildlife and domestic animals. In the marine environment the most newsworthy occurrences have been major intoxications among people who have eaten filter-feeding shellfish (molluscs) which have fed on toxigenic algae, thereby accumulating large amounts of the toxins. Many of these toxic episodes have resulted in fatalities and others in temporary and permanent disabilities. In addition, a number of studies have implicated marine toxins in large fish kills in the wild (adult and larval fish). major kills of marine mammals (whales, porpoises, and seals), as well as threats to cage cultured finfish, e.g. the microcystin-like toxin causing Netpen Liver Disease resulting in serious mortalities among farmed salmon.

In addition to the toxigenic aspects. an arresting and important element, which has not previously received attention, is the role plankton play as vectors for disease agent propagation and transmission. A recent review (Patz *et al.* 1996) examining the question of climate change and infectious diseases looked at the data on the seasonality of cholera outbreaks. The causative agent the bacterium, *Vibrio cholerae*, adheres to the surfaces of both phytoplankton and zooplankton and is transported and transmitted along with the plankton to shellfish and thence to humans;

the bacterial numbers parallel the plankton numbers and the bacterium lives on contributions of nutrients exuded by the plankton. Thus the cholera outbreaks, which are a function of the numbers of *V. cholerae*, increase with the plankton numbers in the spring and fall. Other bacteria have been observed as resident on plankton, and the evidence is increasing showing that plankton are an important vector for spread of diseases in water. This is of major consequence to public health generally and to aquaculture operations in particular, e.g. as indicated by Nese and Enger (1993) who found the salmon pathogen *Aeromonas salmonicida* (the causative agent of furunculosis) carried on marine plankton in the vicinity of the salmon net pens.

Following the 1987 domoic acid/mussel crisis the decision was taken to incorporate a national perspective in dealing with phycotoxins. Accordingly, the Phycotoxins Working Group (PWG), composed of representative toxin investigators from all Department of Fisheries & Oceans (DFO) regions, was formed. It is a national advisory and program management body which reports to the National Science Directors' Committee (NSDC) and is concerned with research projects whose objectives include:

- identification of algae and microorganisms that produce harmful blooms or toxins
- investigation of the distribution of these organisms and the environmental factors that control this distribution
- investigation of the nature and magnitude of the impact of phycotoxins on aquaculture and harvest fisheries
- identification and quantification of toxins by chemical or bioassay techniques and developing innovative, simple analytical methodologies that address both research and product certification requirements
- establishment of the role of toxins in nature and competitive impacts on other species;
- elucidation of the dynamics of blooms and toxin production (nutritional, physiological, biochemical and microbial)
- investigation of the fate of toxins in nature (foodweb transfers, biotransformations) development of warning systems, predictive models and countermeasures; and
- investigation of the effects of toxins on aquatic organisms.

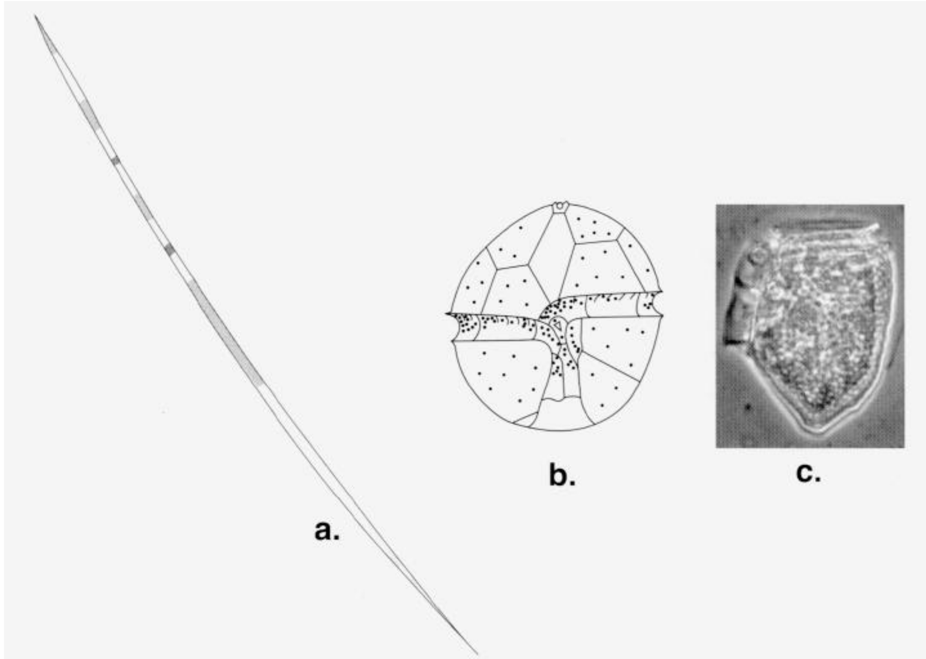


Figure 1: Toxigenic taxa: a. Pseudonitzschia multiseries, *b.* Alexandrium tamarense, *c.* Dinophysis norvegica

Atlantic Canada

In Atlantic Canada, marine toxins pose three major threats. These are Paralytic Shellfish Poisoning (PSP) caused by members of the saxitoxin group, Amnesic Shellfish Poisoning (ASP) caused by domoic acid, and Diarrhetic Shellfish Poisoning (DSP) caused by a family of toxins which include okadaic acid and related dinophysistoxins, pectenotoxins and yessotoxins (Fig. 1 and 2).

Paralytic Shellfish Poisoning resulting from toxins produced by dinoflagellates occurs on both Canadian coasts. In the east it has occurred chronically in the Bay of Fundy and upper Gulf of St. Lawrence with periodic outbreaks elsewhere such as the lower portion of the Gulf of St. Lawrence and Newfoundland. In 1987, the problem of shellfish poisonings broadened dramatically with the addition of a new neurotoxin, domoic acid, which caused a condition subsequently named Amnesic Shellfish Poisoning. This toxin was produced by a diatom, the name of which evolved from *Nitzschia pungens* through several intermediates to its current sobriquet, *Pseudo-nitzschia multiseries.* The mussels cultured in Cardigan Bay, Prince Edward Island, fed on a bloom of this diatom and accumulated massive levels of the toxin, i.e. up to 900 mg/g of soft tissue which is about 45 times the current legally permitted maximum in Canada. Consumers of the mussels suffered an intoxication which resulted in about 150 people being hospitalized; around a dozen were seriously and apparently permanently disabled, and ultimately 3 definitely and possibly a total of 5 died as a direct result of the intoxication.

Diarrhetic Shellfish Poisoning has been confirmed recently in the Maritimes; anecdotal evidence, however. suggests that it has been present for a long time. Elsewhere it is believed to be produced by marine algae *(Dinophysis* sp. and others), but its actual source in Atlantic Canada has not been identified yet. To date it has not been considered as serious a problem locally as the other two toxins.

In discussing the problems arising from toxins a fatalistic attitude is commonly adopted in which it is stated that the toxins will always be with us and that the simplest and most successful course would be to learn how to manage around the toxins. This course may, in fact, be valid for domoic acid in mussels which rid themselves of it readily, but it does not apply to domoic acid or PSP in scallops or other species which retain these toxins. It should be remembered that the toxin problems are completely analogous to the problems

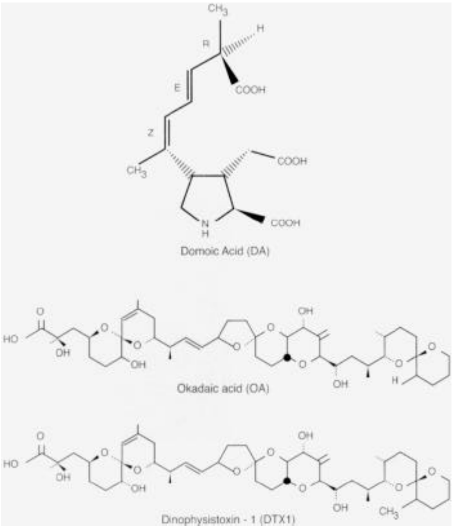


Figure 2a: Toxins: Domoic acid (DA), Okadaic acid (OA), Dinophysistoxin-1 (DTX 1)

posed 150 years ago by infectious diseases. These proved to be amenable to investigation; the basic understanding derived resulted in diagnostic procedures, prediction, protection, and cures. Exactly the same possibilities exist within the phycotoxins field as results gained over the past several years demonstrate, portions of which are presented below.

Domoic Acid: Physiological Aspects of Production

After the identification of the neurotoxin, domoic acid, as the cause of the 1987 mussel crisis by scientists at the National Research Council (NRC) Laboratories in Halifax (Bird et al. 1988; Wright et al. 1989), the source was discovered to be the diatom *Nitzschia pungens* (Subba Rao *et al.* 1988); the toxigenic strains are now named *Pseudo-nitzschia multiseries.* Subsequently, both the diatom and the neurotoxin have been shown to be distributed widely and, in fact, have been particularly troublesome in California where mass die-offs of seabirds have been attributed to the consumption of domoic acid-contaminated anchovies. Major disruptive episodes have occurred also in the shellfish industries of the U.S. Pacific Northwest.

Experimental studies have shown that various strains of *P. multiseries* yield varying amounts of toxin; all have one element in common, they tend to produce domoic acid mainly after growth has entered the stationary phase. This phase occurs after the nutrients sustaining exponential growth are depleted or culture conditions have deteriorated. In either or both events the culture has entered a period of physiological stress (Pan *et al.* 1996a,b), as shown in Figure 3. When the culture was grown in media in which the concentrations of phosphorous or silica were below the required optimum, domoic acid production was enhanced; this enhancement of domoic acid was eliminated proportionately by adding to the growth medium graded amounts of phosphorous or silica, thereby overcoming the nutrient stress (Fig. 4 and 5). Lithium was found in relatively high concentrations at Cardigan in 1987 and through growth studies was shown to enhance significantly the production of domoic acid by *P. multiseries*, as shown in Figure 6 (Subba Rao *et* al., in preparation). Another influence is the ammonium concentration; Bates et al. (1993) showed that very high concentrations of this ion tended to inhibit growth of *P. multiseries* compared to growth with the same nitrogen levels in the form of nitrate. The cells that did grow, however, produced higher concentrations of domoic acid than those growing in the presence of nitrate alone.

Parallel to these findings, work by McLachlan *et al.* (1993) showed that a marker compound, gluconolactone, appeared only in fluids from mussels shown by high-performance liquid chromatography (HPLC) to be contaminated with domoic acid. Gluconolactone was found also in a methanolic extract of a bacterium isolated from close association with the diatom, *P. multiseries,* but not from extracts made from the diatom.

Exposure of the diatom to varying levels of gluconolactone (more properly an equilibrium mixture of gluconic acid/ gluconolactone; the acid is a powerful sequestering agent) showed domoic acid production was enhanced in its presence and that the effect was concentration dependent (Fig. 7). As the concentration of domoic aid increased in relation to increasing concentrations of gluconic acid/ gluconolactone, the proportion of domoic acid released by the diatom to the culture filtrate increased (Osada and Stewart, in press).

Studies by Stewart *et al.* (in press) with bacteria isolated from close associations with *P. multiseries* revealed that, of the four *P. multiseries* strains examined, each had at least one strain of associated bacteria capable of producing. from glucose, large amounts of gluconic acid/gluconolactone. Each diatom strain also had other bacterial strains which grew best with amino acids. It was concluded that these bacteria lived in a symbiotic relationship with the diatom. Further studies showed the *P. multiseries* grown under standard conditions and in different salinities had substantial amounts of glucose free in the cell, and at the highest salinity accumulated a substantial quantity of sorbitol, a presumed osmolyte.

Thus, ingestion, by mussels or other molluscan shellfish, of masses of the *P. multiseries* containing varying levels of domoic acid, as occurred during the 1987 domoic acid/mussel crisis, would bring together the ingredients required to give rise to the circumstances detected within the mussels by McLachlan *et al.* (1993). These were *P. multiseries* cells containing domoic acid and substantial quantities of glucose which could be released through injury to or rupture of the diatom, bacteria capable of converting the glucose to gluconic acid/ gluconolactone and intact *P. multiseries* cells (observed by Scarratt, personal communication) which would still be metabolically active. The gluconic acid/ gluconolactone acting upon these cells would be expected to stimulate and further enhance the production of domoic acid. Thus, it is probable that a significant por-

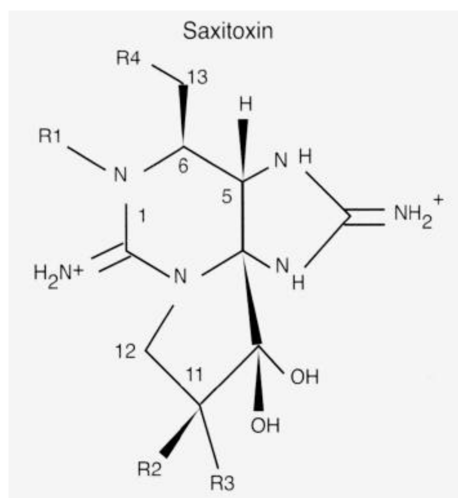


Figure 2b: Saxitoxin

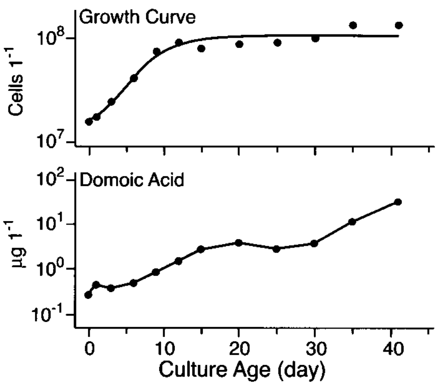


Figure 3: Growth curve of P. multiseries *and variations in domoic acid levels in a batch culture.*

tion of the domoic acid present is actually synthesized within the mussel after ingestion of *P. multiseries.* We believe the reason for this lies in the chemical nature of the two agents gluconic acid/ gluconolactone and domoic acid.

Gluconic acid is a powerful sequestering agent and for that reason is produced commercially for inclusion in cleaning compounds. Domoic acid, as well, has the structure of a powerful chelating agent. The chemical nature of the antagonism suggests the role of domoic acid is that of a chemical scavenger and control agent for the diatom. The proof for this consists of the following: when nutrients become scarce at the end of the exponential period of growth, domoic acid production is enhanced; when nutrients such as phosphorous or silica are present in the media in limiting concentrations, domoic acid production again is enhanced. It is, however, reduced when the nutrients previously in limited supply are returned to normal levels. When a sequestering agent such as gluconic acid is present to tie up various nutrients, domoic acid production is enhanced in proportion to the concentration of gluconic acid present and is released to the surrounding medium to counteract the effect of the antagonistic agent. In addition, when high concentrations of various materials, i.e. lithium or excess silicates, are present major amounts of domoic acid are synthesized and released presumably in attempts to sequester these materials. Much of this would be expected to occur within the shellfish following their ingestion of the diatoms thereby giving rise to the high levels of domoic acid found in the shellfish.

Domoic Acid: Possible Clearance Mechanism

Domoic acid has been shown to be produced widely in nature and in quantity; as it does not appear to accumulate beyond a certain point, mechanisms must exist for its degradation and disposal. Bacteria in the marine environment are prime choices to mediate this activity. Bacteria from the mussel culture area of Cardigan Bay, Prince Edward Island, Bedford Basin, Nova Scotia, the Bay of Fundy, and other marine sources were examined for growth at the expense of domoic acid and the capacity of resting cells to oxidize it using manometric procedures. Despite extensive and intensive trials, the results were uniformly negative. Clearly, the capacity to grow on and utilize domoic acid is not a common microbial attribute.

Published studies have shown that blue mussels *(Mytilus edulis)* routinely are capable of reducing the concentrations of accumulated domoic acid relatively rapidly; in contrast, the results from trials as well as anecdotal evidence indicate that the sea scallop *(Placopecten magellanicus)* eliminates domoic acid very slowly. Through application of enrichment techniques, using gill and digestive gland tissue, we showed that 45 of 46 individual mussels possessed bacteria, the growth of which was enhanced to a limited, but significant extent by domoic acid; in addition, 5 pooled soft-tissue homogenates (each representing 10 mussels) also yielded similar bacteria. Nine of 20 softshell clams *(Mya arenaria)* and 2 of 10 red mussels *(Modiolus modiolus)* had bacteria whose growth was stimulated by domoic acid, while only four of 60 scallops taken from six different locations were positive for such bacteria.

The dominant bacterial genus appeared to be *Alteromonas* followed by *Pseudomonas* sp. Substrate utilization trials were carried out with five of the bacterial isolates which had shown the greatest growth in the presence of domoic acid. A significant portion of the substrates presented, domoic acid or saxitoxin, (depending upon the isolate), disappeared after incubation at 20°C.

It was concluded that the blue mussel virtually always possessed microflora which could utilize domoic acid, while the softshell clam was more variable. The sea scallop and red mussels only occasionally had such organisms. Domoic acid clearance from molluscan shellfish species, as judged from limited trials and anecdotal evidence appear to parallel these microbial findings.

To account for the different microbial capacities evident in the various molluscan species, it is necessary to postulate a selection mechanism; this might involve selection of bacterial types by molluscan lysozymes such as those described in the literature on *M. edulis.* As these bacteria have the potential to play a significant role in toxin elimination in certain molluscan species, it could be profitable to explore these leads. If confirmed as a significant

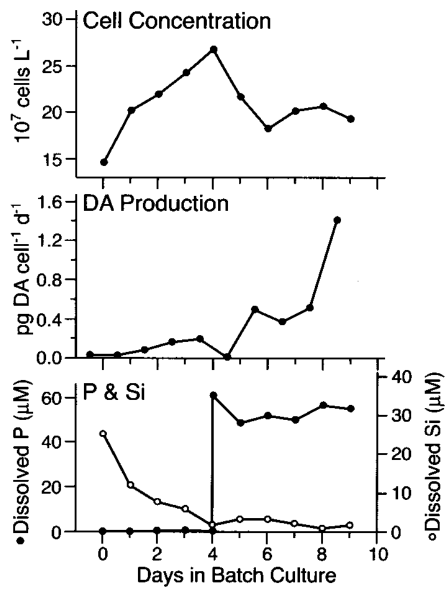


Figure 4: Variations in intracellular domoic acid and dissolved phosphorus in relation to growth rate in P. multiseries *culture. Note at low phosphorus levels the division rates were low which coincided with high levels of domoic acid.*

toxin clearance mechanism in molluscs, practical applications of bacterial clearance could include detoxification procedures based upon favouring autochthonous domoic acid and saxitoxin utilizing bacteria and possibly implanting relevant bacteria (or transferring their capacities to autochthonous bacteria) in those molluscan species which appear to select against the toxin utilizing bacteria. This approach would be

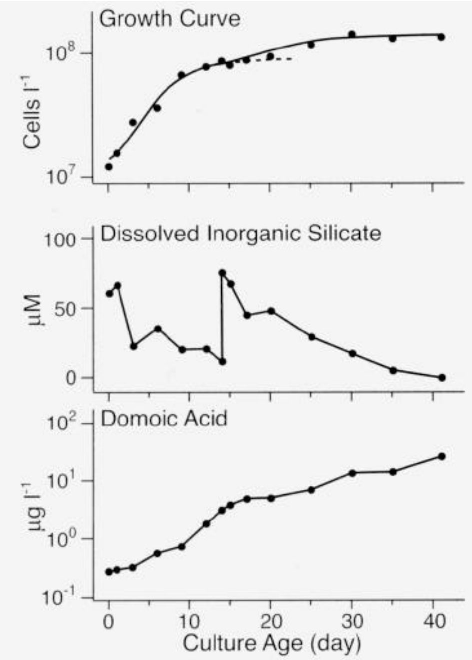


Figure 5: Variations in intracellular domoic acid and dissolved silica in relation to growth rate in P. multiseries *culture. Note at low, silica levels the division rates were low which coincided with high levels of domoic acid.*

in distinct contrast to current shellfish depuration methods which are aimed at eliminating bacteria from the shellfish.

Thus, we now have a much clearer picture of the physiology of the diatom, the probable and important role of domoic acid in the diatom's survival and dominance, many of the factors affecting domoic acid production including the role of excess nutrients and pollutants, the probability that much of the domoic acid is formed within the mussel and other affected shellfish and that bacteria possessed by certain shellfish species are capable of degrading domoic acid and at least one of the major PSP toxins.

We also found that *P. multiseries* growth was stimulated by the presence of an amino acid through the intervention of the bacteria associated with the diatom, raising the possibility that the presence of organic wastes from land run-offs, sewage and other sources, including the aquaculture units themselves, can contribute to blooms of this as well as other diatoms and dinoflagellates. As nutrification and pollution are important elements the process could be qualitative as well as quantitative; i.e. the precise algal species involved and its eventual abundance could be determined largely by materials contributed by man.

Unfortunately space does not permit similar coverage of the work being done at Bedford Institute of Oceanography (BIO) on other toxins. Extensive studies have been carried out with the dinoflagellate, *Alexandrium*, a producer of toxins of the saxitoxin family (PSP). The detailed results and methods developed provide insights comparable in certain ways to those provided by the studies with the diatom, *P. multiseries*, and its production of domoic acid. In addition, attempts have been made to culture in the laboratory algae believed responsible for producing the toxins causing Diarrhetic Shellfish Poisoning; this is a feat that has not been accomplished anywhere to date.

General Remarks

A partial listing of the advances made within Atlantic Canada since the domoic acid crisis of 1987 is impressive. The major obstacles to analytical work with ASP and PSP have been overcome by the provision of reference material for the critical qualitative and quantitative analyses for ASP and PSP. Domoic acid, produced on Prince Edward Island, now is available commercially in quantity; saxitoxin, neosaxitoxin, and gonyautoxins II and III prepared as certified standards can be purchased. Analytical methods for domoic

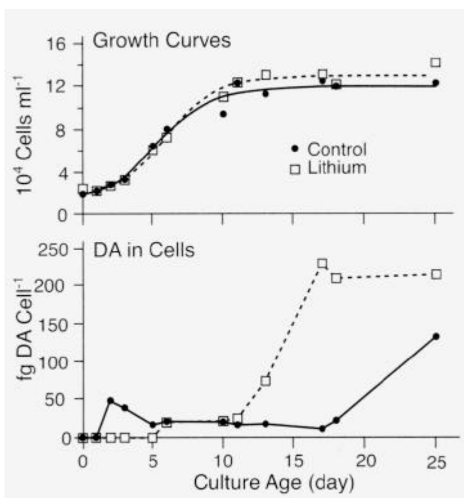


Figure 6: Effect of 385.6 mmol lithium enrichment on cell concentration and intracellular domoic acid in cultures of P. multiseries.

acid, the saxitoxins and DSP toxins have been developed or improved; these include more convenient chemical, serological and bioassay techniques, improved growth techniques, biochemical approaches and surveys with area-wide analyses made of some of the data collected over the past seven years. These activities have provided insights which have made the Canadian Atlantic area a focal point for marine toxins work. With the methodology and techniques now available, the analytical instruments in place, the chemical reference materials and the benefits of an extensive and intensive learning experience, the opportunities for major advances in this field locally have never been better. This position, if capitalized upon, comes at a good time as prospects are very real for an escalation of molluscan shellfish production, especially for some sea scallop culture ventures.

If the Japanese experience (from zero to 250.000 tonnes/year in a 14-year period) with sea scallop culture is repeated here to any degree, it is quite possible that the yield from culture could form a substantial portion of the total regional scallop production within the foreseeable future. The sea scallop industry, which is already the biggest fisheries money earner in the region, is now grossing over $200 million/year; this income is based on the utilization of the adductor muscle only, the only part of the scallop reliably free of PSP. The remainder of the soft parts (65%) are discarded in landfills. There are, however, large markets looking for reliable. continuing supplies of substantially greater portions of the now discarded scallop material, i.e. rims and roe if it could be provided toxin free. It is possible that knowledge gained through the toxin studies could provide the means to overcome the toxins obstacles.

To date, sea scallop culture areas have not been hit by PSP, and while this fortunate state of affairs continues small operators have been able to take advantage of it to break even by selling the whole scallop and thus making substantially more than they could by selling only the adductor muscle. The opportunity to safeguard the integrity and extend the profitability of a developing industry through the further development and application of technology by exploiting the overall advances made in the Atlantic area to date is good and very

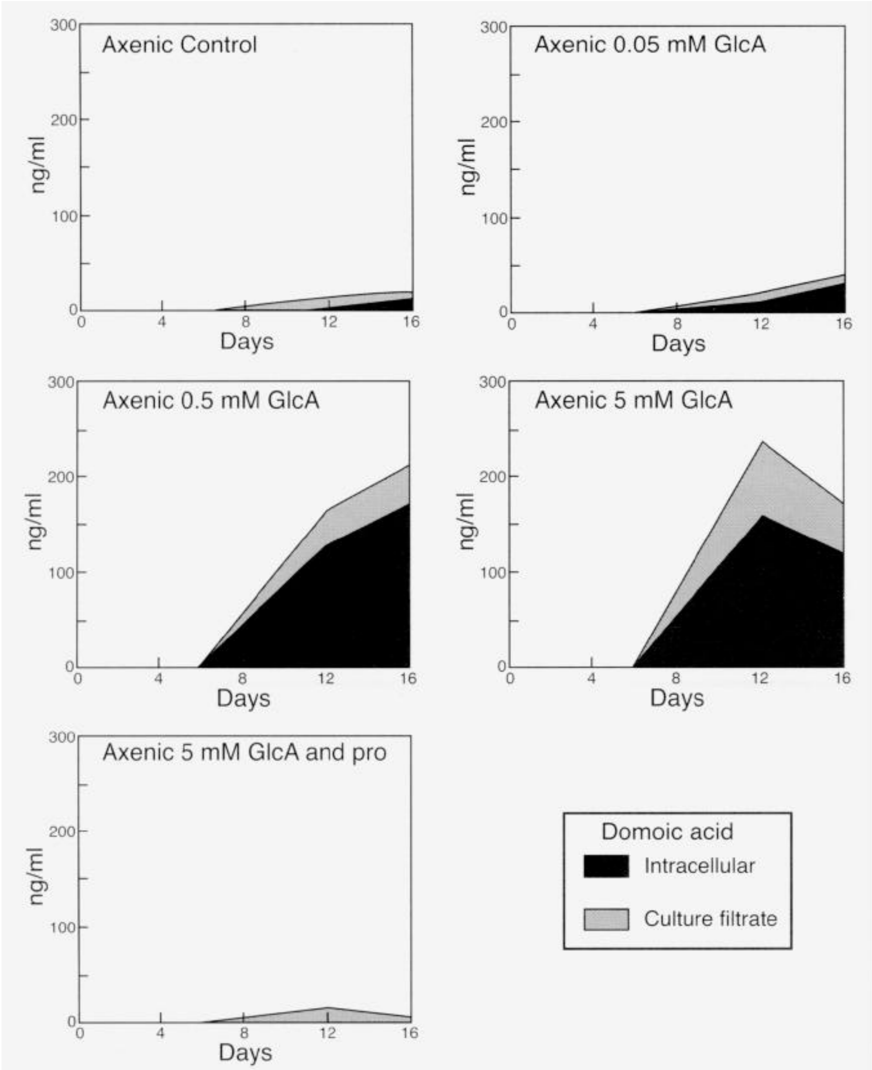


Figure 7: Concentration of domoic acid produced by axenic P. multiseries *cultured with various concentrations of gluconic acid/gluconolactone in the presence and absence of proline (5 mM).*

definitely would be consistent with the departmental interest in Coastal Zone Management. The phycotoxin problems fit comfortably within this context as they are quite broad and actually encompass issues of habitat and environmental concerns as well as fisheries, aquaculture and recreational aspects.

Conclusions

Conclusions derived from these and other studies include the very real possibility that an important part of the problems stemming from toxins, in this case domoic acid, could be a direct consequence of man's own activities. By acquisition of the information outlined above and logical extensions of it we are in a better position to understand how and where the problems are likely to arise. Steps can be taken then to avoid the worst consequences and to exploit the possibility that the bacterial populations of the shellfish can biodegrade the toxins and thus either eliminate the toxins before their concentrations in the shellfish become prohibitive or aid in clearance afterward. With these and similar kinds of data for other toxins, we will also have the basis for selecting different and more effective approaches to monitoring than we have employed in the past.

In closing, it is worth reiterating the essence of the statement made earlier in this essay. The basic understandings derived from the phycotoxins studies are permitting a partial realization of the aims for improved diagnostic procedures, prediction, protection and cures with promise, as more work is done, to permit their full realization. The potential benefits for the fishing industry, and furthering our understanding of phytoplankton dynamics in the Coastal Zone are considerable.

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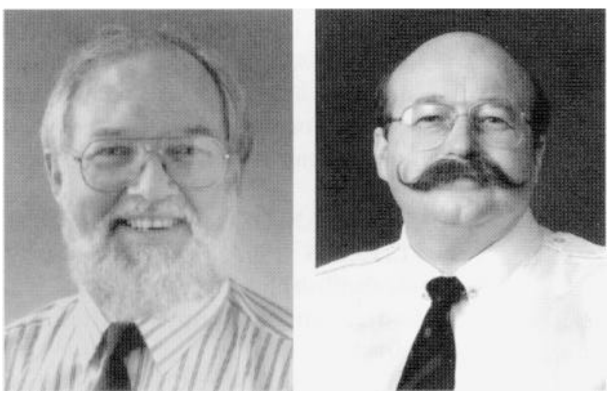
ECDIS: Past, Present and Future

S .T. Grant & J. Goodyear



S.T. Grant *J. Goodyear*

Introduction

Electronic chart technology is taking the Hydrographic and Marine Navigation communities by storm. From its beginnings two decades ago it has progressed to the point where Electronic Chart Display and Information Systems (ECDIS) are now on the verge of being recognized with the same status and authority as the paper chart on the ship's bridge. In this paper the history of electronic charts is briefly reviewed to set the stage for the three main thrusts that are underway today: (1) completion of international standards, including defining tests and procedures to certify equipment, data and updates; (2) developing and implementing the national and international infrastructures to rapidly and efficiently disseminate ECDIS data and updates world wide; and (3) creating ECDIS data, known as the Electronic Navigational Chart (ENC), for all the main shipping lanes of the world. The paper concludes with a look at the future of electronic charts and the impact they may have on a variety of hydrographic and marine related activities.

Background

In Canada, electronic chart technology had its beginning in the late seventies when several companies involved in hydrographic surveying for the petroleum industry developed specialized navigation systems that utilized rudimentary graphics and integrated navigation systems to navigate ships accurately in confined waterways.

In the early eighties, Hydrographic Offices (HOs) in Europe and North America became interested in this emerging technology. A series of Electronic Chart Workshops on both sides of the Atlantic, starting in 1982 at the University of New Brunswick, reflected the growing interest. Today, electronic chart sessions and demonstrations are common at all major marine conferences.

In conjunction with academic studies, several HOs participated with the private sector in at-sea trials and demonstrations of Electronic Chart testbeds with the aim of introducing the technology to the marine community and obtaining feedback. HOs were interested primarily in evaluating the difficulties associated with defining, compiling and maintaining an Electronic Chart Database. At-sea trials included: the Canadian Hydrographic Service (CHS) testbeds from 1985 to 1988 in Halifax Harbour, the North Sea Project onboard the M/V *LANCE* in November 1988, followed by the Seatrans Project onboard the M/V *NORNEWS EXPRESS* in 1989/90.

The International Maritime Organization (IMO) and the International Hydrographic Organization (IHO) began discussions centered around electronic charts in the mid eighties, with the aim of initiating standards for the industry.

In 1989, acknowledging rising concerns regarding Canada's ability to prevent or respond to a major maritime oil spill, the Canadian Federal Cabinet initiated the Public Review Panel on Tanker Safety and Marine Spills Response Capability. The panel, chaired by Mr. David Brander-Smith, Q.C., delivered its final report in 1990. Among many recommendations was the following:

"[to] expedite development of electronic charting technology and the required infrastructure, then introduce regulations requiring the use of electronic charts on all tankers in Canadian waters "

In response to this recommendation, an electronic charting strategy was developed by CHS with the following mission statement:

"To demonstrate to a broad spectrum of potential users, suppliers and benefactors the utility of electronic chart systems and to acquire real-world operational experience in servicing the related evolving national and international digital market."

In order to address the many questions electronic chart technology would generate, a key element of the strategy included the actual testing of operational systems. In order to simulate the expected conditions, the strategy called for a number of systems to be deployed across the country, in a variety of commercial vessels for extended periods of time. The CHS Electronic Chart Pilot Project was designed to identify the stresses and strains of the everyday creation, maintenance and day-to-day delivery of data to a broad clientele.

In June, 1992 Offshore Systems Ltd. (OSL) was awarded a contract by CHS to use OSL's latest Electronic Chart Precise Integrated Navigation System (ECPINS) in CHS's Pilot Project. The belief was that the international standards being developed would lead to modification of the *Canada Shipping Act* which governs the use of such systems onboard vessels operating in Canadian waters. Hence, the CHS, the official purveyors of all charts in Canada, had a requirement to develop a mastery of the production and control of electronic charts.

International Standards

Electronic Charts are categorized by IMO into two main groups: Electronic Chart Display and Information System (ECDIS) and Electronic Chart System (ECS).

The first, ECDIS, must meet the Performance Standards that were developed by the IMO/IHO Harmonization Group on ECDIS (HGE). This standard, approved by the Maritime Safety Committee in May 1994 was submitted to the nineteenth Assembly of IMO and adopted as an Assembly Resolution in November 1995. As defined in the standard, ECDIS is "a navigational information system which with adequate back-up arrangements, can be accepted as an equivalent complying with the up-to-date charts required by regulation V/20 of the 1994 SOLAS Convention". When the IMO, IEC and IHO standards, type approval specifications, etc. are finalized, then the installed ECDIS achieves full equality with the paper chart. Of course, this includes the availability, and installation of a chart updating facility, as well as the employment of government produced chart databases.

By displaying selected information from an electronic navigational chart (ENC) and positional information from navigational sensors, ECDIS should "assist the mariner in route planning and route monitoring, and if required, display additional navigational information". As an automated decision aid capable of continuously determining a vessel's position in relation to land, charted-object, aids-to-navigation, and unseen hazards, ECDIS represents an entirely new approach to maritime navigation and piloting.

In conjunction with the development of IMO Performance Standards for ECDIS, the IHO has developed technical standards related to the digital data format to be used and specifications for the ECDIS content and display. IHO Special Publication No. 57 (IHO S-57) is the IHO Transfer Standard for Digital Hydrographic Data. It includes a theoretical data model, object catalogue and data encoding guide. IHO Special Publication No. 52 (IHO S-52) is the IHO Specification for Chart Content and Display Aspects for ECDIS. It includes four appendices related to updating. color and symbol specifications, data quality and a glossary of ECDIS-related terms. Both S-57 and S-52 are referenced in, and are therefore part of. the IMO Performance Standards for ECDIS.

At the request of IMO, the International Electrotechnical Commission (IEC) is working to identify and describe the necessary performance tests and checks for ECDIS equipment to certify that it is fully compliant with the IMO Performance Standard for ECDIS. Scheduled completion date of the IEC ECDIS Performance Standard (IEC Publication 1174) is summer/fall of 1996. However, some of the IHO Standards that form the foundation of the IMO Performance Standard are still under development; the IHO ECDIS Updating document, for example, is only classified as Guidance at the moment and is due for a major rewrite in the near future when a number of ECDIS Updating trials underway around the world, including Canada, are completed. Also, the specification for an adequate backup for ECDIS has not yet been developed and, once it has, an IEC test procedures document will also have to be developed. Therefore. formal adoption by IEC will not likely occur before late 1997 at the earliest.

Electronic Chart Systems (ECS) comprise the second group of electronic chart equipment and include all electronic charts which do not comply with the ECDIS standard. These are not acceptable by IMO as a paper chart equivalent and paper charts will therefore still have to be carried. ECS is a combined apparatus, as is ECDIS. It involves the combination of an electronic chart with a positioning system, displaying the vessel's position and track, along with the buoys, lights and hazards. It is intended to be an aid to navigation like radar, GPS, echo sounder, speed log, etc. ECS takes many forms; equipment is supplied to be suitable for the whole range of vessels: from small yachts to super tankers. As a result, the range of ECS equipment varies from small plotters to very sophisticated systems.

The United States Radio Technical Commission for Maritime Services (RTCM) issued its standard for ECS in 1994. The RTCM standard calls for ECS to be capable of executing basic navigational functions, providing continuous plots of own ship position and providing appropriate indications with respect to information displayed. The Standard allows for the use of either raster or vector data. However, many of the functions found in ECDIS will not be available in ECS which is classified as an aid-to-navigation that must always be used with an up-to-date chart from a government authorized HO.

In addition, at the last meeting of IMO/IHO HGE, the chairman asked the members to prepare ECS guidelines for submission at the next meeting.

ENC Production

At the time of the grounding of the *Exxon Valdez* less than 10% of CHS charts were digital and none were suitable for use by ECDIS. To-day approximately 300 charts (30% of the CHS inventory) are digital and are being distributed to ECDIS users and manufacturers by our commercial partner Nautical Data International (NDI), St. John's, Newfoundland. Furthermore. about 250 charts (25% of the CHS inventory) have been raster scanned by NDI on behalf of the CHS and are being maintained and distributed by NDI.

Canadian ENC production has been driven largely by user demand as shipping companies have made fleet purchases of ECDIS equipment and demanded CHS approved ENCs to use in them. Lacking the resources to meet this initial demand the CHS consulted users to define a minimum content standard for safe navigation which was used during a first round of digitizing. To-day the content level of most of these charts has been upgraded to the point where they are nearly compliant with the IHO S-57 product specification. Furthermore, most of the major tanker routes in Canada are now completed or are well underway. This process has been very enlightening for both mariners and hydrographers alike in that it has forced them to assess exactly what is required for safe and efficient navigation, not only with ECDIS, but on paper charts as well. The close cooperation and consultation that now exists between mariners, shipping companies and the CHS means that we are focusing our efforts on meeting client needs rather than meeting internally defined production target levels.

Initially all CHS ENCs were created and distributed in the CHS proprietary NTX format. Indeed, most CHS ENCs are still maintained and distributed in NTX but that is about to change. Over the past several years as the IHO DBWG has developed the S-57 Transfer Standard for Digital Hydrographic Data, Version 2, the CHS has actively participated in that development and has, as much as possible, ensured that our ENCs (in NTX format) are as compatible with the IHO standard as possible. Also, software has been developed by CHS in conjunction with Universal Systems Ltd., Fredericton, NB, to interactively convert ENCs from NTX to S-57. At present about 80% of the conversion is automatic and 20% requires human intervention. Eventually the process is expected to be about 95% automatic. A test is presently underway to convert a contiguous set of ENCs between Montreal and Quebec as well as other sites in the Great Lakes. A preliminary test version of S-57 (Version 3) is expected to be released in April 1996, with a final release later in the year, and the CHS conversion software is being upgraded already. The CHS target is to distribute ONLY S-57 data by 1997.

Mariners and shipping companies in increasing numbers are discovering the economic and safety benefits of ECDIS. For example, the Canadian Ship Owners Association has stated that the entire Great Lakes Fleet on the Canadian side will be ECDIS equipped by late 1997. However, shipping companies that operate globally face a more difficult problem since not all HOs are tackling ENC production as aggressively as Canada. Indeed, only a handful of HOs (Japan, Norway. France and Canada) are digitizing their charts in any numbers. Shipping companies who want to use ECDIS globally must therefore rely on commercial ENC providers or ECDIS manufacturers in areas not presently serviced by HOs. Given the global movement towards smaller government. HOs who delay their ENC production programs will have great difficulty dislodging the private sector once it has demonstrated its capacity, efficiency and the quality of its products.

ENC Distribution

Another area that has attracted international attention is the need to address the administrative, technical, financial and legal aspects of distributing ENCs and ENC Updates worldwide. To meet this need, the IHO formed the Worldwide Electronic Navigational Chart (WEND) Committee in 1992. The Committee developed a set of principles and a Conceptual Model which consists of several Regional ENC Coordinating Centers (RENCs) around the world that would accept data from HOs. They would then be responsible for integrating the individual HO's data and subsequent updates and providing a service to international shipping. In principle the mariner would be able to obtain ENCs and updates from anywhere in the world through a communications network linking all the RENCs. Progress in implementation of this model has stalled because many HOs have been unable to divert their diminishing resources away from their traditional paper products.

It isn't clear how the global distribution of ENCs will unfold. The situation is made more uncertain with the strong commitment to produce Raster data by the United Kingdom Hydrographic Office (UKHO) and the intention of the United States Defense Mapping Agency to distribute their chart data in their Vector Product Format. Indeed. an initiative being lead by the UKHO proposes a Raster Chart Display Standard (RCDS) along similar lines to the ECDIS Performance Standard that (a) recognizes that ECDIS is much more than the equivalent to the paper chart and (b) that a system conforming with RCDS is actually 'equivalent' to the paper chart. RCDS could be adopted by the Marine Safety Committee of IMO within the next year. Certification standards similar to the IEC 1174 for ECDIS would then need to be developed by IEC and certification agencies would need to gear up to start testing equipment. Given their experience with ECDIS standards these agencies probably could repeat the process for RCDS quite quickly. RCDS certified systems could be replacing paper charts on ships bridges in a very few years. What impact will this have on the global expansion of ECDIS? Given that it is relatively easy and inexpensive to raster scan paper charts and that RCDS certified systems could be as much as an order of magnitude cheaper than ECDIS, the negative impact on ENC production and therefore ECDIS use globally could be significant.

The CHS has undergone a significant change in both attitude and work procedures in the past 5 years as a result of its commitment to meet the demands for ENCs by Canadian ECDIS users. The CHS has gone from a paper oriented organization that thought in time scales of 1 - 2 years to produce a new product to an organization that produces new Electronic Chart products in 1 - 2 months. Documents that used to spend weeks or months travelling back and forth between Headquarters and the Regional offices are now mailed electronically in seconds. The re-engineering and changes in attitude that are taking place in the CHS are having beneficial effects on our paper products as well. But, we still have a long way to go!

At present, ENC updating in Canada is achieved by total file replacement. While not the desirable final solution, it works surprisingly well with turn-around times of a few days to a few weeks. Major initiatives are underway in Canada and elsewhere to test and evaluate the IHO Guidance on ENC Updating and eventually turn it into an international standard. ENC Updating, ENC Quality Indication and ECDIS Backup are the three major outstanding “holes” in the international ECDIS Standards that need to be ‘plugged’.

The Future of ECDIS

The future of ECDIS in Canada is bright because nearly a half the CHS charts are digital and available for use in ECDIS. However, internationally the future of ECDIS depends on several factors, the most significant of which is the lack of ENCs. This lack, in turn, is suppressing demand for ECDIS with the result that interest in setting up an infrastructure to distribute ENCs and updates has stalled. Given the international trend toward smaller government it doesn’t seem likely that the production of ENCs will dramatically increase in the near future. The introduction of the RCDS will only exacerbate the problem.. Mariners in increasing numbers are discovering the economic and safety benefits of ECDIS and are continuing to exert pressure on HOs to produce more ENCs. Where they can’t get ‘official HO data’ they are reluctantly settling for commercial data which probably exists in greater quantity than the total of HO data worldwide. However, commercially developed data doesn’t have the authority or legality of ‘official HO data’, so, when it is being used, the paper chart is still the only legal navigation document on the ship’s bridge.

The Canadian and US Coast Guards are forging ahead with the implementation of DGPS networks in all coastal waters of North America. The 3-5 metre accuracy available from this system can only be exploited with an ECDIS like system. And, as mariners use these systems with these accuracies they are discovering new and better ways to operate their vessels. ECDIS systems are being used for docking and Canada Steamship Lines was given approval to operate in the St. Lawrence River last year after the buoys were removed for the winter. Normally removal of the buoys signals the end of shipping for the winter. ECDIS is also influencing the way mariners and navigation service providers (typically Coast Guards) approach the safe and efficient management of shipping. For example, they are asking if as many buoys and lighthouses are needed and how should Vessel Traffic Services (VTS) function in the future? A related development, known as Automated Information Systems (AIS) could have ships broadcasting their positions over dedicated radio links and ECDIS systems using this information to display all ships in the vicinity, even when they can’t be seen by radar because, for instance, they are around a bend in a river.

There is no doubt that ECDIS, DGPS and rapid global digital communications, supported by ever faster and smaller computers and higher resolution video displays will continue to revolutionize marine navigation for many years to come. We live in interesting times!

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Design of a Canadian Hydrographic Service Database Using CASE Technology

C. E. Day, H. P. Varma

C.E. Day *H. P. Varma*

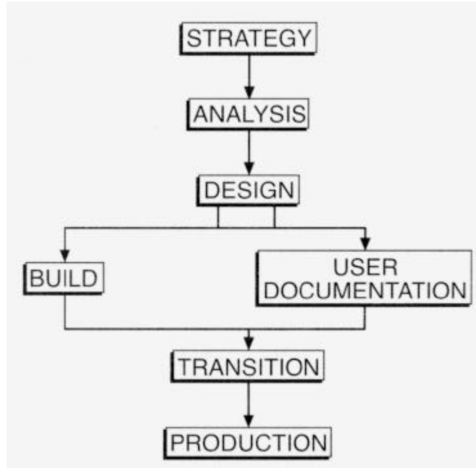

Figure 1: Business System Life Cycle (BARKER 90)

Abstract

The Canadian Hydrographic Service (CHS) is in the process of developing a National Database using ORACLE tools and methodology. The object of this project is to map the business functions of the CHS using computer assisted tools (CASE). The basic components of the CASE Designer is the Functional Hierarchy and Entity Relationship (E-R) diagram. The functional hierarchy is developed by interviewing the clients and mapping their work in terms of business functions. These functions are then mapped to entities mapped on E-R diagram reflecting the CHS data model.

Introduction

Hydrographic data is being collected in the order of 4 gigabytes/hour. The CHS has found it necessary to design and implement an appropriate data model to manage these massive amounts of data. This data model must also be able to handle the legacy information that has been collected in previous years and resides in a digital form. In June 1994, a decision was nationally made to use ORACLE “Multi-Dimension”, designed by CHS (Varma 89), as the database engine and ORACLE CASE methodology to create and build the hydrographic database. The database project, at this point in time, will focus only on point and line data.

Oracle CASE Methodology

Oracle CASE methodology is supported by and integrated with Oracle CASE Tools. These tools provide the user with a full development suite including CASE Dictionary as the repository, CASE Diagrammer for entity relationship modeling, function hierarchy modeling, data flow diagrams and matrix diagramming. CASE Generator provides a 4GL approach to generating the applications. The tools provide project documentation, graphical presentation of models, definition and description of entities and attributes, application constraints and auto code generation for integrated product quality assurance. (Barker 90)

CASE methodology approaches database creation using the Business System Life Cycle, which groups specific tasks into major stages and has specific deliverables attached to each stage. The Business System Life Cycle is shown in Figure 1. The stages are Strategy, Analysis, Design, Build, User Documentation, Transition and Production. The Strategy and Analysis stages define the scope of the project and within that scope what function the organization carries out to complete its mandate. These are the current phases being addressed by the CHS Source Database Team. The remaining stages address the building, testing and implementation of applications to meet production requirements. (Evangelatos *et al.* 1994) This paper will concentrate on the processes and events encountered in each of the Strategy and Analysis stages.

Strategy Stage

The expected deliverable of the strategy stage is a plan of the organization which will take into account organizational, financial and technical constraints. An analysis of the organization is performed and a business model is built from this analysis. The key deliverables from the strategy stage are a statement of business direction, an entity relationship diagram, a function hierarchy that states what the business does now. organizational and technological issues and a phased development plan.

The CHS Source Database Team began the Strategy stage of the project in October 1994. At that time a draft E-R diagram was created to identify the scope of the project and identify some of the entities that would effect the points and lines database. An early version of the E-R diagram is shown in Figure 2.

Interviews of all management and supervisory staff in the Atlantic Region began in November 1994. From these inter-

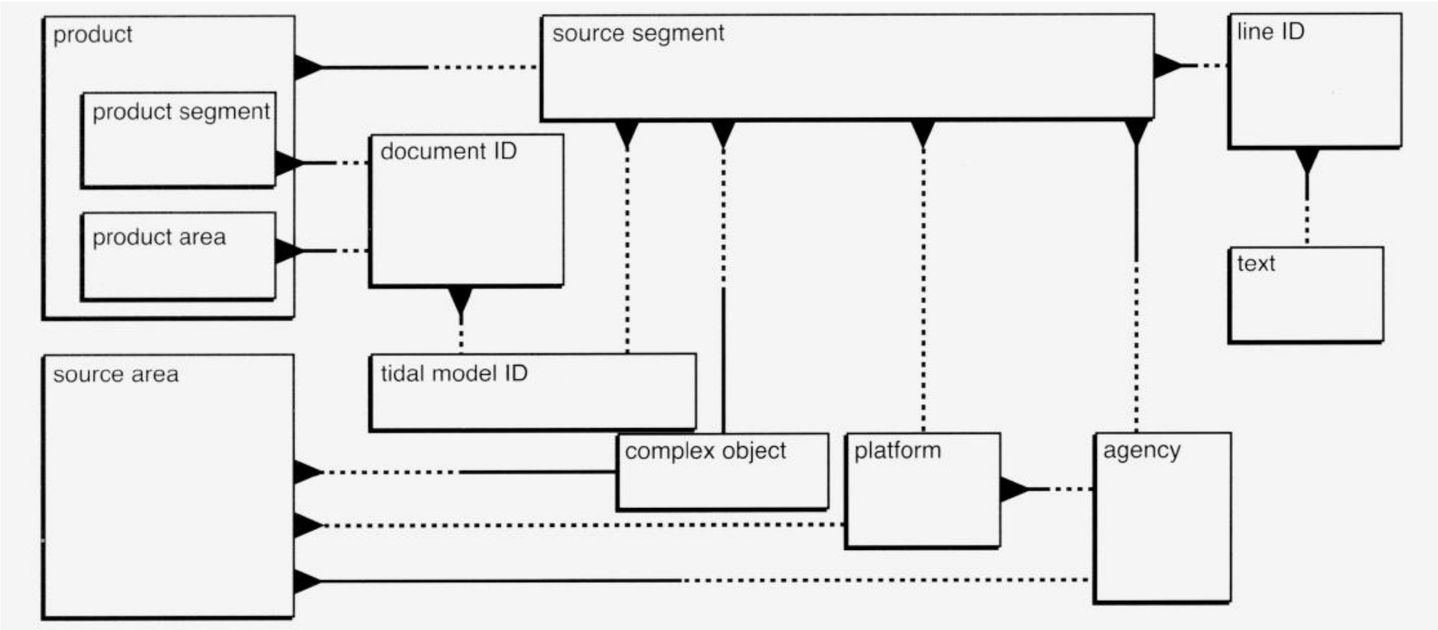

Figure 2: CHS Source Database Project E-R Diagram

views a base functional hierarchy was generated. This hierarchy was used as a model for the interviews that were conducted in the other four CHS Regions: Quebec Region in Mont Joli, Quebec; Central and Arctic Region in Burlington, Ontario; CHS Headquarters in Ottawa, Ontario; and Pacific Region in Patricia Bay, BC. The information gathered during the regional interviews was used to create a function hierarchy for that region. Once all regional hierarchies had been completed, they were distributed to the regional participants on the interviews for corrections, updates and input. All the input was subject to review and necessary changes were made.

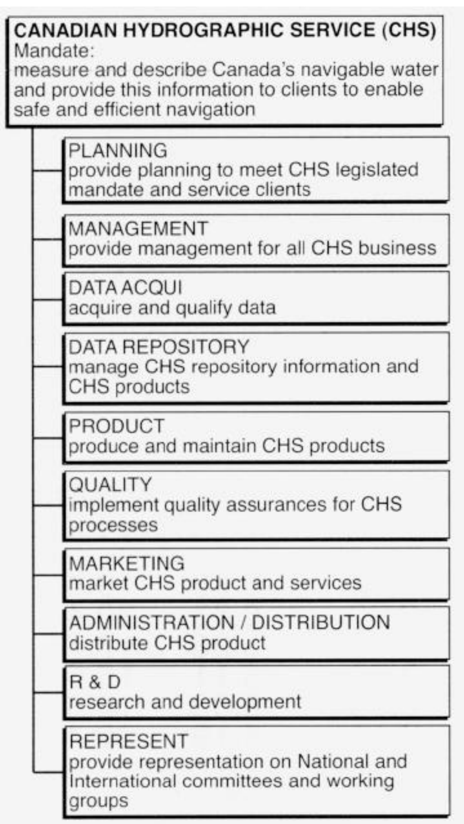

Figure 3: Top Level of CHS Function Hierarchy

The regional function hierarchies were reviewed by the CHS Source Database Team and a high level function hierarchy was created. This function hierarchy shows the overall business functions of the CHS, depicted top level functions. This hierarchy, which is shown in Figure 3, has been approved by the Dominion Hydrographer and is now being presented to all other regions for approval. A strategy report of tasks and deliverables will be produced at the completion of this stage.

Analysis Stage

The analysis stage consists of breaking down the business into detailed functional parts and building them into a statement of what is needed for the future. The key deliverables from this stage are an approved E-R diagram, an approved functional hierarchy of what we need to do, an outline for manual procedures, constraints of the database, an approved approach to the design and build stages and a revised system development plan. This is an iterative stage as a function hierarchy being created will consolidate the business of the entire CHS. The high level function hierarchy that was created in the Strategy stage will be expanded to lower, more detailed levels by consolidating the regional hierarchies as well as interviewing a broader section of the CHS staff from all five regions. Both the E-R diagram and the function hierarchy will be reviewed, expanded upon and approved by all regions before the design stage is started. One concern to keep in mind during the Analysis stage is to ensure what is proposed in the final version of the function hierarchy will be within the available budgetary and human resources and will continue to meet the legislative mandate.

Conclusion

Upon completion of the Strategy and Analysis stages of the Business System Life Cycle used in ORACLE Methodology, the CHS Source Database Team will continue through each step of the remaining stages until a functional and appropriate database has been built for the national Canadian Hydrographic Service.

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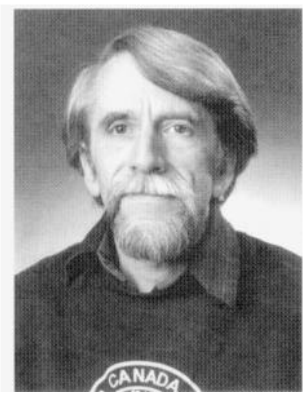
Seismic Prospecting for Massive Sulphides

M. Salisbury, D. Eaton, W. Bleeker and B. Milkereit



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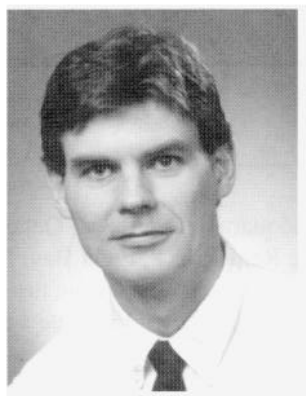

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M. Salisbury *D. Eaton* *W. Bleeker* *B. Milkereit*

Abstract

Laboratory and logging measurements of the density and compressional wave velocity (Vp) of ore and host rock samples from massive sulphide deposits show that sulphides have significantly higher acoustic impedances at elevated pressures than their mafic or felsic hosts. This suggests that it should be possible to detect and delineate large massive sulphide deposits using high resolution seismic reflection techniques. This prediction has been confirmed in recent seismic tests in which a massive sulphide body was detected near the giant Kidd Creek deposit using side-scan imaging techniques.

Introduction

The Canadian mining industry has traditionally relied on mapping, drilling and potential field techniques to locate shallow base metal deposits, but with the known domestic reserves of copper (Cu) and zinc (Zn) declining, there is increasing recognition that new deep exploration techniques must be used if the industry is to remain profitable in the long term. A promising new approach is to search for base metal deposits using high resolution seismic reflection techniques similar to those employed for exploration by the petroleum industry, but modified for the hard rock environment. Over the past three years, the Geological Survey of Canada, in collaboration with INCO, Noranda Mining and Exploration, and Falconbridge, Ltd., has engaged in an extensive directed research program involving laboratory and borehole physical property measurements, seismic modelling and field tests over deposits in the Sudbury, Bathurst, Kidd Creek and Matagami mining camps, to determine if seismic techniques can be used for the direct detection of massive sulphides. The initial results from this program, presented here using data from Kidd Creek as an example, strongly suggest that the answer is yes.

Lithology	n	Density (g/cc)	Vp (km/s)	Acoustic Impedance
Basalt	6	2.91	6.68	19.4
Diorite/ Gabbro	3	2.99	6.83	20.4
Ultramafics (talc)	3	2.92	6.06	17.7
Rhyolite	5	2.71	6.11	16.6
Argillite	3	2.75	6.02	16.6
Massive sulphides	11	4.11	6.19	25.4

Compressional wave velocities (Vp) at 200 MPa.

Table 1: Mean acoustic properties of North Rhyolite lithologies based on laboratory data

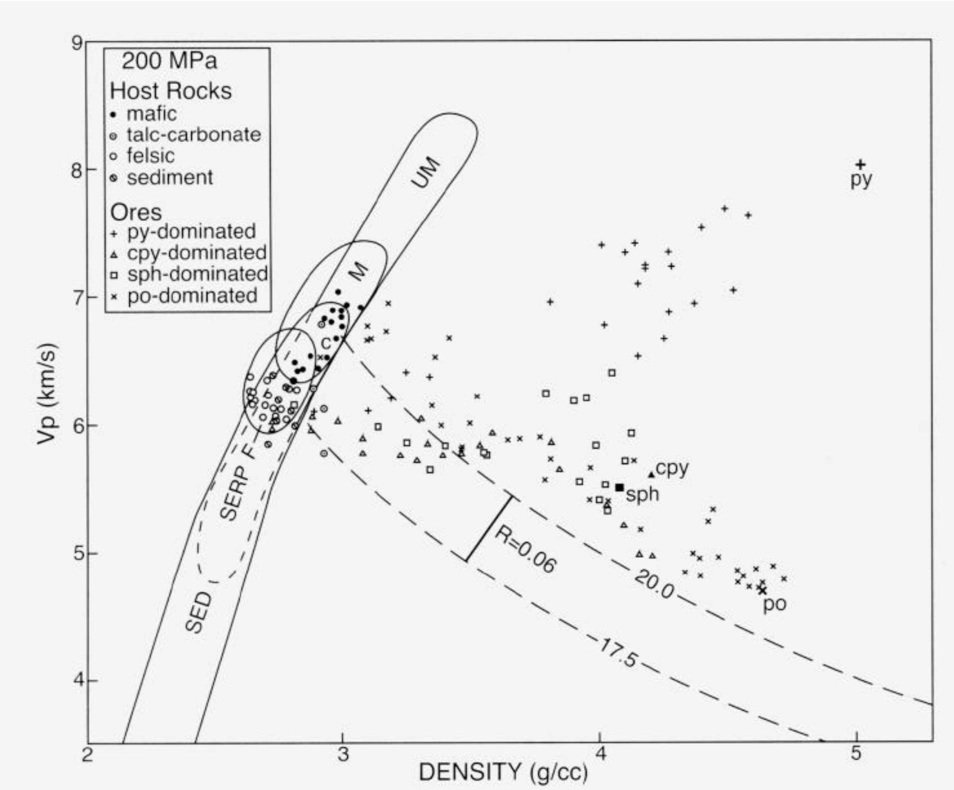

Figure 1: Compressional wave velocities (Vp) versus densities for sulphide ores and host rocks at a confining pressure of 200 MPa. Ores coded by predominant sulphide: py, pyrite; cpy, chalcopyrite; sph, sphalerite; po, pyrrhotite (end-members in bold). Subfields along Nafe-Drake curve: SED, sediments, including carbonates (c); SERP, serpentinite; F, felsic; M, mafic; UM, ultramafic. Also shown are lines of constant acoustic impedance for felsic (Z=17.5) and mafic (20) rocks and the reflection coefficient required to make a strong reflection (R=0.06).

Conditions for Reflection

In principle, an ore body should be seismically detectable if three conditions are met:

Condition 1) The acoustic impedance (Z) or velocity-density product of the ore must be sufficiently greater than that of the host rock to produce a reflection coefficient, R>0.06, where R is defined by the relation,

$$R = \frac{Zo - Zh}{Zo + Zh}$$

and Zo and Zh are the ore and host rock impedances, respectively. Since the impedances of massive sulphides have never been systematically investigated, we measured the densities and compressional wave velocities (Vp) of a large suite of ore and host rock samples of known composition from Sudbury, Kidd Creek and Les Mines Selbaie to a confining pressure of 600 MPa using the pulse transmission technique of Birch (1960). The results, presented at a standard reference pressure of 200 MPa in Figure 1, show that silicate host rocks generally fall within the mafic (M) and felsic (F) fields of the Nafe-Drake curve (Ludwig et al. 1971), but that massive sulphides lie far to the right in a large velocity-density field controlled by the end-member properties of pyrite, pyrrhotite, sphalerite and chalcopyrite (Salisbury et al. 1996). Close inspection of the data shows that the sulphide field can be divided in overlapping subfields (Fig. 2) in which the acoustic properties are controlled by mixing lines connecting matrix and end-member properties. Thus for example, density increases linearly with modal pyrite content in rocks composed of pyrite and felsic gangue, and Vp increases along a trend consistent with the time-averaging relationship of Wyllie *et al* (1958).

If lines of constant impedance are superimposed on the velocity-density data as in Figure 1, it can be seen that sulphide ores have higher acoustic impedances that most common felsic or mafic hosts and that the impedance contrast increases rapidly with pyrite content. As a rule of thumb, a contrast of 2.5 (the contrast between felsic and mafic rocks) is sufficient to give a strong reflection (R=0.06). Thus massive sulphides of any composition should make strong to brilliant reflectors in a felsic setting and sulphides with an admixture of pyrite should do so in either a felsic or a mafic setting.

Condition 2) The orebody must be large enough to detect using seismic methods. Under ideal conditions, a body with a diameter of one wavelength can be detected as a point source or scatterer (Berryhill 1977) but in practical terms, the smallest deposit that can be resolved as a planar body at a given depth, z, must have a minimum diameter, d, equal to that of the first Fresnel zone,

$$d = (2zv/f)^{1/2}$$

where v is the average formation velocity and f is the dominant frequency (Yilmaz 1987). Similarly, the body must be at least 1/4 wavelength thick for its thickness to be resolved (Widess 1973). Thus assuming a formation velocity of 6 km/s, a body which is 60 m across by 15 m thick could be detected as a point source at a depth of 1 km using a seismic frequency of 100 Hz, while a body 350 m across at the same depth could be resolved as a planar reflector.

Condition 3) Finally. the geometry of the body must allow reflected energy to return to the receivers. While shallow-dipping bodies will reflect energy back to the surface, steeply-dipping bodies will shed

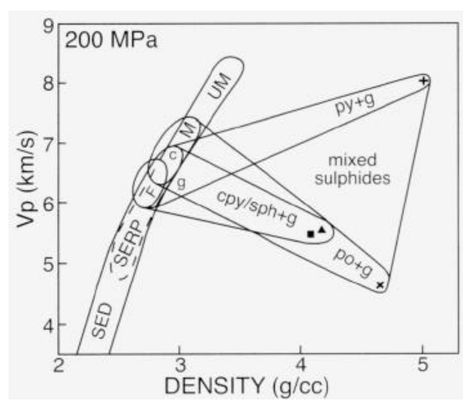

Figure 2: Velocity (Vp) - density fields for common sulphide ores and silicate host rocks; g, gangue; other abbreviations as in Figure 1.

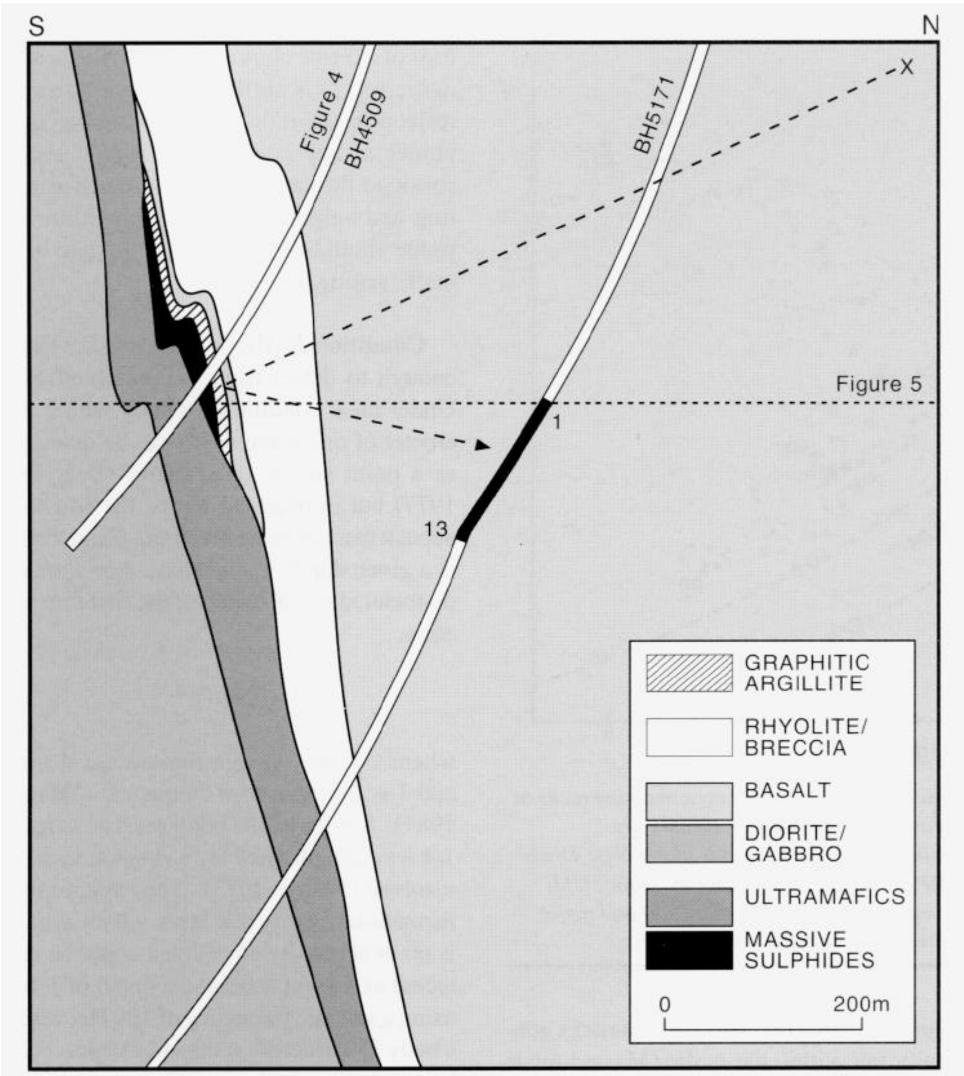

Figure 3: N-S section through the North Rhyolite showing location of orebody. Logs shown in Figure 4 were obtained in borehole BH 4509. The seismic experiment was conducted in borehole BH 5171 with the seismometer occupying 13 stations immediately below the horizontal image plane at 350 m shown in Figure 5 and the shots fired in an E-W arc which intersects the section at X.

most reflected energy downward (Milkereit et al. 1996). In practice, if the dip exceeds 60°, the optimum detection strategy will be to use borehole seismic techniques which place the receivers below the reflection point (Eaton *et al.* 1996).

In summary, it is apparent that while massive sulphide deposits commonly meet the conditions required for reflection, in hard rock terrains, they will often be small, brilliant, steeply-dipping reflectors rather than the continuous, shallow-dipping reflectors commonly imaged by the petroleum industry. Their detection will often require novel acquisition geometries, customized computer processing and a thorough understanding of their acoustic properties.

Field Tests at Kidd Creek

Convincing tests of this technique have recently been conducted by the Geological Survey of Canada at several mine sites in Canada, including the giant Kidd Creek Cu-Zn deposit near Timmins, Ontario. The tests consisted of laboratory measurements of density and velocity on an extensive suite of samples representing the major lithologies encountered in the camp, followed by logging and borehole seismic studies in the vicinity of a steeply-dipping orebody in the North Rhyolite which had been delineated but never mined (Fig. 3). The laboratory results, summarized in Table 1 for the lithologies present in the vicinity of the seismic test, show that large impedance contrasts exist between the felsic and mafic lithologies and between the sulphides and all host rock lithologies. Interestingly, the ultramafics in this locality behave like felsic rocks because they have been altered to talc which has a low velocity and thus a low impedance. If the reflection coefficients between all possible pairs of these lithologies are calculated from Equation 1 using the impedances presented in Table 1, it is clear that strong reflections are to be expected between mafic and felsic units, ultramafic rocks and diorite or gabbro and between the sulphides and any of the other lithologies in the area (Table 2).

While the laboratory results suggest that the ores should be strong reflectors, it is important before conducting seismic field tests, to determine if the impedance contrasts calculated from laboratory data are consistent with in situ data and if they persist at seismic scales of investigation. To this end, an 840 m borehole (BH 4509 in Fig. 3) which intersects all of the major lithologies in the North Rhyolite, was continuously logged with compressional wave velocity and density tools and an impedance log was calculated from the resulting velocity and density data. The results, presented in Figure 4 along with reflection coefficients calculated from the impedance log at key lithologic contacts, show that the impedance contrasts measured in the lab are consistent with in situ values. after corrections have been made for differences in pressure, and that these contrasts persist at formation scales.

Finally, an *in situ* seismic test was conducted to determine if the North Rhyolite deposit could be directly imaged. Since the orebody is steeply dipping (Fig. 3). the test was conducted using a modified vertical seismic profiling (VSP) shot-receiver configuration in which the seismometer was placed in a deep borehole (BH 5171) subparallel to, but below, the hole which was logged, thus allowing the receivers to detect energy reflected off the orebody from surface shots. In a conventional VSP survey, a vertical plane passing through the shot point, the VSP hole and the orebody would be imaged by shoot-

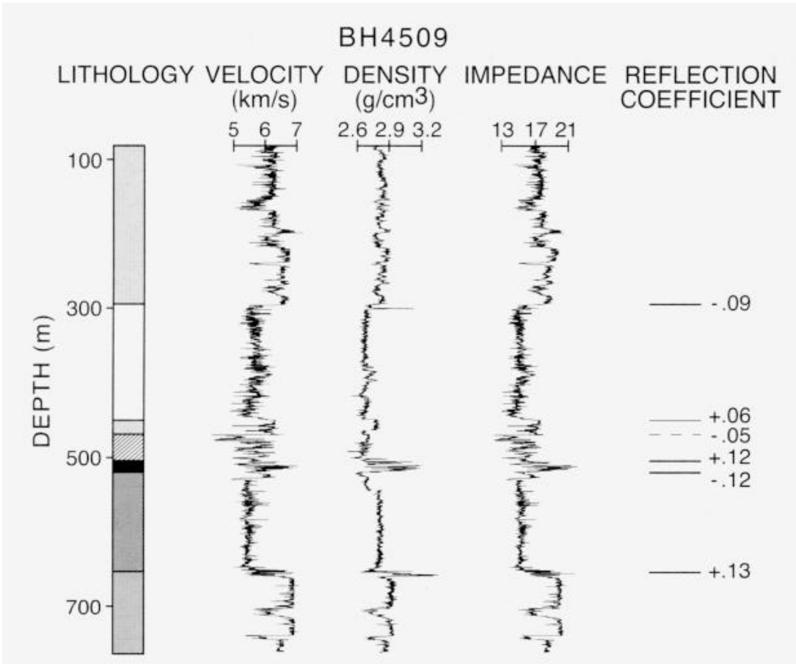

Figure 4: P-wave velocity and density logs versus depth and lithology in hole BH 4509 (lithologies as in Figure 3). Also shown are calculated impedance log and reflection coefficients at key lithologic contacts.

ing repeatedly from the same shotpoint (X) while raising the seismometer in steps from the bottom of the hole to the surface. In the present experiment, however, we imaged a horizontal plane about 350 m below the surface by restricting the receiver positions to 13 levels between 477-642 m downhole and shooting to each receiver level from 83 shallow drillholes located in an E-W arc to the north of the drillhole (Fig. 5a). By this means, the reflection points were effectively confined to the 350 m level and the level was acoustically swept in the horizontal plane using the receivers as a fulcrum. The resulting side-scan imaging data, processed using fairly conventional VSP processing techniques (Hardage 1985) and transformed into geometric coordinates, is presented in Figure 5b for comparison with the geology determined at the 350 m level by drilling (Fig. 5a). As can be seen in this figure, the reflection results

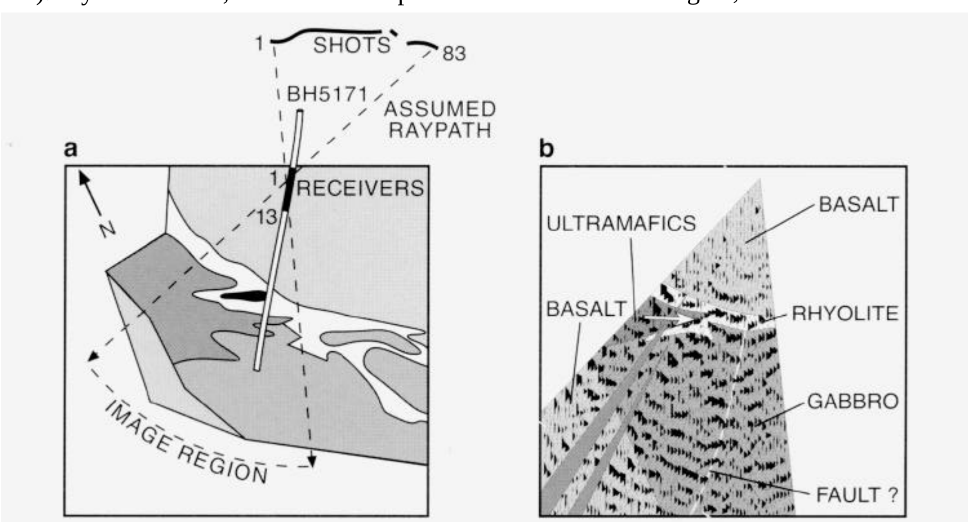

Figure 5: a) Geology at 350 at m level in the North Rhyolite showing 1x1 km region imaged by borehole seismic experiment. Vertical section shown in Figure 3 is subparallel to surface projection of BH 5171. Symbols as in Figure 3. b) Corresponding seismic image showing strong reflections at basalt / rhyolite and rhyolite / gabbro contacts. White arrow shows location of sulphide reflection.

are in good agreement with the predictions of both the laboratory and logging studies and the known geology at the 350 m level. In particular, the basalt / rhyolite and rhyolite / gabbro contacts are strong reflectors and the strongest reflection in the seismic record (white arrow) is coincident with the massive sulphide deposit.

Conclusions

From the results presented above, it is clear that massive sulphide deposits can be directly imaged using high resolution seismic reflection techniques if the ore/ host rock impedance contrasts are sufficiently large and the deposits meet the geometric constraints required for detection. Since large massive sulphide deposits often meet these constraints, we conclude that seismic reflection can be used as a deep exploration tool for base metal deposits in hard rock terrains.

Acknowledgements

We thank Ray Band and Dean Crick from Falconbridge Ltd., Gordon Morrison and Eberhard Berrer from INCO and Laurie Reid from Les Mines Selbaie for providing the samples used in this investigation. Robert Iuliucci at the Dalhousie University High Pressure Laboratory conducted the laboratory velocity measurements and Karen Pflug and Jonathan Mwenifumbo from the Mineral Resources Division of the Geological Survey of Canada provided the logs. Funding for the laboratory and field studies reported here was provided by Falconbridge, INCO and the Geological Survey of Canada under the GSC Industrial Partners Program.

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	Basalt	Diorite/ Gabbro	Ultramafics	Rhyolite	Argillite	Sulphides
Sulphides	.13	.11	.18	.21	.21	---
Argillite	.08	.10	.03	.00	---	
Rhyolite	.08	.10	.03	---		
Ultramafics	.05	.07	---			
Diorite/Gabbro	.03	---				
Basalt	---					
Reflection coefficients based on impedances in Table 1. Coefficients >0.06 should cause strong reflections						

Table 2: Reflection coefficients between North Rhyolite lithologies based on laboratory data

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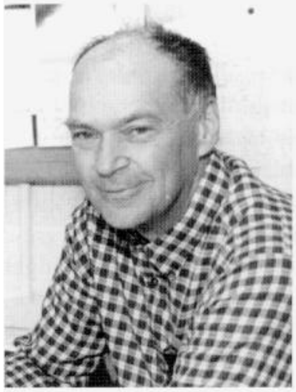
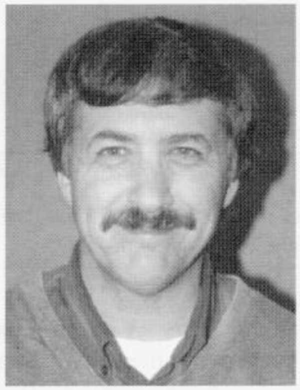
Striped Bass and American Eel Research

R. H. Peterson, D. J Martin-Robichaud and P. Harmon





R H. Peterson *D. J. Martin-Robichaud* *P. Harmon*

Background

Following the early successes of salmon cage culture (now worth 100-150 million annually) in the Bay of Fundy, interest in the culture of other species with high economic value was generated. As a result, research on culture of "alternate" species began about 7 years ago. In a 1991 DFO working group, four species - halibut, haddock, striped bass, and eels - were identified as having potential for development as aquaculture species. Since then, the winter flounder has also emerged as a culture candidate.

Interest in striped bass culture arose with the collapse of the wild striped bass fishery along the east coast of the U.S. in the mid-80's, coincident with some advances by U.S. scientists in successfully inducing spawning of captive striped bass broodstock. Over the past 6 or 7 years, the production of cultured striped bass (actually the production of striped bass-white bass hybrids) has attained an annual volume of about 500 metric tons (MT). This production is split nearly evenly between pond culture and culture in closed, recirculation systems, and represents only about 0.1% of the former wild fishery production (Jessop 1991).

At present, there is only one striped bass population successfully reproducing in the Bay of Fundy - that inhabiting the Stewiacke-Shubenacadie river system in Nova Scotia. The reproductive status of former populations in the Saint John and Annapolis river systems is uncertain. The structure of Northumberland Strait populations is also uncertain. Successful recruitment occurs in the Miramichi estuary and, perhaps, in some of the smaller adjacent rivers as well.

Broodstock

The success of research on any aquaculture species requires the establishment of a successful broodstock as a source of eggs and juveniles. We acquired our first broodstock (three females, two males) (Fig. 1) from gillnets of the Stewiacke driftnet fishery in the spring of 1988. We have relied on the progeny of these five fish for almost all of our research on early development. We have spawned these fish annually since 1991. Their growth during the first 4 years of captivity (Fig. 2) averaged about 0.5 kg/year for females and about half that for males.

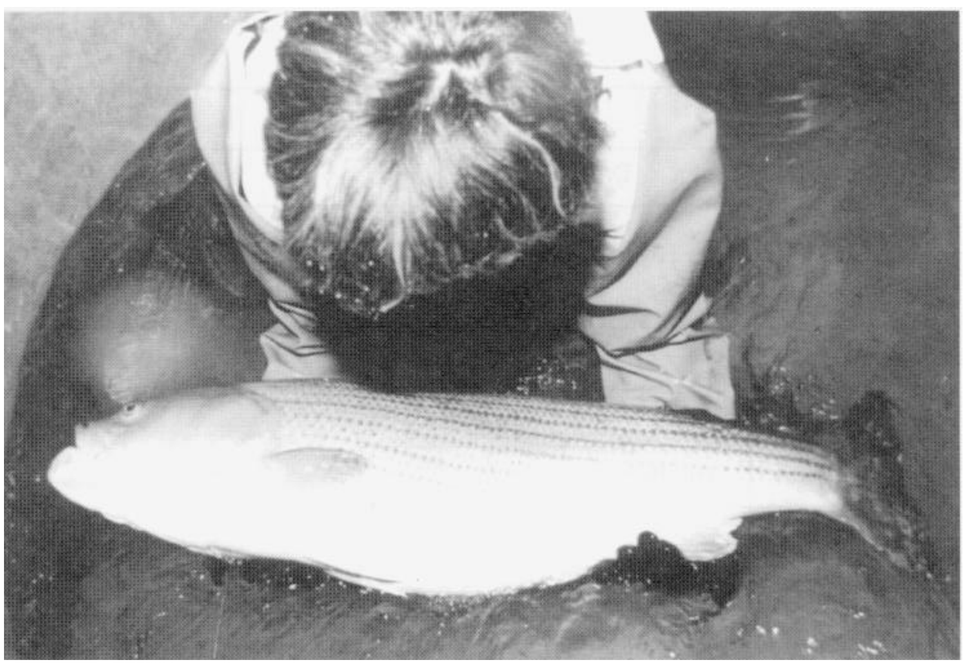


Figure 1: Striped bass broodstock.

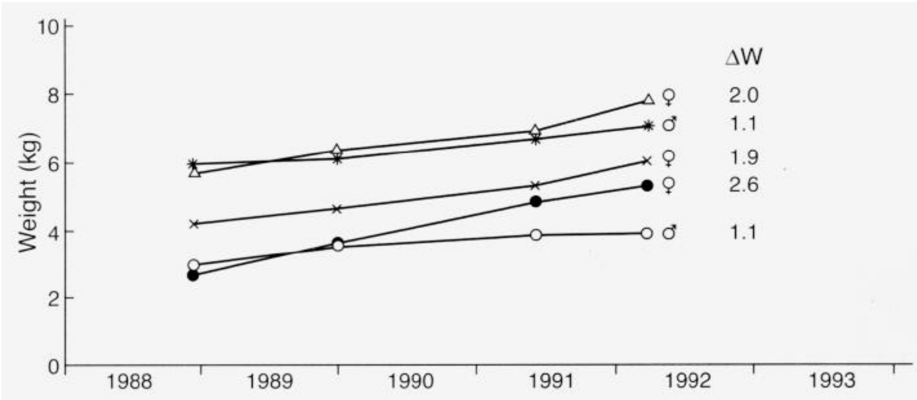


Figure 2: Weight changes in five striped bass broodstock fish for 1988-92. Each symbol represents an individual fish. Dw is the increase in weight from 1988 until 1992.

Spawning striped bass requires precise timing for injection of GnRh into the broodstock. This allows spawning to occur in the tank, and collection of eggs from the broodstock tanks. The eggs hatch in 2 days at about 16°C, and the yolk utilization requires only another 5-7 days. Larvae are first fed live brine shrimp *(artemia)* and can be weaned to artificial diets after 2-3 weeks of *artemia*.

Early Development

Our research has focused on three areas: early development, juvenile growth and performance in an aquaculture setting. Successful swimbladder inflation during yolk utilization is essential for the production of viable juveniles, and has been a recurrent problem for all who culture the species. Our inflation success has been as low as 10% in some years. We have studied optimal environmental conditions for successful early development (Peterson et al. 1996a). Most recently, we have found that light intensity and interior tank color influence the percentage of larvae successfully inflating their swimbladders (Table 1). Larvae reared in tanks with black interiors had 70-80% successful inflation rates, as opposed to 40-50% for larvae reared in tanks with white interiors. We believe that the white interior has an adverse effect on larval behavior. They seem to orient to the walls oddly, standing on their tails and swimming against the sides. A lower overhead light intensity seems to give a slightly better inflation rate as well. A shorter photoperiod (8 hours light, 16 hours dark) also yielded higher percentages of larvae with inflated swimbladders than did exposure to a longer photoperiod (16 hours light, 8 hours dark). In some earlier experiments, all larvae reared in continuous light failed to inflate their swimbladders. Thus, periods of darkness seem to facilitate swimbladder inflation. Larvae reared in dark tanks and under short photoperiods were larger after 12 days post-hatch. It may be that dark tanks resulted in more efficient prey capture, resulting in larger, more vigorous larvae that had more success at filling their swimbladder. Or, conversely, it may be that successful swimbladder inflation resulted in larvae that fed and grew better. Many of these uncertainties might be clarified by some appropriate observations on larval behavior as related to tank color and light intensity.

	Tank Colour			
	Dark		Light	
Intensity	Low	High	Low	High
Inflation	80-85	68-72	45-50	40-45
SL (12 dph)	8.3	8.6	7.3	7.2

	Photoperiod	
	16L:8D	8L:16D
% inflation	20-40	55-65
SL (12 dph)	7.5	8.0

Table I: Influence of tank color and photoperiod on swimbladder inflation (%) and growth (mm) in larval striped bass. SL: standard length at 12 d post-hatch; L: light duration; D: dark duration.

Juvenile Growth

Our work on juvenile growth was performed to determine growth responses at various temperatures and salinities (Harmon and Peterson 1994)) and what rations should be provided for various fish sizes and environmental conditions. The striped bass grows best at temperatures in excess of 25°C. Specific growth rates may exceed 4-5% body weight per day under such conditions for 1- to 50-g fish. At 15 17°C, growth rates of 1-2% per day are obtained. Growth rates are also greater at salinities of 12-30 ‰ than in low salinity (Fig. 3). At the higher temperatures, extremely high rations must be fed to prevent cannibalism. We feed rations of 30% body weight per day up to a size of 20 g, at which point the rations can be reduced to 10% per day. These rations compare with rations of 1.5% fed to salmon of similar size at temperatures of 17-20°C.

Aquaculture Strategies

Our studies on growth responses of striped bass in aquaculture operations is to determine optimal ways to culture striped bass, and to determine feasibility of commercial culture of the species in the Maritimes. Since the striped bass is adapted to warmer temperatures than the Atlantic salmon, a somewhat different strategy is required for successful commercial culture. There are three possible strategies: cage culture in areas with warmer sea surface temperatures in the summer, pond culture, and culture in recirculation systems. We have been involved with the second option

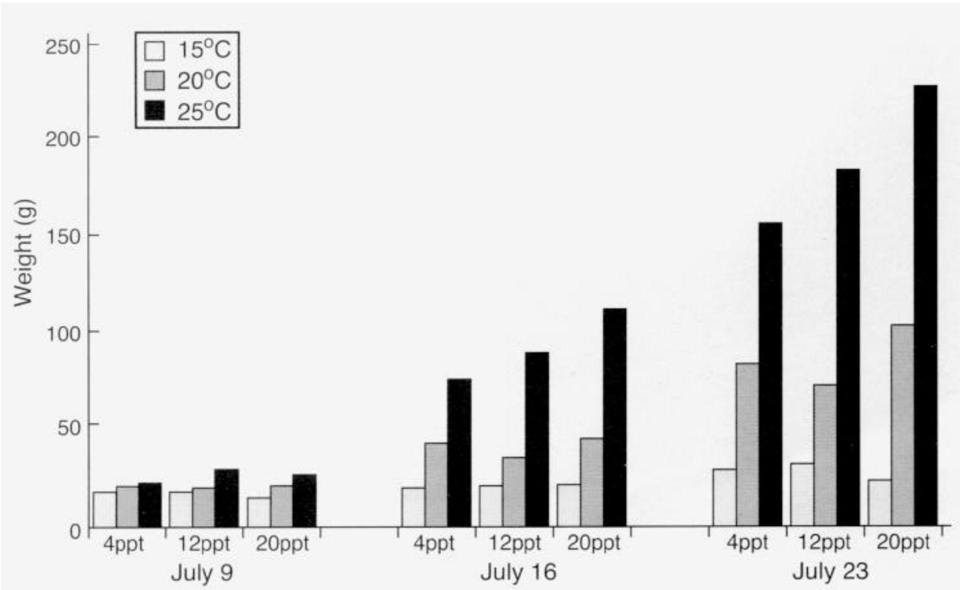


Figure 3: Growth of juvenile striped bass at nine temperature-salinity combinations. Weight gain occurred over 2 mo. Fish in all treatments started at about 1 g. Each bar represents the means of 100 fish.

- pond culture. Rearing striped bass in coastal brackish or saltwater ponds is probably the easiest and cheapest way to culture striped bass. Freshwater ponds with water of sufficient hardness (more than 150 mg/L) is also possible, but growth is less rapid in fresh water.

Ponds of 1-2 m depth in the Maritimes will typically have temperatures exceeding 20°C for 3 months of the year (Fig. 4), during which rapid growth can be anticipated. Some growth will typically occur in May, September and October as well. Striped bass normally spawn in early June, and we consider it necessary to get the juveniles to 40-50 g by the end of the first summer in order to have a market-sized fish (ca. 600 g) by the end of the second summer. Striped bass culture will be profitable if a market-sized fish can be produced in 18 months. The current private striped bass operation produces juveniles averaging 30 g at the end of the first summer, with only the larger individuals attaining 50 g. This operation has transferred a portion of their juveniles to a recirculation system in a greenhouse for an extra 2 months growth (principally October and April). They marketed the first cultured striped bass in the Maritimes last summer (about 500 fish), a mixture of 2-summer and 3-summer fish.

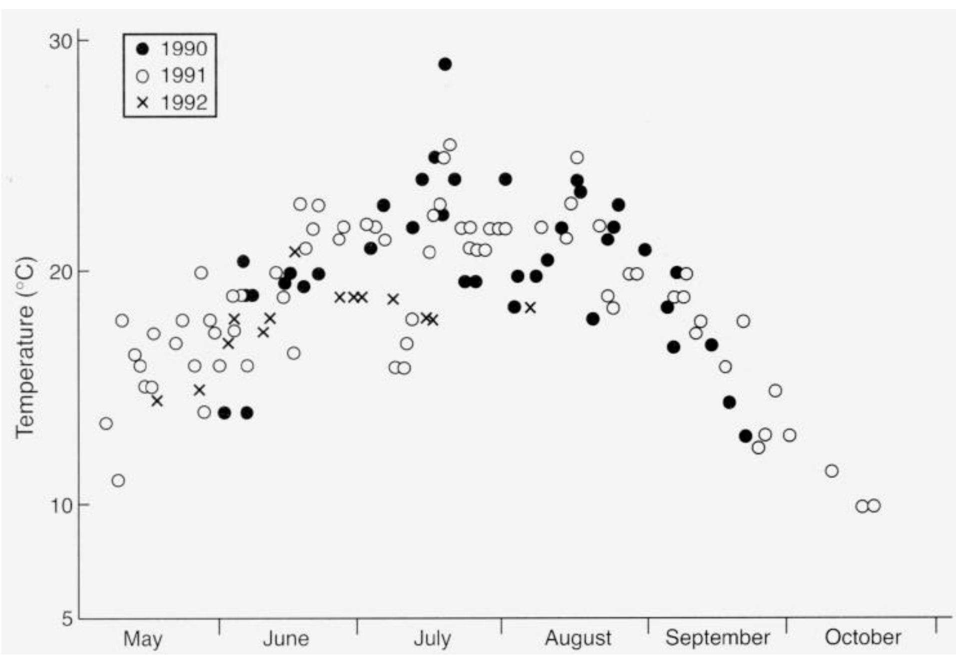


Figure 4: Temperatures recorded in experimental ponds at the St. Andrews Biological Station over three summers

One of the problems in optimizing growth in ponds is developing an optimal feeding strategy. From some casual observations, it would appear that striped bass are nocturnal feeders, so better growth may be achieved by including feedings at night. We are proposing to investigate the use of nocturnal feeding in augmenting growth in some of our experiments next year.

A striped bass culture manual is currently available (Peterson *et al.* 1996b).

Eel Culture

Culture of eels (Fig. 5), unlike that of most aquaculture species, is totally reliant on a source of wild elvers as seedstock. This culture of eels must be integrated with management of wild eel fisheries in the Maritimes. Eels in the Maritimes are currently exploited in three ways: fished and sold as large eels to markets abroad, fished and sold as elvers - either for culture systems abroad or as a food item, and cultured to variable sizes for sale either as seedstock abroad or directly as market-sized eels. There is at present one eel farm in New Brunswick, with a second probably beginning its operation in Nova Scotia in the spring of 1996.

The research we are doing on eels, in collaboration with Dr. Tillmann Benfey at University of New Brunswick (Fredericton), addresses one basic problem in eel culture - why do 90% of cultured eels become males? This problem has market implications because males cease growing at about 150 g with the onset of sexual maturation. Females grow to 500-1000 g before beginning to mature. Some markets (the German for example) will accept only the large females.

In contrast with the situation in culture systems, most wild eels in the Maritimes become females. Our hypothesis to explain the differing sex ratios between wild and

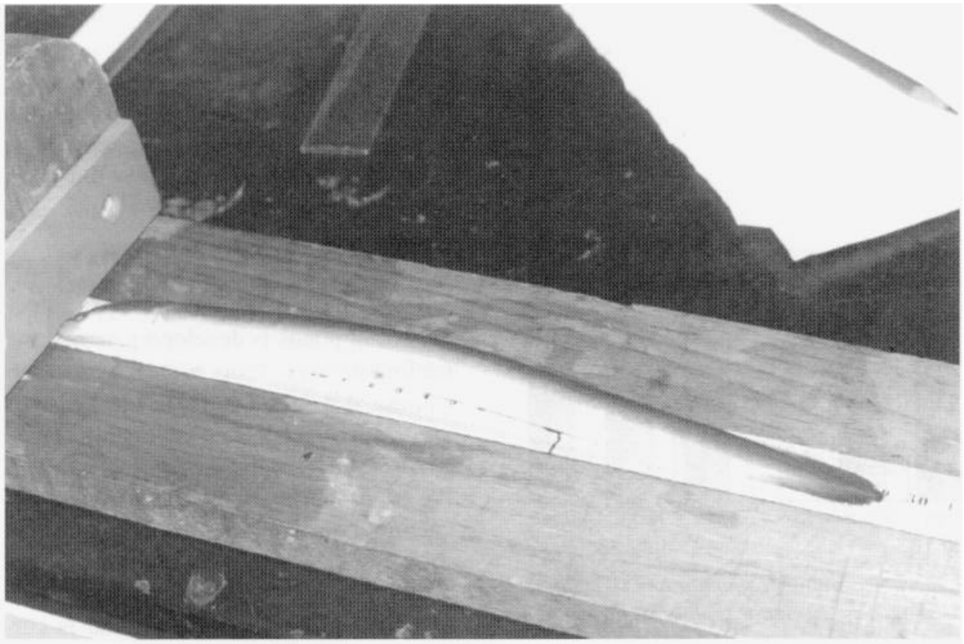


Figure 5: Eel on measuring board.

cultured eels was that wild eels experience a period of cold exposure after the first summer's growth. This period of low temperature, with cessation of feeding, may result in a high percentage of females. Temperature is known to affect sex ratios in some reptiles and fish. So, we set up two temperature treatments in the spring of 1994. In one treatment the eels were held at high (23-25°C) temperature continuously until of sufficient size to sex (ca. 30 cm). Sex must be identified by histological procedures. In the other treatment, eels were exposed to 5°C for 3 months (Dec.-Feb.), after growing at 23-25°C from June until the end of November, then re-warmed to 24°C and reared until a sexable size was attained. Growth rates in eels are highly variable.

We have sexed 38 eels: 15 from cold treatment, 23 from continuous warm temperatures (Table 2). The results indicate that we still have some way to go before we know how to produce female eels. While the only two identified females were from the cold treatments, the percentage (<10%) is not encouraging. There are several factors which could raise some questions as to the reliability of these results. As stated above, eel growth rates are highly variable. In addition, eels are cannibalistic and we had insufficient tank space to segregate small and large eels; hence, many eels were lost due to cannibalism. Several of the eels dissected for histology had smaller eels in their stomachs. The differential loss of slow growing eels may have biased our observed sex ratios.

The eel gonad is reported to become testis-like at first, then may develop oocytes later - this sequence developing from anterior to posterior. Three or four of the testes examined had some oocyte-like cells present, so there is a slight possibility that these eels might eventually have become females.

Treatment	Number of eels examined	Number of females	Number of males	Number uncertain
No Cold	15	0	14	1
Cold	23	2	18	2

Table 2: Sex determinations of eels processed histologically to date. No cold - eels maintained at 23°C throughout; cold - eels lowered to 4-5°C for 3 mo after first summer's growth. A length of about 30 cm must be attained before sex can be determined.

The future of this research is uncertain due to lack of funding. Dr. Benfey is hoping to continue by dosing eels of different sizes with estrogen to determine the size at which sex becomes fixed -i.e. cannot be altered by exposure to estrogen. Another useful approach would be to bring in wild eels of various sizes and grow them to sexable size to see at what size sex is established in wild populations.

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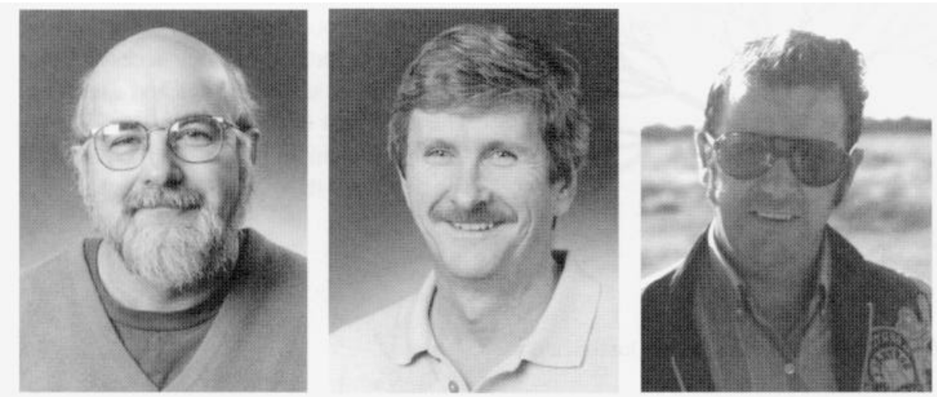
Co-management of Marine Plants in the Atlantic Region

G. Sharp, R. Semple and D. Jones



G. Sharp *R. Semple* *D. Jones*

Background

The harvesting of marine plants is an integral part of the near shore fishery in the Atlantic Zone. The marine plants industry began soon after W W II and developed into a significant industry in the early 1960s. The commercial species of Marine plants are attached to rock with a very defined intertidal and subtidal distribution. The management of the harvest varies from unrestricted harvesting for some species to closely controlled annual harvests in others (Pringle 1981). Harvesting technology ranges from hand harvest gear to sophisticated mechanical harvesters (Sharp *et al.* 1994). Despite some of its "artisanal" characteristics, this industry recently became one of the first fisheries to develop co-management agreements in Atlantic Canada. Two recent examples of co-management agreements. each with very different goals and structure are: the *Furcellaria lumbricalis* (wireweed, foo foo) harvest in Prince Edward Island and the *Ascophyllum nodosum* (rockweed) harvest in southern New Brunswick.

Co-management, Harvester Initiated

Harvesters of *Chondrus crispus* (Irish moss) on Prince Edward Island observed that an increasing abundance of *Furcellaria* in the commercial seaweed beds was becoming a major threat to the sustainability of their Irish moss harvest. The seaweed beds in the Pleasant View area (Fig. 1) had less than 5% of the observations with *Furcellaria* present in the 1978-80 surveys and 67.3% of *Furcellaria* in the observations in the 1991 survey (41.3% of those observations had >20% *Furcellaria* cover) (Sharp *et* al. 1993). A ratio of *Chondrus* to *Furcellaria* exceeding 20: 1 is not marketable. Although these closely associated species have similar size and morphology (Fig. 2), their reproductive cycle and vegetative recruitment mechanisms differ significantly. *Furcellaria* is more subject to detachment with wave action or dragrakes than *Chondrus*. Fully developed *Furcellaria* plants are able to reattach due to the structure of the rhizoidal holdfast while the discoid holdfast of *Chondrus* is firmly attached to the substrata and cannot regenerate quickly.

Few management options to alleviate this problem were available to the harvesters and the Department of Fisheries & Oceans (DFO), due to ice cover and conflicting fishing activity. Dragrakers could cull the beds of *Furcellaria* during the harvest season to promote a purer *Chondrus* harvest and discard *Fucellaria* ashore, which could reduce its biomass. Alternatively they could regard *Furcellaria* as another marketable species and make a separate harvest for this seaweed. A directed *Furcellaria* harvest was made possible by the company. Acadian Seaplants, which

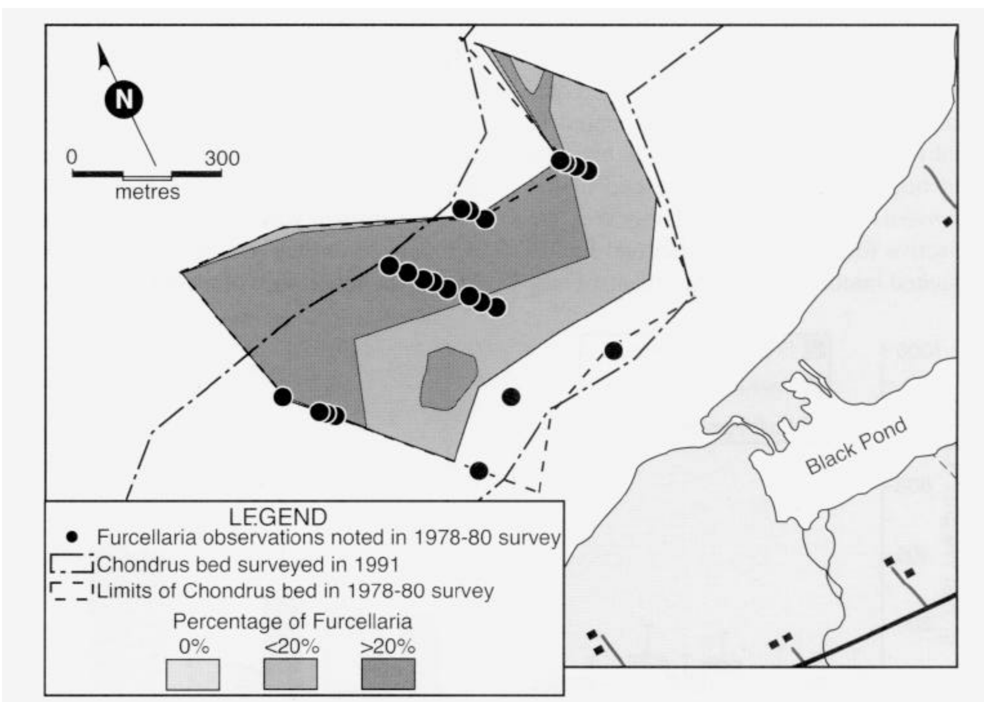


Figure 1: Map of the seaweed bed at Pleasant View, P.E.I. showing the location of the Furcellaria *observations from the 1978-80 survey and the percentage of Furcellaria located on the bed in the 1991 survey.*

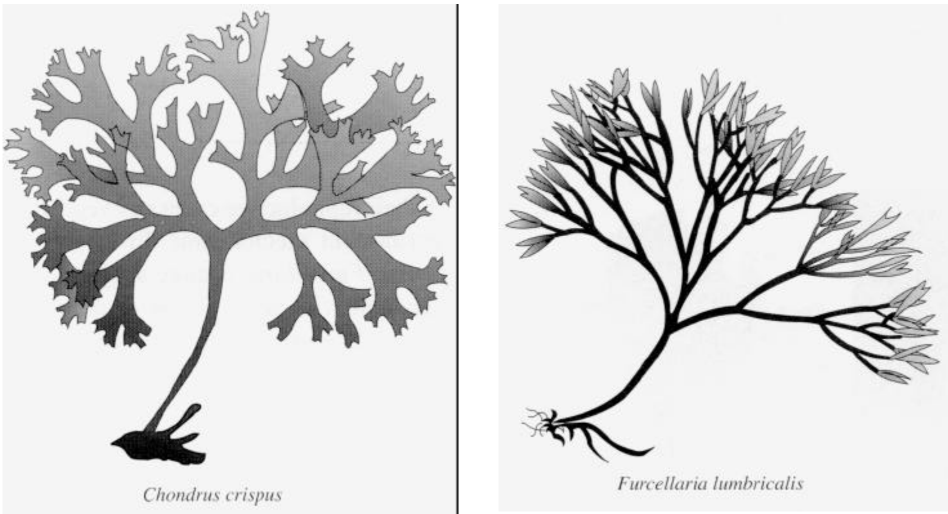


Figure 2: Diagrams of Chondrus crispus *showing its discoid holdfast and* Furcellaria lumbricalis *showing its rhizoidal holdfast.*

was interested in processing, storing, and marketing the seaweed. The P.E.I. Department of Fisheries and Aquaculture supported the handling costs. DFO issued special harvesting permits, set marker buoys to limit the area of harvest and initiated a monitoring program to measure effort distribution, catch characteristics, composition and population dynamics of the marine plant beds.

Over 60 fishers registered for the first year of this harvest and 36 participated in the harvest, landing 542 t of *Furcellaria.* The composition of the beds changed dramatically in the short term compared to control areas (Fig. 3). *Furcellaria* biomass had begun to recover by the end of the *Chondrus* harvest season. Dragrakes are selective for the bushier, taller and lightly attached mature *Furcellaria* plants. Once the fronds longer than 60 mm with over 4 branches are removed, the slender lower-branched fronds are not as vulnerable to the dragrake. The subsequent *Chondrus* harvest that followed the *Furcellaria* harvest in Western P.E.I. was 4013 t greater than the previous year's 5021 t (up 80%). The reduction of *Furcellaria* on the commercial beds prior to the regular season allowed more *Chondrus* to be harvested without exceeding the limit for *Furcellaria* in the mixed yield. The *Furcellaria* harvest of the same beds during the second year was 819 t with no significant change in Catch Per Unit Effort (CPUE) compared to the first year. A similar pattern of short-term reduction and medium-term recovery was noted in 1995. The key to the success of this experiment was the cooperative management of the harvest by the fishermen. Under the leadership of a committee, harvesters took the responsibility to harvest within the boundaries set for the *Furcellaria* harvest. Harvesters made the decision to cease harvesting *Furcellaria* once the amount of *Chondrus* had reached an unacceptable level in the harvest (20%). The harvesters cooperated fully with harvest monitors by providing open access to their vessels for at sea boardings and sampling. The third year of this experiment will confirm the sustainability of a dual season-dual species harvest.

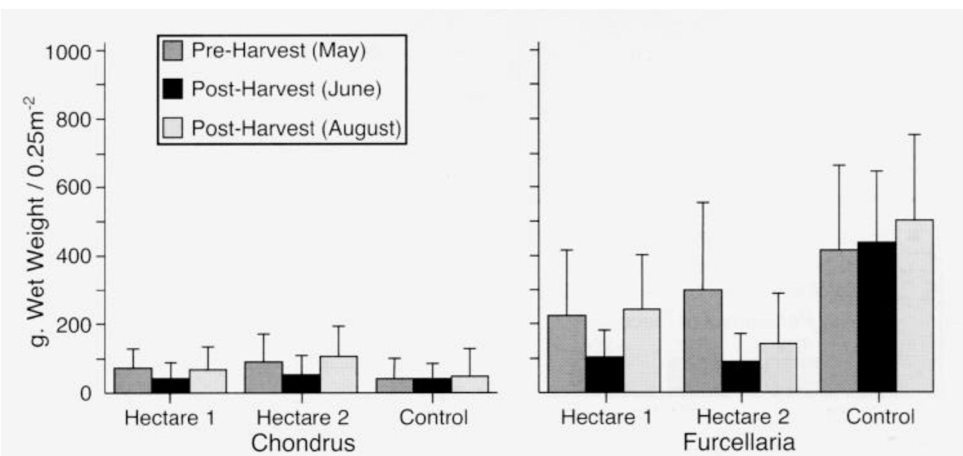


Figure 3: Abundance of Furcellaria and Chondrus in experimental and control hectares, located on the Pleasant View bed. P.E.I.

Figure 4: Diagram of Ascophyllum nodosum *plant.*

Co-management, Agency Initiated

Ascophyllum nodosum (Fig. 4). commonly called rockweed, is the dominant intertidal seaweed in the sheltered to semi-wave exposed coastline of Atlantic Nova Scotia and the Bay of Fundy. This perennial plant is attached to stable substrate and forms a floating canopy as the tide rises. The *Ascophillum* harvest in the Maritimes began in 1959 with few restrictions except for the provision of several exclusive buying areas by the province (Sharp 1987). The

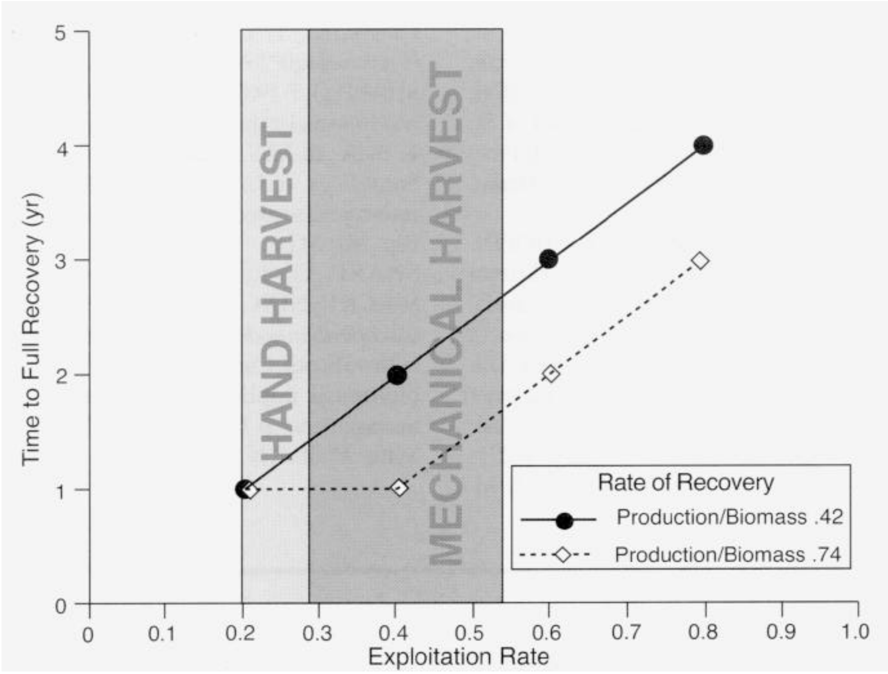


Figure 5: Rate of recovery for Ascophyllum *biomass showing 42% and 74% regrowth rates at increasing rates of removals by harvest.*

industry harvested and processed 4.000 to 6,000 t annually until 1985. A change of processing plant ownership, mechanization and the entry of second buyer/ manufacturer resulted in a rapid rise in exploitation and geographical expansion of the industry (Sharp *et* al. 1994). The response of management agencies to this change was to some degree uncoordinated and piecemeal (Pringle et al. 1996). The industry was interested in expansion to the New Brunswick side of the Bay of Fundy in 1989. Based on past experience in Nova Scotia, a Memorandum of Understanding was signed between DFO and N.B. Department of Fisheries and Aquaculture (NBDFA) clearly dividing management and development responsibilities (Pringle *et* al. 1996). The existing information on the resource base and related habitat issues was reviewed and provided to the proponents prior to a Call for Development proposal (CAFSAC, advisory document). The rate of exploitation was one of the most critical issues, especially if the resource is to be harvested on a yearly basis. The resource must be left fallow to recover yield if the exploitation is greater than 30 % of standing biomass (Fig. 5). A pilot scale harvest was based on an exploitation rate of 50% and a 3 year harvest interval within 90 sub-sectors of the resource (Fig. 6). The call for development proposals required the proponents to enter into a co-management agreement with DFO and NBDFA. The terms of the agreement included: means of harvest, degree, limits to harvest, assessment-monitoring requirements and report-

Figure 7: Aerial photo of Ascophyllum *beds near Letete, N.B. showing computer enhanced area used to determine the biomass.*

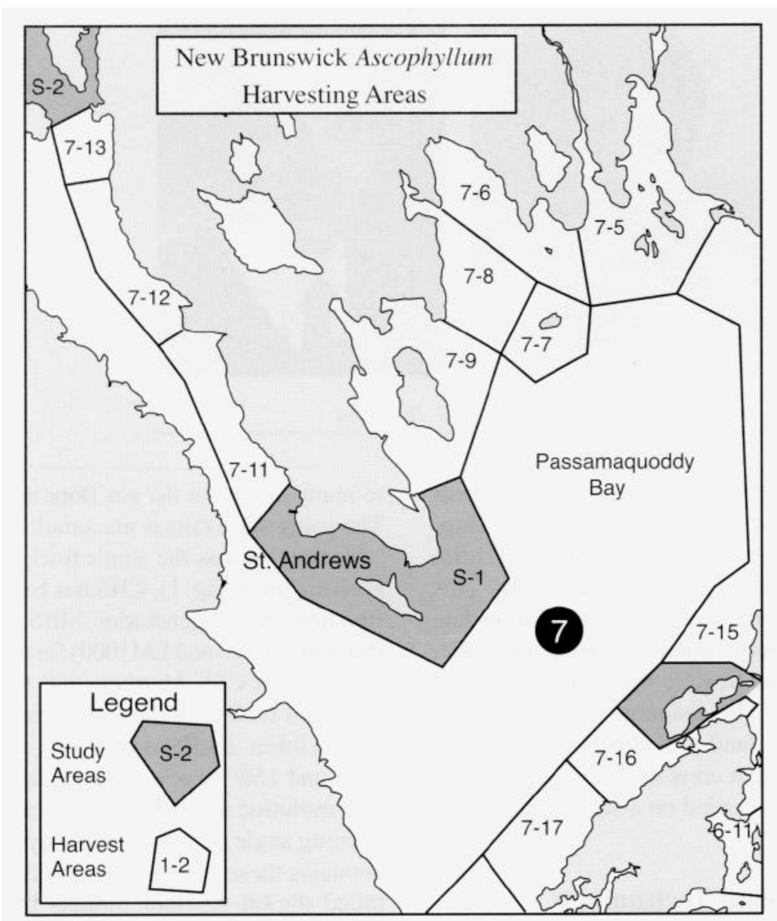


Figure 6: Map of New Brunswick Ascophyllum *harvesting area showing sectors of the harvest areas and study areas.*

ing commitments. Monitoring included not only the degree and extent of harvest and recovery of standing crop, but also addressed the impact on associated fauna. The co-management agreement was put in place July, 1995 and a partial season harvest was completed by October. Close adherence to the terms of the harvest plan has resulted in detailed assessment information. Aerial photography (1: 12,550) associated with gound-truth measurements has increased the resolution of the rockweed areas and decreased the error in biomass estimations (Fig. 7). Other benefits include compilation of data bases on the density and size distribution of key species in the intertidal.

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New Technologies For Near-shore Mapping

D.F. Dinn, G. Henderson, R. Courtney and J. Bradford


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Introduction

Recent improvements in acoustic transducer design and in digital signal proccssing have made wide-swath. multi-beam sonars (MBS) cost-effective for ocean mapping and for port and channel surveying with 100% bottom coverage. In addition, the geo-referenced, sidescan-like imagery and calibrated target-strength information from new MBS systems make them valuable for surficial geology mapping. bottom classification, and military applications, e.g., mine countermeasures.

Building on the work of the National Action Committee on Ocean Mapping (NACOM), and on recent MBS experience in larger vessels, the Canadian Hydrographic Service (CHS) is planning to carry out port and corridor surveys. and near-chore mapping, using new MBS equipment on 10m launches: three are being fitted out. This approach will provide high-resolution data for chart production while being more economical and flexible than using large survey ships. The launches can be readily moved overland to a survey area and can operate with a crew of two. The launches can also be carried on a survey ship when required.

Multi-Ream Technology

Multi-beam echo sounders measure the slant-range travel time of a short acoustic pulse traveling from the sonar transducer to many points on the sea floor and back. The many slant ranges are simultaneously "sounded" across the ship's track on each acoustic ping (Fig. 1). CHS has been using first and second generation MBS systems (Simrad EM 100 and EM 1000) for a number of years on CSS *Matthew* and the NSC *Frederick G. Creed.* These 100kHz systems are useful in 20-500m of water. and their 100° and 150° swaths give moderate spatial resolution using 32 and 64 beams (~3° opening angle). Data from surveys carried out using these systems have produced detailed digital seafloor models for many hydrographic projects and geological investigations.

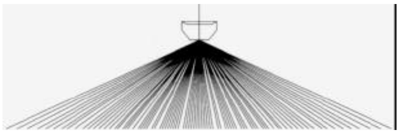


Figure 1: A typical multi-beam sonar coverage pattern

The new, third-generation Simrad EM3000 MBS now being commissioned by CHS, creates 127 separate sonar beams spanning a 120° sector which gives a sounding width about 3.5 times the water depth. Intended for water up to 75m deep, the EM3000 uses a 300kHz acoustic carrier, making the transducer (35cm diameter by 12cm high) suitable for use on a small boat. The 1.5° beam opening angle achieves high, along-track spatial resolution (-2.6% of slant range). Vertical resolution is on the order of 5- 10 cm.

The sounding density giving 100% bottom coverage is determined by vessel speed, beam opening angle and spacing, and ping rate. The latter depends on the two-way travel time of the outermost rays. For the EM3000 the upper limit is -25 pings per second. This sets the maximum speed for full coverage at about 10 knots in water depths of 10m or more.

Attitude Measurement Issues. Acoustic refraction and the vessel's roll, pitch, heading and heave determine where the acoustic beams meet the sea floor. Just as in conventional surveys, factors such as tides, storm surges and vessel draft and settlement at speed are also important in MBS surveys. Position and heading are used to transform slant-ranges and ray angles into geo-referenced depths.

Accuracy standards (90% confidence level) for navigation chart depths are set by the International Hydrographic Organization: 30cm for water less than 30m deep, and 1% for deeper water. Depth accuracy for extreme, off-vertical beams is limited by errors in roll angle and sound velocity. When the error budget is allocated to all sources, the contribution from roll must be 0.08° rms or less for the EM3000, and 0.05° rms or less for the EM1000 with its wider swath.

CHS is using a new position and attitude sensor (Applied Analytics Corporation POS-MV 320) that combines two elements: a) a gyro-based, 6-degree-of-freedom, strap-down, inertial navigation sensor, and b) dual differential global positioning system (DGPS) receivers. These elements enable pitch, roll and heading angles to be measured to 0.05° rms regardless of how the vessel is being conned. Position is determined to 1 m rms by blending the DGPS data (good long term accuracy) with the data from the inertial sensor (good short term accuracy) using a Kalman filter. Measurement bandwidth is 0 to 50 Hz. The combination of DGPS and inertial navigation enables the vessel position to be accurately established even during GPS outages lasting up to 1 minute.

Heave Measurement. In the conventional hydrographic sense, heave is vertical motion of the transducer relative to the average water level; it directly affects measured depths. Because of the wide frequency spectrum in the motion of the vessel and the water level, there are problems in accurately measuring heave and average water level.

POS-MV, like conventional attitude sensors, derives heave data by double integrating vertical acceleration (measured with respect to the earth's centre) and high-pass filtering the result. Filtering forces the measured heave to have zero mean-like the true heave-by removing the effects of initial conditions and zero-point drift in the electronics. However, whenever the heave spectrum has energy near or below the cut-off frequency of the filter (typically one cycle in five to ten minutes), there will be an unavoidable error in the heave measurement. This situation can occur because of oscillations in the survey area (seiches in partly enclosed bays), when operating in long-period, following seas with a fast vessel (e.g., the NSC *Frederick G. Creed),* and when the heave sensor's vertical position changes in steps due to (infrequent) changes in speed, transfer of ballast liquid, or movement of personnel (in small craft).

Normally, heave can be measured to 5 or 10cm rms, but heavy seas and the conditions noted above can increase the error to unacceptable levels. The error can be decreased by the use of DGPS in the 3-D, carrier-phase-tracking mode as long as on-the-fly (OTF) resolution of carrier phase ambiguity is possible. The height of the GPS antenna with respect to the earth ellipsoid (WGS-84) can be determined to about 3cm rms, or in real time, on post processing, thus eliminating the need for installing and maintaining temporary survey tide gauges. Tides, as well as seiche and heave effects, can all be resolved by DGPS-OTF. The approach requires spatial modeling of the present geoid-based chart datums with respect to the ellipsoid used by GPS. CHS is now using 3-D DGPS in the static mode for this modeling, and is examining the use of real-time-kinematic DGPS with OTF for multi-beam surveys.

Sound Velocity. With the phased-array beam-forming technique used in the EM3000, roll angle and the sound velocity at the transducer face control the take-off angles of the acoustic rays. The sound velocity profile (SVP) and Snell's law determine the ray paths through the water. Depth errors from typical SVP errors at non-zero roll angle are shown in Figure 2. The error budget allocated to refraction effects is typically less than 0.4% rms.

The basic accuracy (±0.3 m/s) of present-day SVP instruments is more than adequate to correct for refraction effects. But because the spatial and temporal variations in sound velocity can be ±20m/s or more over the survey area (due to solar heating, fresh water influx and tidal mixing), SVPs must be measured frequently. For the EM3000-equipped boats, CHS is evaluating a method of collecting SVP data while the launch is underway at 10 knots, by using a free-fall, sound-velocity probe and associated winch (being developed by Brooke Ocean Technology). The unit is a small-boat derivative of the larger, moving-vessel CTD (MVCTD) system developed earlier at Bedford Institute of Oceanography (BIO). It will serve to keep survey coverage rates high while giving good spatial and temporal resolution of sound velocity. (See essay by J.G. Dessureault in this Review.)

Hydrographic Impacts. Increasingly, the emphasis on navigational charting is towards site-specific, port and corridor surveys. This approach provides detailed data for the large scale charts needed by vessels entering, docking, departing, and transiting between ports.

For the past three years, CHS has utilized the Simrad EM 100 and EM 1000 MBS systems for corridor and harbour approach surveys, but still carried out much of its

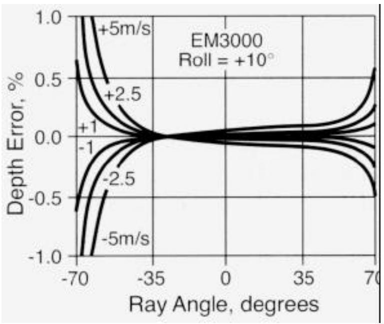


Figure 2: Depth errors at + 10° roll angle for the SVP errors shown in Figure 3.

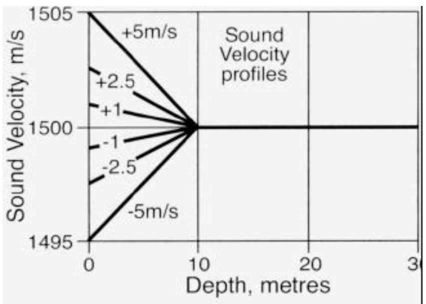


Figure 3: SVPs used in generating Figure 2. The measured SVP was erroneously taken as constant at 1500 m/s. Labels indicate surface sound velocity errors.

charting in ports and docking areas using conventional, single-beam echo sounders. In that methodology there is a risk that an obstruction or hazard will be missed between survey lines-and the task of examining shoals is time consuming. The Simrad EM3000 with POS-MV will enable these surveys to be completed more quickly, with 100% bottom coverage, and at a higher resolution and accuracy. In addition, the requirement for shoal examinations can be virtually removed, given sufficient redundant data. In areas previously surveyed using conventional echo sounders, only those sectors critical to safe navigation will require re-surveying using MBS to meet the needs of today's marine traffic.

Data Processing. The extremely high volume of data produced by the EM3000 (more than 100MB per hour in shallow water) poses a substantial data processing and management task. To date, all MBS data has been processed using the Universal Systems Limited (USL) Hydrographic Information Processing System (HIPS) and, to a much lesser extent, the Sidescan Information Processing System (SIPS). Although HIPS is functionally very powerful, and performs well for editing line soundings, position and attitude records, it is not optimized to deal with the dense data sets from the EM3000 that require interactive 3-D visualization for the rejection of outliers and for quality assurance.

A goal in MBS data processing is to process an hour of logged data in one hour or less; currently it takes several hours. To this end, CHS has recently evaluated "SEE-BED" data-editing and 3-D visualization software (Sirius Solutions Limited). The initial positive results have pointed to the desirable next step of achieving data-transfer compatibility between SEE-BED and HIPS. For the longer term, a National Working Group has been established to address the wider issues of efficient processing, archiving, and value-added re-use of MBS data by many disciplines.

Defense Applications

Navies look to route surveying to provide information on the parameters affecting mine warfare and mine countermeasures. As participants in NACOM, personnel from Maritime Command are working with CHS to examine issues and techniques related to MBS operations.

Acoustic Tag-Team. In mine countermeasures, a combination of complementary tools. techniques and data types is needed. The current technique partly involves identifying changes in "before-and-after", geo-referenced, seafloor images over a shipping route. For detecting objects the size of typical mines (see Figure 4), the vertical and sidescan imagery available from MBS is not always adequate. This is because the area of the insonified spot can be much larger than the target when the grazing angle of the beams with the sea floor is low enough to create good shadow images.

To obtain good sidescan data for route surveying, the angle of incidence should be less than -45". For reasons to do with power and refraction, the practice is to operate with the transducer near the sea floor in a towed body. In this mode, sidescan sonar has excellent across-track and along-track resolution. However, accurately geo-referencing the sidescan data to an accepted co-ordinate system (e.g., WGS-84) is complicated by the need to integrate towfish range and attitude with the attitude and the position of the ship, (from DGPS).

In this situation MBS can be a synergetic partner for towed sidescan sonar. The positional accuracy of salient sea floor features seen using a ship-based MBS can be an order of magnitude (1m rms vs. 10m rms) better than that from a towed sidescan. Using spatially-accurate MBS data, the registration errors of the towed-sidescan imagery can be corrected. By selecting many control points-bottom features common to both data sets-the sidescan imagery can be conformally distorted ("rubber sheeting"), so as to precisely align its features with those in the MBS data.

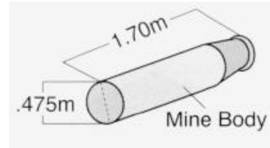


Figure 4: Dimensions of a MK36 air dep loyable ground mine.

High-Speed Sidescan Sonar. Simultaneous operation of towed sidescan sonar and multi-beam bathymetry systems has not been common due to a speed restriction of 2-3 knots imposed by the narrow beam-opening angle of the sidescan sonar. Current MBS systems can operate effectively at speeds of 10-16 knots. Now under development, a new generation sidescan sonar using five parallel beams operating simultaneously will overcome the speed limitation by giving a five-fold increase in towing speed. These sonars have their acoustic beams dynamically steered and focused to provide along-track and across-track resolutions down to ~12cm at ranges of 100m. As the beam pattern is designed for low-angle insonification, the blind area directly below the towfish requires interleaved data from adjacent survey lines for coverage. Real-time MBS data, collected in front by the tow vehicle, can be used to reduce the risk of the towfish colliding with the bottom.

Remote Mine Hunting. The logical follow on to an operational route survey capability is a mine hunting capability. Research and development are now focusing on mine hunting using the DOLPHIN semi-submersible survey vehicle, developed earlier for CHS. DOLPHIN, which has already been used in Canada and in the USA for multi-beam surveys using the EM 100 and EM950 systems, will be used to tow a high-speed sidescan system and, potentially, to carry a MBS system. The new EM3000 is a candidate for inclusion in a remote mine hunting system.

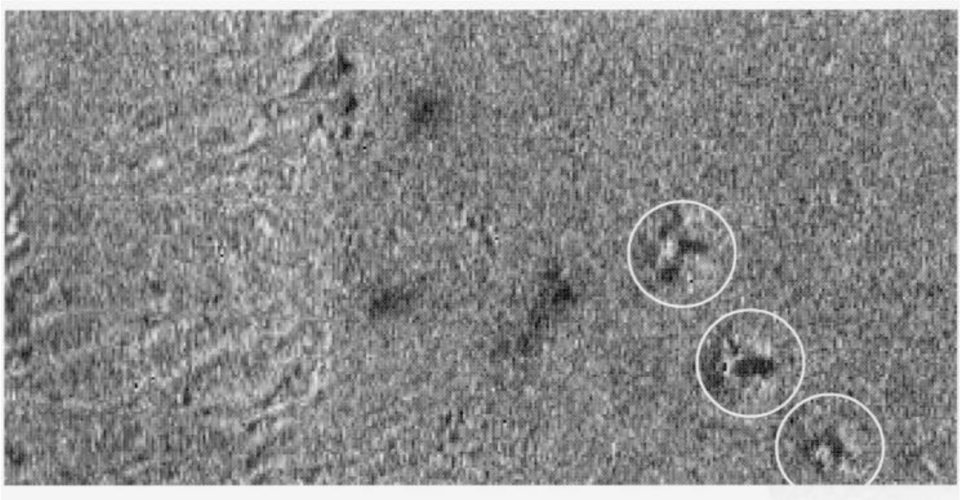


Figure 5: Segment of a sidescan sonar mosaic (30m x 60m) showing three, one-metre objects at bottom right with acoustic shadows extending to the right.

Surficial Geology Uses

Multi-beam bathymetry and backscatter data provide exceptional mesoscale (100m to 1000m) information on the morphological and constitutive character of the seabed, essential for understanding its history and continuing evolution. At the Geological Survey of Canada Atlantic (GSCA), representative multi-beam data sets have now been processed from a wide range of geological environments on Canada's coastal zone. These data have been collected via Canadian Hydrographic surveys, GSC surveys on the east and west coasts and Department of Public Works activities in harbour and channel management. The data sets have been used over the past year to address short and longer term societal needs, ranging from cable route surveys, geo-hazard and seabed dumping assessments, seabed engineering studies and basic research on sediment transport in coastal embayments. This section will focus on one of these applications and the new insights derived from these activities.

Seafloor Subsidence. The GSC, in partnership with the Cape Breton Coal Development Corporation (DEVCO) and CANMET (an agency of Natural Resources Canada), have recently finished the second year of a two-year project to measure subsidence over a sub-seabed coal mine. DEVCO operates the Prince Mine, located about 3 km north of Point Aconi, Cape Breton, and they extract coal from the Hub seam positioned about 200m below the seabed. Layers of coal approximately 2m in height are removed in long narrow strips, or panels, that measure 160m in width and up to 3km in length. This coal is extracted primarily to fuel a new fluidized coal-fired power plant located nearby on Point Aconi.

As coal is removed from the panel, the 200m or so of rock above the workings collapses and the stresses associated with the collapse are transmitted to the seabed. The deformation of the seabed over the panels can be used to quantify the mechanical properties of the overlying roof rock, prerequisite information for optimizing mine operations. Before this study, the subsidence over the centre of the Point Aconi mined panels was predicted by mine geologists to be as large as 1.5m.

The objective of the two year study was to measure the temporal change in the bottom depth over the mine workings in order to ascertain seabed subsidence over new panels and, also, to study the infilling of older, pre-existing subsidence troughs. Detailed bathymetry was first measured over the panels in the summer of 1994 using a Simrad EM1000 multi-beam system operated from the Hydrographic swath vessel NSC *Frederick G. Creed.* A shaded relief image of the 1994 multi-beam data over the workings is shown in Figure 6 along with a companion image overlain with the plan of the workings. The subsidence troughs can be clearly seen at the centre of the panels in the western side of mine (north is at the top). The estimates of panel subsidence taken from the 1994 survey ranged from 1.0m to 1.5m at the centre of each trough. A collapse of the seabed was detected directly over the active working face of the mine (the eastern end of the northernmost trough). It was thought previously that the seabed collapses gradually over a year or two, after the coal has been removed, reflecting gradual deformation in the rock above the workings. The process is now viewed as one of immediate brittle failure, an important piece of information in mine design.

A second survey was conducted over the workings in 1995 with the *Creed* to measure the net subsidence above new workings over a one year period. The analysis of the second year's data set is currently nearing completion. Preliminary results show that water column sound refraction effects are now the most important source of error limiting the accuracy of the multi-beam depth data. Research conducted at the GSCA into the statistical signature of the refraction error has suggested that, with careful analysis, the repeat accuracy of the data from MB surveying systems can be reduced to 10cm to 15cm for water depths up to 50m, some three times better than the standard set by the International Hydrographic Organization. The results of this study will be released in the spring of 1996.

Conclusion

Multi-beam sonars are making a significant impact on nautical charting operations, mine countermeasures work, and marine geology investigations. New research and development activities are being driven by user demands, and current projects are focused on work in the coastal zone where delineation of seafloor features, both natural and man made, is important for navigation safety, for the Canadian military, and for commercial operations.

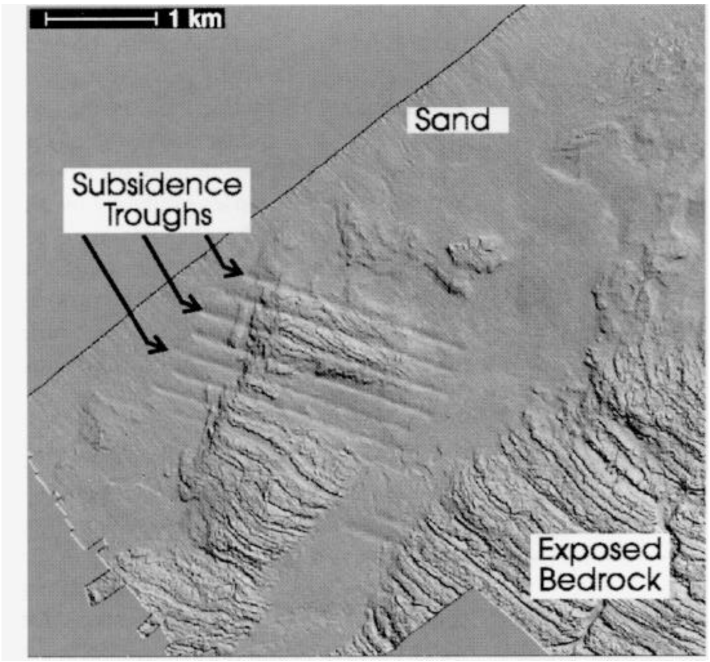
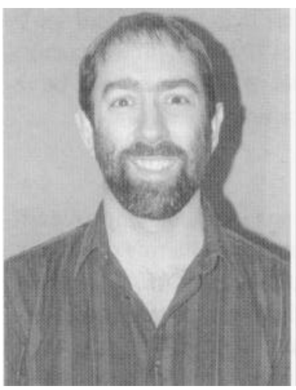


Figure 6: A shaded relief image of the seabed over the Prince Mine, derived from EM1000 multi-beam data collected in the summer of 1994 using the NSC Frederick G. Creed. *The image shows subsidence troughs that have formed over directly over collapsed mine panels lying 200m below the seabed. The image was calculated from the data using a vertical exaggeratioii of 10 with the illumination shining from the northeast.*

Clam Enhancement Trials in the Bay of Fundy

S.M.C. Robinson



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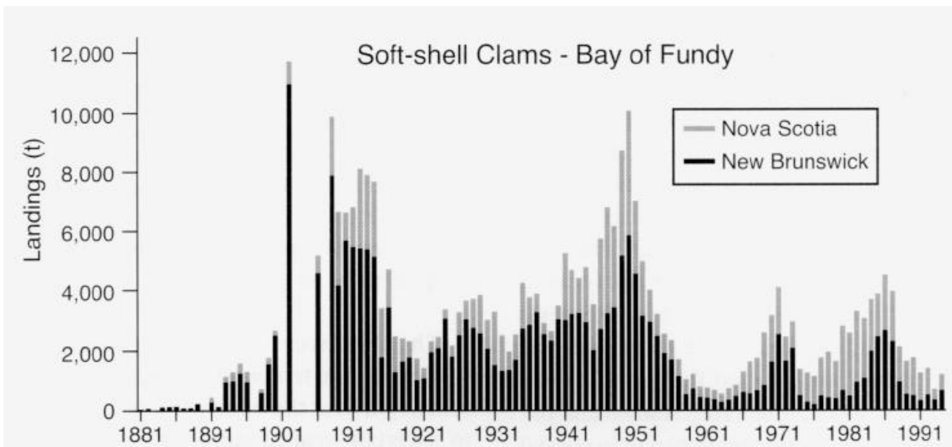

Figure 1: Long-term landing records for the soft-shell clam in the Bay of Fundy.

Introduction

History

The clam fishery for the soft-shell clam, *Mya arenaria*, in the Canadian Maritimes has had a long history with formal catch records dating back to the late 1800s. This species was probably one of the first marine species to be exploited due to its relatively easy access during low tides. The soft-shell clam was an important food source for the native tribes in the area who harvested them extensively for food and the remains of this early exploitation can be seen from the many shell mounds or “middens” in the area. After colonisation by the Europeans, clams continued as a basis for the food industry, first as a direct food source and later as a bait source for the lucrative long-line fishery off the Grand Banks and other groundfishing areas. At the turn of the century, fishing schooners would often stop off in the Annapolis Basin or the Quoddy region in south-western New Brunswick to gather barrels of salted clams for bait. Much of this harvest was very likely unrecorded. In the early to mid 1900s, a canning industry for clams was well established and many clams were exported in this form from the Bay of Fundy.

Recent Past

Harvesting methods have changed very little over the last century with respect to harvesting technology. With the exception of a brief period in the 1960s when automated harvesting techniques were exam-

Method	Concept	Pros	Cons
Rotational Digging	Harvest the clam flats on a rational basis in order to allow certain flats to lie fallow and become more productive.	• allows clams to get a few years of relief from digging pressure • results in better growth and lower mortality • relatively easy management method	• problems arise if there are not enough digging areas to set aside • assumes that the areas closed for conservation will not be lost to pollution
Brushing	Place artificial barriers on the beach in order to increase the rate of natural spat settlement and survival.	• natural method of increasing natural settlement • low-tech and relatively inexpensive	• dependent on natural sources of larvae • very dependent on growth and survival rates • labour intensive for large areas • requires a shift in management towards an ownership-based management style
Relaying	Move juvenile clams for further growout from a high density beach to one that has been depleted through harvesting pressure.	• allows over-harvested areas to be restocked • high-density populations can be thinned for better growth • may allow closed areas to be put back into production • can be linked into a seed/hatchery system	• very dependent on growth and survival rates • labour intensive • requires a shift in management towards an ownership-based management style

Table 1: Summary of the pros and cons of the three enhancement methods tested in south-western New Brunswick.

ined, hand harvesting using a clam fork (hack or digger) is still the only method used in the Bay of Fundy. However, while the harvesting methods have not changed, the landings have generally decreased (Fig. 1). While some of the drops in landings may be due to social conditions at the time (i.e. World War II) and biological events and cycles, the trend of decrease is correct. This drop in landings has had a dramatic effect on the local economies. Although the loss to the communities can not be directly estimated, we can derive an indirect estimate. If we assume that the beaches still have the capacity to support the production levels of the past, then the 10 year average landings of the Bay of Fundy was approximately 5,700 tons from 1945 to 1955. If this biomass of clams was landed today and sold for the current price of $1.90/ kg ($0.85/lb), this would net the diggers and local economies about $10.86 million. In 1994, the total recorded landings amounted to 1191 tons which was worth $2.27 million at $1.90/kg, a drop of 80 %. This loss in potential annual income is significant to the clam industry. Many of its participants work in several primary industry sectors (agriculture, forestry, fishing) over the course of the year and while their annual income may not be great, each portion is important. In addition, the overhead expenses related to harvesting is small so the bulk of the earnings go directly back into the economy rather than servicing fishing-related debt.

The reasons for the drop are many, but the primary one is the loss of many harvesting areas due to health-related closures from coliform bacteria. These closures have a two-fold effect on the fishery. First, it removes the clams from the wild harvesting base (although depuration plants can use moderately contaminated areas) and it concentrates the diggers on the other open flats. At some point, depending on the size and productivity of the open beaches, this concentration of fishing effort can over-harvest the clam populations. Other factors which affect the productivity of beaches for harvesting are: the occurrence of phytotoxins (such as paralytic shellfish poison (PSP), diarretic shellfish poison (DSP) and domoic acid or amnesiac shellfish poison (ASP)) or normal changes in biological cycles in response to environmental changes (i.e. cooling or warming trends). However, these latter conditions are temporary and only affect the clam production for fixed time periods. In comparison, the loss of clam flats to the wild harvesters due to faecal colifom contamination will likely be permanent unless remediation measures are taken.

Objective

The objective of our enhancement work was to investigate techniques to increase the productivity of the open beaches in order to sustain the wild harvest during the interim period while remediation techniques are being developed to clean up the coastal zone. Remediation is the ultimate goal as it will not matter about the production capacity of a beach if the product is unable to be harvested. The projects were all designed in conjunction with industry partners in order to achieve direct technology transfer and easier acceptance of the results.

Three basic methods were investigated: rotational digging, brushing and relaying (Table 1). These techniques are not new and are basically modifications of projects attempted by industry in the New England areas in the 1950s.

Rotational Digging

A project to investigate the potential for rotational digging was initiated in Lepreau Harbour in the spring of 1991. Two 3 x 9 m plots on a commercially harvested clam beach were established and subdivided into three equal sections; one scheduled to be harvested on an annual basis (1992, 1993, 1994, 1995)), one on a biennial basis (1993, 1995) and the third on a triennial basis (1994). All plots were completely harvested on initiation of the project (1991) by commercial diggers using clam forks. The same diggers harvested the plots in 1992 and 1993. Unfortunately. other com-

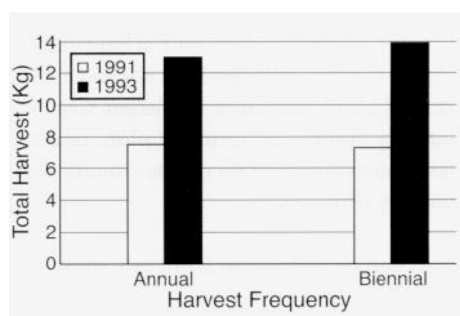

Figure 2: Total weight of clams harvested from the annual (2 harvests) and the biennial plots (1 harvest) between 1991 and 1993. The initial harvests in 1991 from each of the plots are shown so the dark bars represent the new production from the plots from 1991 to 1993.

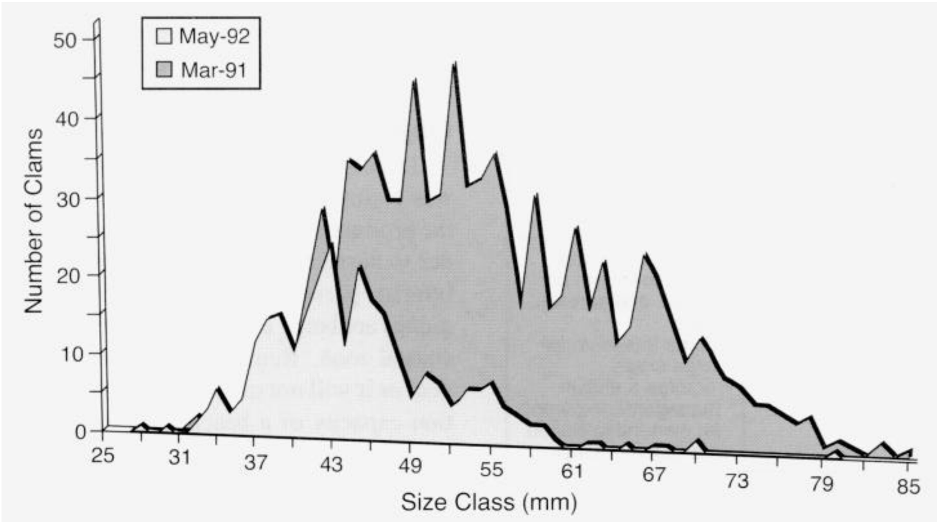

Figure 3: Comparison of the size-frequency distribution between the original harvest of the rotational plots in 1991 vs. the first annual harvest in 1992.

mercial diggers dug through the plots in early 1994 invalidating the remainder of the study (i.e. testing the benefits of triennial harvesting). The clams from each harvesting were taken back to the laboratory at the St.Andrews Biological Station and all were measured using calipers and weighed to the nearest gram.

The results from the first two years of study indicated there were advantages to allowing the plots to lie fallow for a year (Fig. 2). Initially, both the annual and biennial plots had similar harvested biomass of clams, 7.5 vs. 7.3 kg respectively, while at the end of the 2 year trials the biennial plots had approximately 6.5 % more harvested biomass. These results indicate that while the total amount harvested was slightly more in the biennial plots, the catch-per-unit-effort (CPUE) was over double that of the annual plots (13.9 kg/digging vs. 6.5 kg/digging). A comparison of the size frequency distribution between the initial harvest and the first harvest of the annual plots show that the larger sizes are quickly removed from the plots and the harvesters concentrate on the smaller individuals (Fig. 3).

It can be concluded from this study that there are benefits to the concept of rotational digging by increasing the overall catch and increasing the catch rate. Previous work by Robinson and Rowell (1990) indicated there is a definite incidental mortality rate (the mortality rate to those animals left in the beach after the harvesting operation) imparted to the clam population during harvesting. Depending on the time of year of harvesting and the sediment type, the incidental mortality rate may be as high as 50%. While the mortality rate was relatively low in this study based on the relative equality of the total harvested amounts, this study was also conducted in sediment and at a time of year when mortality would have been predicted to be lower. Therefore, if harvesting had occurred at a different time of year, the results may have been more dramatic.

As indicated in Table 1, one of the problems with this technique is that there has to be at least twice as much harvesting area available than is required to maintain the desired landings. Although we were not able to test the triennial harvest, this technique would require three times as much harvesting area. At the present time, with the existing shellfish bed closures, this type of management may have to used in conjunction with other methods for it to be effective.

Brushing

The concept of brushing evolved from early observations of clam diggers on the beaches. They observed that clams were often found around obstructions on the beach, such as logs or rocks. In the late 1950s, according to anecdotal information, clam diggers in Maine tried placing old Christmas trees on the beach to increase the set of soft-shell clams, thus the derivation of the term “brushing”. The theory behind this technique is that the obstacles on the beach surface cause turbulence in the water column as the tide flows over it. This turbulence allows the larvae in the water column, which are competent to settle, more frequent encounters with the bottom. If the bottom is suitable, then the larvae will settle. This concept was revived in the summer of 1990 by industry members in the Lepreau Harbour and Deer Island areas and an experimental site was set up in each area. Each site consisted of two replicate series of four 5 x 5 m plots. One of the four plots had a small fence (1 m wide x 0.5 m high) built of laths on posts spaced 5 cm apart (Fig. 4). The second plot had an identical fence, but also had some crushed clam shell placed on the surface. The third plot had a fence plus a layer of gravel on the surface. The fourth plot was left natural as a control. The plots were established in May of 1990 (before the spawning season) and the plots were sampled in February, June and August of 1991. The experiment was repeated in 1992 at the request of industry, although not at the same locations, and the test of the fences in conjunction with crushed clam shell was eliminated. Plots were sampled for settlement and subsequent survival by taking sediment cores in the experimental plot and sorting the samples in the laboratory. For recovery of small bivalves from the sediment, a floatation technique was developed (Robinson and Chandler 1992) which ensured almost 100% recovery.

Results from the 1990 trials were mixed. The experimental plots at the Clam Cove site on Deer Island were covered with a layer of clam shell approximately 10 cm deep. The same was done for the experimental plots for gravel. The sediment be-

Figure 4: Shot of the clam settlement fences used in the settlement experiments in Lepreau Harbour with Mr. Steven Lomax.

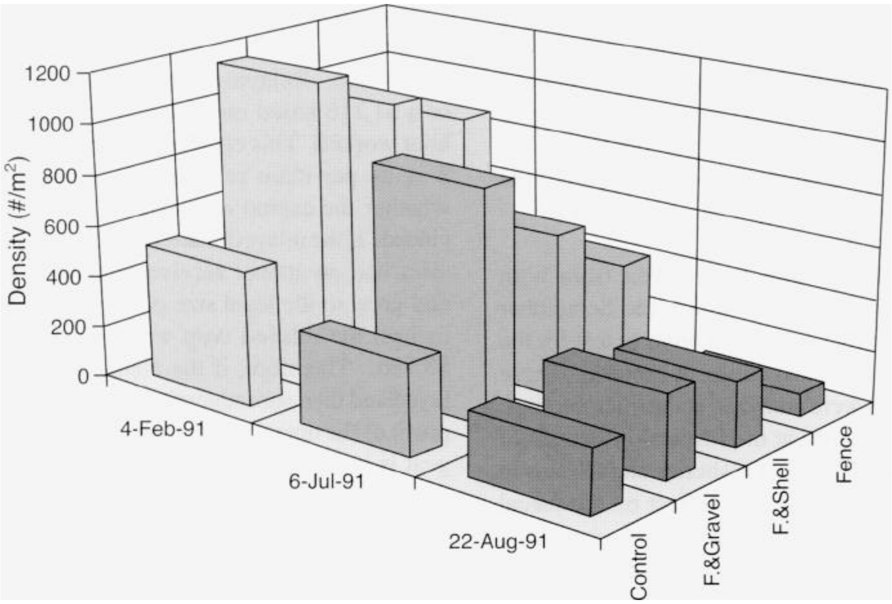

Figure 5: Mean density of soft-shell clams juveniles from core samples taken in the experimental and control plots in February, June and August 1991.

came anoxic underneath and it was impossible for any larvae to settle in these plots. The industry partner from Deer Island lost interest in the project and so this site was abandoned. However, at the Lepreau Harbour site, settlement samples taken in February 1991 indicated there were significant differences in settlement. There were over double the number of spat in the experimental plots compared to the controls (Fig. 5). This difference persisted in the June 1991 samples. However, the pattern of clam density among plots changed after the summer season, based on the August samples.

In 1992, two different sites were chosen by the industry members, one in Northern Harbour on Deer Island and the other in Lepreau Harbour approximately 1000 m east of the 1990 site. Core samples were taken using the same methods used in 1990. The results indicated there was no settlement in Lepreau Harbour at the 1992 site, but there was still significant differences found at the remains of the 1990 control site and the experimental site with the fence and gravel (the other 1990 experimental plots with fences were presumed to have been destroyed by ice) (Fig. 6). The Northem Harbour site on Deer Island showed low levels of settlement in comparison with the other sites and there was no significant differences between the experimental and control plots.

These results from the two years indicate that it is possible to increase the settlement rate of natural larvae and that this increased settlement can result in more spat. However, in determining the number of spat later on in the year, there appear to be more biological processes occurring than simply the number of larvae contacting the bottom. The addition of shell and gravel to the bottom further increased the settlement rates over the simple fences or controls. but only up to a certain point. Too much material can cut off the settlement entirely. Sediment characteristics also play a role. The 1990 Lepreau site was good for settlement based on the densities observed and these patterns persisted. However, the 1992 site at Lepreau was much sandier than the previous site and the Deer Island site had a gravel base with a gelatinous mud layer on top. Both of these types of sediment were unfavourable for either the initial settlement or subsequent survival. Therefore. in conclusion, it appears the brushing technique has some application in certain habitats, but it can not be used tore-stock a beach which has unfavourable characteristics for early juvenile settlement.

Relaying

At present, the only way for beaches. which have been closed due to coliform contamination, to be returned to production, is through depuration. This process involves harvesting the clams with registered diggers and transferring the clams to a shore-based plant where clean water is pumped through the tank, thereby allowing the clams to cleanse themselves. However, another possible solution is moving animals from a contaminated area to a clean, open beach where they can cleanse themselves. This would allow more diggers to participate in harvesting the clams and would also have the potential to put closed areas back into production. In order to test this idea, a project was initiated to relay clams from a closed area on Grand

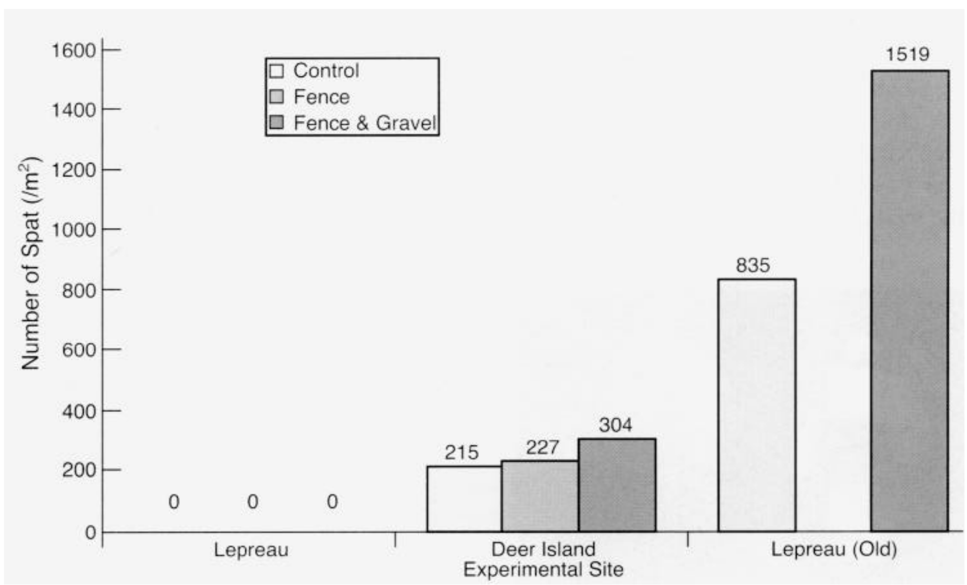

Figure 6: Mean density of soft-shell clam juveniles from core samples taken in the experimental and control plots in Lepreau Harbour and Deer Island in 1992. Samples taken in 1992 from the old Lepreau Harbour site (originally sampled in 1990-91) are shown for reference.

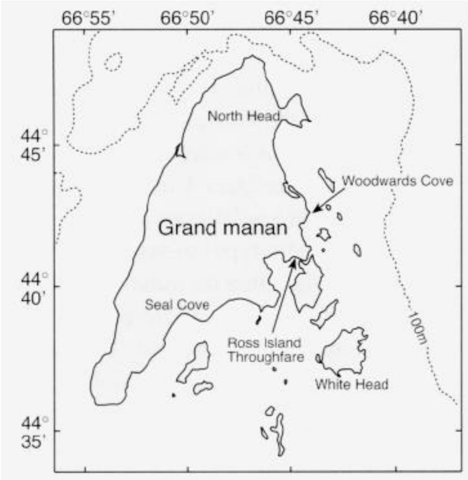

Figure 7: Location of the study sites for the relaying project on Grand Manan where the clams were harvested (Woodwards Cove) and where they were planted (Ross Island Thoroughfare).

Manan (Woodwards Cove) to an open area (Ross Island Thoroughfare) (Fig. 7).

Soft-shell clams were harvested during the first week of September 1993 at Woodwards Cove using a hydraulic rake attached via a 2 inch (50 mm) fire hose to a 5 HP Briggs and Stratton powered impeller water pump (Fig. 8). Over 92,000 clams were harvested, sized and sorted as to small (< 15 mm), medium (15 - 30 mm) and large (> 30 mm). The clams were then taken to the Ross Island Thoroughfare and replanted by broadcasting them into defined 10 x 10 m pre-surveyed plots at a density of 75 per m^2. The background density of clams (from the pre-survey) was estimated to be 25 per m^2 and therefore the final density of clams per plot was 100 per m^2. The plots were then sampled approximately 6 weeks later and 7 months later to examine survival of the transplanted clams. Survival was calculated by assuming no mortality for the original clams in the beach and therefore calculating the survival of those introduced (i.e. at 75/m^2). This method was employed as it we felt the majority of the loss of the clams from the plots would happen to the new clams during their burial process.

Figure 8: Photo of the hydraulic clam harvester used to collect clams from the beach for the relaying project.

Clam samples were taken from both sampling locations during the September and October periods in order to test for the release of faecal coliform bacteria. These samples were analyzed at the microbiological laboratory at the Inspection Branch of the Department of Fisheries and Oceans in Blacks Harbour. The effect on the faecal coliform levels of relaying the clams to a clean, open site from a closed area was quite dramatic (Fig. 9). The levels dropped from 2,400 faecal coliforms per 100 g of clam meat in September to 45 faecal coliforms per 100 g of clam meat 6 weeks later near in October at the open site. This is well below the legal limit for harvesting. At the control site (Woodwards Cove), the counts also dropped, but only to 790 faecal coliforms per 100 g of clam meat which was over 3 times the acceptable limit.

The survival rate of the relayed clams was quite high. Although, there was a 40% drop in the number of small clams over the seven month period from 75/m^2 to approximately 45/m^2, the survival of the medium and large clams was very good (between 90 and 100%).

The economics of the transfer operation from the closed to the open areas was also favourable. Relaying over 92,000 clams cost $1,116 based on 93 hours at $12 per hour worked. This equated to a cost of 2 to 3 cents per clam relayed depending on whether the capital cost of the gear is included. If the relayed clams (based on mean size) had an annual survival rate of 70% and grew to the legal size of 44 mm (1.75 inches) the relayed crop would be worth $3,150. Therefore, if the clams were relayed and then subsequently harvested, the profit of the operation would be $199 if the gear is included or $1,489 if it is not. For the latter case, this equates to creating jobs at a rate of $10.79 per hour. The value of the resource (cost ratio) was about 2:1 to 3 :1 compared to the cost of relaying the animals from the closed area.

Overall, this project was a success. The harvesting of the clams from the closed area (Woodwards Cove) was not particularly difficult and although the efficiency of gathering the clams that were brought to the surface by the harvester could be improved. the operation worked quite smoothly. There appeared to be very low mortality rates through crushing or breaking of the shell. The substrate on Woodwards Cove could be described as a sandy-silt. Therefore. depending on the substrate, this type of harvester is probably best for the collection operation compared to a traditional clam fork which is relatively inefficient and causes much more damage. Although it was only a single test of the relaying proc-

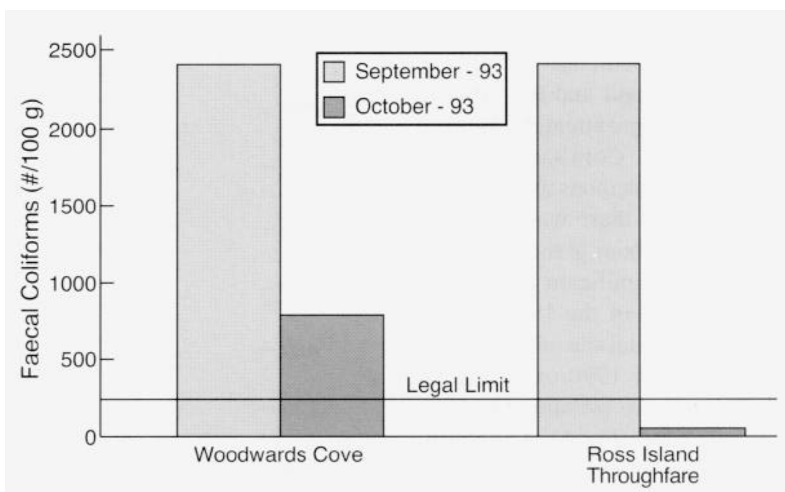

Figure 9: Faecal coliform bacterial levels per 100 g of clam tissue from the harvested beach (Woodwards Cove) and the planting beach (Ross Island Thoroughfare) sampled in September and October 1993. The dashed line indicates the maximum legal level for faecal coliforms in clam tissue

ess, the results confirm that this type of effort has potential and that other efforts should be supported. With enough successful trials. a strong case could be made to incorporate this strategy into the soft-shell clam management plan. However, this approach will only work if there are clean beaches available. The value of open beaches will increase and there will be more incentive to ensure they remain open.

Conclusions

The enhancement efforts which have been tried to date all seemed to have worked to a certain extent. Most of the trials have been done at an experimental scale and it is now time to try them at a larger pilot-scale. However, the efforts must be led by the industry members and the local communities. Enhancement of clam stocks appears achievable, but there has to be a shift in the philosophy of how to exploit and manage the stocks. Brushing and relaying both involve resources to be expended before the final harvest is achieved. Without a spirit of cooperation and consolidation within the present industry, none of these methods can be employed because no person will do all the work without some guarantee of receiving some of the benefits. This is the challenge for the communities and the managers of the resource.

Acknowledgements

These studies were accomplished through the ideas and efforts of many people. Industry people who instigated and toiled on the projects were: Steven and Roger Lomax from Lepreau, Grant Linton and Albion Leslie from Grand Manan, Marvin Neuman, Ken Stuart and Harvey Richardson from Deer Island, and Randy and Wanda Huber from St. Stephen. Sampling and analysis was done at the St. Andrews Biological Station by Ross Chandler, Jim Martin, Bruce Thorpe, Julia Wildish and Ken Beaton and their efforts and diligence is gratefully acknowledged. Some of the projects were funded via the Canada-New Brunswick Cooperative Agreement through the Charlotte County Community Futures Office in St.Andrews. Sharon Ford and Margie Ross were extremely helpful with administration of these projects and dealing with assorted problems along the way. The Inspection Branch at Blacks Harbour (D. Doncaster, S. Eddy and J. Hawkins) generously provided the technical assistance required for the work on coliform testing.

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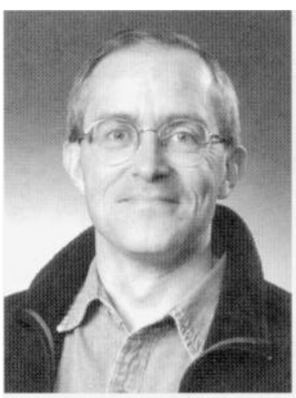
Colloids, Carbon and Contaminants in Coastal Waters

P.E. Kepkay, S.E.H. Niven



P.E. Kepkay

S.E.H. Niven

Marine Colloids - A Global Reservoir of Reactive Carbon

The colloidal fraction of organic carbon in the world's ocean is one of the largest reservoirs of carbon on the planet, outweighing the "living" carbon stored in the biomass of phytoplankton, macrobiota (all commercial species), zooplankton and bacteria by a considerable margin (Fig. 1). On a global scale, this pool of tiny (sub-micron) particles and aggregates is enormous - approximately equal to the carbon stored in the combined biomass of temperate and tropical forests (Hedges, 1987; Kepkay, 1994).

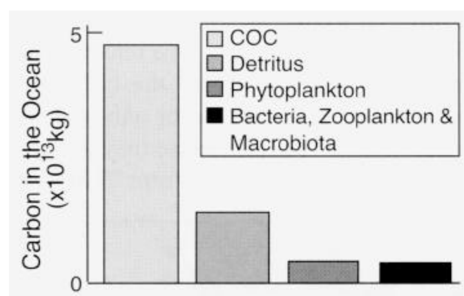


Figure 1: Colloidal organic carbon (COC), detrital carbon and the three major sources of "living" carbon (phytoplankton. macrobiota, zooplankton and bacterial biomass) in the world's ocean. COC is defined solely on the basis of size, and refers to organic carbon particles arid aggregates that are between 0.001 and 1μn in diameter.

Added to the fact that colloidal organic carbon (COC) is a major fraction of the oceanic and planetary carbon budget, a substantial portion of this COC is reactive and is broken down by respiration, releasing the carbon as CO_2 (Amon and Benner, 1994; Kepkay, 1994). The respiration of bacteria and other members of the microbial community is especially intense when colloids are clumped together into aggregates by ocean turbulence (Kepkay, 1994). The COC that escapes respiration is exported as aggregates to the ocean interior.

On a global scale, this downward export of aggregated carbon is a key element in the "biological pump" (Longhurst *et al.*, 1995) which absorbs CO, from the atmosphere at the ocean surface and stores it as "fixed" organic carbon in the deep ocean. The production of aggregates from colloids also acts as a mechanism for concentrating chemical contaminants (Niven *et al.*, 1995) and is one of the main pathways for transporting these contaminants between surface and deep water.

Production and Degradation of Colloids

A number of biological and physical processes contribute to the production of marine colloids (Niven *et al., 1993*, but the excretion of polymers by the phytoplankton is one of the most direct means of COC production. Once released, these exopolymers can take many forms (Hoagland *et al.* 1993), but are most commonly found as microfibrils of polysaccharides (Fig. 2). The microfibrils are thought to remain in the colloidal (submicron) size fraction for only a short time (hours to days) because they are aggregated by turbulence to form "TEP" or

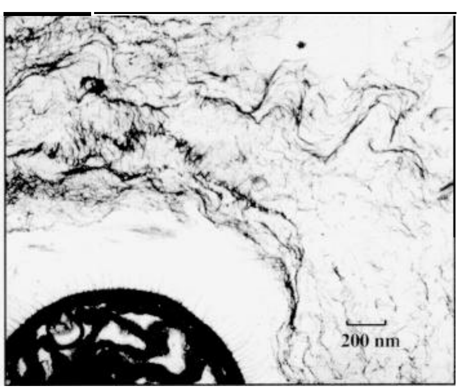


Figure 2: Transmission electron micrograph (courtesy of Dr G.G. Leppard, Environment Canada) of the margin of a phitoplankton cell exuding microfibrils of colloidal organic material.

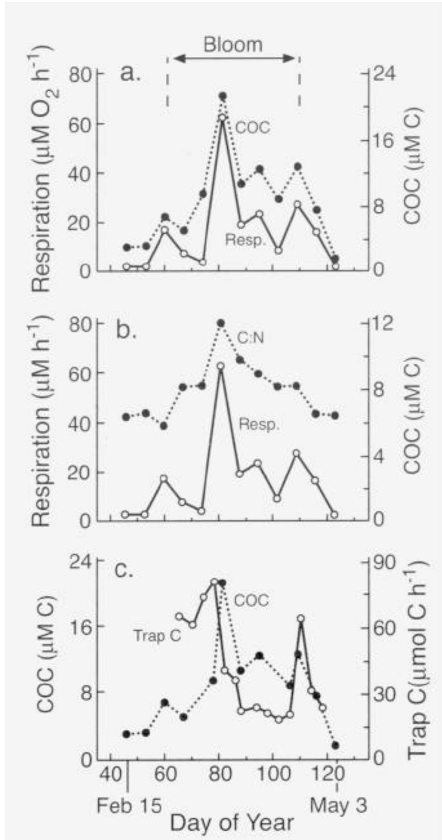


Figure: 3a. Respiration and colloidal organic carbon (COC) at a depth of 5 m during the 1995 spring bloom in Bedford Basin. b. Respiration and the carbon-to-nitrogen ratio of total organic matter (TOM) at the same depth. c. Colloidal organic carbon (COC) at 5 m and the rate of carbon transport into a sediment trap deployed at 15 m.

Transparent Exopolymer Particles. This clumping together of the fibrils into aggregates works in combination with bacterial respiration (Amon and Benner, 1994; Kepkay. 1994) to remove COC from surface waters. Respiration, however, is the major biological process regulating the net production of COC, ie., the amount that remains to be exported deeper.

The Spring Bloom in Bedford Basin - A Case Study

In the spring of 1995, a collaborative study of the annual diatom bloom in Bedford Basin was undertaken to determine the role of colloids in the transport of carbon and contaminants. During the bloom, respiration (primarily by the bacteria) was closely linked to the production of COC by diatoms (Fig. 3a). As Benner *et al.* (1992) have pointed out, the high polysaccharide and carbon content of COC exerts a large influence on the cycling of carbon and the carbon-to-nitrogen (C:N) ratio. This was certainly true in the case of the bloom. where the release of COC by the diatoms initially drove the C:N ratio up (Fig. 3b): later on, the ratio was brought back down by respiration (Fig. 3b) and the settling out of aggregated colloids into deeper water (Fig. 3c). Results from the deployment of sediment traps (Cranford. 1995) suggest that scallop feeding was enhanced during the bloom. when the downward export of aggregates into the traps was at a maximum (Fig. 3c). This means that colloids could be a source of food for a commercially-important species of shellfish.

Results from measurements of the natural isotope. ^{234}Thorium (^{234}Th) - a tracer of

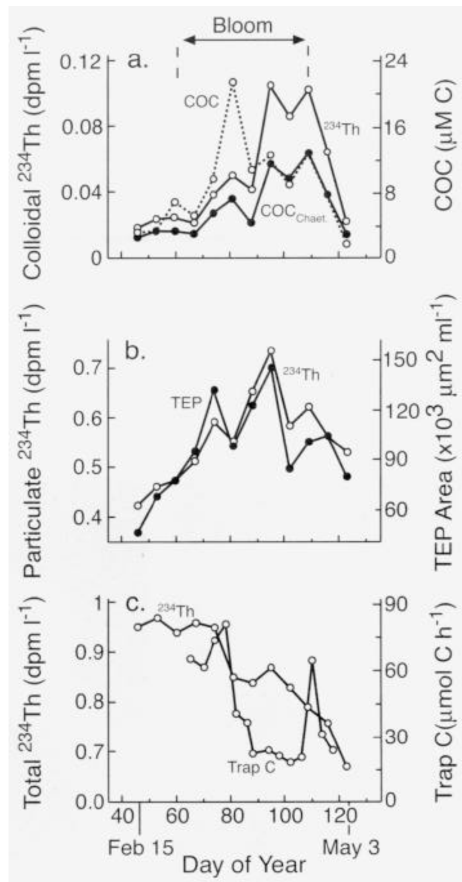


Figure: 4a. Colloidal ^{234}Thorium (^{234}Th) and colloidal organic carbon (COC) at a depth of 5 m during the 1995 spring bloom in Bedford Basin. The association of colloidal ^{234}Th and COC was especially close later in the bloom, when the production of colloids by Chaetoceros socialis *($COC_{Chaet.}$) was at a maximum. b. Particulate ^{234}Ti and TEP area at the same depth. c. Decrease in the total activity of ^{234}Th at 5 m and the rate of carbon transport into a sediment trap at 15 m.*

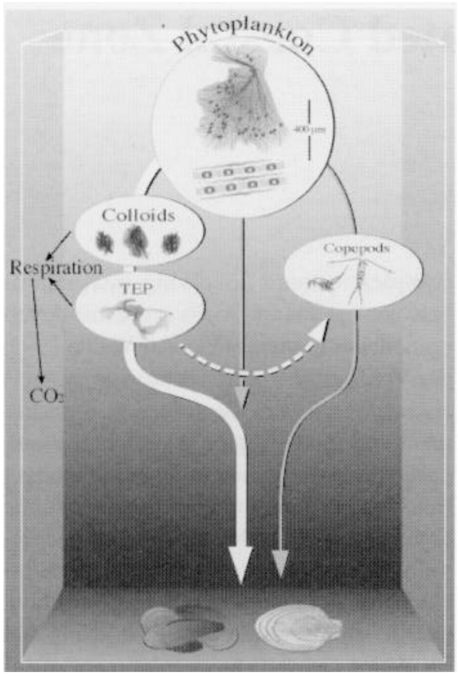


Figure: 5. Illustration of the relationship between colloid production by the phytoplankton (diatoms), colloid aggregation to form transparent exopolymer particles (TEP), respiration (producing CO_2 arid possible pathways for the consumption of aggregated colloids by zooplankton (copepods) and benthic shellfish (scallops and mussels).

marine aggregates and an analogue of chemical contaminants (Niven *et al.,* 1995) - suggest that aggregated colloids may also have been a prime vector for the transport of contaminants to the scallops (Fig. 4). The release of COC by the diatoms, especially the COC associated with *Chaetoceros socialis* (Fig. 4a), transferred ^{234}Th from solution to the colloidal size fraction. Aggregation of the colloids and the formation of TEP moved the colloidal ^{234}Th further up the size spectrum to the particulate fraction (Fig. 4b). Once the ^{234}Th reached the particulate fraction, it settled out of surface waters and into the sediment traps, resulting in an overall decrease in total ^{234}Th (Fig. 4c).

Colloids - A Source of Food or Contaminants for Benthic Fisheries ?

COC may be an important source of food for filter-feeding shellfish or even the zooplankton (Fig. 5), but first the colloids have to undergo degradation by the respiration of bacteria and other members of the microbial community. Only then will the residual colloids remaining in aggregates become available for the filter feeders. Given the overwhelming size of the standing stock of COC in the ocean (Fig. l), a substantial amount of carbon could be transferred to benthic fisheries. This is clearly a positive result of the production of colloids by diatoms but, at the same time, colloid aggregation may also transfer contaminants to the same fishery. This dual role of colloids in the maintenance of traditional and cultured living resources has not been included in current models of aquaculture or coastal management. It certainly merits further attention.

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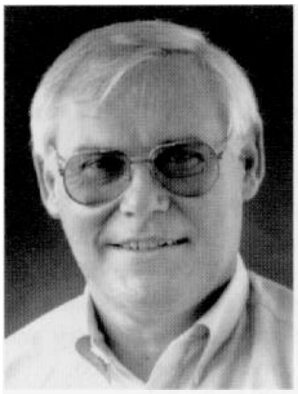
Marine Geoscience Contributions to Integrated Coastal Zone Management

D.B. Prior, R.A. Pickrill



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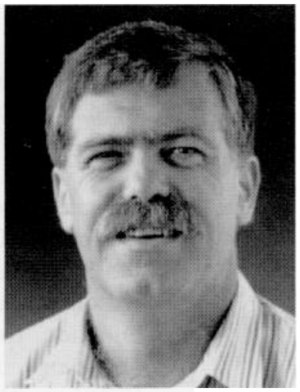

R.A. Pickrill

Introduction

Coastal environments worldwide are subject to increasing pressures from rapid population growth and diversifying resource use. At the same time these environments experience variations in natural processes, over wide magnitude and frequency scales, for example from short duration, high intensity storms to long term relative sea level fluctuations.

Strategies for sustainable resource development involve the management of coastal regions, including the design, construction and maintenance of the required development infrastructure. The World Coast Conference (1993) defines Integrated Coastal Zone Management (ICZM) as involving the "comprehensive assessment, setting objectives, planning of coastal systems and resources . . . a continuous and evolutionary process for achieving sustainable development". "Sustainable" development means that there is a specific commitment to the management of coastal regions and resources in an environmentally responsible manner. The preservation of environmental quality for future generations involves remediation of past deleterious development impacts, and taking informed decisions to reduce future adverse effects and, where necessary to define and acknowledge risk.

An important basis for sound policy decisions and plans is scientific information. A recent (1992) Ocean Studies Board report on ocean policy asserted that "to the extent that such policy decisions are to be useful, they must be consistent with the best available information about how the whole system works: its physics, chemistry, geology, and biology." But a 1995 National Research Council report on 'Science, Policy and the Coast' also suggested that improvements are needed in the interaction between natural and social scientists, and policy makers/implementers at all levels, because there are examples of failures where scientific knowledge was not used.

In this regard different scientific disciplines and science agencies have a responsibility to clearly identify their conceptual, database, and technological contributions to ICZM, as well as the potential for multidisciplinary synergies and linkages. The following discussion seeks to illustrate some of the principal contributions that marine geoscience in general, and Canadian marine geoscience specifically is making to ICZM, and to indicate some future directions of the Geological Survey of Canada's marine program.

Coastal Systems

In functional, planning and scientific terms, coastal areas must be considered complex systems involving interactions between natural and socio-economic development components (Van der Weide 1993, der Vrees *et al.* 1995). A holistic systems approach facilitates identification, measurement and modelling of system behaviour, particularly giving attention to the interactions between natural and socio-economic factors (Fig. 1). The socio-economic development plans for a coastal area include the user functions of food production, energy supply, water supply, housing and recreation. as well as development of industrial and economic activities. These user functions are accompanied by the need for physical infrastructure (eg. communications arteries, harbours, dams) and institutional infrastructure (eg. political, legislative and financial systems).

In relation to ICZM der Vrees *et al.* (1995) describe the natural system component as comprising all non - human aspects, such as air, water, sediment and marine

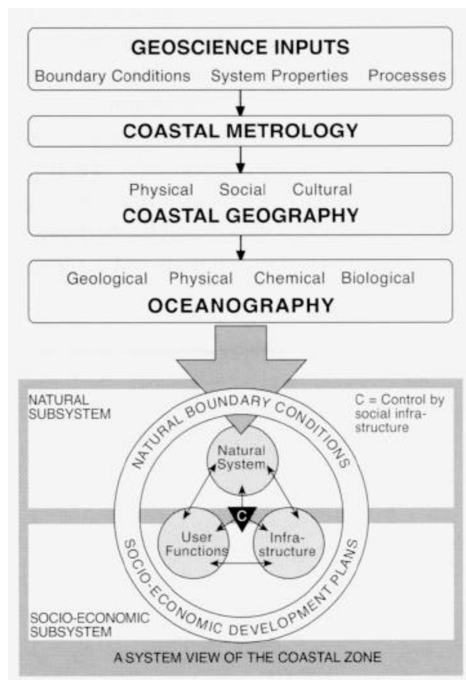

Figure 1: A system view of the coastal zone and the role of geoscience in coastal zone management (modified after Der Vrees and Van Urk, 1995).

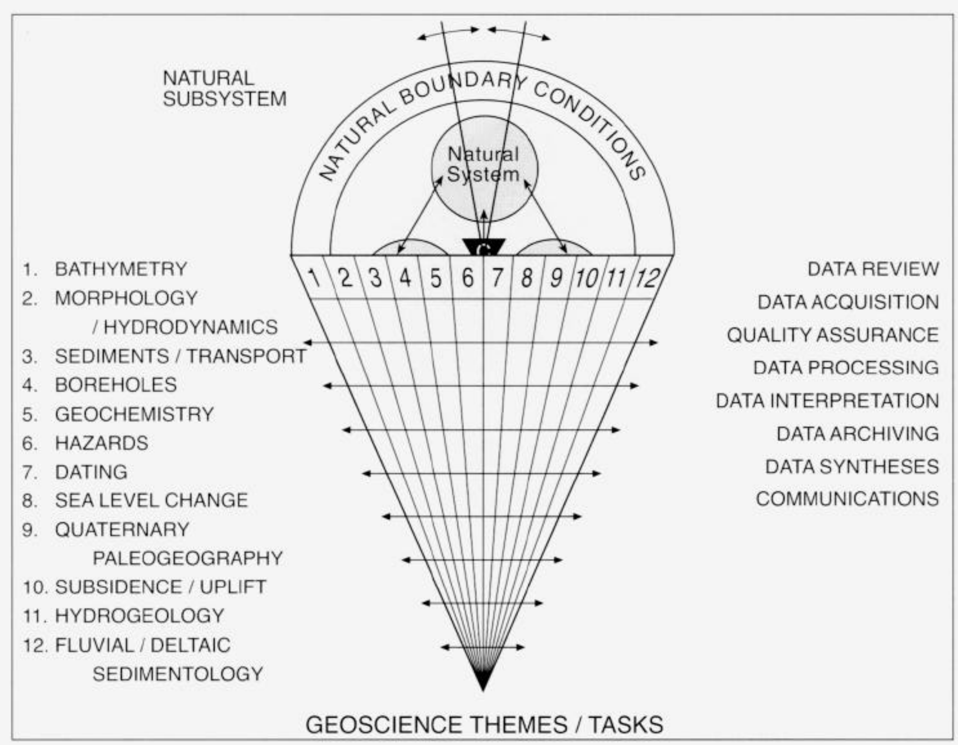

Figure 2: Thematic geoscience knowledge and data management required for effective ICZM.

biology involved in complex dynamic interactions (aerodynamic, geodynamic, hydrodynamic, morphodynamic and ecodynamic). The natural component can be also be further subdivided into:

- natural boundary conditions (such as relative sea level contexts, or climatic regime)
- system properties (such as coastal bathymetry, sediment type, storm frequency, renewable biologic resources and non - renewable mineral and energy resources)
- system processes (such as sediment transport, or tidal water circulation mechanisms)

It will be readily apparent that such a complete treatment of the natural component of coastal systems (Fig. 1) requires combined knowledge from several natural sciences such as oceanography (physical, chemical, biological and geological), coastal geography, and climatology/ meteorology. In some organizations these disciplines are grouped most broadly as "geosciences", whereas in others geoscience refers specifically to geology, geophysics, and physical geography. Whether the definition of geoscience is specific to certain natural science disciplines, or inclusive of many, it is clear that the natural system approach needed for ICZM requires substantive knowledge of the characteristics, origins and behaviour of marine and coastal rocks, sediments, processes and landforms (Figure 2). Baseline knowledge of these components of coastal systems will facilitate ICZM because they contribute fundamentally to:

- the identification of non-renewable resources and their potential for development
- the recognition and definition of potential impacts of development on the environment, both in terms of human health and safety and habitat protection
- the recognition and definition of constraints and hazards to development, particularly in terms of human safety and engineering risk
- the understanding of the differences between natural environmental changes and those induced by human activity, through the definition of baseline environmental conditions and monitoring of changes.

ICZM and the Geological Survey of Canada

Under the newly introduced Canada Oceans Act, the Department of Fisheries and Oceans (DFO) will have a national leadership role in ICZM. It is also recognised that other agencies, at various levels of government, have mandates and capabilities in coastal and marine science, technology and management and will contribute to emerging plans for ICZM on national and local levels. For example, the Department of Natural Resources (NRCan) and its Geological Survey of Canada (GSC) is the major source of coastal marine geoscience information for Canada, with a comprehensive national science program involving projects in the Atlantic, Pacific and Arctic Oceans, and in the Great Lakes. The program is delivered by two divisions: GSC Atlantic located at the Bedford Institute of Oceanography (Dartmouth) and GSC Pacific, at the Institute of Oceanographic Sciences (Sidney). These interagency Institutes facilitate shared technical and scientific resources and joint projects, principally between DFO and NRCan (GSC). Recognising that ICZM can only be successful through multidisciplinary collaboration it is apparent that new momentum in ICZM in Canada will further strengthen existing relationships between DFO and NRCan, as the Geological Survey's marine program continues to provide new geoscience knowledge of Canada's coastal and offshore regions.

The Geological Survey of Canada's Marine Geoscience Program

Canada's coastal and offshore territories comprise almost 40% of its total landmass, and contain proven, valuable hydrocarbon, mineral and biological resources. Canada has one of the longest coastlines in the world, bordering the Atlantic, Arctic and Pacific Oceans, in addition to the Great Lakes coastal areas. Large areas of Canada's offshore are not adequately mapped to modern standards, territorial limits not completely established, the resource potential is poorly defined and environmental knowledge is lacking. The GSC's new marine geoscience information serves wide clientele of marine-based resource and environmental industries, and other federal and provincial agencies with related science or management mandates.

The GSC's marine program addresses problems and needs for geoscience information, generally on a regional or process mechanism basis, for subsequent site-specific exploitation by industry, or for problem solution by task-specific agencies. GSC marine projects use specific site locations to conduct process experiments or as demonstration areas for new capabilities.

The program delivers scientific concepts, data bases and state-of-the-art interpretive maps of Canada's coasts and sea floor. The information is used by industry (e.g. oil and gas, survey, telecommunication, engineering firms) for resource assessments, initial development site selection, detailed site investigation decisions, and regional evaluation of development problems. Moreover the GSC's marine program products find utility, at all jurisdictional levels, in the development of governance strategies for resolution of multiple use conflicts, environmental protection and industrial development - all important components of ICZM.

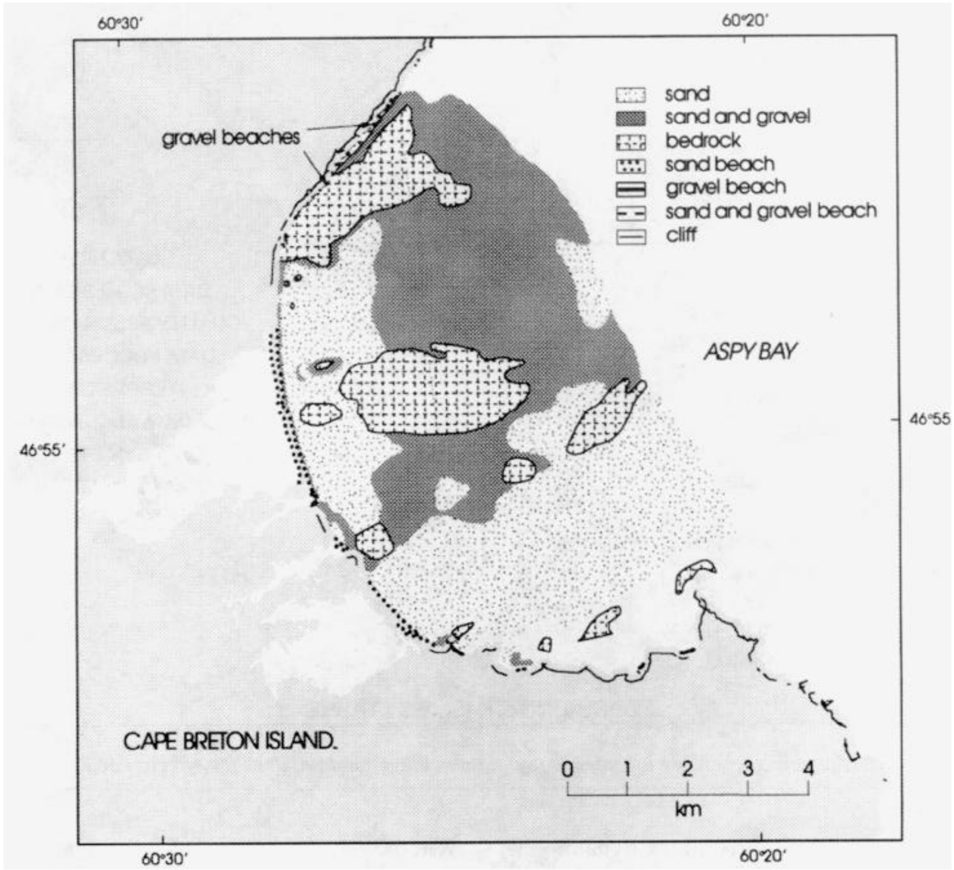

Figure 3: Surficial geology of Aspy Bay integrated with selected features from the GSCA Coastal Information System.

The program's operational plan simultaneously addresses Canada's present and future needs for ICZM information on marine resources and environments. Flexible program implementation facilitates choices in resource deployment to serve high priority, immediate, national and local needs, such as the present focus on coastal, nearshore and lake areas with high population and development pressures. A phased, opportunistic approach (2-5 year time frame) allows modest efforts in remote regions. For example, Arctic and deep water work, truly unknown areas in terms of Canada's resource base, uses joint venture projects with other nations, with shared technical and ship resources. Medium term (5 plus years) research into marine resources, for example frontier deep water oil and gas, and hydrothermal minerals, anticipates changes in economies and technologies of production. Long term (5-10 years) research into fundamental properties of Canada's margins and offshore territories provides basic understanding of process origins of continents and contiguous basins for resource modelling, and an understanding of paleoenvironments for climate change models.

The GSC marine program is organized into three main thematic components:

- **Regional Geoscience** - acquires baseline geological and geophysical data at a variety of scales, seeking new concepts of continental margin evolution, including plate boundary processes, spreading ridges, and basin development. The work includes broad regional geophysical compilations for refinement of global, regional and local scale models of margin evolution, seeking linkages between margin development and the basins they contain, contributing to new hydrocarbon and mineralization resource models.

- **Resources Geoscience** - pursues the identification, understanding and assessment of non-renewable resources in Canada's coastal and offshore areas. The present focus is primarily towards offshore oil and gas, with some interest in offshore minerals, and emerging needs for geoscience aspects of biological habitats. Coastal mineral resource potential is beginning to be assessed using state-of-the-art seafloor mapping technology, which is also being applied to benthic fisheries habitat evaluation.

- **Environmental Geoscience -** seeks understanding of natural geologic processes which affect development of coastal and offshore resources, and evaluates potential or previous impacts on the environment by development. This program provides the geoscience knowledge essential to understand and solve marine and coastal environmental problems, using a combination of mapping and process studies along with capabilities in sedimentology, geochemistry, paleo-

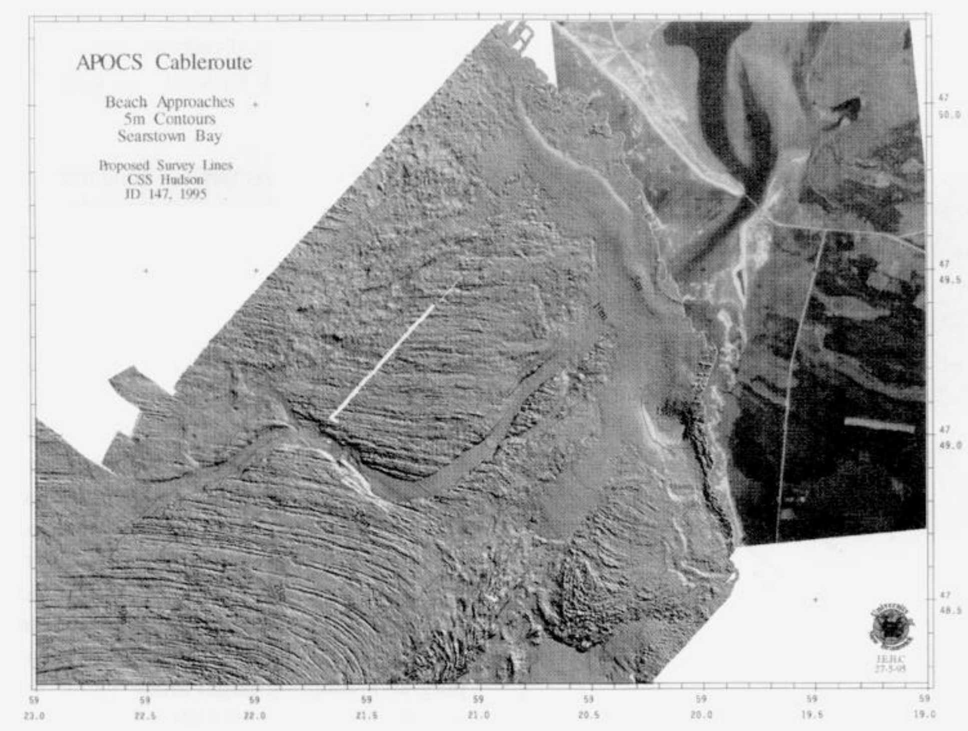

Figure 4: Bathymetric chart compiled from multibeam data of the proposed APOCS cable route landing site in Searstown Bay Newfoundland. The seafloor is largely exposed bedrock, incised by a sediment filled relict river channel cut during a period of lower sea level. The channel provided an ideal conduit in which to protect the cable.

environmental reconstructions, coastal dynamics and geotechnical engineering. The program combines basic and applied research elements to address a broad range of problems on environmental or developmental issues, from waste disposal to offshore hydrocarbon production engineering. For example there are efforts to refine understanding of the distribution, magnitude and frequency of marine geologic hazards, such as seabed erosion, fluid escape, ice/sediment interactions, neotectonics and submarine landsliding. The definition of processes and mechanisms facilitates risk assessment and constraints to construction of coastal and offshore engineering structures and sea bed installations such as jetties, platforms, pipelines and cables. Sedimentary signatures of past process activity are interpreted in magnitude frequency terms and to discriminate natural and anthropogenic events. High resolution paleoenvironmental reconstructions from marine sedimentary records illuminate the types and rates of former natural climatic changes.

Recent Research Relevant to ICZM

Regional and site specific maps of coastal landforms, with classifications usually representing a combination of feature process origins, landform geometries and sediment or rock types have been completed for high priority areas. Regional maps are commonly presented at scales of 1:200,000 or greater while more detailed site descriptions are at 1:10,000 or less. Reconnaissance mapping of Atlantic and Arctic coastal areas has been assisted by video photography from helicopters, in partnership with Canadian Coast Guard. Coastal videos of Atlantic Canada, released in a series of Open File Reports, have been used in combination with ground mapping, monitoring and process studies as the basis for erosion prediction, sensitivity analysis, and for spill contingency planning (Sherin *et al.* 1995). Increasingly coastal landform maps and the data which comprise them use GIS technology for standardization, data manipulation and to facilitate data exchanges. For example recent work has produced a Coastal Information System (CIS) to map coastal landforms utilising dynamic segmentation techniques in ARCINFO (Fig. 3). Design and testing of the prototype is nearing completion and a data base being built with federal and provincial partners for Atlantic Canada. Increasingly, combinations of mapping technologies are allowing continuous coastal mapping from the land to beneath the sea. For example marine surveys are now possible into very shallow water depths facilitating combination with data from aerial video, airborne radar or satellite mapping technologies.

Coastal and nearshore bathymetry is a fundamental property of any coastal system and the data has direct application to a wide range of issues, from habitat definition, navigation routeways, harbour and jetty construction, waste disposal planning and, sea floor installations such as cables and pipelines, and is a basic engineering design parameter. Recently, multibeam survey techniques developed by the Canadian Hydrographic Service in partnership with the GSC have revolutionised bathymetric data acquisition and display, greatly enhancing coverage, survey rates, accuracy and visual display methods - in turn facilitating improved data interpretation and extending the usefulness of the data. Examples of recent high resolution coastal and nearshore surveys are provided by demonstration multibeam surveys over the APOCS cable route between Cape Breton and Newfoundland. GSCA multibeam mapping was able to delineate relict river channels cut across the continental shelf during periods of lowered sea level, providing a natural sediment filled

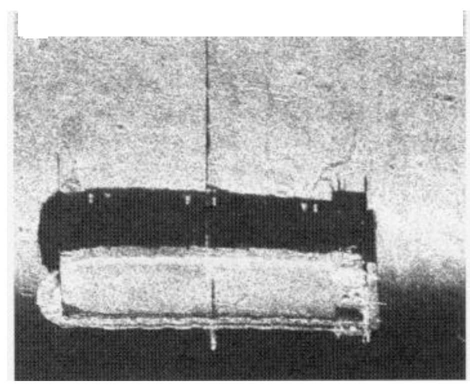

Figure 5: Sidescan sonar image of the wreck Irving Whale, sunk in 67m of water during a storm in 1970. Ships dericks, lines and other debris can be clearly identified. (After Parrott 1995)

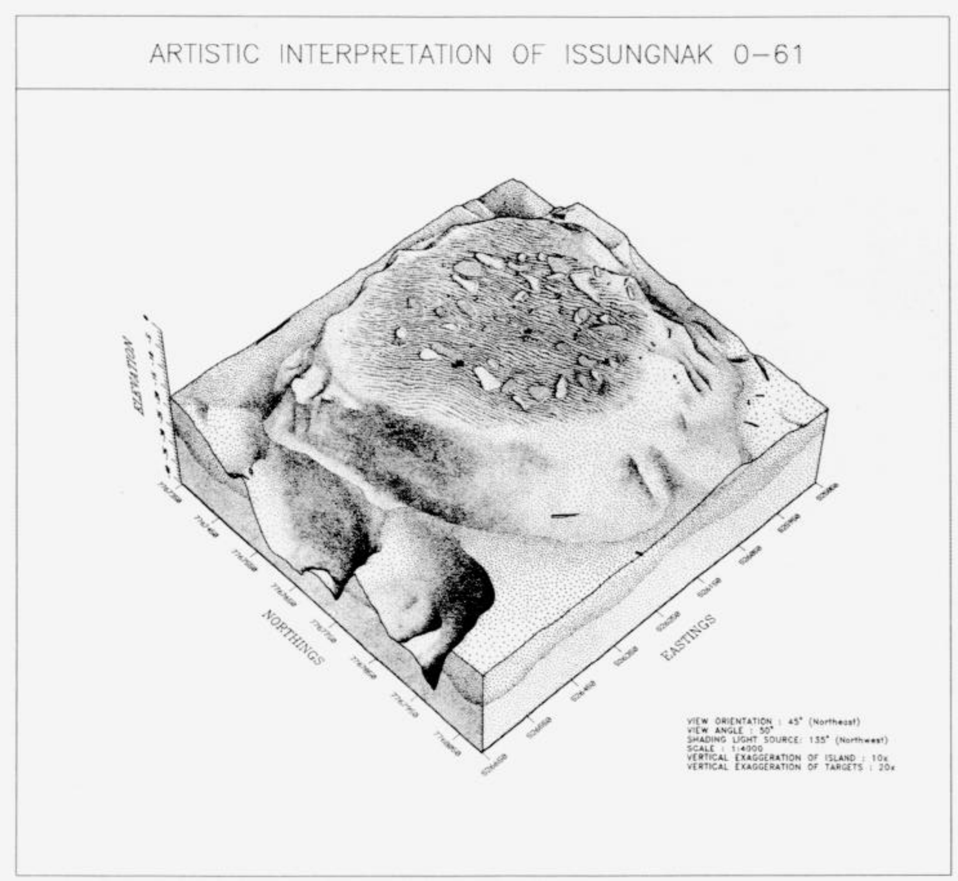

Figure 6: A scaled three dimensional interpretation of an abandoned artificial island in the Beaufort Sea. The borrow pit can be seen in the foreground, the eroding top of the island is littered with debris and active bed forms.

conduit for cable protection. (Josenhans 1995, Fig. 4).

Sea floor imagery, provides spatial data of bottom characteristics to complement water depth data. Typically geoscientists use sidescan sonars and multibeam backscatter systems to make mosaics of the sea floor. At GSC Atlantic both sea floor imagery mosaics and multibeam bathymetry surveys have been significantly improved by the increased navigational accuracy possible with DGPS positioning technology. Sea floor mosaics which can show the location of man - made objects such as shipwrecks, waste dumps, pipelines and cables also contain valuable information about sediment distributions (Parrott 1995, Fig. 5). The imagery also captures the signatures of a wide range of bottom processes such as current erosion and deposition, landslides, gas escape, and faulting - usually identified from specific bottom forms and morphologies. Demonstration of the application of this technology to ICZM has included:

- completion of a major geochemical study of the contamination status of sediments on the floor of Halifax Harbour, the recipient of centuries of urban and industrial effluent discharge. The project results contributed to decisions regarding the design and location of waste remedial and treatment measures (Buckley et al. 1992)

- mapping of anthropogenic waste at former military installations at Argentia and DEW line sites in the Arctic, and modification of artificial islands following abandonment in the Beaufort Sea (Fig. 6)

- partnering with Canadian industry to transfer multibeam mapping technology to the private sector through a demonstration survey for fibre optic cables linking Newfoundland and Nova Scotia.

- collaborative nearshore surveys with Parks Canada to quantify and understand processes of coastal change within National Parks and heritage sites.

Sediment properties are fundamental factors in coastal zones - for example controlling and affecting the way in which coastal and nearshore areas change and evolve under natural conditions. determining the characteristics of different biological habitats, influencing the economic development of mineral resources, and providing limits and constraints to the design. installation and maintenance of engineering structures. As a recent example the GSC offshore mapping program provided the initial scientific framework for designing a federal and provincially funded project to evaluate aggregate potential on the Scotian Shelf. After two seasons mapping and sampling target areas, viable resources have been identified. Follow up laboratory testing is yielding information on the texture, mineralogical, geochemical and geotechnical attributes along with strength to determine suitability of the aggregate for industrial uses (Fader *et al.* 1994). *In situ* procedures are increasingly yielding important new information about the properties of sediments at and near the sea floor, such as porosity. pore fluids pressures, gas contents and shear strength, which affect other behavioural properties such as sediment stability and erodibility.

Sediment budgets are key factors predicting coastline and sea floor changes. For example, the effectiveness of different processes such as longshore drift is a function both of the hydrodynamic regime and the availability of sediment. Deltaic systems, where sediment input usually exceeds dispersal, are areas of coastal progradation, whereas erosion and retreat sometimes are related to a paucity of sediment supply. Recent work is showing that these relationships can be extremely complex with much to be learned about sediment inputs, transport, storage, and renewal, and their relationships with different process magnitudes. At the coast, sediment budgets are derived from long term monitoring of beach profiles, from which effects of storm magnitude and frequency can be determined. In the nearshore, seafloor mapping has been used to identify sources and sinks of sediment and their effects on the sediment budget (Shaw *et al.* in press, Fig. 7). On the Scotian Shelf and Queen Charlotte Islands changes in the seafloor are more subtle, and hydrodynamic processes, sediment property and bathymetric data are combined to generate numerical box models of sediment transport, from which simulated sediment budgets have been developed and calibrated against field observations of coastal response.

Coastal and sea floor processes are the driving mechanisms in the coastal zone. Energy from waves and tides is transmitted to the seafloor and expended in eroding, transporting and redistributing sediments. In the geological time frame coasts are ephemeral features, forming, transgressing and reforming across the continental margin in response to sea level fluctuation, sediment supply and available energy. Understanding processes of sediment transport is fundamental to engineering design in the coastal zone including ports and harbours, coastal protection. cable and pipeline routing, and in developing predictive models of coastal response and in ground truthing sediment budgets. GSCA program in sediment transport has developed a unique suite of tools to monitor sediment dynamics. The stability of sandy sediments in high energy shelf environments has utilised RALPH, an instrumented tripod, to monitor sediment transport rate and direction (Li et al. in press Fig. 8). On the Scotian shelf predictive models of sediment transport and bedform migration have been developed and are being utilised by industry in planned development for offshore production facilities and pipelines. Estuaries, coasts and lakes have long been the repositories for man's waste. This is often untreated and is now being recognised as a major environmental concern. The ability of aquatic systems to absorb anthropogenic materials is being exceeded, the ecology under stress, and viability of ongoing sustainable development in jeopardy. Cohesive muddy sediments are the sink for man's waste. These sediments respond very differently to near bed stresses than sands and consequently require totally different tools to study sediment mobility. The annular flume, Sea Carousel, has been developed to measure bed stability insitu. Studies of immediate application to ICZM have been conducted on the stability of dredged and dumped sediments in Atlantic Canada and (in cooperation with Environment Canada) on artificial restoration of polluted sediments in Hamilton Harbour (Amos *et al.* 1996).

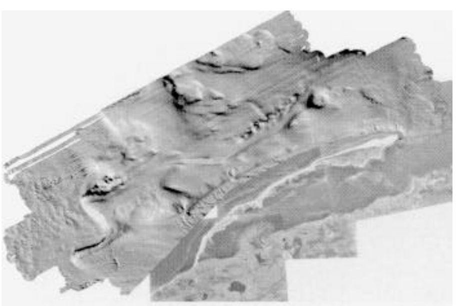

Figure 7: Multibeam swath image of ST Georges Bay Newfoundland. Shore-normal bedforms on the nearshore terrace channel sediment landward into deep water, feeding debris cones and withdrawing sediment from the coastal budget. (After Shaw et al. In press)

Seafloor geologic hazards constrain sustainable development in the coastal zone. The siting, construction and maintenance of engineering structures must take account of hazards such as erosion, sedimentation, landslides, gas and ice scour which, unless properly defined, can stop new engineering development. The GSC contribution to marine hazards research is largely funded through the PERD Program. The research emphasis is on quantifying processes and understanding hazard magnitude and frequency. This research provides the technical base for advising developers, environmental groups and regulatory agencies involved with engineering development in the coastal zone. Research of seabed hazards and constraints to coastal and offshore engineering is conducted in a wide variety of geologic settings, with an equally diverse range of hazards leading to innovative engineering solutions. Research activities presently include, Beaufort sea ice/permafrost effects on foundation conditions, effects of iceberg scour on seafloor sediments, submarine landslide assessments for cable routes crossing the Fraser Delta (Christian et al. Fig. 9), and evaluation of neotectonics activity from sedimentary structures in the Great Lakes.

Vulnerability assessment as defined by The International Panel for Climate Change (IPCC) involves a "Common Methodology" to allow definition of a coastal nation's ability to cope with the consequences of global climate change, including accelerated sea level rise. The IPCC vulnerability assessment process offers one way for a coastal federal, provincial, municipal, or community agency to "review existing capabilities and performances in coastal zone planning and management" (World Coastal Conference. 1993), within the context of a long term approach.

The Common Methodology involves seven steps, and marine geoscience programs at GSC Atlantic make important contributions in at least three - the specification of accelerated sea level rise boundary conditions; the provision of natural system data; and the assessment of physical changes and natural system responses.

In much of Canada relative sea level change is a complex balance between isostatic rebound of the landmass following deglaciation and eustatic sea level rise due to changes in ice cap volume. It is possible to travel short distances along the shore and pass from emergent prograding coasts to submergent erosional shores. The understanding of these natural cycles of sea level change is necessary to place in context sea level rise induced by global warming. Relative sea levels histories from decadal through geologically recent (Holocene) times are reconstructed through analysis of tide gauge records, the changing shoreline geomorphology, drowned coastal landforms, and high resolution paleoenvironmental reconstructions from the coastal and nearshore sedimentary records.

In terms of vulnerability to sea level changes GSC Atlantic maintains an extensive coastal monitoring program to define recent changes in coastline behaviour on a regional basis and at specific coastal sites. These serve to indicate trends which when combined with analysis and modelling of changing storm intensities, allow projections of future coastline changes. This information is essential in defining protective buffer zones for inclusion in ICZM plans to guard against unwise development close to the shore. Different schemes have been used to map coastline changes patterns

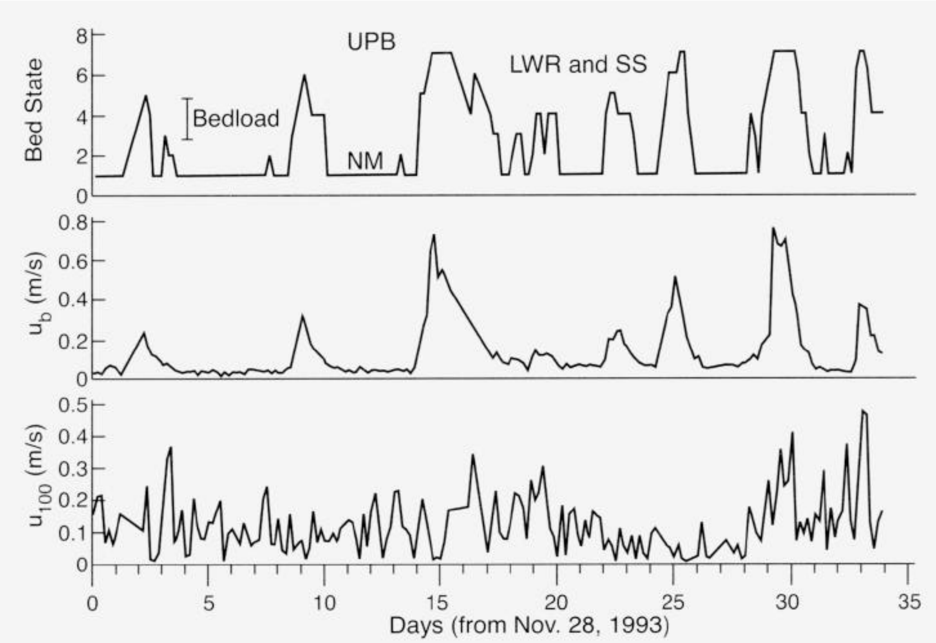

Figure 8: Time series plots of data from instrumented tripod RALPH installed on Sable Island Bank. Water depth (II), mean velocity (U100), significant wave height (Hs), spectral-peak wave period (Tp), and sand suspension in transmission % at 33 cm above the seabed (C33). (After Li and Amos in press).

and responses to relative sea level fluctuations, and one example is provided by Shaw *et al.* (1994) synthesising available knowledge of sea level history and shoreline type to produce a coastal vulnerability map for the entire Canadian coastline.

Some Future Directions

Within Canada demands for geoscience data for ICZM are expected to grow, from communities, municipalities, provinces and other government departments. The GSC Marine Program will continue to contribute the necessary geoscience information for ICZM through a balance, between baseline data acquisition, concept development, and application, supported by technology innovation. Major program objectives will continue to be the provision of marine geoscience information for non-renewable and renewable resources development in coastal and offshore areas, and for environmentally-responsible development decisions. Data will continue to be acquired for high priority areas defined with client consultation, but some overall program directions and initiatives are as follows:

- basic research will introduce new concepts relevant to the identification of non - renewable resources in coastal, nearshore and offshore areas, including oil and gas reserves, and placer minerals. Synthesis, analysis and updating of existing databases will concentrate on areas where there is recent momentum in energy exploration and development such as the Gulf of St. Lawrence, the Grand Banks and the Scotian shelf. A multi-disciplinary team project will commence focusing on the Gulf of St. Lawrence region.

- new Canadian technical capabilities in ocean mapping will be used to develop innovative applications and practices in scientific investigations of environmental problems, such as sea floor hazards, definition of seafloor habitat, pollution of marine sediments and dredging effects. The improved mapping capabilities will also be used for quantitative nearshore mineral potential, in anticipation of leasing legislation and production development.

- a pilot project will be initiated and completed in a severe land loss area of Prince Edward Island, combining mapping, monitoring, modelling in the coastal and nearshore zones as a basis for implementing a “type coast” system approach to other areas of Canada.

- ICZM needs will require further development of ICZM databases for

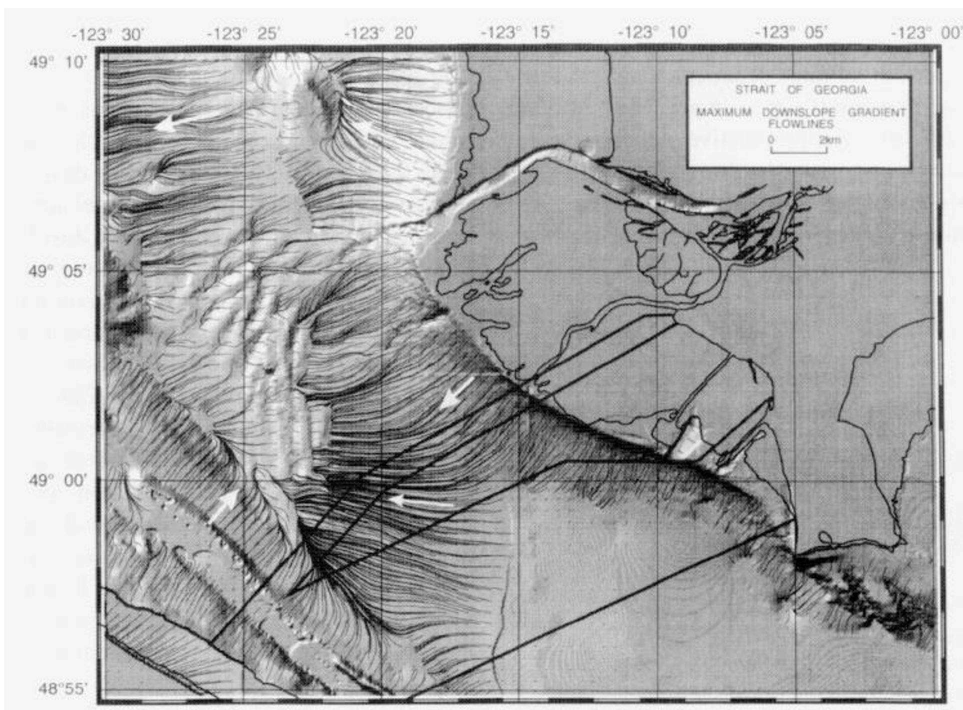

Figure 9: Maximum downslope gradient flow lines on the Fraser Delta, used to predict landslide travel paths. (After Christian. In press)

coastal areas. in formats suitable for wide user access.

- PERD program objectives in reducing the effects of geological hazards to offshore energy issues will continue to identify high priority areas for research into sea floor geotechnical properties and engineering process constraints, including Scotia shelf (gas platforms, pipelines), Fraser delta (electrical transmission lines) and Grand Banks (Hibernia spin off production facilities).

- new geoscience practice developed for Canada's coastal and offshore areas, will be shared with and transferred to Canadian industry, with the objective of wider global application, where there are increasing needs for geoscience information for ICZM. One objective will be the refinement of geoscience data acquisition and practice through demonstration projects in developing countries, in partnership with agencies such as the South Pacific Applied Geoscience Commission (SOPAC) and the Coordinating Committee for Coastal and Offshore Geoscience Programmes in East and South East Asia (CCOP).

- maintained participation in The Ocean Drilling Program will enable advances in understanding of paleoclimates, at high resolution time scales, relevant to sea level histories and characterisation of natural and man-induced environmental changes. For example specific studies of Canadian offshore sediments (eg. Saanich Inlet) will contribute both to local paleoclimatic reconstructions, and to global models.

- GSC marine environmental scientists will take a lead role in a new GSC-wide initiative on lakes research (including the Great lakes), using technology, skills and experience from existing projects in lakes Ontario and Winnipeg, and imported from other marine research themes. Established partnerships with local industries, other government departments, and neighbouring provinces will be specially focussed to new understanding of issues such as lake pollution, shoreline stability, lakebed foundation conditions and hazards, aggregate mining, dredging and disposal, and cultural heritage site descriptions.

- NRCan is one of the proponents of a new interdepartmental Marine Environmental Quality Action Plan (MEQ). The GSC marine program seeks to cooperate with other participating federal agencies in initiatives in coastal pollution studies but will take the lead in selected projects, such as Vancouver Harbour/Fraser delta, where geochemical status studies can be linked to other GSC work in sea floor process studies such as sediment transport modelling.

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Organization and Staff

The Bedford Institute of Oceanography (BIO), the Gulf Fisheries Centre (GFC), the Halifax Fisheries Research Laboratory (HFRL), and the St. Andrews Biological Station (SABS) are research establishments of the Government of Canada and are operated by the Department of Fisheries and Oceans (DFO), both on its own behalf and, in the case of BIO, for the other federal departments that maintain laboratories and groups at the Institute. There are two such departments: Natural Resources Canada (NRCan); and Environment Canada. The former maintains a major unit at BIO, the Geological Survey of Canada (Atlantic). In leased accommodation at BIO are a number of private companies and agencies that undertake work related to the marine sciences.

Presented below are relevant major groups and their managers as at December 1, 1996. In addition to the four research establishments, several staff are located in an office building in Halifax called the Maritime Centre (MC) and one in Dartmouth called Queen Square (OS). Telephone numbers are included.

FISHERIES AND OCEANS CANADA

Maritimes Region

Regional Director-General
N.A. Bellefontaine
MC (902)426-2581

Science Branch
J.S. Loch, Regional Director
BIO (902)426-3492

R.E. Lavoie. Assistant Director
BIO (902)426-2147

Aquaculture Division
W. Watson-Wright, Manager
(and Director, St. Andrews Biological Station)
SABS (506)529-5860

Diadromous Fish Division
J.A. Ritter, Manager
MC (902)426-3136
GFC (506)851-2945

Habitat Management Division
G. Sirois, Manager
GFC (506)851-7768

Hydrography Division
Canadian Hydrographic Service (Atlantic)
P. Bellemare, Manager
BIO (902)426-3497

Invertebrate Fisheries Division
M. Chadwick, Manager
GFC (506)851-6204

Marine Environmental Sciences Division
P. Keizer, A/Manager
BIO (902)426-6138

Marine Fish Division
M. Sinclair, Manager
BIO (902) 426-3130

Ocean Sciences Division
J.A. Elliott, Manager
BIO (902)426-8478

Human Resources Branch
J. Feetham
A/Regional Director
QS (902)426-9427

Finance and Administration Branch
G.C. Bowdridge
A/Regional Director
MC (902)426-6166

Library Servicies
A. Fiander, Chief
BIO (902)426-3675

Communications Branch
A.M. Lanteigne
Regional Director
GFC (506)851-7757

Informatics Branch
E. Doucet, Regional Director
MC (902)426-7433

Technical Support Services
M. Cusack, A/Director
QS (902)426-3939

Engineering & Technical Services
D. Dinn, Manager
BIO (902)426-2009

Vessel Support
G. Putt, A/Superintendent
QS (902)426-5934

Aquaculture Coordination Office
R.H. Cook, Manager
MC (902)426-9068

NATURAL RESOURCES CANADA

Geological Survey of Canada (Atlantic)
J. Verhoef, Director
BIO (902)426-3448

Marine Regional Geoscience
R. Courtney. A/Head
BIO (902)426-2255

Marine Resources Geoscience
K.D. McAlpine, Head
BIO (902)426-2730

Marine Environmental Geoscience
R.A. Pickrill, Head
BIO (902)426-5387

Administration
G. McCormack, Head
BIO (902)426-2111

ENVIRONMENT CANADA

Atlantic Region

Environmental Quality Laboratory
K. Doe
BIO (902)426-3284

Shellfish & Microbiology Laboratory
A. Menon, Head
BIO (902)426-9003

Projects

Presented below is a list of the projects and individual investigations undertaken by the Department of Fisheries and Oceans' laboratories in the Maritimes Region, by the Geological Survey of Canada, (Atlantic), of Natural Resources Canada, and by Environment Canada units at BIO during the review period.

For more information on these projects, many of which are continuing, please write to: Regional Director of Science, Maritimes Region, Department of Fisheries and Oceans, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth. N.S., B2Y 4A2

FISHERIES AND OCEANS MARITIMES REGION

MARINE ENVIRONMENTAL SCIENCES DIVISION

A. ENVIRONMENTAL ASSESSMENT SECTION

1. Marine Emergencies
   J.M. Bewers
2. Canadian Marine Analytical Chemistry Standards Program
   J.M. Bewers
3. International Activities
   J.M. Bewers
4. Regional Assessment - Inshore Areas of the Scotia-Fundy Region
   J.M. Bewers
5. Identification of Synthetic Organic Chemicals in Commercial Species from Municipal and Industrial Harbours and Rivers
   J.M. Bewers
6. Provision of Advice on Toxic Chemical Issues
   J.M. Bewers
7. Development of Public Relations Video on the Health of the Marine Environment
   J.M. Bewers
8. Environmental Assessments/Aquatic Environmental Science Section Management
   D.R. Alexunder
9. Marine Assessment and Liaison/ Science Applications
   H.B. Nicholls

B. ENVIRONMENTAL SCIENCES SECTION

1. Environmental Advice
   V.E. Zitko
2. Harmful Algal Marine Research
   J.L. Martin
3. Risk Assessment of Organic Chemicals to Fisheries
   V.E. Zitko
4. Biochemical Indicators of Health of Aquatic Animals
   K. Haya
5. Aquatic Toxicology of Marine Phytotoxins
   K. Haya
6. Aquaculture Ecology Research
   D.J. Wildish
7. Effects of Changes in Coastal and Marine Environments on Atlantic Salmon
   G.L. Lacroix
8. Monitoring Marine Biodiversity
   D.J. Wildish
9. Biochemical Indicators of Health of Aquatic Animals
   K. Haya
10. Aquaculture Ecology Research
    D.J. Wildish
11. Acid Rain Research and Modelling
    G.L. Lacroix

C. HABITAT ECOLOGY SECTION

1. Section Administration and Management
   P.D. Keizer
2. Organochlorines in Arctic Ocean Marine Food Webs
   B.T. Hargrave
3. Fish Habitat Assessment Advice
   D.C. Gordon
4. Microbial Ecology
   J.E. Stewart
5. Microbial-Marine Toxin Interactions
   J.E. Stewart
6. Physiological Ecology of Toxic Algae
   S.R.V. Durvasula
7. Coastal Phytoplankton Dynamics
   P.D. Keizer
8. Biological-Physical Interactions in Coastal Habitats
   K.H. Mann
9. Sedimentology of Coastal Habitats
   T.G. Milligan
10. Scallop Habitat Research
    P.J. Cranford
11. Coastal Habitat Studies
    G.C. Harding
12. Benthic Habitat Studies
    T.W. Rowell
13. Environmental Interactions with Aquaculture
    P.D. Keizer
14. Bioenergetics of Marine Mammals
    P.F. Brodie
15. Size-Dependent, Bioenergetic Processes in Fish Habitat
    S.R. Kerr
16. Habitat Mapping
    P.R. Boudreau
17. Evaluation of Estuarine and Continental Shelf Habitats
    W.L. Silvert
18. Contaminant Fluxes in Marine Benthic Food Webs
    B.T. Hargrave
19. Instrumentation Support
    W.P. Vass

D. MARINE CHEMISTRY SECTION

1. Climate Variability Recorded in Marine Sediments
   J.N. Smith
2. Distribution of Sea Ice Meltwater in the Arctic
   F.C. Tan
3. Oxygen Isotopes and Mixing on the Scotian Shelf
   P.M. Strain
4. Point Lepreau Environmental Monitoring Program
   J.N. Smith
5. Contaminant Cycling in Estuarine Waters
   J.H. Vandermeulen
6. Black Carbon Particles
   R. Pocklington
7. A Critical Evaluation of "Greenhouse Warming" and the Part Played in it by Emissions from Fossil Fuel Combustion
   R. Pocklington
8. Fish Aging from 210Pb/226Ra Measurements in Otoliths
   J.N. Smith
9. Growth Rates of the Sea Scallop *(Placopecten Magellanicus)* using the Oxygen Isotope Record
   F.C. Tan
10. Sediment Geochronology and

Geochemistry in the Saguenay Fjord
J.N. Smith

11. Trace Metal Geochemistry in Estuarine Mixing Zones
P.A. Years
12. Radionuclide Measurements in the Arctic
J.N. Smith
13. Carbon Isotope Studies on Particulate and Dissolved Organic Carbon in Deep Sea and Coastal Environments
F.C. Tan
14. Trace Metal Transport into the Western North Atlantic
PA. Years
15. Chemical Reactivity in the Surface Ocean
P.M. Strain
16 Composition and Reaction of Marine Colloidal Matter
S.E.H. Niven
17 Nutrient Dynamics in Ship Harbour, N.S.
P.M. Strain
18 Heavy Metal Contamination of Sediments and Suspended Matter on the Greenland Shelf
D.H. Loring
19 Risk Assessment of Toxic Chemicals
J.F. Uthe
20 Sub-lethal Contaminants: Long-Term Fate and Effects of Petroleum Hydrocarbon Pollution in Aquatic Systems
J.H. Vandermeulen
21. Investigations into Amino Acid Shellfish Toxins
R. Pocklington
22. Contaminants in Municipal Harbour Lobster Fisheries
J.F. Uthe
23. Contaminants in Sports Fisheries
J.F. Uthe
24. Endocrinological Sublethal Tests
J.F. Uthe
25. Sources, Distribution and Fate of Metallic Contaminants in Atlantic Estuarine and Harbour Sediments
D.H. Loring
26. Modelling of Distributions of Toxic Chemicals in Harbours and Estuaries
P.A. Yeats
27. Factors Affecting the Concentrations of Toxic Chemicals in Lobsters
C.L. Chou
28. Historical Record of Contaminant Fluxes in Marine Sediments
J.N. Smith
29. Contaminant Trends in Selected Commercial Fisheries: Gulf of St. Lawrence Cod Study
J.F. Uthe
30. Assessment of Input Functions for Toxic Chemicals in Scotia-Fundy Region
P.A. Yeats
31. Application of Biochemical Sublethal Tests for Detecting Pollution-Induced Effects in Commercial Atlantic Fish
D.E. Willis
32. Toxic Chemical Regional Data Management System
P.M. Strain
33. Measurements of Radioactive Contaminants in the Arctic Ocean
J.N. Smith.
34. Assessment and Restoration of Fish Habitat Polluted by Toxic Chemicals
W.L. Fairchild
35. Monitoring of Toxic Chemical Trends in Selected Sites of South eastern Gulf of St. Lawrence
W.L. Fairchild
36. Assessment of the Status of the Gulf Region Coastline with Regard to Toxic Contaminants
W.L. Fairchild
37. Levels of Contamination in Native, Subsistence and Recreational Fisheries Resources
W.L. Fairchild
38. Contamination Levels in Commercial Fish and Their Habitat by Pesticides and Agricultural Chemicals
W.L. Fairchild

MARINE FISH DIVISION 1994
A-BASE PROJECTS

1. 4TVW Haddock Assessment and Associated Research
Zwanenburg
2. 4X Haddock Assessment and Associated Research
Hurley
3. 4Vn Cod Assessment and Associated Research
Lambert
4. 4VsW Cod Assessment and Associated Research
Mohn
5. Silver Hake Assessment and Associated Research
Showell
6. Redfish Assessment and Associated Research
Branton
7. Flatfish Assessment and Associated Research
Annand
8. Continental Shelf Margin Studies and Argentine Assessment
Halliday
9. Population Ecology of Sealworm
McClelland
10. Seal Diet and Energetics Research
Bowen
11. Seal Population Dynamics Research
Stobo
12. Seal Research Infrastructure
Bowen
13. Groundfish Management Research
Halliday
14. National Sampling Program
Zwanenburg
15. International Observer Program
Showell
16. 4VsW Cod Trawl Surveys
Mohn
17. Groundfish Age & Maturity Determinations
Annand
18. Fisheries Recruitment Variability
Frank
19. Otolith Studies
Campana
20. Finfish Tagging Studies
Stobo
21. Shark Assessment and Associated Research
Hurley
22. Oceanographic Data Handling
McRuer
23. EDP Support
Branton
24. Survey Design and Biometrical Research
Smith
25. Cooperative Science-Industry Research and Communications
O'Boyle
26. Stock Structure Studies
Zwanenburg

B-BASE (AFAP) PROJECTS

1. Seal/Sealworm Ecology - Diet/Parasite/Population Monitoring Studies

Bowen / Stobo
2. Toxic Chemicals
Stobo

1995
A-BASE PROJECTS
1. 4TVW Haddock Assess. and Associated Res. & Sentinel Fisheries
Zwanenburg
2. 4X Haddock Assessment and Associated Research
Hurley
3. 4Vn Cod Assess. and Associated Res. & Sentinel Fisheries
Lambert
4. 4VsW Cod Assessment and Associated Research
Fanning
5. Silver Hake Assessment and Associated Research
Showell
6. Developing Fisheries Assessment and Associated Research
O'Boyle
7. Redfish Assessment and Associated Research
Branton
8. Flatfish Assess. and Associated Res. & Monkfish Industry Project
Annand
9. Continental Shelf Margin Studies and Argentine Assessment
Halliday
10. Seal Diet and Energetics Research
Bowen
11. Seal Population Dynamics Research
Stobo
12. Seal Research Infrastructure
Bowen
13. Grey Seal Female Contraception
Bowen
14. Groundfish Management Research
Halliday
15. Stock Assessment Methods
Mohn
16. National Sampling Program
Zwanenburg
17. Groundfish Statistics
Fanning
18. International Observer Program
Showell
19. 4VsW Cod Spring Trawl Surveys
Fanning
20. Groundfish Age & Maturity Determinations
Annand
21. Fisheries Recruitment Variability
Frank
22. Otolith Studies
Campana
23. Finfish Tagging Studies
Stobo
24. Ecosystem Processes
O'Boyle
25. Shark Assessment and Associated Research
Hurley
26. Oceanographic Data Handling
McRuer
27. Survey Design and Biometrical Research
Smith
28. Science Communications
O'Boyle
29. Stock Structure Studies
Zwanenburg

B-BASE
1. Green Plan Toxic Chemicals Project -Studies of the Oceanochloride Residues in the Blubber of Atlantic Grey and Harbour Seals
Stobo (Inst. Of Ocean Coast Sciences)
2. Identification of Mixed Cod Stocks in the Gulf of St. Lawrence
Campana
3. Seal-Fish Interactions
O'Boyle
4. Redfish High Priority Project
Branton
5. National Hydroacoustic Program: Survey Design Project
Smith

St. ANDREWS BIOLOGICAL STATION
PELAGICS AND GROUNDFISH

1994
1. Herring Assessment and Associated Research (Subarea 4)
Stephenson
2. Herring Assessment and Associated Research (Subarea 5)
Melvin
3. Large Pelagics Assessment and Associated Research
Porter
4. Pelagic Acoustics Survey
Buerkle
5. 5Ze Haddock Assessment and Associated Research
Gavaris
6. 4X Cod Assessment and Associated Research
Trippel/Gavaris
7. 5Z Cod Assessment and Associated Research
Hunt
8. Pollock Assessment and Associated Research
Neilson/Trippel
9. Groundfish Trawl Surveys
Hunt
10. Groundfish Age Determination
Hunt
11. Winter Flounder Assessment and Associated Research
Page
12. Oceanography and Fish Distribution
Page
13. Oceanographic Data Handling (ODH)
PagelMcRuer
14. Herring Biological Studies
Iles
15. Groundfish Ecosystems Research Information - Survey Data
Clark

1995
1. Herring Assessment and Associated Research (Subarea 4)
Stephenson
2. Herring Assessment and Associated Research (Subarea 5)
Melvin
3. Large Pelagics Assessment and Associated Research
Porter
4. Fisheries Systems Evaluation
GavarislStephensori
5. Marine Mammals-Fisheries Interactions
Trippel
6. Herring Biological Studies
Iles
7. 5Ze Haddock Assessment and Associated Research
Gavaris
8. 4X Cod Assessment and Associated Research
Trippel
9. 5Z Cod Assessment and Associated Research
Hunt
10 Pollock Assessment and Associated Research
NeilsonlTrippel
11 Groundfish Trawl Surveys
Hunt
12 Groundfish Age Determination

Hunt
13. Yellowtail Flounder Assessment and Associated Research
Neilson
14. Oceanography and Fish Distribution
Page
15. Oceanographic Data Handling
PagelMcRuer

NON-DFO RESEARCH MISSIONS
1. *Lady Sharell*, 8 February - 15 March 1995, off Southwest Nova Scotia;
2. Size selection of longlines for cod and haddock in relation to hook type and size and bait size.
R.G. Halliday
3. *Cape Chidley,* 6- 16 November 1994 and 7-15 March 1995 (2 cruises), along Scotian Shelf Slope;
4. Fishery resources survey of continental slope in 900-1800 m using otter trawls
5. Halliday (Scientific Authority), in conjunction with the Atlantic Reference Centre, St. Andrews, N.B., and National Sea Products Ltd., Lunenburg, N.S.

PROJECTS, MONCTON
1994
1. Herring Research Surveys
2. Groundfish Coordination
3. Assessment and Biology of the 4T-Vn Cod Stock
4. Sampling and Surveys
5. White Hake and Understudied Groundfish
6. Fisheries Dynamics and Modelling
7. Flatfish research and assessments
8. Data Compilation

PROJECTS, MONCTON
1995
1. Herring Research Surveys
2. Groundfish Coordination
3. Biology and Assessment of the 4T-Vn Cod Stock
4. Sampling, Surveys and Community Analyses
5. Fisheries Dynamics and Modelling
6. Flatfish research and assessments
7. Statistical Analysis - Fish Species

ENVIRONMENTAL PROTECTION BRANCH

SHELLFISH SECTION
1. Conduct Shellfish Growing Areas classification studies to determine the suitability of harvesting molluscan shellfish (mussels, oysters, clams) based on sanitary surveys and bacteriological water quality in Nova Scotia
J. Young, D.M. Tremblay, C. Craig
2. Conduct Shellfish Growing Areas classification studies to determine the suitability of harvesting molluscan shellfish (mussels, oysters, clams) based on sanitary surveys and bacteriological water quality in New Brunswick
B.J. Richard

HYDROGRAPHY BRANCH
CANADIAN HYDROGRAPHIC SERVICE (ATLANTIC)

A. HYDROGRAPHY
1. **Ocean Mapping (Ship Based):**
Inner Scotian Shelf near Halifax, Saint John, N.B.
Victoria Strait/Strait of Georgia, N.W.T. Ground Truthing Projects Bay of Fundy (UNB)
G. *Costello*
2. **Revisory and Sweep Surveys (Atlantic Provinces) (Ship Based):**
Halifax Harbour, Sydney Harbour and Strait of Canso, N.S.
J. Ferguson
3. **Newfoundland and Labrador Surveys (Ship Based):**
Notre Dame Bay, Labrador Coast, Bonavista Bay
C. Stirling
4. **Revisory Surveys (Shore Based):**
Saint John River, Evandale to Grand Bay & Reversing Falls, N.B.
Charlottetown, P.E.I.
G. Henderson

B. TIDES, CURRENTS AND WATER LEVELS
1. Ongoing Support to CHS Field Surveys and Chart Production
C. O'Reilly, C.P. McGinn, G.B. Lutwick, F. Carmichael
2. Operation of the Permanent Tide and Water Level Gauging Network
C. O'Reilly, C.P. McGinn, G.B. Lutwick. F. Carmichael
3. Review and Update of Tide Tables and Sailing Directions
C. O'Reilly
4. Scientific and Engineering Project Support: Calibration and Maintenance of Portable Gauges

C. NAUTICAL PUBLICATION PRODUCTION
1. **Production of Charts** as follows:
2 New Charts
17 New Editions
156 Electronic Navigational Charts
22 Chart Correction Patches
160 Notices to Mariners
S. Grant, Keith Crawford, A. Hantzis
2. **Sailing Directions**
Publication of Sailing Directions (Saint John River, Newfoundland - East and South Coasts (Cape Bonavista to Ferryland Head)
R. Pietrzak, G. Smith

D. DATA MANAGEMENT
1. **Hydrographic Data Centre**
Updates and maintenance of the Source Directory Files Management System
C. Day-Power, S. Nickerson
Interaction with the Validation Unit
C. Day-Power, S. Nickerson
2. **Validation**
E. Crux, D. Nicholson, N.Palmer, D. Roop

a. Validation of New Charts
4857 Greenspond Harbour to Pound Cove
4858 Indian Bay to Wadham Islands
b. Validation of New Editions
4641 Port aux Basques
4118 St. Mary's Bay
c. Validation of ENC's
76168 Lewisporte
76172 Bay of Exploits, Sheet 5, S.E.
76236 Nortre Dame Bay Orange Bay to Cape Bonavista
d. Sailing Directions Diagrams
Salvage, Newfoundland
Summerville, Newfoundland
Summerford, Newfoundland
Happy Adventure. Newfoundland
Lumsden, Newfoundland
e. Validation of Incoming Documents from Outside Agencies
40 NTM Recommended as a result of New Document Review

7000 Notices to Shipping and 260 Foreign Notices to Mariners Booklets reviewed 804 Accessions Lists Documents Validated
D. Blaney F. Burgess, E. Crux, B. MacGowan, S. Nunn. N. Palmer, D. Roop. T. Rowsell

3. **Navigation**
LORAN-C Chart Latticing
N. Stuifbergen
Navigation - User Support and Training
N. Stuifbergen

4. **Database Management Systems & Electronic Charts**
Green Plan DBMS and Electronic Chart Research
S. Grant, D. Frizzle, G. MacLeod, C. Day-Power, H. Varma, M. Eaton, H. Boudreau, J. Davison, R. Pietrzak, M. MacDonald, C. Stirling

E. HYDROGRAPHIC DEVELOPMENT

1. Coordination of Research and Development within CHS
R.G. Burke
2. Implementation of Hydrographic Data Processing System
R.G. Burke, S. Forbes
3. *ISAH* and GPS Implementation
S. Forbes
4. ORACLE MD - Multi-Dimensional Spatial Information Management System
H. Varma
5. Ocean Mapping Initiative for Canada (OMIC)
G. Costello
6. Enhancing Computer-Assisted Chart Production Techniques
S. Forbes, K. White
7. Informatics Support and Coordination
S. Forbes, L. Norton, K. White, M. Ruxton

AQUACULTURE DIVISION - PROJECTS 94 AND 95

MOLLUSCAN DEVELOPMENT SECTION, MONCTON

1. Bivalve pathology
S. McGladdery
2. Mollusc productivity
T. Landry
3. Scallop biology
L.-A. Davidson
4. Finfish Health and Aquaculture
M.I. Campbell

MOLLUSCAN FISHERIES SECTION, HALIFAX

1. Molluscan culture and assessment
K. Freeman
2. Molluscan early life history physiology and ecology and oyster aquaculture
J. Kean-Howie
3. New candidate species research
E. Kenchington

FISH HEALTH AND NUTRITION SECTION, HALIFAX

1. Nutrition - lipid research
J.D. Castell
2. Nutrition - salmonids and disease
S.P. Lull
3. Fish disease and immunology research
G. Olivier
4. Histology and parasitology
C.A. Morrison
5. Fish Health Services Unit
A.-M. MacKinnon
6. Population ecology of sealworm
G. McClelland

APPLIED AQUACULTURE SECTION, ST. ANDREWS

1. Salmonid growth, smolting & reproduction
R.L. Saunders
2. Marine fish culture
K.G. Waiwood
3. Early fish behavior
R.H. Peterson
4. Physiology & production of grow-out stages of aquaculture species
R.H. Peterson
5. Finfish reproduction and broodstock development
D.J. Martin-Robichaud
6. Invertebrate aquaculture research
D.E. Aiken
7. Soft-shell clam fishery ecology and aquaculture
S.M.C. Robinson
8. Scallop aquaculture and enhancement research
S.M.C. Robinson
9. Resource potential of underutilized invertebrate species
S.M.C. Robinson, P. Lawton
10. Quoddy Region Bio-physical Interactions
W.M. Watson- Wright, S.M.C. Robinson, F.H. Page
11. Salmon Genetics Research Program (collaborative project with Atlantic Salmon Federation)
W.M. Watson- Wright
12. Alternative treatments for sea lice in farmed Atlantic salmon
B.D. Chang, G. McClelland
13. Transgenic salmon (joint project with A/F Protein Canada, Inc.)
R.L. Saunders
14. Atlantic Reference Centre (collaborative project with Huntsman Marine Science Centre)
W.M. Watson- Wright

DIADROMOUS FISH DIVISION

1. Habitat enhancement tests.
D. Cairns
2. Morell salmon assessment.
D. Cairns
3. Impoundment limnology.
D. Cairns
4. Bibliography of PEI fresh waters.
D. Cairns
5. Cormorant foraging patterns
D. Cairns
6. Herring spawning bed surveys
D. Cairns
7. Diadromous Fish Stock Assessments, Salmon Enhancement and Associated Research
G. Chaput
8. Quantify habitat use of, and production by, diadromous fishes in Maritimes Region aquatic environments.
R. Cunjak
9. Assess natural environmental fluctuations in, and anthropogenic perturbations to, fish habitat and production.
R. Cunjak
10 Head of Hatchery Operations and Salmonid Enhancement Research, Gulf Region
K. Davidson
11 Salmon hatchery operations and research.
G. Farmer

12. Anadromous Species Statistical Data Collection and Analysis
C. Harvie
13. Fish Culture Engineering Enhancement and Fish Passage Engineering
H. Jansen
14. Non-Salmonid Asssessment Research
B. Jessop
15. Stock assessment and associated research on diadromous fishes, northern New Brunswick
A. Locke
16. Salmon Assessment Research SWNB & Cape Breton
L. Marshall
17. Salmon Assessment Research I
R. Cutting
18. Finfish and Invertebrate Introductions and Transfers
R. Cutting
19. Salmon Assessment Research (North and Eastern Shore N.S.)
S. O'Neil
20. Freshwater Habitat Research
W. Watt, W. White

OCEAN SCIENCES DIVISION 1994

OCEAN CLIMATE SERVICES

1. Microstructure Studies in the Ocean
N.S. Oakey
2. Investigations of Air-Sea Fluxes of Heat and Momentum on Large Space and Time Scales using Newly Calibrated Bulk Formulae
F.W. Dobson, S.D. Smith
3. Newfoundland Basin Experiment
RA. Clarke, R.M. Hendry, E.P. Jones
4. Problems in Geophysical Fluid Dynamics
C. Quon
5. Norwegian/Greenland Sea Experiment
R.A. Clarke, E.P. Jones, J. Reid (Scripps), J. Swift (Scripps)
6. Studies of the North Atlantic Current and the Seaward Flow of Labrador Current Waters
J.R.N. Lazier
7. Ship of Opportunity Expendable Bathythermograph Programme for the Study of Heat Storage in the North Atlantic Ocean
F. Dobson
8. Data Management & Archival
D.N. Gregory
9. Eastern Arctic Physical Oceanography
C.K. Ross
10. Seasonal and Interannual Variability in the Gulf of St. Lawrence
G.L. Bugden
11. Tidal and Residual Currents - 3-D Modelling Studies
K.-T. Tee
12. CTD's and Associated Sensors
A.S. Bennett
13. Handling and Operational Techniques for Instrument/Cable Systems
J.-G. Dessureault, R.F. Reiniger
14. The Carbonate System & Nutrients in Arctic Regions
E.P. Jones
15. Intergyre Exchange: Flow Across 50°W South of the Grand Banks
R. Hendry
16. World Ocean Circulation Experiment (WOCE) Hydrographic Programme Sections
R.A. Clarke, R.M. Hendry, E.P. Jones, J.R.N. Lazier
17. CO, Exchange at the Air-Sea Interface
S.D. Smith, R. Anderson, F. Dobson, E.P. Jones
18. CTD System for Ship-of-Opportunity Program
J.-G. Dessureault, R.A. Clarke, B. Beanlands, S.W. Young
19. Turbulent Mixing Studies during the North Atlantic Tracer Release Experiment
N.S. Oakey, B.R. Ruddick
20. Development of Efficient Models for the Study of Long-Term Climate Variations
D.G. Wright, T.S. Stocker
21. Radar Viewing Mechanisms for Ocean Feature Mapping
B.J. Topliss, T.H. Guymer
22. Temperature/Salinity Chain Development
G.A. Fowler, R.A. Clarke
23. Sea Surface Temperature Climatologies: Insitu and Satellite
B. Topliss
24. Data Management/Analysis
A. Vromans
25. Toxic Chemicals Data Management
A. Vromans
26. Brander-Smith Sensitivity Mapping
A. Vromans

MARINE DEVELOPMENTS AND TRANSPORTATION

1. Oil Trajectory Analysis
D J. Lawrence, P.C. Smith
2. Winter Processes in the Gulf of St. Lawrence
G. Bugden
3. A Novel Vibracorer for Surface, Subsurface Remote, or ROV Support Operation
G. Fowler

OFFSHORE ENERGY RESOURCES

1. Labrador Coast Ice
S. Prinsenberg, I. Peterson
2. Wind Sea Dynamics
W. Perrie
3. Modelling of Ice and Icebergs Flowing along the Labrador and Baffin Island Coasts
M. Ikeda
4. A Large-Scale Circulation in the Labrador Sea and Baffin Bay
M. Ikeda
5. Labrador Ice Margin Studies
C. Tang, M. Ikeda
6. Oceanography of the Newfoundland Continental Shelf
B.D. Petrie
7. Study of Current Variability and Mixed Layer Dynamics on the Northeastern Grand Banks
C.L. Tang, B.D. Petrie
8. Anemometers for Drifting Buoys
J.-G. Dessureault, D. Harvey
9. Development of a Lagrangian Surface Drifter
D.L. McKeown
10. Horizontal and Vertical Exchange on Georges Bank
J. Loder, K. Drinkwater, E. Horne, N. Oakey
11. Oceanic CO_2
E.P. Jones
12 Wave-Wind Field Interactions
F. Dobson, S. Smith, W. Perrie
13 Oceanographic Data Management System
D. Gregory, G. Boudreau
14 Ocean Currents over Atlantic Canada Waters using Satellite Altimeters and Models
M. Ikeda
15 Development of an Ice-Resistant Mooring Assembly
G. Fowler, D. Belliveau, J. Hamilton
16 Development of Continuous Ocean

Data Acquisition Systems
D. Belliveau, J. Hamilton, G. Fowler

17. Development of a Platform for Atmospheric Data in Real Time (PADIRT)
J. Hamilton, G. Fowler, D. Belliveau
18. Sea Ice Flux onto Nfld. Shelves
S. Prinsenberg, I. Peterson
19. Cross-Shelf Exchange and Ice Motion on the Northern Grand Banks: The Oceanographic Component of the Canadian Atlantic Storms Program (CASP 11)
P. Smith, C. Tang, S. Prinsenberg, M. Ikeda
20. Development of Low-Cost Ice Beacon/ Instrumentation
G. Fowler, S. Prinsenberg, J. Hamilton
21. Three-Dimensional Circulation Model for the Gulf of Maine Region
J. Loder, D.A. Greenberg
22. Sea Ice Thickness
S. Prinsenberg
23. Impact Monitoring System (MIMS)
D. Belliveau
24. Data Assimilation and Remote Sensing in Ocean Wind Models
W. Perrie
25. Sea Ice Ablation Study
C. Tang
26. Ice Pressure in Mobile Pack Ice off the Canadian East Coast
S. Prinsenberg
27. Verification to Satellite Ocean Surface Information
F. Dobson
28. Assimilation of Satellite Remote Sensing Data into Sea Ice and Ocean Simulation
M. Ikeda
29. Study of Sea Ice Using ERS- 1 Data
C. Tang
30. Eastern Canada Climate Variation Related to Sea Ice
S. Prinsenberg, M. Ikeda
31. Coupling Ocean Wave Models to Operational Atmospheric Models
W. Perrie, B. Toulany
32. Predictive Circulation Model for the Atlantic Canadian Shelf
J. Loder, D. Greenberg

LIVING RESOURCES

1. Circulation off Southwest Nova Scotia: The Cape Sable Experiment
P.C. Smith, D. LeFaivre (Quebec), K. Tee, R. Trites
2. The Shelf Break Experiment: A Study of Low-Frequency Dynamics and Mixing at the Edge of the Scotian Shelf
P.C. Smith
3. Long-Term Temperature Monitoring
D. Gregory, B. Petrie, E. Verge
4. Development of a Remote Sensing Facility in Physical & Chemical Sciences Branch
C.S. Mason, B. Topliss, M. Stepanczak
5. Horizontal and Vertical Exchange on the Southeast Shoal of the Grand Bank
J.W. Loder, C.K. Ross
6. Optical Properties of Canadian Waters
B J. Topliss
7. Biological Arctic Instrumentation
A. Herman, M. Mitchell
8. Multi-Frequency Acoustic Scanning of Water Column
N.A. Cochrane
9. Effects of Hudson Bay Outflow on the Labrador Shelf
K. Drinkwater
10. Environmental Variability - Correlations, Patterns, and Response Scales
K. Drinkwater
11. Ocean Feature Identification via Multi-Spectral *In-Situ* and Remote Sensing Techniques
B. Topliss
12. Exchange between Offshore Waters and the Estuaries, Inlets, and Coastal Embayments of the Scotia-Fundy Region
G. Bugden
13. Physical Oceanography in Conjunction with the Phytoplankton Profiling Program
G. Bugden
14. Classification of Estuaries, Inlets, and Coastal Embayments
R.W. Trites, B.D. Petrie
15. Quoddy Region Oceanography
R.W. Trites
16. Halifax Harbour Studies
D J. Lawrence, B. Petrie
17. Advanced Technology Multifrequency Sonar
N.A. Cochrane
18. Development of Finite Element Models for Coastal and Shelf Circulation
D. Greenberg
19. Optical Microzooplankton Detector
A.W. Herman, E.F. Phillips, M. Mitchell, S. Young
20. Diagnosis of Current Measurement Problems with Aanderaa Paddle-Wheel Current Meters in High Flows
J.M. Hamilton, G.A. Fowler
21. The Temporal and Spatial Scales of Current Variability on Western Bank
K.F. Drinkwater, J.W. Loder, B. Sanderson (Memorial U), and K.R. Thompson (Dalhousie)
22. Climate Variability in the Water Mass Characteristics of the Shelf Waters in the Scotia-Fundy Region
K.F. Drinkwater, J.W. Loder, B.D. Petrie, P.C. Smith, D. Lawrence, F. Page (BSB), S. Smith (BSB)
23. Fibre Optic Fluorometer
M. Mitchell, A.W. Herman
24. Benthic Survey System: The Platform
D.L. McKeown
25. Long-Term Monitoring of Zooplankton / A Moored Optical Plankton Counter
A. Herman, D.D. Sameoto, N. Cochrane
26. Importance of Physical & Biological Processes to Population Regulation of Cod and Haddock on Georges Bank: A Model-Based Study
D. Lynch, F.E. Werner, J.W. Loder, M.M. Sinclair, R.G. Lough, R.I. Perry F.H. Page, D.A. Greenberg, P.C. Smith, W. W. Smith
27. Long-Term Variations of the Northern Section of the Nova Scotia Current
M.R. Mitchell, B. Petrie, K. Drinkwater, A. Herman, D. Sameoto, N. Cochrane

BIOLOGICAL OCEANOGRAPHY

1. Bio-Optical Properties of Pelagic Oceans
T. Platt
2. Nutrient Dynamics: Effects on Primary Production, Global Climate and Fisheries
W.G. Harrison, T. Platt, E. Horne, E. Head
3. Physical Oceanography of Selected Features in Connection with Marine Ecological Studies
E.P. Horne
4. Productivity of Marine Microorganisms
W. Li, P. Dickie
5. Carbon Dioxide and Climate: Bio

geochemical Cycles in the Ocean
T. Platt, W.G. Harrison

6. Secondary Production and the Dynamic Distribution of Micronekton in the Scotian Shelf
D. Sameoto, M. Kennedy
7. Biological Stratification in the Ocean and Global Carbon Flux
A. Longhurst
8. Copepods in Vertical Fluxes of Carbon and Pigments in the Ocean
E. Head
9. Dissolved Organic Carbon, Colloid Aggregation and Respiration
P. Kepkay, A. Boraie

IO. Monitoring the Biological Productivity of Canadian Atlantic Waters
T. Platt, W.G. Harrison, E. Head, E. Horne, W. Li, D. Sameoto

11. Carbon and Nitrogen Utilization of Zooplankton and Factors Controlling Secondary Production
R. Conover
12. Shore-Base Studies of Under-Ice Eponic and Pelagic Plankton Communities
R. Conover
13. Year-Round Plankton Research in the Arctic
R. Conover
14. Harmful Algal Blooms and the Management of their Effects
J. Smith
15. Indicators of the Biological Impacts of Toxic Contaminants
J. Smith
16. Physiological Ecology of Harmful Algal Blooms
P. Cormier-Murphy

1995

OCEAN CLIMATE SERVICES

1. Microstructure Studies in the Ocean
N.S. Oakey
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G.A. Fowler, R.A. Clarke
21. Sea Surface Temperature Climatologies: *In-situ* and Satellite
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J. Loder, K. Drinkwater, E. Horne, N. Oakey
11. Oceanic CO_2
E.P. Jones -
12. Wave-Wind Field Interactions
F. Dobson, S. Smith, W. Perrie
13. Oceanographic Data Management System
D. Gregory, G. Boudreau
14. Ocean Currents over Atlantic Canada Waters using Satellite Altimeters and Models
M. Ikeda
15. Development of an Ice-Resistant Mooring Assembly
G. Fowler, D. Belliveau, J. Hamilton
16. Development of Continuous Ocean Data Acquisition Systems
D. Belliveau, J. Hamilton, G. Fowler
17. Development of a Platform for

Atmospheric Data in Real Time (PADIRT)
J. Hamilton, G. Fowler, D. Belliveau

18. Sea Ice Flux onto Nfld. Shelves
S. Prinsenberg, I. Peterson
19. Cross-Shelf Exchange and Ice Motion on the Northern Grand Banks: The Oceanographic Component of the Canadian Atlantic Storms Program (CASP II)
P. Smith, C. Tang, S. Prinsenberg, M. Ikeda
20. Development of Low-Cost Ice Beacon/ Instrumentation
G. Fowler, S. Prinsenberg, J. Hamilton
21. Three-Dimensional Circulation Model for the Gulf of Maine Region
J. Loder, D.A. Greenberg
22. Sea Ice Thickness
S. Prinsenberg
23. Impact Monitoring System (MIMS)
D. Belliveau
24. Data Assimilation and Remote Sensing in Ocean Wind Models
W. Perrie
25. Sea Ice Ablation Study
C. Tang
26. Ice Pressure in Mobile Pack Ice off the Canadian East Coast
S. Prinsenberg
27. Verification to Satellite Ocean Surface Information
F. Dobson
28. Assimilation of Satellite Remote Sensing Data into Sea Ice and Ocean Simulation
M. Ikeda
29. Study of Sea Ice Using ERS-1 Data
C. Tang
30. Eastern Canada Climate Variation Related to Sea Ice
S. Prinsenberg, M. Ikeda
31. Coupling Ocean Wave Models to Operational Atmospheric Models
W. Perrie, B. Toulany
32. Predictive Circulation Model for the Atlantic Canadian Shelf
J. Loder, D. Greenberg

LIVING RESOURCES

1. The Shelf Break Experiment: A Study of Low-Frequency Dynamics and Mixing at the Edge of the Scotian Shelf
P.C. Smith
2. Long-Term Temperature Monitoring
D. Gregory, B. Petrie, E. Verge
3. Development of a Remote Sensing Facility in Physical & Chemical Sciences Branch
C.S. Mason, B. Topliss, M. Stepanczak
4. Horizontal and Vertical Exchange on the Southeast Shoal of the Grand Bank
J.W. Loder, C.K. Ross
5. Optical Properties of Canadian Waters
B J. Topliss
6. Multi-Frequency Acoustic Scanning of Water Column
N.A. Cochrane
7. Effects of Hudson Bay Outflow on the Labrador Shelf
K. Drinkwater
8. Environmental Variability - Correlations, Patterns, and Response Scales
K. Drinkwater
9. Ocean Feature Identification via Multi-Spectral *In-Situ* and Remote Sensing Techniques
B Topliss
10. Exchange between Offshore Waters and the Estuaries, Inlets, and Coastal Embayments of the Scotia-Fundy Region
G. Bugden
11. Physical Oceanography in Conjunction with the Phytoplankton Profiling Program
G. Bugden
12. Classification of Estuaries, Inlets, and Coastal Embayments
R.W. Trites, B.D, Petrie
13. Halifax Harbour Studies
D J. Lawrence, B. Petrie
14. Advanced Technology Multifrequency Sonar
N.A. Cochrane
15. Development of Finite Element Models for Coastal and Shelf Circulation
D. Greenberg
16. Optical Microzooplankton Detector
A.W. Herman, E.F. Phillips, M. Mitchell, S. Young
17. Diagnosis of Current Measurement Problems with Aanderaa Paddle-Wheel Current Meters in High Flows
J.M. Hamilton, G.A. Fowler
18. The Temporal and Spatial Scales of Current Variability on Western Bank
K.F. Drinkwater, J.W. Loder, B. Sanderson (Memorial U), and K.R. Thompson (Dalhousie)
19. Climate Variability in the Water Mass Characteristics of the Shelf Waters in the Scotia-Fundy Region
K.F. Drinkwater, J.W. Loder, B.D. Petrie, P.C. Smith, D. Lawrence, F. Page (BSB), S. Smith (BSB)
20. Fibre Optic Fluorometer
M. Mitchell, A.W. Herman
21. Benthic Survey System: The Platform
D.L. McKeown
22. Long-Term Monitoring of Zooplankton /A Moored Optical Plankton Counter
A. Herman, D.D. Sameoto, N. Cochrane
23. Importance of Physical & Biological Processes to Population Regulation of Cod and Haddock on Georges Bank: A Model-Based Study
D. Lynch, F.E. Werner, J.W. Loder, M.M. Sinclair, R.G. Lough, R.I. Perry, F.H. Page, D.A. Greenberg, P.C. Smith, W. W. Smith
24. Long-Term Variations of the Northern Section of the Nova Scotia Current
M.R. Mitchell, B. Petrie, K. Drinkwater, A. Herman, D. Sameoto, N. Cochrane
25. The Water Circulation of Inlets
K.-T. Tee, B. Petrie, and J. Wang

BIOLOGICAL OCEANOGRAPHY

1. Bio-Optical Properties of Pelagic Oceans
T. Platt
2. Nutrient Dynamics: Effects on Primary Production, Global Climate and Fisheries
W.G. Harrison, T. Platt, E. Horne, E. Head
3. Physical Oceanography of Selected Features in Connection with Marine Ecological Studies
E.P. Horne
4. Productivity of Marine Microorganisms
W. Li, P. Dickie
5. Carbon Dioxide and climate: Biogeochemical Cycles in the Ocean
T. Platt, W.G. Harrison
6. Secondary Production and the Dynamic Distribution of Micronekton in the Scotian Shelf
D. Sameoto, M. Kennedy
7. Biological Stratification in the Ocean and Global Carbon Flux
T. Platt

8. Copepods in Vertical Fluxes of Carbon and Pigments in the Ocean
E. Head
9. Dissolved Organic Carbon, Colloid Aggregation and Respiration
P. Kepkay, A. Boraie
10. Monitoring the Biological Productivity of Canadian Atlantic Waters
T. Platt, W.G. Harrison, E. Head, E. Horne, W. Li, D. Sameoto
11. Environmental Effects on Biological Production in the Gulf of St. Lawrence
J. Smith
12. Biological Productivity
P. Cormier-Murphy

ENVIRONMENT CANADA

ENVIRONMENTAL CONSERVATION BRANCH
ENVIRONMENTAL QUALITY LABORATORY, BIO

1994

1. Industrial compliance/enforcement monitoring - *Fisheries Act.*
K. Doe, O. Vaidya, P. Hennigar.
2. Ocean dumpsite monitoring (New Brunswick and Quebec).
K. Doe, K. Tay (EPS).
3. Oil spill bioremediation experiment.
K. Doe, K. Lee (DFO).
4. Toxicity of oil spill treating agents.
A. Huybers, K. Doe.
5. Toxicity test methods R&D - Polychaete worms as test organisms.
K. Doe, P. Pocklington, M. Pocklington.
6. Metals in shellfish tissue - Gulfwatch.
O. Vaidya.
7. Mercury distribution in peat bogs.
O. Vaidya.
8. US-Canada Gulf of Maine mussel watch “Gulfwatch” project: Provision of PAH, PCB and pesticide data to the Gulf of Maine Environmental Monitoring Committee, data interpretation; QA support; and report preparation.
9. Oil Identification: Oil spill chemical identification and matching service in support of EC and CCG spill investigations and legal prosecutions under the FA and the Canada Shipping Act.
10. Quality Assurance Guidelines: Development of analytical QA/QC guidelines for the Canadian Shellfish Contaminants Monitoring program and the Ocean Disposal program.

1995

1. Industrial compliance/enforcement monitoring - *Fisheries Act.*
K. Doe, O. Vaidya, P. Hennigar.
2. Toxic effects of chlorobenzenes in sediments.
K. Doe, D. Vaughan, S. Wade, A. Huybers.
3. Pollution Gradient Study, Belledune, N.B.
K. Doe, S. Wade, A. Huybers, G. Wohlgeschaffen.
4. Biological effects of fluoride in marine sediments.
K. Doe, S. Wade, A. Huybers, G. Wohlgeschaffen.
5. Determination of oil and grease using tetrachloroethylene: An Interlaboratory Comparison Study.
O. Vaidya.
6. Determination of metals in mussels, a comparative study of analytical methods.
O. Vaidya, R. Rantala (DFO).
7. Mercury in fish tissues from Nova Scotia.
B. Horne, O. Vaidya.
8. Metals in shellfish tissue - Gulfwatch.
O. Vaidya.
9. *Irving Whale* Raising Project: Provision to project management of scientific and technical information on the physical and chemical proper ties of bunker oil, PCBs, chloroben zene, chlorinated dioxin and furans; sediment and biota chemical data; assessment of environmental levels of PCBs and other contaminants near the Whale site and project quality assurance support.
10. US-Canada Gulf of Maine mussel watch “Gulfwatch” project: Provision of PAH, PCB and pesticide data to the Gulf of Maine Environmental Monitoring Committee, data interpretation; QA support; and report preparation.
11. Quality Assurance Guidelines: Development of analytical QAQC guidelines for the Canadian Shellfish Contaminants Monitoring program and the Ocean Disposal program.

GEOLOGICALSURVEY OF CANADA (ATLANTIC)

COASTAL GEOLOGY PROGRAM

1. Beaufort Sea Coastal Zone Geotechnics
S. Solomon
2. Geological *Mapping* of the Coastal Zone
R. Taylor
3. Sediment Dynamics and Depositional Processes in the Costal Zone
D. Forbes
4. Relative Sea-level Changes and Coastal Response
J. Shaw
5. Nearshore Sediments and Non-Fuel Minerals - Nova Scotia MDA 2
G. Fader
6. Coastal and Marine Proxy Data
J. Syvitski
7. Fraser Delta Studies
H. Christian

GEOLOGY OF THE SOUTHEASTERN CANADIAN MARGIN

1. Surficial and Shallow Bedrock Geology of Grand Banks and Scotian Shelf
G. Fader
2. Engineering Geology of the Atlantic Shelf
R. Parrott
3. Ice Scouring of Continental Shelves
M. Lewis
4. Physical Property Studies of Canadian Eastern and Arctic Continental Shelves and Slopes
K. Moran
5. Quaternary Geological Processes on Continental Slopes
D. Piper
6. Stability and Transport of Sediments on Continental Shelves
c. Amos

EASTERN ARCTIC AND SUB-ARCTIC GEOLOGY

1. Eastern Baffin Island Shelf and Hudson Strait: Bedrock and Surficial Geological Mapping Pro-gram
B. MacLean
2. Quantitative Quaternary Paleoecology, Eastern Canada
P. Mudie
3. Surficial Geology, Geomorphology.and Glaciology of the Gulf of St. Lawrence, Labrador Shelf and Hudson Bay
H. Josenhans

WESTERN ARCTIC GEOLOGY

1. Surficial Geology and Geomorphology, Beaufort Sea Continental Shelf
   S. Blasco

GEOCHEMISTRY

1. Diagenesis and Geochemical Cycling
   R. Cranston
2. Early Diagenesis in Quaternary Marine Sediments of Eastern and Arctic Canada
   D. Buckley
3. Environmental Marine Geology of Halifax Inlet and Approaches, Nova Scotia
   D. Buckley

REGIONAL GEOPHYSICAL SURVEYS

1. Interpretation of Potential Field Data
   J. Verhoef
2. Magnetic and Gravity Anomalies over Sedimentary Basins
   B. Loncarevic
3. Magnetic Data Compilations
   R. Macnab
4. Regional Geophysics of Mesozoic-Cenozoic of Newfoundland Margin
   K. Coflin
5. Evolution of Continental Margins
   G. Bassi

HYDROCARBON RESOURCE APPRAISAL

1. Hydrocarbon Inventory of Sedimentary Basins of Eastern Canada
   D. McAlpine
2. Maturation Studies
   D. McAlpine

BIOSTRATIGRAPHY

1. Biostratigraphic Zonation of the Mesozoic and Cenozoic Rocks of the Atlantic Shelf
   P. Ascoli

QUANTITATIVE DATABASES

1. Sample and Data Curation
   I. Hardy

GEOLOGICALTECHNOLOGY DEVELOPMENT

1. Large Diameter Piston Corer Development
   W. McKinnon
2. Development and Implementationof Remotely Operated Vehicle Technology
   K. Manchester
3. Systems Development
   D. Heffler

SPECIAL GEOLOGICAL PROJECTS

1. Basin Atlases - Offshore Eastern Canada
   D. Ross
2. Bedrock Geology of Hudson Bay and Gulf of St. Lawrence
   A. Grant
3. Appalachian Initiative
   P. Giles

INVESTIGATION OF DEEP GEOLOGICAL STRUCTURES

1. Evolution of Deep Ocean and Adjoining Sedimentary Basins off Eastern Canada and Western Greenland
   S. Srivastava
2. Crustal Properties
   M. Salisbury
3. Geophysical Study of the Gulf of St. Lawrence Region
   F. Marillier
4. Marine Deep Seismic Reflection Studies - Eastern Canada
   C. Keen
5. Seismic Refraction - Labrador Sea and Baffin Bay
   R. Jackson
6. Dynamic Modelling of Canadian Cratonic Basins -Western Canada and Hudson Basins
   R. Courtney

THEORETICAL GEOPHYSICAL MODELLING

1. Rift Processes and the Development of Passive Continental Margins
   C. Keen

BASIN ANALYSIS AND PETROLEUM GEOLOGY

1. Palynostratigraphic Atlases
   R. Fensome
2. Regional Geology of the Mesozoic and Cenozoic Rocks of the Atlantic Continental Margins
   J. Wade
3. Stratigraphy and Sedimentology of the Mesozoic and Tertiary Rocks of Atlantic Continental Margin
   L. Jansa
4. Sedimentary Basin Evolution of the Continental Margin of Newfoundland, Labrador and Baffin Bay
   D. McAlpine
5. Hydrocarbon Charge Modelling Offshore Eastern Canada
   M. Williamson

Voyages

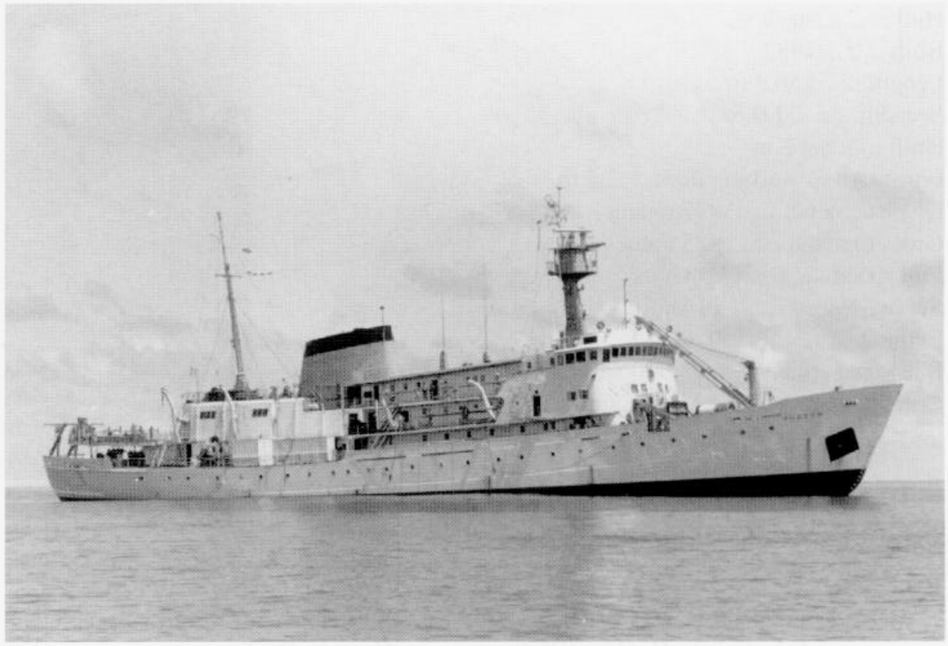
This section describes the vessels that the federal Department of Fisheries and Oceans (DFO), Maritimes Region, operates for the purpose of scientific research and hydrographic surveys. It also lists the voyages that these vessels made during 1994 and 1995, and the nature of the research carried out. Voyages on vessels not operated by the department but which involved scientific personnel from DFO's Maritimes Region are included as well.

In the following pages, these abbreviations are used:

ADCP	Acoustic Doppler Current Profiler
AGC	Atlantic Geoscience Center
BSB	Biological Sciences Branch, Maritimes Region
CHS	Hydrography Branch, Canadian Hydrographic Service
CM	Anchored sub-surface current meter
CTD	Conductivity-Temperature-Pressure profiler
FHM	Fisheries and Habitat Management Maritimes Region
JGOFS	Joint Global Ocean Flux Study
Mun	Memorial University of Newfoundland
NAFO	North Atlantic Fisheries Organization
NCSP	Northern Cod Science Program
Nfld	Department of Fisheries and Oceans, Newfoundland Region
PCS	Physical and Chemical Sciences Branch, Maritimes Region
Que	Department of Fisheries and Oceans, Quebec Region
SAR	Synthetic Aperture Radar
WOCE	World Ocean Circulation Experiment

C.S.S. *HUDSON*

is a diesel-electric powered ship designed and used for multi-disciplinary marine science research. The ship is owned by DFO and is operated by the department's Maritimes Region. The Geological Survey, Atlantic of Natural Resources Canada is a major user of this vessel.



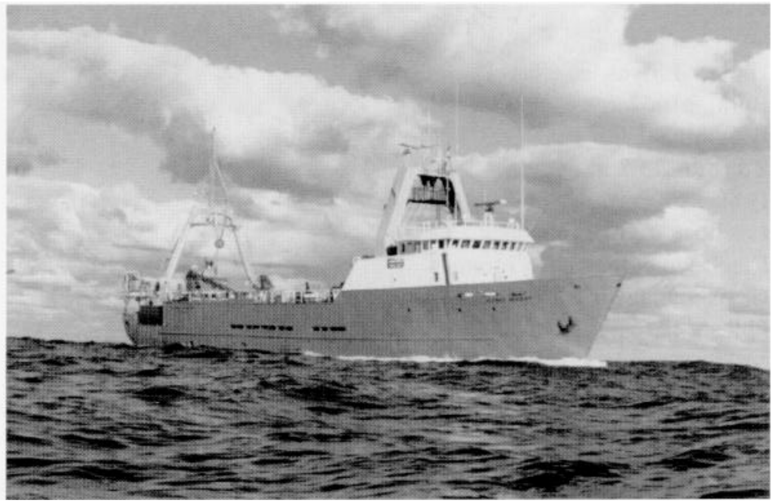
Hull . . . . . . Lloyds Ice Class I
Built 1962
Length . . . 90.4 m
Breadth . . 15.2 m
Draft . . . . 6.3 m
Freeboard to working deck . . 3.2 m
Displacement . . . . 4847 tonnes
Gross tonnage . . . . 3721 tonnes
Full speed . . . . 17 knots
Service Speed . . . 13 knots
Endurance . . . . 80 days
Range at service speed 23,000 naut.mi.
Complement . . . . 31 scientific staff
Twin screws
Bow thruster for holding position
Computer system
Heliport and hangar
205 m^2 of laboratory space
Four survey launches

Year & Number	Voyage Dates	Person-in-charge	Area of Operation	Objectives of Voyage
1994				
94-002	2 May- 13 May	E. Colbourne(NFLD)	Nfld Shelf	Physics
94-008	24 May- 12 Jun	J. Lazier (BIO)	Hamilton Bank/Lab. Sea	Physics/JGOFS Biol.
94-016	3 June- 30 June	G. Ingram/JC.Therriault (McGill/IML)	Gulf of St. Lawrence	Physics/JGOFS Biol.
94-017	2 Jul- 22 Jul	S. Narayanan (NFLD)	Grand Banks	Physics
94-027	15 Aug- 2 Sept	A. Grant (GSC-A)	Laurentian Tr.	Geophysics
94-021	6 Sept- 7 Oct	G. Sonnichsen (GSC-A)	Laurentian Tr.	Geophysics
94-030	12 Oct- 10 Nov	A. Clarke (BIO)	Nfld. Basin	WOCE Physics
94-032	15 Nov- 25 Nov	G. Fader (GSC-A)	Scotian Shelf	Geophysics
1995				
95-003	19 Apr- 17 May	A. Clarke (BIO)	NFLD Basin	WOCE Physics
95-006	23 May- 3 Jun	H. Josenhans (GSCA)	Cabot Strait	Geophysics
95-011	8 Jun- 4 Jul	A. Clarke (BIO)	Labrador Sea	WOCE Physics
95-016	6 Jul- 23 Jul	T. Platt (BIO)	Labrador Sea	JGOFS Biology
95-020	9 Aug- 5 Oct	E. Brown (CHSC)	Rankin Inlet	Hydrography
95-030	14 Oct- 6 Nov	G. Fader/R.Courtney (GSCA)	Bay of Fundy/Scotian S.	Geophysics
95-033	15 Nov - 8 Dec	D. Piper/C. Amos (GSCA)	Grand Banks/Gulf	Geophysics

C.S.S. *ALFRED NEEDLER*

is a diesel-powered stern trawler owned by DFO. It is operated by the department's Maritimes Region and is used for fisheries research including acoustics, juvenile fish ecology, and recruitment studies.

Hull . . . . steel
Built 1982
Length . . . . 50.3 m
Breadth . . . . 11.0 m
Draft . . . . 4.8 m
Freeboard to working deck . . . . 2.5 m
Displacement . . . . 877 tonnes
Gross tonnage . . . . 925 tonnes
Full speed . . . . 13.5 knots
Service Speed . . . . 12 knots
Endurance . . . . 30 days
Range at service speed 3.000 naut. mi.
Complement . . . . . . 10 scientific staff



Year & Number	Voyage Dates	Person-in-charge	Area of Operation	Objective\ of Voyage
1994				
93-197	5 Jan- 24 Jan	C. LeBlanc (GFC)	S. Gulf of St. Lawrence	Herring/Cod Biomass
93-200	15 Feb- 25 Feb	J. Hunt (BIO)	Georges Bank	Groundfish Survey
93-201	26 Feb- 10 Mar	R. Mohn (BIO)	4VsW	Groundfish Survey
93-202	14 Mar- 26 Mar	E. Trippel (BIO)	Georges Bank	Acoustics/ Cod Trawl
94-220	6 May- 12 May	M. Showell (BIO)	Scotian Shelf	ICP Training
94-205	16 May- 20 May	F. MacLellan (BIO)	Sable Is.	Fish sampling
94-203	24 May- 26 May	B .Nichols(GSCA)	Bedford Basin	Gear Trials
94-206	6 Jun- 8 Jun	M. Strong (SABS)	Scotian Shelf	Gear Trials
94-208	9 Jun- 13 Jun	M. Showell (BIO)	Scotian Shelf	ICP Training
94-204	13 Jun- 28 Jun	F. Gregoire (IML)	Gulf of St. Lawrence	Groundfish Survey
94-207	29 Jun- 30 Jun	J. McRuer (BIO)	Scotian Shelf	Gear Trials
94-221	4 Jul- 15 Jul	J. Hunt (BIO)	Gulf of Maine	Groundfish Survey
94-221	18 Jul- 29 Jul	J. Hunt (BIO)	Gulf of Maine	Groundfish Survey
94-219	1 Aug- 12 Aug	G. Robert (BIO)	Georges Bank	Scallop Survey
94-209	16 Aug- 9 Sept	Frechette (IML)	Northern Gulf of St. Lawr.	Shrimp/Groundfish Survey
94-210	10 Sept- 1 Oct	DSwain (GFC)	S. Gulf of St. Lawrence	Groundfish Survey
94-223	4 Oct- 6 Oct	M. Strong (SABS)	Scotian Shelf	Gear Trials
94-212	14 Oct- 31 Oct	M. Showell (BIO)	Scotian Shelf	IYGPT Survey
94-211	1 Nov- 15 Nov	R. Stephenson (SABS)	Scotian Shelf	Herring larvae Survey
94-213	16 Nov- 29 Nov	G. Melvin (SABS)	Georges Bank	Herring Survey
94-218	30 Nov- 11 Dec	C. Leblanc (GFC)	Chaleur Bay	Juv. Herring Survey
1995				
94-214	10 Jan- 29 Jan	G. Chouinard (GFC)	Cabot Strait	Herring/Cod Biomass
94-215	20 Jan- 3 Feb	D. Marcogliese (IML)	Sable Island	Sealworm Studies
94-216	16 Feb- 24 Feb	J. Hunt (BIO)	Georges Bank	Groundfish Survey
94-217	26 Feb- 12 Mar	R. Mohn (BIO)	4VsW	Groundfish Survey
95-223	19 Apr- 22 Apr	M. Showell (BIO)	Scotian Shelf	Observer Training
95-225	21 Jun- 22 Jun	J.McRuer (BIO)	Emerald Basin	Equipment Trials
95-226	26 Jun- 7 Jul	J. Hunt (BIO)	Scotian Shelf	Groundfish Survey
95-227	9 Jul- 20 Jul	J. Hunt (BIO)	Scotian Shelf	Groundfish Survey
95-229	5 Aug- 6 Sept	Frechet/F.Gregoire (IML)	Gulf of St. Lawrence	Shrimp/Groundfish Surv.
95-230	7 Sept- 1 Oct	D. Swain/MacLellan (SABS/BIO)	Gulf of St. Lawrence	Groundfish Survey

95-231	13 Oct- 30 Oct	M. Showell (BIO)	Scotian Shelf	Silver Hake Survey
95-232	31 Oct- 13 Nov	R. Stephenson (SABS)	Bay of Fundy	Herring Studies
95-233	15 Nov- 28 Nov	G. Melvin (SABS)	Georges Bank	Herring Studies
95-234	4 Dec- 15 Dec	C. Leblanc (GFC)	Gulf of St. Lawrence	Herring Studies

C.S.S. *MATTHEW*

is a multi-disciplinary science vessel primarily used by the Canadian Hydrographic Service. The vessel is owned by DFO and is operated by the Maritimes Region.

Hull . . . . steel
Built 1990
Length . . . . 51.2 m
Breadth . . . . 10.5 m
Draft . . . . 3.2 m
Freeboard to working deck . . . 1.1 m
Displacement . . . . 745 tonnes
Gross tonnage . . . . . . 857 tonnes
Full speed . . . . 12 knots
Service speed . . . . 10 knots
Endurance . . . . . . 20 days
Range at service speed . . . 4.000 naut. mi.
Complement . . 7 scientific staff
EM100
Autopilot
Various positioning systems

Year & Number	Voyage Dates	Person-in-charge	Area of Operation	Objectives of Voyage
1994				
94-026	25 Apr- 3 Jun	CHS (BIO)	Scotian Shelf	Hydrography
94-004	7 Jun- 14 Jul	CHS(BI0)	Notre Dame Bay	Hydrography
94-004	12 Aug- 2 Sept	CHS(BI0)	Labrador Coast	Hydrography
94-004	6 Sept- 14 Oct	CHS(BI0)	Bonavista Bay	Hydrography
94-042	17 Oct- 28 Oct	B. Loncarevic (GSCA)	Scotian Shelf	Geophysics
1995				
95-004	27 Apr- 7 Jun	D. Blaney (BIO)	SE Coast of Newfoundland	Hydrography
95-014	23 Jun- 14 Jul	R. Sterling (BIO)	Bonavista Bay	Hydrography
95-021	9 Aug- 15 Sept	G. Henderson (BIO)	Labrador Coast	Hydrography
95-026	19 Sept- 27 Oct	D. Blaney (BIO)	S. Coast of Newfoundland	Hydrography

C.S.S. *PARIZEAU*

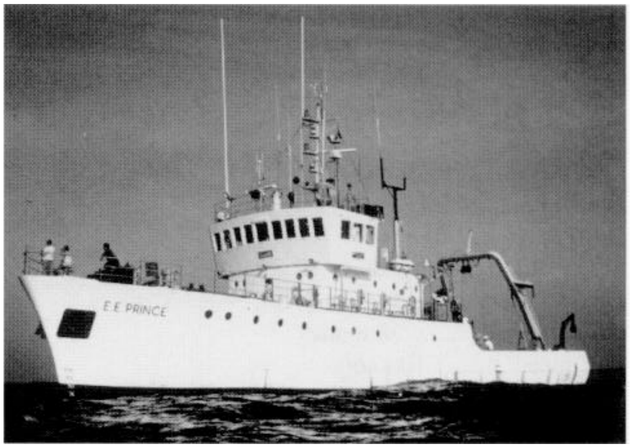
is a diesel driven ship designed and used for multi-disciplinary oceanographic research, hydrographic surveying and handling of moorings in deep and shallow water. The ship is owned by DFO and is operated by the department's Maritimes Region.

Hull . . . . steel
Built 1967
Length . . . . 64.6 m
Breadth . . . . 12.2 m
Draft . . . . 4.6 m
Freeboard to working deck . . . 1.5 m
Displacement . . . . 2047.6 tonnes
Gross tonnage . . . . 1359.5 tonnes
Full speed . . . . 14 knots
Service speed . . . . 12 knots
Endurance . . . . 45 days
Range at service speed . . . 11,000 naut. mi.
Complement . . . 13 scientific staff
Twin screws, variable pitch
Bow thruster for holding position
Computer suite
65 m^2 working space in two laboratories

Year & Number	Voyage Dates	Person-in-charge	Area of Operation	Objectives of Voyage
1994				
94-001	11 Apr- 15 Apr	K. Muschenheim (BIO)	Sable Island	Particle Dynamics
94-007	18 Apr- 2 May	J.Gagne/Castonguay (IML)	Gulf of St. Lawrence	Gear Trials
94-012	3 May- 20 May	P.Quellet/D.D'Amours (IML)	Gulf of St. Lawrence	Cod Larvea studies
94-005	25 May- 2 Jun	M. Mitchell (BIO)	Scotian Shelf	GLOBEC physics
94-009	6 Jun- 11 Jun	D. Sameoto (BIO)	Scotian Shelf	Zooplankton
94-011	14 Jun- 23 Jun	D. Belliveau (BIO)	Emerald Basin	Equipment Trials
94-018	24 Jun- 30 Jun	P. Smith (BIO)	Georges Bank	GLOBEC Physics
94-015	4 Jul- 21 Jul	T. Rowell (BIO)	Grand Banks	Trawl Impact Studies
94-028	20 Aug- 30 Aug	Simard (IML)	Gulf of St. Lawrence	Biology
94-037	1 Sept- 9 Sept	Rouge (IML)	Gulf of St. Lawrence	Krill studies
94-036	10 Sept- 17 Sept	LeBeuf (IML)	Gulf of St. Lawrence	Contaminants
94-038	19 Sept- 7 Oct	J. Gagne (IML)	Gulf of St. Lawrence	Cod Studies
94-035	11 Oct- 20 Oct	E. Colbourne (NFLD)	Nfld Shelf	Physics
94-029	24 Oct- 4 Nov	S. Niven (BIO)	Scotian Shelf	Particle Chemistry
94-033	14 Nov- 29 Nov	G. Bugden (BIO)	Gulf of St. Lawrence	Ice Forecast Physics
94-034	30 Nov- 14 Dec	F. Dobson (BIO)	Grand Banks	PERD Physics
1995				
95-001	4 Apr- 7 Apr	D. Moore(NSERC)	Scotian Shelf	Equipment Trials
95-002	18 Apr- 29 Apr	M. Mitchell (BIO)	Scotian Shelf	GLOBEC Physics
95-007	23 May- 28 May	D. Belliveau (BIO)	Scotian Shelf	Equipment Trials
95-007	30 May- 1 June	T. Rowell (BIO)	Georges Bank	Equipment Trials
95-010	6 Jun- 13 Jun	P. Smith (BIO)	Georges Bank	GLOBEC Physics
95-013	19 Jun- 12 Jun	T. Rowell (BIO)	Grand Banks	Trawl Impact Studies
95-017	13 Jul- 2 Aug	S. Narayanan (NFLD)	Grand Banks	Physics
95-018	3 Aug- 4 Aug	G. Fader (GSCA)	Halifax Harbour	Geophysics
95-022	21 Aug- 8 Sept	J. Gagne (IML)	Gulf of St. Lawrence	Cod Studies
95-024	9 Sept- 18 Sept	J. Therriault (IML)	Gulf of St. Lawrence	JGOFS
95-027	19 Sept- 29 Sep	J. Runge (IML)	Gulf of St. Lawrence	Krill Studies
95-028	10 Oct- 18 Oct	D. Sameoto (BIO)	Scotian Shelf	Zooplankton Studies
95-031	20 Oct- 9 Nov	P. Galbraith (IML)	Gulf of St. Lawrence	Physics
95-032	14 Nov- 21 Nov	G. Bugden (BIO)	Gulf of St. Lawrence	Ice Forecast Physics
95-034	24 Nov- 3 Dec	P. Smith (BIO)	Georges Bank	GLOBEC Physics

C.S.S. *E.E. PRINCE*

is a stern trawler used for fisheries research including experimental and exploratory fishing and resource surveys. The ship is owned by DFO and is operated by the department's Maritimes Region.



Hull . . . . steel
Built 1966
Length . . . . 39.6 m
Draft . . . . 3.65 m
Freeboard to working deck . . 0.7 m
Displacement . . . . 580 tonnes
Gross tonnage . . . . 406 tonnes
Full speed . . . . 10.5 knots
Service speed . . . . 10 knots
Endurance . . . . 14 days
Range at service speed . . . . 3.000 naut. mi.
Complement . . . . 6 scientific staff

Year & Number	Voyage Dates	Person-in-charge	Area of Operation	Objectives of Voyage
1994				
94-454	24 Feb- 3 Mar	G.Robert (BIO)	Scotian Shelf	Scallop Survey

C.S.S. *NAVICULA*

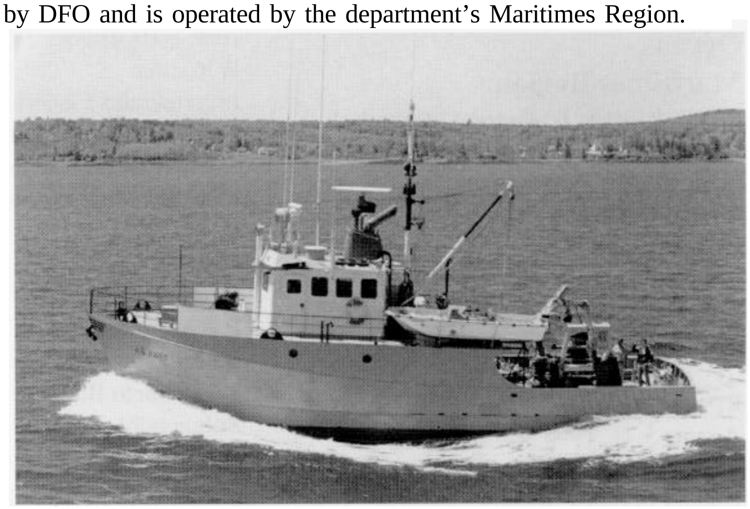
is a fishing vessel owned by DFO. It is operated by the department's Maritimes Region and is used for biological oceanographic research in the near shore coastal ocean.

Hull . . . . wood
Built 1968
Length . . . . 19.8 m
Breadth . . . . 5.85 m
Draft . . . . 3.25 m
Freeboard to working deck . . 2.5 m
Displacement . . . . 104 tonnes
Gross tonnage . . . . . . 78 tonnes
Full speed . . . . 10 knots
Service speed . . . . 9 knots
Endurance . . . . 8-10 hours
Range at service speed . . . 1,000 naut. mi.
Complement . . . . 3 scientific staff

Year & Number	Voyage Dates	Person-in-charge	Area of Operation	Objectives of Voyage
1994				
94-019	3- May	J. Vandermeulen (BIO)	Bedford Basin	Hydrocarbon pollution
94-006	16 May- 31 May	C. Amos (GSCA)	Miramichi Bay	Sediment Dynamics
94-010	1 Jun- 6 Jun	D. Willis (BIO)	Cape Breton	Hydrocarbon Biochemistry
94-010	18 Jun- 21 Jun	D. Willis (BIO)	Cape Breton	Hydrocarbon Biochemistry
94-020	2 Aug- 21 Aug	J. Smith (GFC)	Cape Breton	Microbiology
94-022	22 Aug- 30 Aug	D. Willis (BIO)	PEI Coastal Waters	Hydrocarbon Biochemistry
94-024	6 Sept- 10 Sept	J. Smith (GFC)	Southern Gulf of St. Lawr.	Microbiology
94-025	12 Sept- 21 Sept	T. Lambert (BIO)	Cape Breton	Groundfish Surveys
94-031	22 Sept- 30 Sept	D. Willis (BIO)	Sidney Bight	Hydrocarbon Biochemistry
94-041	1 Oct- 16 Oct	J. Vandermeulen (BIO)	Georges Bay/ Sidney B.	Hydrocarbon Pollution
94-040	17 Oct- 25 Oct	D. Willis (BIO)	Lunenburg/Shelburne	MFO Studies
94-043	1 Nov- 8 Nov	J. Smith (GFC)	Gulf of St. Lawrence	Microbiology
1995				
95-009	29 May- 14 Jun	D. Willis (BIO)	Sidney Bight/Georges Bay	Pollution Monitoring
95-012	15 Jun- 28 Jun	T. Lambert (BIO)	Sidney Bight	Trawling
95-015	29 Jun- 9 Jul	J. Smith (GFC)	Gulf of St. Lawrence	Toxicology
95-019	8 Aug- 17 Aug	J. Smith (GFC)	Gulf of St. Lawrence	Toxicology
95-023	5 Sept- 15 Sept	J. Smith (GFC)	Gulf of St. Lawrence	Toxicology
95-025	18 Sept- 5 Oct	T. Lambert (BIO)	Sidney Bight	Trawling
95-029	10 Oct- 20 Oct	J. Smith (GFC)	Gulf of St. Lawrence	Toxicology
95-035	23 Oct- 27 Oct	D. Mossman (BIO)	St. Margaret's Bay	Winter Flounder

JL HART

is a stem trawler used for fisheries research, including light trawling operations (bottom and midwater), ichthyoplankton surveys, oceanographic sampling. and scientific gear testing. The ship is owned by DFO and is operated by the department's Maritimes Region.



Hull . . . . steel
Built 1974
Length . . . . 19.8 m
Breadth . . . . 6.1 m
Draft . . . . 3.65 m
Freeboard to working deck . . 0.5 m
Displacement . . . . 109 tonnes
Gross tonnage . . . . 89.5 tonnes
Full speed . . . . 10 knots
Service speed . . . . 8.5 knots
Endurance . . . . 7.5 days
Range at service speed . . . 2,000 naut. mi.
Complement . . . . 3 scientific staff

Year & Number	Voyage Dates	Person-in-charge	Area of Operation	Objectives of Voyage
1994				
94-131	18 May- 1 Jun	G. Fader (GSCA)	Cape Breton	Geophysics
94-132	5 Jun- 24 Jun	E. Kenchington (BIO)	Digby	Scallops Studies
94-133	27 Jun- 15 Jul	B. Waiwood (SABS)	St. Marys Bay	Biol. Sampling
94-134	20 Jul- 5 Aug	S. Robinson (SABS)	Passamaquoddy	Scallops Studies
94-136	8 Aug- 11 Aug	R. Stephenson (SABS)	Passamaquoddy	
94-131	15 Aug- 2 Sept	E. Kenchington (BIO)	Lurcher Shoal	Scallops
94-140	7-Sep	K. Manchester (GSCA)	Halifax Harbour	Geophysics
94-138	14 Sept- 7 Oct	J. Shaw (GSCA)	SW Nfld/Canso	Geophysics
94-139	12 Oct- 1 Nov	C. LeBlanc (GFC)	Gulf of St. Lawrence	Herring Studies
1995				
95-140	23 May- 6 Jun	C. Amos (GSCA)	Lunenburg Harbour	Geology
95-141	7 Jun- 13 Jun	R. Stephenson (SABS)	Passamaquoddy Bay	Plankton Studies
95-142	14 Jun- 30 Jun	E. Kenchington (BIO)	Bay of Fundy	Scallops Studies
95-143	4 Jul- 11 Jul	H. Madill (NBDF)	Southwest Shelf	Haddock Broodstock
95-144	13 Jul- 26 Jul	G. Melvin (SABS)	Scots Bay	Herring Studies
95-145	27 Jul- 5 Aug	S. Robinson(SABS)	Passamaquoddy Bay	Scallops Studies
95-146	8 Aug- 17 Aug	D. Willis (BIO)	St. John Harbour	Pollution Studies
95-148	21 Aug- 8 Sept	E. Kenchington (BIO)	Brier Island	Scallops
95-149	12 Sept- 21 Sept	G. Fader (GSCA)	Shelbourne Harbour	Geology
95-150	25 Sept- 5 Oct	H. Madill (NBDF)	Bay of Fundy	Scallop Studies
95-151	7 Oct- 13 Oct	P. Lawton (SABS)	Bay of Fundy	Lobster Studies
95-1.52	16 Oct- 20 Oct	G. Melvin (SABS)	Grand Manaan	Herring Tagging
95-153	21 Oct- 27 Oct	H. Madill (NBDF)	SE Bank	Hand lining

Participation in Other Research Cruises

Department of Fisheries and Oceans
Maritimes Region

CCGS *Louis S. St. Laurent* (Canada)
July 17 to September 9, 1994
K.M. Ellis, R.W.P. Nelson
Marine Chemistry Section
Arctic Ocean
Collection of sediment and water samples from the Arctic Ocean for measurement of artificial and natural radioactivity

R/V *Onrust* (United States)
August 5 - 11, 1995
T.G. Milligan
Habitat Ecology Section
Hudson River Estuary
Hudson River Estuary sediment study

CCGS *Louis S. St. Laurent* (Canada)
August 18 to September 8, 1995
R.W.P. Nelson, J.H. Abriel
Marine Chemistry Section
Arctic Ocean
Collection of sediment and water samples from the Arctic Ocean for measurement of artificial and natural radioactivity

Grace and Benjamin
September 19-23, 1994
J. Tremblay and M. Eagles
Invertebrates Fisheries Division, HFRL
Little River, Cape Breton Development of lobster recruit abundance index

Foxy Lady, Ceilidh Time
September 18-28, 1995
J. Tremblay and M. Eagles
Invertebrates Fisheries Division, HFRL
LittleRiver, Cape Breton Development of lobster recruit abundance index

MV *Cody, Kathryn*
June 1-10, 1995
P. Koeller
Invertebrates Fisheries Division, HFRL
Eastern Scotian Shelf Shrimp biomass estimate of inshore and offshore shrimp holes for stock assessment

HMCS *Cormorant*
October 11-13,1995
P. Koeller
Invertebrates Fisheries Division, HFRL
Chedebucto Bay
Submersible (Pisces) observations on shrimp traps and shrimp habitat

CCGS *Louis S. St. Laurent*
July 17-September 09, 1994
E.P. Jones
Arctic Ocean
Trans Arctic Hydrographic Tracer Transit

R.S. *Discovery*
August 25-October 04, 1994
T. Platt
Arabia Sea
Primary Production Studies/Remote Sensing

R.S. *Discovery*
November 16-December 19, 1994
T. Platt
Arabia Sea
Primary Production Studies/Remote Sensing

R.S. *Meteor*
November 14-December 23, 1994
J.R.N. Lazier
Labrador Sea
Fall Hydrographic Survey, North Atlantic

Seaward Johnson
April 24-May 05, 1995
N.S. Oakey
Mid Atlantic Bight
GLOBEC Field Experiment

R.V. *Sonne*
May 03-July 06, 1995
T. Platt
South East Pacific
Primary Production Studies/Remote Sensing

CCG *Simon Fraser*
May 22-27, 1995
D.J. Lawrence
Gulf of St. Lawrence
Irving Whale Drifter Tracking

Seaward Johnson
June 04- 18, 1995
N.S. Oakey
Mid-Atlantic Bight
GLOBEC Field Experiment
CCG *Mary Hichens*
August 09, 1995
D.J. Lawrence
Gulf of St. Lawrence
Irving Whale Drifter Tracking

CCG *Mary Hichens*
August 12-15, 1995
D.J. Lawrence
Gulf of St. Lawrence
Irving Whale Drifter Tracking

Charts and Publications

1994

New Charts

4209 Lockeport and/et Shelburne Harbour

New Editions

4731 Forteau Bay to/a Domino Run
5001 Labrador Sea/Mer du Labrador
8011 Grand Bank/Grand Bane Northern Portion/Partie nord
8012 Flemish Pass/Passe Flamande
8013 Flemish Cap/Bonnet Flamand
8014 Grand Bane/Grand Bank Partie nord-est/ Northeast Portion
8015 Funk Island and Approaches/et les approches
8048 Cape Harrison to St Michael Bay

1995

New Charts

4852 Smith Sound and/et Random Sound

New Editions

4001 Gulf of Maine to/a Strait of Belle Isle
4016 Saint-Pierre to St John’s
4017 Cape Race to Cape Freels
4049 Grand Bank, Northern Portion/Grand Bane, partie nord to/ à la Flemish Pass
4520 Orange Bay to Cape Bonavista
4634 La Poile Bay to Ramea Islands
4700 Belle Isle to Resolution Island
4728 Epinette Point to Terrington Basin

DEPARTMENT OF FISHERIES AND OCEANS MARITIMES REGION

SCIENCE BRANCH

AQUACULTURE DIVISION

1994

Aiken, D.E. (ed.). 1994. World Aquaculture 25(1): 80 p.

Aiken, D.E. (ed.). 1994. World Aquaculture 25(2): 64 p.

Aiken, D.E. (ed.). 1994. World Aquaculture 25(4): 64 p.

Anderson, D.M., S.P. Lall, and D. Langille. 1994. Nutritional evaluation and utilization of underutilized fishery by-products by Atlantic salmon. Aquaculture Canada '94. Annual meeting Aquacul. Assoc. Canada, Yarmouth, NS, 1-4 June 1994. Program and abstracts, p.23 (abstract).

Anderson, J.S. and S.P. Lall. 1994. Nutritive value of fish meal for salmonids. p.389-393. In D.D. MacKinlay (ed.) High performance fish. Proc. International Fish Physiology Symposium, University of British Columbia, Vancouver, 16-21 July 1994.

Benfey, TJ., R.L. Saunders, D.E. Knox, and P.R. Harmon. 1994. Muscle ornithine decarboxylase activity as an indication of recent growth in pre-smolt Atlantic salmon, *Salmo salar*. Aquaculture 121: 12.5-135.

Bower, S.M., D. Hervio, and S.E. McGladdery. 1994. Potential for Pacific oysters, *Crassostrea gigas* to serve as reservoir hosts and carriers of oyster pathogens. ICES C.M. 1994/F:30 Mariculture Committee, Parasites in Mariculture.

Bower, S.M., S.E. McGladdery, and I.M. Price. 1994. Synopsis of infectious diseases and parasites of commercially exploited shellfish. Annual Review of Fish Diseases. 4: 1-199.

Castell, J.D., J.G. Bell, D.R. Tocher, and J.R. Sargent. 1994. Effects of purified diets containing different combinations of arachidonic and docosahexaenoic acid on survival, growth and fatty acid composition of juvenile turbot *(Scophthalmus maximus)*. Aquaculture 128: 315-333.

Castell, J.D., L.D. Boston, and DA. Nanton. 1994. Marine fish larval nutrition: the live food problem. Aquaculture Canada '94. Annual meeting Aquacul. Assoc. Canada, Yarmouth, NS, 14 June 1994, Program and abstracts, p.21 (abstract).

Chang, B.D. (ed.) 1994. St. Andrews Biological Station activity report 1990- 1993. Can. Manuscr. Rep. Fish. Aquat. Sci. 2269: iv +55 p.

Charmentier-Daures, M., G. Charmentier, K.P.C. Janssen, D.E. Aiken, and F. Van Herp. 1994. Involvement of eyestalk factors in the neuroendocrine control of osmoregulation in adult American lobster *Homarus americanus*. Gen. Comp. Endocrinol. 94: 281-293.

Daly, J.G., A.R. Moore, and G. Olivier. 1994. Bactericidal activity of Brook trout *(Salvelinus fontinalis)* peritoneal macrophages against avirulent strains of *Aeromonas salmonicida*. Fish & Shellfish Immunol. 4: 273-283.

Daly, J.G., AR. Moore, G. Olivier, and A.K. Kew. 1994. Vaccination of Atlantic salmon with live, attenuated *Renibacterium salmoninarum*. Aquaculture Canada '94. Annual meeting Aquacul. Assoc. Canada, Yarmouth, NS, 1-4 June 1994, Program and abstracts, p.20 (abstract).

Duston, J. and R.L. Saunders. 1994. Production of underyearling Atlantic salmon smolts and long-term performance in a sea cage. p.105-109. In D.D. MacKinlay (ed.) High performance fish. Proc. International Fish Physiology Symposium, University of British Columbia, Vancouver, 16-21 July 1994.

Duston, J. and R.L. Saunders. 1994. Increases in Atlantic salmon smolt production by elevated water temperature. p.63-37. In D.D. MacKinlay (ed.) High performance fish. Proc. International Fish Physiology Symposium, University of British Columbia, Vancouver, 16-21 July 1994.

Freeman, K.R. 1994. Shellfish aquaculture, introductions and transfers of marine molluscs, and the vulnerability of the commons. Aquaculture Canada '94. Annual meeting Aquacul. Assoc. Canada, Yarmouth, NS, 14 June 1994, Program and abstracts ,p.17 (abstract).

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Harmon, P. and R. Peterson. 1994. The effect of temperature and salinity on the growth of striped bass *(Morone saxatilis)*. Bull. Aquacul. Assoc. Canada 94-2: 45-47.

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Kean-Howie, J.C. 1994. The application of sodium alginate microparticulate diets for nutrition research on juvenile and larval bivalve molluscs. Ph.D. Thesis, Dalhousie University, June, 201 p.

Kean-Howie, J.C. 1994. The potential for shellfish aquaculture in the Bras D'Or lakes. Aquaculture Canada '94. Annual meeting Aquacul. Assoc. Canada, Yarmouth, NS, 1-4 June 1994, Program and abstracts, p.17 (abstract).

Kean-Howie, J.C., J.D. Castell. R.G. Ackman, R.K. O'Dor, and C.J. Langdon. 1994. New techniques for the study of molluscan nutrition. Bull. Aquacult. Assoc. Canada 94-2: 27-29.

Kean-Howie, J.C., J.D. Castell, R.G.A. Ackman, R.K. O'Dor, G.F. Newkirk, and C.J. Langdon. 1994. New techniques for the study of molluscan nutrition. Aquaculture Canada '94. Annual meeting Aquacul. Assoc. Canada, Yarmouth, NS, 1-4 June 1994, Program and abstracts, p.22 (abstract).

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Lall, S.P. and G. Olivier. 1994. Nutrients and additives recommended in salmon feeding: myths and realities. Pathology and Nutrition in the Development of Aquaculture: Key to success, Puerto Mont, Chile, October 3-7, 1994 (abstract).

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(Pseudoterranova decipiens) in eastern Canada. Can. Manuscr. Rep. Fish. Aquat. Sci. 2260: viii + 26p.

Martell, D J. and G. McClelland. 1994. Diets of sympatric flatfishes, *Hippoglossoides platessoides* (Fabric&), *Pleuronectes ferrugineus* (Storer), *Pleuronectes americanus* (Walbaum), from Sable Island Bank, Canada. J. Fish. Biol. 44: 821-848.

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Martin-Robichaud, DJ., R.H. Peterson, T.J. Benfey, and L.W. Crim. 1994. Direct feminization of lumpfish *(Cyclopterus lumps L.)* using 17b-oestradiol-enriched Artemia as food. Aquaculture 123: 137-151.

McClelland, G. 1994. Current laboratory and field research on the life cycles and population dynamics of economically important anisakid nematodes. Bull. Stand. Soc. Parasitol. 4: 2. (Abstract)

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McClelland, G., D.J. Marcogliese, and J.R. Arthur. 1994. Parasites as indicators of Gulf of St. Lawrence fish stocks. Fisheries Oceanography Committee meeting, 23-25 March 1994, Dartmouth, NS, WP94/39. Summarized in D. D'Amours, K.T. Frank, and G. Bugden (eds.) Report of the Working Group on Oceanographic Effects on Stock Migration and Mixing - reviewed by the Fisheries Oceanography Committee (FOC). DFO Atl. Fish. Res. Doc. 94/54: 18-19.

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McGladdery, S.E. and Whyte, S.K. 1994. Mollusc biology and husbandry. Course text for Canadian Aquaculture Institute, University of Prince Edward Island, Charlottetown, PEI.

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Morrison, C.M., J.P. Leger, and C.A. Morrison. 1994. A light microscopy and ultrastructural study of the sporulation of *Goussia gadi (Apicornplexa: Coccidia)* in the swim bladder wall of haddock *Melanogrammus aeglefinus.* Dis. Aquat. Org. 17: 181-189.

Olivier, G., S.P. Lall, A. Kew and R.A. Keith. 1994. Effects of commercial b-glucans on immune response and disease resistance in Atlantic salmon. Aquaculture Canada '94. Annual meeting Aquacul. Assoc. Canada, Yarmouth, NS, 1-4 June 1994, Program and abstracts, p.20 (abstract).

Parazo, M., S.P. Lall and R.G. Ackman. 1994. Apparent absorption of dietary tocopherols by Atlantic salmon *(Salmo salar).* Aquaculture Canada '94. Annual meeting Aquacul. Assoc. Canada, Yarmouth, NS, 1-4 June 1994, Program and abstracts, p.21 (abstract).

Parrish, C.C., J.D. Castell, J.A. Brown, L. Boston, J.S. Strickland, and D.C. Somerton. 1994. Fatty acid composition of Atlantic halibut *(Hippoglossus hippoglossus)* eggs in relation to fertilization. Aquaculture Canada '94. Annual meeting Aquacul. Assoc. Canada, Yarmouth, NS, 1-4 June 1994, Program and abstracts, p.25 (abstract).

Parsons, G.J. and S.L. Waddy (ed.). 1994. Special issue on scallop culture. Bull. Aquacul. Assoc. Canada 94-3: 32 p.

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NATURAL RESOURCES

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