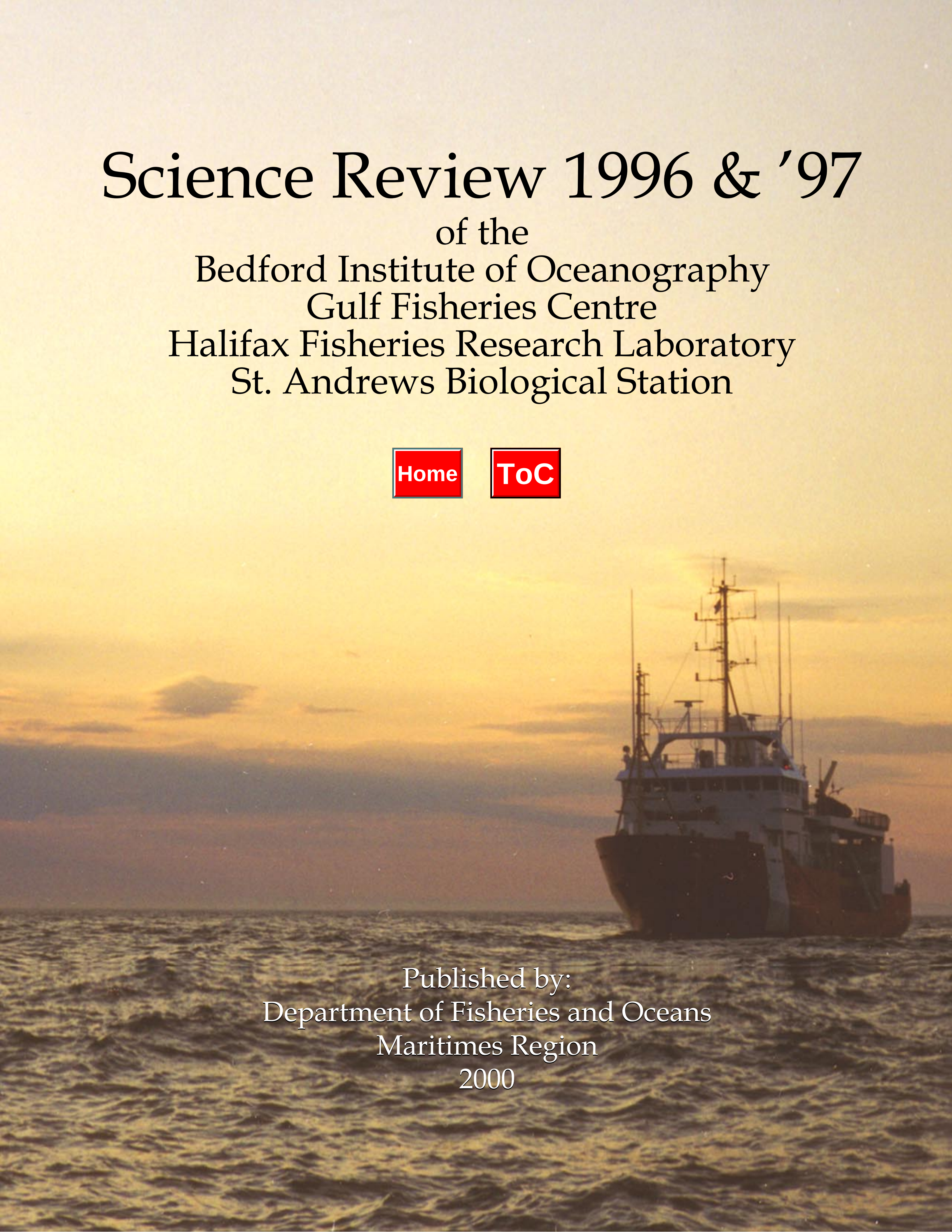

Science Review 1996 & '97

of the
Bedford Institute of Oceanography
Gulf Fisheries Centre
Halifax Fisheries Research Laboratory
St. Andrews Biological Station

Home ToC

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OVERVIEW

The years 1996 and '97 were ones where organizational and budgetary reductions decisions taken in 1995 began to take full effect. Reductions throughout the federal government under its "Program Review" will mean, for example, an approximate 40% reduction in staff and financial resources in DFO Maritimes' Science Branch by the end of Fiscal Year 98/99. Most of the impacts were felt in the first two fiscal years of the Program Review as many people accepted early retirement incentives, leaving by March , 1998 or earlier. New staffing opportunities were scarce to nil. Consequently, concerns over the aging of the Government of Canada's scientific population mounted.

John Loch

In the spring of 1996, following organizational changes approved in 1995, DFO Maritimes' Science Branch became fully operational. It had a new Director, John Loch and a new management structure with eight divisions, a Program Coordination office, an office for the coordination of our regional scientific advisory process ("RAP"). These units were spread across three Maritime provinces and four laboratories (the Bedford Institute of Oceanography (BIO) in Dartmouth, N.S., the Gulf Fisheries Centre (GFC) in Moncton, N.B., the St. Andrew's Biological Station (SABS) in St. Andrew's N.B., and the Halifax Fisheries Research Lab (HFRL) in Halifax, N.S.) Clientele varied from the traditional harvest fisheries to aquaculture to marine navigation and transportation to oceans sciences and marine environmental interests at local, regional, national and international levels. We were involved in climate change, *Irving Whale*, cod collapse, hydrocarbon development, etc. This report will provide information from all of these program and geographic areas.

The GeoScience Centre Atlantic (GSC) of the Department of Natural Resources Canada, internally reorganized in May 1996. The program support subdivision ceased as a separate identity and was integrated within the three science subdivisions.

In Environment Canada, the Environmental Quality Laboratory (ECL) has moved to the Environmental Science Centre at the University of Moncton Campus. The Environmental Protection Microbiology Laboratory remains at BIO to carry out shellfish water quality monitoring throughout the three maritime provinces.

STAFF

A number of key staff changes occurred within DFO Maritimes Science Branch during the review period. John S. Loch was named as the new Regional Science Director for the Maritimes Region of DFO effective 01 April, 1996. Joan Guilderson retired as the Director's secretary and was replaced by Marie Charlebois-Serdynska. René Lavoie was named as Assistant Director and Branch Coordinator for scientific communications & liaison as well as Occupational Health & Safety. Joni Henderson moved to support René in those roles. Richard Eisner was named as Chief of the Program & Policy Coordination Division. He is supported by Sharon Morgan in BIO, Dartmouth and Yves Després in GFC, Moncton. Bob O'Boyle moved from Marine Fish Division to become the Coordinator of our Regional Assessment Office. He is supported by Dianne Geddes and Val Myra. The RAP Office is located at BIO, Dartmouth. During the review period, an Oceans Act Coordination Office (OACO) was created by Neil Bellefontaine, our Regional Director General. Faith Scattolon is that program's first Director; Faith also represents DFO on the Gulf of Maine

Marine Environmental Council, ably assisted by Paul Keizer who replaced Brian Nicholls in that role with Brian's retirement. Various staff have been assigned from Fisheries Management, Habitat Management, Canadian Coast Guard, Policy and Economics to support Faith in OACO. There are staff in the OACO both in BIO in Dartmouth and the GFC in Moncton. Jim Elliott returned to his post as head of Oceans Science Division after serving as the interim head of the former Scotia Fundy Science Branch. Late in the review period, Jim took on an international assignment, OceanTec, and handed over the reins for the Oceans Science Division to Allyn Clarke. Guy Sirois, named as Division Manager of Habitat Management during the 1995 reorganization, retired in 1997 and was replaced by Brian Thompson. Wendy Watson-Wright, former Director of St. Andrews Biological Station and Division Chief of our Aquaculture Division, moved to DFO, Ottawa and was replaced by Tom Sephton. John Pringle, who was our Division Chief for Marine Environmental Sciences, took a similar post in the Pacific Region and was replaced by Paul Keizer. Paul Bellemare, longtime Director of Canadian Hydrographic Service (CHS) Atlantic departed BIO in August 1997 to take on the position of Director, Policy, Planning & Marketing in CHS Headquarters. Paul was very active in developing new database management technology to enable CHS to take advantage of the rapid advances in multibeam surveying. Paul was also a strong proponent of government, academic and private sector partnering and initiated a number of projects in this area to the benefit of all. Paul was replaced by Laureen Kinney, originally from Coast Guard in Vancouver, who was assigned to CHS Atlantic for one year. This assignment is part of a Fisheries & Oceans initiative to ensure cross fertilization between Sectors and develop the team management culture.

In the Invertebrates' Fisheries Division, Bob Rodger (HFRL), Don Jones (Miminegash) retired. Through an inter-divisional exchange, Stephen Smith became Section Head of Molluscan Fisheries Section.

Program review and budget cuts resulted in major changes in staff in the Marine Environmental Sciences Division during 1996 and 1997. The research program on the dynamics and physiology of harmful algal blooms was reduced substantially with the early retirements of Dr. James E. Stewart and Dr. Subba Rao Durvasula. Dr. John Vandermeulen's early retirement due to chronic health problems was a serious loss of expertise with respect to the fate and effects of oil spills. A wealth of knowledge and experience with toxic chemical issues, regionally, nationally and internationally, was lost with the retirement of Dr. Michael Bewers. It was also during this period that we saw the end of the Marine Assessment and Liaison Division, responsible for the coordination and provision of scientific advice, with the retirements of Brian Nicholls and Gerald Siebert. In 1997, Dr. Jocelyn Hellou transferred to Maritimes Region from Newfoundland Region to establish a research program to investigate the biological fate and effects of organic contaminants in the marine environment.

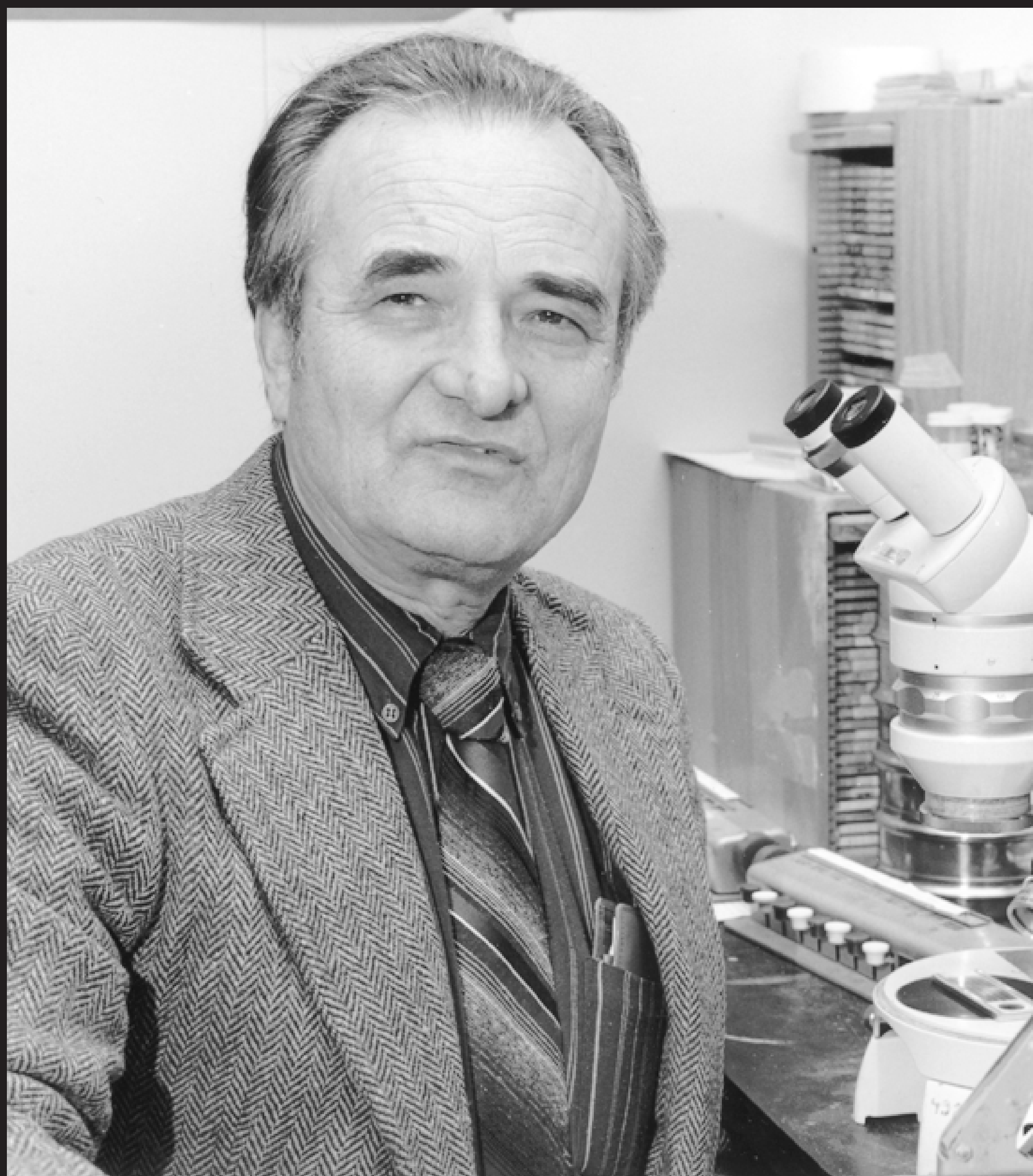
There were several departures from the Aquaculture Division during '96 and '97: from the Halifax Lab there were Santosh Lall (Sep 96) - left to join Natural Resources Canada, Carol Morrison (Oct 97) – retired and Mabel McMenemy (Jan 97) – retired; from St. Andrew's Biological Station there were Richard Saunders (Dec 96) – retired, Richard Peterson (Jul 97) – retired, Jeanine Hurley (Jun 96) – retired and Ross Chandler (May 97) – retired. From the Gulf Fisheries Centre, there was Clair Bryan (Dec 97) – retired.

There were also staff movements related to the closure of HFRL. John Castell's fish nutrition research program and John Martell transferred to SABS in '97, and the Fish Health Unit transferred to GFC in '97 (G. Olivier and G. McClelland transferred to GFC in '98)

In March 1996, Dr. David Prior resigned as Director of GSC Atlantic. He was replaced on an acting basis by Don McAlpine. In September 1996, Dr. Jacob Verhoef was named as the new Director of GSC Atlantic. In May 1997, Dr. Mark Williamson was appointed Head of the Marine Regional Geoscience Subdivision.

Obituary - Gus Vilks

Dr. Gus Vilks, a long time member of the GSC Atlantic staff, passed away in July 1997. Dr. Vilks was a well recognized pioneer in the international micro-palaeontology community. Over his 32 year career in scientific research, Gus made outstanding contributions in Quaternary marine geology, palaeoecology, and paleoceanography, especially as applied to Arctic Ocean environments. From his early work on deducing the paleoenvironments of the Arctic polar continental shelf, he extended his studies into the deep Arctic Ocean basins, the Beaufort Sea, the Arctic island channels, Baffin Bay, Hudson Strait, the Labrador Sea, and the Gulf of St. Lawrence. Collaboration with colleagues in sedimentology, geochemistry, and physical oceanography included studies of coastal and estuarine systems in Atlantic Canada. Dr. Vilks was recognized for his scientific achievements by many invitations as a guest lecturer at universities and research institutes; he was one of the first Canadian scientists to participate in a lecture tour in China after the Cultural Revolution. He held an Honorary Research Associate appointment at Dalhousie University, and was awarded honorary membership in the North American Micro-palaeontology Section of the Society for Sedimentary Geology.



Gus Vilks

AWARDS & PRESENTATIONS

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

- Departmental Merit Awards:
  Michael Chadwick

- Deputy Minister Commendations:
  Bob Miller (Invertebrate Fisheries Division)
  Ken Drinkwater (Ocean Sciences Division)

  Herman Varma received a Smithsonian Award during this period.

A team from Ocean Sciences Division, Maritimes Region, was awarded a silver medal for excellence in the category "Renewing Services and Program Delivery: Service Delivery on the Information Highway". The team included Doug Gregory, Helen Hayden, Bob Lively, Liam Petrie, and Roger Pettipas. (Article appeared in Vol. 3, No. 1 Spring Issue 1998 of SONAR.)

Dr. Graham Williams, a research scientist at GSC Atlantic was awarded two prestigious medals in 1996. The annual E.R.Ward Neale Medal (Geological Association of Canada) is given to an

Each year the Government of Canada presents awards to employees who invent equipment, or software, that is licensed to Canadian industry. The companies market the equipment in Canada and internationally creating jobs for local people. The table below lists the licensed product, the staff presented with awards and the company the holds the license.

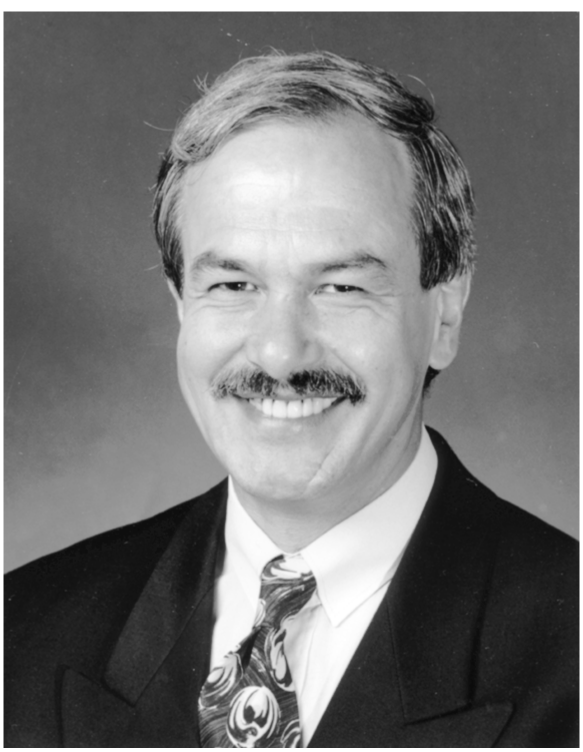
"BIONESS" Mark (BIO Net Env Sampling System)	Douglas D. Sameoto	Open Seas Instrumentation Inc. Musquodoboit Harbour, NS
Ice Growth Ablation Measuring System	Donald Belliveau Charles Tang Albert Hartling	Axiom Engineering Ltd. St. John's NF
Instrumented Metering Sheave Block	Jean-Guy Dessureault Scott Young Brian Beanlands	Brooke Ocean Technology Dartmouth, NS
Moving Vessel CTD System	Jean-Guy Dessureault E.F. Phillips Brian Beanlands Scott Young	Brooke Ocean Technology Dartmouth, NS
Optical Measurement of Marine Conditions	Alex W. Herman E.F. Phillips Brian Beanlands	Focal Technologies Inc. Dartmouth, NS
Pop-Up Float	Mark Chin-Yee	Corepro Ltd. Dartmouth, NS
Sea-Ice Movement Prediction Model	Charles Tang	Coretec Inc. St. John's NF
Streamlined In-Line Buoyancy Package	Jim Hamilton George A. Fowler	Open Seas Instrumentation Inc. Musquodoboit Harbour, NS
Trawl Resistant Package	Jean-Guy Dessureault Scott Young	Open Seas Instrumentation Inc. Musquodoboit Harbour, NS
Wave Powered Ocean Profiler	George A. Fowler Roger Cassivi Brian Beanlands Donald Belliveau Jim Hamilton	Brooke Ocean Technology Dartmouth, NS

individual who has made significant contributions to the public awareness of geoscience. The award recognizes Dr. Williams' substantial commitment in sharing his specialist knowledge with school children and the broader community. The American Association of Stratigraphic Palynologists (AASP) Medal for Scientific Excellence is awarded every four years and is given to individuals with the highest scientific achievements. The medal recognizes Dr. Williams' extensive and innovative contributions to palynology, as a pioneer and a world leader in the application of fossil dinoflagellates to geological problems, especially in the oil prone basins such as those offshore Atlantic Canada.

Huntsman Award

The A.G. Huntsman Award for excellence in the marine sciences is administered by a private foundation based at the Bedford Institute of Oceanography. It was first awarded in 1980, and up to the end of 1997, 19 recipients had received the Huntsman Medal. Two awards were made since the last Science Review.

The eighteenth recipient, Professor Victor Smetacek, Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany, was presented the award in the category of biological oceanography at a ceremony held November 22, 1995, at the Bedford Institute of Oceanography. His research interests range over the ecology and



Professor Victor Smetacek

Dr. Robert Detrick

natural history of the microflora and microfauna in shallow-water ecosystems, the pelagic ecology of the southern ocean, and biogeochemical processes, especially the vertical flux of particles. He has worked in a spectrum of oceanographic regimes from the coastal waters of northern Europe to the deep-sea ecosystems of the Antarctic and the is also known for his ability to synthesize information from diverse fields to draw new conclusions about the structure and function of the great biogeochemical cycles of the ocean. The title of Professor Smetacek's distinguished lecture was, "The Rise and Fall of Diatom Blooms".

The nineteenth recipient, Dr. Robert Detrick Woods Hole Oceanographic Institution, USA, was presented the award in the category of marine geosciences at a ceremony held January 15, 1997, at the Bedford Institute of Oceanography. Dr. Detrick was selected for his seminal contributions to our understanding of the genesis and evolution of the oceanic lithosphere. Dr. Detrick has led the marine geosciences community into a new era of marine seismological investigation of the ocean crust. His work in seismic imaging of magma chambers below fast-spreading ridges has been used to define the principle characteristics of mid-ocean ridges. In addition, he has had a major influence on important international programs, such as RIDGE (international mid-ocean ridge studies) and ODP (ocean drilling program). The title of Dr. Detrick's distinguished lecture was, "Mid-Ocean Ridge Magma Cambers".

RESEARCH AND SURVEY HIGHLIGHTS

Examples of the research undertaken, together with some of the major events that occurred during the 1996-97 biennium, are outlined below by broad geographic region.

Gulf of Maine/Georges Bank/Bay of Fundy

In response to an outbreak of sea lice among farmed salmon in southwestern New Brunswick, DFO Science Strategic Research Funding was obtained to conduct research on these parasites and methods to control them. This project involved researchers from the Aquaculture, Marine Environmental Sciences, and Ocean Sciences Divisions, in collaboration with Environment Canada, the Huntsman Marine Science Centre, the University of New Brunswick, the New Brunswick Salmon Growers' Association, and the New Brunswick Department of Fisheries and Aquaculture. Research was conducted on sea louse distribution and life cycles, toxicological effects of the sea louse pesticides azamethiphos and cypermethrin on non-target organisms, and the dispersion of these pesticides in the marine environment after deployment in salmon cages. The dispersion research included dye release trials of simulated sea louse pesticide treatments, as well as oceanographic research involving deployments of current meters and drogues and the development of a 3-dimensional circulation model for the southwestern New Brunswick salmon farming area.

A collaborative project involving the Aquaculture, Marine Environmental Sciences, and Ocean Sciences Divisions and the New Brunswick Salmon Growers' Association examined factors affecting productivity of 20 salmon farms in southwestern New Brunswick. The study began in the spring of 1995 and followed one year class of smolts until harvesting. At each site, salmon production was related to husbandry and environmental factors. Husbandry factors measured included smolt size, stocking densities, cage types and volumes, feed types, and feeding procedures. Environmental factors measured included water temperature, dissolved oxygen, and water currents. A submersible dual camera system was developed at the Bedford Institute of Oceanography to allow measurement of fish lengths without requiring removal of fish from the cage.

DFO researchers continued to collaborate with Provincial governments, universities, the National Research Council, and industry in research on the development new species which could help to diversify the aquaculture industry. The goal of the aquaculture research is to develop an aquaculture industry which is both economically and environmentally sustainable.

In the Gulf of Maine a three-year study on lobster catchability and juvenile recruitment of lobster was undertaken as well as a comprehensive survey of Bay of Fundy scallop.

Research on the environmental impacts of Atlantic salmon cage culture in the Western Isles area focused on defining methods for assessing and regulating the impacts of the industry to help insure its environmental sustainability. The environmental degradation at many of the sites was being evidenced in chronic parasite and disease problems. An overall assessment of waste discharges into the area helped to put the aquaculture industry's impacts into perspective.

With renewed interest in developing petroleum hydrocarbon reserves on the continental shelf of Atlantic Canada, there was also increasing concern about the potential impacts that this type of development might have on fish and fish habitat. With assistance from the Panel on Research Energy and Development, investigations were intensified to understand the long term and sublethal impacts of discharges from these operations. Initially much of the emphasis was on Georges Bank in order to provide scientific advice for the review of the drilling moratorium for this area in 1998. The focus was on impacts on scallops, the most valuable fishery on Georges Bank. Development of the

Cohasset-Panuke reserve on Sable Bank provided an opportunity to validate models to predict the fate and biological effects of discharges.

The Canadian Hydrographic Service (CHS) commenced multi-beam sonar survey work on German Bank in late 1997. It is intended to survey the complete bank in following years.

A four-year first phase of GLOBEC (Global Ocean Ecosystems Dynamics) Canada - a collaborative national program funded jointly by DFO and National Science & Engineering Research Council (NSERC) - started in 1996. GLOBEC is an international climate research program that is examining how the abundance, distribution and productivity of marine populations are affected by variability in their environment. DFO Maritimes scientists are participating actively in the Atlantic component of GLOBEC Canada which is focusing on important zooplankton species on the NW Atlantic Shelf, and on the early life stages of finfish in selected spawning areas on the Scotian Shelf and Gulf of St. Lawrence. Retrospective analyses of historical data and new computer models of shelf circulation are being used to evaluate the influences of physical environmental and food-supply changes on the target species. New field studies targeted on key areas are being carried out by BIO and university scientists in 1997 and 1998, focused on zooplankton sources on the Scotian Shelf and the survival of fish larvae on Western Bank.

Staff in the herring program developed approaches which have ensured that fishing effort is spread proportionately over the various spawning components that comprise the Northwest Atlantic Fisheries Organization (NAFO) Division 4WX management unit. This approach involved close liaison with industry to provide real time estimates of the size of the spawning aggregations. Through immediate consultation with DFO managers and scientists and industry appropriate harvest levels were established. The DFO Strategic Science funding for hydroacoustic investigations has been instrumental in the development of techniques for determining spawning biomass.

Approaches for quantifying the uncertainty in fish stock assessments have been developed, and the risk of exceeding fisheries targets such as increasing stock biomass or not exceeding target fishing mortality has been determined. While the current approach focusses solely on uncertainty associated with yearly abundance and does not yet include variations in other input, this important initial step has been very well received by users of DFO fisheries advice. Knowledge of uncertainty in our advice has often prompted fisheries managers to select more conservative levels of exploitation.

Scientists at GSC Atlantic published a major review of the geological framework and petroleum potential of the Triassic/ Jurassic Fundy Basin in 1996. This study revealed the presence of thick fluvial and lacustrine sediments with good potential for oil and gas source rocks and reservoirs.

Environment Canada has been working very closely with the community groups in the Southwest Bay of Fundy in New Brunswick to promote pollution remediation and enhance the growth of soft shell clam industry in the area. Remediation activities have been successful in reopening 100 hectares of productive clam growing area for commercial harvesting and generating over $300,000 to the local economy. During the fall of 1998, funding over $100,000 was awarded to the local community group to develop a shellfish management plan and water quality monitoring program for the SW Bay of Fundy in partnerships with EC, DFO, Canadian Fish Inspection Agency (CFIA), New Brunswick Department of Fisheries & Aquaculture (NBDFA) and the private sector.

Scotian Shelf

Scientists from BIO conducted the first in-depth stock assessments of the Northwest Atlantic porbeagle, blue and shortfin mako shark populations in the spring of 1996. While the analyses suffered from problems in data availability, there was enough information to guide the development of the 1997-2000 Atlantic Coast Management Plan. This plan is one of only four worldwide existing to manage shark resources. The 1996 assessment particularly highlighted areas where future research and data collection efforts were required, many in cooperation with the fishing industry.

A collaborative study involving Dalhousie University and the Marine Fish Division is addressing birth control of grey seals. The seal population on the eastern Scotian Shelf which breeds primarily on Sable Island has been increasing exponentially for several decades. There has been interest in developing new techniques for controlling population growth. A single-administration birth control vaccine based on liposome delivery of antigens reduced pup production by about 90%. Contrary to expectation, females with two or more recaptures had stable or increasing antibody levels during the three year monitoring period. This suggest the immunocontraceptive vaccine could be effective for more than three years.

On the Scotian Shelf the first survey of snow crab resource on eastern coast of Cape Breton was conducted; the survey was funded by industry. A zonal larval lobster program was also started in 1997.

The decline of many of the ground fisheries in Atlantic Canada brought renewed concern that the mobile gear used by many of the fishing sectors was damaging the habitat needed to support recruitment into these fisheries. A new initiative was undertaken to evaluate this impact. Initial emphasis was on the application of new technologies to sampling equipment to gather information from the ocean bottom. New multi-beam sonar, high-resolution side scan, and accurate satellite positioning techniques were employed in the design and application of rigorous experimental designs. Conventional sediment grabs were modified to allow reliable and representative sampling of benthos. New devices were designed and constructed to allow sampling of the sediment water interface. These experiments are now well underway on both Middle Bank on the Scotian Shelf and Grand Banks off Newfoundland.

The Canadian Hydrographic Service (CHS) carried out extensive multi-beam sonar surveys on Brown's Bank during 1996 and 1997. This information has enabled scientists and hydrographers, for the first time, to "see" what the ocean floor in the Brown's Bank area really looks like. It has been described as similar to removing a blindfold. A great deal of enthusiasm for this technology has developed among fishers, geologists and habitat managers.

CHS carried out a joint project with Seabed Exploration Associates, in 1997, to collect multi-beam imagery for a proposed gas pipeline across the Scotian Shelf.

Browns Bank Geological Habitat Research: A team of marine geologists, hydrographers, scallop biologists and the fishing industry are investigating new opportunities to enhance the scallop fishery on Browns Bank. The basis of the research is the collection, processing and display of multibeam bathymetric data and its interpretation in terms of scallop habitat. The relationship between marine geology and biological habitat characterization is a new and emerging activity that is expected to generate essential information for both management and sustainable development of the scallop fishery.

Sable Island sediment transport study: GSC Atlantic, in collaboration with Mobil Oil Canada Ltd, is quantifying the hazards to seabed installations for gas production near Sable Island. As part

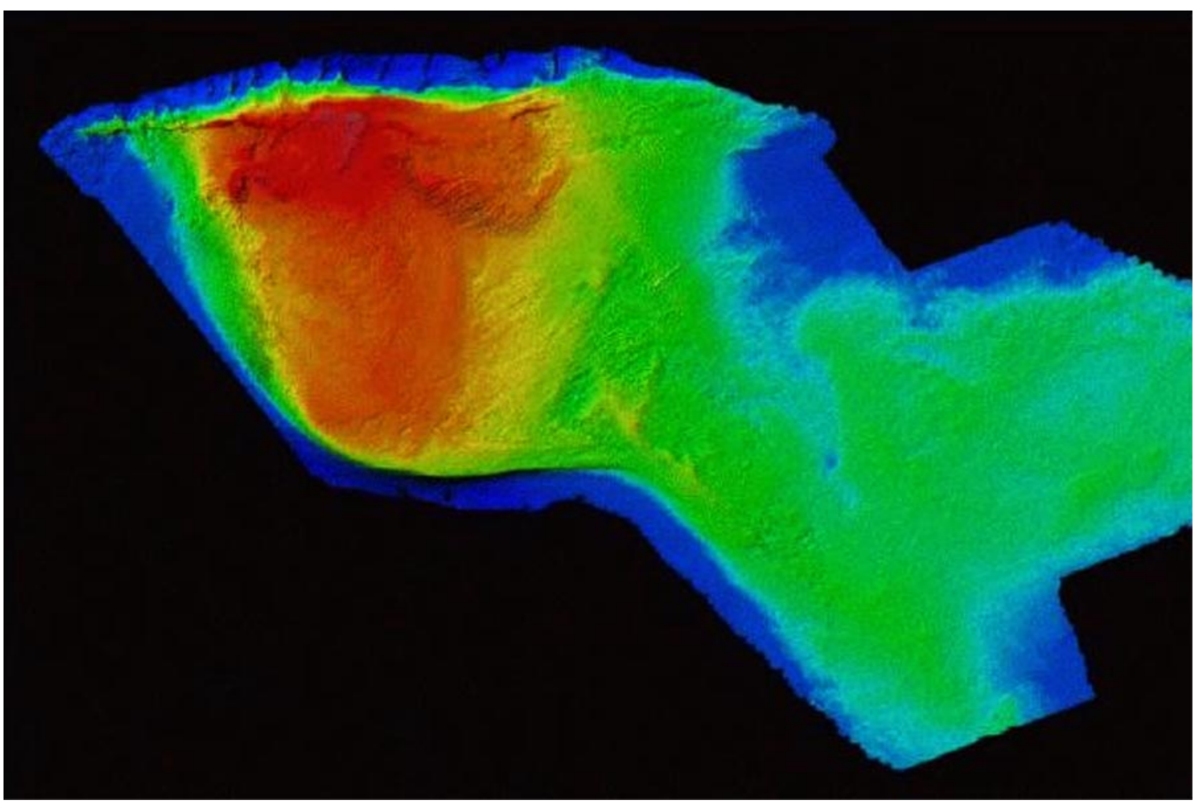


Image of seafloor generated from EM1000 multi-beam data collected on the FG Creed by the Canadian Hydrographic Service -Atlantic. It took sixty days and over 120 million soundings were acquired on Browns Bank (~ 130 km by 70 km)

lution (35x35 km) winds to drive CANSARP predictions. The surprising result was that over the critical period of the first 24 hours of drift, the high-resolution winds provided no obvious improvement over the low-resolution fields. On the other hand, forecasts using a Dalhousie University surface current model, which assimilates both coastal sea level and low-resolution CMC winds, showed significantly more skill than CANSARP predictions

of this study, GSC Atlantic participated in a drilling program to determine the maximum depth below the sea floor of the mobile sand layer. This information is important for both overall sediment transport studies on the continental shelf and pipe line design. Innovative seabed instrumentation, developed at GSC Atlantic, enabled real-time monitoring of sediment transport during storms. The physics of sediment transport was documented and is currently being applied to processes of large-scale bedform migration during storms and scouring. These measurements also provide ground truth to refine regional models of sediment transport.

Improving the Skill of Search-and-Rescue Forecasts - With the support of the Canadian Coast Guard's (CCG's) New Initiatives Fund, scientists from the Canadian Meteorological Centre (CMC), Dalhousie University, and BIO conducted an experiment on the Scotian Shelf during February 1996. The main goal of the experiment was to test and improve the forecast skill of the CCG's primary planning tool for search-and-rescue (SAR) operations, known as CANSARP. The field component of the experiment consisted of four weekly drift trials in which clusters of SAR targets (e.g. life rafts, dories, buoys simulating a person-in-water) were released and tracked over the Scotian Shelf by satellite. Ancillary data, such as water currents, local wind, coastal sea level, and bottom pressure were also collected during the trials.

Two tests of CANSARP's forecast skill were conducted using data from the field experiment. The first assessed the potential benefits of using high-resolution (12x12 km grid) versus low-resolution (35x35 km) winds to drive CANSARP predictions. The surprising result was that over the critical period of the first 24 hours of drift, the high-resolution winds provided no obvious improvement over the low-resolution fields. On the other hand, forecasts using a Dalhousie University surface current model, which assimilates both coastal sea level and low-resolution CMC winds, showed significantly more skill than CANSARP predictions over 0-30 hours and beyond. In terms of search areas, CANSARP errors typically exceeded those of the Dalhousie model forecasts by an order of magnitude (x10). Thus, the major recommendation of this study is for implementation of the Dalhousie surface current model within the CANSARP system.

Country Harbour and Ship Harbour were the sites of extensive physical oceanographic measurements in 1996-1997. Instrumented moorings recording currents, temperature and salinity were complemented by seasonal hydrographic surveys, bottom sediment sampling and local meteorological observations. The two inlets have contrasting topographies: the depth in Country Harbour decreasing from mouth to head; whereas, Ship Harbour features an inner deep basin isolated from the open ocean by a shallow sill. The project is examining the rate at which these contrasting inlets are flushed and the mechanisms that cause the flushing. The results from these inlets can be extended to other coastal harbours in the Maritimes Region. The project is supported by the Strategic Science Fund, Toxic Chemicals Program.

Gulf of St. Lawrence

A large scale lobster tagging study was conducted throughout the southern Gulf. It was funded by industry. The study showed that adult lobsters do not move very far along the coastline.

Sentinel Surveys: with the closure of directed fisheries on many of the stocks in the Northwest Atlantic, information on the status of the stocks from the commercial fishery was no longer for stock assessments. This information was previously being used in combination with information from research vessel surveys to assess the status of the resources. In 1994, sentinel surveys were implemented to obtain additional information on the status of the stocks. These surveys consist of limited removals from the stocks under a pre-determined protocol for the purpose of collecting biological information. The primary objective is to collect information on the trends in the stocks (i.e. whether stocks are increasing or decreasing) but the information collected is also useful to study the distribution, migration, condition, maturity stage of the fish as well as collecting information on water temperature. In 1996 and 1997, ten sentinel survey projects (5 fixed gear and 5 mobile gear) were conducted for the southern Gulf of St. Lawrence (including the Gaspé Coast, Gulf N.B., Gulf Nova Scotia, P.E.I. and the Magdalen Islands). The projects involved a total of over 30 groundfish fishing vessels. Information obtained from these surveys is important in terms of providing a "second opinion" of the status of the stocks. The view obtained from these data is relatively consistent with that from the research vessel data . It has the advantage of providing information over several months.

Since 1994, sentinel surveys projects have been conducted in the Southern Gulf of St. Lawrence. These projects are designed to collect information on the abundance of groundfish and collect general biological characteristics of the stocks. Commercial fishing vessels following a pre-determined scientific protocol are used in the projects. In both 1994 (2 vessels) and 1995 (16 vessels), projects were largely funded by the Dept. of Human Resource Development. DFO provided scientific expertise to oversee the projects and provided funds for scientific equipment and the observer coverage.

The PCB contamination of sediment in the Gulf of St. Lawrence following the lifting of the barge, the *Irving Whale*, has been carefully examined to determine the extent and potential biological effects. Most of the PCBs carried on the barge were lost and cannot be accounted for by the residues remaining in the sediments in the vicinity of the former sunken barge. Monitoring and sampling of sediments and biota from the area continue in order to provide scientific advice on potential remediation efforts and to insure that commercial fisheries in the area remain closed until levels of contamination are well below those that might cause concern. In support of the Irving Whale Recovery project, the GSC Atlantic, and Canadian Coast Guard completed a detailed aerial video survey along the shores of Iles de la Madeleine in 1996. In addition, a detailed survey was completed of Plage and Dune de l'Ouest in support of activities to recover bags of oil that were disposed in the backshore in 1970 after the original Irving Whale spill. The video will be used for documenting the physical character of the shoreline, changes in its morphology and land-use activities.

GSC Atlantic has initiated a broad-based investigation of shore-zone stability, sediment budgets, and coastal response to sea-level rise along the north shore and off East Point, PEI. This project was designed to address widespread public concern about coastal sensitivity to climate change in PEI, one of the most vulnerable areas identified in a recent GSC analysis of the entire Canadian coastline. The project also contributed to resolution of a major coastal management issue in the Rustico Bay area, where public concerns about water quality and navigation safety were related to dramatic changes in the bay since construction of the Rustico Island causeway in the mid-1950s and more recent extensive aquaculture development, as well as the termination of dredging at North Rustico. Early highlights of this project include a detailed multibeam bathymetric survey and studies of water and sediment dynamics in Rustico Bay. The project is a collaboration between GSC, CHS, PWGSC, Parks Canada, North Rustico Harbour Authority, Baird & Associates Coastal Engineers, Challenger Oceanography, and Acadia, Mount Allison and Dalhousie Universities.

In 1996, GSC Atlantic carried out swath bathymetric surveys in three areas off western Newfoundland. A survey in the Bay of Islands, in collaboration with a leading oil company, revealed previously unknown features on the seafloor, showing clearly the extent of an underwater slump. Data collected off Port au Port, in partnership with government and university researchers, resulted in exciting high resolution images of bedrock outcrops on the seafloor which will be used to solve geological problems in an area of active hydrocarbon exploration. The survey conducted off Stephenville was a repeat of the 1995 survey, its purpose being to demonstrate how SWATH imagery can be used to detect changes in the seafloor. This technique is of great interest to resource companies working offshore in Canadian waters and internationally.

Gulf of St. Lawrence Initiative: GSC Atlantic commenced a major initiative in the Gulf of St. Lawrence, to more completely link preserved onshore and offshore geological features in the area.

The project focuses on: defining the Maritimes Basin crustal framework; examining onshore-offshore stratigraphic and sedimentological correlations and reviewing what these mean for petroleum systems in the region. In order to accomplish these objectives, the project makes use of the full scope of geoscientific expertise ranging from crustal geophysics and modeling to fine scaled biostratigraphic assessment.

GSC Atlantic conducted a repeat swath bathymetry survey over the undersea mines off Cape Breton. The purpose of this collaborative project, with the Cape Breton Development Company and the Canada Centre for Mineral and Energy Technology was to determine the annual subsidence of the seafloor over the mine workings. This information helps scientists determine the potential hazard of seawater flooding the mine and is useful for future mine planning.

Validation of Sea Ice Signatures in RADARSAT SAR Imagery with Helicopter-borne Sensors' Data - Helicopter-borne sensors are being used to collect ice property data from the Canadian East Coast pack ice to identify and validate ice signatures seen in the RADARSAT SAR imagery. Two sensor systems are used, one is an electromagnetic (EM) induction and Laser system and the second is a Video-Laser system; both use GPS sensors to position the data. Ice-plus-snow thickness profiles were collected in the winters of 1996 to 1998 using an electromagnetic (EM) induction system towed 15-25 m above the ice surface by helicopter. Measurements from the laser altimeter contained in the EM system were high-pass filtered to derive ice surface topography profiles. The EM system uses frequencies of 30 and 90 kHz and a horizontal coplanar coil configuration; thus the footprint is about 3.7 times the height of the "bird" or about 74 m, while that of the laser is a few cm's. Video imagery was collected using a downward-looking S-VHS video camera mounted in a pod on the outside of the helicopter. The imagery was annotated with position and timing information using a video overlay unit.

A helicopter-mounted Video-Laser-GPS system was used in 1998 to collect Video images for different backscatter regions seen in the RADARSAT imagery. The Video system framegrabs digital video images and logs laser altimeter profiles along with GPS position data. The system uses the expected flying height, flying speed, field of view and frame size to establish the frame capture rate which ranges from 0.5 sec when flying at 50 m to 3.0 sec at 300 m (1000 ft). Since the video frame has 240x320 pixels and the video frame view width is approximately equal to the flying height, the video pixel size is about 1 m when flying at 300 m. GPS data is logged at 1/sec, radar altimeter at 10/sec and laser altimeter at 30/sec.

In 1996, many large dark-toned floes were visible west of the Magdalen Islands in the ScanSAR Narrow RADARSAT image. They corresponded to EM-measured ice thicknesses of about 0.5 m in agreement with auger hole measurements, and there was negligible ridging in the laser profiles. The surrounding areas were brighter-toned due to the presence of many leads containing young brash ice. However in these areas, EM-measured ice thicknesses of up to about 2.5 m and laser-measured ridge elevations of 1.5 m were also encountered since ridging generally occurs in areas of thin ice. The overall mean ice thickness was 50% higher than that of the under formed ice. The brightest-toned areas in the SAR image corresponded to pancake ice having EM-measured ice thicknesses of less than 20 cm, and negligible ridging.

Along the Labrador coast, offshore winds in early March resulted in low ice thicknesses and low ice concentrations close to shore. Thus in the March 10 ScanSAR Wide image, the inshore ice appeared dark, however bright streaks were visible southeast (downwind) of small coastal islands. These streaks corresponded to ice rubble with EM-measured ice thicknesses of about 1-2 m and laser-measured ridge elevations up to 0.9 m. EM-measured ice thicknesses in the surrounding dark areas were generally less than 20 cm.

In 1998, over 20,000 video frames were collected from the pack ice in the southern Gulf of St. Lawrence and in Northumberland Strait, where the Confederation Bridge connects the mainland and Prince Edward Island. The bridge cuts the pack ice into small floes (10 - 20 m), as the ice moves back and forth past the bridge in response to tidal currents and wind forcing. The position of the ice area affected by the bridge was monitored by satellite-tracked ice beacons. The different backscatter brightness in RADARSAT imagery near the bridge is related to sub-pixel scale properties seen in the video images. When the small floes converge, the brightness in the RADARSAT image (February 20, 1998) increases relative to unaffected areas. As the small floes diverge and open water appears, the backscatter decreases as low backscatter from the water (light winds) nullified the increase in backscatter due to rough floe topography. Similar ice convergence zones of small wave-damaged ice floes existed at the edge of the pack ice compacted against the coastline. These bright areas in the RADARSAT images were seen in the February 28 image of the southern Gulf of the St. Lawrence and in the March 4 image from the Labrador coast. In both cases, floes were less than 20 m in size and rafted several meters thick in a wide band that appears as bright areas on the SAR images.

The long-term inshore temperature monitoring program continued with increased sampling in the southern Gulf of St. Lawrence mainly through the efforts of the invertebrate fisheries group at the Gulf Fisheries Centre. The long-term sites were maintained on the Atlantic coast of Nova Scotia and in the Bay of Fundy. A new site for a temperature gauge was established in North Sydney.

Maritimes inland waters

Diadromous Fish Division divested to the private sector eight of the nine hatcheries it operated in support of salmonid enhancement in the Maritime Provinces. The eight divested hatcheries continue to produce salmonids in support of the public fisheries resource. They are operated by non-profit organizations. Mactaquac Hatchery and its operations, situated on the Saint John River, New Brunswick, were not devolved because of a long standing legal agreement that obligates the federal government to ensure operation of the hatchery and maintenance of fish passage as compensate and mitigation for the Mactaquac Hydro development project on the river.

Diadromous Fish Division co-sponsored with the Newfoundland Region a special workshop to assess the lower than expected returns of Atlantic salmon to Canadian rivers in 1997. The Workshop concluded that reduced returns were widespread through most North American rivers and common to both one-sea-winter (grilse) and multi-sea-winter salmon. The cause of the low returns was not explained although it was noted that low returns common during the 1990s coincided with cold marine conditions and a shift in the marine ecosystem to favouring the production of cold-water species. Expectations for the 1998 season were for low returns of multi-sea-winter salmon and uncertainty as to the returns of grilse.

Dr. T. Larry Marshall of the Diadromous Fish Division is the Chairperson for the ICES Working Group on North Atlantic Salmon. He assumed this position in April 1997.

Grand Banks, Labrador Sea, Labrador

During April and May, 1996, the Canadian Hydrographic Service (CHS) carried out route and harbour surveys on the south coast of Newfoundland. The purpose of this work was to obtain modern data for electronic charts and provide a safe navigation corridor between communities on the South Coast. Survey areas included Gaultois, Hermitage and Burnt Islands. This is a long term project to improve chart coverage where many locations have never been surveyed and the existing data is more than 100 years old.

During the second part of the survey season, a standard route survey was conducted in the Jeanette and Byron Bay areas of the Southern Labrador Coast. This will result in chart upgrades and improved navigation for the area.

The South Coast of Newfoundland project resumed during May and June, 1997. Work continued in several areas including Gaultois, Hermitage, Rose Blanche, Grey River, Burgeo, Ramea and Burnt Islands.

A ground truthing survey was carried out in the approaches to Voisey's Bay near Nain on the Labrador Coast. This was done to provide quality control for major survey work done under private contract for the Voisey's Bay Nickel Company. CHS has agreed to produce new charts and new editions as a result of this work. In addition, chart revisory surveys were conducted on the Labrador Coast.

Data collection for the third and final new chart of Bonavista Bay series was completed in September and October, 1997. This will enable CHS to cancel a British Admiralty chart in use for over 100 years.

GSC Atlantic is collaborating with companies involved in major East Coast energy projects. For example, with the Hibernia Management and Development Company Ltd, scientists are assessing how faults act as migration routes into petroleum reservoirs and the potential problems they may pose in the eventual draining of the reservoirs. Other collaborations with industry involve the development of innovative three-dimensional seismic interpretation techniques to better image subsurface, paleo-sedimentary systems. This aids hydrocarbon exploration for subtle stratigraphic traps, such as turbidite fan deposits.

Sea Ice Forecasts on the Labrador Shelf - In operational oceanography, the research was focused on development of accurate ocean forecast models for the Labrador/Newfoundland shelves,

and collection of sea-ice data including ice drift, ice melt, ice thickness and ice pressure for model validation. The Princeton Ocean Model was implemented for the Labrador Sea and coupled to a multi-category sea-ice model. This coupled model was used for seasonal simulation of ice distribution and short-term ocean forecast. To demonstrate the operational use of the forecast models, an automated software system integrating the operations of inputting wind data, performing numerical calculation and displaying forecast results was developed. Daily forecasts of ice and ocean conditions were generated. To make the forecasts accessible by the general public, forecast maps and animation were put on DFO Maritimes Region's Internet site. The ocean forecasts were also transmitted to BIO's ships at sea and used by ship personnel to plan their operations. Other potential users include fishing, marine transportation and offshore oil industries.

Labrador Sea - During 1996 and 1997, the World Ocean Circulation Experiment (WOCE) organized a program to observe the full depth circulation of the North Atlantic. Because the Labrador Sea was a known site of oceanic deep convection, it was chosen as a region of special study. Hudson carried out its regular survey of the Labrador Sea section in the spring of 1996 then carried out more extensive surveys in the fall of 1996 and the spring of 1997. During the fall 1996 survey, *Hudson* set a large number of current meter moorings, acoustic sources, acoustic tomography moorings, subsurface and surface drifters and even a large meteorological buoy to monitor conditions over the winter of 1996/97. Some of this equipment was supplied by DFO, Maritimes but much more was set for our German and American colleagues in this experiment. *RV Knorr*, from Woods Hole Oceanographic Institution, surveyed the Labrador Sea during February/March of 1997 as part of this experiment. A team from DFO, Maritimes participated in this voyage, making measurements of the wind and wave fields in order to determine the exchanges of momentum, heat and water vapour between ocean and atmosphere under these extreme conditions. Fortunately, all this observational effort was rewarded when convection to depths of 1400 metres was observed in the western Labrador Sea during March, 1997.

Arctic

BIO scientists from the Ocean Sciences Division took part in ARCTIC 96 on board the German icebreaker *Polarstern*, and in the Joint Ocean Ice Study (JOIS 97) on board CCGS *Louis S. St-Laurent*. Both expeditions were international in scope and both were motivated by concerns regarding global climate and climate change. The ARCTIC 96 expedition explored the eastern Eurasian Basin of the Arctic Ocean, where the flow goes from one of the two major basins of the Arctic Ocean to the other. The JOIS 97 expedition took place in the Canadian Archipelago and in the Canada Basin of the Arctic Ocean.

The Arctic Ocean, far from being an isolated ocean that does not interact much with the other oceans of the world, has recently been found to be quite variable and dynamic. Further, evidence now suggests it to be an integral component of global thermohaline circulation. New findings from these expeditions include the observation of significant changes in the distribution of water masses that have occurred over the last decade and an unexpectedly large number of eddies. These expeditions have further elucidated circulation patterns in the Arctic Ocean, in particular illustrating a double gyre flow in the Canada Basin. With the more complete data sets provided by these expeditions, it is now possible to map the relative distributions of water of Pacific and Atlantic origins in the Arctic Ocean. This has led to an understanding that much of the water in the Canadian Archipelago and along the Labrador coast is of Pacific rather than of Atlantic origin.

Beaufort Sea Research: GSC Atlantic undertook shore-zone studies along the Canadian Beaufort Sea coast, to improve our understanding of coastal evolution in ice-rich permafrost terrain, as a basis for better prediction of coastal response to changing climate. This research was funded under the Green Plan and by Ivvavik National Park. Parks Canada and members of the Inuvialuit community were interested in the impacts of erosion at archaeological sites along the Yukon and Mackenzie coast. Tuktoyaktuk, the only coastal settlement and the dominant port in the area, has a difficult erosion problem. Historical erosion estimates based on air photographs at 10 sites revealed an impressive range of annual rates (from <1 m/year to >10 m/year). The documented high spatial and temporal variance of coastal response demonstrates the need for long-term monitoring at a range of sites as the only viable means of addressing critical scientific and management issues in the Beaufort Sea region.

NATO project for preservation of Russian seismic data: GSC Atlantic released a catalogue of seismic refraction data of the Arctic. In addition to the western data (mainly Canadian and Norwegian), this catalogue makes available for the first time to Western scientists, part of the Russian refraction data from the region. After restrictions on the Russian data were relaxed, GSC Atlantic scientists were invited to help consolidate the records, preserve them in digital from and make them known to the Western geoscience community. The project was funded with a NATO grant as part of an initiative by the International Arctic Science Committee (IASC) to assist in the preservation of unique and costly data collected by the former USSR between 1961 and 1990. The project will enhance Canadian scientific knowledge of the Arctic Ocean and provide information needed for implementation of Article 76 of the Law of the Sea.

Offshore and International

From the Invertebrates Fisheries Division, M. Moriyasu was invited to Japan to establish snow crab survey using the same protocols as in Canada. E. Kenchington was invited to Chile for her expertise on scallop genetics. S. Smith was appointed to US National Research Council Committee on Stock Assessment Methods. Doug Pezzack participated in Stock Assessment Review of US lobster stocks. CHS worked with Nova Scotia Oceans Initiative (NSOI) to develop Law of the Sea and Ocean's related business in Uruguay. The Uruguayan Navy recognizes Canada's leadership in ocean's technology and there is potential for a closer relationship.

Magnetic compilation: GSC Atlantic scientists initiated and led a project with over 40 participating organizations from 14 countries to compile magnetic data of the North Atlantic and the Arctic Ocean and their surrounding landmasses. The entire database, valued at several hundreds of millions of dollars, was merged into one comprehensive digital data set and released on a CD-ROM, together with a comprehensive report documenting the procedures followed in combining the data. The final database will improve our understanding of the resource potential of the continental margins of Canada's Arctic and Atlantic coasts.

GSC secondments to SOPAC : A Memorandum of Understanding between the GSC and the South Pacific Applied Geoscience Commission (SOPAC) provided the framework for cooperation in the geological sciences through scientific exchanges, training, technical assistance and joint investigations on subjects of mutual interest. Two GSC Atlantic scientists were seconded to SOPAC in Suva (Fiji), to supply coastal geological expertise. SOPAC functions as a regional geological survey for 16 island member countries in the central and south Pacific Ocean. In addition to work on a number of regional issues, GSC Atlantic staff were involved in assessing the vulnerability of coastal communities to sea-level rise and other natural hazards (including storm surges and tropical cyclones).

Non-Site specific

The Maritimes' Regional Advisory Process (RAP) office was established on April 1, 1997, Since its creation, the RAP has become the focus of the provision of peer reviewed science to DFO clients on the marine and freshwater populations in the region, many emerging habitat issues and, increasingly, fisheries management approaches and measures. Of particular note during the review period was a workshop on ecosystem approaches to forage species fisheries, the provision of advice on the Middle Shoals Channel dredging project, a workshop to review conservation principles for Atlantic Salmon in Eastern Canada, and a workshop on the management of the Region's herring resources. These were in addition to the 12 or so meetings conducted throughout the year, the majority involving stakeholder participation, to assess the region's 120 aquatic resources. The Secretariat coordinated the meeting schedule, processed the documents produced by the meetings and distributed these to stakeholders. It has thus also become a key communication vehicle for Science in the Region.

A joint study with NOAA and the Atlantic zone regions of DFO has analysed the accumulated groundfish survey data sets from 1970 to 1994 from Cape Hatteras to the Davis Strait in order to describe assemblages and biogeography of the demersal fishes of the east coast of North America. The study is unique in its geographical scope, being based on over 20 years of travel data. At a time when ecosystem approaches to management of fisheries are being promoted, the study represents a first attempt to examine ecosystem patterns at a spatial scale which properly addresses the distribution patterns of demersal marine fishes. Fish assemblages identified by several methods were spatially coherent. However, the statistical analyses explained about half of the variance in distribution of the species, indicating that the assemblages should be interpreted as indeterminate, potentially adaptable entities, rather than rigid ecological constructs. Assemblages were persistent in composition through time, but appeared to shift in location. The apparent looseness of the assemblages and their persistence through time, in spite of severe impacts from fishing on some species, suggests that single species management approaches may not be entirely inappropriate for the major groundfish species in the study area.

Massive interannual fluctuations in the abundance of marine fish populations are commonly observed, but are often difficult to explain. According to the current paradigm, a survival advantage goes to fish growing quickly through a "mortality window", a period of several months during which as much as 99.99% of a cohort may die. By taking advantage of the daily growth record encoded in the otoliths (earstones) of young cod, a Marine Fish Division scientist reported the first direct evidence of a link between juvenile growth and mortality rates in a wild marine fish. Reconstruction of the daily growth history of 5 year-classes of cod demonstrated that the growth trajectories were highly correlated with the survival rate to the adult stage. Differences in growth rates and associated exposure times to high larval mortality rates were sufficient to account for much of the 400% difference in adult abundance among the cohorts.

Storm Impacts on the Coast: Hurricane Hortense struck the Nova Scotian coastline in September 1996, causing damage to several coastal communities. The last hurricane landfall in Nova Scotia occurred in 1975 and residential development along the coastline has increased considerably since then. GSC Atlantic scientists examined the impact of Hortense on the coast and beaches of Nova Scotia. Strong winds combined with high tides during Hortense produced a storm surge of 1 m and a maximum significant wave height of almost 9 metres. Physical impacts of Hortense were measured at several sites near Halifax. Gravel and sandy barrier beaches enclosing lagoons were most severely affected. Some low barrier beaches were pushed landward 10 to 20 metres during the hurricane. Higher beaches backed by dunes or gravel ridges were less severely affected by minor scouring of the seaward duneline. Sequential surveys of the same shore sites illustrated their post-storm recovery and the resilience of different shore types to major storm events. Continued monitoring and surveying will enhance emergency preparedness, and lead to a better understanding of shoreline dynamics and stability.

Climate change: Paleoceanographic studies at GSC Atlantic have focused on providing data for the Climate Systems History and Dynamics Program which is directed to improving Canadian capability in developing global scale climate models (GCM's) and in predicting the future environment. Reconstruction of climate and ocean environments 6,000 years ago (6 ka) has been chosen as the major target of paleoclimate simulations and for inter-comparison of GCM's. Marine microfossils from 67 sediment cores were used to determine sea surface conditions at this time in the Eastern Canadian Arctic and the Atlantic region. At 6 ka, most sub-regions appear to have been warmer than now. In the Eastern Arctic, moving ice replaced the present permanent polar pack ice, subarctic East Greenland water penetrated into northern Baffin Bay and a larger volume of Labrador Shelf water probably flowed into Foxe Basin. On the Labrador and Newfoundland margins, relatively warm Labrador Current water filled shelf basins and reach outer fiords. On the Grand Banks and Scotian Shelf, basins were filled with Warm Slope Water and coastal waters were also warmer. Offshore, there appears to have been more frequent mixing of subtropical Gulf Stream and temperate North Atlantic Drift waters around the Grand Banks and in southern Labrador Sea, but there is no clear record of warming in the NE Labrador Sea.

Law of the Sea: Studies by GSC Atlantic and CHS are intended to determine the offshore area over which Canada could have sovereign rights when it ratifies the United Nations Convention on the Law of the Sea (UNCLOS). Under UNCLOS, Canada's sovereign rights could extend well beyond the minimum 200 nm limit, particularly in the Atlantic and Arctic Oceans. Article 76 specifies how a coastal state may define the area of its continental margin over which it can exercise sovereign rights for the purposes of exploring it and exploiting its natural resources. Using these criteria, CHS and GSC are compiling available bathymetric data in the Atlantic region and investigating its accuracy and completeness to determine whether it is sufficient to define the outer limits of the Canadian continental shelf or whether, and if so, where, additional surveys are required.

Coastal sediments and the human factor: To understand the processes that transfer waste materials from land to sea, GSC Atlantic carried out studies in marine environments associated with major urban centres: Halifax Harbour, and the Fraser Delta (Vancouver). Identical methods were used to collect sediment cores and to measure sedimentation rates and metal concentrations. Natural and anthropogenic (human) sources and sinks, regional geometry, water budgets and tides are different in each area. Halifax Harbour has poor water circulation, allowing high levels of zinc, copper, lead and cadmium to accumulate. For Vancouver, these are substantially lower because effluent processing is better and because the large volume of natural sediments supplied by the Fraser river dilutes the anthropogenic materials to such a degree that they are below the detection limit. These two projects are providing information that will be used by local agencies to monitor and manage effluent discharge.

The Canada Oceans Act - The Oceans Act, passed by Parliament in December 1996, outlines Canada's duties and responsibilities in its oceans territories and introduces a new oceans management model - a model based on collaboration among stakeholders and on the principles of sustainable development, integrated management and the precautionary approach. The Maritimes Region, DFO, Oceans Act Coordination Office has been established to lead and coordinate delivery of DFO's responsibilities under the Oceans Act.

The Oceans Act comprises three parts:

- Part I - defines the oceans area under Canada's jurisdiction and asserts Canada's management and protection rights and responsibilities;

- Part II - assigns the Minister of Fisheries and Oceans the responsibility, in collaboration with other federal departments and agencies, provincial and territorial governments, affected Aboriginal org anizations, coastal communities, and other persons and bodies..., to lead and facilitate development and implementation of a national strategy for the management of estuarine, coastal, and marine ecosystems. Part II describes the specific tools that may be used to give effect to an oceans management strategy:

    * plans for integrated management of all activities or measures in or affecting estuaries, coastal water and marine waters;
    * marine environmental quality guidelines; and
    * marine protected areas.

- Part III - outlines the powers, duties, and functions of the Minister of Fisheries and Oceans, including the responsibility to provide Coast Guard and Hydrographic services, and marine services (including carrying out scientific research).

The approach envisioned in the Oceans Act means collaboration with other government agencies, other levels of government and stakeholders, seeking partnerships, and supporting stakeholders in resolving conflicts at the planning stage.

A number of initiatives in support of the Oceans Act were undertaken throughout 1996, including:

- development of background documents on development of a national oceans strategy;

- early drafting of a discussion paper on integrated coastal zone management;

- public discussion on the provisions of the Oceans Act and how they can used for oceans management and conservation.

Coastal resource mapping programs were continued throughout 1996. These maps, identifying valued coastal resources, were often developed in partnership with coastal community organizations and are an important tool for integrated coastal management and planning.

The Oceans Act Coordination Office (OACO), Maritimes Region, was established in October 1997. The OACO has responsibility for leading the Region's participation in the development of the Oceans Strategy and for leading and coordinating implementation of the Oceans Act in the Maritimes Region. The OACO serves as the focal point for Maritimes Region's stakeholders dealing with the Oceans Strategy and implementation of the Oceans Act. The Office is also coordinating Maritimes Region's participation in International Year of the Ocean events in 1998.

The Oceans Act commits the Government of Canada to a new approach to managing oceans: an approach based on principles of sustainable development, integrated management and the precautionary approach. The Oceans Act assigns DFO the responsibility to lead and facilitate the development of Canada's national Oceans Strategy and lead the integrated planning and management of oceans activities involving all stakeholders. The Act provides for the development of the policies, processes and tools, including marine protected areas and marine environmental quality guidelines, to implement the Oceans Management Strategy.

During 1996 and 1997, the Canadian Hydrographic Service continued to increase its coverage of Electronic Navigational Charts (ENC). Recognized as a major improvement in navigation safety and efficiency, ENCs are quickly becoming a standard on large commercial vessels in Canada and the world. To meet the requirements of the International Hydrographic Organization (IHO) and the International Maritime Organization (IMO), the CHS has now begun a major campaign to convert all ENCs to S57 format. This generic and non-proprietary format will provide an international standard for marine navigation.

Multibeam sonar technology has matured during recent years. It has reached a stage where it can be used as a regular data collection tool. Data sets, such as the Brown's Bank Survey, have generated a great deal of interest and enthusiasm among groups such fishers, geologists and habitat managers. The veil has been lifted and they are able to see detail never before possible. The Canadian Hydrographic Service with the support of Natural Resources Canada is continuing to refine data collection, processing and related software. This technology represents a revolution for hydrographic surveying, ocean exploration and resource management.

APPOINTMENTS

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

- Michael Chadwick was appointed editor of *ICES Journal of Marine Science* and member of NSERC Interdisciplinary Committee and chair of *Site review committee*.

- Stephen Smith appointed Associate editor of *Canadian Journal of Fisheries and Aquatic Sciences*.

- Allyn Clarke was appointed in 1996 as Co-Chair of the Scientific Steering Group for the Climate Variability and Predictability Progamme (CLIVAR) of the World Climate Research Program (WCRP).

- Allyn Clarke was appointed Member of the Oceanography Committee of the International Council for the Exploration of the Seas (ICES)
- Ken Drinkwater was appointed Chairman of ICES Cod and Climate Change Working Group.

- Peter Jones was appointed (April 1997) member of the World Climate Research Program (WCRP), World Meterological Organization (WMO), Scientific Steering Group - Arctic Climate Systems Study (ACSYS).

- Trevor Platt was appointed Chairman/International Ocean-colour Coordinating Group

- David Piper, a senior research scientist at GSC Atlantic, has been appointed as the third Editor-in-Chief of *Marine Geology*, one of the leading international journals in marine geoscience. Dr. Piper has just completed a five-year term as Editor of the Canadian Journal of Earth Sciences, the leading *Canadian journal in the Earth Sciences*.

- Gordon Fader: The Halifax Regional Council approved the appointment of Gordon Fader of GSC Atlantic to the Halifax Harbour Solutions Stakeholder Advisory Committee. The committee will advise the Halifax Regional Municipal Council on the selection of appropriate approaches to providing wastewater treatment for Halifax Harbour and provide recommendations which will lead to a final solution to the long standing problem of sewage disposal in Halifax Harbour.

CONFERENCES AND WORKSHOPS

During the review period, several major conferences and workshops were held at, or sponsored in whole or in part by one or more of our laboratories:

- In 1997, BIO hosted a meeting of one of the panels of the Ocean Drilling Project. The meeting was held concurrent with a visit of the ODP drill ship to Halifax.

- As part of the outreach activities of GSC Atlantic, staff were instrumental in organizing the annual EdGEO workshops to help teachers understand, and later teach earth science concepts.

- In 1996, the 22nd annual Aquatic Toxicity Workshop was held in St. Andrew's NB

- In 1996, April 10-19 the ICES Working Group on North Atlantic Salmon held in Moncton NB

- In 1996, October 22-25 - Oceans Optics III held in Halifax, NS

- Workshop on Harmful Algae Research in the DFO Maritimes Region, Gulf Fisheries Centre, Moncton, NB, June 19, 1996. Proceedings published as: Bates, S.S. and P.D. Keizer. 1996. Proceedings of the Workshop on Harmful Algae Research in the DFO Maritimes Region. Can. Tech. Rep. Fish. Aquat. Sci. 2128, 44 p.
- The Canadian Hydrographic Conference "CHC '96" was held at the Halifax World trade and Convention Centre from June 3rd to 6th, 1996
- Notable events held at or sponsored by St. Andrew's Biological Station:
- Gulf of Maine Ecosystem Dynamics: A Scientific Symposium & Workshop (16-20 Sep 96)
- Convened by the Regional Association for Research on the Gulf of Maine (RARGOM). Hosted by the Biological Station at the Algonquin Hotel, St. Andrews.
- CANUSLANT '96 exercise (23-24 Sep 96) The Biological Station served as Command Centre for these two days for this mock oil spill exercise involving government (federal, provincial, state) and industry officials from Canada and USA.
- 13th Canada/US Fisheries Discussions (8-10 Oct 96) held at SABS. These are informal discussions held every 2-3 years between Canadian and USA federal fisheries agencies providing fisheries science in support of resource management. The themes of the '96 discussions were fisheries input data (present and future in both countries) and transboundary fisheries resources in the Gulf of Maine.
- Infectious Salmon Anemia/Hemorrhagic Kidney Syndrome (ISA/HKS) Research Workshop (5 Nov 97). Sponsored by the HKS Industry Committee, held at SABS
- Maritime Atlantic Ecozone Science Workshop (11-15 Nov 97) - Quoddy Ecological Monitoring and Assessment Network (EMAN), Bay of Fundy Ecosystem Project, sponsored by Huntsman Marine Science Centre, held at SABS

PARTNERING AND TECHNOLOGY TRANSFER

Partnering and technology transfer events and highlights during the review period rose in number and complexity and included the following:

DFO Science : more than 80 partnering arrangements were in place in 1996 and 1997 in the DFO Maritimes Region's Science Branch. These agreements with industry members, public bodies, international institutions and academia generated contributions of the order of $6,5 millions in

1997 from partners. Partnering and technology transfer events and highlights during the review period included the following:

• In April 1997, a 5 year Joint Project Agreement was signed between five snow crab fishermen associations representing the 160 snow crab fishers from Quebec, New Brunswick, Prince Edward Island and Nova Scotia from the Gulf of St. Lawrence Snow Crab Fishing Areas 12, 25 and 26 and Fisheries and Oceans Canada. Industry contribution to research (direct and transferred funds to DFO) reaches $647 000 yearly while Science contribution is $318,000 per year. The research is conducted by a team under the direction of Dr. Mikio Moriyasu at the Fisheries Research Center in Moncton. This Joint Project Agreement is part of an Integrated Management Plan also in place until 2002.

• A collaborative experiment on field evaluation of bioremediation for mudflats was initiated in April 1997 between Fisheries and Oceans and IFREMER(France), AEA(UK) AND TNO(Netherlands). The experiment is conducted within a controlled mesocosm experiment with fine sediments to evaluate the potential of nutrient enhanced bioremediation strategies to cleanup contaminated residues. The European Economic Community is providing financial ($300,000) and human resource support while DFO is providing the expertise of Dr. Ken Lee from the Maurice Lamontagne and Bedford Institutes. The project team identified the limiting factors to the biodegradation of oil on mudflats and evaluated operational strategies to enhance natural removal rates and thus reduce the residence time of oil following a spill incident. In terms of fisheries impacts, this study included a comprehensive monitoring program to assess the impact of treatments on naturally occurring invertebrate species. Appropriate cleanup strategies for mudflat environments will be recommended to oil spill response organizations.

• As part of the WOCE Program a collaborative project between Fisheries and Oceans, the University of Rhode Island and the U.S. Office of Naval Research was initiated in May 1996 to measure the evolution and distribution of water properties of the Labrador Sea over the 1996/97 winter. U.S. bodies invested close to $440,000 in the project while Fisheries and Oceans contribution reached $576 000 until the end of the project in May 1998. Dr. Allyn Clarke is project leader from Fisheries and Oceans at BIO. The collaboration allowed an array of sound sources to be moored within the Labrador Sea to serve as an acoustic navigation system covering the Northwest Atlantic. This system was used to position a large number of subsurface drifters that were deployed in the region over the following 12 months.

• Laboratories and expertise from the Bedford Institute were made available again to Brooke Ocean Technology Ltd. from Dartmouth, N.S. in 1997 and 1997 to design, construct and test a Moving Vessel CTD with the assistance of Dr. Alex W. Herman's team. Dr. Herman is well know for his regular contribution to technology transfer in the area of ocean science technology.

• A project to produce seafloor maps and images of Brown's Bank for fisheries habitat management, navigation charting and geological mapping is being executed by the Canadian Hydrographic Services at the request of the local Scallop Seafood Industry Ltd following a marketing agreement with Nautical Data International from St. John's, Newfoundland. This project initiated in 1997 will make data on sea floor mapping available to the fishing industry and other potential clients on CD format.

• The aquaculture team within the Region continues to make valuable contributions to industry partners via direct technology transfer with funding from the Canada-New Brunswick Cooperation Agreement on Economic Development for alternative aquaculture species, focusing on haddock and halibut broodstock development, larval rearing, larval nutrition and diet formulation, and fish health diagnostics; scallop and clam larval dynamics and recruitment enhancement; and shellfish disease and parasites . During 1996, a joint project on rearing of transgenic Atlantic Salmon was completed in partnership with A/F Protein Canada Inc. and during 1996-97 a project to develop mass production techniques for juvenile halibut was conducted in partnership with Maritime Mariculture Inc. We are also involved in matching investment fund research projects with members of the shellfish aquaculture industry through the PEI Aquaculture & Fisheries Research Initiative, examining methods to improve aquaculture of clams, mussels and oysters.). Applied salmon aquaculture research continues in conjunction with industry partners examining the effects of cage lighting on fish maturation and grilsing.

• The Canadian Hydrographic Service was very active in developing partnering arrangements to collect multibeam sonar data on the Scotian Shelf and improve charting on the Labrador Coast. A joint project was conducted with Seabed Exploration Associates, in 1997, to transfer technology and collect multi-beam imagery for a proposed gas pipeline across the Scotian Shelf. A long term joint project began with Voisey's Bay Nickel Company to quality control surveys and produce new charts for Voisey's Bay, Labrador. Negotiations were completed with Nautical Data International to support the processing of Brown's Bank multi-beam data and to market and develop resulting products.

• Sri Lanka: The GSC Atlantic, at the request of the United Nations Revolving Fund for Natural Resources Exploration, carried out a nearshore survey for heavy minerals off the coast of Sri Lanka. In a collaborative venture with Canadian Industry, the team utilized Seistec, a Canadian seismic reflection system, ideally suited to image coarse sediments in shallow water. The survey, which was fully cost recovered, achieved its goals in mapping potential economic deposits and identifying sites for future core sampling and resource evaluation.

• Equipment rental: GSC Atlantic has unique marine equipment which is available to external partners under certain arrangements. International requests for scientific collaboration often involve usage of this specialised equipment. Under an agreement, GSC Atlantic can make this equipment available to industry to enable them to tender a contract. For example, GSC Atlantic made its ocean bottom seismometers available to the Canadian company Geoforce, so it could bid on a contract with the British Antarctic Survey to conduct surveys in the South Atlantic.

Fishermen and Scientists Research Society

The Fishermen and Scientists Research Society (FSRS), a non-profit organization, is an active partnership between fishermen and scientists, developed with the overall objective to establish and maintain a network of trained fishing industry personnel to collect information relevant to the long-term sustainability of the marine fishing industry in the Atlantic Region, as well as to facilitate and promote effective communication between fishermen, scientists, and the general public. More specifically, the purpose is to form a partnership between fishermen and scientists to increase interaction, communication and cooperation in the areas of:

- participation of fishermen in the stock assessment process;
- enhancing the stock assessment process by making available information that only the fishermen can obtain on a daily basis;
- developing a better understanding of the others in the FSRS; and
- participation of fishermen in the development of a sound information base, with the key objective being to contribute to more effective resource management.

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:

- Dr. Raquel Guerstein of the Universidad Nacional del Sur, Bahia Blanca, Argentina, visited GSC Atlantic for one year, funded by an Argentinian fellowship to work on biostratigraphy.
- During 1996-1997, GSC Atlantic hosted over 75 visits from oil industry. The companies generally ask to be briefed on the activities off Canada's Atlantic coast, and specifically on the GSC's site specific studies, such as the hydrocarbon charge modeling of the Hibernia drainage and environmental studies concerning offshore hazards.

Notable visitors to SABS:

- Liberal caucus task force on aquaculture (led by George Rideout) (5 Nov 96)
- Jim Barkhouse, NS Min of Fisheries & Aquaculture (20 Jun 97)
- Kevin MacAdam, PEI Min of Fisheries & Environment (20 Jun 97)

- delegation of Norwegian scientists invited by NBDFA for discussions on the Infectious Salmon Anemia problem (28 Nov 97) (Tor Håstein, Knut Falk, Tyrgve Poppe, Are Nylund, Yngve Torgersen, Martin Binde, Asgeir Østvik)

- Gilbert Normand, Federal Secretary of State for Fisheries (5 Sep 97)

Visitors to BIO 96-97:

- July 15, 1996 - FRCC Chair Fred Woodman

- August 27, 1996 - 20 Fellows from the Centre for International Affairs, Harvard University visited BIO where they received a presentation on BIO's Scientific Exploration in the Atlantic & Arctic Oceans.

- March 21, 1997 - His Royal Highness, Prince Phillip chaired a World Wildlife Fund Workshop at BIO on Endangered Species.

- July 4, 1997 - DFO Minister, David Anderson, visited BIO and participated in the Employee Awards Presentation Ceremonies. (Deputy Minister's Commendation & Merit Awards)

- September 3, 1997 - Honourable Gilbert Normand, MP and Secretary of State for Fisheries & Oceans and Agriculture and Agri Food visited the Institute.

FACILITIES AND SUPPORT SERVICES

PUBLICATIONS

The establishments reach their respective clients and customers through a variety of means, including journal articles, reports and nautical charts. During 1996 and 1997, the published output of the establishments continued at a high level. Selected highlights are noted below:

- Among the New Charts and New Editions produced by the Canadian Hydrographic Service in 1997, two particular products have a special significance. These are:

- New Chart 4854 Catlina Harbour to/à Inner Gooseberry Islands

- New Chart 4855 Bonavista Bay Southern Portion/Partie Sud

- Representing years of effort in data collection and compilation, these new products replace British Admiralty charts based on hydrographic surveys dating back to the late 1800's. Published in coincidence with the Cabot 500 Celebrations and the opening of the Marine Interpretation Centre in Terra Nova National Park, Newfoundland, these charts are a welcomed improvement for the marine community.

- a handbook on striped bass culture was published in 1996: PETERSON, R.H., D.J. MARTIN-ROBICHAUD, P. HARMON, AND Å. BERGE. 1996. Notes on striped bass culture, with reference to the Maritime Provinces. Department of Fisheries & Oceans, Communications Branch, Halifax NS, ii + 35 p. (aussi disponible en français)

- one notable publication by a SABS employee was a book co-authored by Dave Wildish: WILDISH, D. and D KRISTMANSON. 1997. Benthic suspension feeders and flow. Cambridge, UK: Cambridge University Press. 409 p.

ToC

Cutting Edge Sonar Technologies Explored For Pelagic Stock Assessment

ToC

N.A. Cochrane

Introduction

Those readers who have used vertical beam echosounders or fish finders have probably been impressed by the visibility of fish echoes. During the past 30 years academic and industrial effort has developed the conventional vertical beam acoustic echosounder into an increasingly useful tool for both measuring total fish stock biomass and for counting and characterizing individual fish echoes using so called "dual beam" and "split beam" techniques. This year (1998) has seen the first official use of conventional echosounding in Maritime Region in assisting herring stock estimation.

While presently useful for stock assessment acoustic techniques and methodologies can still be refined. Application of "conventional" acoustic survey methods to pelagic herring stocks present two special difficulties: First herring schools can be sufficiently small and widely dispersed that they are only infrequently encountered during an acoustic survey. For example, herring schools of 10's of meters size spaced 100's of meters apart will be encountered during about 1% of the total survey time when using a narrow vertical beam echosounder. Unless one has the resources to run many survey lines across a fishing ground, fish population estimates may be imprecise since only a small and possibly unrepresentative sample has been glimpsed. The second problem involves fish behaviour. Herring hear well and are known to swim away from the rumble of approaching ship engines. Again this is a problem for the traditional survey echosounder which "sees" only directly beneath the vessel - a problem particularly difficult to quantify.

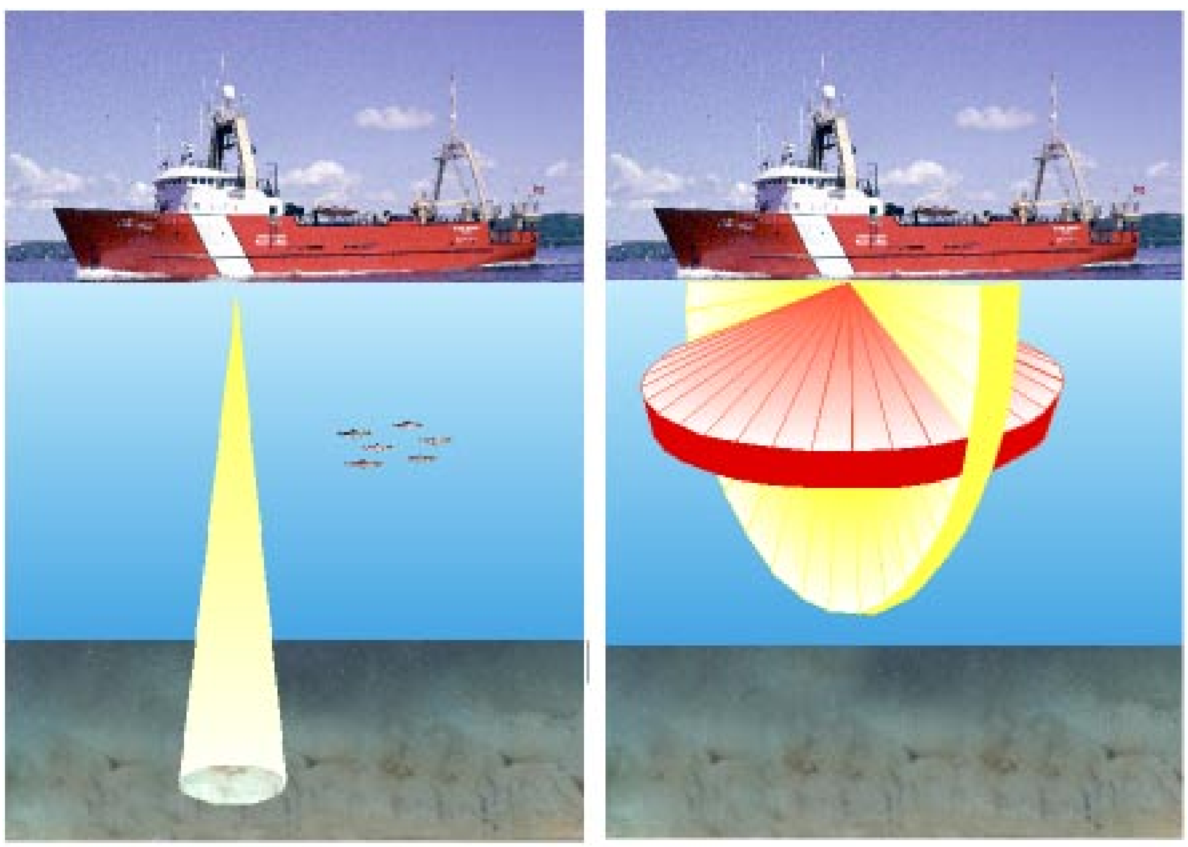


Figure 1: Conventional echosounder vs sonar spatial coverage.

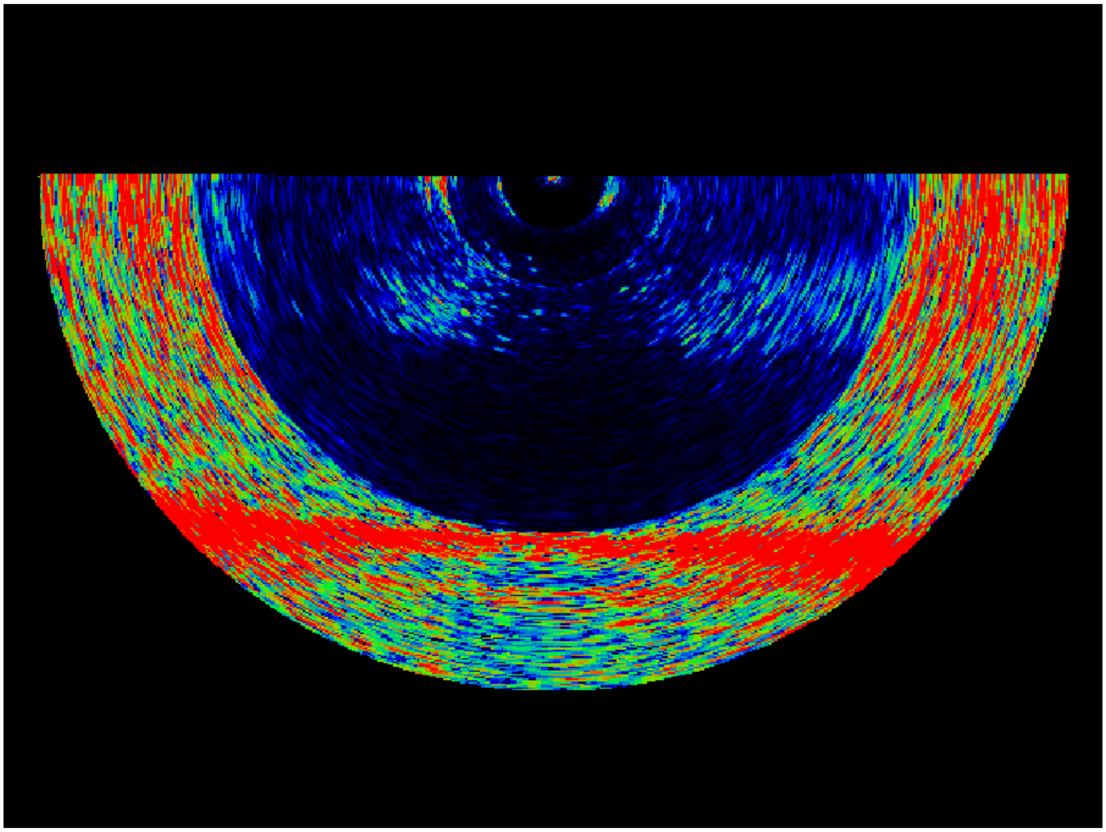


Figure: 2. Herring echoes (elongated dots on black background) recorded on German Bank in a single vertical multibeam section. Total range about 70 m. Outer "ring" consists of noise reflected off-bottom (horizontal red line about 2/3 of distance from lower edge).

Field Program

Early Work

Beginning in the summer of 1995 DFO fishery's scientist Gary Melvin, of the St. Andrews Biological Station, and myself, an acoustician at the Bedford Institute of Oceanography, began to explore sonars designed to look both outwards as well as downwards from a vessel as a potential way to improve acoustic estimates. For example, use of a sideways looking sonar operating in a port - starboard "vertical slice" mode (Fig. 1), results in a much wider survey track than use of a vertical beam echosounder. Our first field deployment was of a SIMRAD MS 900 330 kHz scanning sonar operating off Margaretsville in the Bay of Fundy. In this "scanning" type sonar the sound emitting transducer was mechanically turned over a series of orientations, some far off the vertical. First results were encouraging with herring schools being observed in some detail to ranges of 70 - 100 m, The summer of 1996 brought further tests of the MS 900 both in the Bay of Fundy using the J.L. HART and on German Bank using DFO's acoustic research trawler TELEOST. The following months saw development of quantitative processing algorithms at BIO and the application of advanced data visualization techniques by the Dept. of Geodesy and Geomatics Engineering at UNB lead by Larry Mayer and grad student Yanchao Li. Discovered was a tendency for the survey vessel to repel fish downward and outward from the survey track, findings communicated at the OCEANS' 97 scientific conference.

A scanning sonar like the MS 900 requires a relatively long time to map a vertical "slice" or section. First an acoustic sound pulse is sent out; echoes are waited for, received and recorded; then the transducer moved to a slightly different orientation and the process repeated until the section around the ship has been fully defined. With a ship in rapid forward motion the "vertical slice" operational mode samples only an undulating 2-D surface within the 3-D ocean volume, a much sparser sampling than desired. Fortunately, technology comes to the rescue with new "multi-beam" sonars which deliver both rapid and complete 3-D coverage. In a multi-beam sonar a fixed acoustic transducer is divided into a number of independent electrical components or "elements". Sound signals received by individual elements are electronically combined so that a large number of sonar beams can be simultaneously "synthesized", each beam pointing in a different direction so as to enable extremely rapid imaging of a space around a vessel. Multi-beam sonars for commercial fish-

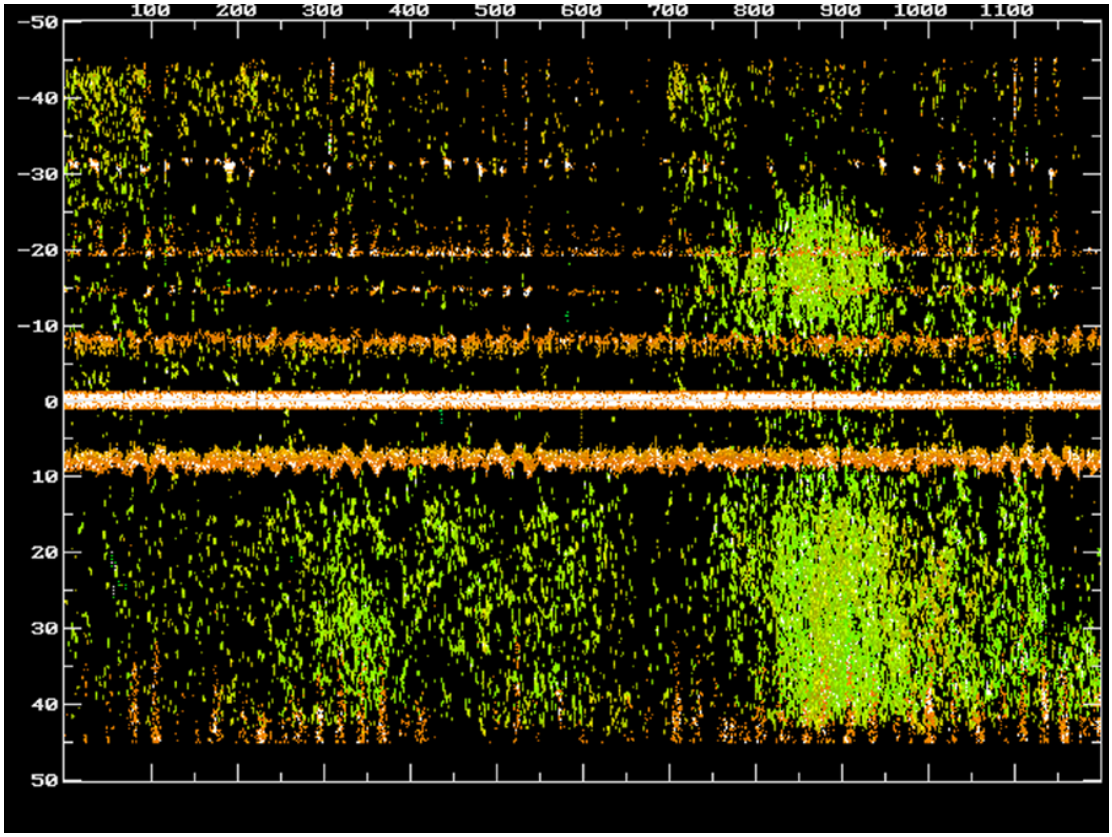


Figure: 3. Horizontal distribution of herring along German Bank survey line as viewed from above. Granularity results from resolution of individual fish.

ing applications have been available for some time but few incorporate scientific precision or provision for extracting and logging data.

During 1996 valuable experience was gained with TELEOST's 24 kHz Simrad SR 240 multibeam sonar. This afforded a fairly low resolution view (11° beamwidth) of herring schools about the vessel out to about 200 - 300 m using either a vertical slice or a 360° circular umbrella-like coverage pattern (Fig. 2). At BIO, acoustic models were used to examine the effects of refraction, the bending of sound waves as they move obliquely through water layers of differing sound speed. Refraction affects only oblique angle sonars - not vertical beam sounders. In extreme cases the apparent size and depth of fish schools can be severely distorted or some schools may become completely undetectable. Distortion of sonar images was shown to be substantial at ranges of several hundred meters, especially in the early summer when large temperature changes occur at depths just below the transducer. While results with the SR 240 sonar were encouraging the need existed for a higher resolution multi-beam type unit with the quantitative outputs lacking on the SR 240.

Recent Work

After the 1996 field season word was received that Simrad's Mesotech Div. in Port Coquitlam, B.C. was completing development of a 200 kHz high resolution multi-beam sonar which seemed applicable to our studies. A trial of the new SM 2000 was conducted on a German Bank survey in September 1997. Impressive results were obtained in "vertical slice" mode consisting of 180° port-starboard sweeps at 1.5° resolution repeated up to 5 times a second with digital data recording. Development of off-line beamforming and display and quantitative processing software quickly followed at BIO along with theoretical studies of beam characteristic for different processing options.

Fig. 3 shows a post-processed view, looking down from above, of the horizontal distribution of fish to 50 m port and starboard (Y-axis) of the central tow track (zero of Y-axis, the sonar being towed about 10 m Port of the vessel). The X-axis extends over 750 m of profile and is labeled in acoustic transmission number. Of particular interest is the apparent splitting of a herring school starting near transmission # 800 with a "clear" lane running just under the sonar. This probably represents an avoidance reaction to the engine and propellor noise of TELEOST. The portion of the school originally lying starboard of the ships path, has been split off and repelled further to starboard. The school fraction lying directly ahead of the vessel, which may have been partially shielded from vessel noise, passes with less disturbance under the vessel. One seeks to understand such avoidance effects since they may influence the quantitative accuracy of ship-based vertical beam echosounder assessment.

In May 1998 an SM 2000 purchased by the Pelagic Research Council with DFO assistance was fielded near "The Patch" on the central Scotian Shelf. Use of a seperate transmit transducer reduced the fore-aft beamwidth from about to 20 to 1.5° extending high resolution to fore-aft as well as port-starboard. It was now possible to resolve individual echoes from fish packed 10 times as densely as previously and to observe delicate spatial details such as the hollow "bee hive" shape of individual herring schools. This recent data is still being evaluated.

Future Directions

In spite of progress in hardware and signal processing tough challenges confront routine sonar use in stock assessment. In particular, the strength of sonar echoes far off the vertical depend strongly on fish orientation or swimming direction - which is not the case for an ordinary echosounder. While statistical signal averaging techniques mey ease the problem the greater volumes of data required could somewhat compromise the inherent efficiency of sonar use. At the very least, school numbers, areas and volumes over wide survey swaths can be extracted as keys to abundance. Potential also exists for the direct counting of some pelagic fish echoes over successive overlapping vertical sections, a new and exciting form of assessment where applicable. A realistic short-term goal is accurate definition of fish-vessel avoidance and relating this to vessel noise characteristics and fish behaviour. Ultimately, ship avoidance corrections for conventional echosounder surveys may formulated or survey criteria defined (e.g. depth ranges, or times of day, proximity to spawning) to minize avoidance effects.

Acknowledgments

Special thanks should go to DFO personnel Gary Melvin of SABS, who has been a partner in this work from its inception, and Chris Stevens of NWAFC, who has facilitated the use of TELEOST and its systems. These studies have been supported by Kongsberg Simrad-Mesotech Ltd., especially acknowledged is Mr. John Gillis of Simrad's Dartmouth office. The Pelagics Research Council furnished equipment and personnel for the 1998 field season. Funding has been provided through DFO's National Acoustics Program.

Improving the Skill of Search-and-Rescue Forecasts

Peter C. Smith, Donald J. Lawrence, Keith R. Thompson, Jinyu Sheng, Gilles Verner, Judy St. James, Natacha Bernier and Len Feldman

ToC

Introduction

The success of a marine search-and-rescue (SAR) operation depends on timely and accurate information about surface drift on the ocean. The Canadian Coast Guard's Rescue Coordination Centre (RCC) has the responsibility for obtaining this information and using it to plan the search operation. The primary planning tool used by the RCC is known as the CANSARP system. To predict the motion of a SAR object from its last known position, this system uses a combination of background surface current maps based on historical observations, a simple model estimate for the wind-driven component of surface current, and empirically-derived leeway factors (additional surface drift due to wind acting on exposed surfaces). Driven by forecast winds from the Canadian Meteorological Centre (CMC) and using the estimated uncertainties in the leeway factors, CANSARP predicts a range of possible drift trajectories (Figure 1) from which the search area is defined to encompass the most probable locations of the object. Accurate information is critical during the early hours of a SAR response because:

- the forecast errors and hence the search area grow rapidly with time, and
- under extreme conditions (e.g. severe winter storms, frigid waters), the risk to human life also increases dramatically as time passes.

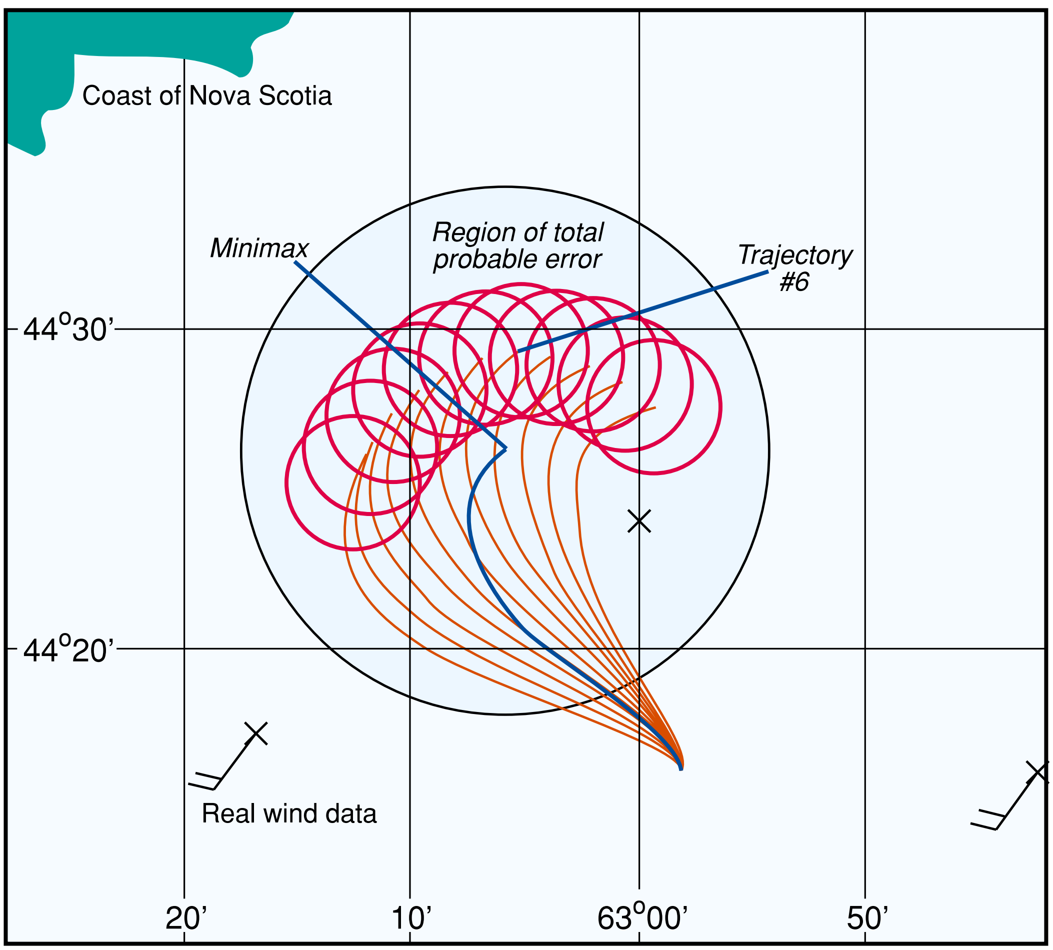


Figure 1 Sample CANSARP drift predictions. The larger circle represents the region of total probable error, which encompasses all of the trajectory end points and their errors (Verner et al. *1998)*

Clearly then the success and cost of search-and-rescue operations depends heavily on the short-term forecast skill of CANSARP.

To improve the forecast skill of CANSARP, a research and development project was undertaken jointly by the Canadian Coast Guard, the CMC, Dalhousie University, and the Bedford Institute of Oceanography. The program was designed to test improvements to both the wind and surface current fields, using the observed drift rates from a mid-winter field experiment on the Scotian Shelf as a standard against which to compare various model calculations, including: CANSARP driven by a) standard or b) high-resolution CMC winds, and c) a new Dalhousie University ocean model.

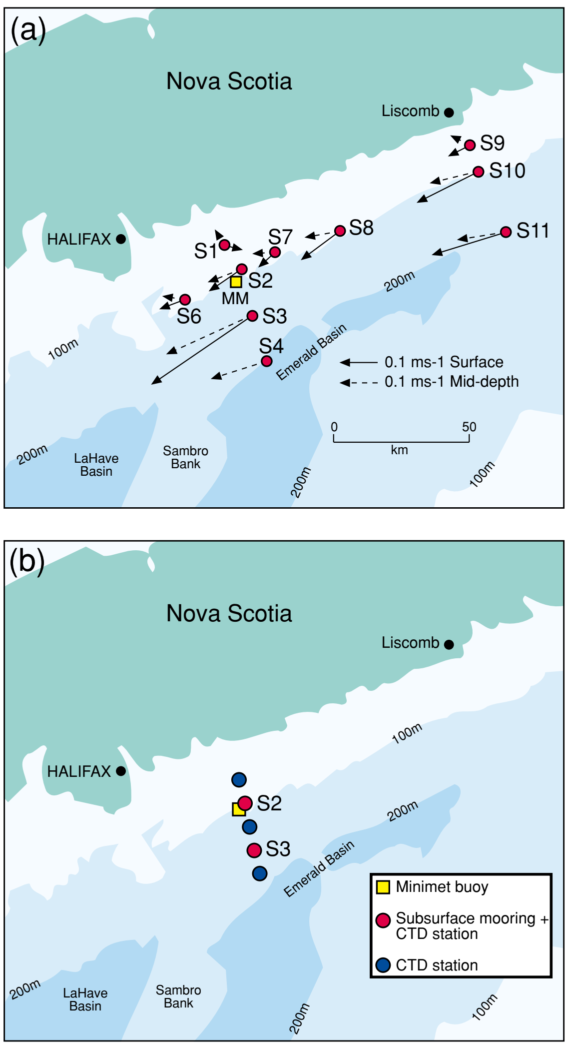


Figure 2 a) Mean current observations 1985-1986. b) Mooring and primary CTD line locations for the CANSARP field experiment, February, 1996.

The Field Experiment

Description

The CANSARP field experiment was conducted on the Scotian Shelf off Halifax in February, 1996. Based on experience from the earlier Canadian Atlantic Storms Program (CASP; Anderson and Smith 1989), the CANSARP experiment included a small array of two current meter moorings and a MINIMET meteorological buoy (Figure 2b), weekly hydrographic measurements, and deployments of clusters of surface drifters along the mooring line. The CASP experiment had revealed that the strongly sheared mean surface flow of the Nova Scotian Current lay roughly between the 100 and 170m isobaths (Figure 2a), and that severe winter storms dramatically disrupted this picture as they passed over the area at a rate of twice per week. Therefore, the weekly CANSARP drifter trials were expected to show significant effects of current- and wind-driven variability.

Five different types (or configurations) of surface drifters were used in these trials (Figure 3a). The SEIMAC Accurate Surface Tracker (AST) is a barrel-shaped drifter with 80 cm draft and a small mast protruding above the surface. Its drift characteristics (i.e. leeway) resemble those of a person-in-water and are well known from previous studies. SEIMAC's Convertible Accurate Surface Trackers (CAST) were equipped with drogues centred at 15 m (the depth of the shallowest moored current meters), and were intended to track the currents at that depth. Finally, three more realistic SAR objects were also used: a small dory (5.2 m) ballasted with 159 kg and tethered to an AST for tracking, and ballasted 6-person and 4-person liferafts, with and without sea anchors. Most of the ASTs had navigational systems, providing hourly positions with an accuracy of ±10 m, but the CAST drifters and the ASTs placed in the life rafts and dory had more limited accuracy of only ±150 m.

A different array of drifters was deployed in each weekly trial (Figure 3b).

Field Results

The drifter trajectories (Figure 4) show great variability of the surface drift field among the four trials. All tracks for Trial #1 (Figure 4a) lead offshore to the southwest at high rates, apparently following a topographic ridge (Sambro Bank) as suggested by the background mean circulation (e.g. Sheng and Thompson 1996). Tracks for Trial #2 (Figure 4b) lead generally in the same direction, but at much lower rates, while for Trial #3 (Figure

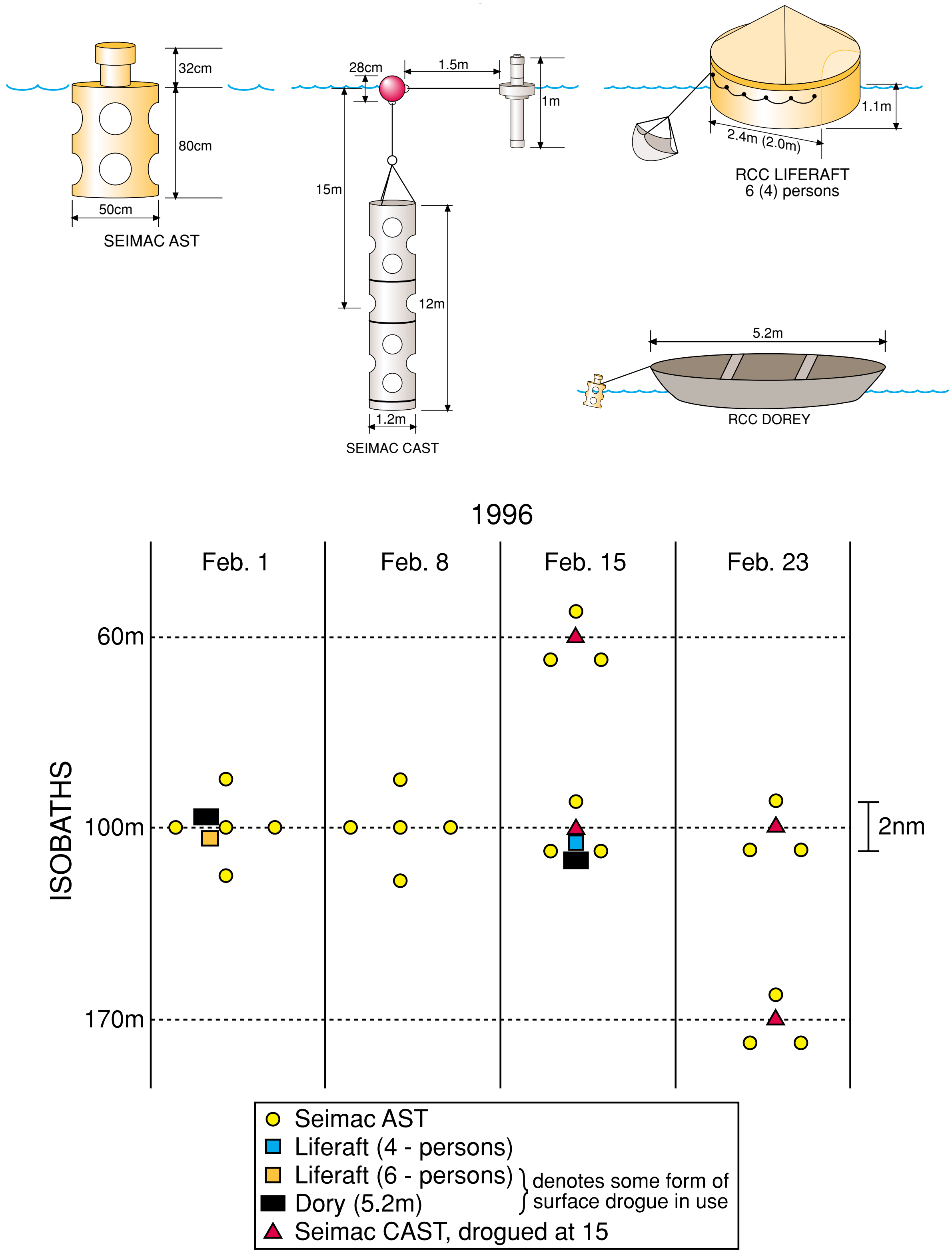


Figure 3 The CANSARP field experiment:
a) Four classes of drifters used
b) Drifter deployment patterns

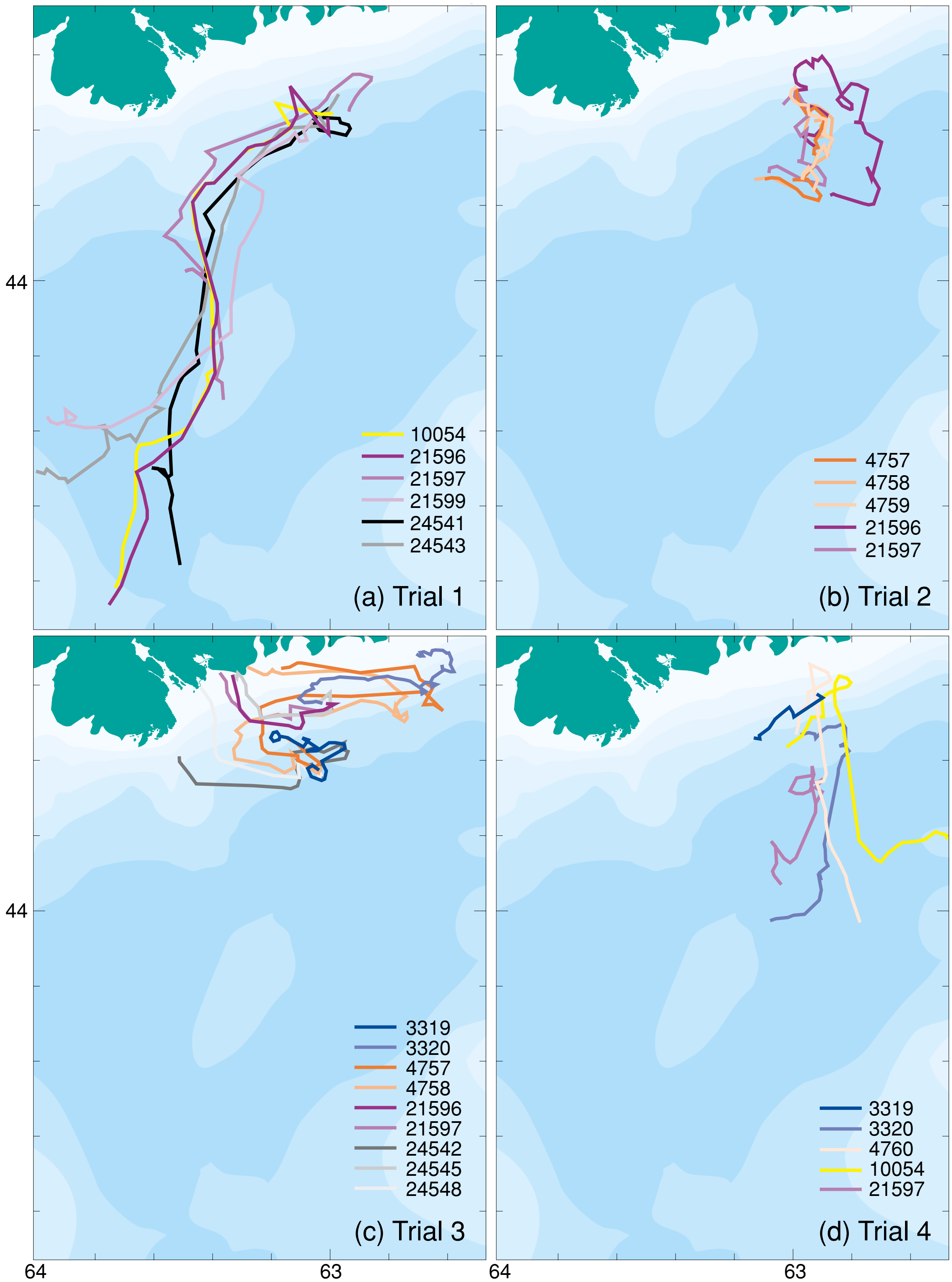


Figure 4: Trajectories of near surface drifters during the four field trials of the CANSARP Experiment, February, 1996.

4c) all but four drifters (2 CASTs and 2ASTs) were blown ashore by strong southerly winds on 16-18 February. Finally, tracks for Trial #4 (Figure 4d) lead offshore, but splay to the east and west at around 44°N, suggesting the importance of small-scale (~10 km) features in the surface current field. Clearly, this degree of variability between trials and the absence of a dominant wind event (i.e. storm) throughout the period will challenge the abilities of any forecast system. Nevertheless, drift velocities were found to be correlated with Halifax sea level and the cross-shore components of near-surface currents from the moorings

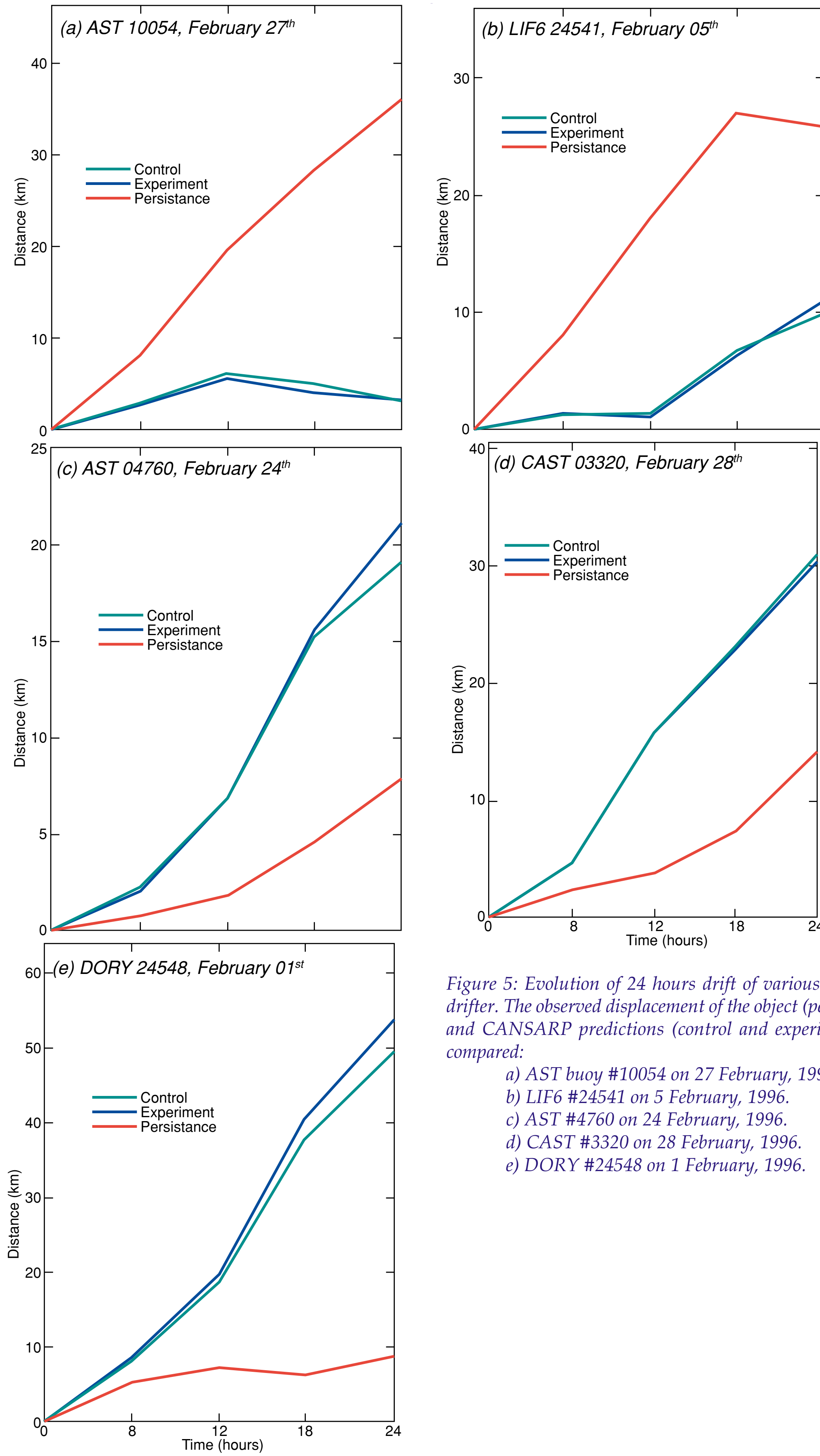


Figure 5: Evolution of 24 hours drift of various classes of drifter. The observed displacement of the object (persistence) and CANSARP predictions (control and experiment) are compared:

a) AST buoy #10054 on 27 February, 1996
b) LIF6 #24541 on 5 February, 1996.
c) AST #4760 on 24 February, 1996.
d) CAST #3320 on 28 February, 1996.
e) DORY #24548 on 1 February, 1996.

(Sheng, *et al.*, 1999), suggesting that, to some extent, the drift may be inferred from remote measurements.

Better Winds ?

During the CANSARP field experiment, forecasts of surface winds were produced by the operational forecast model at CMC, known as the RFE (Regional Finite Element) atmospheric model. Two versions of the RFE model were prepared: for control purposes, the standard North American operational model at 35-km resolution; and for testing, a high-resolution 12-km version configured to operate over the CANSARP area. Preliminary testing of the 12-km and 35-km configurations against observations for one set of forecasts (November 14th 1995 at 12 UTC) had suggested that the higher resolution forecast was not significantly more accurate than the standard. Specifically, the bias and RMS errors of the wind speed and wind direction forecasts with respect to the observations at 22 stations on the Canadian east coast were highly variable but roughly comparable for the two products,. Nevertheless, it was decided to test the two products within CANSARP.

To test the ability of the high-resolution CMC winds to improve CANSARP simulations of surface drift, 54 independent cases of drift of various objects during the field trials were analyzed over selected 24-hour periods. Standard CANSARP surface currents and leeway factors from the National SAR Manual were used in these calculations. Sample plots of displacements vs. time (Figure 5) indicate that there is very little difference between the test (12-km winds) and standard (35-km) predic-

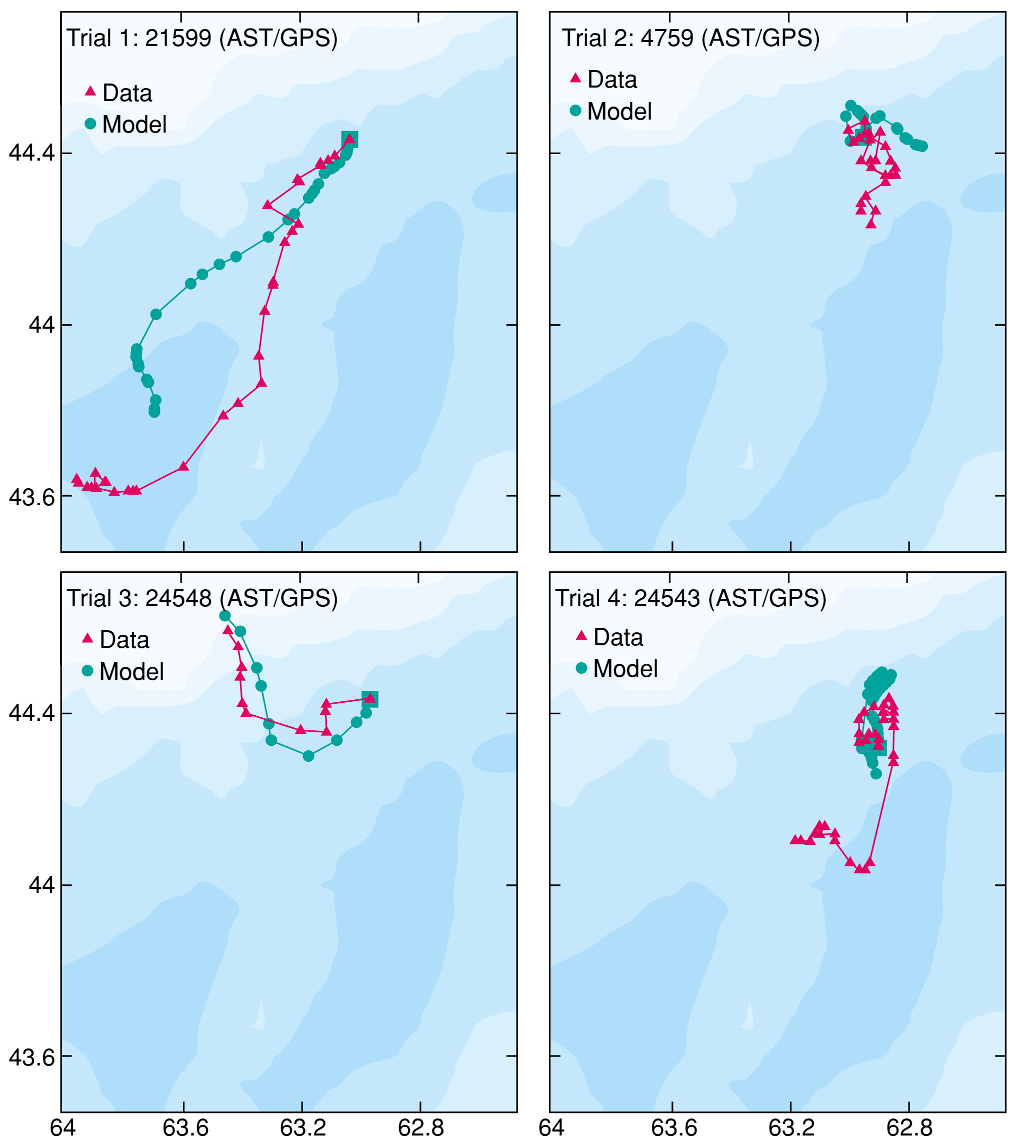


Figure 6: Typical observed and predicted drift trajectories during the CANSARP field experiment.

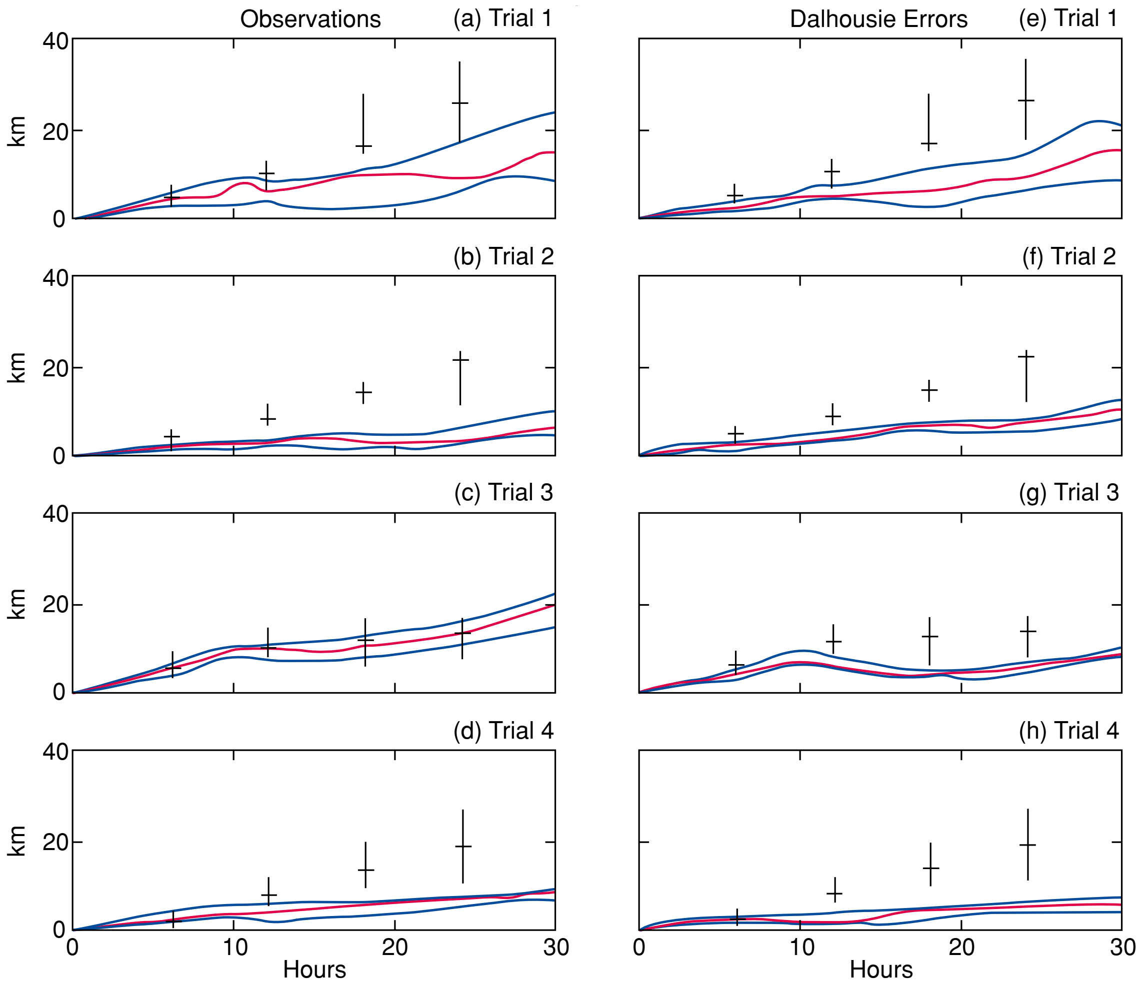


Figure 7: Drifter displacements with respect to their initial positions (a-d: left panels) and predicted positions (e-h: right panels) for the first 30 hours of drift only. The red line shows the time-varying radius of a circle which encompasses 50% of the drifters; the blue lines represent the 25% and 75% quartiles, respectively. The crosses represent the median, first and third quartiles of the CANSARP error radii at intervals of 6, 12, 18 and 24 hours after release.

tions in any of the cases considered. Thus the high resolution wind fields provide no measurable skill to CANSARP relative to the standard fields. Furthermore, in cases where the net displacement of the object is small, a persistence forecast (i.e. zero drift), outperforms both standard and test cases. This result is confirmed by the overall averages of displacement for the 54 cases considered, but was not true for the liferafts (LIF4, LIF6) in particular. This discrepancy may be an indication of the dominance of wind forcing in the liferaft dynamics. However, the primary result remains that the new high resolution winds do not lead to better CANSARP forecasts.

A Better Model ?

In a further attempt to improve the forecast of surface drift, a 3-D circulation model, developed at Dalhousie University (Sheng and Thompson 1993), was modified to calculate the trajectories of surface drift objects and tested against the CANSARP field data. The model is based on the assumption that the flow may be approximated by the sum of two components:

a) a seasonally-varying component diagnosed from the observed density field, and
b) a component forced by wind and flows through the open boundaries.

The density-driven winter surface flow was estimated by the robust diagnostic method proposed by Sheng and Thompson (1996), which assumes that the background field is in dynamical balance and invariant at time scales shorter than seasonal. The wind/boundary forced component results from application of the so-called Galerkin spectral method in which the vertical structure of the current is represented by the linear combination of a limited number (10) of basis functions. This method captures most of the short-term variability of the field while considerably simplifying the computation.

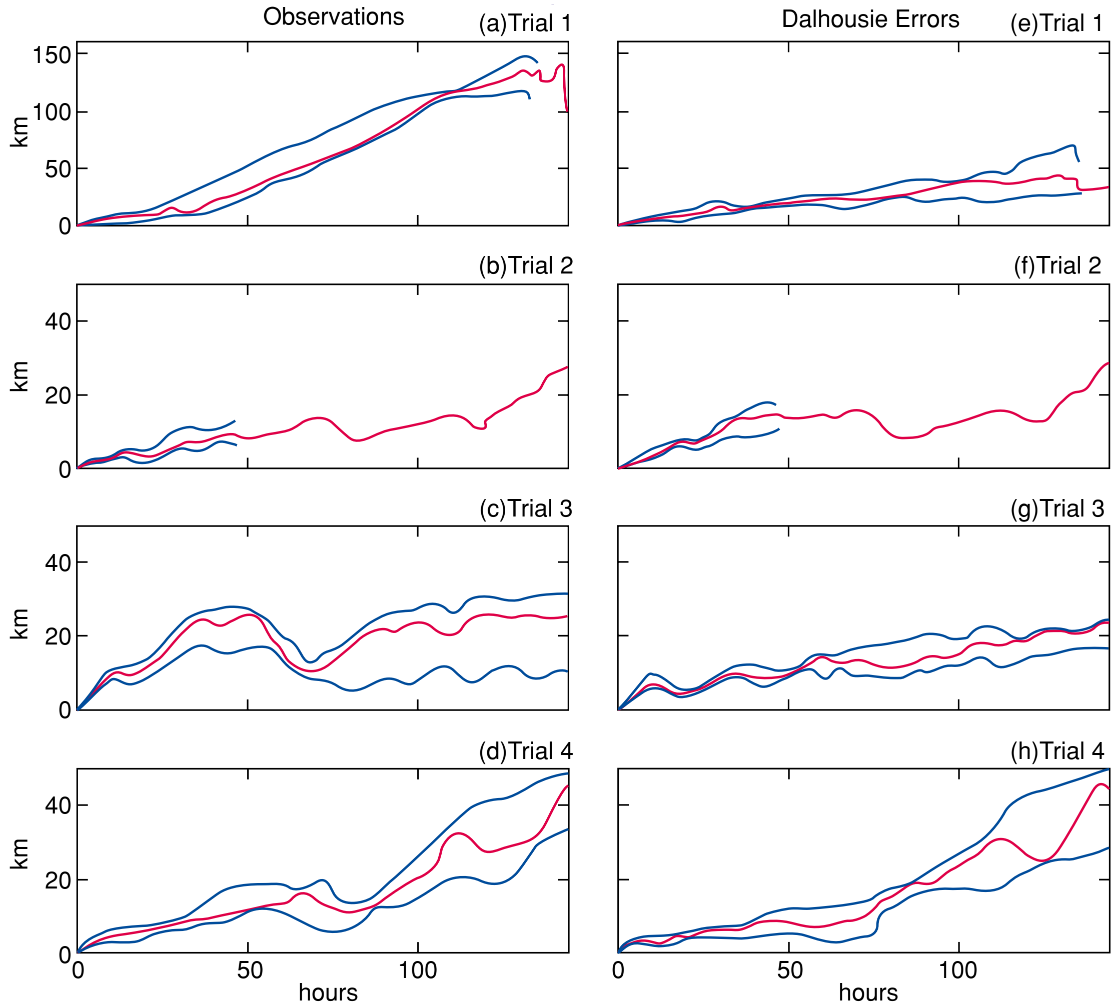


Figure 8: Drifter displacements with respect to their initial positions (a-d: left panels) and predicted positions (e-h: right panels)as per Figure 7, but for the full 140 hours of drift.

The trajectories of drifters were estimated from the model by integration of the equation:

$$d\underline{x}(t)/dt = \underline{u}(\underline{x},t) + \alpha\underline{w}(\underline{x},t) \ ,$$

where $\underline{x}(t)$ is the drifter position at time t, $\underline{u}(\underline{x},t)$ is the model velocity, $\underline{w}(\underline{x},t)$ the wind velocity, and α is the leeway factor. The leeway factors applied to the Dalhousie model integrations were based on recent field measurements and model studies and hence differed from those selected from the National SAR manual for use in the CANSARP simulations. Further details about the model formulation and implementation are described by Thompson *et al.* (1999).

Comparison of Trajectories

Representative model trajectories compare reasonably well with the observed trajectories (Figure 6). The model captures the strong southwestward displacement in Trial #1 as well as the onshore displacement in Trial #3. But the offshore motions in Trials #2 and #4 appear to be underestimated.

Comparison of Errors at Short Timescales (0-30 hours)

To make the comparisons more quantitative, statistical measures of three sets of errors were plotted over the first 30 hours of drift (Figure 7):

- observed displacements, representing errors in the persistence (zero drift) forecast,
- CANSARP forecast deviations from observed positions of drifters,
- Dalhousie model deviations from observed positions.

In this figure, CANSARP error statistics are plotted over both the observed (left) and Dalhousie error (right) displacements at 6, 12, 18, and 24 hours, as crosses representing the radii of circular regions containing 25%, 50% and 75% of the drifters, i.e. typical search radii. On this most relevant SAR timescale, the Dalhousie model clearly outperforms CANSARP in all trials and persistence (comparing left and right panels) for Trial #3 only. After 24 hours, the Trial #1 50% containment radii for CANSARP and the Dalhousie model differ by roughly a factor of 3, which is equivalent to a factor of 9 in the search areas. The persistence forecasts (left panels) also show more skill than CANSARP for all but Trial #3.

Comparison of Errors at Long Timescales (0-140 hours)

The same statistical measures of observed drifter displacements is presented in left-hand panels of Figure 8, but over longer times. The top left panel, for example, shows that after 100 hours, only half the drifters in Trial #1 are within 100 km of their initial positions; the bottom left panel indicates that in Trial #4, half the drifters moved less than 20 km in 100 hours. Hence the persistence forecast in Trial #4 is expected to be better than for Trial #1.

The right-hand panels in Figure 8 show similar statistics for the observed displacements with respect to the Dalhousie model-predicted positions. Here the top right panel shows that after 100 hours, half the drifters in Trial #1 are within roughly 40 km of their predicted positions, representing an improvement factor of 2.5 (6.3) in search radius (area) over the persistence forecast. For Trials #2, #3 and #4, the radii containing half the drifters are closer to 20 km after 100 hours, and improvements over persistence are reduced.

Conclusions

The primary conclusions of this study are:

1.) The use of high resolution (12-km) CMC winds provides no apparent benefit over low resolution (35-km) in estimating surface drift with either CANSARP or the Dalhousie model.

2.) At critical search-and-rescue timescales of 30 hours or less, the Dalhousie model forecasts have significantly more skill than CANSARP and also outperform persistence by a lesser amount. In Trial #1, however, the persistence forecast radius (area) containing half the drifters exceeds the model error radius (area) by a factor of 3 (9).

3.) At longer timescales (140 hours), the Dalhousie model forecast is again better than persistence, especially in Trial #1.

Based on these results and the implied increases in search-and-rescue efficiency, we have recommended that steps be taken to incorporate Dalhousie model forecasts (or equivalents) into the CANSARP planning system, in order to better protect the lives as well-being of all mariners.

Acknowledgments

The authors are grateful to Mr. A. Patterson of the Canadian Coast Guard for his initial encouragement and guidance and for providing leeway factors and operational support to the project. This project (EC-2/95) was supported by the National Search and Rescue Secretariat (NSS) New Initiative Fund (NIF).

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ToC

Studies on the Impact of Mobile Fishing Gear on Benthic Habitat and Communities

D.C. Gordon Jr., P. Schwinghamer, T.W. Rowell, J. Prena, K. Gilkinson, W.P. Vass, D. L. McKeown, C. Bourbonnais and K. MacIsaac

INTRODUCTION

Due in part to recent declines in groundfish resources in many regions around the world, questions are being asked about the possible impacts of mobile fishing gear on benthic habitat and communities. Mobile fishing gear is widely used in Atlantic Canada and includes otter trawls, scallop rakes, and hydraulic clam dredges (Messieh et al. 1991). Limited scientific information is available to answer these important questions. Beginning in 1990, the Department of Fisheries and Oceans (DFO) has been conducting a research program which is investigating the effects of mobile fishing gear on benthic marine ecosystems in Atlantic Canada. Specific objectives include: 1) obtaining quantitative information on the impacts of mobile fishing gear on benthic habitat (both physical structure and biological communities), 2) obtaining quantitative information on the recovery rate of benthic habitat after disturbance by mobile fishing gear, and 3) developing new instrumentation for viewing and sampling marine benthic habitat in order to quantify its productive capacity. The program has involved a large number of DFO scientists and engineers in the Maritimes and Newfoundland Regions, and has benefited from collaboration with the Geological Survey of Canada (Atlantic), university and European colleagues, and various contractors. Large scale field experiments of mobile fishing gear effects are being conducted at carefully selected locations in Atlantic Canada.

MINAS BASIN OTTER TRAWLING EXPERIMENT

The first experiment was conducted in the intertidal region of the Bay of Fundy in collaboration with Acadia University (Brylinsky et al. 1994). Experimental otter trawling was conducted by a commercial fisherman at high water while sampling to assess the effects was carried out when the tide was out (Fig. 1). Overall, the impacts were judged to be minor. These results are not surprising because the intertidal ecosystem of the Minas Basin is exposed to high levels of natural physical stress due to a very large tidal range, storms, and ice. These results can not be applied directly to the less energetic subtidal ecosystems found on offshore fishing banks.

DEVELOPMENT OF INSTRUMENTATION FOR OFFSHORE STUDIES

Studying the effects of mobile fishing gear on offshore benthic ecosystems requires specialized equipment for sampling and imaging the habitat and communities. Such equipment was not available at the start of the program. In consequence, considerable effort was given to instrumentation development with the assistance of the Engineering and Technical Services Division at BIO. Four major pieces of sampling equipment developed are described below. This suite of instruments has generated considerable interest in the international scientific community and can used for investigating a wide spectrum of benthic habitat issues. More detail can found in Rowell et al. (1997).

Figure: 1. Collecting samples from the track made by an otter trawl door in the intertidal region of the Minas Basin, Bay of Fundy.

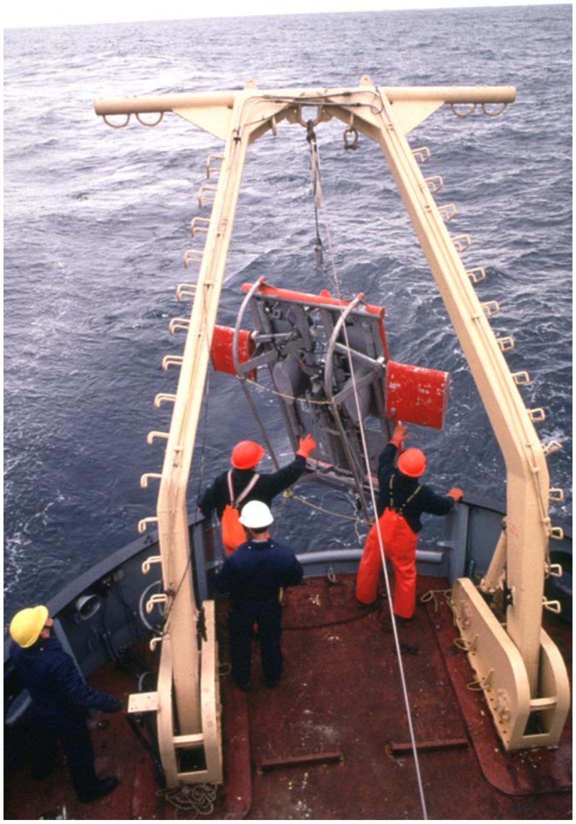


Figure: 2. BRUTIV, a towed vehicle used to collect video imagery of seabed habitat.

BRUTIV(Bottom Referenced Underwater Towed Instrumented Vehicle)

Substantial improvements have been made to an earlier model of BRUTIV, including the purchase of a new winch, cable, and video camera. BRUTIV (Fig. 2) can be towed at a speed of several knots just a few meters above the seafloor to obtain continuous colour-video imagery of benthic habitat and large epibenthic organisms (sand dollars, crabs, scallops, etc.) along transect lines several kilometers long.

Figure: 3. Epibenthic sled which collects large organisms living on the seabed (samples approximately 18 m^2 on a 50 m tow).

Epibenthic Sled

Substantial improvements have also been made to the Aquareve III epibenthic sled to make it more quantitative when sampling sandy bottom ecosystems (Fig. 3). This device is pulled short distances (i.e. 50 m) over the seafloor to collect large organisms living on or within the upper 2-3 cm of the sediment surface (sand dollars, starfish, sea urchins, etc.). These improvements include stability wings, wider skids, a narrower sampling mouth (0.34 m), a positively closing door, and an improved video system to monitor performance.

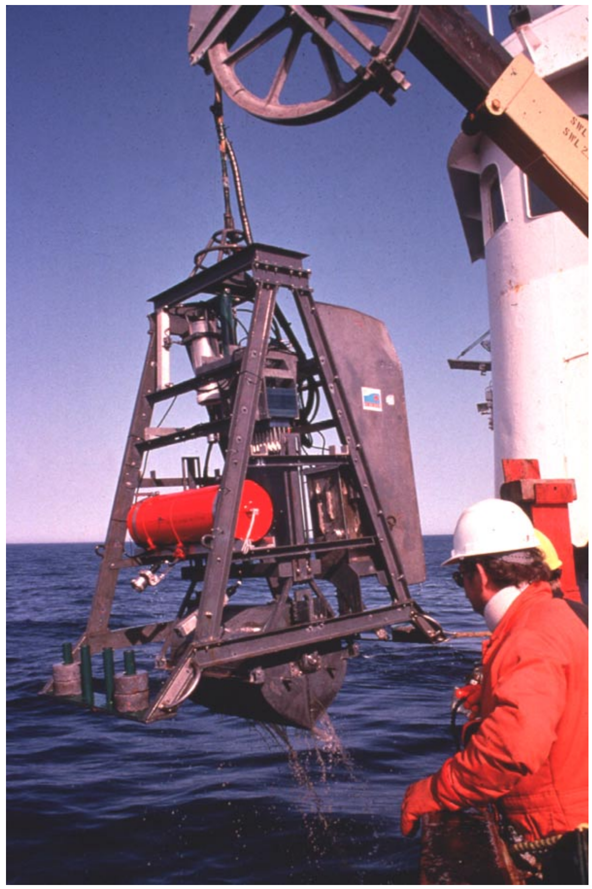
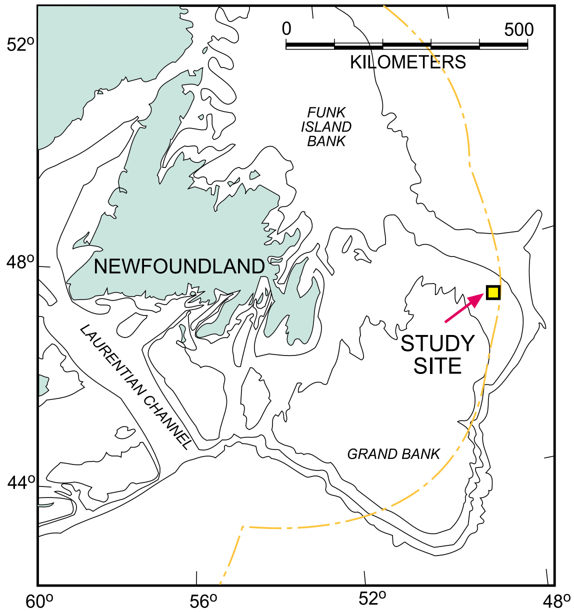


Figure: 4. Videograb (with DRUMS attached) which collects organisms living on and in the seabed (samples 0.5 m^2).

Videograb

A completely new video-equipped 0.5 m^2 grab, with hydraulically operated jaws, has been designed and built to collect sediment and benthic organisms (Fig. 4). The new system has remote controls which allow a scientist in the ship's laboratory to take over operation of the grab winch once the seafloor comes into view. The position and operation of the grab is monitored by high-resolution colour video and, with practice, it can be landed in precisely chosen micro-habitats on the seafloor. If there are problems with closure, the grab can be raised off the bottom, opened hydraulically, and landed again in a different area.



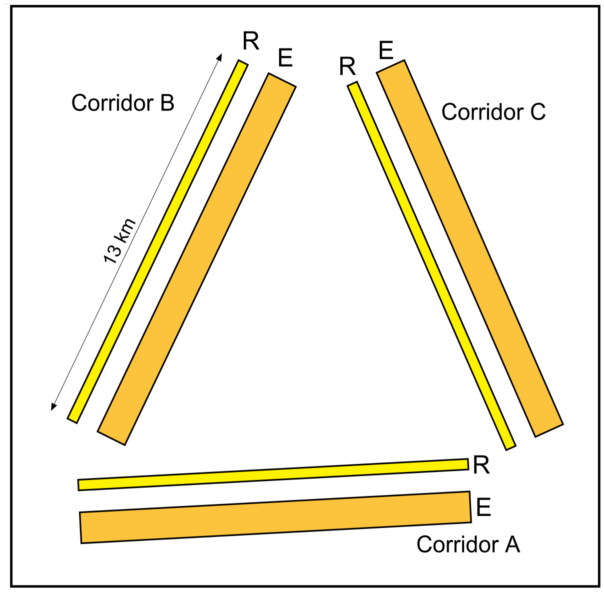


Figure: 5. Location of the otter trawling experimental site on the Grand Banks of Newfoundland and orientation of the three trawled (T) and reference (R) corridors.

DRUMS (Dynamically Responding Underwater Matrix Sonar)

The DRUMS™ acoustic imaging system has been developed specifically for this project under contract by Guigné International Ltd. in Paradise, Newfoundland. It utilizes new technology in broad-frequency spectrum, narrow-beam acoustics to provide high-resolution measurement of sediment habitat structure. For the program, DRUMS has been mounted on the videograb (Fig. 4) so that acoustic data are collected from exactly the same area of seafloor being grab sampled. For other applications, it can be deployed from a stand-alone tripod. Further details on DRUMS and its application to this program are given in Schwinghamer et al. (1996).

The application of all this equipment to mobile gear impact experiments requires the ability to position it accurately on the seafloor. This is done using dGPS (differential Global Positioning System) for accurate positioning of the research vessel (to within 3-4 m), an ORE Trackpoint acous-

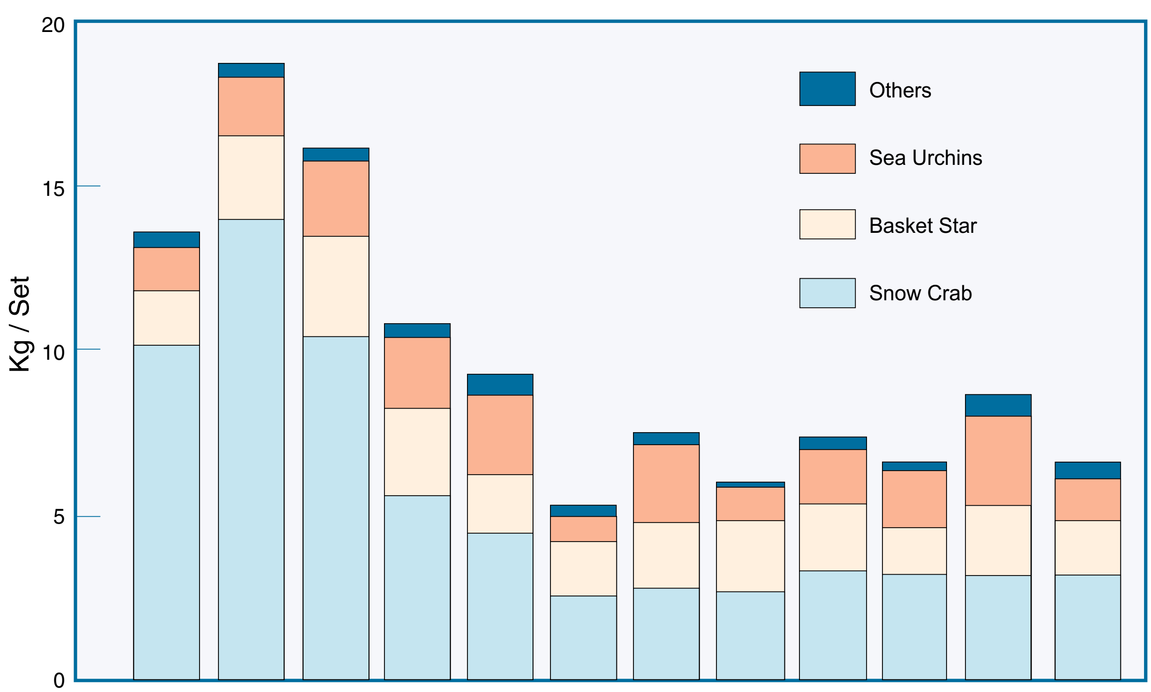


Figure: 6. Invertebrate bycatch by consecutive trawl set (kg wet weight biomass per 13 km trawl set). Average of three years (1993-1995) and three corridors (A, B and C).

Figure: 7. Dominant species captured by the epibenthic sled.

tic positioning system for recording the position of sampling equipment relative to the ship (to within 4-20 m depending upon distance from the ship) and the AGC navigation system for the display and logging of navigation data (McKeown and Gordon 1997).

GRAND BANKS OTTER TRAWLING EXPERIMENT

Once suitable sampling equipment had been developed, a three year (1993-1995) otter trawling experiment was conducted at an offshore site in 120-146 m of water on the Grand Banks of Newfoundland (Fig. 5). Reasons for selecting this site are provided by Prena et al. (1996). A 10 x 10 nautical mile experimental box was established and has been closed to all fishing activity indefinitely. This site had not been fished intensively for over ten years. The seafloor is a homogeneous, well-sorted fine sand sediment. The benthic community is species rich, high in biomass, and relatively homogeneous.

Experimental design is described in detail by Rowell et al (1997). Within the experimental box, three 13 km long corridors (Fig. 5) were trawled twelve times each year with an Engel 145 otter trawl (equipped with rockhopper foot gear) by the CSS *Wilfred Templeman.* This gear is standard for both commercial fishing and, until 1995, DFO research surveys in the Newfoundland Region. Parallel reference corridors were established, with 300 m between the centre lines of the two corridors. In 1995, a RoxAnn′ acoustic bottom classification system was used to determine whether the trawling produced a noticeable change in bottom acoustic characteristics. The trawl catch (both fish and invertebrates) of each set was sorted by species and weighed in the ship-board laboratory.

The CSS *Parizeau* collected information on benthic habitat and communities before and after each trawling event in the trawled corridors as well as in the parallel reference corridors. An additional cruise was run in September 1993 to collect data two months after the initial trawling event. Sidescan sonar and BRUTIV video surveys were carried out along with epibenthic sled and videograb (equipped with DRUMS) sampling. Invertebrates were sorted by species and damage categories, counted, and weighed.

The impacts of trawling on physical habitat were clearly demonstrated (Schwinghamer et al. 1998). Trawl marks on the seafloor were readily apparent in the sidescan sonar surveys immediately after trawling and in some instances were still faintly visible after one year. RoxAnn data indicated an increase in the E2 signal (a proxy for sediment disturbance) with each consecutive trawl set.

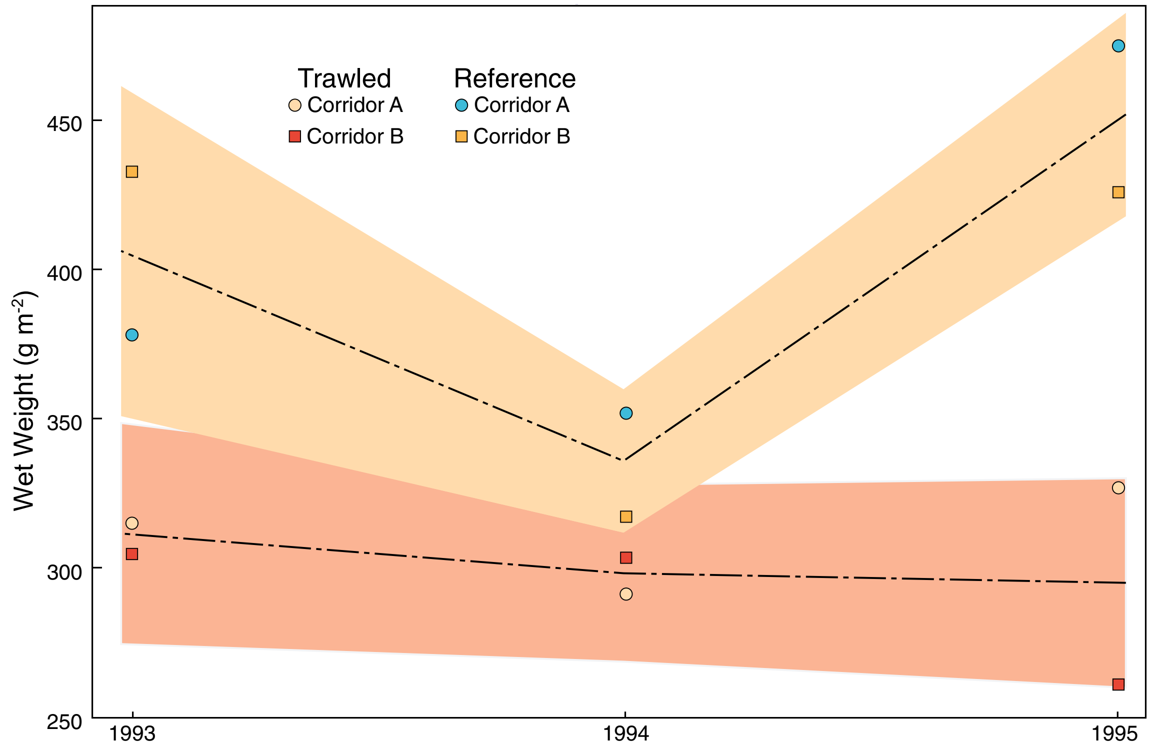


Figure: 8. Total biomass of invertebrates collected by the epibenthic sled in trawled and reference corridors (A and B only) each year of the experiment. Shaded areas represent 95% confidence intervals.

DRUMS data demonstrated that trawling reduced the complexity of small-scale internal sediment structure down to a depth of 4.5 cm. Video footage from BRUTIV indicated that the colour of the surface sediment was lighter and more uniform in trawled corridors compared to reference corridors. High-resolution video observations made with the videograb indicated that trawling reduced biogenic sediment structures and the abundance of flocculated organic matter. There was no significant effect of trawling on sediment grain size but natural interannual variations were detected.

The biomass of epibenthic organisms caught in the otter trawl (primarily the snow crab *Chionoecetes opilio*, the sea urchin *Strongylocentrotus pallidus* and the basket star *Gorgonocephalus arcticus*) decreased significantly with repeated trawl sets, especially in the first six sets (Fig. 6) (Prena et al. 1999). An influx of scavenging snow crabs was observed during the later trawl sets (approximately 10-12 h after trawling began). The fish catch was very low (< 25 kg wet weight per 13 km set) and declined steadily over the three years.

The dominant organisms caught in the epibenthic sled were sand dollars (*Echinarachnius parma*), sea urchins, brittle stars (*Ophiura sarsi*), snow crabs, soft corals (*Gersemia* sp.) and four species of molluscs (*Astarte borealis*, *Clinocardium ciliatum*, *Cyclocardia novangliae* and *Margarites sordidus*) (Fig. 7). The total biomass of organisms sampled by the epibenthic sled was on average 25% lower in the trawled corridors than in the reference corridors (Fig 8). The biomass of sand dollars, brittle stars, snow crabs and soft corals was significantly lower in the trawled corridors. Some of the sand dollars, sea urchins, and brittle stars were physically damaged by trawling. There were also indications of size-specific impacts, especially on sand dollars which were significantly smaller in the trawled corridors. There was no apparent significant effect of trawling on the four dominant mollusc species. The extensive data base of epibenthic and infaunal invertebrates collected with the videograb before and after trawling each year is currently being analyzed.

Under contract to DFO, C-CORE (Centre for Cold Ocean Research Engineering at Memorial University) has conducted a series of laboratory experiments to study the physical interaction of an otter trawl door with a simulated Grand Banks sandy seafloor containing bivalve molluscs planted at different depths. It was observed that considerable displacement of molluscs occurred along with sand in the fluidized zone in front of the moving door. This displacement resulted in a low incidence of damage (Gilkinson et al. 1998). These experimental observations support the field data indicating little damage to molluscs.

FUTURE PLANS

There are numerous information gaps that have to be filled before the effects of mobile gear on the sustainability of marine habitat and fisheries can be fully understood. Because the effects vary depending upon the type of gear fished, the kind of habitat, and the species present, it is necessary that additional well-designed experiments with other kinds of gear and seabed be conducted. In 1996, a cruise explored potential study sites for future experiments on the Scotian Shelf. On the basis of the results and input from fisheries managers and industry, it was decided to conduct two new experiments. The first, begun in October 1997, is investigating the effects of otter trawling on an area of gravel bottom on Western Bank. This site is within the 4TVW Haddock Nursery Area which has been closed to mobile groundfish gear since 1987 to protect undersized (or immature) haddock from capture in trawls. The second experiment, begun in May 1998, is investigating the effects of hydraulic clam dredges at a site on Banquereau in collaboration with the offshore clam industry.

Once the effects of different kinds of mobile gear on benthic habitat and communities are better understood, it is important to determine if these effects have important consequences for commercial fisheries. For example, will changes in physical habitat structure change the vulnerability of small fish to predation? Will commercial species of fish find better feeding conditions because trawls may make benthic prey more available, or poorer feeding conditions because trawls may reduce populations of benthic prey? As they become available, the results of this research will be incorporated into the fisheries management process to ensure that the best decisions are made to protect the long-term sustainability of fisheries resources and the habitat supporting them.

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Designing and Building a CHS Bathymetric Data Warehouse

ToC

S. R. Forbes, R. G. Burke, H. Varma

Introduction

During the past decade the Canadian Hydrographic Service (CHS) has implemented new digital bathymetric data collection systems. These systems provide the capability for 100% sea floor coverage. Systems such as the Simrad EM3000 Multi-beam Swath Sounder have the potential to gather approximately 2800 million depth measurements during a three-month survey. This translates to 280 Gigabytes of information to manage. Five similar EM3000 surveys in one survey year can gather in excess of one terabyte of data to manage. This volume of data requires new techniques for the aggregation and management of spatial information.

The CHS is addressing this problem by designing a Source Database to manage the bathymetric information using a Relational Database Management System (RDBMS). The data warehouse addresses requirements to aggregate, partition, and perform vertical and horizontal datum transforms for bathymetric information. The design of the data base prototype and implementation described extends the Oracle Spatial Data Option (SDO) product developed by Oracle Corporation with some spatial cartridge components. These additional components are required to manage very large volume bathymetric data within a data warehouse environment.

The CHS has been investigating the management of spatial data in the RDBMS environment since the 1980's. The development of a spatial data type called Helical Hyperspatial Code (HHCode) (Varma 90) by the CHS during 1989 facilitated the encoding and manipulation of spatial data (multiple dimensions) using a single key. This technology was transferred to Oracle Corporation, Redwood, Ca. and incorporated in the Oracle RDBMS Version 7.1.3. The product was released in March 1996 and is marketed as Oracle SDO.

Design Criteria

The management of very large volumes of spatial information that does not have a predictable growth rate requires a specific design approach to optimize the storage, access and management of the information. The primary objectives that determined the design criteria for the bathymetric data warehouse are:

1) Provide seamless geographic coverage.

2) Ensure the data access is consistent and the response time to satisfy queries is predictable regardless of the volume of data managed in the warehouse.

3) Minimize data storage costs by supporting a Hierarchical Storage Management (HSM) model to store the data. This model supports data storage on low cost media for information that is not required to be on-line at all times.

4) Design the warehouse to be scalable. The warehouse is designed to grow as the volume of data collected grows. The storage and compute resources are scaled to the data storage requirements.

5) Support the horizontal and vertical transformation of data when the information is queried.

There is no commercial product at this time using RDBMS that addresses all of the objectives as stated. The CHS and CubeWerx Inc., Hull, Quebec designed a product and applications that are intended to meet these requirements.

Design Concepts

To meet the design criteria and satisfy the business requirements of the hydrographic discipline the solution had to address the following:

1) The spatial and temporal nature of hydrographic information.

2) Reduction of data storage by developing a data aggregation application for dense data sets.

3) Data access using the concept of data partitioning.

4) Minimize data storage costs through support of the HSM architecture using data archive and import / export modules.

5) Implement vertical and horizontal datum transform functionality by addressing this issue in the data model and providing mechanisms to perform the transforms when the data is queried.

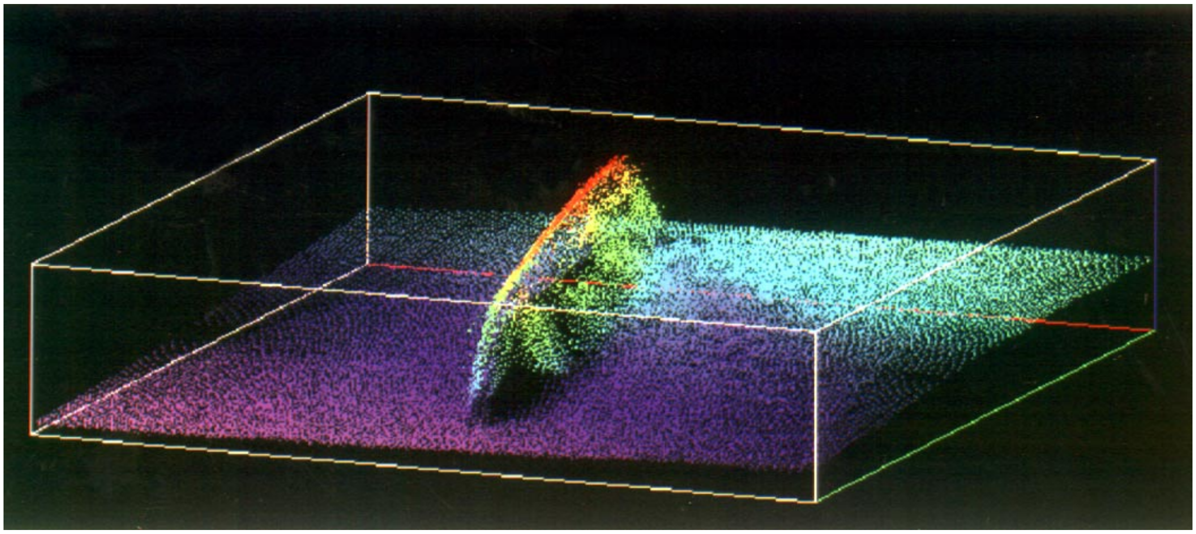

Figure 1: 3D representation of the Empress of Ireland created using the EM1000 point data set.

Spatial and Temporal Information

Each sounding or tile (see Data Aggregation) in the data warehouse has a spatial and temporal reference. The management of bathymetric information requires the implementation of time lines to address the temporal nature of the information. Examples of temporal related activities are physical change in the sea floor topography due to natural or man made influences, the requirement to periodically re-survey critical marine areas, such as harbours, with improved technology or the Hydrographic Office is notified of a hazard to navigation.

The implementation of time lines provides a means to supersede the data without physically removing this data from the warehouse. These permit queries for standard hydrographic processes that do not return superseded data and also supports queries for retrieving data for trend and prediction analysis.

Data Aggregation

CHS has investigated and developed algorithms based on HHCodes to aggregate[1] dense bathymetric data sets. An example of a candidate data set for aggregation is one acquired using the Simrad EM3000. Aggregation of bathymetric data sets involves creating a single HHCode cell that contains multiple smaller cells. The criteria for the single HHCode cell (tile) is based on a user defined criteria. For bathymetric information this is the maximum tolerance defined for a given depth;

Maximum depth - Minimum depth = User defined tolerance

This technique aggregates the data set, preserves the user defined depth resolution and minimizes the data, which must be loaded or queried. Preliminary tests using this algorithm aggregated seven million depths from an EM3000 Multi-beam survey in six minutes and reduced the data storage requirement by a factor of 9.33.

Figure 1 is an example of the point data set from a Simrad EM1000 survey. Figure 2 is the aggregated data set using these techniques. The survey was done in the St. Lawrence River over the wreck of the Empress of Ireland.

Data Partitioning

Management of very large volume spatial data dictate new techniques for storage and retrieval of the information. A poorly predicted growth rate using a traditional data management approach may require the database to be re-engineered and the data periodically reloaded. Data partitioning (Varma 91) alleviates the requirement to accurately predict the data growth rate. Oracle SDO uses this technique to store the data in multiple partitions (tables) that dynamically and automatically subdivide when the data is loaded or updated.

The primary benefit of data partitioning is to ensure consistent and predictable query performance for a very large database (VLDB) where growth rate is not easily predicted.

Data Archive and Import / Export Modules

The purpose of the Archiver module is to store data in directories as standard files. If the data is not required on-line, the loading process becomes a registration process of data partitions in the data dictionary and the archived data is placed on-line when needed.

1 Application developed for the CHS by M. McConnell Information Technologies, Lunenburg, Nova Scotia.

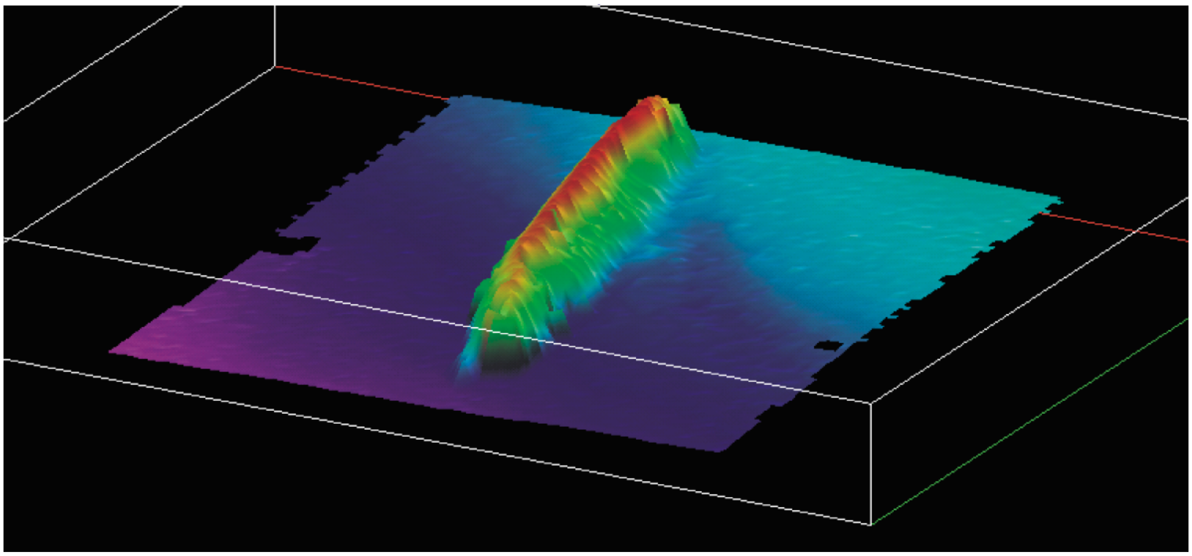

Figure 2: 3D representation of the Empress of Ireland derived from the aggregated data set.

The Import module extracts data from the archive directory and places the data in the database when users require access to the data. When data has been updated in the database the Export module extracts data from the database and places it in the archive directory. The Import / Export process is shown in Figure 3.

The data warehouse is stored in a file system that can be managed by a HSM system where there are three states of data; on-line, near-line and off-line.

The warehouse design does not require the implementation of a HSM system. The objective is to organize the data for cost effective data storage, efficient access and prevent overloading of limited resources.

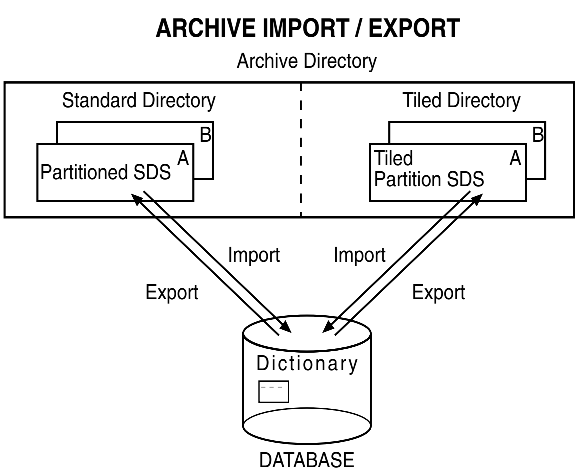

Figure 3: The Import / Export Process

Implementation of Horizontal and Vertical Datum Transforms

Bathymetric information requires a vertical and horizontal datum reference. The clients querying the spatial information may require the data on a different datum than was used to store the information. For example, to compare and verify historical bathymetric data with a modern survey would require the historical data to be transformed to the datums on which the new survey is referenced. As the warehouse grows to terabytes of data it is impractical to unload, transform, and reload the data into the warehouse to address the new datum references required to satisfy the majority of client queries. Also, an error in the datum transformation application would compromise the integrity of the source bathymetric data.

This limitation is addressed by storing transform models in the database. The datum transforms are performed when the client queries the data warehouse.

An example of a vertical transform model is shown in Figure 4. The bathymetric Digital Terrain Model (DTM) (*left*) contains a defined spatial area with a bathymetry value and a unique spatial identifier. The datum adjustment DTM (*centre*) is illustrated with the vertical datum adjustment in decimeters and its unique spatial identifier. The adjusted bathymetry DTM (*right*) is derived by simply adding the bathymetric values and the datum adjustment model values. For example, area 12 with a depth value of 62 is added to datum adjustment model value of -3 producing a new depth value of 59 for area 12. Note in the figure, bathymetry area 13 has been subdi-

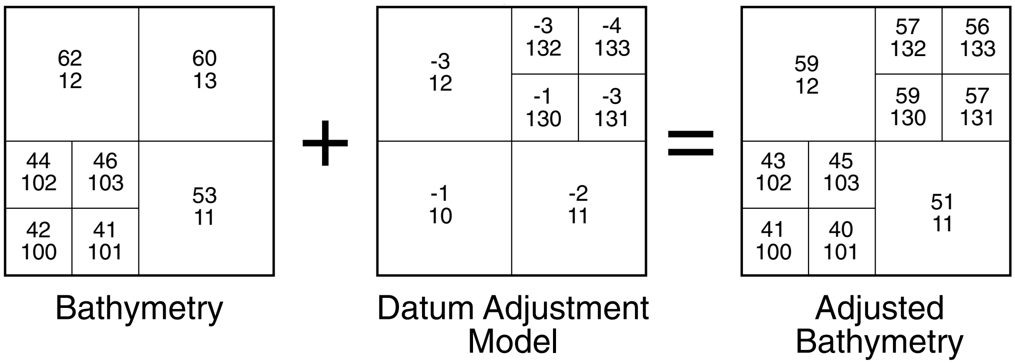

Figure 4: A Bathymetric Vertical Transform Model

vided into four new areas to match the areas defined for the datum adjustment model (*areas 130 to 133 inclusive*). If the bathymetry source area is larger than the datum adjustment model then the area must be subdivided until it matches the resolution of the datum adjustment model areas.

A similar approach is used for horizontal datum adjustments. The horizontal datum adjustment model has a datum adjustment value for latitude and longitude (x and y) for each area.

In conclusion this design supports the storage of bathymetry referenced to several datums with the query and extraction of the bathymetry on one or more client defined datums. The bathymetry is referenced to a known datum, verified and entered into the data warehouse. This approach ensures the integrity of the source bathymetry.

Spatial Data Warehouse Prototype

A prototype[2] of the Spatial Data Warehouse was developed and tested in November, 1997. The purpose of the prototype was to:

1) Verify the data structures are appropriate and meet the performance requirements for very large spatial data sets.

2) Demonstrate fast access to large volume spatial data in the RDBMS without the need for enterprise servers. The ability to scale the data warehouse to the required class of hardware architectures is an important design feature.

3) Demonstrate that the data aggregation and area portrayal of the bathymetric data can be managed in the relational environment.

4) Verify the archive approach to minimize storage costs is a practical solution. It is important to show that the archive approach minimizes the cost of data storage and that the time required to be import the information from the archive into the data warehouse is acceptable.

The prototype successfully demonstrated the design criteria was easily met or exceeded. The prototype verified that the point data sets and the area aggregate data sets could co-exist in the data warehouse using the same spatial data architecture. The results also indicated that the spatial load and query performance was linear for the load and access times versus the number of data points addressed.

Source Data Base Implementation

The infrastructure for managing the bathymetric information in a RDBMS environment using spatial addressing is nearly complete. Additional tasks include designing and implementing the client interface and benchmarking the data warehouse and associated applications.

A benchmark has been undertaken to determine the hardware required to meet the anticipated workload. The benchmark is scheduled to take place at Digital Equipment Corporation benchmark facility in Markham, Ontario, July, 1998. These benchmarks will include performance tests for sorting, data aggregation, loading , querying and retrieving data from the data warehouse. The benchmark results will determine the hardware architecture CHS will choose for the national implementation of the data warehouse.

Conclusion

The CHS bathymetric data warehouse is being developed using new techniques and technologies to convert, aggregate and manage bathymetric information to facilitate the production of CHS products and services. A prototype has been developed and tested to resolve functional and op-

2 Developed for the CHS by CubeWerx Inc., 200 Montcalm, Hull, Quebec.

erational issues and to test assumptions made during the development. CHS Regional implementation of the bathymetric warehouse is planned for 1999.

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The World Ocean Circulation Experiment Observation Program

ToC

Allyn Clarke, Fred Dobson, Ross Hendry, Anthony Isenor, Peter Jones, John Lazier, George Needler, Neil Oakey and Dan Wright

The World Ocean Circulation Experiment (WOCE) is by far the largest, most ambitious oceanographic experiment ever carried out. The WOCE observational program began in 1990, but the origins of WOCE go back to the late 1970s. The experiment has involved the efforts of more than 40 nations over a period of more than 10 years, making use of several different satellites, dozens of ships, and thousands of instruments. These observations have already improved our knowledge of the present state of the global ocean, its spatial and temporal variability, and its role in the global climate system. The final impact of this experiment will not be realized for at least a decade, as researchers around the world digest the enormous amount of information it has provided.

Oceanographers and meteorologists have long recognised that the global ocean plays a critical role in decadal and longer time-scale climate changes. WOCE was conceived when the oceanographic community realized that the time had arrived for a truly global ocean experiment. Advances on several fronts made it possible to imagine such an effort. First, they had an important new tool for observing the global ocean: satellite remote sensing. The Seasat mission had demonstrated the capability of making useful observations of sea surface elevation and surface wind stress from space. The now highly successful Topex/Poseidon altimeter mission was in the planning stage. At the same time, rapid advances in computer capability made possible realistic global ocean models and allowed the analysis of the large amount of data that would result from a global ocean experiment. Finally, there was strong support from a significant part of the oceanographic community for a global experiment. This led the international Committee on Climatic Change and the Ocean (CCCO) to consider the initiation of a global scale oceanographic experiment. In 1983, the CCCO and the Joint Scientific Committee of the World Climate Research Programme established a Scientific Steering Group (SSG) to design and implement a global scale oceanographic experiment — the World Ocean Circulation Experiment.

The formal goals of the international WOCE program are:

- To develop models useful for predicting climate change and to collect the data necessary to test them.
- To determine the representativeness of the specific WOCE data sets for the long-term behaviour of the ocean, and to find methods for determining long-term changes in ocean circulation.

The WOCE Observation Program

The observational objectives of the international WOCE program are demanding.

The field program has been designed to determine and understand, on a global basis, the following aspects of the World Ocean circulation and their relation to climate:

- The large-scale fluxes of heat and fresh water, their divergences over years and their annual and interannual variability.
- The dynamical balance of the World Ocean circulation and its response to changing surface fluxes.
- Components of ocean variability on time scales of months to years, length scales of megametres to the global scale and the statistics on smaller scales.
- The rates and nature of formation, ventilation and circulation of water masses that influence the climate system on time scales from ten to one hundred years.

In addition to these lofty goals, the scientists involved want to provide high quality data sets that will serve as valuable long term information, and they want to get the information out to the wider community more efficiently than ever before. The short time deadlines for the submission of datasets to the WOCE Hydrographic Program

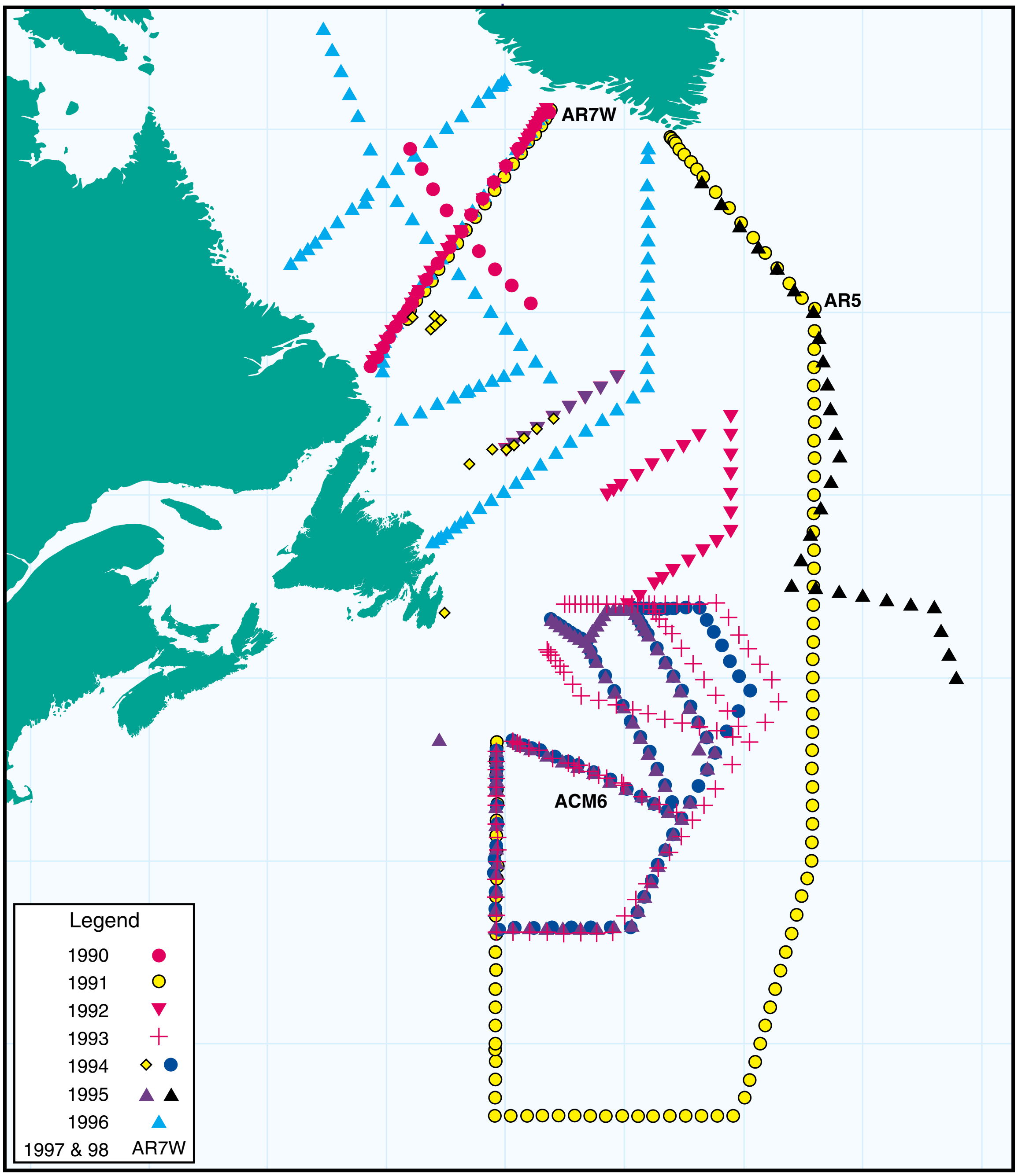

Figure 1: WOCE Cruise Tracks, 1991-1998. Labels refer to the designations used in the main text.

Office and the need for information dealing with how the data is collected, processed and calibrated have presented considerable challenges to the Bedford Institute of Oceanography (BIO) and other institutions around the world. To achieve the required data submission targets, our shipboard data collection and data quality control procedures have been substantially redesigned.

The Department of Fisheries and Oceans (DFO) has undertaken several major WOCE field programs in the North Atlantic. In keeping with the traditions of international science, many of these efforts have involved partnerships with colleagues in Canadian, American, and European universities and oceanographic institutions.

Some contributions to WOCE represent continuations of ongoing efforts. For example, the Expendable Bathythermograph (XBT) Section AX2 from Halifax to Iceland has been occupied quarterly since mid-1985. It was continued into the 1990s as part of the WOCE intensive XBT program, and was taken over by the United States (US) National Oceanographic and Atmospheric Administration (NOAA) in 1996 as part of its world-wide XBT program.

The Labrador Sea has been studied by oceanographers at BIO since the 1960s. It is one of the few places in the world where water is transformed through cooling into denser water. The dense water sinks, mixing with deeper levels to form "Labrador Sea Water" which spreads into the North Atlantic Ocean at mid-depths. As part of WOCE, a greatly enhanced program to observe the Labrador Sea was initiated in 1990. Since then, expeditions have occupied the WOCE AR7W line (Figure 1) at least once a year to observe the changes in processes and properties. Additional measurements in the Labrador Sea and neighbouring regions of the North Atlantic Ocean were also made to assess seasonal and interannual variability in ocean properties.

The WOCE period (1990-1997) was one of considerable variability in the Labrador Sea. There were large differences from one year to another in the depth to which newly-formed water penetrated. In 1993, following unusually severe winter conditions, deep convection reached more than 2000 metres, twice the depth observed in previous studies. Figure 2 illustrates this with salinity and CFC-11 ("Freon-11") distributions. They show a homogeneous body of Labrador Sea Water in the central Labrador Sea in 1993. In 1995, deep convection was still quite active. In contrast, by 1997, deep convection reached to depths of only about 1000 metres and the salinity and CFC-11 sections show much more vertical structure.

During 1996/97, the international WOCE community surveyed the sub-polar gyre of the North Atlantic during the fall, winter and spring as part of an Atlantic Circulation Experiment. The BIO team mapped the entire Labrador Sea during expeditions in October 1996 and May 1997. In addition, as part of US-DFO and German-DFO collaborative programs, a large number of autonomous floats, surface drifters, and moorings were deployed in the fall of 1996 in order to observe the temperature, salinity and circulation between research expeditions. These deployments set the stage for a multinational Labrador Sea expedition during February/March 1997, on board the *RV Knorr* of the Woods Hole Oceanographic Institution.

The principal objectives of the *Knorr* expedition were to document the convection and its driving mechanisms in the winter Labrador Sea. Researchers were fortunate that a major mixing event took place during this experiment and they were

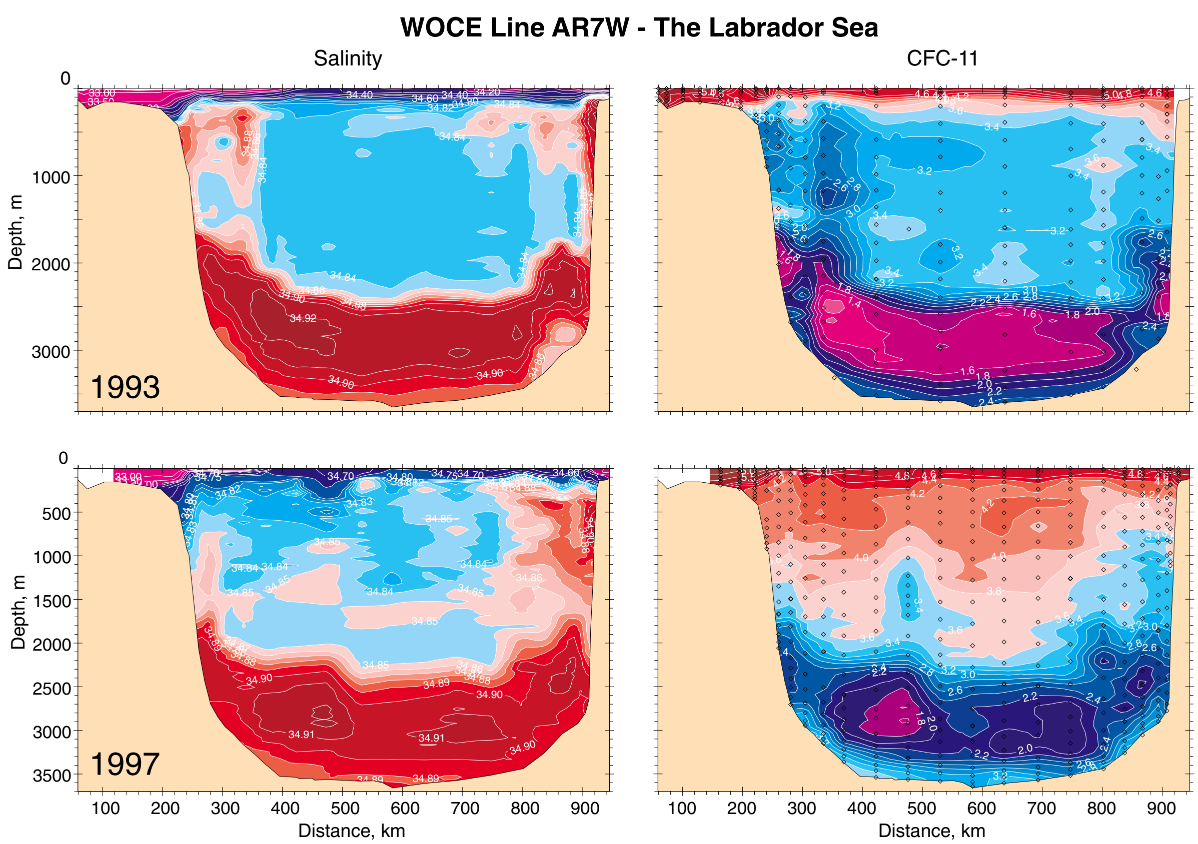

Figure 2: Salinity and CFC-11 distributions across WOCE repeat section AR7W, extending from Hopedale, Labrador on the left to Greenland (see Fig. 1 for location).

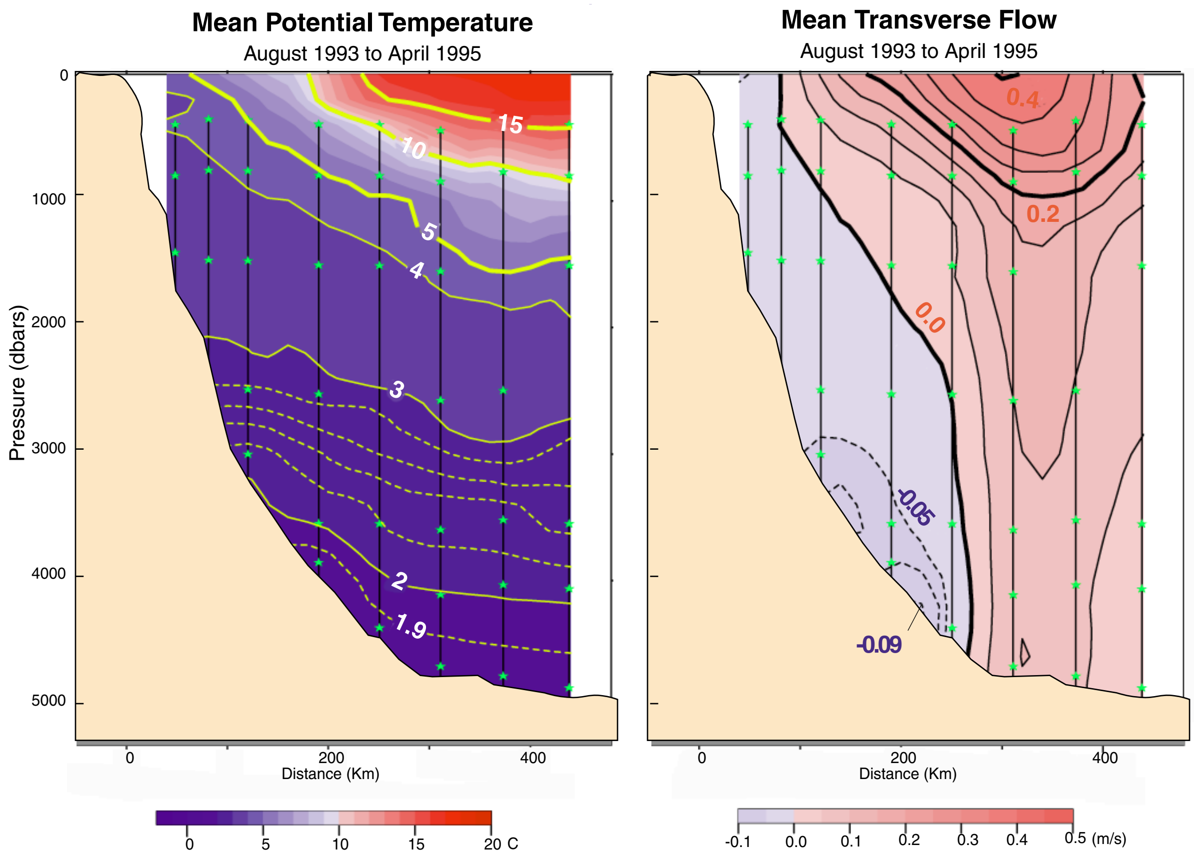

Figure 3: Temperature and velocity sections from the WOCE current meter array ACM6, extending eastward from the Grand Banks of Newfoundland (see Fig. 1 for location).

able to document conditions in the atmosphere and the ocean from top to bottom and from shore to shore. The Canadian team made direct measurements of the air-sea fluxes from *Knorr*, a real achievement given the severity of the conditions. The results are now beginning to appear in the literature and have generated great excitement in the marine physics and climate research communities.

Deep convection in the Labrador Sea has been suggested to be a major sink of anthropogenic carbon dioxide and may play a significant role in limiting the associated greenhouse effect. The detection of anthropogenic carbon dioxide in the ocean is a difficult problem, but initial estimates based on WOCE data suggest that the Labrador Sea may be sequestering up to 40% of the total amount entering the deeper waters of the world's oceans. Researchers are now critically examining this estimate. One approach is to make use of other tracers which have similar atmospheric input histories but are more easily measured. CFC-11 meets both of these criteria and hence represents a potentially useful indicator of how carbon dioxide is entering the ocean. Vertical profiles of anthropogenic carbon dioxide and CFC-11, estimated as part of the WOCE program in the central region of the Labrador Sea, are indeed very similar, indicating a promising future for this approach.

In the region to the east of the Grand Banks of Newfoundland, BIO scientists led a joint Canadian, US, and German effort to estimate the heat, salt, and volume transports of the North Atlantic Current. This warm current is thought to be the principal route for the northward transport of heat and salt by the North Atlantic thermohaline circulation. The temperate climate of northwestern Europe depends on this warm current and the associated air-sea exchanges. The Canadian contribution to the project consisted of an array of eight current meter moorings extending from the eastern continental slope of the Grand Banks to the centre of the Newfoundland Basin. Three hydrographic/tracer surveys of the Gulf Stream / North Atlantic Current system from the Tail of the Banks to Flemish Cap were also obtained. The hydrographic/tracer sections were designed to allow estimates of the flows in the North Atlantic Current, the Labrador Current, and various proposed branches of this complex system. The surveys were also designed to take advantage of Topex/Poseidon altimeter measurements.

The eight current meter moorings constituted WOCE Current Meter Array ACM6 (Figure 1). They formed a line cutting across the North Atlantic Current near 43N, deployed in August 1993 and recovered in June 1995. The moored array provided direct measurements of the heat and mass transports of the North Atlantic Current. The measurements also quantified the transports of deep and intermediate waters carried southward by the Deep Western Boundary Current and associated currents found shoreward of the North Atlantic Current. The University of Rhode Island contributed current metres to the array, and also deployed an array of inverted echo sounders to determine whether these instruments could be used as a less expensive means of monitoring these transports. During this same period, the Bundesamt für Seeschiffahrt und Hydrographie (BSH), in Hamburg carried out three occupations of a trans-Atlantic section from the mouth of the English Channel to the Grand Banks of Newfoundland. The western end of this section overlaps the current meter array. The combination of basin-wide hydrography and direct current meter measurements in the energetic western boundary region will provide estimates of the basin-wide meridional heat and salt fluxes at a nominal latitude of 48 N.

A joint BIO-Dalhousie University field experiment contributed hydrographic and microstructure measurements on two expeditions to a region centred near 33E, 28N (formally WOCE Control Volume AR10) as part of the North Atlantic Tracer Release Experiment (NATRE). A tracer was injected into the pycnocline and its distribution and concentration were measured four times over a period or two years by teams from the US and the UK. Analysis of the results gives an estimate of vertical diffusivity but does not examine the associated physical processes. To this end, measurements were made by the BIO-Dalhousie team to estimate diapycnal diffusivity (i.e., mixing across density surfaces) from small-scale turbulence and microstructure and to compare these results with those from the dye diffusion study. Consistent estimates of vertical diffusivity of order 2×10^{-5} m^2/s were observed, which is about an order of magnitude smaller than values traditionally inferred from vertical advection-diffusion models. Progress has also been made in understanding how to parameterize the mixing rates so that these results can be extrapolated from the experimental sites to the global ocean. Such observations are extremely rare. The conclusions drawn from them strongly influence the dynamically important parameterizations of diapycnal mixing required by large scale ocean models.

Into the Future

The observational phase of WOCE will soon be completed, but its influence is only beginning to be felt. One important outcome of the observational program is that serious discussions have been initiated on how to apply our new ability to make coordinated global ocean measurements for practical use through a proposed Global Ocean Observing System. Results are also being used to help plan the next generation of experiments, aimed at better understanding the nature and cause of large scale climate variability.

On the modelling side, the analysis and interpretation of WOCE observations is helping to define key processes and components of the climate system that must be included in climate models.

The WOCE observation program has helped to lay a solid foundation for future work, and researchers are anxious to build on it.

The Emerging Role of Marine Geology in Benthic Ecology

ToC

Gordon B. J. Fader, R.A. Pickrill, Brian J. Todd, Robert C. Courtney and D. Russell Parrott

Introduction

Over the past decade, marine geologists have become increasingly involved in the application of marine geoscience to biological issues of habitat characterization, gear impact assessment and fisheries management. This new application of geoscience information is a direct result of significant advances in the resolution and accuracy of seabed mapping technologies and an improved understanding of complex seabed processes. Early seabed maps were generally inadequate to meet the requirements of the biological community because they could not provide sufficient detail for a direct correlation between sediment type and biological habitat (Kenchington and Halliday, 1994). The goal of these early regional maps was to characterize the seabed sediment distribution over broad areas of continental shelves for geological purposes and was based on sparse samples and acoustic echogram interpretations from widely spaced data sets.(King, 1970; King and Fader, 1986). While not designed for biological purposes, they did assist the fishing community in specific applications, such as the avoidance of regional seabed hazards (boulder zones and rough terrain) and the location of new grounds for potential fisheries such as clam, Icelandic scallop and lobster. Ongoing data collection and supplementation with regional bottom photographic data bases (Lawrence et al., 1989) and data from the use of new technologies, such as sidescan sonar, enhanced these maps. For example, a series of regional maps, know as Canadian Fishermen's Charts, designed specifically to support the fishing industry, (produced by Nordco Ltd. of Newfoundland) depicted surficial geology from the earlier mapping of the Geological Survey of Canada, bathymetry, and the location of seabed hazards to bottom fishing gear determined by the fishing industry.

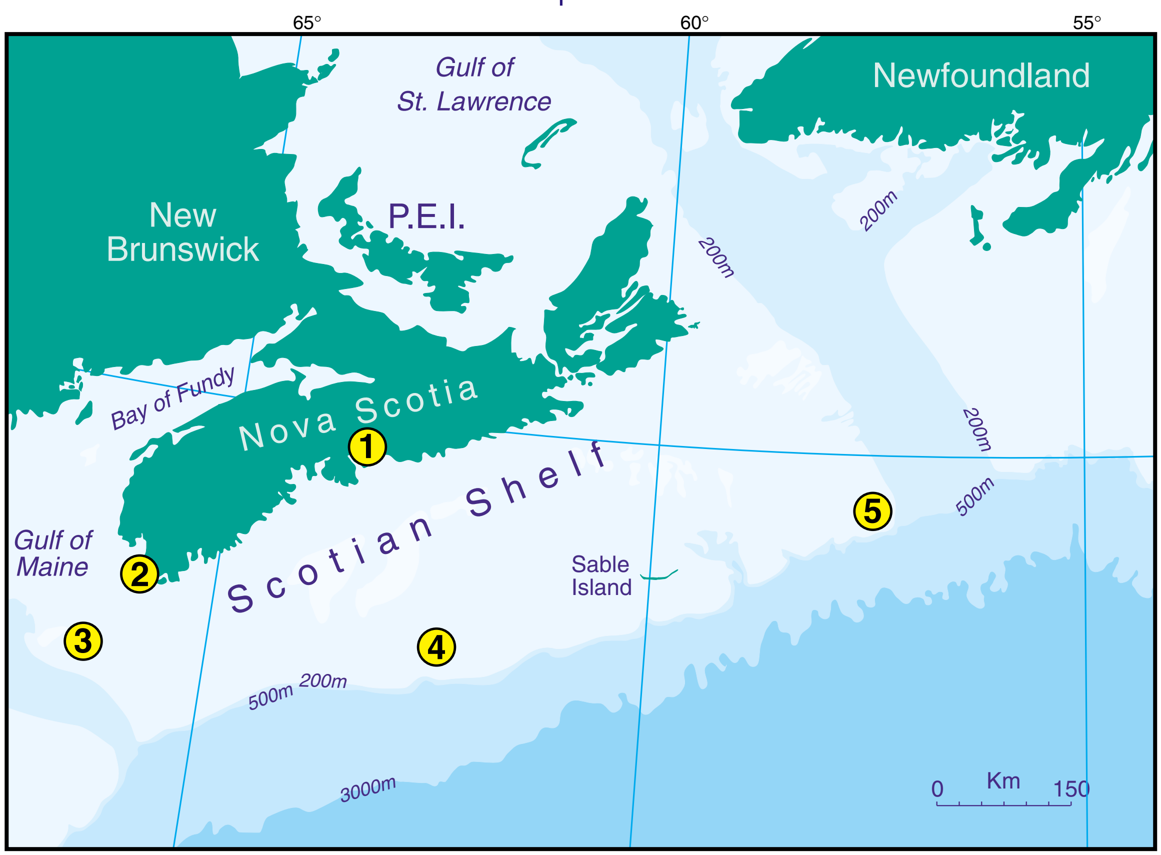

Figure 1: Index map of study area with locations of following illustrations.

Traditional geological seabed mapping has focused on defining surficial sediment units or formations, which are basic map units that can be traced over large areas. These early regional geological maps relied on statistical sample grids spaced at a variety of distances from 100s of metres to kilometres. The advent of sidescan sonar presented the geologist with imagery of the seabed similar to aerial photography of land. Consequently the sample methodology changed to focus on providing ground truth for the sediment acoustic characteristics and features interpreted from this data. That significantly reduced the requirement for a large number of samples and allowed accurate correlation between samples. Until the 1980s, a lack of precise navigation was also a major limiting factor in the production of detailed seabed maps.

Over the past 10 years, major developments in seabed mapping technology have occurred that meet many of the requirements of the marine biological community. These include high-resolution sidescan sonars, multibeam bathymetric mapping systems, precise navigation, precision sampling and photographic systems, and advances in digital data processing and scientific visualization techniques. In this paper we describe recent research at GSC Atlantic utilising these seabed mapping techniques that contributes to habitat mapping, ecological research and fisheries management.

Geological Habitat

Adequate attention to habitat is considered by some to be the most fundamental of ecological concepts, often missing from ocean fisheries management (Willison and Butler, 1998). To address this issue, closer cooperation between marine biologists and marine geologists is essential. The following is a list of critical geological seabed attributes considered to be of ecological importance based on initial and ongoing discussions through cooperative projects:

- micro relief - centimetres to decimetres (roughness)
- macro relief - metres to 100s of metres (topography, morphology, slope)
- grain size (gravel, sand, silt and clay)
- lithology (rock composition)
- patchiness (local variability, shape, spatial patterns)
- sediment distribution
- sediment sorting
- porosity (pore spaces, packing)
- grain shape (roundness, sphericity)
- stratigraphy (layering - centimetres to decimetres)
- dynamics/processes (relict to modern and combinations)
- bedforms (all scales, centimetres to 10s of km)
- sediment transport pathways (net and varying directions)
- sediment thickness (centimetres to metres)
- regional setting (e.g. sandbank, moraine, beach ridge, basin)
- geological history (origin)
- anthropogenic features (shipwrecks, anchor marks, cables, debris)

Some of these attributes, such as sediment grain size and lithology, are more easily determined than other attributes, provided that valid seabed samples can be collected. This is not a trivial matter in coarse gravely sediment. Other characteristics such as porosity and high-resolution stratigraphy are more difficult to determine, as the process of sampling frequently destroys the fabric of the seabed material, particularly in coarse-grained sediments. For these areas, reliance is placed on remote sensing by acoustic means and insitu geotechnical methods for assessment. The measurement of many of these attributes remains an area of continued research.

Tools and Techniques

The use of sidescan sonar demonstrated to the marine geologist that the morphology and distribution of sediments on the seabed was considerably more complex than previously thought. Additionally, sonograms could be interpreted to assess seabed dynamic conditions using geological knowledge of sediment bedforms, transport pathways and other seabed processes to determine temporal and spatial mobility.

As awareness of the capability of this new technology increased, the biological community recognised an application to address some of its concerns. This led to co-operative programs for assessment of habitats such as lobster off Cape Breton Island; clam, Icelandic scallop and the sea cucumber fishery of the Grand Banks of Newfoundland and the shrimp fishery in Chedabucto Bay. New and unforeseen biological applications of geological mapping technology included the detection of ghost nets on the seabed, the optimum siting of water intakes for lobster pounds, and the assessment of aquaculture sites and their effluent effects on the seabed.

Both the biological and geological communities, desire a capability for higher-and higher- resolution mapping of the seabed. Within the Geological Survey of Canada (Atlantic), one approach has

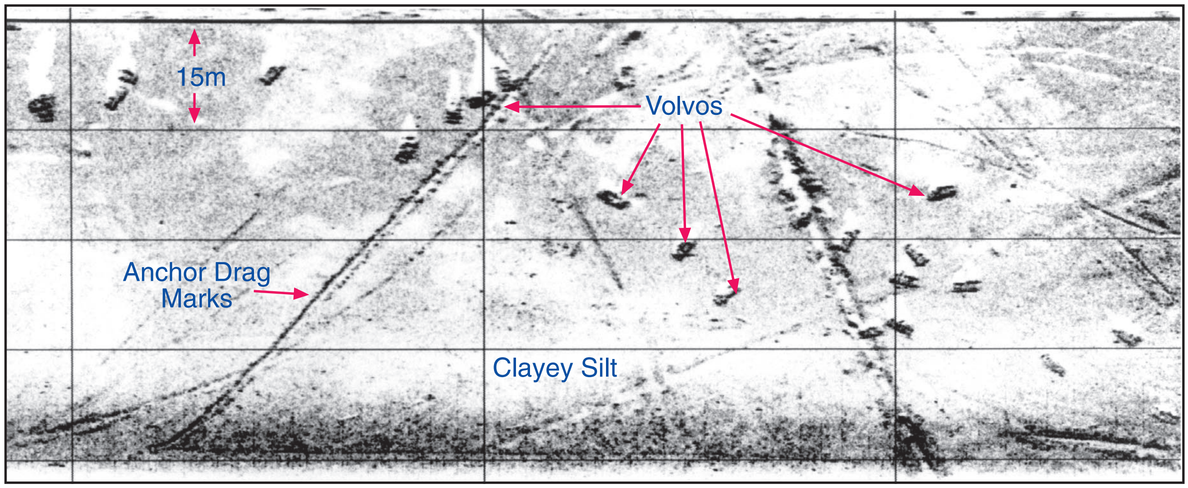

Figure 2. 330 kHz sidescan sonogram from Bedford Basin, Halifax Harbour, collected with a neutrally bouyant and decoupled towfish, configured to minimize towfish motion. Image shows flat muddy seabed with linear anchor drag marks. The approximately 20 rectangular features on the seabed are discarded Volvo automobiles whose roofs have been colapsed before dumping. Known targets like these provide calibration for trials to improve sonar resolution. The resolution and image quality is considerably better than data collected with conventional towing arrangements.

been to maximise the resolution of existing systems that traditionally have been operated in a lower resolution regional mapping mode. For example, 330 kHz sidescan sonars can be operated with ranges of 25 m and slow towing speeds of 2 knots to approach their theoretical resolution limits of approximately 10 cm and 100% seabed insonification. To achieve this resolution routinely, modifications to existing sidescan systems have been made to reduce tow fish motion and increase stability. Depressor weights are positioned on the tow cable, from which a neutrally bouyant fish is towed close to the bottom. This decouples the tow fish from ship motion. In conjunction with improving towing characteristics, positioning has been improved by using short baseline transponders to position the tow fish relative to the ship, while inertial motion sensors provide data on pitch, roll and heave to correct sonograph distortion. The net result of these developments has been a significant improvement in mapping resolution and micro habitat mapping. (Figure 2).

A second approach toward high resolution seabed mapping is the extraction of seabed attributes from digital multibeam bathymetry, sidescan sonar and seismic reflection data. At present much of the backscatter and reflectance data (sediment type) represents only relative changes in seabed character. Through the calibration of existing acoustic surveying systems, additional information on seabed roughness, slope and relief can be extracted. We are in the early stages of this approach and have completed the calibration of seismic and sidescan systems. A series of acoustic experiments were conducted on Browns Bank in the summer of 1998. The results from this effort, when coupled with theoretical modelling, should lead to a better understanding of which of the physical parameters of the seabed are manifested in the acoustic reflection and backscatter data.

Multibeam bathymetric mapping has provided a new opportunity to produce high-resolution maps of seabed morphology over relatively large areas. It was first applied in Canada in the eastern offshore in 1990 (Courtney, 1993; Courtney and Fader, 1994, Courtney et al., 1993), through the use of vessels fitted with an array of boom-mounted transducers, followed by more sophisticated hull-mounted multibeam transducer arrays. The most significant aspects of this new technology are 100% coverage of seabed morphology, an ability for interpretation of regional seabed processes, and the portrayal of subtle aspects of deposition and erosion through techniques of scientific visualization. In addition to the complete coverage of the seabed, producing detailed morphological images (shaded relief bathymetry), these systems also provide backscatter information from the seabed (texture, roughness and lithology). This is a major improvement in seabed geological assessment as it provides a remote mapping tool of seabed type that is georeferenced with morphology, and generated by the same sensor package. These systems, and the products produced, have revolutionized the marine geologists' view of the seabed and understanding of seabed processes.

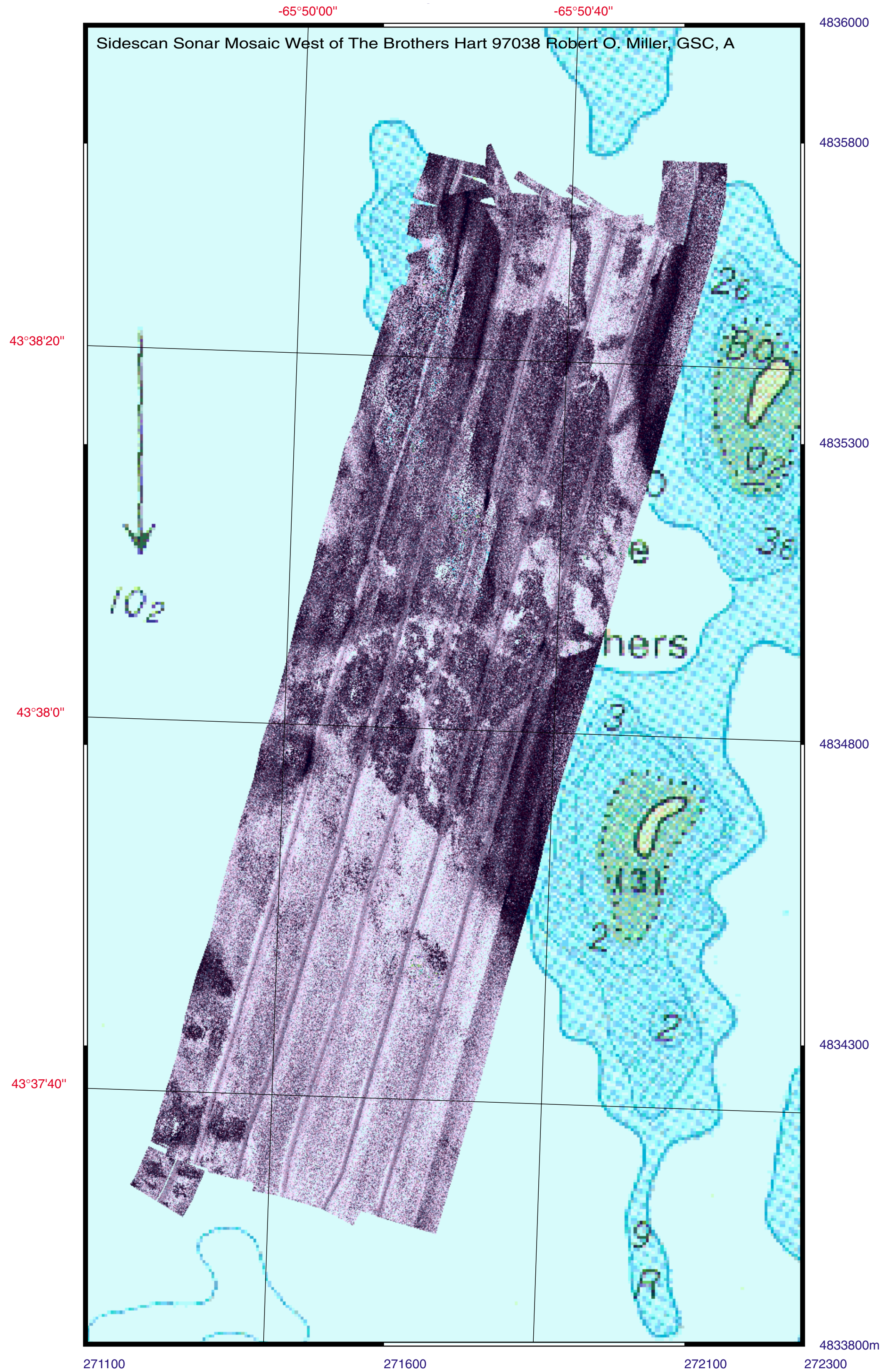

Figure 3. High resolution sidescan sonar mosaic of the seabed in Lobster Bay, southwest Nova Scotia. The sidescan data were collected and processed at 50 m range and 330 kHz. This provides very high resolution and can identify individual boulders at the seabed greater than 0.20 m. The image shows hard boulder-covered seabed as an offshore extension of drumlin shoals and islands in Lobster Bay. Deeper areas are sand to muddy sand. These mosaics provide the geological framework as a basis for conducting lobster assessment surveys.

PARTNERSHIPS

As a direct result of the applicability of modern geological tools to fisheries and benthic habitat issues, and in response to pressure for sustainable management of fish stocks, GSC Atlantic has partnered with DFO on several new research projects in the last two years. GSCA has provided the geological framework within which these issues can be addressed. The following is a discussion of several of these co-operative projects that illustrate the new and evolving role of geoscience in habitat assessment. These include a zonal lobster research project (ZLORP); an assessment of scallop habitat on Browns Bank and studies on the effects of trawling and clam harvesting on the seabed.

ZLORP

The zonal lobster research program (ZLORP) uses geological mapping to develop an understanding of the spatial dynamics of benthic settlement patterns of lobsters in relation to seabed characteristics in terms of habitat structural elements and biotic assemblages. Fisheries managers require information on the location, nature and areal extent of lobster recruitment habitats within the broad regional lobster production areas. Understanding the ecology of lobsters during the first three years of benthic existence provides essential information for long-range (five to seven year) recruitment forecasting for the Canadian fishery. Additionally, detailed knowledge of habitat location and characteristics is essential for design of a recruitment monitoring program and successful stock management.

High-resolution geological mapping and seabed characterization of nearshore lobster habitat was undertaken in areas of the western Gulf of St. Lawrence and southwestern Nova Scotia. High-resolution sidescan sonar mosaics (Figure 3) have been constructed, geologically interpreted and provided to lobster biologists to form the basis for ground-truthing visual, video and sampling diver transects. Initial results indicate that the geological assessment of seabed sediment distribution, topography and dynamic conditions of sediment transport provides essential information for understanding the spatial and temporal distribution of lobster recruitment habitats.

Scallop Assessment

A new co-operative project between industry, DFO and GSCA has been developed to explore the application of geoscience information to the sea scallop fishery on Browns Bank, western Scotian Shelf. The sea scallop is one of the most important commercial invertebrate species in eastern Canada, second only to lobster in landed value. Sea scallops are generally found in areas of gravely seabed but little is known concerning other preferred bottom characteristics. Multiple objectives being pursued are:

- to understand the relationship between historical catch effort, returns and substrate,
- to understand the relationship between scallop distribution, ecology and seabed habitat,
- to provide information to enhance fishing efficiency such as obstacle and hazard avoidance and optimize fishing practices,
- to provide a knowledge base for the sustainable management of the fishery.

In meeting these objectives, GSC Atlantic has also collected critical information for the primary geoscience program, to understand the glacial and postglacial evolution of the Scotian Shelf which provides the framework for the distribution of surficial sediments and features.

Initiated with the collection, processing and interpretation of multibeam bathymetry, grids of high-resolution seismic reflection and sidescan sonar data have been collected along with large-volume samples, video and photographic information. The integration of these data sets provides considerable insight, enabling the separation of ancient and modern processes acting on Browns Bank, both of which affect the distribution and abundance of scallops. For example, the northern flank of Browns Bank is the Fundian Moraine, a prominent 15-m high, 2-km wide and 80-km long, steep-walled feature, covered with large boulders. The moraine formed during the retreat of glaciers from the western Scotian Shelf approximately 20,000 years ago (Figure 4). Observations from the northern side of the moraine show the presence of dense communities of juvenile scallops associated with gravel in the granule to pebble size range. Other areas to the south of the moraine consist of larger more mature scallops. The distribution of the juvenile scallops in this preferred location suggests that strong currents moving from northwest to southeast across the bank from the Bay of Fundy, are modulated by the prominent moraine, developing suitable seabed habitat characteristics and concentrating a source of abundant food for the juvenile scallops.

Future developments in this project will explore the extraction of additional information on sediment properties from the calibrated

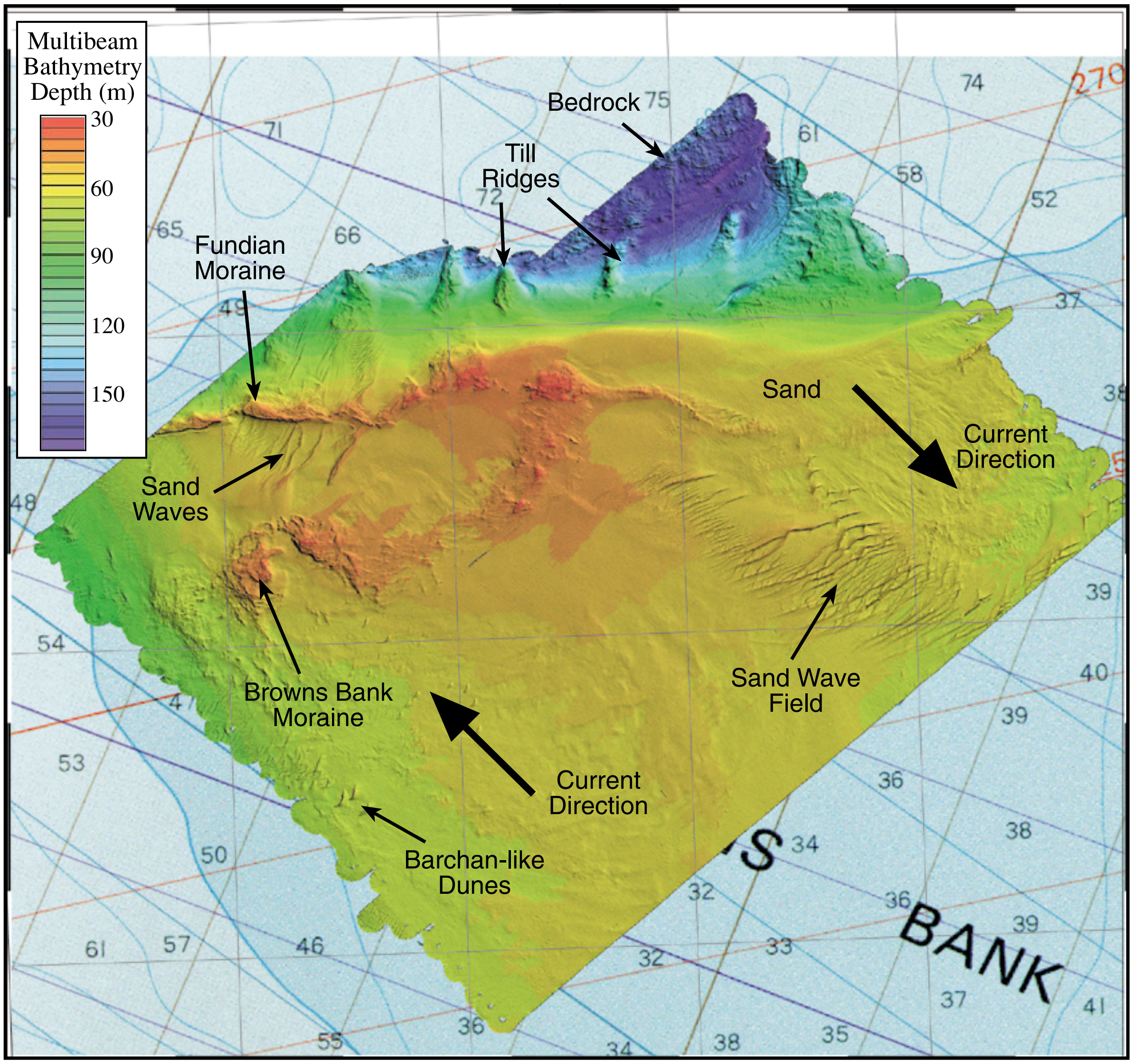

Figure 4. Multibeam bathymetric image of western Browns Bank, western Scotian Shelf. The image shows colour-coded depths and is artificially-shaded from the northwest to enhance the portrayal of morphology. Prominent features include bouldery ridged moraines, fields of sandy bedforms, shelf-edge low stand deltas, and a variety of other subtle terrain types. The bank is largely formed of glacial materials, reworked and modified by a transgressing sea in post glacial time. Both glacial (relict) and modern (present day) seabed features occur adjacent to one another.

multibeam bathymetric backscatter information. This information will be combined with scallop catch data and sediment transport information to better understand the complex relationship between scallop distribution and seabed geology. It is envisioned that a series of geological seabed assessments, provided as layers of information on seabed characteristics and dynamic conditions, will provide an underpinning for both improved fishing practice and fisheries management.

Effects of Trawling

Of global concern to both the fishing industry and government regulators are the effects of mobile fishing equipment on seabed habitat and benthic ecosystems (productivity and biodiversity). Trawling causes a number of direct and indirect changes in the ecosystem such as changes to fish populations and benthic communities, and the release of organic and inorganic nutrients (De Groot, 1984). Bottom trawling directly alters the structure and morphology of the seabed and the pressure of the gear affects the subsurface sediment fabric including habitat structure. Undisturbed sites commonly contain epifaunal bryozoans, hydrozoans, sponges and polychaete and amphipod tubes which provide protection and large surface areas for fragile taxa such as shrimps, brittle stars and polychaetes (Collie et al., 1997). By contrast, trawled sites often exhibit reductions in epifaunal communities and reduced porosity of coarse-grained sediments.

Previous studies have been largely qualitative and geological characteristics of the seabed have in many cases been omitted or not properly evaluated. A recent project of DFO, NRCan and industry is attempting to address these issues in a three-year study of the effects of bottom trawling on Western Bank and the effects of clam dredging on Banquereau. This is a follow-up to an earlier study on the Grand Banks of Newfoundland over a sandy seabed substrate, which indicated a reduction of 25 % of invertebrates in trawled corridors versus untrawled controlled corridors. (Gordon et al., this publication)

The present area of study is termed the 4TVW Haddock Nursery Area on Western Bank, Scotian Shelf, which has been off limits to mobile groundfish gear since 1987. Controlled trawl surveys have been conducted, together with before and after sidescan sonar, sampling and video observations in both test and control areas. A unique millimetre-resolution acoustic imaging system (DRUMS ™) was also deployed to provide very high resolution of the structure beneath the seabed to a depth of 0.5 m. (Schwinghamer et al., 1996). This system provides a calibrated measure of the sediment fabric (habitat structure) as an additional independent acoustic method to quantify disturbance by trawling.

The sidescan sonar data clearly show that the trawl doors make the deepest linear furrows on the flat cobble-pebble, gravel lag surface, but both the cod end and the ground line produce a distinct linearity to the seabed (Figure 5). This is interpreted as a subtle alinement of particles to which the sidescan sonar system is particularly sensitive. Sonar surveys conducted concurrent with the trawling operation correlate the effects of each component of the bottom trawl gear with distinct seabed markings. Benthic samples collected from the trawled areas are presently under study, but preliminary observations suggest a reduction in biodiversity and a change in sediment porosity. Samples collected from the trawled areas were also reduced in volume. This is interpreted to result from rearrangement of gravel clasts into more closely-packed associations making sampling less effective.

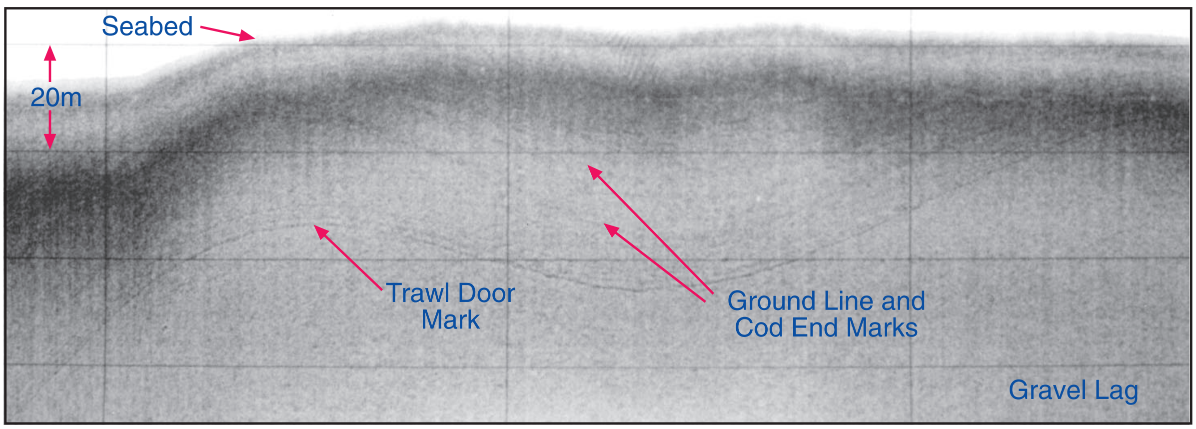

Figure 5. Sidescan sonogram of trawl marks on gravel seabed of Western Bank, Scotian Shelf. The outermost mark produced by the trawl doors is deeper and more continuous than the linear marks made by the ground line and cod end. These marks can persist for long periods of time measured in years, particularly when formed in hard gravely seabeds.

Impacts of clam harvesting

Two types of clam harvesting are being assessed: in the nearshore and on offshore banks. In New Brunswick and Prince Edward Island, surf clams are harvested from the intertidal zone using small hydraulic rakes. The impact of the rake on the clam population is unknown, but declining returns have forced the closure of the fishery in both provinces. GSC Atlantic has contributed to a controlled experiment to assess the impact of harvesting on juvenile clam recruitment. Hydraulic rakes fluidise the top 30 cm of sediment. Short core samples driven through the sand before and after raking show that raking increases porosity and decreases bulk density of the clam beds for periods of up to three to four weeks. Recruitment of juvenile clams is higher in these “ploughed” beds than in neighbouring control sites, suggesting that raking has a beneficial effect on surf clams during the early stages of their life cycle. Geotechnical soil properties provide a simple yet effective technique to quantify the physical changes in the clam beds induced by harvesting.

On a larger scale, offshore clam harvesting on Banquereau, eastern Scotian Shelf, uses 4 metre clam dredges equipped with high-pressure water jets to liquefy the sediment. Before, after and control corridor surveys show that the hydraulic dredge is more invasive than bottom trawling, with the water jets producing a trough up to 20 cm in depth. Plumes of sand suspended by the fishing operation fall to the seabed to a distance of 10 to 15 m beside the dredged track and can be

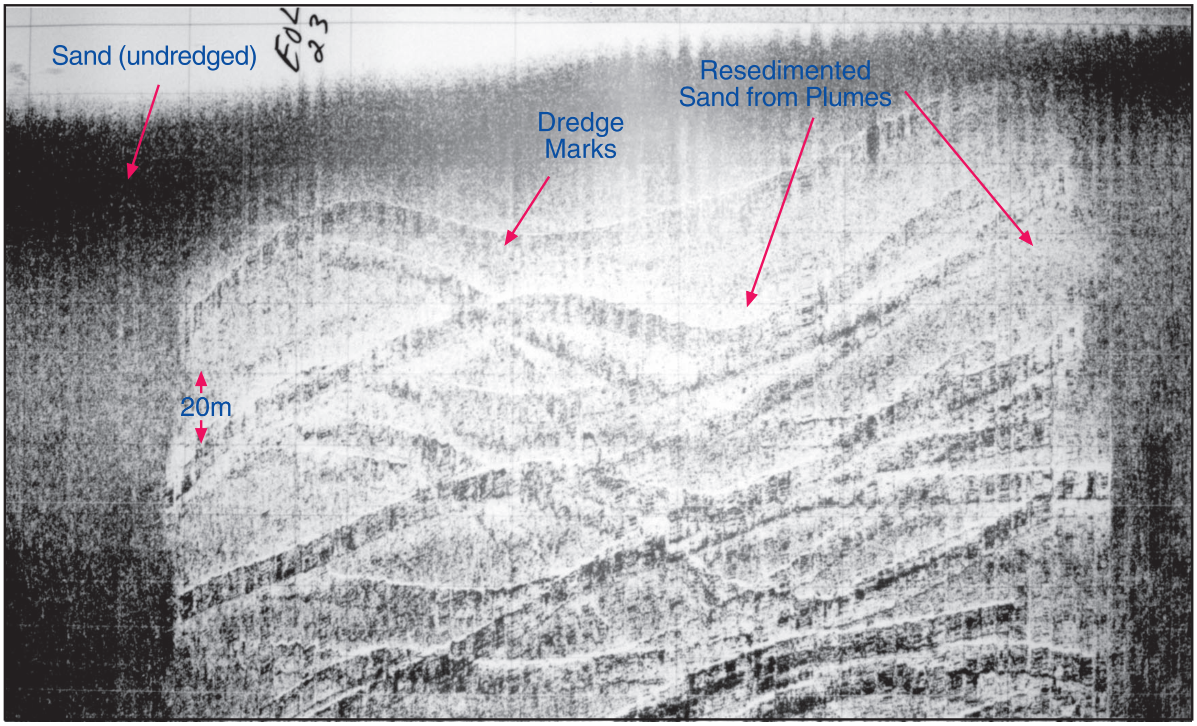

Figure 6. Sidescan sonogram of a clam dredge trawled area of southern Banquereau, Scotian Shelf. The untrawled seabed consists of medium sand with a dense benthic community including many siphon holes of propeller and surf clams. It presents a medium intensity backscatter on the sidescan data. The clam dredge marks are 4 m wide, medium intensity backscatter, linear, 20 cm deep depressions. The seabed between dredge marks is of lighter tone indicating low acoustic backscatter. It results from resettling of sand plumes generated by the clam dredging operation. Note the crisscrossing and convoluted pattern of dredge tracks.

clearly seen on the acoustic and photographic data as a fresh deposit of fine-grained sand, largely devoid of browsing organisms (Figure 6). Analysis of the benthic samples is continuing to provide a quantitative assessment of mortality.

The use of sidescan sonar technology provides essential pre-survey confirmation of undredged seabed as well as a map of dredging survey tracks. Despite attempts to dredge parallel, equi-spaced tracks, the sidescan data show that the tracks are often convoluted, criss-crossing and overlapped, as a result of strong currents and inability to sometimes control the track of the dredge on the seabed. The sonar information allows accurate sampling to be conducted post dredging, and to position sampling equipment both in and out of dredged tracks.

Other Habitat Related Projects

In the Bay of Fundy, studies of benthic-pelagic coupling are underway (Wildish et al., 1998 and Wildish and Fader, 1998) involving linear bivalve reefs (horse mussels) that cover large areas of the seabed. These reefs were discovered with sidescan sonar during GSC Atlantic geological mapping projects. They occur as long linear bioherms up to 3 m in height above the surrounding seabed, 20 m in width and km in length. This research has expanded in cooperation with DFO to include assessment of other benthic communities and relationships to sediment provinces within the Bay of Fundy.

The possibility of open ocean scallop aquaculture has been proposed for areas of the Bay of Fundy. Knowledge of seabed sediment type, and especially sediment transport, is essential for such a fishery to be successful.

The provision of geoscience knowledge to the inshore aquaculture industry is also an increasing new opportunity. Like any large seabed facility or engineering installation, assessment of the environmental conditions of proposed aquaculture sites is an essential first step in project location. The new high-resolution mapping tools of the geologist, including multibeam bathymetry, provide a characterization of proposed aquaculture areas to determine transport pathways for contaminants, the presence of seabed and subsurface hazards, and to define conflicting resources such as placer gold and marine aggregate. Subsurface data can be interpreted to extrapolate these characteristics and environments back through time at very high resolution.

Discussion

Globally, and in Canada, the development and application of high-resolution seafloor mapping tools and geotechnical techniques to traditional marine geoscience research has been coincident with declining fish stocks, more efficient fishing technology, exploitation of new commercial fish stocks and a global decline in the sustainability of ocean ecosystems. This has presented fisheries researchers and managers with new challenges to understand seabed ecology for the maintenance of sustainable fisheries. Geoscience tools are recognised as providing valuable information toward resolving some of these questions in benthic ecological research, habitat definition and delineation, fisheries management, and gear impact studies. The long term goal is to systematically understand the coupling between seabed characteristics and associated benthic communities.

Future application of geoscience knowledge to ocean issues will be strengthened, contributing to projects such as the delineation of Marine Protected Areas, the development of strategies for the protection of critical habitat, artificial reef construction for lobster farming, and aquaculture site assessment. Seabed use maps will become common, much as land use maps play a major role in urban and rural development. For the marine geologist, future research will concentrate on the extraction of geological attributes from remotely-acquired acoustic data.

Competing demands for scarce nearshore resources have lead to the development of an integrated coastal zone management policy for Canada. This policy provides a framework within which competing land use, such as aquaculture, fishing, mining, tourism, waste disposal, cable and pipeline corridors and oil field development can be prioritised, controlled and sustained. Under the recently enacted Oceans Act, seabed mapping will provide baseline maps as the essential underpinning to integrated coastal zone management, and links between oceanographers, fisheries managers, industry and marine geologists, will continue to be strengthened.

Acknowledgements

We thank geoscience technicians Austin Boyce and Bob Miller for the collection and processing of sidescan sonar data and mosaic construction. The Canadian Hydrographic Service has provided multibeam bathymetric data over many years of cooperative surveys and projects and we thank them for their support. We have enjoyed many discussions and cooperative projects with marine biologists who have contributed habitat knowledge and enlightened the geological community. This list is long and includes Don Gordon, Peter Lawton, Dave Wildish and their technicians. Our surveys could not be conducted without the support of Canadian Coast Guard vessels. The munuscript was reviewed by Gary Sonnichsen and Don Forbes of the GSC (Atlantic).

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Northern Shrimp in Southern Waters - The Limit to the Fishery are Clearly Environmental

ToC

Peter Koeller

The Northern shrimp, *Pandalus borealis* (Figure 1), is aptly named - it is found throughout the northern regions of the world's oceans, including the North Pacific, North Atlantic, and in the Barents and Bering Seas. On the Scotian Shelf it is approaching its distributional and, by inference, its physiological limits. Here conditions are not always ideal for survival of the animal, and the fishery that depends on it - while its preferred habitat of mud is relatively common, preferred temperatures (1-6°C) are not found everywhere, and not always. In southern waters (e.g. south of Halifax in the western North Atlantic) northern shrimp tend to conduct seasonal migrations in search of colder water. Longer term increases in temperature are associated with decreases in abundance, as would be expected for a northern species that prefers cold temperatures. Colder water in the 1990's undoubtedly helped build up the southern stocks to their current high levels, but at the same time the most important predators of shrimp, like cod, have been at historical lows. If temperatures increase and groundfish stocks rebuild, shrimp stocks will probably decline. The challenge is to devise a management regime which provides the greatest possible catches from a population so strongly influenced by environmental and ecological changes. How does one obtain a "sustainable yield" from a population that has difficulty sustaining itself ? The answer - *very carefully*. The main elements of caution: a thorough understanding of the biology and population dynamics of northern shrimp relative to its environment, and; a management regime that monitors the fishery and the population accurately enough to allow swift reductions of quotas in response to environmentally caused downturns, and increases when conditions are favourable.

The first shrimp fishery on the Scotian Shelf started in the Bay of Fundy in the mid 1960's (Figure 2) but it declined quickly after 1969. In 1970 most Fundy shrimp trawlers moved offshore to known shrimp concentrations in Roseway Basin, but catch rates continued to decline and the fishery disappeared within a few years. The western Scotian shelf (i.e. west of Chedebucto Bay) shrimp

Figure 1. P. borealis at 300m during submersible dive off Louisbourg.

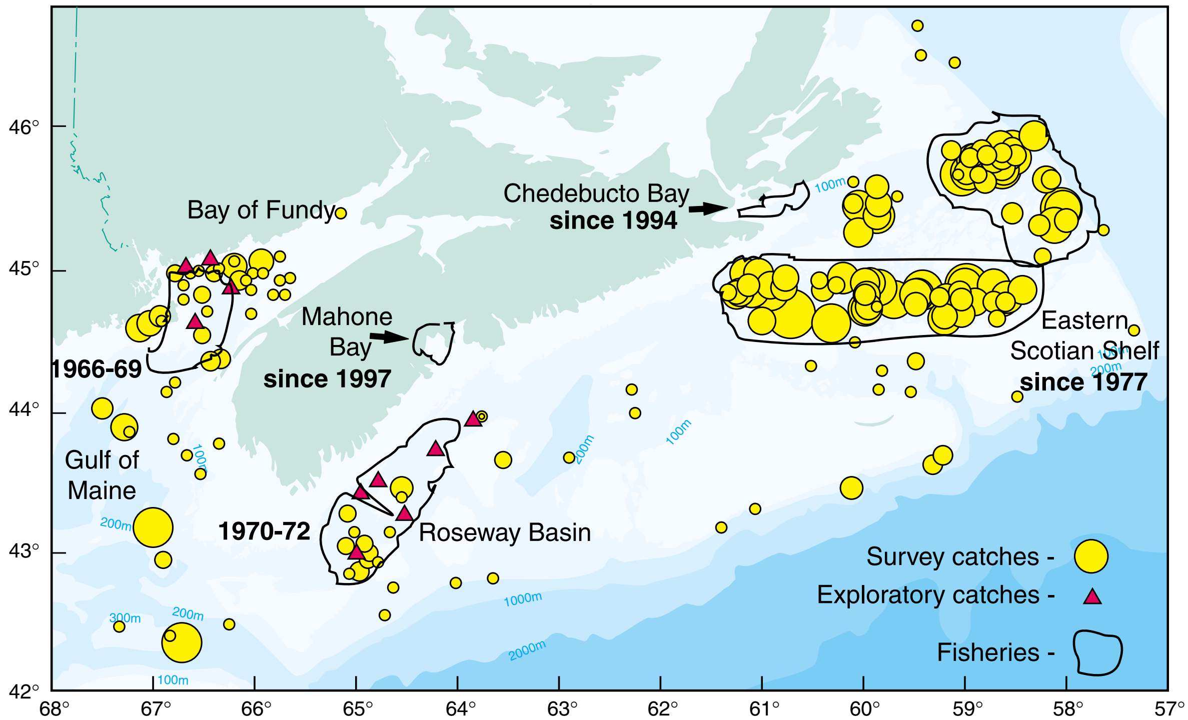

Figure 2. Distribution of shrimp catches during DFO groundfish surveys on the Scotian Shelf (1970-84), location of significant catches on the western Scotian Shelf during exploratory fishing trips conducted by the N.S. and N.B. Department of Fisheries, and locations of shrimp fisheries, past and present. Sizes of circles are proportional to the amount caught.

fishery coincides with historical high catches in the Gulf of Maine (Figure 3A, and with high abundance indices from fishery independent surveys conducted in both areas (Figure 3C). The high shrimp abundances in the Gulf of Maine and on the western Shelf were preceded by a period of exceptionally cold water temperatures favourable to shrimp (Figure 3B).

A shrimp fishery has been conducted on the eastern Shelf (defined here as south and east of Chedebucto Bay) without interruption since the mid 1970's (Figure 2) although its full development was hindered until the early 1990's because of bycatch restrictions. At that time fishers began to use a device which allowed groundfish to escape the trawl and retain only shrimp. The subsequent success of the fishery only on the eastern Shelf, the greater abundance of shrimp in this area (Figure 2), and the different population trend with time (Figure 3C) indicate that environmental conditions here are fundamentally different than in the west. The two main environmental determinants of shrimp abundance and distribution on the Scotian Shelf (i.e. temperature and habitat) are shown in Figure 4. The western shelf has a much smaller and more unstable population, but it also has the most shrimp habitat, so habitat is not a restriction here. On the other hand, temperatures favourable to shrimp are rare in the west, and with the exception of the Roseway Basin area are above the species range. The situation is virtually the opposite in the east, where habitat is relatively rare, but temperatures are favourable over large areas. Apparently temperatures are restricting shrimp population growth in the west, while habitat availability may be restricting it in the east. Ironically, the relatively small amount of shrimp habitat on the eastern Shelf may also be contributing to the success of the fishery - the population concentrates in the small area of preferred habitat which is easily accessible and where catches are consistently high.

Despite its greater abundance, the eastern Scotian Shelf shrimp population can still change greatly over time (Figure 5). Both surface temperatures (which could affect larval survival) and cod abundance mirror shrimp abundance rather well throughout this period, suggesting that on the eastern Shelf predators are at least as important as temperatures as a determinant of shrimp abundance.

The eastern Shelf is also the only area where a shrimp population has established itself inshore. This is probably because it is the only area where habitat (mud in deep water), and favourable temperatures throughout most of the year, are found inshore (Figure 4). This has led to the development of an inshore trap fishery in Chedebucto Bay which stops only during spring and early summer when the large trapable shrimp move out of the

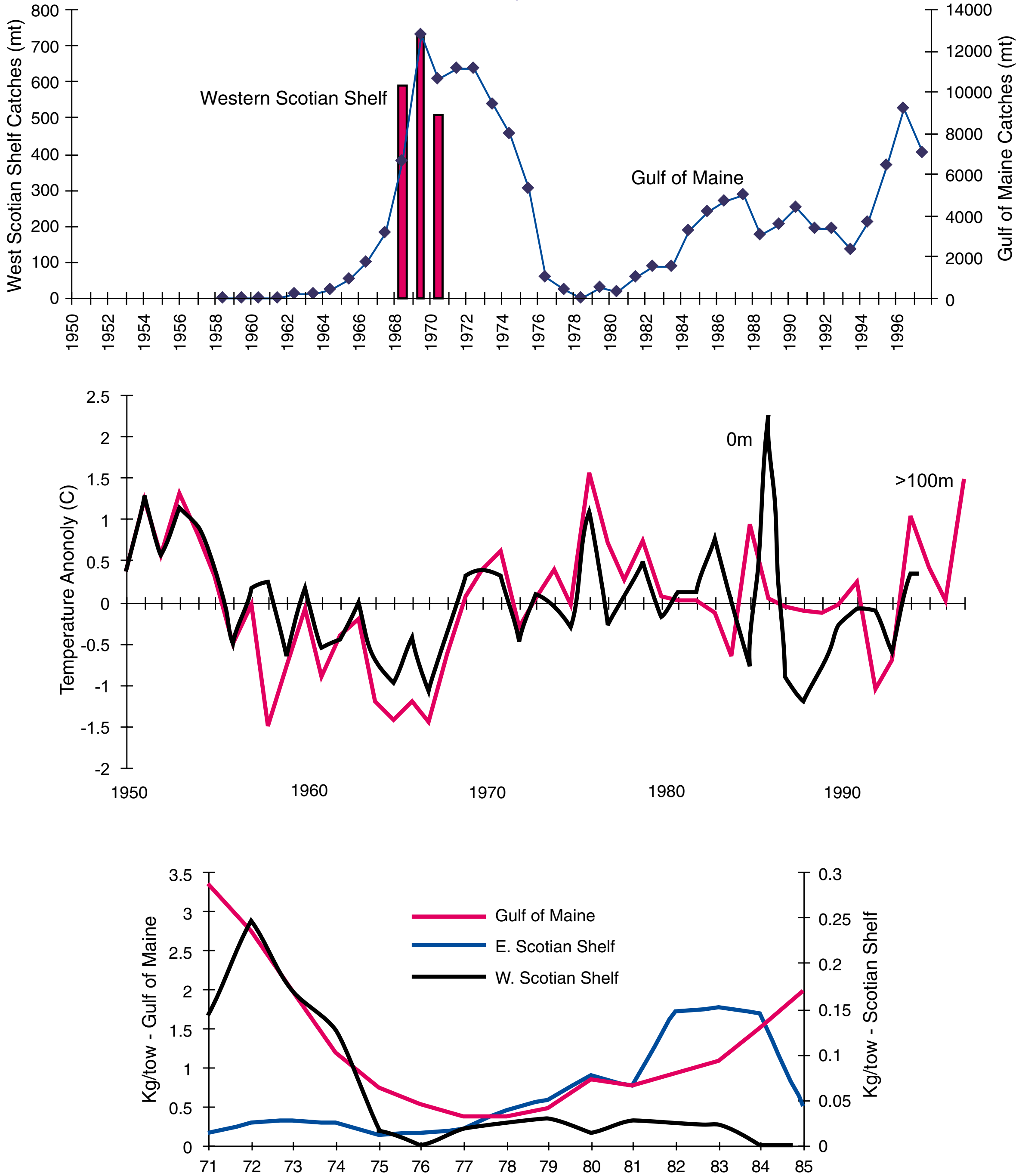

Figure 3. A. Commercial shrimp catches on the western Scotian Shelf and in the Gulf of Maine, B. Temperature anomalies for surface and deep water from one location on the western Scotian Shelf, and C. incidental catch of shrimp (stratified mean kilograms per tow) from groundfish surveys in the Gulf of Maine and on the Scotian Shelf.

Bay due to very cold water temperatures (Figure 6). Surprisingly, a trap fishery has also developed in Mahone Bay (Figure 2), where there are no large areas of shrimp habitat comparable to the eastern Shelf, but only a small patch of mud within Mahone Bay itself. Unlike the inshore area on the eastern Shelf where the presence of all life history stages indicate a self-sustaining local population, the Mahone Bay fishery catches only egg-bearing females. This indicates that Mahone Bay shrimp have migrated from elsewhere, probably from the known offshore population in Roseway Basin fished in the early 1970's. This situation is similar to the Gulf of Maine, where egg-bearing females are known to move into shallow, inshore water during winter in search of colder water. Shrimp in Roseway Basin have not been abundant enough for commercial catches since the 1970's, yet the same shrimp appear to support a small trap fishery when they migrate inshore and concentrate in a small area.

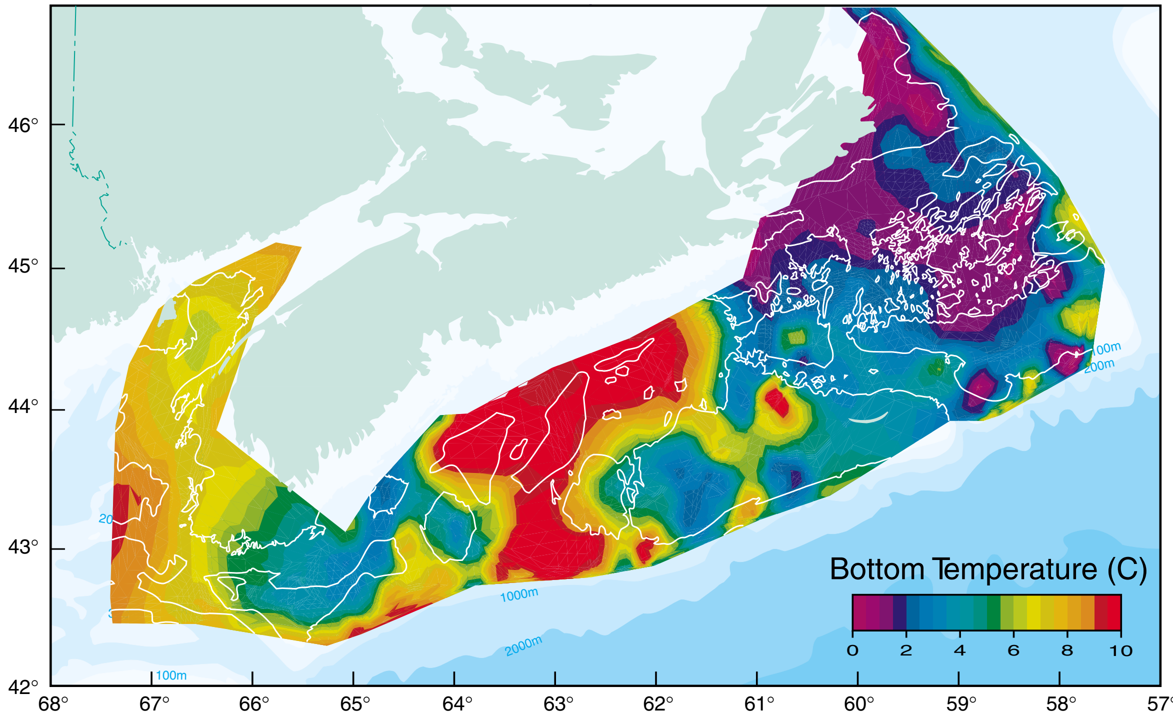

Figure 4. Distribution of bottom temperatures from the July 1996 groundfish survey and location of shrimp habitat (LaHave clay) on the Scotian Shelf (delineated by the white and dashed black line).

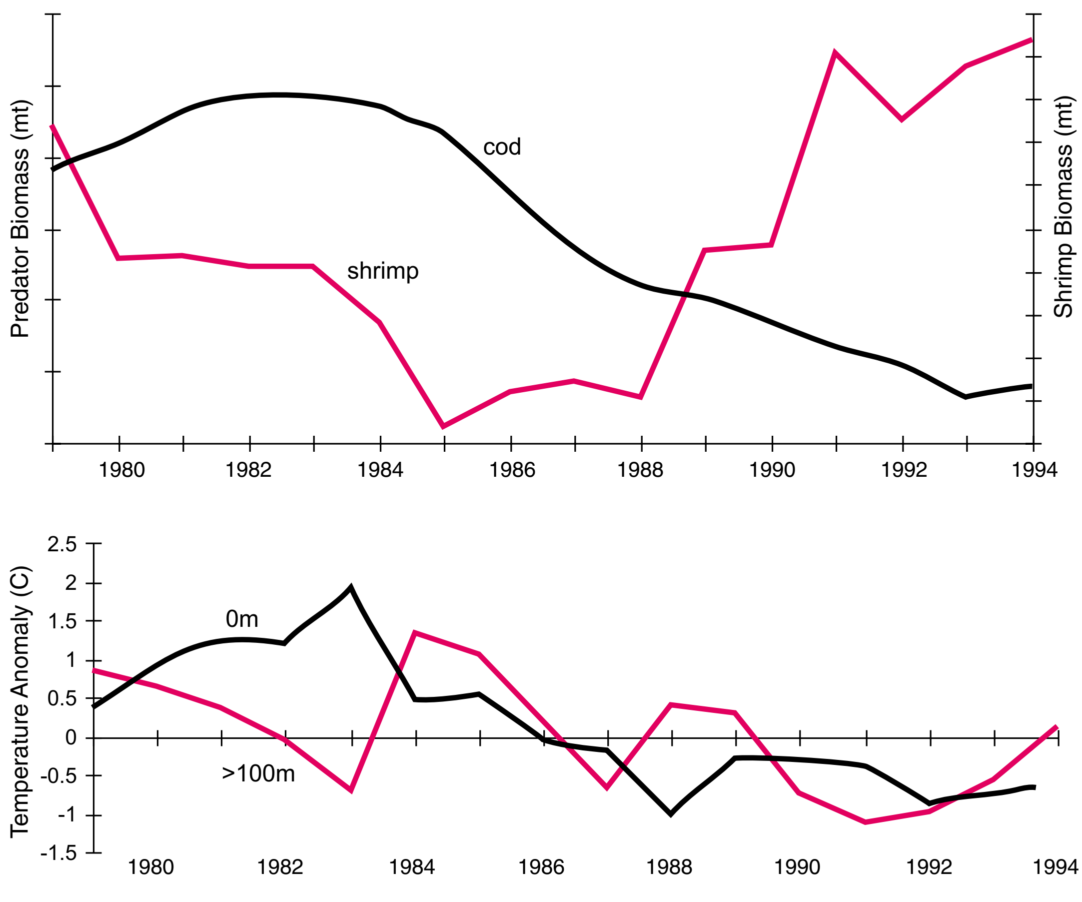

Figure 5. Abundance of shrimp and cod, and average July temperature anomalies on the eastern Scotian Shelf, 1979-94.

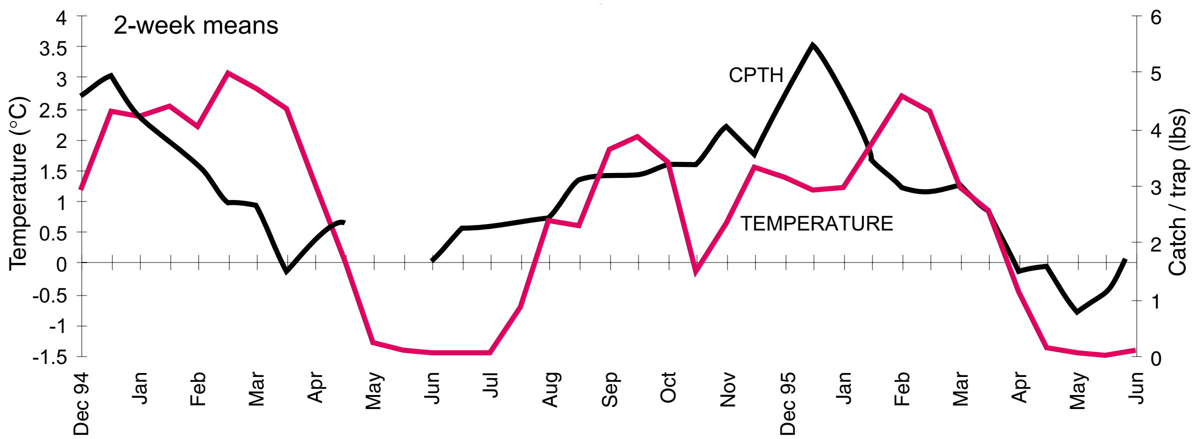

Figure 6. Mean bi-weekly catch per trap haul and bottom temperatures on the shrimp fishing grounds in Chedebucto Bay, Nova Scotia. No data for May 1994.

Why do shrimp migrate inshore in some areas and not in others? The answer probably lies in regional differences in the seasonal pattern of water temperature changes. In the central Scotian shelf offshore temperatures in the deep water mud habitat that shrimp prefer are too warm (>6∞C) throughout the year (Figure 7A) - no shrimp populations have established themselves here. In the Gulf of Maine, offshore temperatures are only in the preferred range from spring to summer. As offshore temperatures increase in the fall and winter, larger shrimp move into the shallow inshore areas where temperatures are within their range, and they return to the deeper offshore water when it cools again in spring and the inshore areas warm up (Figure 7A & B). This is similar to the western Shelf, where large shrimp move into and out of Mahone Bay in fall and spring, probably from the offshore grounds in Roseway Basin. Off Newfoundland, shrimp are well within their preferred temperature range throughout the year and seasonal migrations do not occur. On the eastern Scotian Shelf shrimp are found inshore all year round, but they move into slightly deeper water during the spring and early summer when temperatures close to shore are too cold Figure 7B).

The foregoing suggests that for northern shrimp the Scotian Shelf is an area of transition. The western shelf shows large fluctuations in abundance caused by temperature changes as in the Gulf of Maine, while the eastern Shelf harbors a much larger population whose dynamics are governed by predator abundance, temperatures and habitat availability. Any successful offshore fishery on the western Shelf would require scouting surveys to determine periods and areas of abundance, with rapid mobilization of the fishing fleet when catches reach commercially viable levels.

Although the eastern Shelf can apparently sustain a fishery for long periods, catch rates and abundances still fluctuate by a factor of at least 3 (Figure 5). A computer simulation shows how a shrimp population under environmental stress might react to additional pressure from fishing. A simulated population with initial numbers, size composition, growth rate, egg production and biomass similar to the eastern Shelf shrimp stock can be subjected to changing natural mortality (predation), egg survival (due to changing water temperatures), and fishing pressure. One can impose a hypothetical “threshold” egg production(E_{s-r}) above which the environment is always saturated with shrimp larvae and results in the maximum number of recruits to the population, and below which the number of recruits is related to the size of the spawning stock. Figure 8A shows an unfished population where changes to natural mortality (predators) occur during a 20 year period. E_{s-r} is 30% of maximum observed egg production. Figures 8B-D show three fishing scenarios where fishing always occurs after egg hatching in the spring, including B - a constant catch of 5000 metric tons, C - an unlimited catch of the entire spawning stock with no fishing if egg production drops below 20% of maximum, and D - same as C, but with the fishing moratorium maintained for an additional 5 years. In B the fishery obtains a reasonably constant catch, but prior to the environmental change a large portion of the resource is lost to natural mortality, and after the change the population does not recover to previous levels. In C. the fishery has a much higher total yield but has resulted in an unstable population. In D, total yields are even higher despite a longer moratorium, and the population has stabilized.

The removal of all spawning females by fishing is not as potentially catastrophic for *P. borealis* as it would be for finfish, since the shrimp starts

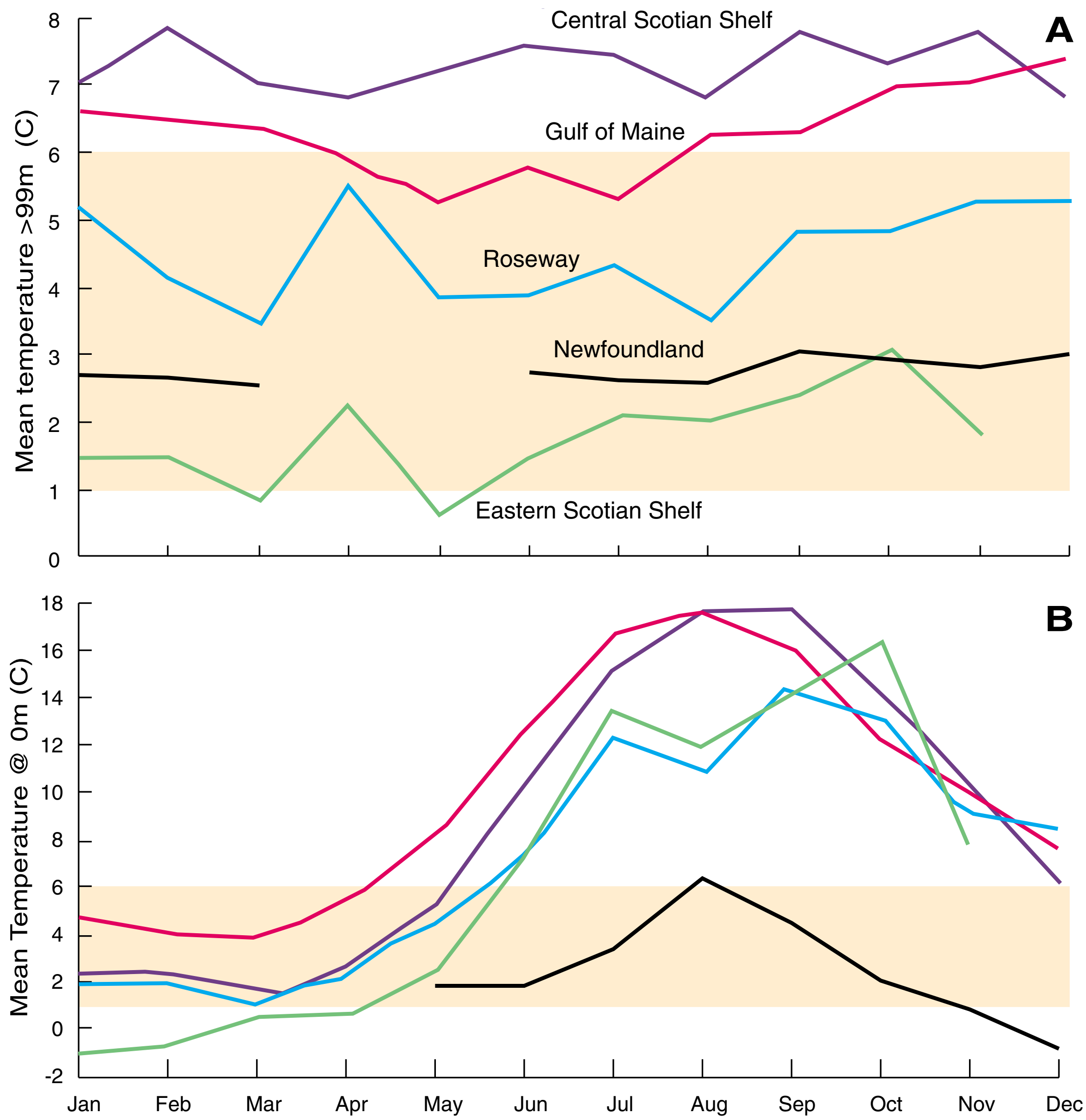

Figure 7. Average monthly temperatures from various areas at A. >99m, and B. 0m. The shaded areas show the preferred temperature range of P. borealis.

off its mature life as a small male, and changes to a female in its 3rd or 4th year. This has the effect of replenishing the spawning stock twice as fast as a fish with a 50:50 sex ratio throughout its life. However, the timing of the change from male to female and the maturation of males from juveniles is crucial to ensure successful mating. The model doesn't account for this because we don't know enough about the species life cycle and reproductive behaviour in the area. We also know nothing about the "stock-recruitment" relationship - how many new shrimp are produced from any given size of spawning stock, and the exact value of E_{s-r}. Without this kind of information it is impossible to set "harvest control rules" such as the 20% cutoff in the model, or even the overall objective of the fishery: should we maximize catches over an extended period, or guarantee a smaller catch every year?

It appears the model mostly provides insights into what we don't know. Still, the simulation confirms the observation that under certain conditions shrimp stocks can be remarkably resilient to high levels of exploitation, due largely to high growth rates, short life span, and tendency for the fisheries to remove the largest animals. The simulation also illustrates the kind of information required to make timely decisions on the appropriate catch for current conditions - a scientific monitoring program that detects population changes as they occur - at a minimum, annual trawl surveys covering the entire shrimp grounds. Equally important, the management regime must be flexible enough to facilitate rapid changes in quotas and number of licenses.

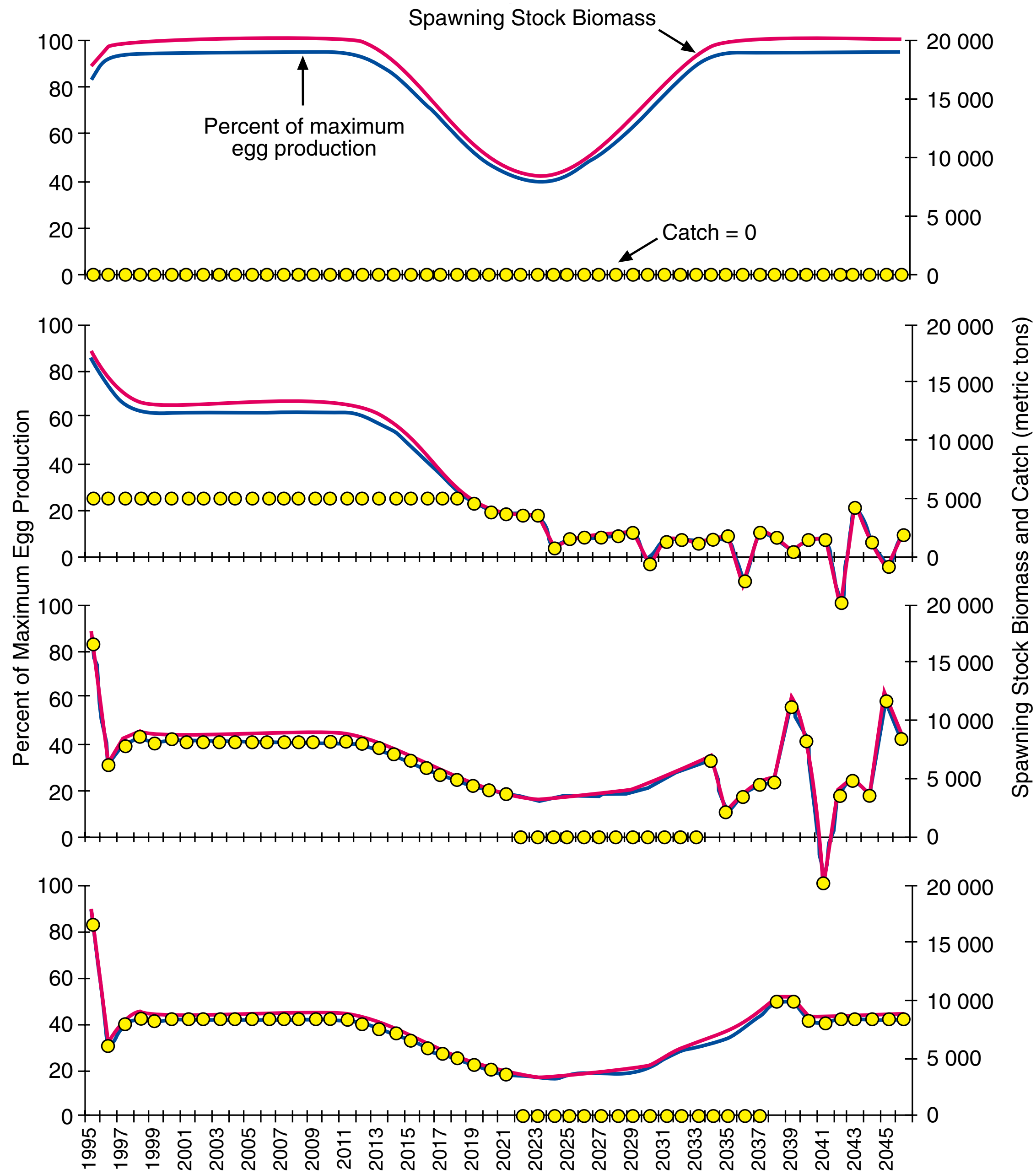

Figure 8. Results of simulations of a shrimp population with initial spawning stock biomass, egg production, growth rates and fishing selectivity similar to the eastern Scotian Shelf, fishing after spring hatching, and a change in natural mortality due to predation over a 20-year period. A. no fishing, B. constant catch of 5000 metric tons, C. unlimited fishing removing the entire spawned stock with a moratorium on fishing after the decrease in natural mortality, and C. same as D but with the moratorium lasting 5 years longer.

On the eastern Scotian Shelf the objective of a sustainable shrimp fishery that provides maximum benefits to fishers without endangering the resource has only partially been met. An annual survey has been implemented for several years, and data on water temperatures and predator abundance are readily available. Co-management of the fishery should provide a more workable balance between the flexibility of private enterprise with the enforcement clout of government. But major gaps in knowledge remain. Until key population parameters have been determined, hopefully not from bitter experience, management of the shrimp fishery will have to include a precautionary component which may well err on the wasteful side of "maximum sustainable yield".

Fate and Effects of Offshore Hydrocarbon Drilling Waste

ToC

T.G. Milligan, D.C. Gordon, D. Belliveau, Y. Chen, P.J. Cranford, C. Hannah, J. Loder, D.K. Muschenheim.

The Canadian East Coast offshore frontier contains extensive reservoirs of oil and gas and current government policy, at both the federal and provincial levels, is to encourage their development. PanCanadian Nova Scotia Ltd. (formerly LASMO) began production at the Cohasset and Panuke (CoPan) fields on Sable Island Bank in 1992 and the first Grand Banks well started production in the fall of 1997 by the Hibernia Management and Development Corporation. Development proposals for the Sable Offshore Energy Project and Terra Nova have recently passed regulatory review and are now being implemented. Further development of hydrocarbon resources on both Sable Island Bank and the Grand Banks is possible, and exploration on Georges Bank is again being considered.

Hydrocarbon exploration, development and production activities produce environmental risks and impacts. Of particular concern in the offshore frontier are the impacts on fisheries and wildlife of not only accidental discharges resulting from blowouts or spills, but also permissible discharges of operational wastes such as drilling mud, cuttings, and produced water. Protection of these renewable resources and their habitats, which will be present long after the drilling rigs and pipelines disappear, is a high priority and requires objective, credible and timely scientific information. It is important to understand exactly what the potential effects are, if and how they can be mitigated and the significance of any effects that can not be mitigated. This information needs to be incorporated into a continually evolving, scientifically based regulatory framework for the offshore hydrocarbon industry that protects valuable renewable living resources. At the same time, it must be efficient and not impose unnecessary constraints on this rapidly developing industry.

In the late 1980's, the Panel on Energy Research and Development (PERD) began funding a program on the fate and effects of drilling wastes that has been conducted by the Department of Fisheries and Oceans (DFO), primarily at the Bedford Institute of Oceanography. At that time, despite extensive exploratory drilling on the East Coast frontier, there was limited Canadian scientific experience on the fate and effects of drilling wastes. The proposal by Texaco to drill exploratory wells on Georges Bank met with strong opposition, which resulted in the 1988 drilling moratorium that closed the area until 2000. Therefore, the initial focus of the PERD program was on Georges Bank to determine if the concerns raised about potential impacts on fisheries, especially sea scallops, were valid. With time, the geographic coverage of the program expanded to include Sable Island Bank and the Grand Banks in order to conduct collaborative studies with industry at hydrocarbon development and production sites. The scientific collaboration has also expanded in recent years to include scientists from DFO laboratories in St. John's and Mont Joli as well as Natural Resources Canada scientists from the Geological Survey of Canada (Atlantic) at BIO.

A series of focused and well-integrated research projects was designed that would provide the information necessary to understand the fate and effects of drilling wastes on benthic resources, in particular the sea scallop. Because of the nature of the questions being asked, these projects have covered a wide range of scientific disciplines. The research has included physical oceanographic field programs on Georges Bank, sedimentological field studies on Georges Bank, Sable Island Bank and the Grand Banks, laboratory studies on the flocculation of drilling mud and on the effects of various drilling wastes on sea scallops, the development of new instrumentation for measuring drilling wastes in the offshore environment, and the development of numerical circulation and dispersion models.

Physical Oceanography

The first project undertaken in the program was a detailed field study of frontal circulation and mixing over the scallop grounds along the northern edge of Georges Bank (Loder et al. 1992). It included moored current measurements, drifter tracking, turbulence profiles, and detailed hydrographic surveys. The study has revealed intermittent surface convergence at the tidal front and enhanced vertical mixing at the Bank edge

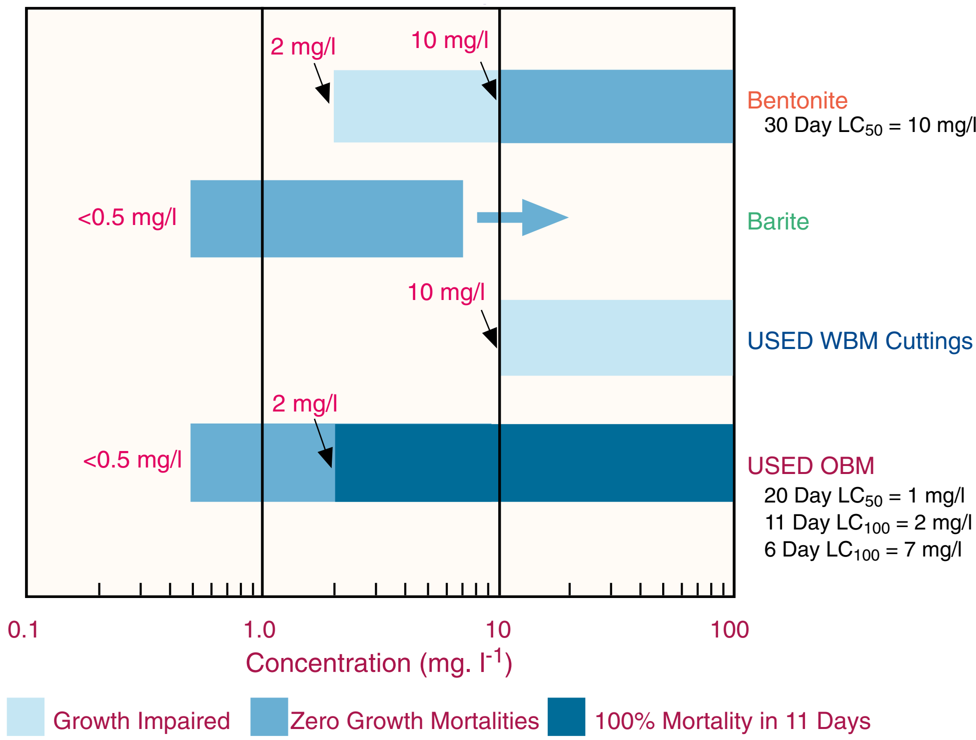

Figure 1: Illustration showing the lethal and sublethal effects of drilling wastes and some of their components on the growth of sea scallops (Placopecten magellanicus). Scallops were exposed to various concentrations over periods of up to 70 days.

due to the breaking of internal waves, which can have a pronounced influence on the trajectories of oil spills and the dispersion of drilling wastes released in this region. The study has also provided a comprehensive observational data set for the forcing and validation of circulation and dispersion models.

In collaboration with US scientists, a three-dimensional finite-element circulation model of the Gulf of Maine region has been developed (Greenberg et al., in press). This modeling approach provides high spatial resolution in key areas, which is important for such a complex system as Georges Bank. The model has provided vertically-varying mean and tidal flow fields on a seasonal basis which are being used as input to the benthic impact models described below. It has also been used successfully in studies of the early life history of cod, haddock and scallops on Georges Bank. Similar high-resolution models for the Scotian Shelf and Grand Banks are being developed.

Biological Effects

Initial studies demonstrated that the exposure of sea scallops to mineral oil-based mud cuttings has potentially damaging implications for production, reproductive success and population survival in the vicinity of a drilling platform (Cranford and Gordon, 1991). These were followed by a lengthy series of laboratory experiments under en-

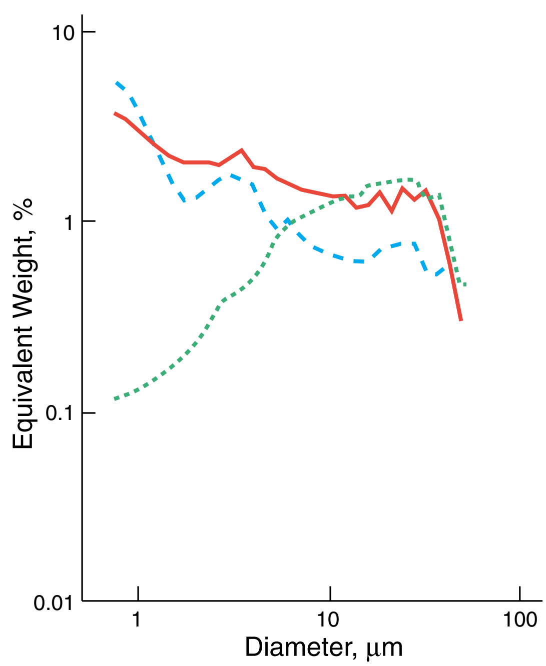

Figure 2: Disaggregated inorganic grain size distributions for used drill mud (solid), and two of its major components bentonite (dashed) and barite (dotted). The characteristic shape of the bentonite distribution is used to identify drill mud in samples collected offshore.

Figure 3: BOSS being recovered after sampling near the Hibernia Platform on the Grand Banks. Suspended sediment samples are collected from the benthic boundary layer by spring loaded syringes at 7 depths between 5 and 50 cm above the sea floor.

vironmentally representative conditions in flume tanks in which adult scallops were exposed for up to 70 days to different kinds and concentrations of drilling fluids and major constituents to determine the effect of chronic exposure on mortality, tissue growth and physiological responses (Cranford and Gordon, 1992). The results indicate that sea scallops are very sensitive to low concentrations (10 mg·l^{-1} or less) of drilling waste and associated contaminants in their food supply (Fig. 1). Threshold concentrations causing effects are now available and can be used to interpret the output of impact assessment models. The relative toxicity of the four wastes tested (in increasing order) is water-based mud, bentonite, barite and oil-based mud.

Instrumentation has been developed whereby sea scallops can be placed just above the sea floor in the field and their growth response to chang-

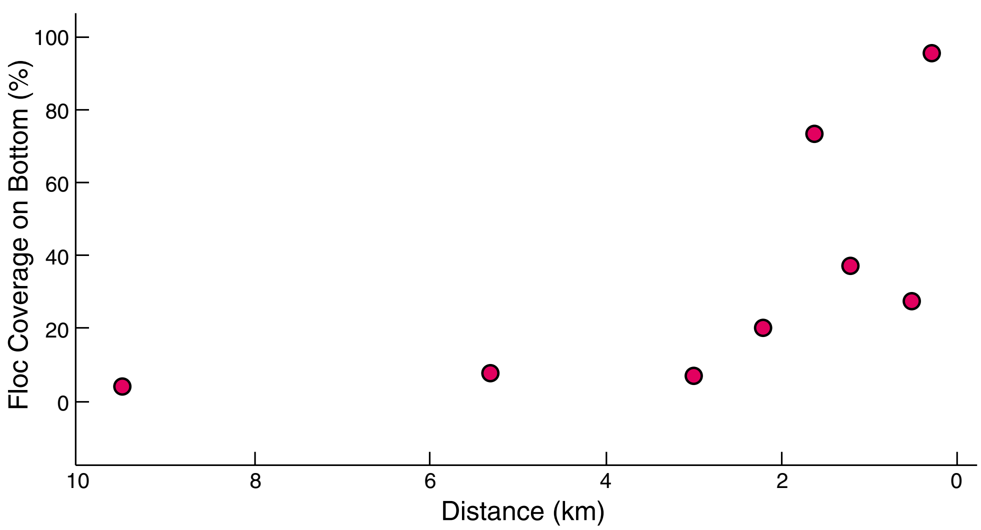

Figure 4: Graph showing the % of bottom covered by floc containing drill mud along a transect running from the west to the Rowan Gorilla III on Sable Island Bank.

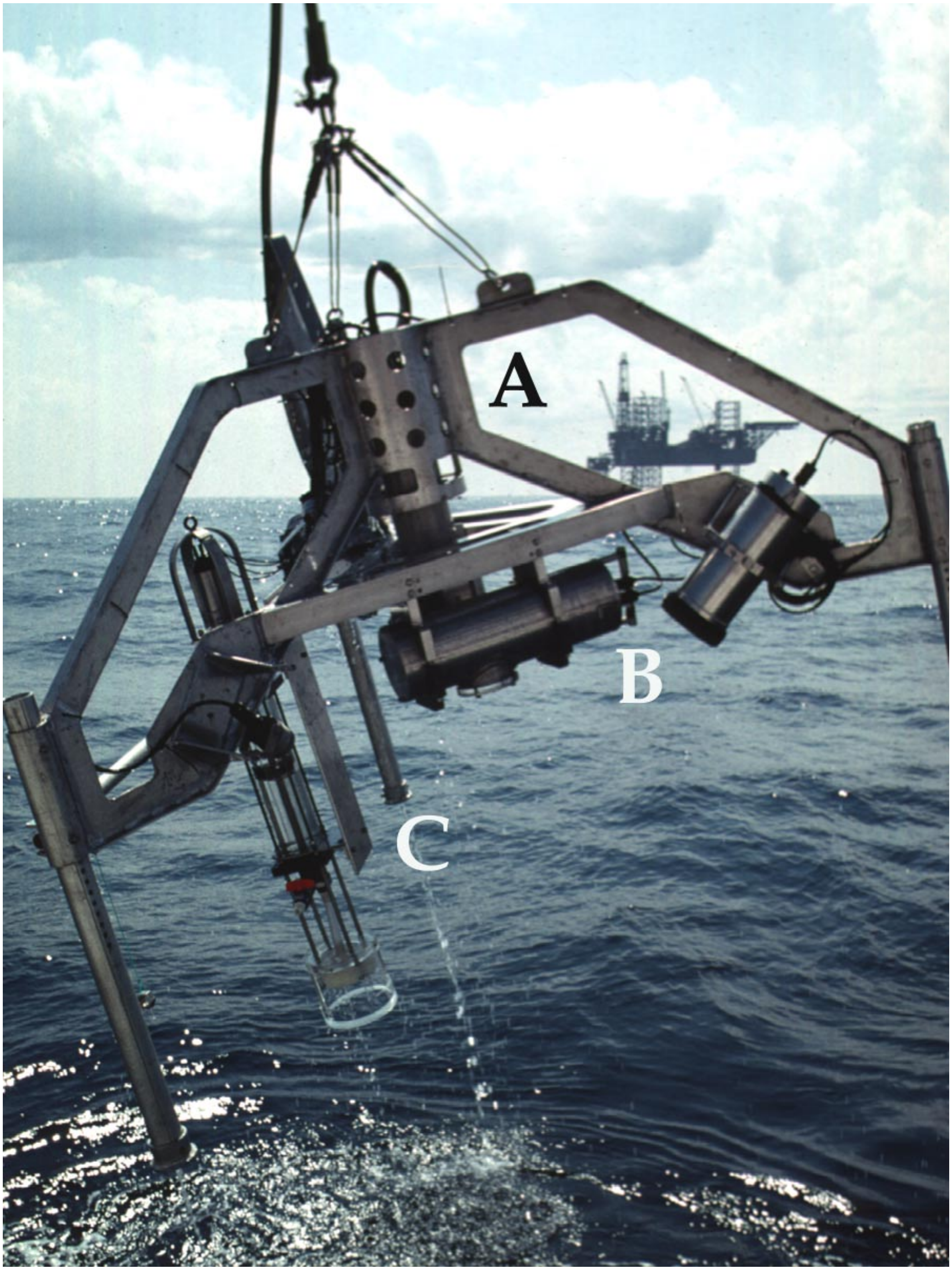

Figure 5: The camera tripod Campod being deployed near the Rowan Gorilla III drilling on Sable Island Bank. A high resolution video camera is mounted on the central axis of the tripod looking down (A). Also mounted on the Campod are a 35 mm camera and flashes (B) and special floc sampler called Slurper (C).

ing environmental conditions accurately measured. This allows the detection of sublethal responses to chronic exposure to drilling wastes contaminating food supplies under actual exposure conditions. These techniques will be tested at Hibernia beginning in 1999 and will hopefully be suitable for use in industry-funded environmental effects monitoring programs.

Fate of Drilling Wastes:

Under present guidelines, used water-based drill mud and cuttings may be discharged to the ocean without limitation. When drilling with oil-based mud, only cuttings containing <15% oil by dry weight are permitted. A major component of this study has been to determine what happens to these materials after they are discharged. Essential to this study was the ability to differentiate drilling wastes from naturally occurring material.

Particle size analysis of the principal components of drill mud, bentonite clay and barite, and of used water-based drill mud shows that they consist mainly of fine silts and clays. More precise analysis of the disaggregated inorganic grain size of these materials using a Coulter Multisizer shows that bentonite has a very distinct size distribution with a modal diameter <1mm and, when plotted as log concentration vs. log diameter, a steep negative slope between 1 an 10mm (Fig. 2)(Muschenheim et al, 1995, Muschenheim and Milligan, 1996). This characteristic size distribution can be seen in a sample of used drilling mud obtained from the inclined shaker discharge of the Rowan Gorilla III drilling at CoPan (Fig. 2). In contrast, the disaggregated inorganic grain size of naturally occurring suspended particulate material (SPM) collected during studies on Georges Bank, Sable Island Bank and the Grand Banks have very low concentrations of fine sediment the size distribution for which is either positive or flat in the 1-10mm range. Using a specially designed benthic boundary layer sampler called BOSS (Fig. 3), it has also been shown that SPM concentrations are highest in this near bed region and vary with current speed.

In the past it has been assumed that material such as drill mud that consists of very small particles with settling velocities <0.001 mm·s^{-1}, would readily dissipate to negligible concentrations on the energetic offshore banks of the Canadian East Coast. Laboratory studies conducted as part of this study, however, have shown that drilling wastes readily flocculate in seawater to form fragile aggregates on the order of 0.5-1.5 mm in diameter with settling velocities > 1 mm·s^{-1}. This means

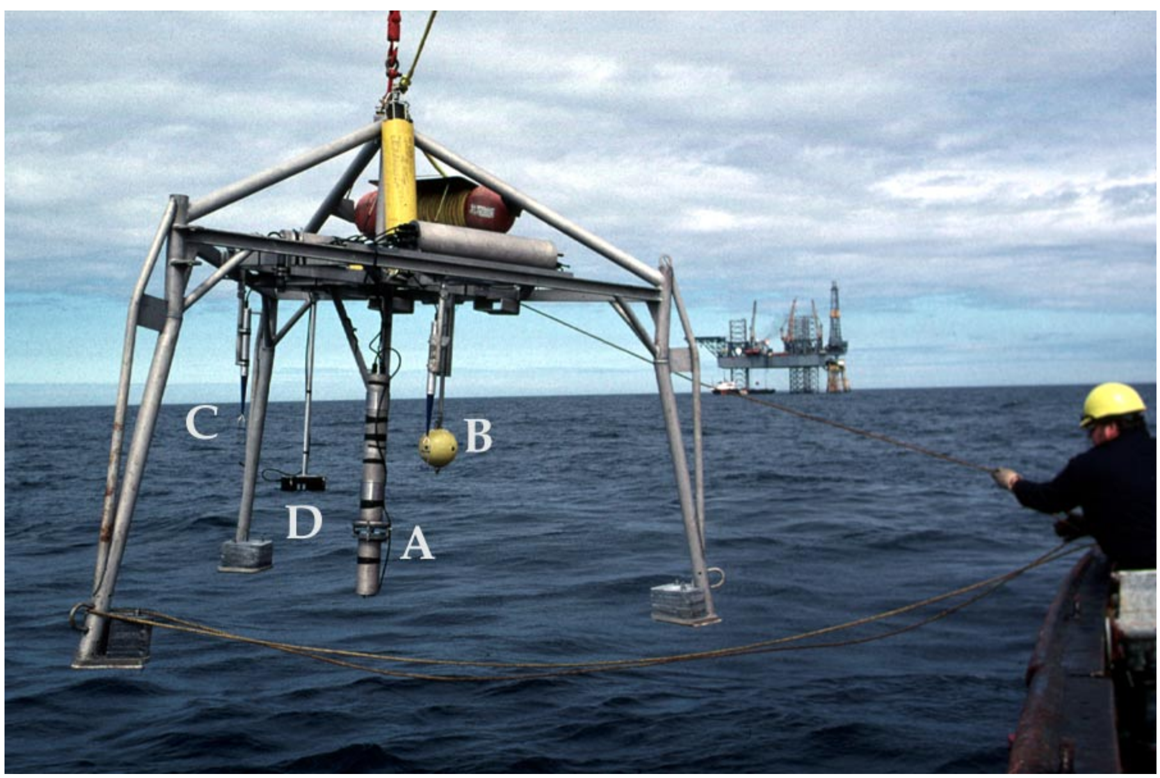

Figure 6: MIMS tripod being deployed near the Rowan Gorilla III drilling on Sable Island Bank. Visible sensors are A) Digital silhouette floc camera, B) S$ Current Meter, C) VDV current meter and D) Tranmissiometer.

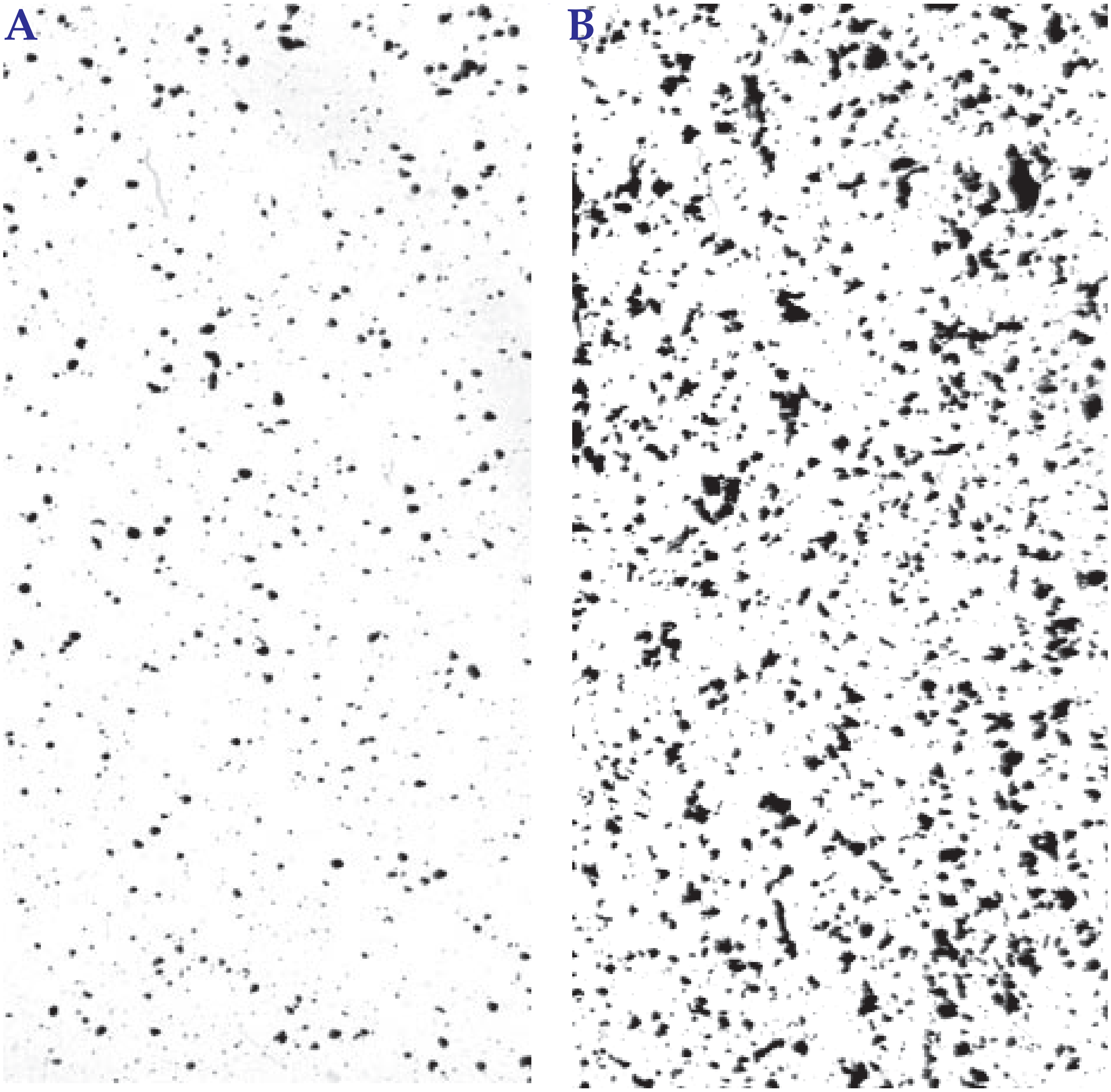

Figure 7: Silhouette images of suspended sediment 0.5 m off bottom captured during and after a storm on Sable Island Bank. Image A taken at the height of the storm shows 180-μm sand in suspension and no floc. Image B taken as the storm dissipates shows abundant flocs in suspension. Later images indicate that the floc in suspension settles below 0.5 m above bottom as turbulence decreases further. Scale: Silhouette image is 2 cm x 4 cm and has a depth of 3.8 cm.

that drilling wastes could sediment rapidly and be concentrated in the benthic boundary layer near a drilling rig. In 1991, a sampling program carried out from an industry support vessel near the RGIII used particle size distribution data to confirm the presence of drilling wastes not only in the surface plume but also in the benthic boundary layer.

The fragility of flocs makes it impossible to sample them using conventional methods. A second study conducted at CoPan in September 1993, after an extended period of drilling, confirmed that drilling mud does flocculate and concentrate in the benthic boundary layer. Images collected using a SONY 3-CCD high resolution colour video camera mounted in a grab, found dense accumulations of dark flocculant material on the seabed with the highest concentrations near the RGIII (Fig. 4). Size analysis of the BOSS samples confirmed that the flocs contained drilling mud and that drilling mud could be detected as far away as 8 km from the platform. Further observations indicated that these flocculated drilling wastes were alternately resuspended and deposited over a tidal cycle.

In the spring of 1994, a third survey, 5 months after drilling operations at CoPan had ceased, was carried out using a newly designed, light weight

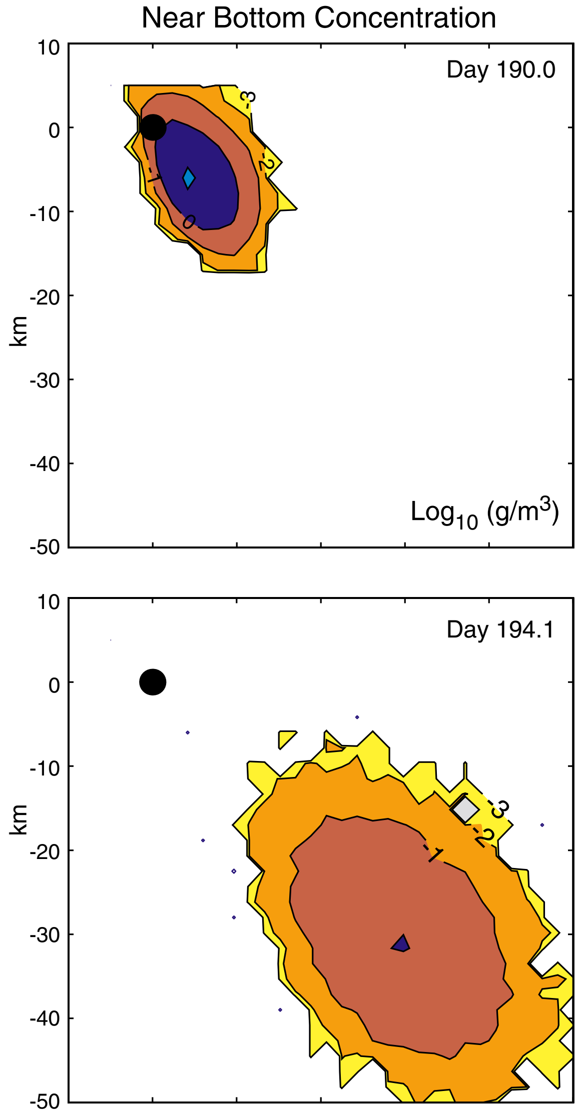

*Figure 8: Example output from the **bblt** model showing predicted concentrations of drilling waste in the bottom 10 cm at 1 and 4 days after bulk discharge of 95 tonnes of drilling mud located at a frontal site overlaying the scallop grounds on the Northeast Peak of Georges Bank. The simulation assumes a settling velocity of 0.5 cm•s^{-1} for the flocculated mud and is forced with moored current meter observations.*

camera frame called Campod (Fig. 5). The open profile of Campod allows video and still images to be taken with minimum disturbance of the floc layer found at the seabed. Although there were very abundant flocs in the water column and benthic boundary layer, no trace of drill mud was found. The hypothesis that this was the result of resuspension and dispersion through the winter months was later supported by data collected during a 10 day deployment of MIMS (moored impact monitoring system) tripod (Fig. 6). A digital floc camera designed and built at BIO collected silhouette images of suspended sediment during a storm. The new instrument uses a single CCD to allow characterization of sediment properties critical for obtaining settling velocity. Results showed that during the height of the storm, flocs were dispersed and sand was in suspension at 0.5 m above the bottom, the height of the camera windows (Fig 7a.). As the storm abated, flocs reformed and settled back to the bottom (Fig 7b.).

The new sampling methods developed during this project are now being used to study drill waste dispersion at Hibernia. Results from October 1997 suggest that in contrast to CoPan, drill wastes were not reaching the bottom but were trapped in the surface water. This could be the result of the greater water depth and stratification of the water column. In June 1998, however, flocs were observed on the seafloor near the platform. It has not yet been determined if they contain drill mud.

Numerical Modeling of Impacts

Existing plume dispersion models have been used to determine the likelihood of drilling wastes reaching the seafloor under different discharge conditions at the CoPan site on Sable Island Bank and on Georges Bank (Andrade and Loder, 1997). Factors that significantly affect the depth of descent include the mud density, depth of release, initial downward flux of the discharge, current strength and water column stratification. At the relatively shallow CoPan site, wastes generally reach the seafloor rapidly under most anticipated conditions. On Georges Bank, where depths are generally greater and tidal currents stronger, there is greater dilution and horizontal displacement during descent, and impacts on the seafloor are quite variable, depending on location.

A new benthic boundary layer transport model called **bblt** has been formulated to simulate the dispersion and transport of drilling wastes near the seabed (Hannah et al, 1995). A key feature of the model is the simplified representation of vertical mixing through the random shuffling of packets of material and the use of observed suspended sediment profiles as probability density functions for the overall vertical distribution. Horizontal transport is represented through the advection of the packets in the vertically- and time-varying flow fields taken either from current meter records or the three-dimension finite-element circulation model described above. Model output includes contours of near-bottom concentrations of drilling wastes around the release point (Fig. 8) as well as concentration time series at fixed locations. Model applications to Sable Island and Georges Bank indicate sensitivity to the effective settling velocity of drilling wastes, as well as im-

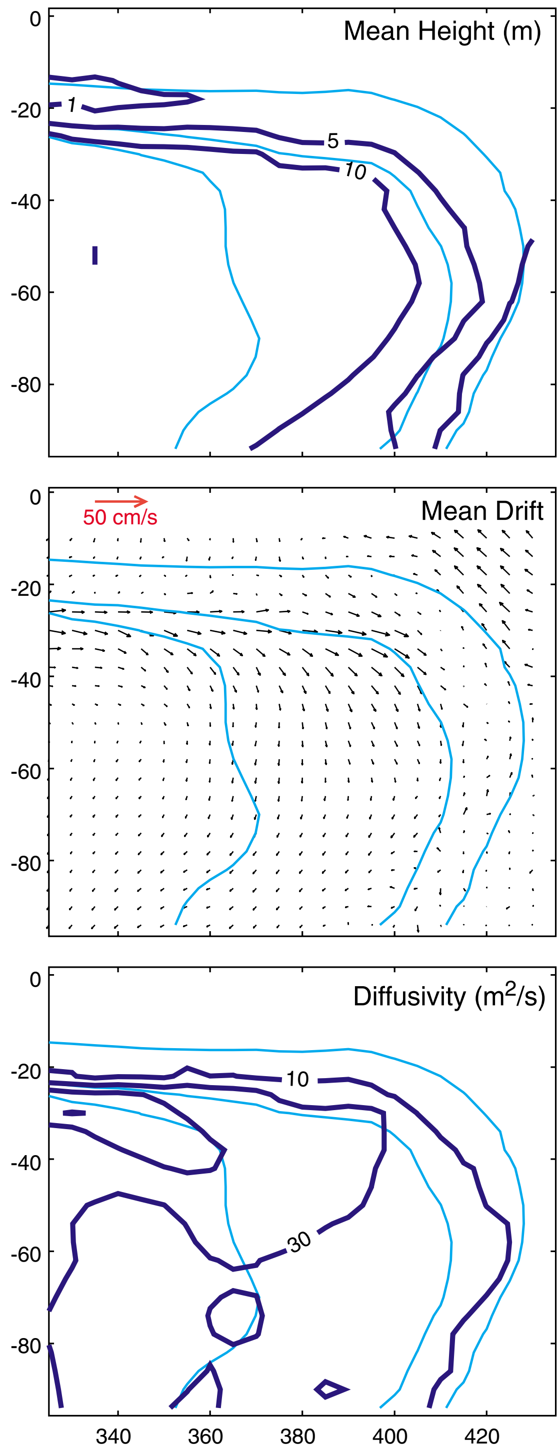

Figure 9: Spatial variability of drift and dispersion on Georges Bank illustrated for the September-October period with a settling velocity of 0.5 cm.s^{-1}. The mean height of the sediment concentration profile is largest over the shallowest regions where the tidal currents are largest. The drift and diffusivities are largest under the frontal jet along the northern flank. The forcing is provided by the 3-d mean and M2 circulation fields derived from the circulation model of Naimie (1996).

portant spatial variations in the dispersion and drift characteristics of offshore banks such as those illustrated in for Georges Bank (Fig. 9).

Researchers are now in the process of linking the various pieces of the puzzle together to develop an impact assessment model. Results from the biological impact work on scallops are being used to interpret the output of the **bblt** model in terms of loss of growth resulting from exposure to drilling wastes. Simulations of realistic discharge scenarios on Georges Bank are being linked to both real-time series and to output from the Georges Bank finite element model to predict zones of impact at various locations. Initial results indicate that impact levels would be very dependent on the site of the drilling operation.

Summary:

One of the most important general results of the overall program is the realization that the fate and effects of drilling wastes are dependent upon a large number of factors including the type of waste, discharge properties, physical oceanographic setting and the time of year. There is no such thing as a typical situation and each drilling proposal must be assessed and evaluated on its own particular conditions. Existing offshore drilling waste treatment guidelines tend to be generic and only consider the properties of the discharge from a platform. More realistic guidelines must take the properties of the receiving environment into consideration. Some discharge conditions may be acceptable at one location but not at another.

As a result of the research conducted in this program, government and industry are much better prepared to manage future offshore hydrocarbon developments in Canada. There is a much better overall scientific understanding of the fate and potential effects of drilling wastes in the offshore environment that can be used to evaluate concerns raised by the public. There are improved numerical models that can be used to predict the environmental impacts of specific development projects. New instrumentation and methodology are available to conduct more efficient and meaningful environmental effects monitoring programs at approved development sites. The results of the effects monitoring programs can provide immediate feedback into the daily operation of the project (e.g. adaptive environmental management) as well as be incorporated over the longer term into improved discharge regulations. They can also be used to improve the numerical predictive models. This iterative process will help to protect valuable renewable resources without placing unnecessary burdens on the offshore hydrocarbon industry.

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Risk Assessment in Fisheries Management

Alan Sinclair, Stratis Gavaris, Bob Mohn,

ToC

How long has it been since you've heard a weatherman say "it's going to rain at 3 o'clock the day after tomorrow"? When has an investment dealer told you that your RRSP will be worth $1,000,000 when you reach 55, and then you can retire. If you heard statements like this, would you believe them? Would statements like this help you decide whether to take an umbrella to work or increase your RRSP contributions?

The point is that no one can say exactly what the actual weather will be at a given time in the future or what an investment will be worth in 10 years. There are simply too many unknowns. Current weather forecasts cover relatively short periods of time (up to 5 days) and are often expressed in terms of the probability of precipitation. Research may help better understand these complex situations and improve forecasts but the results will be slow in coming. In the meantime, we still have to make day to day decisions about what we are going to do and how we are going to deal with what we don't know. More and more decisions are based on the chance of something bad happening as a result of the decision rather than on a single expected outcome. This trend is becoming apparent in fisheries management and, as a result, changes are being made in the type of information science provides decision makers.

Uncertainty in Fish Stock Assessment

Fish stock assessments traditionally produced point estimates of stock size that were used to calculate a total allowable catch (TAC) at a fixed rate of harvest. There was little room for decision makers and the fishing industry to exercise judgement on the consequences of implementing that TAC because there was little indication of the associated uncertainties. As years passed and assessments were repeated with longer time series, it became evident that annual results had a high degree of variation. Preliminary estimates of the confidence intervals of stock size estimates were at least +/- 25%. Not all assessments were equal. Some were more precise than others. Simple point estimates could not capture all this information and changes in the type of scientific information stemming from stock assessments were needed.

Fisheries scientists have been looking for ways to calculate and convey the necessary information about uncertainty in a useful and practical way to those who make the decisions, fishery managers and the fishing industry. A fundamental change in approach was needed. Instead of using a simple point estimate to determine the TAC, the question had to be recast by asking what are the chances of something undesirable happening as a result of implementing that TAC. Several alternative undesirable events can be specified such as stock size declining, stock size falling (or remaining) below an established critical level, or the annual rate of fishing exceeding an established target. It has been our experience that when decision makers have been given this additional information, they tend to be risk averse. That is to say, they prefer a less than 50% chance that the undesirable event will occur. Just how much below 50% seems to depend on the status of the stock in question, the mix of individuals involved in the decision, and presumably their risk tolerance. Most of the work to date has been focused on estimating the probabilities of specific events occurring as a result of specific management actions. This is only part of a full blown risk analysis which would include an evaluation of the costs of the undesirable event occurring.

The following approach for assessing the risk of short term management actions has recently been introduced to the Department of Fisheries and Oceans Maritimes Regional Assessment Process (RAP). The management regime for groundfish fisheries uses a strategy which restricts harvest rates to at or below $F_{0.1}$[1]. The abundance of many groundfish stocks has become so low that fishing has been either completely closed or restricted to rates well below $F_{0.1}$. Fisheries managers would like to see some growth in stock size in the short term (1 - 2 years) and eventually see stock sizes attain levels that would justify making fisheries fully operational again. Thus, the undesirable events for risk assessment have been defined as 1) stock size declining, 2) the rate of fishing exceeding $F_{0.1}$. We estimate the probability of these events in relation to a range of TACs using a procedure known as bootstrapping[2]. An example of the graphical presentation of the results is given for cod in the southern Gulf of St. Lawrence in Figure 1. For a catch of 5,000 t there was about a 10% chance that the spawning biomass would decline. This increased to 50% for a catch of 8,000 t and to 90% for a catch of 12,000 t. The probability of the fishing mortality rate to be above the target was about 10% for a catch of 19,500 t and this increased to 90% for a catch of 24,000 t. These probability estimates do not, as yet, include all possible sources of variation. For example, we assume that the rate of natural mortality is known and fixed, that the catches are known without error,

1 Canada accepted the $F_{0.1}$ harvest rate target in 1977. It arises from considerations of growth and mortality of a cohort of fish. $F_{0.1}$ is defined as the rate of fishing mortality at which an additional small increase in fishing effort will bring only 10% of the yield per unit of recruitment that the same increase in effort would bring from an unfished population

2 Bootstrap estimates of the distribution of population estimates are made by repeating the estimation process using pseudo-data generated from the original estimation procedure. In stock assessments, the estimation procedure matches predicted stock size estimates obtained from a model to observed values from research vessel surveys. The difference between the predicted and observed values are called residuals. The residuals are resampled to generate new pseudo observed values, and the estimation procedure is repeated. Each separate population estimate is then used to do a series of catch projections for a range of TACs. The probabilities of either the stock biomass declining or the rate of fishing mortality exceeding $F_{0.1}$ is then determined from the results.

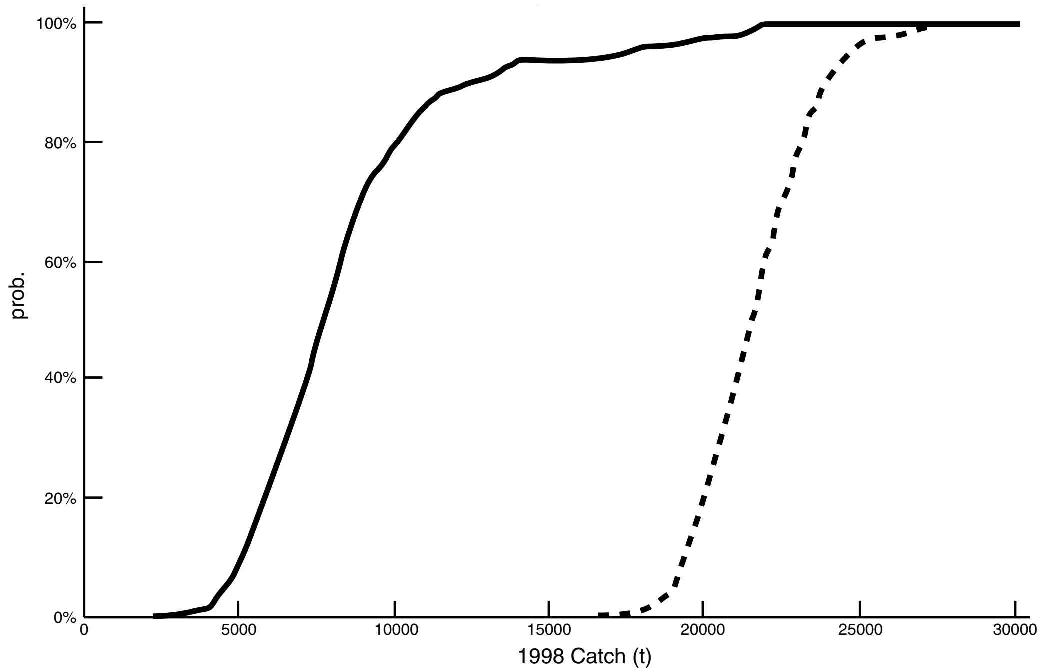

Figure 1: Probability of a reduction in spawning biomass (solid line) between 1998 and 1999, and of the 1998 fishing mortality exceeding $F_{0.1}$ (dashed line) in relation to a range of 1998 total catches for southern Gulf cod. The probabilities were estimated from a sequential population analysis which assumes a rate of natural mortality].

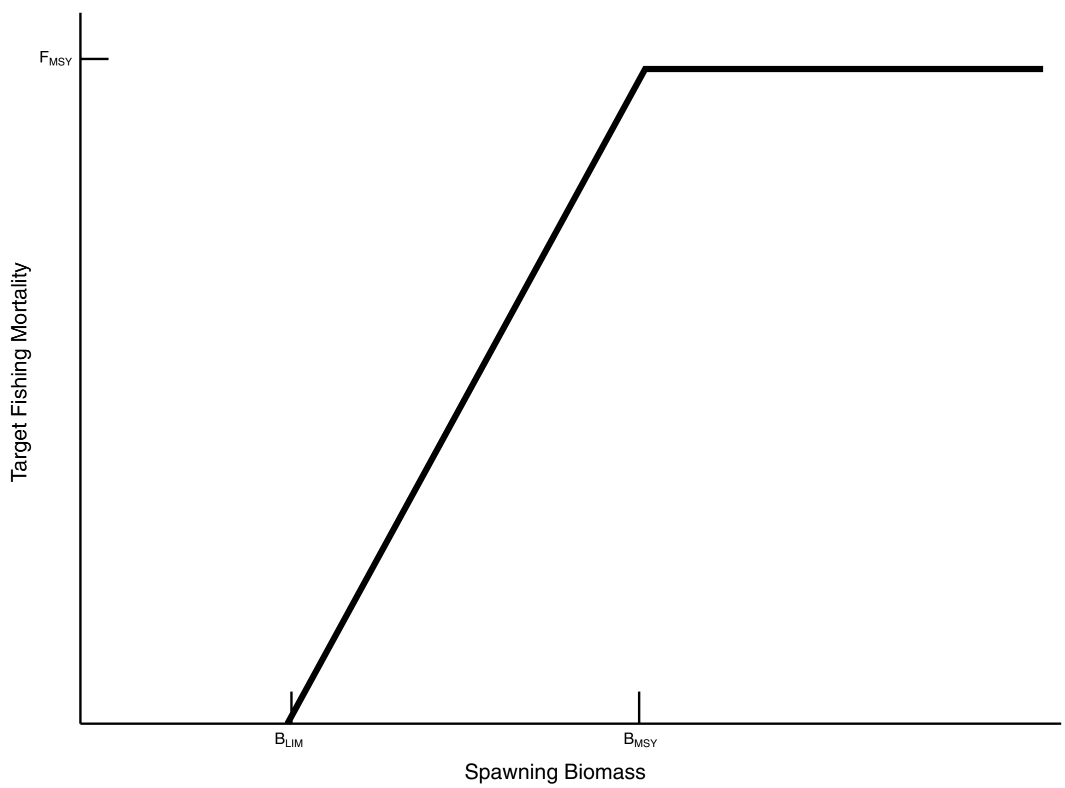

Figure 2: An example decision rule associated with the Precautionary Approach to Fisheries Management. The rule sets the annual target fishing mortality in relation to the current spawning stock biomass.

and that the projected population weights at age and exploitation pattern at age are known without error. Research is continuing into how these additional factors can be included in the risk assessment process.

Establishing Long Term Management Strategies

Long term management strategies have been founded on yield per recruit considerations and avoidance of yield loss due to high exploitation rates. In recent years, increased attention has been directed towards production considerations and avoidance of negatively impacting the recruitment potential of stocks. The objective of risk analyses for management strategies is to evaluate alternative sets of pre-defined rules which would be used to determine short term actions. The general approach is based on simulating a fishery system that includes plausible population characteristics regarding growth, maturation, stock/recruitment dynamics, and interactions with other species; stock assessment where the processes of data collection and analysis are simulated; and of course fishing which is controlled by alternative sets of decision rules. Simulations are required because there is little chance of undertaking experimental studies of this nature. The main goal is to investigate the robustness of the management strategy to uncertainties about the fishery system itself. For example, little is known about possible relationships between stock size and recruitment (i.e. the number of young fish entering the fishable population). This research is not designed to elucidate such relationships, but rather to ask what might happen to the stock and the fishery if we assume the wrong relationship or, alternatively, is there a 'safe' assumption about the stock recruitment relationship?

Research is currently underway in the Northwest Atlantic Fisheries Organization (NAFO), the International Council for the Exploration of the Seas (ICES), and DFO Science Branch to develop decision rules consistent with recent international agreements which define a Precautionary Approach to Fisheries Management[3]. These conventions indicate desirable qualities of fisheries management systems including:

- Fishing should be limited to sustainable levels
- Uncertainty should not be a reason to maintain high fishing mortality
- Stock biomass should be kept above that which will produce maximum sustainable yield (B_{MSY})
- Fishing mortality should be kept below that which will produce MSY (F_{MSY})
- There should be only low probability that biomass might fall below B_{MSY} and that fishing mortality should rise above F_{MSY}.

An example of a decision rule that meets these criteria is illustrated in Figure 2. It relates spawning stock biomass to the target fishing mortality in a given year. The upper limit to fishing mortality, as defined by the Precautionary Approach, is the fishing mortality associated with maximum sustainable yield (F_{MSY})[4]. This would be the fully operational maximum fishing mortality which would be used as the target when the stock biomass is at or above that associated with maximum sustainable yield (B_{MSY}). When stock size is determined to be below B_{MSY}, the target fishing mortality would be reduced in order to promote stock recovery. If spawning stock biomass gets so low that the stock is considered to be in danger ($<B_{LIM}$), then the target fishing mortality would be reduced to the lowest practicable level.

There is much work that remains to be done in order to quantify risks adequately. The course has been set however by these inaugural works and clients are realizing the benefits of receiving scientific advice for fisheries management in a form which quantifies the uncertainties and risks.

References

The following special publication contains several articles on the topic of risk assessment in fisheries.

Smith, S.J., J.J. Hunt, and D. Rivard 1993. [ed.] Risk evaluation and biological reference points for fisheries management. Can. Spec. Pub. Fish. Aqua. Sci. 120.

The following documents provide current examples of the application of risk assessment to Canadian groundfish fisheries.

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Sinclair, A. and S. Gavaris. 1996. Some examples of probabilistic catch projections using ADAPT output. DFO Atlantic Fisheries Research Document 96/51.

Sinclair, A.F., G.A. Chouinard, L. Currie. 1998. Assessment of cod in the southern Gulf of St. Lawrence, January 1998. Canadian Stock Assessment Secretariat Research Document 98/08.

3 Two agreements are commonly cited with respect to the Precautionary Approach, The Agreement on the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks adopted by the United Nations General Assembly in August 1995 and the Code of Conduct for Responsible Fisheries adopted by the FAO Committee on Fisheries in November 1995.

4 F_{MSY} and B_{MSY} are theoretical reference points associated with the surplus production model of fish populations. This model includes aspects of the growth of individual fish, their rate of maturation, the age-specific rates of fishing and natural mortality, and the relationship between spawning stock biomass and recruitment. The model predicts a rate of fishing mortality and spawning stock biomass that will produce the maximum sustainable yield from the population at equilibrium. There is also a rate of fishing mortality that is unsustainable (F_{CRASH}), above which the stock cannot produce enough recruits to replace the original spawning population.

Shellfish Water Quality Protection Program

ToC

Amar Menon

Introduction

The Canadian Shellfish Sanitation Program is jointly administered by the Department of Fisheries and Oceans (DFO), Canadian Food Inspection Agency (CFIA) and Environment Canada (EC). Environment Canada is primary responsible for the classification of shellfish growing waters based on the sanitary and bacteriological water quality conditions of the area. The primary objective of the Shellfish Water Quality Protection Program is to protect the public from the consumption of contaminated shellfish by ensuring that bivalve shellfish (oysters, clams, mussel and whole scallop) are harvested from waters of acceptable sanitary quality. The second objective of the program is to promote pollution prevention, remediation and restoration of contaminated shellfish growing areas.

History

The Canadian Shellfish Sanitation Program (CSSP) has been developed over the years as a direct result and response to an outbreak of typhoid fever in the United States during the winter of 1924-25. This outbreak involved 1500 cases and 150 deaths and was traced to the consumption of contaminated oysters. Canada passed regulations under the Fish Inspection Act on July 3, 1925 requiring that they be a “safe food product”. The states of New York and Massachusetts also extended requirements for certification to all shipments consigned to their markets. The mutual concerns of Canada and the United States to protect the public from the consumption of contaminated bivalve mollusks led to a formal Bilateral Shellfish Agreement signed on April 30, 1948 dealing with sanitary practices in the shellfish industries of both countries.

Legislation

The legal authority for the Canadian Shellfish Sanitation Program is the Fisheries Act, Management of Contaminated Fisheries Regulations, the Fish Inspection Act, and Fish Inspection Regulations. These acts and regulations enable the departments to classify all actual and potential shellfish growing areas for their suitability for shellfish harvesting on the basis of sanitary quality and public health safety. This authority also allows the responsible departments (DFO and CFIA) to: control the harvesting of shellfish from closed areas; regulate and supervise relaying, transplanting, cleansing and replanting; restrict harvesting of shellfish from actual and potentially affected areas in a public health emergency; prevent sale, shipment or possession of shellfish from unidentified sources; certify, inspect and determine the sanitary compliance of the operations of each shipper or processor; regulate the shipping conditions and labeling requirements for shellstock; regulate the export, import, processing, packaging, shipping storage and repackaging of shellfish; regulate the controlled purification of shellstock; suspend operations or decertify shellfish processors; evaluate laboratories performing shellfish analyses; collect samples and conduct appropriate bacteriological, chemical and physical tests to determine product quality; prohibit the export, or possession of shellfish from unidentified sources, uncertified dealers etc.

The management of contaminated fisheries regulations authorize the Regional Director General of DFO to issue orders prohibiting harvesting of fish (finfish and shellfish) from areas where any kind of contamination or toxicity is present to an extent to be of public health significance. Environment Canada administers the pollution abatement section 36(3) of the Fisheries Act which control the deposits of any deleterious substances to water frequent by fish or affects the use by man of fish that frequent that water.

Guidelines

The Canadian Shellfish Sanitation Program (CSSP) Manual of Operations follows closely the American National Shellfish Sanitation Program (NSSP) guidelines. The purpose of the Canadian Shellfish Program Manual of Operations is to provide DOE, CFIA and DFO staff with the policies and procedures to be employed when applying the Fisheries Act, Fish Inspection Act and related regulations governing the control of shellfish growing areas, and the harvesting, processing and distribution of shellfish. The Canadian manual will contribute to uniformity of interpretation and consistency in the application of policies and regulations.

The water quality criteria used in the classification of shellfish growing areas is based on the level of fecal coliform bacteria. These bacteria are

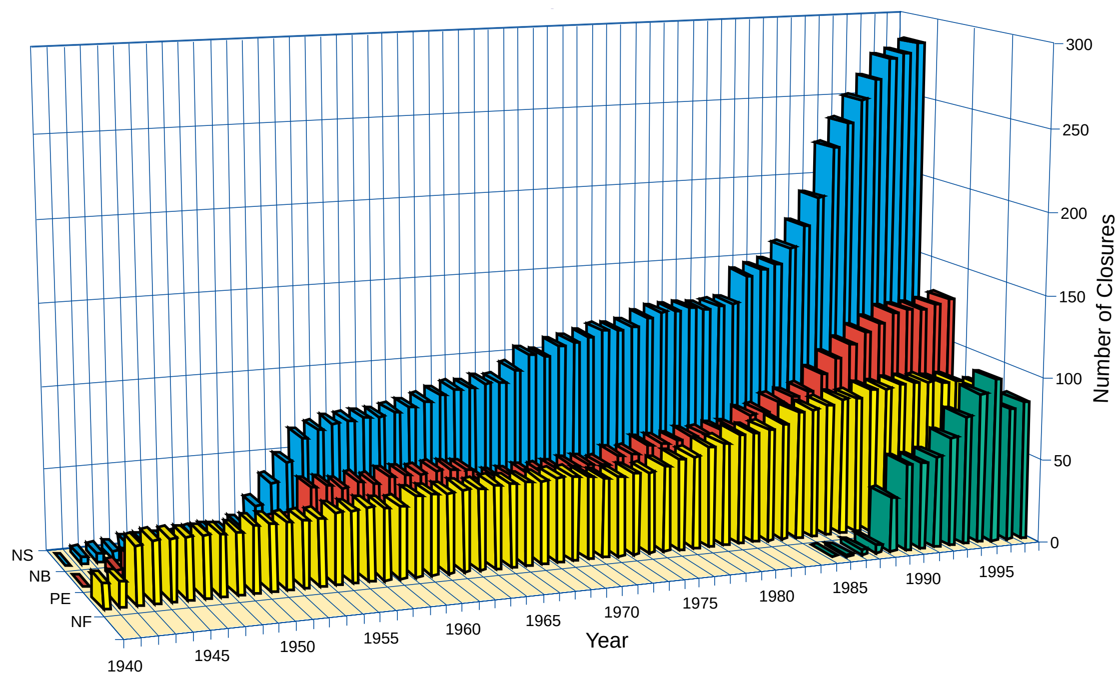

Figure 1: Atlantic Canada Shellfish Closure Trends (1940-1997)

found primarily in the intestinal tract of humans and all warm-blooded animals. The presence of these organisms in waters usually indicates fecal contamination and a potential health hazard. Shellfish growing areas are closed to harvesting if the fecal coliform densities in the water exceed a median or geometric mean of 14 Most Probable Number (MPN) or more than 10 % of the samples are greater than 43 MPN per 100 mL. In additional to bacteriological standard, shellfish growing areas may also be closed to the harvesting of shellfish because of the presence of marine biotoxin.

Although shellfish harvesting is prohibited from closed areas for direct marketing, this does not imply that these shellfish cannot be utilized commercially. Contaminated shellfish can purify themselves if placed in clean waters for a certain period of time under suitable conditions. Permission to harvest shellfish from closed areas can be obtained from the shellfish control agency by permit under specific conditions for relaying, depuration and other approved processing to render the contaminated shellfish safe for human consumption. In the relaying operation, contaminated shellfish are harvested and transported to an approved site where they are relayed for at least two weeks for natural biological purification before they are harvested for marketing. In depuration operations, shellfish are being harvested from marginally contaminated areas and placed in trays in tanks of purified seawater, usually by UV treatment, in controlled environmental conditions that allow the shellfish to rid themselves of fecal bacteria within 24 hours. The effectiveness of the depuration process is influenced by temperature, salinity, dissolved oxygen, suspended particles and the degree of contamination in the shellfish. Controlled studies have shown that marginally contaminated shellfish can reach acceptable market quality by depuration after the 24 hour period, whereas shellfish contaminated with high levels of bacteria and viruses are not completely depurated during this period (Metcalf et al., 1979). Therefore no shellfish are allowed to be harvested from grossly contaminated areas for depuration.

Under the program guidelines, each shellfish growing area must undergo a comprehensive survey before it can be approved for harvesting. Resurveys are conducted regularly to determine if sanitary conditions have undergone significant change. Change in pollution source conditions is evaluated in all approved growing areas annually by means of a formal reappraisal conducted both in the office and in the field. A complete reevaluation of each approved area is conducted at least once every three years. This evaluation includes the field review of pollution sources, analysis of at least the last fifteen water samples from each key station and other field works as deemed necessary to determine the appropriate classification for the area.

IMPACT OF COASTAL POLLUTION

Coastal pollution has adverse impact on local fisheries. Nowhere is this more evident than in the shellfish fishery of Atlantic Canada, where the number of shellfish growing areas closed to harvesting have steadily increased since 1940 (Figure 1) due to fecal contamination. Pollution sources can be characterized as point and non-point. Bacterial contamination from human and animal wastes is primarily responsible for the closures of many molluscan shellfish growing areas in Atlantic Canada.

Point sources are pollution that discharge to the environment through a discrete pipe or ditch. Point sources of bacterial contamination include discharges of untreated as well as treated municipal and industrial effluents. In Atlantic Canada, approximately 5×10^5 m^3 / day of municipal waste are discharged directly into coastal waters and not more than 50% received wastewater treatment.(Chambers et al. 1997).

In recent years, it has become more and more evident that point sources of pollution are only a portion of the total pollution problem. It has been realized that the cleaning up of municipal and industrial discharges may not bring about dramatic improvements in water quality of some estuaries. Non-point source of pollution is diffuse, entering the environment via stormwater runoff or groundwater infiltration. These pollutants do not enter at discrete, identifiable locations, and are difficult to measure or define. This type of pollution cannot be corrected by the usual abatement measures. Control methods usually emphasize prevention at the source rather than end-of-pipe treatment. Agricultural runoff is the major non-point source of pollution affecting shellfish growing areas in Prince Edward Island. It contributes to nearly 50 % of the shellfish closures in the Island. Other non-point sources include leachate from failing septic systems, stormwater runoff, boats and wildlife.

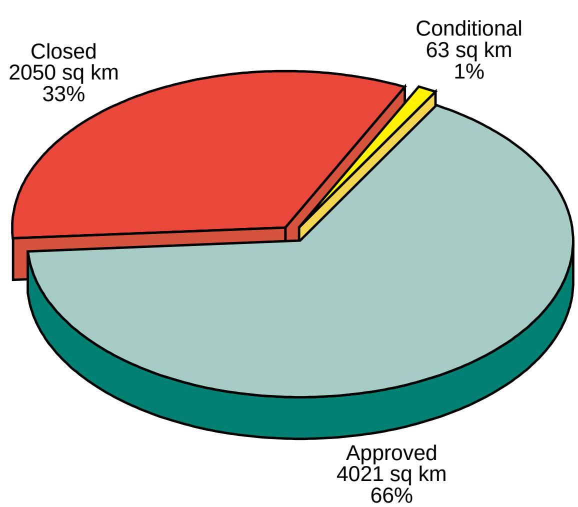

Figure 2: Shellfish Area Classification in Atlantic Canada (1997)

Conclusions

Domestic sewage is a major threat to shellfish growing area water quality. In 1997, approximately 200,000 hectares of coastal waters in Atlantic Canada have been closed to the harvesting of shellfish due to fecal bacterial contamination, representing 33% of the total classified shellfish growing area (Figure 2). Unless adequate measures are taken to control the pollution of coastal waters, further reduction in the acreage of available shellfish areas for harvesting will inevitably result, thereby causing socioeconomic hardships to the region.

The cleanup of pollution sources and improved water quality also addresses human health concerns. The recent National Academy of Science report on seafood indicate most human health risks associated with seafood originate in the environment. Molluscan shellfish consumed raw or partially cooked constitute the highest consumer risk as a result of microbial contamination from fecal pollution. Cleaner water also supports recreational activities and the preservation of the aesthetic quality of coastal areas. Often the coastal residents and those participating in coastal recreation and development contribute to the pollution of shellfish areas. Therefore education of coastal communities and school children is critical in the remediation and restoration of contaminated shellfish areas.

Several coastal communities in Atlantic Canada have begun remediation and shellfish restoration activities, and the numbers are increasing. In Charlotte County along the Bay of Fundy in New Brunswick, the Premier's Clam Bed Action Committee and the Atlantic Coastal Action Program (ACAP) groups are active in pursuing the clean up of bacterial contamination in the area. Similar cleanup activities have also taken place in other parts of New Brunswick, PEI and Nova Scotia. Remediation activities have been successful in re-opening a portion of the productive shellfish growing areas in Yarmouth Harbour, NS, Caraquet, NB and Murray River, PEI. A total of 2485 hectares of shellfish closures have been reopened for commercial shellfish harvesting as a result of pollution remediation since 1990.

Control of pollution to shellfish growing areas is only one element of the total problem facing the Atlantic Canada shellfish industry. The other elements are shellfish resource management, rehabilitation and coastal zone planning. Many federal and provincial agencies have jurisdiction and responsibilities for pollution control, shellfish resource management and coastal zone planning and development. These multiple jurisdictional authorities complicate implementation and enforcement of regulations to protect shellfish growing waters. It is important that all levels of government and communities should coordinate and develop means to ensure that activities related to coastal development and waste discharge adequately protect marine environmental quality. The preservation of our estuarine and coastal waters is critical to the health of our shellfish industry. Improved water quality , in concert with habitat improvement and the expansion of aquaculture activities will allow Atlantic Canada to reach its potential in the world production of molluscan shellfish.

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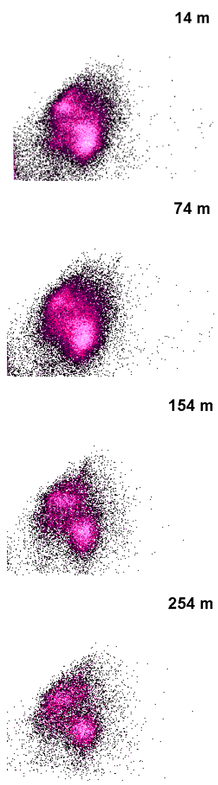
Distribution and Abundance of Bacteria in the Ocean

ToC

W.K.W. Li and P.M. Dickie



Introduction

Bacteria are found everywhere in the ocean. However, they are not distributed uniformly over depth, region or time. In a well-known textbook, Charles J. Krebs (1972) has succinctly stated his view of ecological research: “Ecology is the scientific study of the interactions that determine the distribution and abundance of organisms. We are interested in where organisms are found, how many occur there, and why”.

Since the last century, it has been known that bacteria are part of the marine plankton. For most of this period, the study of marine bacteria has followed the tradition of the microbiological giants Pasteur and Koch wherein cells are first isolated from nature and then cultured in the laboratory on artificial media. This is the species approach. In recent decades, a different approach has developed which emphasizes the role of microbes in their natural habitats. This is the process approach. In marine studies, this approach led to a new tradition pioneered in 1962 from Nanaimo by the oceanographers Parsons and Strickland wherein the biological activity of cells are assayed in situ. A flourish of new ideas and results have followed which clearly point to the vital importance of bacteria in the ocean.

In the pelagic realm, bacteria are indispensable for two major reasons: they are eaten by other organisms, and they degrade organic matter. In a loose sense, bacteria are at both the start and end of the food chain: they contribute to the first production of particulate food-stuff (by conversion of dissolved organic substrates), and they are responsible for the ultimate breakdown of organic matter leading to the return of nutrients to the sea. Bacteria may be the crucial link or sink between detritus, dissolved organic matter and higher trophic levels. For these reasons, bacteria occupy a central role in two inter-connected environmental issues of global concern, namely the sustenance of harvestable living resources and the mitigation of climate change by sequestration of carbon into the deep ocean.

Counting Bacteria

The most basic information we need is the number of bacteria at a given place and time. Without this, we cannot even offer a descriptive geography, much less any assessment of microbial impact on marine production. Not all bacteria are the same. Some are metabolically active while others are not. Further, in a given water parcel, it is possible to find genetically distinct populations which, though adapted for optimal growth under different conditions, co-occur in the given permissible environment. Yet, the first-order task of counting bacteria, assuming (incorrectly) that they are all the same, is not as straightforward as perhaps might be imagined. Unlike other important oceanographic variables such as temperature, salinity, irradiance, oxygen and colour which can all be monitored in an automated and continuous fashion, or in the case of some be sensed remotely by airborne platforms, bacteria need to be counted manually in discrete samples of seawater.

Remarkably, it has only been in the last 20 or so years that oceanographers have had accurate counts of the total number of bacteria. Before this time, marine bacterial populations were severely underestimated because of inadequate methods. The breakthrough that ushered in the modern view of planktonic bacteria was a methodological one. With the availability of chemical stains that specifically bind to biological macromolecules in general, and DNA in particular, it became possible to visualize all the bacteria mounted on a microscope slide and made to fluoresce by light of a suitable wavelength. As researchers everywhere adopted this method of epifluorescence microscopy, data slowly began to accumulate, contributing to the development of the contemporary idea known as the “microbial loop” in which the role of free-living bacteria in marine food webs is paramount.

At the Bedford Institute of Oceanography (BIO), we have semi-automated the procedure for counting DNA-stained bacteria (Li et al. 1995). Microscopic examination is an extremely time-consuming and labour-intensive task. By using a flow cytometer to perform electronic detection of cells based on optical characteristics, the

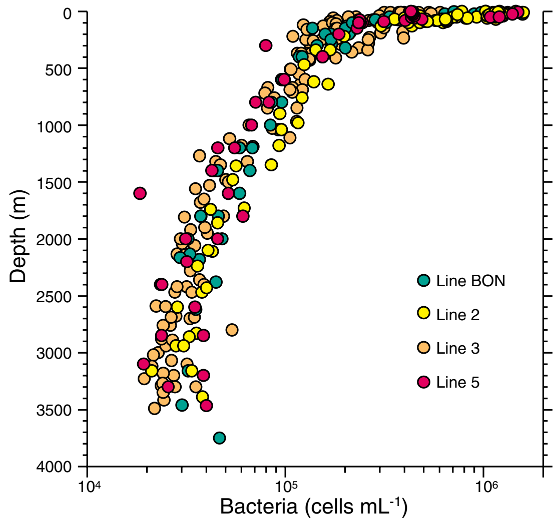


Figure 1: Depth distribution of bacteria in the Labrador Sea in May, 1997.

counting procedure is greatly improved by enhanced precision, speed, and ease of operation. Thus, whereas it requires 10 minutes to count 500 bacteria by microscopy, it only takes 10 seconds to count 5,000 bacteria by flow cytometry. Recently, researchers in France (Jacquet et al. 1998) have made flow cytometric counts of cells collected at high frequency (minutes) by an autonomous sampler consisting of a microprocessor controlled system of fraction collector, peristaltic pump and a set of tube-pinching electrovalves. It is therefore now feasible to map the distribution of bacteria at a resolution approaching that of chlorophyll when both are monitored at sea. This ability to match the scales of variation for microorganisms of different nutritional modes is important as we seek to understand how ocean food webs function.

Depth Distribution

Typically, bacteria are most abundant in the sunlit upper layer, and their numbers decrease with depth. For example, in the Labrador Sea (Figure 1), bacteria are present at concentrations on order 10^5 to 10^6 per millilitre in the top 100 metres, and on order 10^4 to 10^5 per millilitre at greater depths. Bacteria are sustained by the flux of dissolved organic matter from phytoplankton and zooplankton. Therefore the restriction of primary production to the sunlit layer is an obvious determinant in the vertical distribution of bacteria. Bacteria persist deep into the aphotic zone where phytoplankton are absent; there they are a dominant metabolic agent mediating the dynamics of organic material.

Regional Distribution

In general, the distribution of bacteria at the regional scale is not well-studied. Broadly, typical bacterial abundances (cells ml^{-1}) in eutrophic lagoons and estuaries (10^7), in coastal zones (10^6), and in the open ocean (10^5) are set by the magnitude of the flux of dissolved organic matter: a manifestation of the dominance of "bottom-up" (resource limitation) over "top-down" (grazing pressure) control factors at large time and space scales (Ducklow 1992). An example of the coherence of bacteria and phytoplankton can be seen in summer from Nova Scotia to the Labrador Sea (Figure 2).

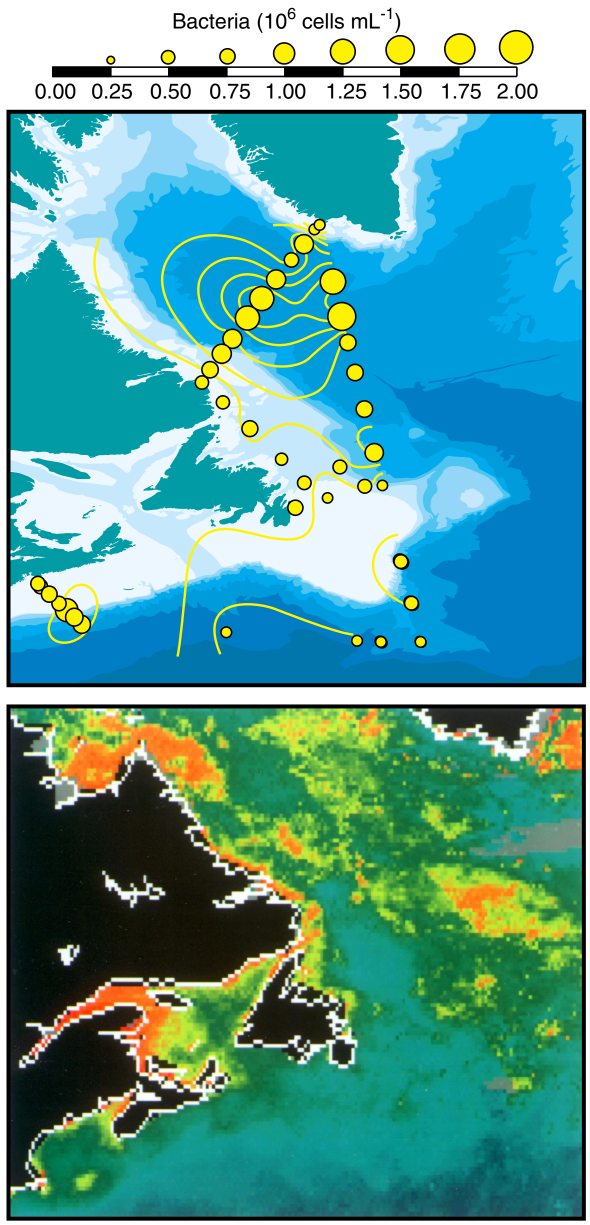
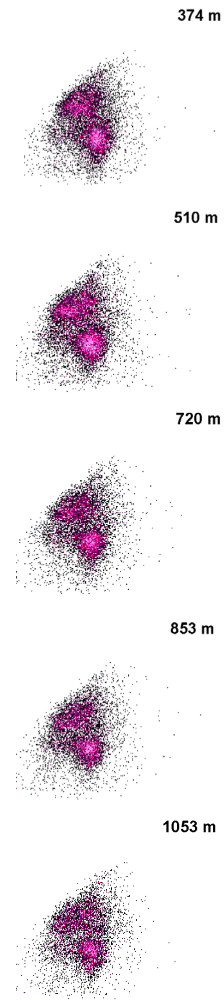
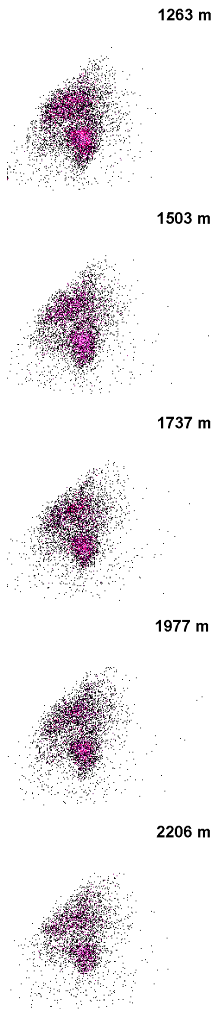


Figure 2. Abundance of bacteria in surface waters in July, 1995 (upper panel) and the mean distribution of chlorophyll in July from the Coastal Zone Colour Scanner (lower panel)





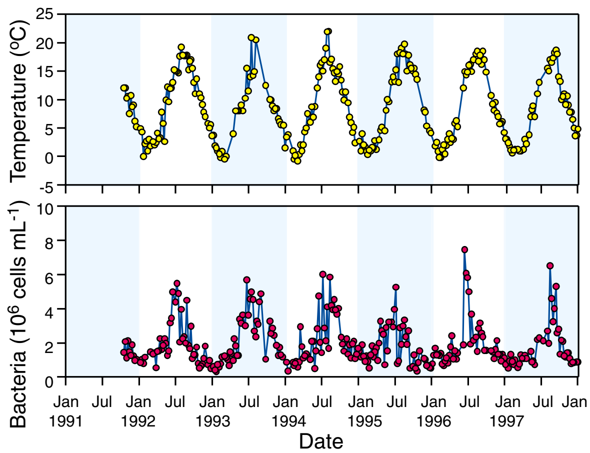


Figure 3. Seasonal cycle of surface temperature and bacteria in Bedford Basin.

Seasonal Distribution

In temperate waters, the annual cycle of bacterial abundance may be quite regular. Generally, cells are most abundant in summer and least so in winter. Long term monitoring of plankton at fixed locations offer the opportunity to detect annual and decadal variabilities. In the Bedford Basin, a time series was initiated in October, 1991 to establish an uninterrupted record of important physical, chemical and plankton variables, including bacterial abundance. Weekly observations (Figure 3) show that short term responses of bacteria to presumed shifts in controlling factors do not obscure the underlying annual cycles.

At the seasonal scale, temperature emerges as a dominant influence. Monthly averages of bacteria and temperature are tightly correlated from January to June. The monthly average temperature of 14ºC in June marks the start of bacterial decline, presumably due to the dominating effects of another factor. An earlier study (Taguchi and Platt 1978) had shown that microzooplankton biomass in Bedford Basin was low through the winter and increased from May to a peak in September, suggesting significant grazing pressure in summer. The role of substrate supply to bacteria has not been investigated here but it can be assumed to be increasingly important in the summer when metabolic rates increase with temperature.

Biomass Pyramid

One of our most persistent views of food webs is the pyramid of biomass. In this construct, we visualize a pyramid whose broad base represents the large biomass of plants supporting successively smaller strata of consumer organisms up to the apex predator. Bacteria, being dependent (directly and indirectly) on photosynthetic production, are at a stratum higher than that of the phytoplankton. Yet it is not uncommon to find bacterial biomass exceeding phytoplankton biomass; in other words, an "inverted pyramid".

In the past 10 years, the Bedford Institute of Oceanography has collected plankton bacteria on more than 1000 occasions (Figure 4) from both near (e.g. Bedford Basin) and far (e.g. coastal waters of Greenland, northern Africa, etc). We, like other researchers (Gasol et al. 1997 and references cited therein), have found that as phytoplankton biomass decreases from nutrient-rich waters to nutrient-poor waters, so too does bacterial biomass. However, the relative decrease in bacteria is less than that of phytoplankton. In other words, the decline of bacteria from nutrient-rich to poor waters is less marked than the decline of phytoplankton. A plot of the ratio of biomasses indicates 2 domains: in chlorophyll-rich waters, phytoplankton exceed bacteria; conversely in chlorophyll-poor waters, bacteria exceed phytoplankton (Figure 5).

When the other heterotrophic (i.e. dependent on organic substances) members of the food web (i.e. animals) are included with the bacteria, the demand for phytoplankton production is even greater. Apparently, this demand can be satisfied by a high turnover of phytoplankton, a high level of detritus, or an import of organic matter from outside the system.

Global Perspective

In temperate waters, bacterial abundance can evidently track water temperature throughout the year (Figure 3). A broader issue, however, is whether temperature exerts a significant influence on abundance across a biogeographical range. In

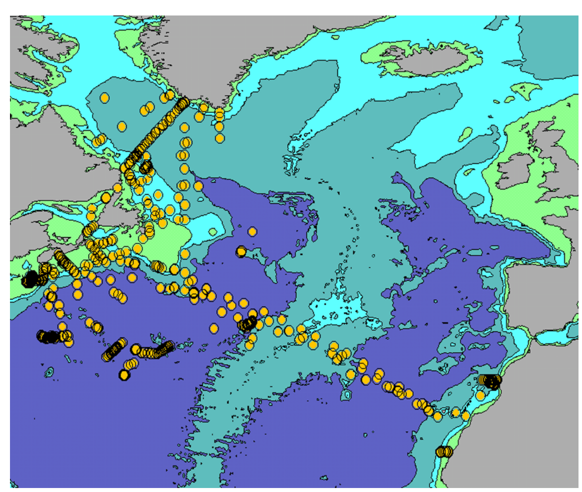


Figure 4. Locations sampled by BIO for bacteria, 1987-1997.

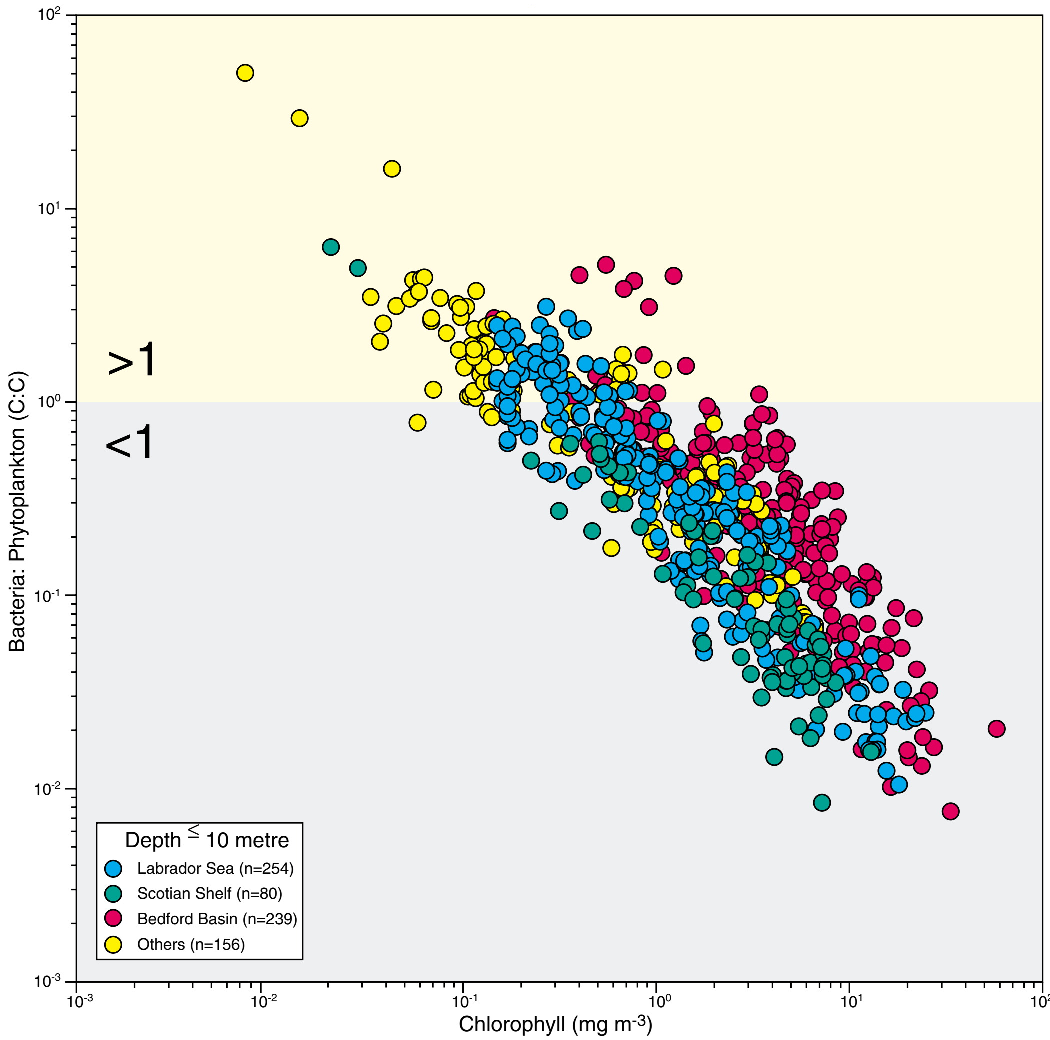


Figure 5. The biomass dominance of bacteria over phytoplankton in chlorophyll-poor waters.

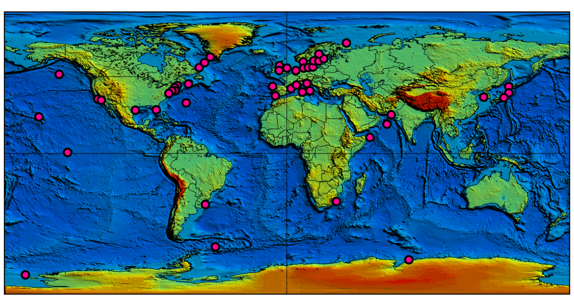


Figure 6A. Locations of datasets that document seasonal variation of bacterial abundance.

other words, is there a relationship between climatological averages of abundance and temperature in diverse marine habitats? If so, the large scale distribution of these cells might conceivably be mapped by temperature.

A global annual climatology of bacterial abundance was developed based on 45 separate studies (Figure 6A) covering the full range of prevailing annual temperatures. Below 14ºC, annual average abundance of bacteria is directly related to annual average temperature; however, above 14ºC, no relationship is discernible (Figure 6B). In other words, on an annual worldwide basis, the

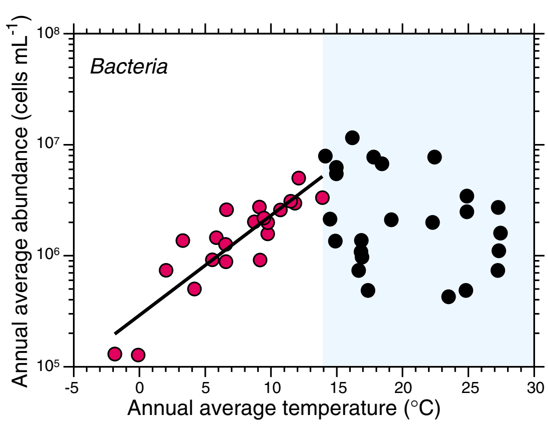
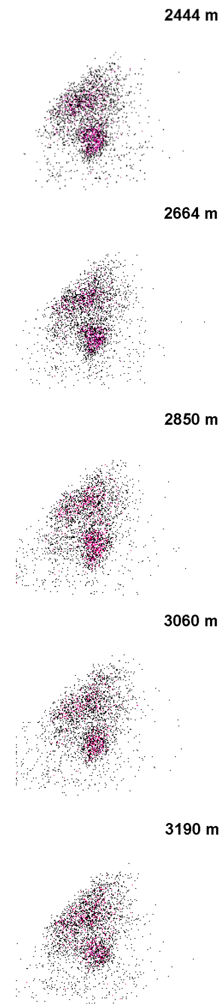
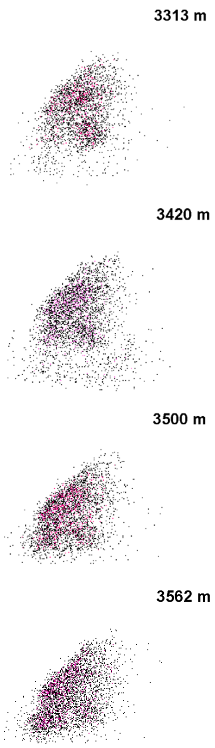


Figure 6B. Relationship between bacterial abundance and temperature at the annual scale from datasets in Fig. 6A.



abundance of bacteria is predicted with reasonable accuracy by temperature in regions where the average is less than 14°C.

In the world oceans, 49% of all one-degree latitude-longitude grid boxes, representing a global ocean area of 32%, exhibits an average surface temperature below 14°C. For these regions which extend towards the north and south poles from approximately 40° latitude in each hemisphere, it appears that marine bacteria may have a surface distribution that is largely a reflection of the poleward decrease in temperature. This pattern in observable cell abundance is the net manifestation of the underlying processes of growth and loss upon which the direct physiological effects of temperature are exerted. Further progress in the ecological geography of marine bacteria can be expected when climatological averages are compiled for the rates of growth and loss and when due consideration is given to the entire population in the upper mixed layer.



Depth profile of autumn Labrador Sea bacteria shown as flow cytograms of SYTO-13induced fluorescence versus orthogonal light scatter.

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Ocean Forecast for the East Coast of Canada

ToC

Charles Tang, Brendan DeTracey, William Perrie and Bechara Toulany

We are all familiar with weather forecasts. We depend on them to plan our daily activities - what to wear, whether to fly in an airplane, sail a boat, have a picnic, or play a ball game. Of equal importance, to people who make their living at sea or inhabit coastal areas, are ocean forecasts. The latter people need to know how high the seas will be, where they will encounter sea-ice, how high the water level will rise in a storm, how fast an oil spill or a capsized vessel will drift. Ocean forecasting, the counterpart of weather forecasting for the ocean, can provide this information.

From a global societal perspective, 50% of the world's population today live within 10 km of the sea; 16 out of the world's 20 largest cities are also located in this 'coastal zone'. The advantages of living there are obvious, but accompanying these advantages are natural hazards. Storm surges, hurricanes and beach erosion all inflict severe damages to the immediate coastal region. These damages are a concern in eastern Canada, but given the relatively low population levels in this region, they are generally of lesser importance when compared to the global situation with many heavily populated coastal regions.

Of greater concern to eastern Canadians are the routine and emergency situations that arise due to human activities, such as boating and related recreational usage of coastal waters. Each year sees loss of life and significant financial loss because of storms that propagate along the continental shelves of Canada and the USA. Human activities off eastern Canada are, of course, not relegated solely to recreation. Economic concerns include the fisheries on the Scotian Shelf, Grand Banks, and in related waters. Offshore activities at Hibernia and on Sable Bank presently involve many people and make important contributions to the economies of this region. The importance for timely environmental forecasts of winds, ice, waves and currents is evident. In normal operating situations, accurate forecasts are needed to organize work schedules. In the event of human accident, support vessels and aircraft must have accurate timely estimates of environmental factors. In the event of extreme storm conditions, such as the 30m waves of the Halloween Storm (1991), the Storm of the Century (1993) or Hurricane Luis (1995), all of which passed over the Scotian Shelf or the Grand Banks, lead time is needed to shut down operations, secure equipment and remove all but essential personnel.

Research on ocean forecasts conducted at the Bedford Institute of Oceanography (BIO) is focused on the development of accurate forecast models and an automated forecast system to demonstrate operational use of the models and provide valuable expert information to BIO clients. The forecast ocean parameters include wave height and direction, ice coverage and velocity, surface drift trajectories, and sea surface elevation.

Sea surface elevation, surface current and sea-ice

The short-term movement of sea-ice and surface water is mainly determined by surface winds, but a number of other factors can also have a significant influence in localized areas. Wind moves sea-ice and surface water by exerting a stress over the ice and water surfaces. As a rule of thumb, ice and the sea surface move at 3% of the wind speed. Because of the earth's rotation and friction in the upper ocean, the ice and sea surface velocities do not align with the wind direction. Instead, they veer to the right of the wind direction by an angle that is typically 30∞, but varies greatly with wind conditions and location.

Other factors of surface motion include mean currents, sea-surface slope, tides, inertial motions, and topography related oscillatory motions. Mean currents are the result of large-scale atmospheric forcing, density distribution of the water and topography of the ocean basin, which do not change with short-term winds. In general, mean currents are strongest over the edge of the continental shelf and weakest in the open ocean. Sea-ice and surface water on a sloping sea surface can move by gravity. The velocity of this motion is much smaller than that directly forced by wind stress, except at the coast where sea surface variation is large. Sharp changes in the wind field can generate an oscillatory motion, called inertial currents, due to the earth's rotation. The period of inertial currents varies with latitude. At 45∞ N, the period is 17 hours, increasing to 35 hours at 20∞ N. The interaction of currents and topography can give rise to another type of oscillatory motion known as topographic waves, which are most prominent over the shelf edge during periods of strong winds.

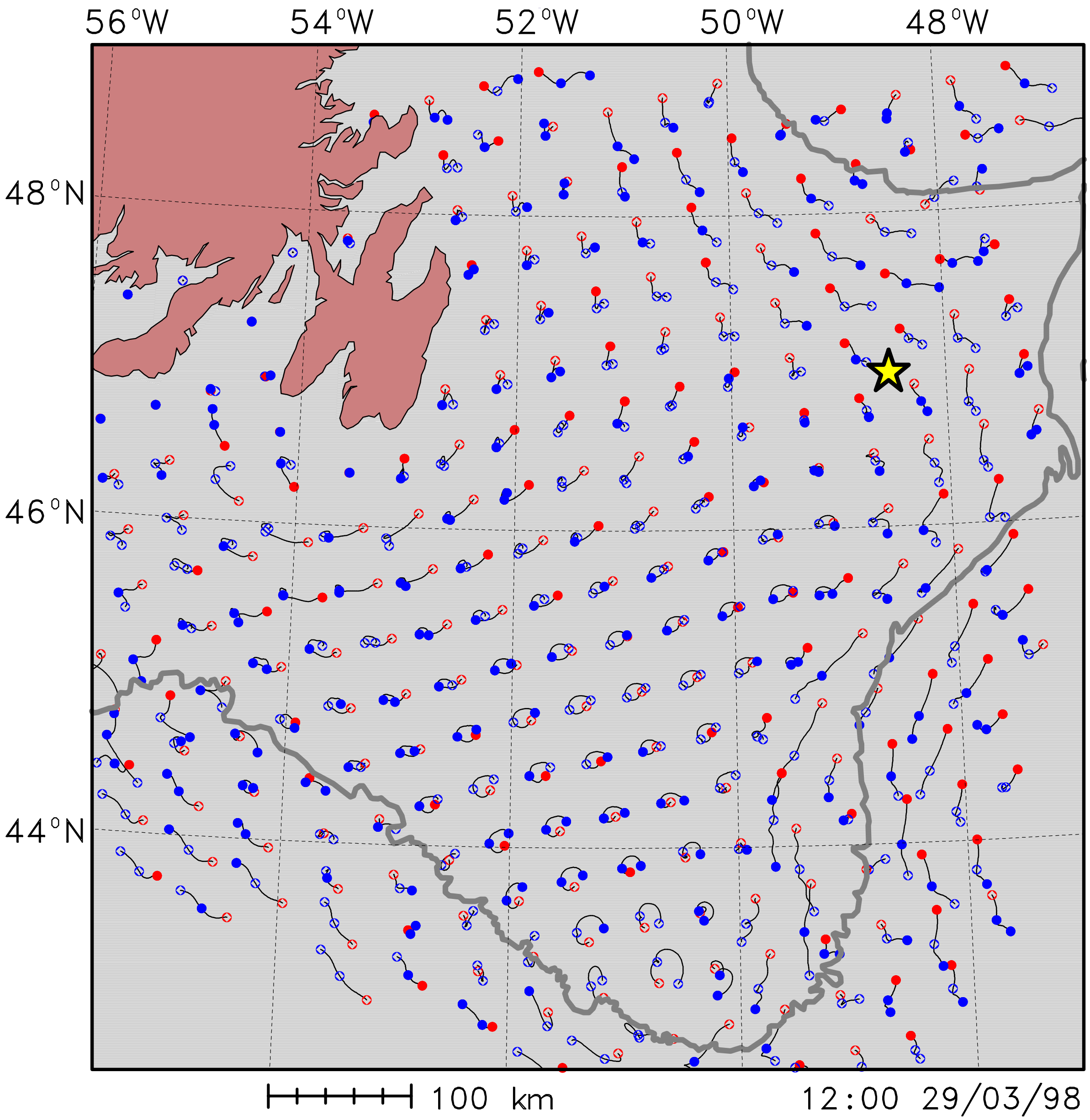

Figure 1. Ocean surface drift during the two day forecast period started on March 27, 1998. The track diagram depicts the trajectories of water parcels, or light floating objects at the sea surface, during the two day period. Red circles indicate the track starting points, blue circles indicate one day intervals, and the location of Hibernia is shown on the map as a yellow star. The grey line is the 1000m bathymetry contour.

Surface waves

Waves are generated by wind stress on the water surface. Waves grow and evolve in space and time, reflecting the structure and development of the wind stress fields that generated them and that continue to influence them. In turn, the wind stress fields themselves are influenced by the waves, in an interactive process that continues throughout their entire history. This history begins with the formation of tiny ripples and capillary waves, continues as the waves develop, possibly into huge 'Storm-of-the-Century' waves, and ends with the progressive dissipation of old swell waves. By the time of their ultimate disappearance, waves have often crossed ocean basins traveling global-scale distances from their points of origin. Many aspects of wave generation and evolution are poorly understood, or are just now emerging as tentative theory. For example: What is the correct method to calculate the energy input to waves from wind, or the energy removed from waves by wave-breaking and white-cap formation? What is the effect of finite depth on these processes?

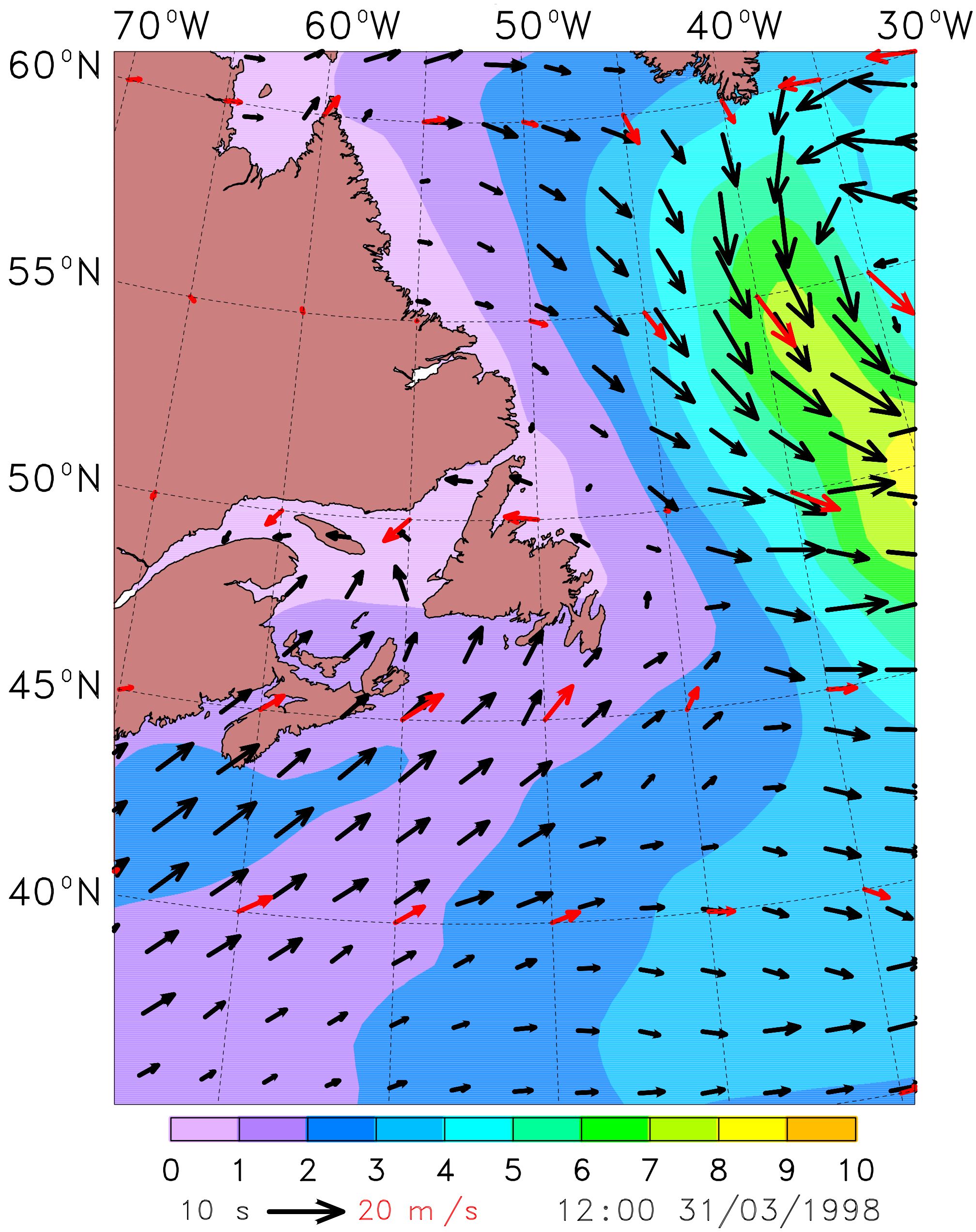

Figure 2. Forecast wave height and direction for March 31,1998. Colour contours indicate wave height in metres, black arrows indicate wave direction, and red arrows indicate speed and direction of surface wind.

In practice, the processes associated with wave generation and evolution are approximated. A compromise is sought, balancing computer efficiency with accurate representation. Wave growth and evolution, as a measure of 'wave age', is represented in terms of the nondimensional peak frequency of the wave spectrum. Experimental results, obtained by using an idealized, constant, uniform wind forcing field, have determined that nonlinear wave-wave interactions cause the peak frequency of the spectrum to migrate from high to low frequencies as the wave field ages. Nondimensionalization of the peak frequency is achieved using the wind speed (or wind stress) and the acceleration due to gravity. Energy input to the waves by the wind is represented by a rather simple function of 'wave age', derived from parameterizations of field data collected during dedicated experiments.

It is the nonlinear wave-wave interactions described above that are the most time-consuming and costly component of a wave model to compute. Although rather exact formulations of these processes have been available for more than three decades, these formulations are mathematically complex. Computer codes fast enough for operational applications are still far from perfect, and await both faster computers and more efficient numerical methods. In principle, dissipation due to wave-breaking is at least as complicated as wind input energy, or nonlinear wave-wave interactions. However, dissipation is much more poorly understood. Therefore, parameterizations are formulated based on a few physical principles and 'tuning', so that the final estimates from the wave model agree with accepted parameterizations from well-calibrated field experiments measuring wave growth and evolution under well-defined forcing situations.

The wave models used at BIO are so-called second generation and third generation models. Second generation models are discrete spectral models which model wind input, dissipation and nonlinear wave-wave interactions together, as a somewhat peaked Gaussian 'wave shape function', dependent on five or six parameters. As the wave fields are generated, grow, and evolve, the peak of the 'shape function' migrates to lower frequencies and the 'shape function' itself sharpens. Third generation models are the 'state-of-the-art'. They explicitly attempt to represent the wind input, dissi-

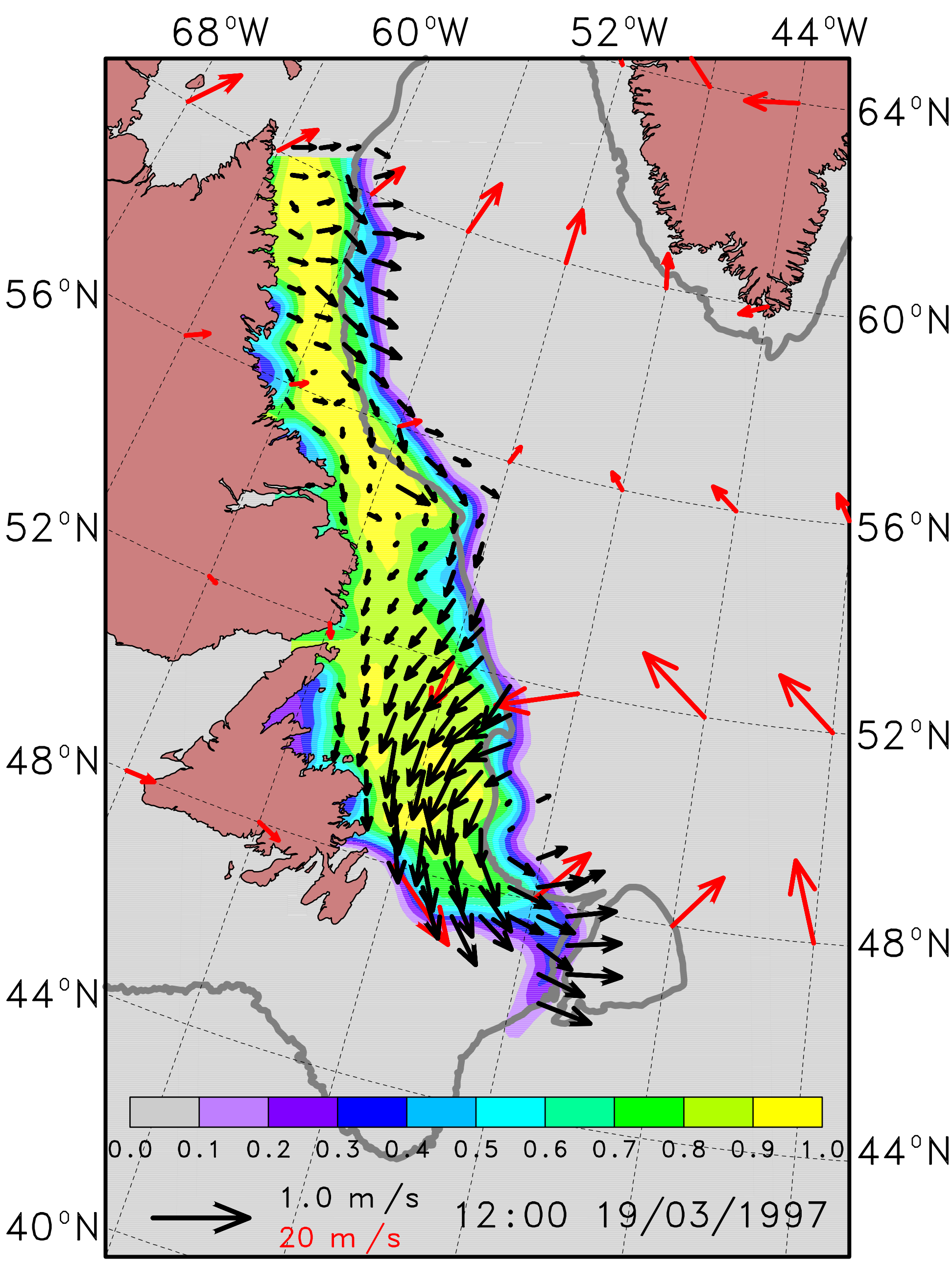

Figure 3. Ice conditions for March 19,1997. Colour contours indicate ice concentration (0 for no ice to 1 for complete ice cover), red arrows indicate surface wind, and black arrows indicate ice speed and direction. The grey line is the 1000m bathymetry contour.

pation, and nonlinear transfer terms from first principles. However, as suggested above, the unknowns in these processes are sufficiently daunting that numerous approximations and assumptions must be implemented. In real operational tests, where second and third generation models are compared, it is not always clear which is superior to the other.

Making ocean forecasts

The various types of motions outlined above are governed by a set of hydrodynamic equations. These equations can be directly solved only for the most simple situations. In the real world with complicated wind patterns, bathymetry and coastlines, the equations can be solved only with today's powerful computers using numerical methods. To perform a forecast, surface wind fields both in the past few days and in the future are required in the forecast models, since the ocean state is determined not only by the wind field at the forecast time but also by the time history of the wind field.

To integrate the operations of inputting wind fields to the models, performing numerical computations and displaying forecast results, a software package, the Ice-Ocean Forecast System (IOFS), has been developed in-house at BIO to produce daily ocean forecasts, and make the results available to the general public via the worldwide web. IOFS is comprised of an automation module written in Microsoft Visual Basic, a coupled ice-ocean forecast model (Tang and Gui, 1996) and a second generation spectral wave forecast model (Perrie et al, 1989). The 'state-of-the-art' WAM (WAve Model) third generation model (Komen et al, 1994) is presently being implemented to replace this second generation wave model. All forecast models are coded in FORTRAN and are driven by forecast wind data downloaded every 12 hours from the Canadian Meteorological Centre (CMC). Initial ice states required for the coupled ice-ocean model are derived from digitized ice charts downloaded every day from the Canadian Ice Service (CIS). Forecast variables include surface currents, sea surface elevation, wave height, direction and frequency, and ice concentration (percent coverage), thickness and velocity. Forecasts are of 48 hours length starting at 1200 UTC. Forecast procedures take approximately 90 minutes to execute, commencing at 1200 AST upon the download of the day's CMC 1200 UTC forecast data, and concluding with the upload of forecast results to the DFO Maritimes Region web server.

In the event of missing CMC and CIS data, due to either power outage or network failure, the IOFS has a simple decision procedure that enables it to attempt a forecast. Temporal overlap of the CMC forecast data may allow 'patching' if only partial data loss has occurred. Missing CIS ice charts may be replaced by using recent forecast ice conditions as the initial state for the day's forecast. In the event of total data loss, the IOFS will wait until sufficient data are available and then continue forecasting.

Display and use of forecast results

Forecast results are available as maps and animations on the Ice-Ocean Forecast page (http://www.mar.dfo-mpo.gc.ca/science/ocean/icemodel/ice_ocean_forecast.html) of the DFO Maritimes Region Internet web site. All of the aforementioned forecast variables are displayed. The maps can be transmitted to ships by e-mail or fax. Animations of the season's ice thickness and concentration, and a 48 hour forecast of ocean surface drift on the Grand Banks, are also available.

Figs. 1-3 are examples of forecast maps made in the past year. Fig.1 shows the trajectories of surface water on the Grand Banks in a two-day period. If an oil spill occurs at any location covered by the map, the forecast trajectories give the distance and direction of the oil drift in two days. Fig.2 shows the wave height on the eastern Canadian seaboard. Ships and boats sailing in these waters can use the information in the maps to plan their navigation or offshore operations. Sea-ice appears off the coast of Newfoundland from February to May. Fig. 3 shows ice coverage and ice velocity at the end of March when the ice extent is at its maximum. In heavy ice years, the southern ice edge can reach the Hibernia oil field (see Fig.1 for location of Hibernia).

At present, the maximum forecast period is 48 hours. This limit is imposed by the availability of wind data. As the skill of long-range weather forecasts improves, ocean forecasts can also be extended to a longer period.

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The Maritime Shellfish Health Program and its role in molluscan aquaculture and environmental monitoring.

ToC

Sharon E. McGladdery and Mary F. Stephenson

Introduction

Over the last thirty years, Atlantic Canada has witnessed significant growth in shellfish production and aquaculture. Concomitant with this development has been increasing attention to optimising growth rates and productivity. A significant increase in monitoring and manipulation of stocks, has led to earlier detection of health problems such as stunted or abnormal growth, spawning failures, gaping and mortalities. Increased transfers and production densities, however, have also increased the risk of accidental introductions of new disease or pest organisms and proliferation of opportunistic organisms to potentially pathogenic levels. In the late 1980's, in recognition of the increasing need for health support for this developing industry, DFO established a shellfish health program at the Gulf Fisheries Centre (GFC) in Moncton. This followed a rich history in shellfish health research, dating back to the 1930's, when DFO established the Shellfish Research Centre at Ellerslie, Prince Edward Island, in response to Malpeque disease of American oysters (Crassostrea virginica). Eventual recovery of the oysters in the late 1960-70's, led to a decrease in support for molluscan disease research, however, enlightenment returned with the growth, especially over the last 20 years, of molluscan aquaculture and enhancement. Today, DFO has the only two laboratories in Canada which are dedicated, full-time, to shellfish health - one at the Pacific Biological Station, Nanaimo, BC and the other at the Gulf Fisheries Centre, Moncton, NB..

The Shellfish Health Program at GFC, consists of two full-time personnel, graduate students (working on and off-site), undergraduate co-operative students, as well as occasional trainees from other institutions. It operates in close collaboration with industry and, with their support, has compiled an extensive reference collection of material from a wide range of molluscs - principally oysters, mussels, clams and scallops - (McGladdery et al. 1993). The Shellfish Health Program also conducts research on problems affecting the health and marketability of shellfish in Atlantic Canada, and provides diagnostic services to growers, provincial departments and academic institutions. The material generated from this research and diagnostics is also used to teach students, growers and managers, what to look for when monitoring the health of their shellfish. It also forms the basis for providing advice on disease risks associated with moving live molluscs from one area to another.

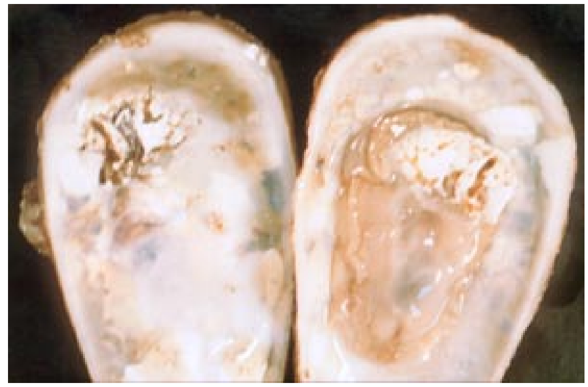

*Figure 1: Shell damage in American oyster (*Crassostrea virginica*) due to boring sponge (*Cliona sp.*) and polychaete worms (*Polydora sp.*).*

Research Activities

Molluscan Aquaculture Development

Atlantic Canada doesn't currently suffer from any significant molluscan diseases compared with other major shellfish growing areas of the world, however, there are still health problems which plague the molluscan aquaculture industry and these stimulate a broad diversity of research projects. Some address problems associated with marketing aesthetics, e.g., shell damage due to boring sponges (Cliona spp.) and burrowing polychaetes (Polydora spp.) (Figure 1), while others address problems directly affecting the health of the shellfish. A few examples are summarised below.

Malpeque Disease Research: Malpeque Disease (Figure 2a,b) was one of the first epizootic diseases recorded in molluscan shellfish. It hit American oysters (Crassostrea virginica) in Malpeque Bay, PEI, in the early 1900's, following

Figure 2a: Malpeque disease in American oyster (Crassostrea virginica) *- abscess lesions (arrows).*

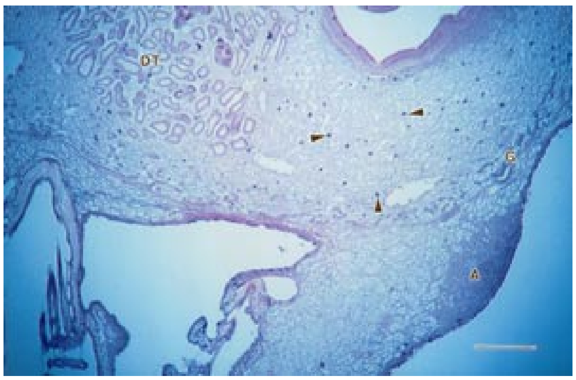

Figure 2b: Light micrograph of a tissue section through a Malpeque diseased oyster. Note abscess lesion (A), shrunken digestive tubules (DT) and gonoducts (G), and accumulation of ceroid (arrows). Haematoxylin and eosin stain. Scale bar = 500 µm.

transfers of apparently healthy seed from New England (Needler and Logie 1947). The disease spread throughout PEI in the 1930's and then to the Gulf shore of NB in the 1950's. Offspring of the oysters which survived each outbreak developed resistance to the disease so, today, there is little evidence of Malpeque disease (Drinnan and Medcof 1961, McGladdery et al. 1993) (Figure 3). Normally, this would be considered good news, however, recent experiments transplanting historically "susceptible" oysters from Cape Breton to PEI and the Gulf shore of NB, have shown that oysters from the southern Gulf of St. Lawrence can still be infective to naïve oysters (McGladdery and Stephenson, unpublished data). Therefore, even though the Gulf oysters appear "healthy", their infective status precludes transfer to areas which have not, historically, been exposed to Malpeque disease. Research to identify the causative agent of the disease continues and, it is hoped to develop diagnostic tools 'sensitive to the agent' in order to detect resistant "carriers". This will help determine the true distribution of the disease agent in Atlantic Canada and, possibly, New England, as well as distinguish healthy carriers from uninfected oysters. This will also be useful for researching the factors involved in the rapid development of resistance/tolerance of the infectious agent.

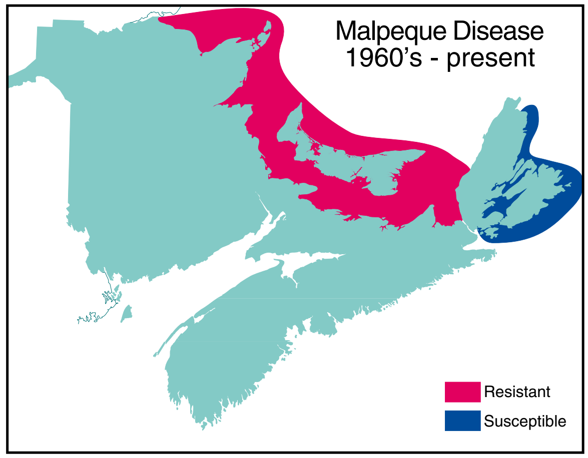

Figure 3: Current status of Malpeque disease in the Maritimes.

Soft-Shell Clam Neoplasia: As with many bivalves, soft-shell clams (Mya arenaria) have diseases caused by neoplasia. One of the better known

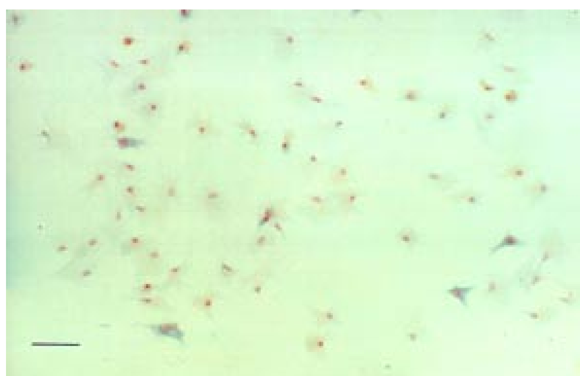

Figure 4a: Normal soft-shell clam (Mya arenaria) *haemocytes. Haematoxylin and eosin stain. Scale bar = 25 µm.*

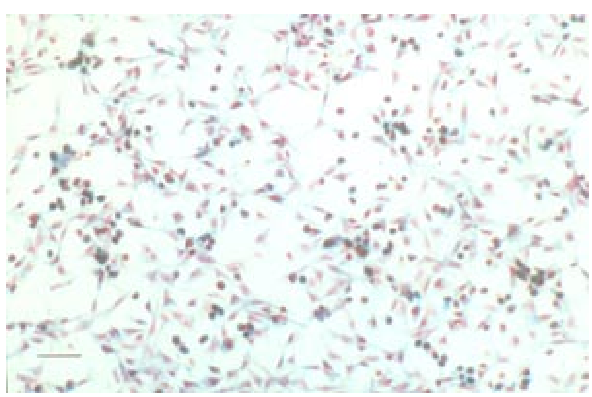

Figure 4b: Neoplastic soft-shell clam (Mya arenaria) *haemocytes. Haematoxylin and eosin stain. Scale bar = 25 µm.*

soft-shell clam neoplasms is haemic (erroneously called haematopoietic) neoplasia (Figure 4a, b). This condition is present in Atlantic Canada (Morrison et al. 1993) but has not been associated with the massive mortalities attributed to the same disease in Chesapeake Bay, Virginia (Farley et al. 1986). A doctoral study[1] of clam diseases continues to find low prevalences (< 4%) of haemic neoplasia in Bay of Fundy and Gulf of St. Lawrence populations (Bacon, pers. comm.) and, although not a significant disease problem, there is interest in pursuing the condition from an environmental perspective. As with other neoplasms, some positive correlations between prevalence of infection and aquatic pollutants suggest a cause-effect association (Leavitt and Capuzzo 1989, Gardner et al. 1991). It is hoped that the data collected for the University of New Brunswick, Saint John-DFO study will provide a reference base for a more detailed examination of this environmental health question in the near future. Recent developments in the production of monoclonal antibodies to detect neoplastic cells (Bachère et al. 1995), should improve such studies, since they distinguish early stages of neoplastic transformation which can easily be confused with other types of haemocyte alteration using routine diagnostics, such as, histology. Immunoassays will also permit significant increases in the sample sizes which can be examined practically.

Another neoplasia recently detected in northern Gulf of Maine soft-shell clams (Barber 1996) affects the germinal epithelial cells of the gonad. Proliferation of the epithelial cells occludes the lumen of individual gonoducts early in the infection. As the disease progresses, more of the gonoducts are affected, until it proliferates to other tissues. The same disease was recently detected by Bacon and Barber (unpublished data) in histological sections of soft-shell clam gonads, collected by S.M.C. Robinson (DFO, Saint Andrews Biological Station) as part of a spawning study in the Bay of Fundy between 1990-91. Work is now ongoing to see if the disease occurs elsewhere in Atlantic Canada and determine if it has an effect on the recruitment dynamics of infected populations (Barber 1996). This study is being conducted in collaboration with Dr. Bruce Barber, University of Maine, and Dr. Shawn Robinson, DFO St. Andrews Biological Station.

Bonamiasis of European oysters: European (= flat or Belone) oysters (Ostrea edulis) were introduced to Atlantic Canada in the 1970's and 80's for aquaculture purposes (Newkirk et al. 1995). Due to cold-water and low salinity suppression of gametogenesis, broodstock are overwintered in

[1] G.S. Bacon, University of New Brunswick, Saint John and GFC, personal communication.

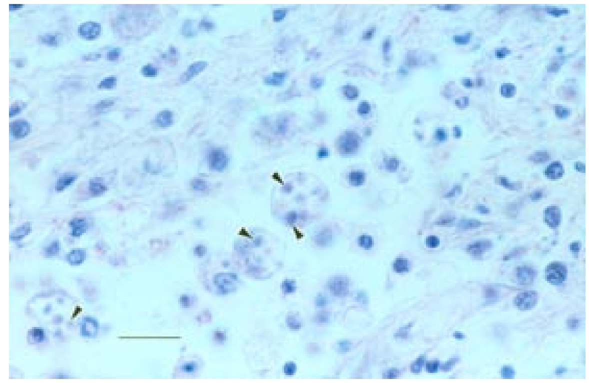

Figure 5: Light micrograph of European oyster (Ostrea edulis) haemocytes infected by the protistan parasite Bonamia ostreae (arrows). Haematoxylin and eosin stain. Scale bar = 15 µm.

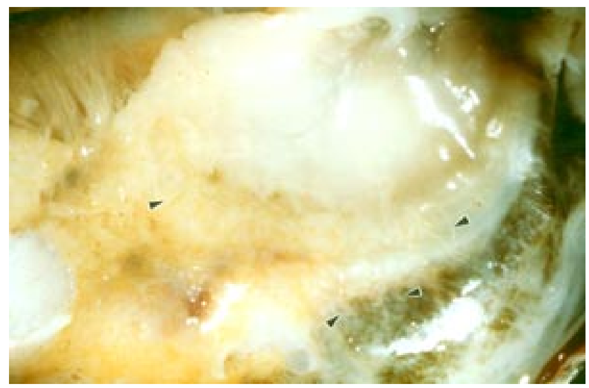

Figure 6: Blue mussel (Mytilus edulis) tissues infected by sporocyst larvae (arrows) of the digenean flatworm Prosorhynchus squamatus.

hatcheries. Their high market value and the absence of disease problems makes the necessity for overwintering handling economically viable. Of special interest is the fact that Atlantic Canadian populations have no record of infection by a microscopic protistan, Bonamia ostreae (Figure 5), which has plagued European oyster culture elsewhere since the early 1970's. This "disease-free" status has meant tight restrictions on oyster movements from Maine and elsewhere, into Atlantic Canada, but has also led to keen interest in export of the Maritime seed. This raises the question of how well Atlantic Canadian European oysters can be expected to perform in Bonamia-enzootic waters. Collaborative research with Dr. Bruce Barber and his PhD student, Ryan Carnegie, University of Maine, and with Dr. Tristan Renault, IFREMER, France, is currently underway. This involves exposure of uninfected Canadian stock to infected oysters in Maine and France, as well as purified parasite. Maritime European oysters are also being used to study new diagnostic tools developed to detect B. ostreae. As with Malpeque

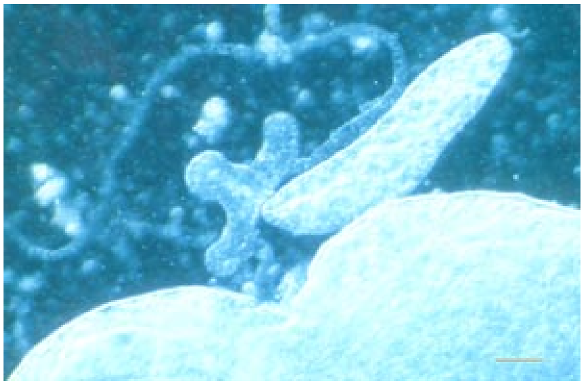

Figure 7: Whole mount of Prosorhynchus squamatus *cercaria showing characteristic tri-lobed tail. Phase contrast. Scale bar = 25 μm.*

disease, sub-clinical carriers of B. ostreae are extremely difficult to identify using routine diagnostics (histology and blood smears). This complicates identification of negative control oysters in enzootic areas and makes historically uninfected populations, like those in Atlantic Canada, attractive for testing the specificity and sensitivity of these new diagnostic tools.

Digenean infections of blue mussels: In 1997 a high prevalence of a larval digenean (Platyhelminthes), Prosorhynchus squamatus, was found in blue mussels (Mytilus edulis) at a single site in Nova Scotia (Figure 6). This was the first confirmed observation of this parasite in mussels from Atlantic Canada (McGladdery and Stephenson, 1997[2]), since previous observations were solely from tissue sections of single specimens from New Brunswick and the Magdalen Islands. Dissections of infected Nova Scotian mussels revealed the cercarial stage, with its characteristic tri-lobed tail (Matthews 1973) (Figure 7), confirming its identity as P. squamatous, a parasite previously described from M. edulis and M. galloprovincialis in northwestern Europe and Great Britain (Coustau et al. 1990). Although the earlier observations from Atlantic Canada were not associated with poor mussel health, the infected Nova Scotian mussels showed signs of weakness, shortened shelf-life and mortality. The parasite branches throughout the gonad and, eventually, spreads through the rest of the body. It's life-cycle and seasonal dynamics are being investigated in collaboration with the Aquaculture Association of Nova Scotia, mussel growers and provincial aquaculture biologists from Nova Scotia and Prince Edward Island, in order to determine why the parasite is so common at the affected site and whether or not it can spread to other mussel growing areas.

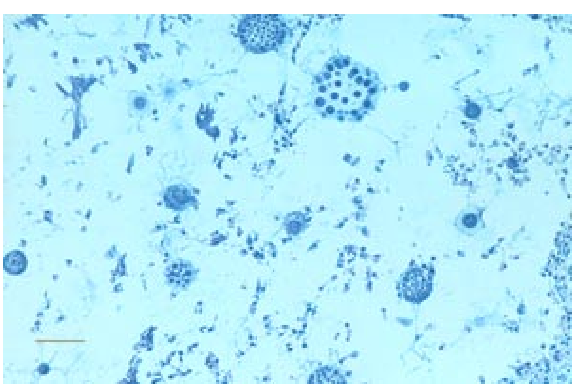

Figure 8: Light micrograph of QPX ("quahaug parasite X"; Chytrid-like fungus) infection of hard-shell clam (Mercenaria mercenaria) *tissues. Haematoxylin and eosin stain. Scale bar = 25 μm.*

"QPX" infection of hard-shell clams: QPX ("quahaug parasite unknown") is a fungal-like organism first described from hard-shell clams (= quahaugs), Mercenaria mercenaria, Drinnan and Henderson (1963) (Figure 8) suffering mortalities along the Gulf shore of NB. Since that time, QPX has not generally been a severe problem, except in some hatchery-held broodstock (Whyte et al. 1994). In contrast, QPX has caused mass mortalities of hard-shell clams in Massachusetts and Virginia (Smolowitz and Leavitt 1997, Calvo-Ragone et al. 1997). The reason for the difference in virulence of infection in Canadian and New England clams is not clear, but the dynamics of infection, including an apparent lack of infection in exposed juveniles, is being investigated by the doctoral student working on clam diseases (Bacon, pers. comm.). This work is being done in collaboration with the Ellerslie Shellfish Hatchery (PEI Department of Fisheries and Environment) and is of interest to the researchers at the Woods Hole Laboratory in Massachusetts and the NOAA-DNR laboratory in Oxford, MD, who are working on the Massachusetts and Virginia mortalities.

Pearl oyster diseases: Mass mortalities of cultured pearl oysters (Pinctada maxima and Pteria penguin), following transfer from collection grounds to grow-out sites in The Philippines, led the Bureau of Fisheries and Aquatic Research (BFAR) of the Philippines, to initiate a joint investigation of the problem with the GFC Shellfish Health Program (Reantaso and McGladdery 1997[3]). Increasing pressure on dwindling wild oyster populations had focused grower attention on finding out the causes of the mortalities and establishing mechanisms to monitor and improve the health of their stocks, especially since optimum pearl development requires a healthy oyster. Little work has been done on pearl oyster diseases (Pass et al.

[2] McGladdery, S.E.and Stephenson, M.F. *A parasite castrator of blue mussels, Mytilus edulis from Atlantic Canada*.- Atlantic Canadian Association of Parasitologists. - Fredericton, August 1997.

[3] Reantaso, M.B. and McGladdery, S.E. *Parasites, Pests and Disease of the Pearl Oyster Industry in The Philippines*. Atlantic Canadian Association of Parasitologists. - Fredericton, August 1997.

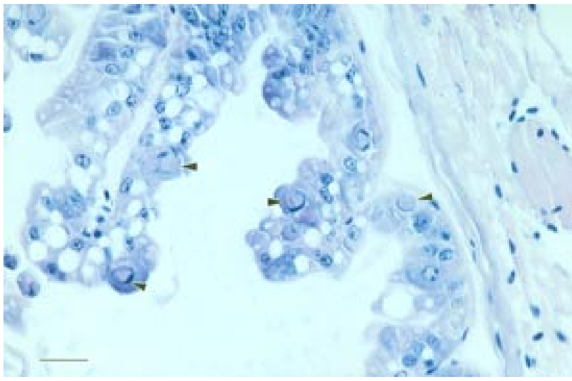

Figure 9: Light micrograph of hepatopancreal epithelium inclusion bodies (arrows) in sand shrimp (Crangon septemspinosa). *Haematoxylin and eosin stain. Scale bar = 25 µm.*

Figure 10: Gross examination of oyster (Crassostrea virginica) *for any external lesions which may have an effect on the internal soft tissues.*

1987, Norton et al. 1993), thus, initial involvement consisted of a base-line survey of the main pearl oyster species. On-site training in shellfish health assessment and sample collection was also provided to the personnel at several pearl farms. Advice was also provided to the personnel of the Fish Health Unit at BFAR on developing a shellfish health program, including diagnostic protocols, to service the pearl oyster industry. The material collected for this work was examined by Dr. M. Reantaso, BFAR, with Shellfish Health Program personnel at GFC in 1997, and will form the basis for a reference manual of normal and abnormal pathology in pearl oysters and other Philippine bivalves (Reantaso 1997).

Environmental Monitoring

In addition to studying mollusc diseases caused by infectious organisms, the Shellfish Health Program at GFC, also conducts research into environmental effects on the health of invertebrates (molluscs and crustaceans). Molluscs are particularly suited to such investigations due to their close physiological ties to the microbiotic and abiotic components of the sediment and water column. Two preliminary investigations have been completed to date, and it is hoped these will form a basis for continuation of this type of research.

Invertebrate Pathology Survey of Gulf of St. Lawrence Estuaries: A survey of the histopathology of sand shrimp (Crangon septemspinosa), mussels (Mytilus edulis) and rock crab (Cancer borealis) was conducted on samples collected from five estuaries in the Gulf of St. Lawrence. Three of the estuaries (Pictou, Miramichi and Restigouche) support Pulp Mill industrial activity and the other two (Margaree and Kouchibouguac) were negative controls. The work was conducted by Dr. J.P. Ochieng-Mitula, a histopathologist working with the Shellfish Health Program, in collaboration with Dr. S.C. Courtenay, head of the aquatic toxicology program of the Environmental Studies Division at GFC. Preliminary results found a wide diversity of parasites and diseases, some of which showed variation between the estuaries surveyed. The variations detected were not consistent, however, with some parasites and pathologies being higher in polluted estuaries, while others showed the opposite infection pattern. In addition, some tissue pathologies have multiple aetiologies, so the causative factor in one estuary could not be assumed to be the same as in another estuary. One interesting observation, however, was the presence of inclusion bodies in the hepatopancreal epithelia of some sand shrimp which resemble significant viral infections of cultured penaeid shrimps (Lightner and Redman 1992) (Figure 9). Since this is the first documented investigation of the histopathology of this shrimp species, further work is required to identify the inclusions, confirm the dynamics of the infections observed, and distinguish between general and specific histopathology (Ochieng-Mitula and McGladdery 1997a).

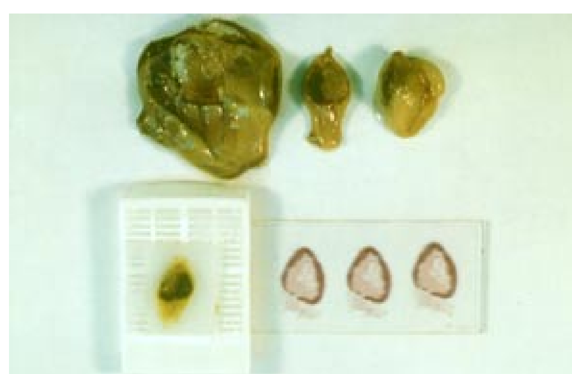

Figure 11: Specimen collection from American oyster (Crassostrea virginica) *tissues for light microscopy.*

Survey of Invertebrate Pathology and Peat Moss Spillage in the Richibucto River: Samples of sand shrimp and soft-shell clams were collected upstream, on site and downstream from a peat moss spill in Mill Creek, a branch of the Richibucto River. Preliminary observations of the histopathology showed many clams to be infected by intracellular bacteria (Rickettsiales), however, the infections were generally light and not considered to be of disease significance (Ochieng-Mitula and McGladdery 1997b). Kidney infections by a coccidian protistan and gonadal displacement by a digenean infection (similar to the one described above in mussels), were also detected, but again, without any distinct correlation to placement in the peat moss flume or to clam health. Nothing of disease significance was detected in the shrimp. As with the pulp mill effluent survey, more data is necessary, before any conclusions can be drawn.

Diagnostic Activities

The basis for many of the research activities described above has been the diagnostic service provided by the Shellfish Health Program to clients wishing to have the health of their bivalves examined. Reasons for diagnostic submissions vary from abnormal growth and mortalities to health checks prior to live transfer from one area to another. Over the last ten years, the number of diagnostic requests has increased from under twenty per year to over one hundred and this now constitutes a full-time responsibility of the Shellfish Health Program. As mentioned in the introduction, Atlantic Canada is blessed by having no major shellfish disease problems to work against, however, mortalities caused by sub-optimal environmental conditions are common and diagnostic services are required to distinguish such mortalities from those caused by infectious disease agents. For example, mortalities of oysters (C. virginica) in the spring are commonly associated with a poor fall plankton bloom. This results in low energy reserves when the oyster starts to overwinter. Since oysters in the Maritimes are at the northernmost boundary of their geographic range, they rely especially heavily on adequate energy reserves in order to survive the long winter. Summer mussel mortalities also appear to be linked to environmental-physiological-based health problems. For example, certain stocks of Magdalen Island mussels are particularly vulnerable to mortality when exposed to inadequate food resources after spawning (Myrand and Gaudreault 1995).

Disease-screening for introduction and transfers usually requires a minimum of sixty (60) individuals, in order to detect a single infection present at 5% prevalence in a population of over one million animals (Simon and Schill 1984). Sample size may be smaller, however, when the sample is from a limited number of animals, such as hatchery broodstock. Ideally, the molluscs are delivered live to the laboratory, or preserved on-site, to prevent post-mortem degeneration of the tissues. The whole animal is examined, including the shell, since any external damage can have a serious effect on the underlying soft-tissues. For example, chronic shell repair, in the form of blister or pearl formation (Figure 10), is energetically costly to the bivalve, so gametogenesis or soft-tissue defenses against otherwise benign infections may be impaired (McGladdery et al. 1993).

Most disease-screening requires histology (Figure 11), since few immunodiagnostic or nucleic-acid based diagnostic tools are currently available for molluscs, although they are under development (Bachère et al. 1995). In addition, there are no self-replicating cell-lines available for detecting molluscan viruses. This means disease diagnosis is time-consuming (the Shellfish Health Program generally provides a turn-around time on diagnostic cases of approximately three-four weeks) and requires a trained eye to identify significant pathogens and distinguish normal from abnormal lesions. Health examinations to meet conditions for transfer licenses have to be conducted by diagnosticians at GFC who are trained in molluscan histopathology. The Shellfish Health Program is aiming to expand this expertise through training shellfish health diagnosticians and it is hoped that Newfoundland will soon have their own molluscan histopathology unit to expedite transfer screening (Couturier, pers. comm.[4]). Since most cases are introduction and transfer requests, the reference material collected over the last ten years is currently being examined in an effort to map zones within which all mussels (M. edulis) or all oysters (C. virginica) have the same parasites, pests and diseases. The work on zonation is near completion and is aimed at providing a data-based justification for transfers which do, or do not, require health screening (McGladdery et al. in preparation).

Acknowledgments

Special thanks are due to the colleagues and growers, too numerous to mention individually, who have helped build the Shellfish Health Program at the Gulf Fisheries Centre into what it is today. With their support, shellfish health in Atlantic Canada has become an integral part of shell-

4 Cyr Couturier, Chair, Aquaculture Programs, School of Fisheries, Marine Institute, Memorial University of Newfoundland.

fish aquaculture development, and reflects a federal, provincial and industry collaboration for which we are truly grateful.

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ToC

Origin and Abundance of Southern Gulf of St. Lawrence Striped Bass: New Perspectives

Ron Bradford

Background

The anadromous striped bass (*Morone saxatilis* Order Perciformes; Family Percichthydae) has a natural range that extends from the Gulf of Mexico in the south northward to the St. Lawrence River estuary (Scott and Scott 1988). The Chesapeake Bay region of the eastern United States of America is generally regarded to be the center of their distribution and the region of highest abundance. There are two sites within the Maritimes Region where striped bass are known to spawn on a year to year basis, the Northwest Miramichi Estuary, southern Gulf of St. Lawrence, and the Shubenacadie River, inner Bay of Fundy (Figure 1). The two populations are genetically discrete (Wirgin et al. 1993) and both differ genetically from the Hudson River and Chesapeake Bay stocks (Wirgin et al. 1993).

Adult striped bass enter freshwater to spawn during the vernal spring. The upstream migration in the eastern Canadian rivers occurs during May-June and rarely extends far above the head of tide. Individual fish usually return to the sea within two weeks. Spawning appears to be triggered when water temperatures climb to 16-18 ^{0}C (Robichaud-LeBlanc et al. 1996). Eggs and milt are released directly into the water column where the fertilized eggs, being semi-buoyant, remain suspended for the duration of the incubation period. Free swimming, pelagic yolk-sac larvae hatch out after about 72 h. Yolk reserves are exhausted within about seven to 10 days after which the larvae forage on zooplankton within the estuary (Robichaud-LeBlanc et al. 1997). The transition from larva to juvenile occurs within about six weeks after which the young fish form schools and assume a more demersal mode of existence. Adult and juvenile striped bass can range several hundred kilometers beyond their natal rivers during the summer and autumn months, usually remaining within a few kilometers of the shore. Males reach maturity at about age three whereas females generally spawn for the first time at age four (Bradford and Chaput 1996).

Striped bass is a highly prized and economically valuable game fish along the eastern seaboard of the United States. Recreational angling fisheries for striped bass in eastern Canadian waters have remained poorly developed, a reflection in part of the uncertainty of the supply of fish available to capture from year to year. Trends in reported landings indicate that striped bass native to eastern Canada rivers have been prone to cycles of 'boom and bust'. The underlying causes of these cycles were never clearly elucidated, although environmental factors and fishing mortality were both considered to be contributing factors (Chaput and Randall 1990).

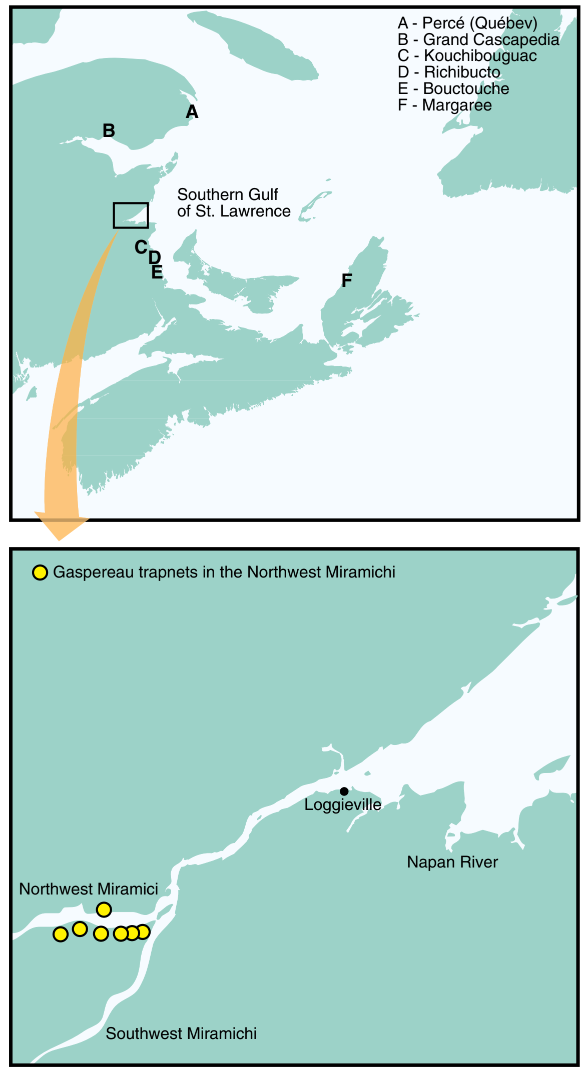

Figure 1. Map of Maritimes Region showing the location of place names used in the text and a detailed representation of the Northwest Miramichi River Estuary.

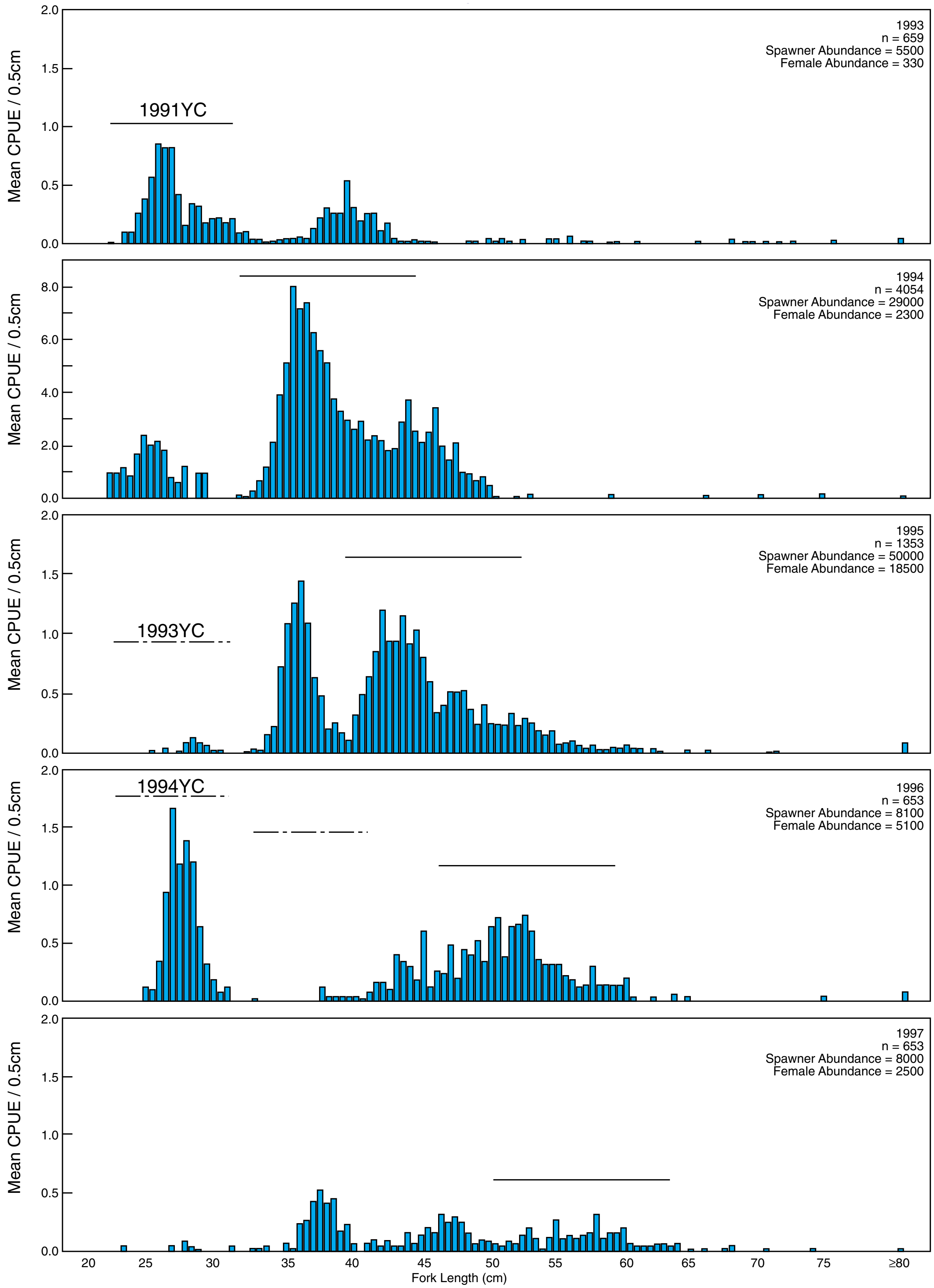

Figure 2. Length frequency distributions of adult striped bass on the Northwest Miramichi River Estuary for the years 1993 to 1997. Also shown are the sample sizes, estimates of spawner abundance, and the number of females represented in the population (YC =yearclass).

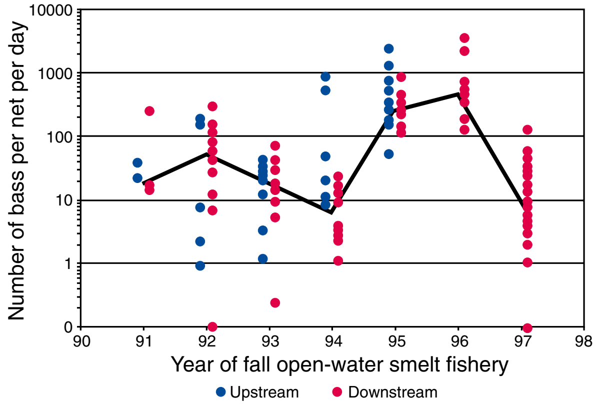

Figure 3. Catch per unit effort (fish per net per 24 h period) of young of the year striped bass in the open water smelt fishery of the Miramichi River at upstream and downstream locations, 1991 to 1997. Solid line is the annual geometric mean at the downstream sampling location. Individual points may represent several observations.

Conservation Management Plan

Concern for the long term viability of the resource arising from the absence of formal resource management and the suspected negative consequences of unregulated fishing (Chaput and Randall 1990) led to the development of a conservation management plan in 1993 (Dept. Of Fisheries and Oceans 1993). The major elements of the plan are:

- arrest the decline in abundance increase abundance
- and sustain abundance at levels corre spondent to supporting habitat.

The plan was fully implemented in March, 1996: sales of Canadian, wild-caught, striped bass are now illegal. Management is now in support of the development of recreational angling fisheries, which are anticipated to generate economic activity in excess of $10 million annually within New Brunswick alone (Loftus et al. 1993). Striped bass continue to serve the traditional food, social, and ceremonial needs of native Americans throughout the region (Perley 1852; Bradford and Chaput 1996).

A research program in support of the conservation management plan and recreational fisheries development was launched in the spring of 1993. The principle goals were to establish the protocols for calculating both adult abundance and recruitment, as well as the stock structure, migration patterns, and habitat requirements of striped bass in the southern Gulf of St. Lawrence (Figure 1). The major elements of this program and the results to date are summarized below.

Southern Gulf of St. Lawrence Striped Bass Project

The southern Gulf of St. Lawrence (southern Gulf) is the center of striped bass production within the Maritime Provinces (Chaput and Randall 1990). There, striped bass have been fished commercially since before Canadian Confederation (Perley 1857) with reported landings exceeding 40 t in some years (LeBlanc and Chaput 1991). Interestingly, relatively little fishing effort has ever directly targeted striped bass. Instead, fish intercepted as a bycatch in the inshore commercial fisheries were landed and sold (LeBlanc and Chaput 1991; Bradford et al. 1995). Early results from the research program indicated that striped bass bycatch from the gaspereau fishery during May-June could provide a basis for assessments of adult abundance and that the bycatch from the smelt fisheries during October-November could provide an indication of the abundance of juveniles produced from the spawning of the previous spring (Bradford et al. 1995). Furthermore, the gear types used in both fisheries hold the captured fish live until the nets are fished and the catch loaded onto the fishing vessel. Thus, striped bass can be sorted from the catch, sampled, and returned live to the water.

The Northwest Miramichi Estuary (Figure 1) was identified as the most likely site within the southern Gulf for obtaining reliable annual estimates of adult abundance while the fish were concentrated on the spawning grounds. First, interannually persistent high levels of adult bycatch in the gaspereau fishery during May-June were evident in the time series of reported landings of striped bass from the commercial fishery (LeBlanc and Chaput 1991). Second, biological sampling of the bycatch on the Northwest Miramichi Estuary demonstrated that the fish were in spawning condition (Bradford et al. 1995). Third, striped bass eggs and larvae are members of the planktonic community within the estuary at the same time that reproductively mature striped bass dominate the bycatch in the gaspereau fishery (Bradford et al. 1995; Robichaud-LeBlanc et al. 1996).

Mark-recapture experiments are used to estimate adult abundance. A sample population of adult fish are marked (with external, individually numbered tags inserted into the anterior dorsal fin) about one to two weeks prior to spawning. Each fish is also measured, examined externally to determine its sex, and a scale sample is extracted for age and growth studies. During the spawning season, the number of adult striped bass caught in the gaspereau traps are counted and the total

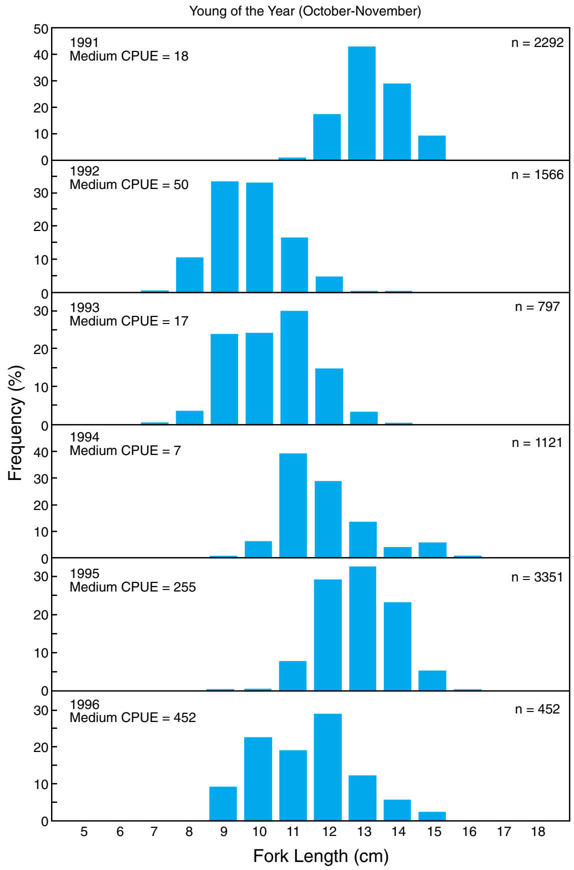

Figure 4. Length frequency distributions of young of the year striped bass in the open water smelt fishery of the Miramichi River for all locations, 1991 to 1996. The modal length is shaded (n =sample size).

number of recaptures noted. Thus by knowing the number of tags available, the number of recaptures, and the total number of striped bass in the sampled catch, one can estimate the total number of adult striped bass. Furthermore, the tag numbers for all recaptured fish are recorded before the fish are returned to the wild. Over a period of several years these data can resolve seasonal migrations, whether or not individual fish spawn every year, and the degree of fidelity that individual fish exhibit to the Miramichi estuary as a spawning location.

Range and Spawning Site Affinity

The known range of the Miramichi population encompasses the entire mainland portions of the southern Gulf of St. Lawrence. Recaptures have been reported from Percé, Québec and fish marked at DFO Science Traps on the Margaree, Nova Scotia (Figure 1) have been recaptured as spawners on the Northwest Miramichi. Multiple year recaptures indicate that Miramichi striped bass spawn every year from age 3 through to age seven, and all return to Northwest Miramichi estuary in subsequent years to spawn.

Spawner Abundance

Adult abundance estimates for the years 1993 to 1997 are shown on Figure 2 along with the corresponding length frequency distribution of the catch for that year. The dramatic 80% decline in adult abundance between the years 1995 and 1996 was nearly completely a consequence of the unregulated commercial fishing that occurred during this time (Bradford and Chaput 1997). This demonstrates how unregulated fishing has contributed to the characteristic cycle of 'boom and bust' for this population. Inspection of the adult size

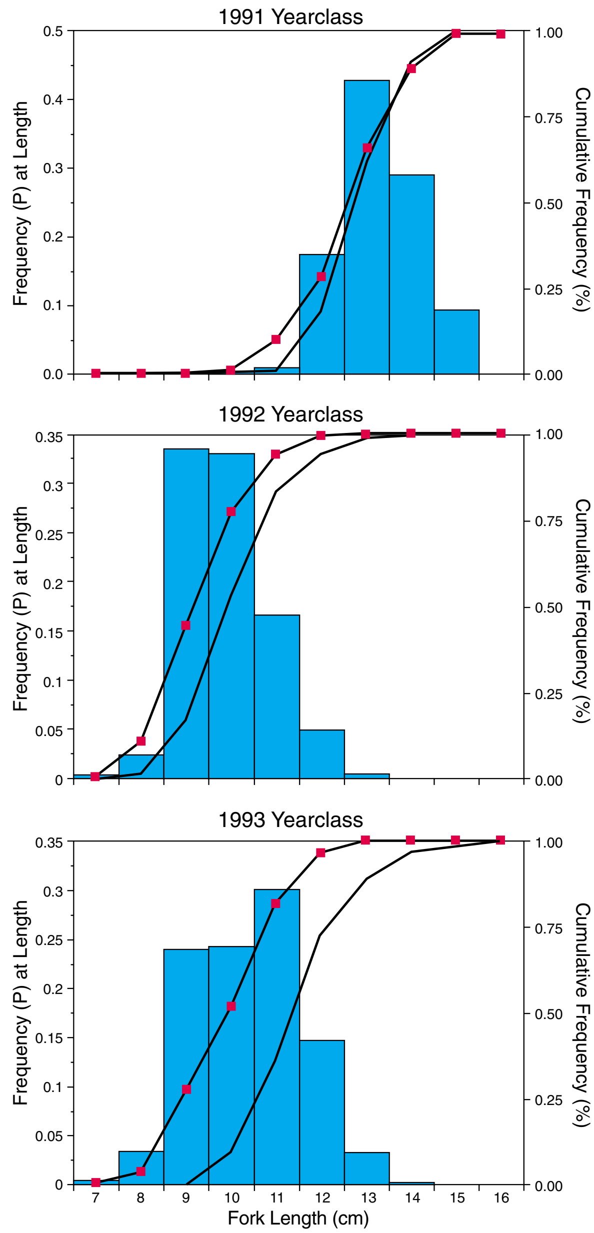

Figure 5. Length frequency histograms and cumulative frequency distibution (line and symbol) of observed prewinter lengths of young of the year striped bass on the Miramichi River, 1991 to 1993. The solid line with no symbol shows the cumulative length frequency of survivors to age 1 as estimated by back-calculation of length at age from scale annuli.

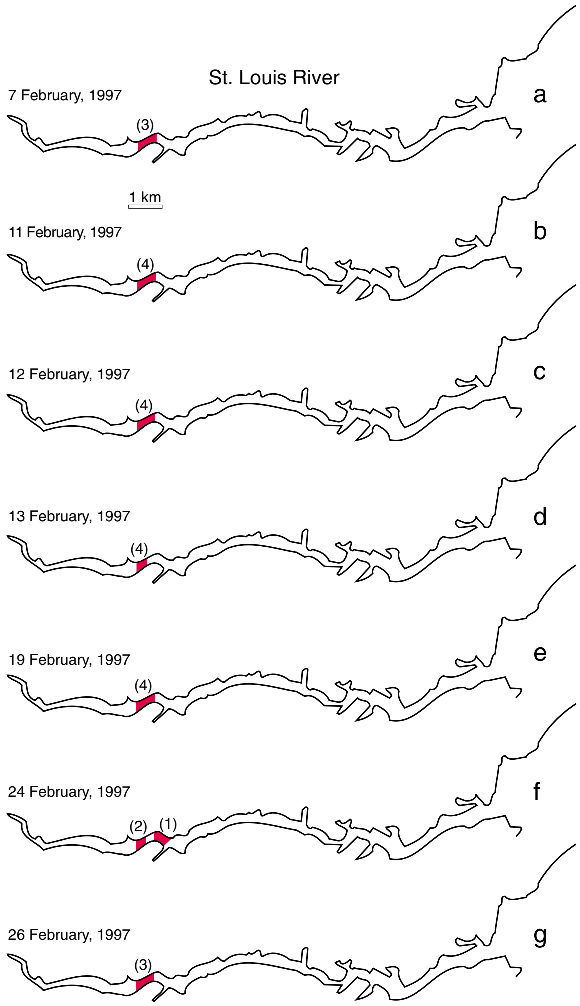

Figure 6. Spatial distribution (shaded portion) of striped bass tracked under the ice on the St. Louis River by day of sampling for the month of February, 1997. Numbers in parentheses represent the number of striped bass implanted with ultrasonic transmitters that were located on the day of sampling. The 1 km scale bar is shown.

distributions for each year shows that the 1991 yearclass that first recruited at age 3 (males only) in 1994 has remained the dominant component of the spawning population through to 1997 (Figure 2; fish smaller than ~32 cm Fork Length are age 2^+ and immature). One can also note that a yearclass failure occurred in 1993 with the result that recruitment to the adult population was negligible both by males at age 3 in 1996, and by females at age 4 in 1997 (Figure 2). This can be partially explained by the fact that <350 females spawned during the spring of 1993 (Figure 2) with the result that the production of young of the year was correspondingly low (Figure 3). In comparison, the highest juvenile abundance from the autumn smelt fishery occurred during the years when female abundance was higher than 5000 fish (years 1995 and 1996; Figure 3). However, studies on size at age indicate that additional factors can significantly influence recruitment, as explained below.

Environmental/Physiological Constraints on Juvenile Production

The Miramichi estuary represents the northern limit of spawning for striped bass (Bradford et al. 1995a; Rulifson and Dadswell 1995). Like most fishes that reproduce at the geographic extremes of their natural range, southern Gulf striped bass are highly susceptible to the vagaries of environmental factors that can influence growth. A striking feature of the juvenile populations of striped bass sampled from the southern Gulf is the variability among years in body size at the end of the first growth season. Figure 4 shows that median length can vary by up to three centimeters among years. It can also be noted that the strong 1991 yearclass although not highly abundant when compared to the other age classes was composed of relatively large bodied individuals (Figure 4). These observations indicate that there is a size-dependent component to survivorship for northern populations of striped bass.

Comparisons of the observed juvenile prewinter size distributions (Age 0^+) for the 1991, 1992, and 1993 yearclasses (the bycatch from the autumn Miramichi smelt fishery), with the length frequency of survivors to age 1 (estimated by back-calculating to length at age 1 from the annuli recorded in the body scales of the fish) shows (Figure 5) that striped bass need to be larger than about 10 cm Fork Length at the end of their first growth season in order for there to be a reasonable chance for survivorship through the first winter. The underlying mechanisms are not fully resolved at this time but seem to be a consequence of the fact that southern Gulf striped bass do not feed when water temperatures drop below 4 ^{0}C. Instead, energy stored as fats are utilized by the fish to sustain their metabolic obligations throughout the ensuing 4 months of winter. Under similar circumstances elsewhere and for other species of fish it has been shown that larger bodied fish have greater starvation endurance, and perhaps lower osmotic stress, and therefore higher survival through the first winter (Shuter and Post 1990).

Winter Habitat

Within the southern Gulf, striped bass return to freshwater habitats at the onset of winter conditions (Hogans and Melvin 1984; Hanson and Courtenay 1995; Rulifson and Dadswell 1995; Bradford and Chaput 1996), presumably to avoid lethal low marine temperatures. Site selection for overwintering appears to be opportunistic, and largely dependent on their geographic location at the onset of winter (Bradford and Chaput 1996), such that Miramichi-spawning fish do not necessarily return to the Miramichi before winter (Bradford et al. 1995a; Bradford and Chaput 1996).

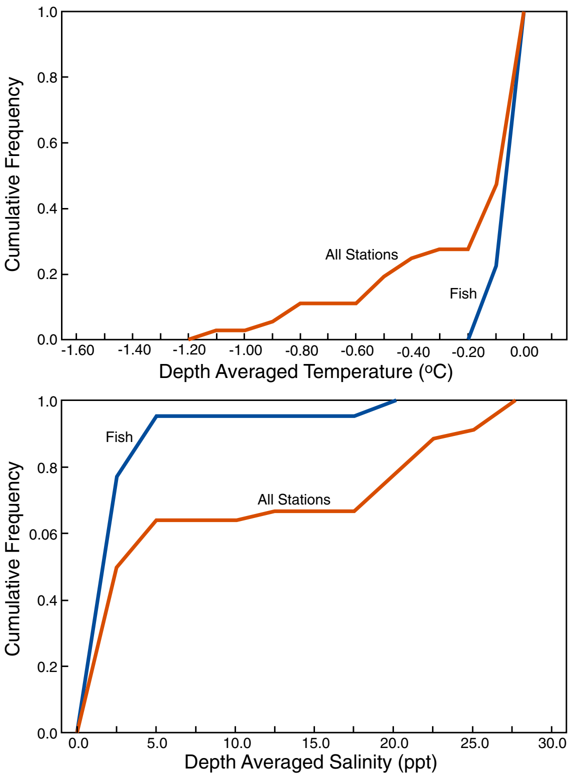

Figure 7. Cumulative ogives of depth averaged temperature and depth average salinity for all hydrographic stations sampled on the St. Louis River, January-March 1997 and for stations where striped bass implanted with ultrasonic transmitters were located.

Virtually all of the major rivers flowing to the southern Gulf of St. Lawrence harbour wintering populations of striped bass. This fact has been common knowledge throughout the region for well over a century (Perley 1852), and not surprisingly the winter aggregations of striped bass were fished for food and for income through to ice-out the following spring. The association between the hydrographic conditions in the estuary and the actual distribution of the wintering fish was not well understood and without this information it was impossible to determine if the sites where winter fishing occurred reflected the limits of the fishes winter distribution or simply sites where the fish were more susceptible to capture. Although commercial fishing is no longer allowed, this kind of knowledge has contemporary value in offering a basis to fine tune protective measures against poaching, and in assessments of the consequences of land- and sea-use practices on habitat viability. In order to address these issues 10 striped bass were implanted with ultrasonic transmitters and tracked under the ice on the Kouchibouguac and St. Louis Rivers of southeastern New Brunswick during the winter of 1996-1997.

The results offer a compelling analogy to the proverbial 'fish in a barrel'. The tracked fish were restricted to the less than 1 km of estuary that corresponded to the historical distributions of the winter fisheries. Hydrographic profiles of the estuary showed the fish to be aggregated within the salt-wedge of the estuaries (where the fresh water discharge from the rivers met the sea). The February distribution of striped bass on the St. Louis River is shown in Figure 6 by way of example. Figure 7 demonstrates the affinity of the wintering striped bass with the salt-wedge throughout the winter months.

Conclusions and Further Studies

The cumulative results to date from the continuing studies on the southern Gulf of St. Lawrence striped bass offer a rather stark reminder of how human activities, in the absence of a resource management framework, can detrimentally affect the natural cycle of fish populations. The constraints on removals of both juvenile and adult striped bass embedded within the conservation management plan must be viewed as a positive development for the long term. Natural factors are now more likely to define the dynamics of this population, and for the first time since Canadian Confederation. The extent to which human land- and sea-use practices impact on striped bass spawning, rearing, and wintering habitat will, however, bear further consideration.

The stock structure of the southern Gulf of St. Lawrence striped bass remains, perhaps, the most important unresolved component of the current resource management effort. The weight of accumulated evidence indicates that these fish comprise a single biological unit that spawns exclusively on the Northwest Miramichi Estuary. Eggs and larvae have not been found outside of the Miramichi River Estuary (Robinson et al. 1997; Bradford and Chaput 1998) and the mark-recapture data indicates that fish known to have spawned at least once on the Miramichi show no tendency to spawn elsewhere in the southern Gulf in subsequent years (R.G. Bradford, unpublished data). However, there is the possibility that the unregulated fishing practices of the past resulted in the extirpation of striped bass populations elsewhere in the southern Gulf. Extension of spawning activity in future years to estuaries beyond the Miramichi River cannot be discounted. If this were to occur the continued management of southern Gulf striped bass as a single biological unit would come into question. Thus, a means to identify quickly when a shift in spawning distribution has occurred would have tremendous value as a resource management tool. The usefulness of the mark-recapture experiment as a means to monitor change in the spawning distribution of striped bass in the southern Gulf is currently under evaluation.

Past and Current Partners

- Burnt Church First Nation
- Eel Ground First Nation
- Kouchibouguac National Park
- Miramichi River Environmental Assessment Committee
- Miramichi Watershed Management Committee
- New Brunswick Wildlife Federation
- Southeast Anglers Association

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ToC

Snow Crab: A Successful Fishery

Michael Chadwick and Mikio Moriyasu

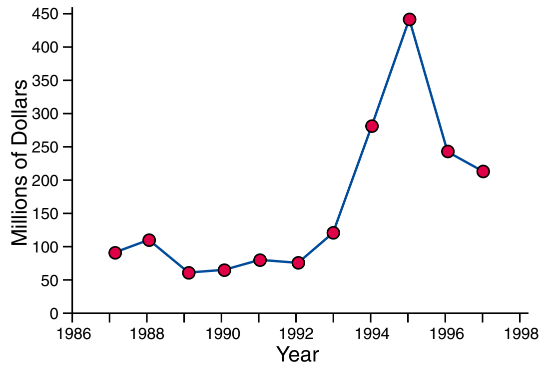


Figure :1 Landed value of eastern Canada snow crab fisheries, 1987-1997.

Introduction

Snow crab in the Maritimes Region is one of Canada's most successful fisheries. The four reasons for its success include: the high value, the excellence of the science program, the management targets are truly conservative or precautionary, and the consultation process is open and effective. We also briefly discuss the future of the fishery, which includes increasing fishing effort and a change in environmental conditions that could be unfavourable for snow crab.

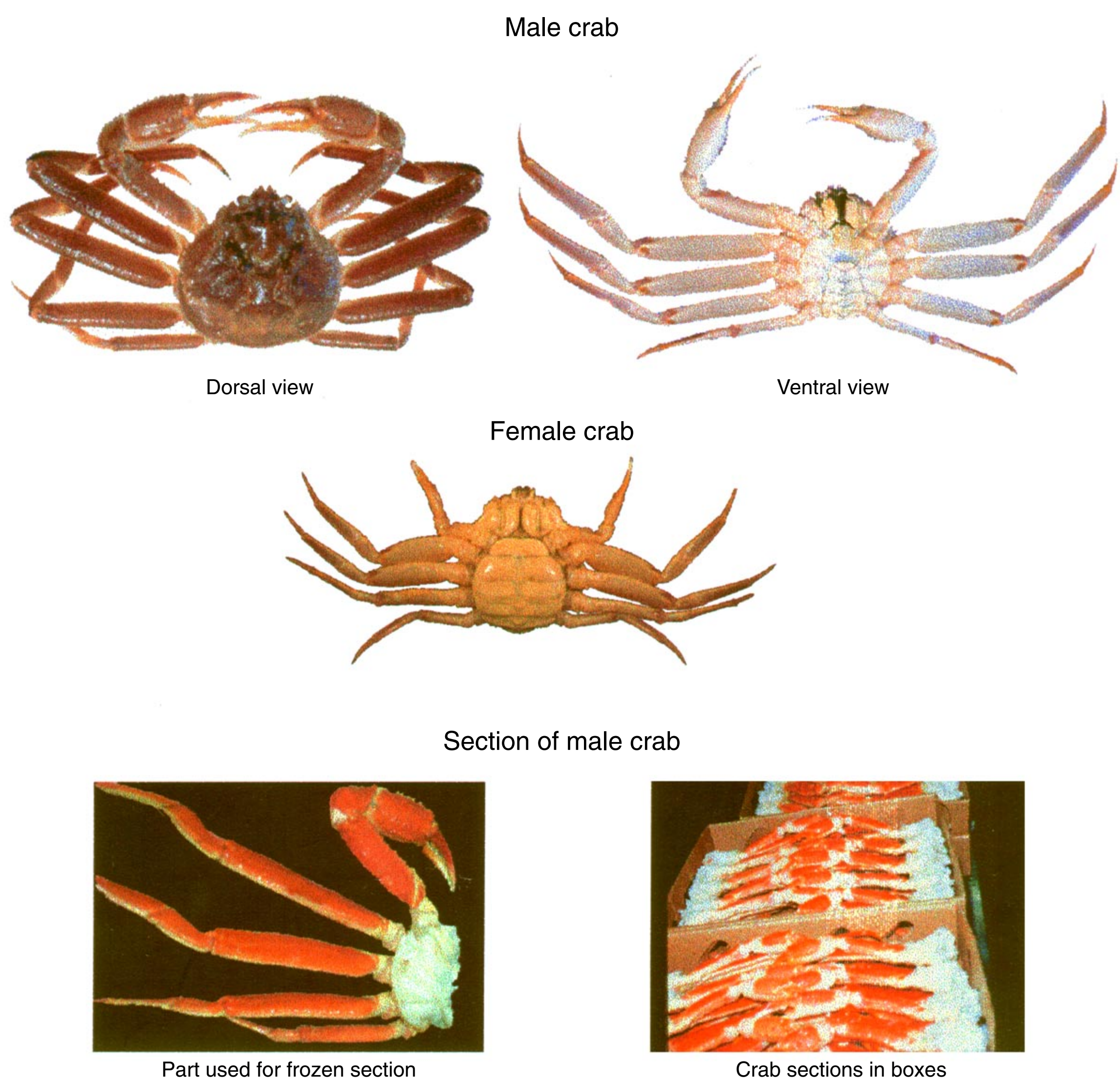


Figure 2: Male and female snow crab and the part used for frozen sections

The high value of snow crab

Landings of snow crab are worth about $200 million (Fig. 1). The sole market is Japan, where snow crab fetch a high price. Quality is the focus of this industry. The animals are caught in baited traps. Each licence in the southern Gulf has a limit of 50 to 150 traps. On average these traps catch about 50 kg of crab per haul. Only mature male crab larger than 95 mm carapace width are kept. Because the traps are carefully designed, there is almost no bycatch of non-target animals. Crab are held in refrigerated conditions until unloading at the plant several hours later. They are then cooked, cleaned, sorted by size, colour and shell condition, packed and frozen. Most crab in the southern Gulf are sold as sections (Fig. 2). The visual presentation of crab is as important as the quality of the meat. Japanese technicians are present at all times in the plants to ensure that only crab of the highest standard are shipped to Japan. Because of this focus on quality, the demand for snow crab has remained high, despite changes in the financial markets.

The excellence of the science

The science program has strived to visualize the state of the resource so that fishery managers and fishing industry are able to make informed decisions on the management of this species. Snow crab live on the bottom in fine sediment and don't move very much and are therefore easily caught by trawl gear. Before the fishery opens, the bottom is sampled at randomly-picked stations using a trawl that digs into the ocean bottom and is able to scoop crab out of the mud. The survey is designed using the same techniques as an opinion poll and is able to estimate the abundance of crab, for all sizes and sexes, including those of commercial size and those that will be of commercial size in the next year or two. Maps are drawn to show the location and density of these different types of crab (Fig. 3). Fishers use the maps to target mature males and to avoid areas that have a high percent of immature or softshell crab.

The design of the survey and the analytical techniques were developed by scientists working in the southern Gulf. The survey has been conducted in this area annually for nearly a decade. We know that the survey is reliable because we are able to follow changes in crab distributions from one year to the next (Fig. 4). The survey in the Gulf indicates that catch and effort data from the fishery are accurate because changes in commercial catch rates closely follow changes in stock biomass (Fig. 5). We have been able to follow the

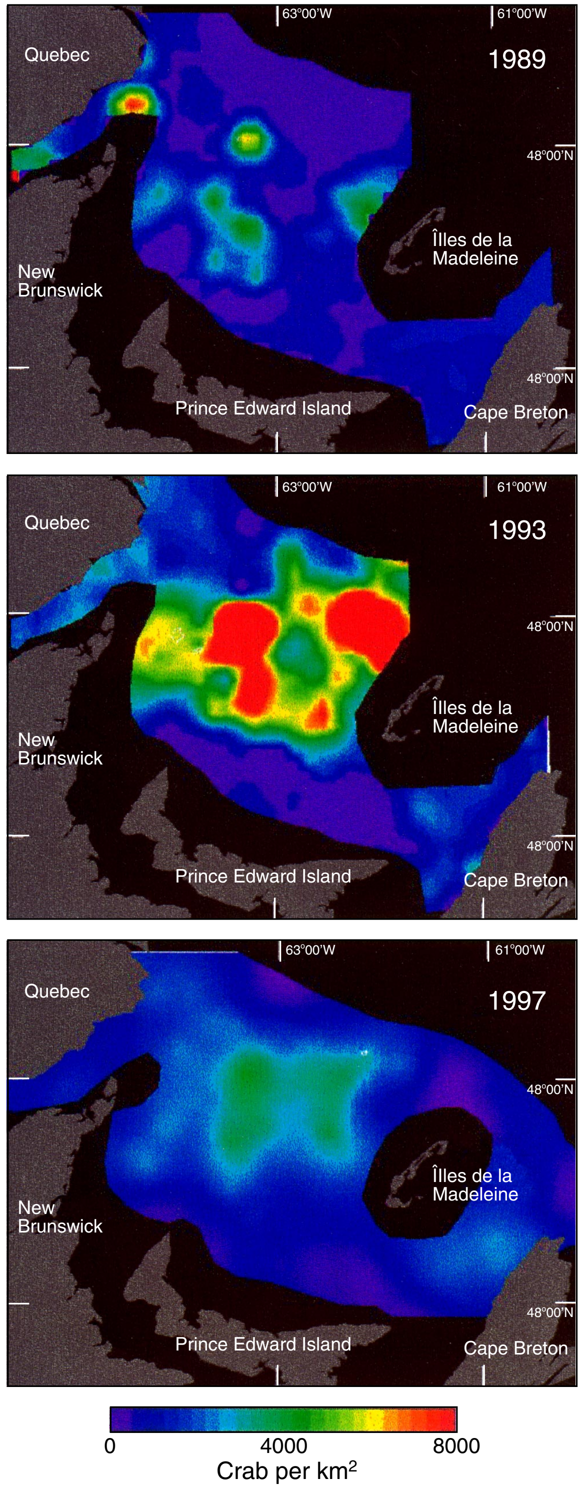


Figure 3: Density contours of exploitable adult snow crab (≥ 95 mm carapace width) for 1989, 1993 and 1997 trawl surveys.

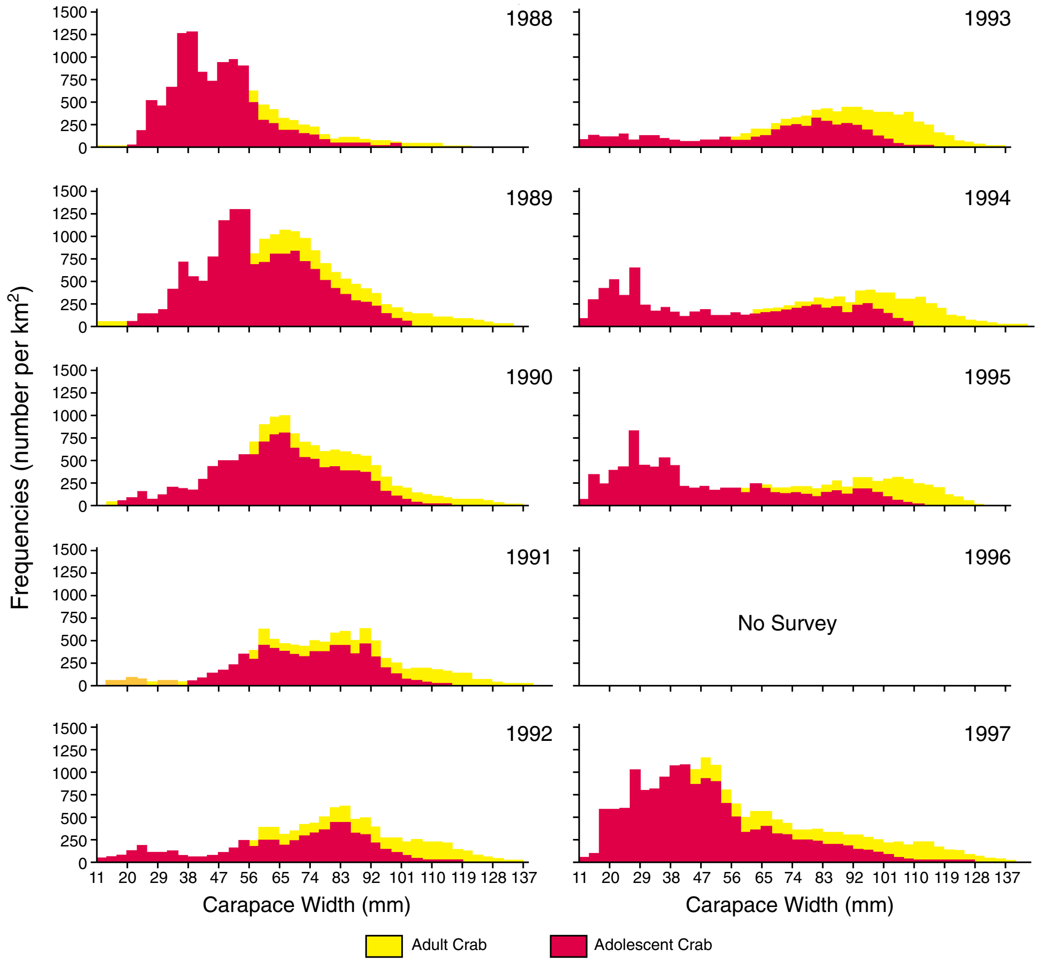


Figure 4: Size frequency distributions of male crab taken during the research surveys in southern Gulf (Area 12), 1988 to 1997.

growth of one complete generation of crab from when small dollar-sized crab were first seen in the survey to their recruitment into the fishery about six years later. We know that another wave of recruitment is about to enter the fishery in the next couple of years. Fishers find the maps are useful and feel that our assessments are reliable. The result is that industry pays for most of the science program.

Part of the success in the partnerhsip between industry and science is that the products are clear. These products include: contour maps of the abundance of females, white or soft-shelled males and hard-shelled males; estimates of exploitable biomass; prediction of future trends in biomass; analysis of in-season observer data; monitoring of white crab by fishing ground; and, analysis of logbooks for distribution of catch, effort and catch rates.

Stock	Landings tonnes 1997	DFO science budget (K)	Industry partnership (K)	Public meetings	Licences	Survey stations	Crab sampled	Sea samples
S. Gulf	17,750	190	500	14	228	220	25,000	17
S. Shelf	1,700	80	170	10	129	240	15,000	9
Total	19,450	270	670	24	357	460	40,000	26

Table 1: Information on the snow crab fishery and science program in the Maritimes Region

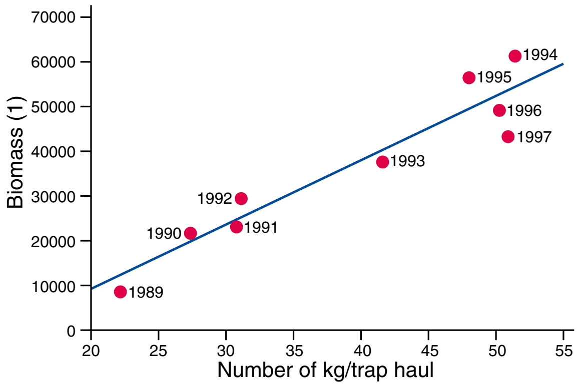


Figure 5: Commercial catch rate in the southwestern Gulf of St. Lawrence snow crab fishery compared to the biomass of exploitable crab in the research survey, 1989-1997. About 90% of the annual variation in catch rates can be explained by changes in biomass

Precautionary management

One of the most important reasons for the success of this fishery is the very clear management target. The number of tonnes of hard-shelled male crab, >95mm carapace width, is clearly identified before the season opens. The target is conservative because female crab are excluded from the fishery and male crab are sexually mature before they reach commercial size. The fishery is conservative because the gear is passive and highly selective, avoiding the unwanted types of crab. The fishery is conservative because it protects commercial-sized but immature crab, which will recruit into the fishery in subsequent years. It is also worth noting that the fishing season occurs when the yield of crab meat and the quality of the shell are at their highest value.

While science provides an estimate of the exploitable biomass, it is industry that decides on the appropriate exploitation rate. The role of industry in the management of this species has been the key to success. Exploitation rates are usually set at about 30%, which means that it would take three years to remove the harvestable biomass. But this value can change by fishing zone.

The true test of a fishery, however, is its performance relative to the management target. Since 1990, the snow crab fishery has achieved and not exceeded its target (Fig. 6), indicating that this fishery has been performing well, at least for the past decade.

An open consultation process

One of the most successful aspects of this fishery is the consultation process. It is no coincidence that comprehensive harvest plans and joint partnerhship agreements were first developed with the snow crab industry. These agreements between Department of Fisheries and Oceans (DFO) and industry define how the fishery will be managed, what science will be done and what criteria will be used for opening and closing fisheries. The framework has always been based on scientific evidence and open dialogue has been essential. During the past year there were 24 public meetings between science staff and the fishing industry. These meetings have included discussions of the survey, sampling, observer programs, and various aspects of the biology of snow crab.

One example of this consultation was a recent initiative to expand fishing effort in eastern Nova Scotia. A pilot survey indicated there were more crab in this area than we thought. Although the survey was preliminary, non-traditional fishers were interested in access. Science led the consultation process by insisting that all issues would be discussed openly around the table. It was decided that the current fishery could lay claim to the part of the sea bottom that had been historically fished. Not surprisingly, this area covered the extent of the pilot survey. The non-traditionals agreed to explore areas outside the traditional grounds. In this sense, snow crab has provided a model on how to set up new fisheries. The secret is to ensure that good information is freely available.

What about the future?

Snow crab like cold water; their preferred temperature ranges from 0 to 3 ßC. If waters on the ocean bottom warm up, snow crab could become less abundant. It is quite possible that cold weather during late 1980s and early 1990s allowed the distribution of snow crab to extend outward into the deeper channels of the Gulf of St. Lawrence and southward into the waters off eastern Nova Scotia. It is clear on the enclosed map that cold, bottom water was very extensive during the mid 1990s (Fig. 7). A return to normal and warmer conditions

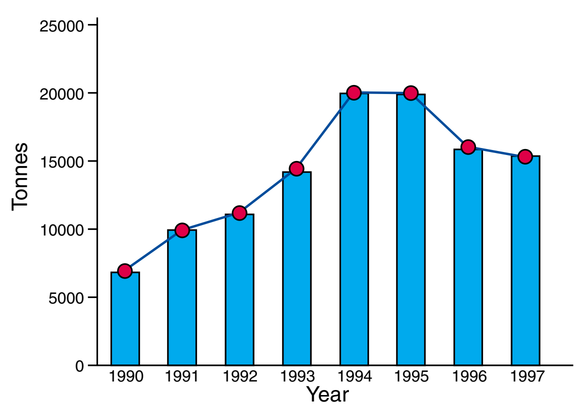
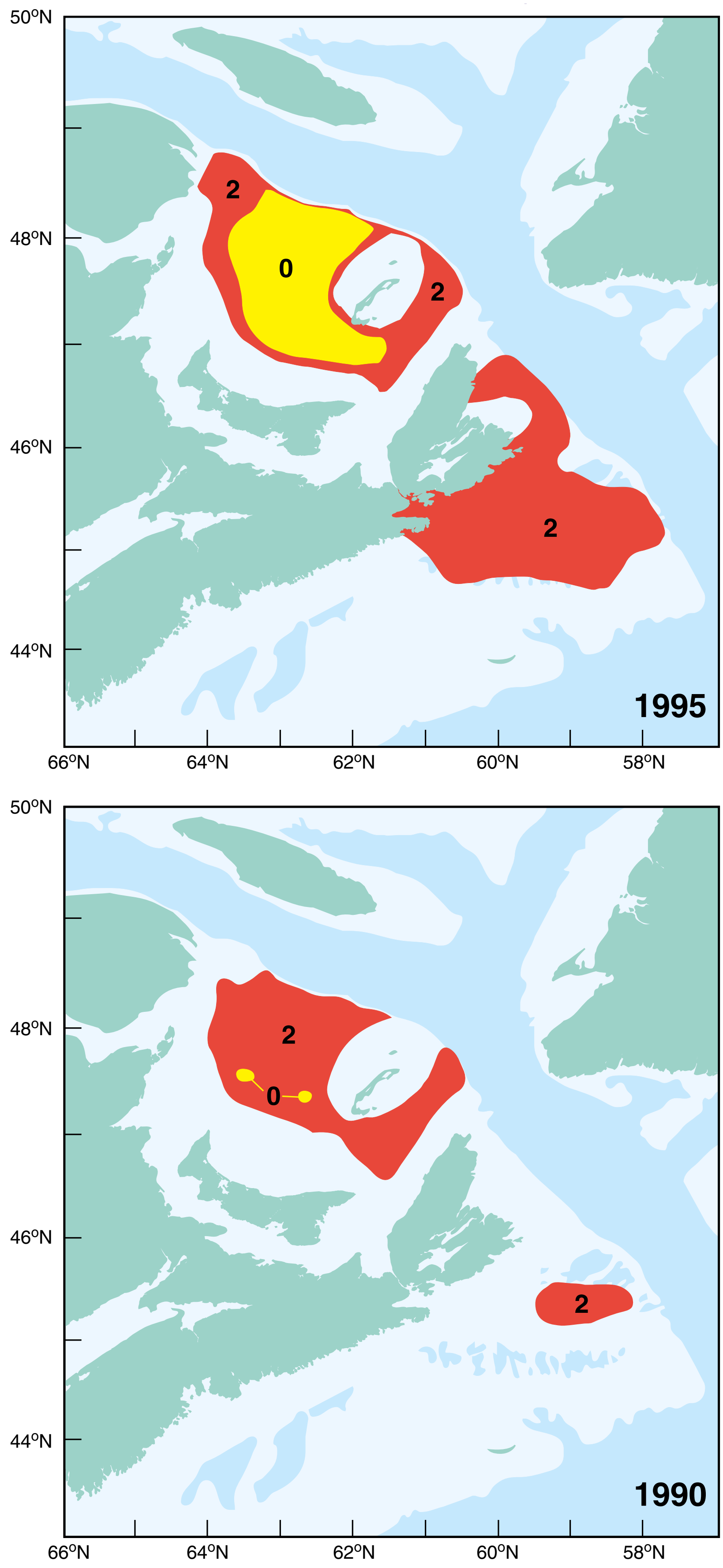


Figure 6: Landings of snow crab compared to the management target (total allowable catch - TAC) for the southern Gulf of St. lawrence, (Area 12).



could mark the end of this extended distribution. Because the waters off Cape Breton are at the southern limit of snow crab's range, the warm temperatures of the last three years may have an impact and the resource may not remain at the levels we see today.

In some ways the success of the science program has brought its own set of problems. The fishing industry has expectations that are greater than the ability of the small science group to deliver. In this light, we need to educate fishers on risks and uncertainties of the survey; we need to spend more time explaining the limitations of our surveys; and we need to link costs of science to the precision of our advice. It needs to be clear that more surveying results in better precision. One approach to increasing precision is to allow more participants in the collection and analysis of the advice. In this regard, we intend to train more people to do mapping and to include uncertainties with our survey maps. Finally, we intend to better publicize the success of this fishery and to show that scientific management of fisheries is not only possible, but is the way of the future.

Figure 7: The areal extent of the bottom waters less than 0°C (yellow) and less than 2°C (red) on the Magdalen Shallows and the northeastern Scotian Shelf during summer in 1990 and 1995. Note the much larger area of cold water in 1995.

Geoscience Research in Support of Offshore Energy Development

ToC

M. A. Williamson; R. Pickrill, and K.D. McAlpine

The development context

Eastern Canada is experiencing a sustained boom in hydrocarbon exploration and production activities. The most significant of these are the currently producing Hibernia Oil project and the Sable Offshore Energy (Gas) Project both of which lie in offshore waters under Canadian jurisdiction. Onshore, and non-traditional offshore basins have not been immune to these developments as witnessed by activities in western Newfoundland; Nova Scotia, and the offshore Gulf of St Lawrence and Sydney Basin regions. This interest in east coast energy investment opportunities is likely to be more sustainable than previous cycles as they are underpinned by capital intensive production activities. The multi-billion dollar price tag that accompanies the Hibernia and Sable project brings with it infrastructure developments which become key factors in the economic assessment of further resource developments.

The resurgence of industry interest in the east coast offshore as an attractive energy option did not arise overnight. It is founded on a rich history of exploration risk taking and assessment activity cycles played out over several decades. Throughout these cycles, the GSC Atlantic (GSCA) has played a significant supporting and facilitation role through the timely provision of both basic and applied geoscientific knowledge and information. Two examples will be used to illustrate how the GSC Atlantic, through its deliberate long term marine geoscience research strategy, is uniquely positioned to deliver a mix of highly relevant basic, and applied geoscience to an increasingly diverse client set. Currently in great demand, these diverse geoscientific products contribute greatly to the regions competitivenes with regard to other energy investment opportunities throughout the world.

Geoscience and Canada's offshore energy options

The Canadian Government promotes economically and environmentally sound decision making regarding Canada's energy options through its sustainable development policy. The GSC Atlantic's role over several decades has been to develop the comprehensive geoscientific context for east coast offshore energy options to act as the basis for such decision making.

There are two key geoscientific aspects to the economic and environmental assessment* of east coast offshore developments:

- estimation of the oil and gas prone nature of Canada's offshore sedimentary basins, and the likelihood that discovered and yet to be discovered reserves will be in sufficiently large volumes and producible at sufficiently high rates as to render them competitive with reserves discovered or predicted elsewhere.

- levels of understanding of the geological and engineering hazards and environmental implications of producing discovered reserves.

*Full assessment of the economic viability of offshore energy investment opportunities for commercial organizations, government regulators and policy makers is a complex process involving full cycle economic risk analysis, legal and regulatory analysis, detailed engineering cost analysis, and environmental impact studies etc.

Comprehensive and interlinked geoscientific knowledge of the complex land-ocean system is required to address these elements. Such complexities all but prohibit a meaningful short term approach to the gathering of the required knowledge which requires instead, a longer term, deliberate marine geoscience research strategy.

GSC Atlantic and offshore development

The GSC has undergone several phases of east coast marine geoscience research. In the 1960'S and 70'S, regional geophysical surveys including 2D observations of deep crustal structure (refraction seismology) coupled to mapping of the earth's magnetic and gravity fields defined the broad geological and basinal framework of the east coast margin. This was accompanied by the examination of basin sediment fill using sedimentological, paleontological, and seismic reflection techniques. Concurrently, a systematic surficial mapping program was underway developing sub-sea, high resolution geophysical survey technologies used in conjunction with extensive direct sampling and coring. Although much of this work was discipline specific and observational in emphasis, it provided baseline data required for both the investigation of deep crustal and basin structures and the shallower, present day sedimentary environments. Throughout the 1970's and 80's, GSCA scientists were able to devise and present innovative models of continental margin evolution which drew international acclaim.

The disciplinary nature of this type of research evolved during the late 1980's and 1990's into what is now generally termed Earth System Science which essentially recognises the connection between many key earth or basin processes. Although this inter-connectedness has long been recognized, there has been a tendency for the multidisciplinary integration required for significant gains in understanding Earth Systems to take place after the fact ie. after the geophysisist, the chemist, the geologist etc. had developed their scientific models. Earth System Science basically seeks interaction/ integration throughout the formulation of earth models.

In the context of the Earth System Science, oil and gas distribution within a sedimentary basin is a consequence of the interplay among many different geological processes. Understanding this interplay begins with the examination and formulation of mechanisms of basin formation which are considered within the general framework of plate tectonics and mantle convection. Such basins form as surface depressions, which then receive sediments due to the creation of topographic and/or bathymetric gradients. The mode and tempo of deposition of sediments into these basins is related to the interplay between tectonics and eustacy. Each basin has a distinct thermal history or fingerprint which is related to the mechanism of its origin. This thermal influence on a basins sediment fill can be traced through independantly observed proxies for past temperature conditions such as vitrinite reflectence, fluid inclusions and fission track data. This in turn helps determine the time temperature history of source rocks which, based on their contained organic matter chemistry, determines the time and rate of hydrocarbon generation, expulsion and migration. Basin thermal history and structuration also influences other water-rock interactions such as diagenesis which has a key role in reservoir producibility and storage capacity.

Observation and understanding present day sedimentological processes is a key element in establishing a comprehensive, sound position regarding the geological and geo-environmental consequences of offshore development. Within Earth System Science, understanding these processes requires not only the quantification of the physics of sediment movement and failure but also includes biotic and other influences. Many of the processes responsible for deposition of source and reservoir rocks preserved in the deep in the sedimentary record are in operation at the present day which means that a comprehensive understanding of modern day sedimentological processes and inter relationships is also a key element in understanding the observed rock record.

This high degree of inter-connectedness demands well integrated, multi-disciplinary research. Such efforts have allowed the GSCA to uniquely position itself to provide the essential geoscience context within which some of the more short term demands/needs of our industry and other clients can be met.

Two examples which serve to illustrate this include our efforts to:

- quantify the role faults play as barriers, seals and conduits to fluid movement within sedimentary basins.
- develop an understanding of modern sedimetation dynamics active on offshore banks offshore Eastern Canada.

Faults as barriers, conduits and/or seals

Faults are fractures in the earths crust often with vertical and or lateral offset, and are a key structural feature of both the Jeanne dArc and Sable offshore basins. They occur on many scales from tens of metres (and less) to tens of kms in length. Preserving evidence of past and present stress distributions, faults have been shown to provide efficient conduits to fluid movement, including hydrocarbons, in the sub-surface. Paradoxically, under some circumstances faults, can also act as effective seals and/or barriers to such fluids. In some cases, faults behave as barriers throughout part of their development and as conduits at other times. Regional understanding of the dynamic behaviour and fluid transmissive history of faults therefore is important not only in understanding the structural evolution of basins but also for their influence on hydrocarbon distribution. GSCA studies initially addressed the structural and basin forming role of faults. However, in order to fully understand their influence on hydrocarbon distributions, more detail on the geometrical relationships between faults and sediments was required. Such detail is only available from industry 3D seismic data to which GSCA has been given access through numerous collaborations with petroleum exploration companies. These studies have allowed a greater appreciation of the control faults have had on oil and gas distribution throughout east coast sedimentary basins. Furthermore, at the individual petroleum accumulation level, understanding fluid transmissive capacities of faults is vitally important to reservoir production predictions that companies need to make, which in turn is one of the key geoscientific elements in the economic assessment equation described earlier. So, GSCA fault studies have been driven by a long term need to gain a regional understanding of basin structure and petroleum migration within offshore basins. This has provided the essential context whereby the more detailed short term need of petroleum companies, specifically the role of faults on petroleum pool depletion rates, is being partly satisfied .

Sable Island Bank and Sediment dynamics

The seabed around Sable Island is known for its "shifting sands". This takes place largely during severe winter storms and late summer hurricanes. The sand motion reworks the seabed into large, mobile bedforms called sand ridges. Sable Island Bank has for many years provided GSCA with a natural laboratory for studies of the creation and migration rate of these sand ridges and the depth of seabed reworking. Such modern sedimentation process and seabed stability studies are key to engineering designs for scour protection of sea bed installations and pipelines, and to the evaluation of the environmental impact of drill waste dispersal. Through its expertise in observing and understanding modern sediment dynamics the GSCA has been able to contribute significantly to the design of the gas pipeline from the Venture discovery to landfall. Systematic measurements using swath bathymetry in association with detailed seabed observations using the GSCA benthic lander RALPH provided the data which contributed to pipeline designs.

Scouring of seabed installations can be significanted and has led to rig settlement. This takes place during storms when waves, tides and wind-driven currents operate energetically together. Years of repetitive deployment of seabed instrumentation throughout the winter season has allowed the development of predictive numerical models which are being used by industry for engineering design, by universities for research, and by government for regulation. Recently, GSCA has been approached by the Sable Offshore Energy Project to instrument the production platform at Thebaud to monitor seabed scouring during storms. The purpose of this is to provide baseline data on scouring that may be applied to rigs worldwide.

The modern day stratigraphy of surface sediments on Sable Island Bank also provide valuable information to oil and gas development agencies. High resolution seismic surveys, large box cores and surficial cores have shown the evolution of the Bank over the last 10,000 years and extends data collected within decades to the perspective of centuries and millenia. Such data is vital to the definition of geohazards such as gas escape and liquifaction. One example is the discovery of gas escape and associated liquifaction of the seabed on Sable Island Bank. Such events have caused rigs in the Gulf of Mexico to topple.

Long term research on modern sediment dynamics therefore has equipped the GSCA with the necessary expertise, experience and baseline knowledge set to provide for the short term needs of the petroleum industry and regulators as they consider and mitigate the environmental and geohazard consequences of offshore development.

Summary

- The Petroleum Industry has returned to Canada's east coast in a substantive manner.
- Comprehensive geoscientific knowledge is a key element in the economic and environmental assessment of offshore energy investment options.
- Short term geoscience needs for offshore development issues can only be satisfied on the basis of an adequate, regional geoscientific context.
- The time scale required to acquire and disseminate such a geoscientific knowledge infrastructure is substantially longer than that upon which energy investment opportunities and assessments are made.
- The GSC Atlantic, through its long term marine geoscience research program, is uniquely positioned to serve both the short and long term needs of the petroleum industry and those tasked with regulatory assessments.

Research on the Dispersion of Sea Louse Pesticides in the Marine Environment

ToC

F. Page, B. Chang, W. Ernst, G. Julien, and R. Losier

Introduction

Commercial culture of the Atlantic salmon (Salmo salar) began in Atlantic Canada in 1979. Since then, the industry has grown exponentially so that it is now worth well over $100 million. The majority of the industry is located in the Quoddy Region of southwestern New Brunswick (see Fig. 1).

In recent years, the industry has experienced outbreaks of an external copepodid parasite, the salmon louse Lepeophtheirus salmonis. This parasite occurs naturally on wild salmon and, until recently, occurred in only low numbers on farmed salmon in southwestern New Brunswick (MacKinnon 1997). In the fall of 1994, an outbreak of L. salmonis occurred among New Brunswick farmed salmon (Hogans 1995) and in 1996, the New Brunswick salmon industry experienced for the first time outbreaks of Infectious Salmon Anemia (ISA), a viral disease believed to be transmitted, in part, by sea lice (Nylund et al. 1993). Together, these outbreaks have cost the industry tens of millions of dollars in lost revenue.

Chemical treatments are, and will likely continue to be, necessary to control sea lice for the foreseeable future. Currently, the only permitted chemical treatment in Canada is the organophosphate azamethiphos (Salmosan®), which has had temporary registration in Canada since 1995. The industry has also requested registration of Excis® (1% cypermethrin), which has an Investigational New Animal Drug (INAD) exemption for use in the State of Maine from 1995 through 1999, and has been used extensively in fish farms on the Maine side of Passamaquoddy Bay.

Unfortunately, these chemicals can be toxic to non-target marine organisms, including commercially valuable crustaceans such as lobster, and to other marine crustaceans that may be important

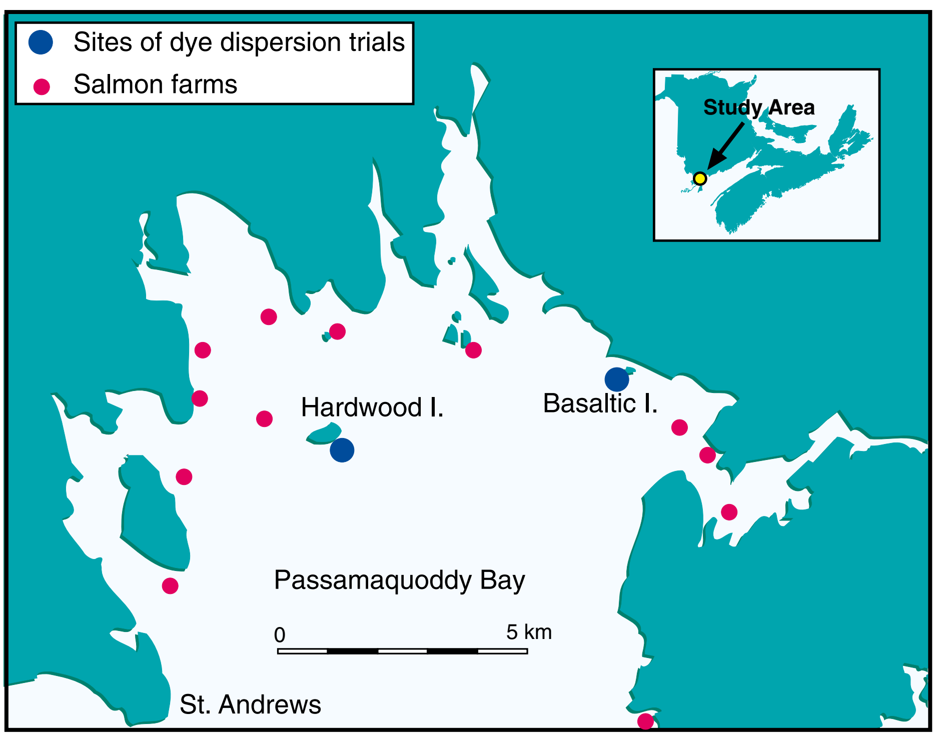


Figure 1: Map showing sites of Hardwood Island and Basaltic Island dye dispersion trials in Passamaquoddy Bay, southwestern New Brunswick, September 1997. Salmon farms are also shown.

to the coastal ecosystem. It was recognized that very little was known about the dispersal of sea louse pesticides; the exposure histories that non-target organisms might likely experience; and the toxicity consequences of experiencing particular exposures. Given these concerns, a multi-disciplinary and multi-partner research program was initiated to help fill some of these knowledge gaps, in part to assist the Pest Management Regulatory Agency in the registration process for these chemicals. The program consisted of dispersal and toxicity studies conducted by researchers from Fisheries and Oceans Canada and Environment Canada, in collaboration with the New Brunswick Salmon Growers' Association. Aspects of the dispersal studies are described below.

The dispersal studies consisted of four main activities:

1. a series of dye and chemical releases;
2. a series of drifter releases made in the vicinity of selected fish farms;
3. a series of current meter moorings; and
4. the development of three dimensional circulation, advection-diffusion, and particle tracking models.

The purpose of the dye and chemical releases was to quantify empirically the rate of pesticide dispersal and dilution in areas typical of those occupied by fish farms, to use these data in conjunction with toxicity data to help assess the impact of the chemicals on non-target organisms, and to provide data for validation of the circulation and advection-diffusion models. The purpose of the drifter releases was to determine the direction and extent of the surface drift from half a dozen fish farms during the first few hours after a pesticide release and to provide drifter trajectories for validation of the circulation and particle tracking models. The current meter deployments provided information on current speed and direction throughout the tracking period at each study site and at 20 fish farms throughout the area. This enabled the dye release sites to be compared to actual fish farm sites. The models are being developed to allow extrapolation and prediction throughout the southwestern New Brunswick area. This report deals only with data from the dye releases. The analyses reported are preliminary and are in the process of being refined.

Methods

In the fall of 1996 and 1997, six dye release trials were conducted in nearshore waters of the Quoddy Region of southwestern New Brunswick. In this report we provide information from the two most complete trials, conducted in Passamaquoddy Bay in 1997 (Table 1). During each trial a circular salmon sea pen (16 m diameter), with no net attached, was moored offshore of the intertidal zone. The locations were chosen to meet the criteria specified in the licence, issued by the Province of New Brunswick, permitting the release of the dye solutions. The criteria included the provisions that the dye release could not be conducted within 1 km of an existing fish farm and that the dye solution should not drift into the space occupied by an existing fish farm within a few hours of release.

Once the cage was moored, an InterOcean S4 current meter was moored several hundred meters away from the cage. A tarpaulin, typical of those used for sea louse pesticide treatments, was manually stretched across the inside of the cage. The tarpaulin was then allowed to fill with seawater to a depth of approximately 1 m and secured to the cage frame.

A solution of Rhodamine WT dye (10 kg active dye per trial), methanol, and cypermethrin was introduced into the enclosed water. A stream of air bubbles, generated by pumping air through a commercial air stone, was used to induce water movement and mix the dye solution throughout the enclosed volume of water.

After approximately 1 h, the duration of a typical commercial application of sea louse pesticide, the sides of the tarpaulin were released, and the dye began to advect out of the cage and disperse. Within about 30 minutes of the dye release, 5-10 GPS drifters were deployed into the dye patch and were tracked throughout the duration of the dye experiment. The horizontal and vertical extents of

Date	Location	Depth (m)	Release time (ADT)	Tide (ADT)
10 September 1997	Hardwood Island	18.2	13:05	13:00 low
11 September 1997	Basaltic (McDougalls) Island	7.3	13:12	14:00 low

Table 1: Two dye release trials conducted in Passamaquoddy Bay, southwestern New Brunswick, 1997.

the dye patch were surveyed regularly using a submersible pump, hose and fluorometer system deployed from the CCGC Pandalus III, a 12.8 m research vessel. Water samples were taken at frequent intervals for laboratory analyses of dye and chemical concentration and for use in toxicity experiments. Vertical profiles of water temperature and salinity were also taken during each trial. A Canadian Coast Guard helicopter was used to take aerial photographs at several time periods during these two trials.

We estimated the horizontal dimensions of the patches from aerial photographs and from the fluorescence data. The dye patches began as circles and elongated into ellipses. For the aerial photographs, the lengths of the major and minor axes of the ellipses were estimated using the overall length of a vessel, or the diameter of a fish pen, appearing within each photograph as a length scale. For the fluorescence data, the vessel path and fluorescence readings were used to divide the total data record (for each trial) into spatially and temporally separate patches. Patch dimensions were then estimated as the maximum distances along the major and minor axes between points having dye readings of 1% or more of the maximum post-release readings (Elliott et al. 1997).

The area of the patch (A) was then calculated as

$$A = \pi \bullet a \bullet b \qquad (1)$$

where 2•a and 2•b were the lengths of the major and minor axes of the patch. The radius (R_e) of a circle with equivalent area can then be calculated as

$$R_e = \sqrt{\frac{A}{\pi}} \qquad (2)$$

The rate of change in size of a dispersing patch of neutrally buoyant substance instantaneously released into the marine environment has been estimated to be within an order of magnitude of that predicted by the empirical relationship developed by Okubo (1971, 1974). Okubo's relationship relates s_{rc}^2, the horizontal variance of concentration in the elliptical dye patch, to the time (t) after release (eq. 3)

$$\sigma_{rc}^2 = c_1\ ?\varepsilon\ ?t^3 \qquad (3)$$

where $c_1e = 2.5 \bullet 10^{-5}$ cm^2 sec^{-3} (117 m^2h^{-3}) for time scales of about 1-12 h and length scales of about 100-1000 m (Okubo 1974).

The Okubo relationship is based on dye releases conducted in offshore areas. Elliott et al. (1997) compared the Okubo relationship to dye release data compiled from releases conducted within a few hundred meters of the shoreline in areas off Ireland and showed that the Okubo relationship provided a reasonable order of magnitude estimate of dispersal in at least these nearshore areas. In this study, we compared the Okubo relationship with the dye dispersal at our nearshore sites.

Elliott et al. (1997) found that the length scales (diameters) of a patch (whose outline was defined by the locations at which the dye concentration had fallen to 1% of the peak value) represented 4s, where s was the standard deviation of the dye concentration profile in the selected direction. This means that we can estimate Okubo's s_{rc} as

$$\sigma_{rc} \smile \frac{R_e}{2} \qquad (4)$$

When the initial patch size is non-zero, as in the case of dye released from a fish cage, equation (3) can be modified as follows

$$\sigma_{rc}^{=} c_1\ \varepsilon\ ?(to + t)^3 \qquad (5)$$

where *to* is the calculated time at which s_{rc}^2 equals the initial patch size (i.e. the cage area), which is given by $\sigma_{rc} = r_0/2$, where r_0 is the radius of the cage (8 m in our study) and

$$R_e = 3\sqrt{\sigma_{rc}^2 / c_1\ \varepsilon} \qquad (6)$$

If the patch size vs. time data agreed well with the Okubo relationship, we also wished to compare the temporal decay in dye concentration, as measured by the fluorescence data, with values predicted by the Okubo relationship. We assumed that the dye was homogeneously mixed within a cylinder with area equal to that of the patch and a constant depth representative of the observed depth of dye mixing. To calculate the predicted dye concentrations, the initial amount of dye (10 kg in each trial) was divided by the patch volume, which was estimated using patch areas estimated by the Okubo relationship and a constant depth estimated from vertical dye profiles. These predicted values were compared to the observed values for mean dye concentrations for each patch, calculated as the mean of all fluorescence readings taken within each patch (mostly near surface readings).

Figure 2: Aerial photograph of the Hardwood Island dye release (10 September 1997) approximately 30 min after release.

Results

Dye Patch Size vs. Time

In the Hardwood Island trial, the dye was released at the onset of flood tide. Initially, the dye moved and dispersed very slowly (see Fig. 2). The dye then began moving slowly in a north-easterly direction, and shortly after 2 h, the plume moved around the eastern tip of Hardwood Island. The plume then continued moving and dispersing in a northerly direction.

In the Basaltic Island trial, the dye was also released at the onset of flood tide. As in the Hardwood Island trial, the dye initially moved and dispersed very slowly. It then began moving and dispersing slowly northward past the western tip of Basaltic Island. Within 1.5 h, the plume had extended to the mouth of the channel between the island and the mainland. The dye then began moving eastward into the channel.

The relationships between observed patch size and time for Hardwood and Basaltic Islands are shown in Fig. 3 along with values predicted by the Okubo (1974) relationship. As indicated by the plots, the temporal increase in the observed scale of the dye patches agrees reasonably well with the Okubo (1974) relationship for time scales of about 1-12 h. For the Basaltic Island trial, observed patches beyond 2 h after dye release (t_o + t > 2.4 h) appear to fall below the predicted Okubo values, probably because the dye patch had entered a shallow, narrow channel, thus forcing the dye patch to be constricted.

Dye Concentration vs. Time

In Fig. 4 we compare the observed temporal decay in dye concentration with predicted values based on the Okubo (1974) relationship. The depths used to estimate the patch volumes (which were required to calculate the predicted values) were 3 m for Hardwood Island and 4 m for Basaltic Island, except 1 m depth was used for the initial patch volume in each trial (when the dye was still within the cage and tarpaulin).

The predicted and observed concentrations are in good qualitative agreement and suggest that the simple model is of some practical value. The dye, and hence pesticide, is diluted by approximately three orders of magnitude within about 3-5 hours.

Discussion

The dispersal of pesticides, like that of most substances, is a complex process. Because of this, there is often a tendency to develop complex circulation and advection-diffusion models that represent many of the physical and chemical details of a specific area. Although such models are often desirable and warranted, their development takes considerable time and money. Hence, relatively quick and cheap approaches, that give reasonable, but perhaps less precise, indications of the relative dispersal and dilution of a pesticide are desirable.

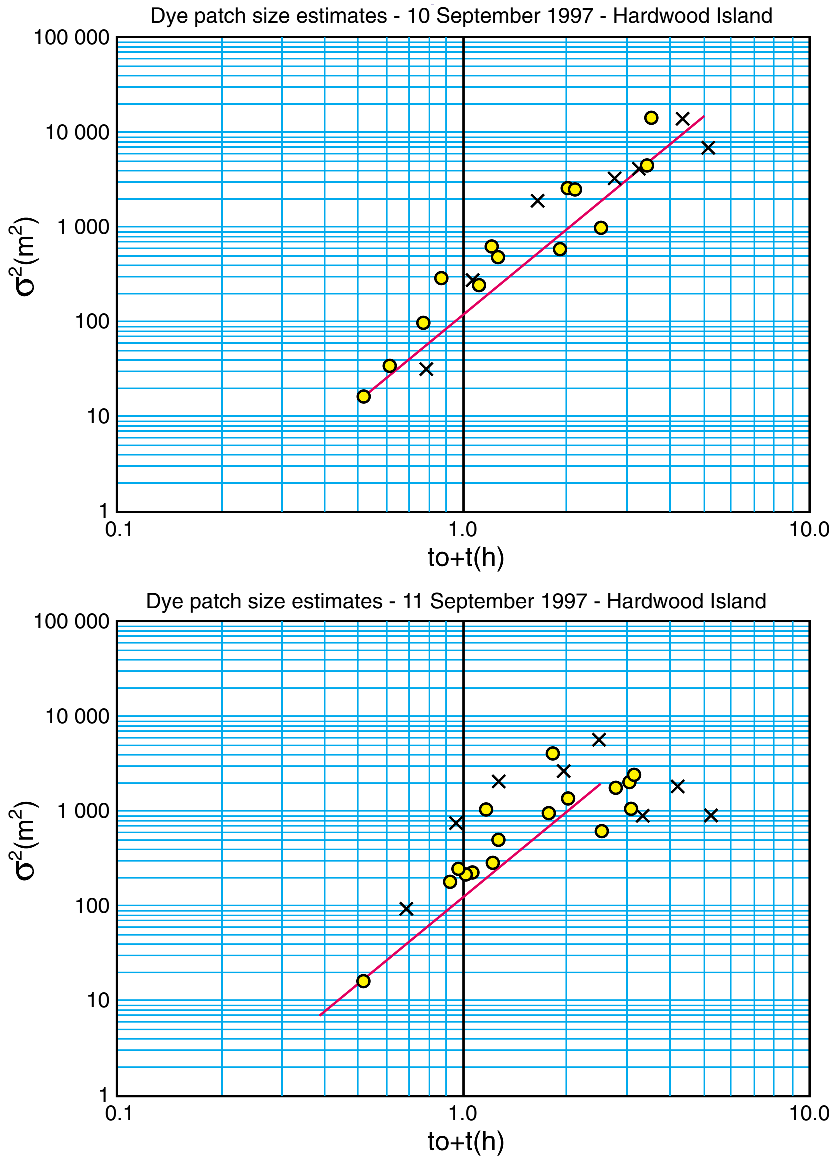


Figure 3: Dye patch size estimates from fluorescence data (X) and aerial photographs (o) in Hardwood Island and Basaltic Island dye release trials. Also shown is the modified Okubo (1974) relationship, $\sigma_{rc} = c_1\ \varepsilon\ ?(to + t)^3$ *(solid line).*

The empirical relationships developed by Okubo (1974) fall into this category. Although, they were derived from dye releases conducted in offshore continental shelf regions where dispersal is not influenced by the close proximity of coastlines and complex circulation patterns, they appear to give a useful guide for dispersal rates in at least some inshore areas.

Although the data analyses and model development are not yet complete, the results to date have already demonstrated that:

- the distance travelled by a pesticide patch during the first 2 to 4 h after release ranges from a few hundred to a few thousand metres, and hence may be carried through an adjacent fish farm (currently, the minimum allowable separation distance between salmon farms in New Brunswick is 300 m);
- dispersal rates in at least some of the farmed areas of the Quoddy Region are consistent with those observed elsewhere in the world (Elliott et al. 1997) and with empirical relationships describing dispersal rates (Okubo 1974);
- dispersal of the pesticides is a three dimensional process that is likely dominated by vertical shear diffusion; and
- dispersal results in dilution of the pesticide by 3 to 4 orders of magnitude within 3-5 h.

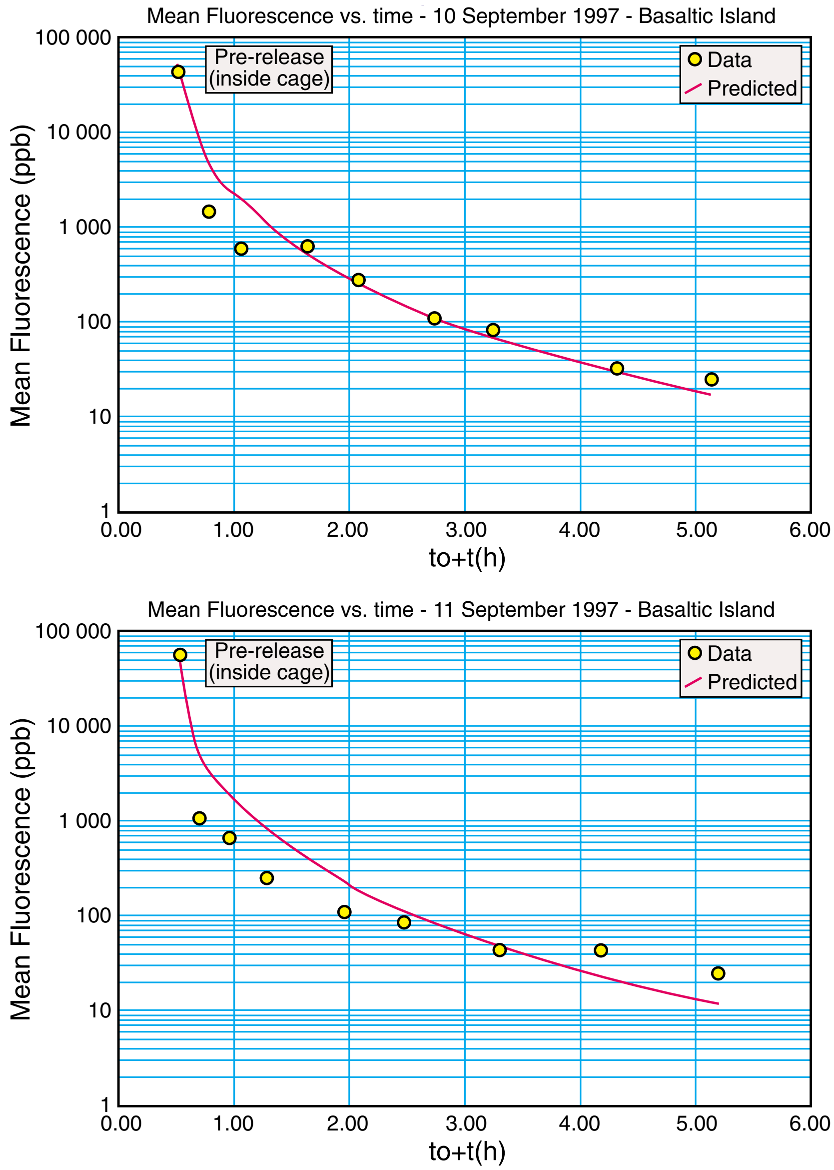


Figure 4: Comparisons between the observed mean concentration of dye with the predicted homogeneous concentration assuming an Okubo patch radius and a specified constant patch depth in Hardwood island and Basaltic Island dye release trials.

These findings have countered the often held belief by some government officials and industry that pesticides released into the marine environment of the Quoddy Region are instantaneously diluted. They have also reinforced the reality that many of the fish farms are sharing the water from adjacent farms on a regular basis and that knowledge of the circulation and dispersal patterns is valuable and necessary information. These findings also made a significant contribution to the Pest Management Regulatory Agency's evaluation of azamethiphos and cypermethrin. Hopefully, as the data analyses, field data collection, model development, and information exchanges with industry and regulators continue, regulations and industry practices will be developed that will ensure the development of a sustainable and competitive salmon culture industry that produces a minimal environmental impact.

Acknowledgements

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Applications of MultiBeam Data

ToC

M J Lamplugh, T. A. Kearns and A. C. Craft

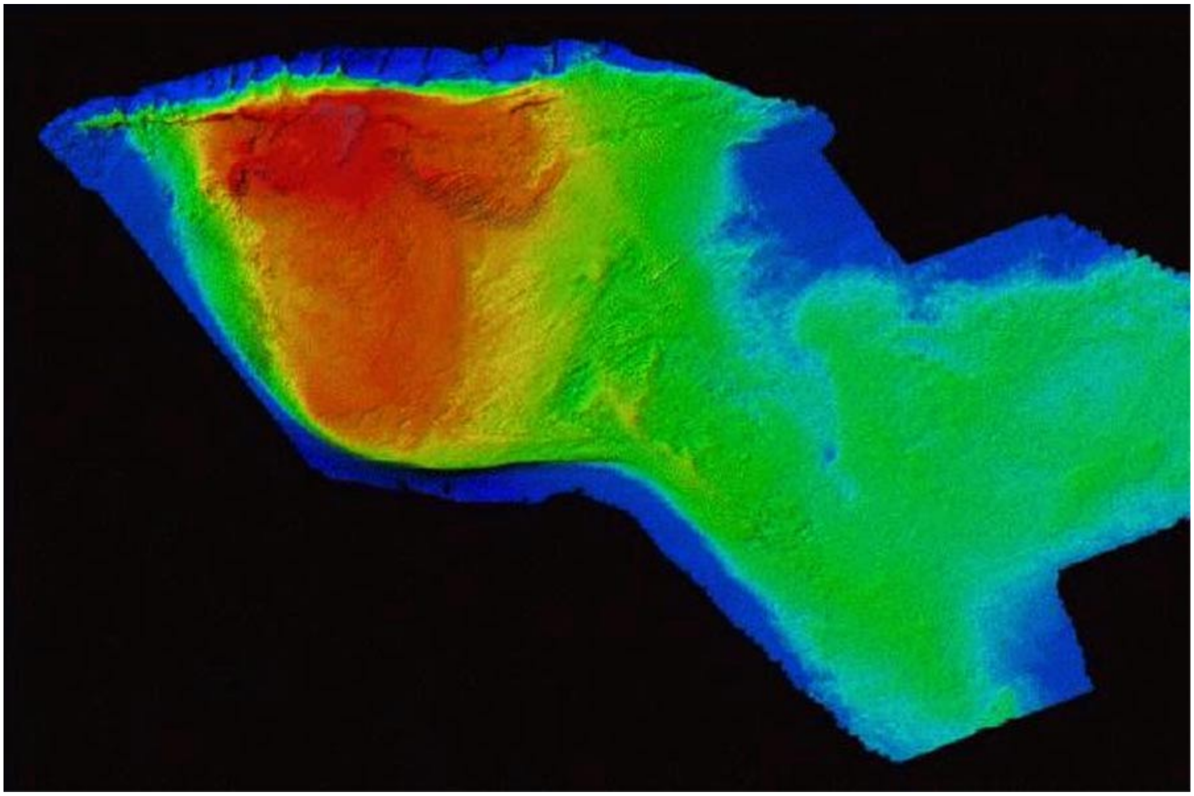

Image of seafloor generated from EM1000 multi-beam data collected on the FG Creed by the Canadian Hydrographic Service -Atlantic. It took sixty days and over 120 million soundings were acquired on Browns Bank (~ 130 km by 70 km)

Introduction

Recent advances in computer technology (speed, data handling and storage capability) and a growing demand for digital databases and computer based mapping production capabilities have encouraged the use of remotely sensed data as an information source for a variety of cartographic applications. As well, the economic "necessity" of the last few years has fostered (forced) a diversification from traditional users to commercial applications. To some extent this has resulted in a new demand for a wider range of mapping products. Both of these changes have spawned a new market for the Canadian Hydrographic Service (CHS). Although quite different than our traditional charts, bathymetric imagery with the benefits of improved information content and scale can only serve to enhance the CHS product line.

Over the past few years we have been working to identify many applications for this type of data including marine operations where a knowledge of the ocean floor is important for dredging, dumping, pipeline and telecommunications installation and maintenance, underwater construction and fisheries applications. The end users of this bathymetric imagery can include resource companies (fisheries, mining, oil), support and service industries (engineering), utility and infrastructure development agencies (pipelines, telecommunications, transportation, power), other government mapping agencies, and the military.

There is a listing of acronyms and their definitions at the end of this article.

Background

At the Canadian Hydrographic Service we are primarily concerned with the charting (mapping) of Canada's navigable waterways, in fact, it is our mandate. Not only do hydrographic surveys and cartography constitute the bulk of what we do, it is an integral component of the role and responsibility CHS plays within Department of Fisheries and Oceans – an important component of managing our ocean's resources. Mapped information is the common product of the analysis of remotely sensed data. It is now possible to see the imagery created from multibeam sonar used as a step in this direction, albeit one that has more in common with airborne and space borne remote sensing than with traditional hydrographic surveying.

MultiBeam systems used by CHS

In 1986 CHS-Atlantic started using the FCG Smith a multi-transducer vessel ("acoustic sweep" system with booms) that gave 100% bottom coverage in depths greater than 7.5 metres. The swath covered by each pass of the vessel was 42 metres. With systematic swath overlap the coverage capability with the high accuracy of the sounding and positioning systems soon proved to be a powerful combination. The advantage and added safety to navigation that was guaranteed by utilizing this technology quickly became apparent. All of the major ports in this region were sounded between 1987 and 1993 with this vessel.

By the late '80s there were new (single transducer) methods available to acquire 100% bottom coverage that offered the advantages of working in deeper water, with faster acquisition speeds and less weather related limitations. The first to be acquired by CHS was a Simrad EM100 system (32 beams per ping) which was installed on the CSS Lauzier in 1988, followed by the FG Creed in 1989 and in 1990 the CSS Matthew. In 1991 the Creed was upgraded to an EM1000 (60 beams). Starting in 1996 CHS took delivery of four Simrad EM3000 which were installed in nine meter launches for use in each DFO region across Canada. These shallow water systems (127 beams in up to 100 metre depths) have greatly enhanced CHS's ability to quickly and accurately survey critical navigational areas such as harbours, wharves, dredged areas and governing depths for a channel.

Advent of Imagery
GSC contribution

In 1992, Bob Courtney (GSC-Atlantic) was the first to create images at BIO from bathymetry (see Science Review 1993-94). He did this initially with CHS data in Halifax Harbour. This technique has now become a standard requirement for many of their surveys. CHS has also started using this methodology to create images for our own purposes.

CHS advances

In 1997, a relationship was established with the College of Geographic Sciences and CHS. The value of techniques and methodologies used by Remote Sensing specialists to process and display image data was recognized by CHS. This played an important role in the evolution of multibeam imagery display. The primary shift in image manipulation and display was the incorporation of chromostereoscopy in the final output. The technique of chromostereoscopy is discussed below.

Choosing colours to highlight desired features

There were two main approaches taken that enhanced the impact and quality of the images that were now produced. The first was the implementation of a colour palette that followed that fell under the definition of chromostereoscopy. Chromostereoscopy utilizes the process whereby co-planar coloured stimuli (wavelengths) are perceived as different in apparent depth. When viewed with Chromodepth™ glasses the depth encoded image is decoded using micro-optics in the lenses. This gives the illusion of apparent depth; as outlined on the Chromatek Website [see http://www.chromatek.com for more information]. The essence of this approach entailed allocating the red end of the spectrum to the shallower depths and then applying the rest of the colours through to the dark blues as the seafloor gets deeper. The statement below from their website explains this approach.

"The core concept of ChromaDepthTM is straightforward; encode depth into an image by means of color, then optically decode the color to create a true holographic image. There are a variety of color palettes that produce effective programming of holographic depth, but the simplest one is this:

On a black background, red will appear closest, blue furthest, and the other colors will fall in-between according to their place in the rainbow (red, orange, yellow, green, blue)".

The second implementation was the application of a depth proportional colour ramp. By allocating the number of colours used based upon a histogram analysis of the depths, a balanced colourful image resulted. Prior to this approach, a linear application of the colour table had been utilized, which had the potential to colour the image in such a way as to not enhance or highlight sea floor features. In the example shown in the diagram, the depths range from 30 to 225 metres and it was possible to apply up to 256 colours at this stage (once the sun illumination is applied this becomes over 4000 colours with the associated shadows etc). Since we were primarily interested in the shallow part of the bank (less than 95 metres) it was decided to allocate a smaller proportion of the colours to depths between 95 and 225 metres; this resulted in a colour change every 5 metres or so. The remaining colours were then allocated such that all features subtle and striking were easily observable. This was done by initially having a change every 5.0 decimeters in the shallow (red) areas, as the slope becomes more gradual the colour changes are made more frequently until eventually they became every 1.1 decimeters in the southeastern part on the bank (greens). The diagram gives a good example of the difference between a linear fit and a customized fit as described and the clarity of feature visualization this allows.

The images generated are very striking and quickly give the viewer a very good grasp of the geomorphology of the ocean floor. This is even more pronounced when viewed through Chromodepth™ glasses (special 3D glasses) that are available from Chromatek. From a hydrographic perspective, this sort of rendering is extremely effective when wishing to visualize and plan the coverage of a survey, quickly see problem areas in the data and to show the general nature of the seafloor. However, many other applications have become apparent, some of which will be described below and others speculated upon.

Recent Projects

During the field season of 1996 & 1997 the CHS deployed the F G Creed on Browns Bank (20 NM south Cape Sable Island, NS). The survey was initiated as a demonstration seafloor habitat mapping project following a workshop at the University of New Brunswick. Due to the subsequent intense interest expressed by the offshore scallop industry a pilot project was initiated and a partnering arrangement was reached between them, NDI and CHS. The industry wishes to use the imagery to avoid hang-ups on the ocean floor so that they can harvest areas that have been inaccessible up to now. They would (in conjunction with DFO Fisheries staff and using current EAs), pursue responsible fishing in order to optimize harvesting. They would primarily harvest the more mature/larger ones in the new areas and leave their traditional areas alone for a year or more, this which would allow those scallops to further mature. Overall impact would be to increase the scallop biomass & profitability (less gear loss, less ship time & larger scallops), all with one innovative approach.

The enhanced images (colour and grayscale) will be sent to NDI in early 1998 along with positional information so that they can be properly geo-referenced. NDI will then release this data in a form that can be used with an Electronic Chart System (ECS). This data has the potential to become a new product line for CHS. Subsequently CHS carried out the first survey of German Bank in the fall of 1997. It is anticipated that this Bank will be the next step in the pilot project will possibly available for evaluation by mid-1999.

Specific uses for Bathymetric Imagery

A better understanding of the seafloor is clearly what these advances allow science to accomplish. The implications are many, from Marine Protected Areas (MPA) to habitat studies, from geological mapping to aquaculture site monitoring. Multibeam bathymetric imagery and related backscatter information can be used to extract information about the surface structure, composition or subsurface. Structural geology plays an important role in mineral and hydrocarbon exploration, and potential hazard identification and monitoring. Structures such as faults, folds, synclines and anticlines and lineaments as well as glacial action can be seen quite clearly in bathymetric imagery. Understanding these structures is a key to interpreting crustal movements that have shaped the present terrain.

As our colleagues at GSC-Atlantic can tell you, what becomes apparent immediately when working with bathymetric imagery is the great potential for geological applications of sonar remote sensing. The imagery created from multibeam data provides a superb base for interpretation of surficial deposit / bedrock mapping, structural mapping, mineral and hydrocarbon exploration, environmental geology and geo-hazard event mapping and monitoring.

GSC carried out a full geological survey of Browns Bank in 1997 with the CCGS Hudson, using the “first draft” image from the 1996 survey as the “base map” for their work. They have plans to do a second trip with the full image since the survey of the Bank was completed in 1997 by CHS. This is a large data set with over 140 million soundings covering an area of nearly 7000 square kms. There are many remarkable geological features that can be readily visible in this image. The capability is now here to systematically map the Canadian shelf with multi-beam, this would provide the base data for a much better understanding of the wet part of our country.

Future

In the coming years we hope to identify further contributions for multibeam sonar remote sensing to the larger oceanographic community. The application of space-based marine remote sensing is already becoming increasing common in oceanography. Many of the dynamics of the open ocean and changes in the coastal region can be mapped and monitored using remote sensing techniques. We feel that the application of multibeam sonar remote sensing imagery could provide a wealth of data to ocean disciplines already employing satellite remote sensing. These include the study of ocean pattern identification, storm forecasting, fish stock and marine mammal assessment (using water temperature monitoring, water quality, ocean productivity, phyto-plankton concentration and drift). As well, space based pollution monitoring and oil spill detection can provide timely information about threats to our offshore resources. By combining modeling and comparing the linkages between our seafloor imagery data sets and the data collected from other remote sensing applications we may come to a much better understanding of our oceans and their resources.

The types of products this bathymetric imagery can create (i.e. baseline, thematic, and hypsographic maps) are essential for planning, evaluating, and monitoring, for military or civilian reconnaissance or resource management, particularly if integrated into a database with GIS access. The derived information can be used to support territorial sovereignty issues, assess and monitor resource potential and exploitation and encourage economic opportunity.

Imaged structures can be examined for clues to crustal movement and potential hazards, such as earthquakes, or volcanic activity. The study of these types of potential hazards shows a role for multibeam bathymetric imagery in geo-technical studies relating to construction and engineering. We can see that the application of sonar remote sensing need not be limited to direct geology applications - it may also be used to support logistics, such as route planning for pipeline access to a mining area, and generating base maps upon which geological data can be referenced or superimposed. Identification of fault lines can facilitate planning by limiting construction over potentially dangerous zones of seismic activity.

Perhaps the most exciting prospect for bathymetric imagery is in areas of multi-temporal, multi-sensor and modeling applications. The demand for digital elevation models (DEMs) for use with land based remote sensing applications is skyrocketing. This demand for DEMs is growing with the increase in use of GIS and with an increase in the quality of information extracted using elevation data (for example, in discriminating wetlands, flood mapping, and resource management). Development of these models is seen as a critical source of information for analysis.

While bathymetric imagery provides us with an improved vision of the seafloor, bathymetric digital terrain models or DTMs are the real strength of multibeam sonar remote sensing. Already, integrated imagery has resulted in improved decision making for resource management, telecommunications planning, and military mapping. The application of 3D digital terrain models and products created from these models (for example slope and aspect models, and thematic classification data sets) can only better serve to aid in the sustainable development of our ocean resources. Of course, a DTM can be used as a sole data source for modeling 3D surface and perspective views.

The changes brought about by economic development and changing land-use patterns on these environmentally sensitive areas, and our response to it is a coming imperative. More than 60% of the world's population now lives close to the ocean. The coastal zone is a region subject to increasing stress from human activity. Government agencies, like DFO, concerned with the impact of human activities in this region need new methodologies with which to monitor such diverse changes as coastal erosion, loss of natural habitat, urbanization, effluents and offshore pollution. Plans are afoot to take a multi sensor approach to modeling tidal and storm effects and the impact of human activity on the inter-tidal zone. By using RADAR and LIDAR to map the land and shoreline through the inter-tidal zone into existing multibeam bathymetry models we hope to create images that map our coastal zones. The resulting georeferenced imagery could be used in the production of hypsographic maps and models that will allow for more accurate delineation of the land / water interface and better modeling of coastal features and dynamics for improved management decision making.

Definitions

IHO definition of Hydrographic Surveys: - Hydrography is the science of measuring and depicting those parameters necessary to describe the precise nature and configuration of the seabed, its geographical relationship to the landmass, and the characteristics and dynamics of the sea. These parameters include bathymetry, tides, currents, waves, and physical properties of seawater, geology and geophysics.

The primary use of the data collected is to compile marine charts and other graphic documents to facilitate and ensure safety of navigation for mariners in all the seas of the world, and for use by others concerned with the marine environment such as ocean engineers, oceanographers, marine biologists and environmental scientists.

Among the most important applications of hydrographic knowledge is its use in the planning of exploration and exploitation of marine resources, the determination of seaward limits of national jurisdiction, and the delimitation of maritime boundaries.

Acronyms

COGS - College (Centre) of Geographic Sciences, Lawrencetown, NS

CHS – Canadian Hydrographic Service, part of the Science sector of DFO. It has the mandate to survey and publish charts of Canada's navigable waters

DEM and DTM - Digital Elevation Models (DEMs) and Digital Terrain Models (DTMs) are computer models of the earth's topography derived from images that display elevations as different gray (or colour) levels. Using a GIS, digital data describing terrain are processed to derive a three dimensional view of that terrain. Often these terms are used interchangeably. Here we use DEM to describe models that display only elevations from sea level and DTM to describe models that show total surface topography including both elevations and bathymetry.

EA – Enterprise Allocation, applies to the amount of a species allowed to be harvested in a specific geographic area by an individual or company. Allocated by DFO.

ECS - Electronic Chart System, these PC based systems display a raster image of a chart and position the vessel (typically with GPS) on the image. Also displayed can be track, ship's head, speed and many other pieces of information that are relevant to the safe navigation of a vessel. This is proving to be a very useful aid to navigation for many mariners.

GIS - An acronym for Geographic Information System. A GIS is a computer based relational database that can be used to catalogue, query and run analyses to spatially relate diverse sources of data. These systems are capable of handling positional data of features as well as related attribute data.

GSC – Geological Survey of Canada, a division of the Natural Resources Canada. GSC-Atlantic is located at the Bedford Institute of Oceanography

Hypsography - From the Greek hypso; meaning height. A description of, or mapping of, the contours of the earth surface.

IHO - International Hydrographic Organization, based in Monaco

LIDAR - is an acronym for (LIght Detection And Ranging. As with RADAR, LIDAR systems are active remote sensing systems system. Pulses of coherent laser light are transmitted from beneath an airborne platform. The terrain below is illuminated and the coherent laser signal is reflected and recorded, thus the elevation of features on the ground may be determined with high accuracy. There is also a variant of this system that allows for the measurement of water depth, however is very dependent on the clarity of the water column.

MultiBeam - The capability to insonify a swath (90 degrees to ship's track) such that many distinct depth measurements can be derived. The swath width is typically a function of the depth of water with 3.5 times water depth being a usable number to plan line spacing such that the entire seafloor is sampled. This is the most effective way to meet IHO specifications of "100% bottom search"

NDI - Nautical Data International it is the private sector partner of CHS that markets digital data.

RADAR - is an acronym for RAdio Detection And Ranging. RADAR systems are active remote sensing systems that operate in the microwave portion of the electromagnetic spectrum. These systems illuminate the earth's surface with radio waves ranging from 1mm to 1m and measure the reflection of these microwaves (referred to as backscatter). Unlike other remote sensing systems RADAR can be used day and night is unaffected by cloud cover or weather condition can see through tree cover and in very dry sandy environment can actually see into the soil to a depth of several meters.

Most RADAR remote sensing systems are referred to as SAR or synthetic aperture RADAR. These systems are side looking; that is, they look at the earth not straight down but rather at an angle. As a result RADAR imagery has many inherent distortions and requires substantial processing before any analysis of the data is possible. The resultant imagery can show fine details of topography and ground cover in a gray scale image. Thematic - From land cover mapping. Thematic images or maps show data sets relating to specific subjects, topics or themes.

RGB - Digital images are typically displayed as additive color composites using three primary colours Red, Green, and Blue. This is not a new principle; it is how a colour TV or computer monitor works. This model of color called the RGB colour cube or simply RGB; the brightness levels of each of the primary colors define it. In image processing, this is often referred to as 24-bit color in a 24-bit image; eight bits of data per pixel (each dot on your monitor) are encoded for each of these three primary colors. The range of possible values in 24 bit colour images for each primary color brightness is 0 to 255. Hence there are 256^3 or 16, 777, 216 possible combination of red, green and blue values that may be displayed to the screen.

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BASIN: A Hydrocarbon Exploration Database and Model for Data Distribution

ToC

P. N. Moir

Introduction

Creation and maintenance of digital databases are a valuable product of the Geological Survey of Canada's Atlantic Division petroleum geoscience research program. Historically, access to such databases has been cumbersome, often requiring the help of skilled data extraction experts, accessing data from several dispersed and unrelated database architectures. The GSC's own need for simplified access and better archiving of the data, coupled to the dramatic increase in demand for external access by clients prompted change. The unique solution was to use the Internet and World Wide Web in conjunction with a relational database system to create easy to use graphical user interfaces that extract and display data quickly and effectively. This article highlights the development of the BASIN database and its Web interface as an important science knowledge archive centre and distribution media. It presents examples of completed database interfaces and presents a successful model for cost effective data distribution to clients.

The BASIN Digital Database

BASIN contains a wealth of geological, geophysical and engineering information related to many years of petroleum exploration, primarily offshore eastern Canada (figure 1). BASIN includes both raw and interpreted information for all petroleum industry exploration wells and a large number of seismic surveys (Moir et al. 1995). Data has been gathered from many sources including: well history and drilling reports; purchased proprietary data sets containing electrical log traces and rock cuttings descriptions and interpretative data such as formation picks, geochemical analysis, age determinations and vitrinite reflection (organic maturation) values. In the summer of 1998, BASIN contained 6.5 million records from 389 well locations, and almost 1 million records from 458 seismic surveys covering 780,000 line kilometres. Most of the data is contained within one relational database constructed using Oracle's relational database model software.

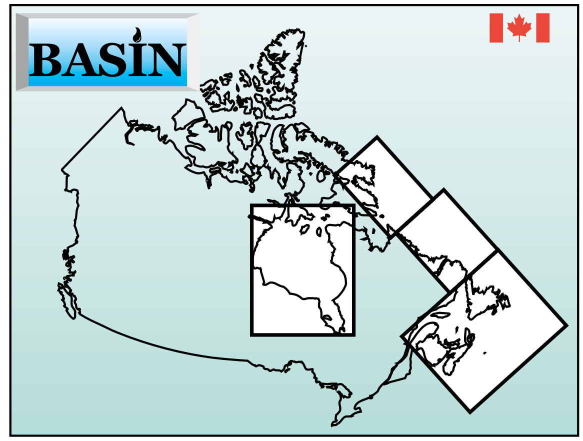

Figure 1: Map of Canada showing areas of data coverage in the BASIN database.

The BASIN database represents over 25 years of work capturing and recording data in a digital form in support of basic science and resource appraisal. The GSC Atlantic did not set out with the sole purpose of creating a digital database, but rather it grew as a natural by-product of its science. Foresight by several staff members in recognizing that data in digital form could be useful for future projects led to creation of various databases. During the early 1990's these databases like Wellsys (Lake, 1991), Seismic Navigation, Geochem, Biostrat, Pressure, and Lithodata were integrated into a single data model (BASIN). This work continues to capture new information and interpretations related to ongoing science objectives. The data model is dynamic and evolving to include new data types and better interoperability.

The original data model was based on simple observations of data use and expectations to meet immediate demand. A petroleum industry standard data model, the Public Petroleum Data Model (PPDM), is being phased in to increase usability, flexibility, consistency, interoperability and compatibility with third party software. New tables adopt existing PPDM architecture which reduces need to develop, evolve and maintain internal data models.

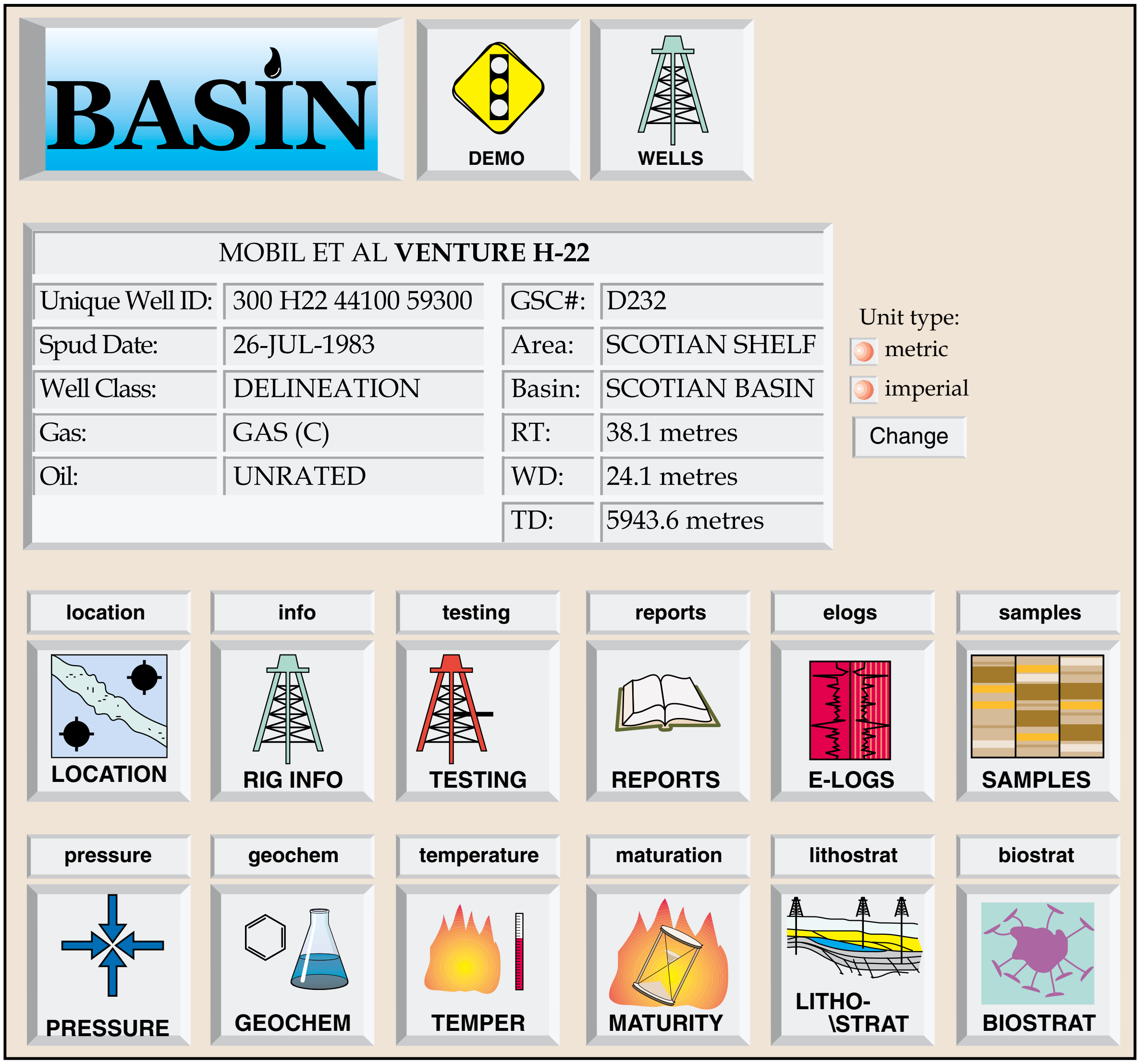

Figure 2: Example of selection page from single well interface.

The BASIN Web Interface

Since 1995, GSC Atlantic has developed graphical user interfaces to BASIN by making full use of the World Wide Web and the Internet. A Standard Web browser connected to the Internet is the only requirement for access. No special web browser 'plug in' software are needed. Data are accessed by a series of buttons that run static database language scripts (SQL). These are called from computer programs written in Perl, which in turn create dynamic Web pages. The static queries are based on observations of data use by clients both internal and external. This simple approach does not allow for every conceivable query of the database nor does it allow great flexibility in extraction output; however, it does focus on database server efficiency and speed by not allowing untested, time consuming or complex queries to slow access for clients. For external clients unique queries are handled by the data broker or by their own database query experts working with their own copy of BASIN. This model has worked well for both the GSC and its clients, with positive and constructive feedback.

Figure 2 shows a selection page from the BASIN single well interface. From this page the user accesses basic well information and 12 other categories of information related to the well. These range from well location information to detailed analytical results of studies conducted on sediments or hydrocarbons.

Figure 3 demonstrates a graphical output that was created dynamically based on limited user input. Graphs in the BASIN Web interface are used

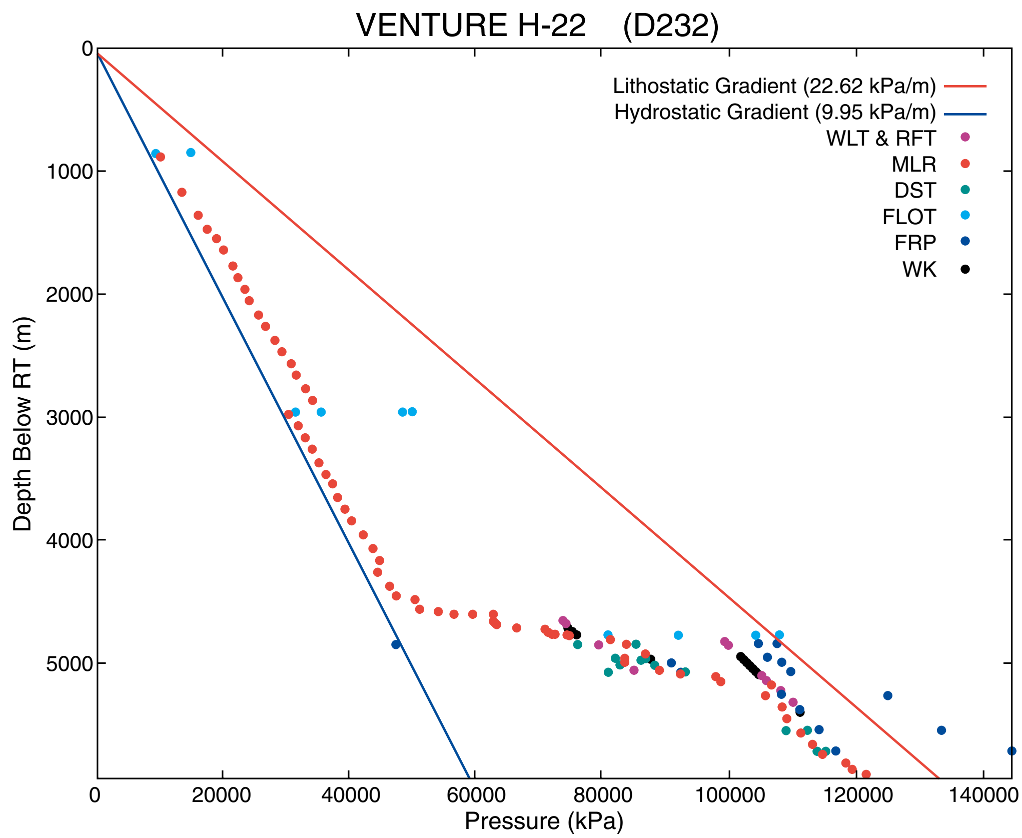

Figure 3: Example graph of pressure data created by BASIN Web interface. Used as a visual aid to understand data distribution and availability.

primarily as a visual aid to quickly understand data distribution. For further analysis the user 'cuts and pastes' the data into other application software.

Figure 4 is a map output of a user selected seismic reflection program. The seismic reflection data in BASIN is presently limited to program information and disseminated shotpoint coordinates. Actual seismic traces are not stored in this structure.

A 'demo' version of the BASIN Web interface is publicly available on the Web: This demo illustrates most of the functionality of the Web interfaces through full access to one well and one seismic program.

Clients

Although the interfaces were designed for internal use, they have become a popular working tool for many petroleum exploration companies, provincial surveys, and regulatory agencies.

The interfaces provide large volume of data quickly and easily. BASIN has helped the GSC identify its clients, the knowledge they need and the scientific problems that they face. Feedback helps keep GSC science projects in tune with client needs. It has also provided a source of revenue that has been applied to improving BASIN and completing other science objectives.

Through the power of the Internet, explorationists extract data from the comfort of their own offices in Calgary, Houston, London, and Paris. Many use the Web access on a daily basis. Others have incorporated the data with their own internal databases and access it with their own software. Most major petroleum industry companies, 13 by the summer of 1998, exploring and producing offshore of eastern Canada oil and gas have purchased the database. Three regulatory agencies, Natural Resource Departments from three provinces, and other federal departments access the database at no cost through the Web interface. Again, in some cases on a daily basis. Internal GSC access is daily, not only GSCA but also GSC divisions in Calgary and Quebec. University researchers and students are provided with limited access upon request.

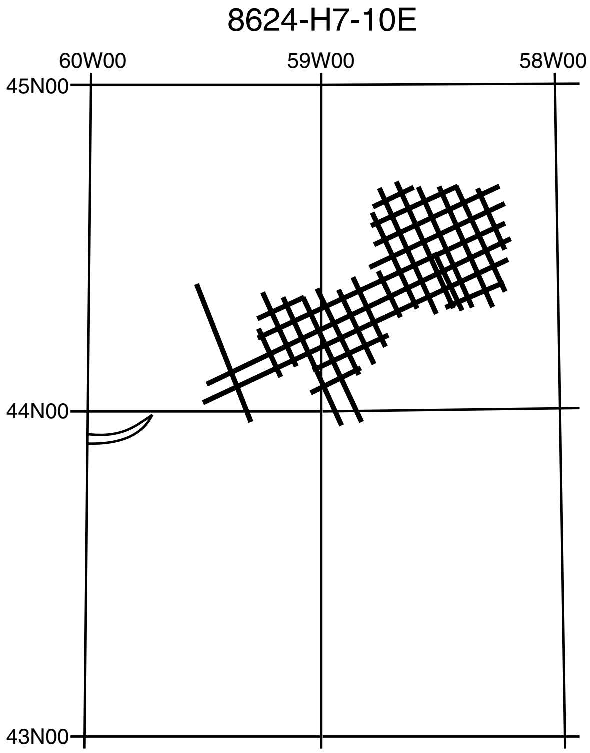

Figure 4: Seismic Navigation Map is a quick guide to area covered by program.

Data Distribution Model

The data distribution model is viewed as a successful model for working with commercial data brokers and not competing with them. The BASIN database and Web interface are marketed through QCData in Calgary. QCData won the right to market this database through a competitive bids process. The data broker provides access to the data quickly and in many other formats different than those provided by the GSC. This allows customized versions of the database for clients and integration with their own databases. The GSC provides BASIN in two forms only to external clients, an export format file created by Oracle and the Web interface. For the GSC this model eliminates the time consuming task of foreseeing and creating interchange formats to meet client requests, and puts it in the hands of data broker experts that do this job routinely. The data broker also takes care of the process of billing clients, collecting yearly maintenance, distributing updates, and answers many common questions regarding the database. The GSC Atlantic is solely responsible for maintaining the Web site and allowing access to clients.

Future Directions

Presently the GSC Atlantic is striving for a higher degree of completeness and quality control in the database. Data from various reports are being identified and added regularly. Data from new offshore wells and seismic programs are being added as they become available. The Web pages will be expanded to improve access to the data, and will include linkages to other data sources including maps, references, pictures and knowledge on other web sites. New and innovative data extraction, plotting and visualization capabilities are being considered such as a Geographic Information System (GIS) interface for a more dynamic map interface and as a means of map distribution.

Acknowledgements

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Climate change and the Canadian coast

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ToC

Introduction

The global climate system is being modified by human activities (Houghton et al., 1996), the principal effect being a predicted increase in global mean surface air temperature of 2 Celsius degrees above the 1990 value by 2100. How might global climate change affect the Canadian coast? In this brief paper we will highlight some of the concerns that are presently being addressed by GSC researchers and their collaborators, namely the effects of:

1- reduction in the extent and duration of sea ice;
2- changes in storm climatology; and
3- sea-level rise.

Reduction in sea-ice extent and duration

It is possible that with climate warming, the duration and extent of sea ice could be reduced (Solomon et al., 1993). When the ocean is frozen, wave reworking of beaches ceases (although sea ice can then be an active geomorphic agent). On the Beaufort Sea coast, the ice edge moves up to several hundred kilometres offshore for a few months in late summer, allowing sufficient fetch for waves and surges to cause extensive erosion, such as at the settlement of Tuktoyaktuk. If the ice-free season were to be significantly lengthened the increased frequency and cumulative intensity of storm waves and surges would be reflected in increased erosion on a coast already experiencing rapid change.

The ice-free season in the southern Gulf of St. Lawrence is much longer (typically about 8 months) but the lack of protective ice cover in the early winter, when storm-surge activity is at a peak (Parkes et al., 1997) would accelerate geomorphic change on the gulf coast of Prince Edward Island, which is already undergoing rapid erosion (see below).

On much of the Atlantic coast of Nova Scotia, sea ice is generally absent, but pack ice flowing out of the Gulf of St. Lawrence can extend as far south as Halifax and shorefast ice can develop during very cold snaps in some winters. Increased temperatures in winter would prohibit the formation of shorefast ice which protects the shores from significant storm waves, and the southern extent of sea ice flowing out of the Gulf of St. Lawrence along Atlantic Nova Scotia would be reduced. In March 1993 shorefast ice and floating brash ice protected the shores of Atlantic Nova Scotia during the 'Storm of the Century' (Taylor et al., 1997).

Changes in storm climate

Houghton et al. (1996) were uncertain how global climate warming could be reflected in changes in mid-latitude storminess and the formation of tropical cyclones, including hurricanes, (although recent research suggests that Pacific Ocean hurricanes might be stronger with global warming). Most beaches endure long periods of fair weather, during which little change occurs, punctuated by brief violent storms during which large waves superimposed on storm surges cause significant changes to the coast. Surveys on Nova Scotia's Eastern Shore show how beaches have responded to decadal-scale changes in storm-surge intensity and frequency. There were many surges in the 1920s and 1930s, few in the 1940s and early 1950s, and many after 1954; beach retreat and erosion were coupled to these cycles. Increases in storm intensity and frequency would therefore be reflected in accelerated geomorphic change at the coast (Forbes et al., 1997).

Great damage is caused on Nova Scotia's Atlantic coast by tropical cyclones, most of which are tracking northeast when they reach the Canadian Maritimes. Parkes et al. (1997) highlighted the vulnerability of the upper Bay of Fundy to storm-surge flooding caused by a tropical cyclone. The highest risk is posed by an intense storm tracking up the Gulf of Maine during a run of perigean spring tides, and crossing the New Brunswick coast just west of Saint John as the tide rises in the Bay of Fundy. The storm surge during the notorious Saxby Gale, a tropical cyclone in 1869, amounted to an estimated 1.8 m, and extensive areas were flooded (Fig. 1). It is by no means the worst case because firstly, the astronomical tide could have been 0.6 m higher during the Saxby Tide at the head of the head of the Bay of Fundy; and secondly, relative sea level has risen about 0.4 m since 1869. The risk to this area is presently being assessed, especially in the light of accelerated sea-level rise and global climate change.

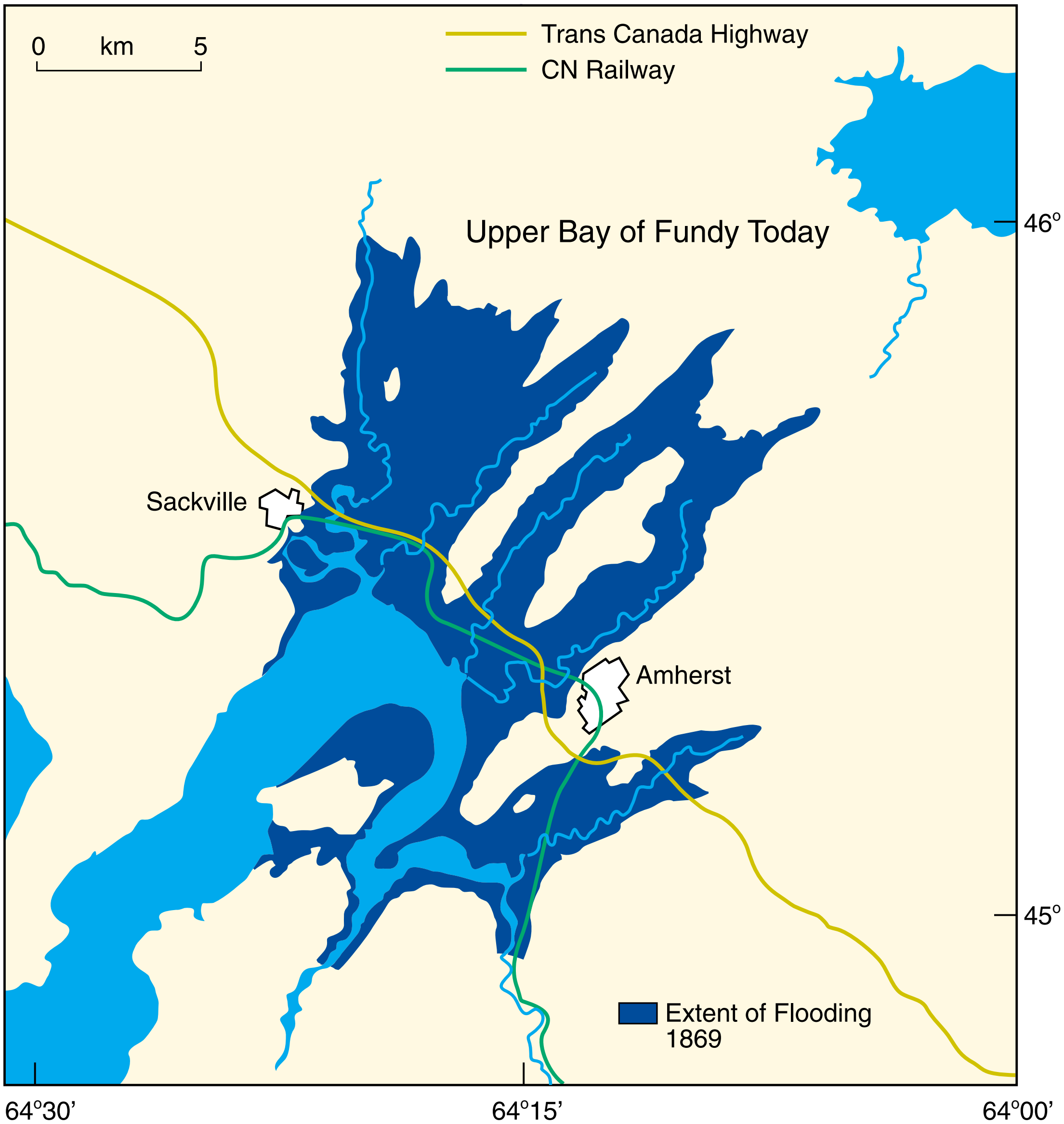

Figure 1: Extent of flooding at the head of the Bay of Fundy during the Saxby Gale, 1969

Sea-level rise

The projected temperature increase will raise mean sea level 0.49 m by 2100 (Houghton et al., 1996); this increment must be added to existing trends of sea-level change. Where relative sea level (RSL) is falling rapidly today (because of crustal rebound), it would fall less rapidly in the future. Where RSL is falling today at moderate rates, or is stable, the trend would be reversed, and RSL would start to rise, so that the zone of submergence would expand towards the interior of the Canadian landmass (Fig. 2). In the areas of submergence shown in Figure 2, rates of submergence would increase. At Halifax, for example, sea level has risen at a rate of ~0.3 m/century since 1896, mostly because of crustal subsidence, and over the next century it could rise 0.8 m.

Coastal sensitivity to sea-level rise

To describe the sensitivity of the Canadian coastline to accelerated sea-level rise, we produced a sensitivity map (Fig. 3) (Shaw et al., 1998) which indicates that 67% of the coast has low sensitivity, 30% is moderately sensitive, and 3% is highly sensitive. The high sensitivity areas comprise extensive parts of the Maritime Provinces of Atlantic Canada, the mainland Beaufort Sea coasts, and the Fraser Delta and northeastern Graham Island in the Pacific region. The regional descriptions of coastal sensitivity that accompanied the map are over-generalised, so we have initiated a new project in one of the highly sensitive regions: the north coast of Prince Edward Island. Our objective is to provide improved prediction of how this coast will evolve over the coming century.

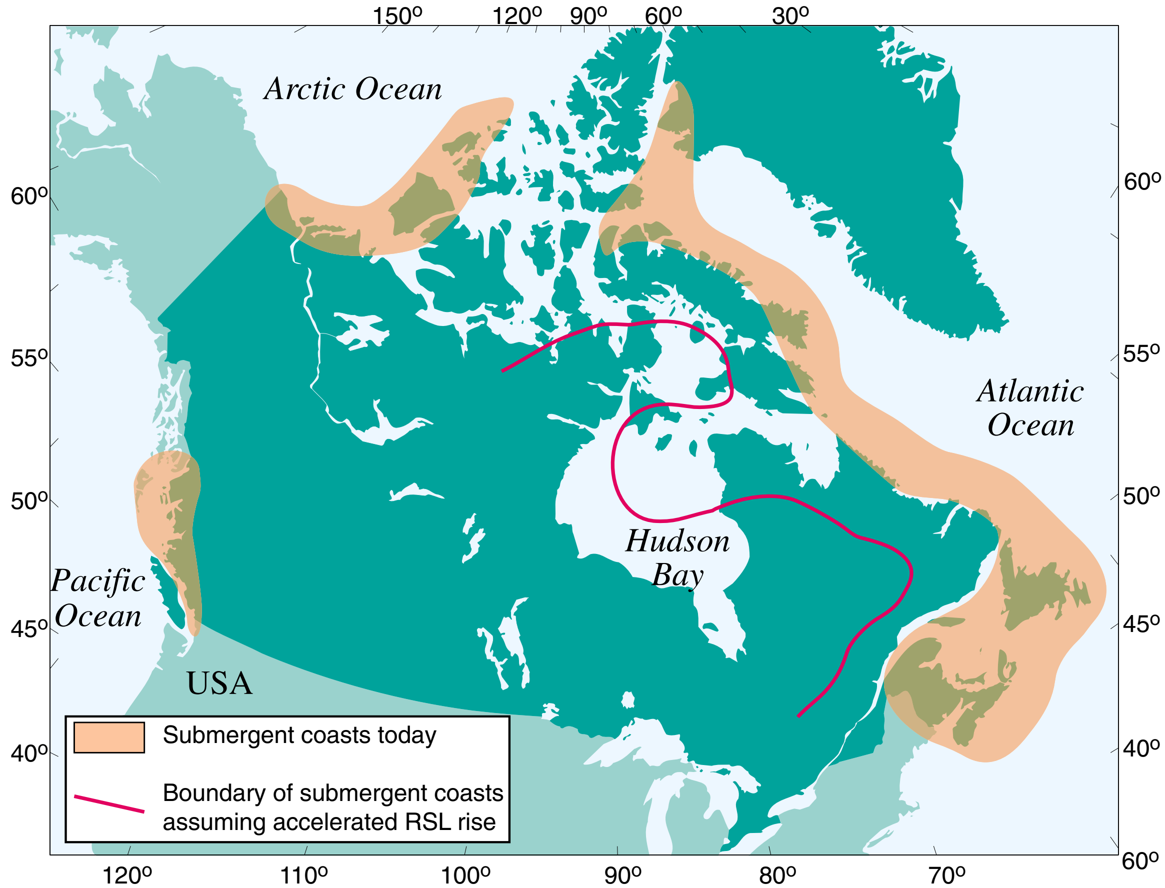

Figure 2: Extent of submergent coasts in Canada, i.e., areas in which sea level is rising today. The possible extent of submerging areas by 2100 is based on IPCC predictions (Houghton et al., 1995).

Evolution of the Gulf coast of Prince Edward Island by 2100 AD

Predicting the future evolution of the north coast of Prince Edward Island under a scenario of continued or accelerated sea-level rise requires an understanding of past evolution, a working hypothesis of contemporary coastal morphodynamics, and extrapolation of measured rates of change. Some preliminary conclusions are presented here.

The geography of the southern Gulf of St. Lawrence (Fig. 4) at 9000 radiocarbon years BP (about 10,000 sidereal years) shows land extending from Nova Scotia to beyond the Magdalen Islands. Rivers and large lakes (Kranck, 1972) are not shown in this reconstruction. Subsequent sea level rise caused the coastline to migrate across the Magdalen Shelf at rates up to 14 km/century, isolating the Magdalen Islands about 8000 BP, and separating Prince Edward Island from the mainland by 5000 BP. In the past several millennia the rate of sea-level rise in northern Prince Edward Island decelerated, and is now just over 0.3 m/century (Shaw and Forbes, 1990). With the global increase, sea-level rise could amount to about 0.8 m by 2100 AD.

To facilitate prediction we partition the north coast of the island into three morphodynamic segments (Fig. 5). The Western Conveyor extends southwest from North Point and consists of eroding, soft bedrock cliffs. Sand is transported to the southwest in the nearshore zone at an annual rate of 38,000 m^3 into the coastal foreland at West Point, the sub-tidal sand body offshore from West Point (Kranck, 1971), and also into Egmont Bay. It is conservatively estimated that the entire West Coast will retreat 30-100 m by 2100 AD.

The Transgressive Embayment (Fig. 5) extends from North Point to Cable Head and comprises several long intervals of soft, eroding bedrock cliffs and six estuary complexes, each consisting of sandy barrier beaches with coastal dunes, protecting shallow, flood-dominant estuaries. Sediment moves along a littoral corridor from both ends of the embayment towards the centre. This coast is envisaged as an erosional front that is migrating landward in concert with sea-level rise. Migration is achieved through cliff, dune and beach erosion, beach overwashing, flooding of the estuaries, transport of sand into flood deltas within estuaries, and lateral migration of tidal inlets.

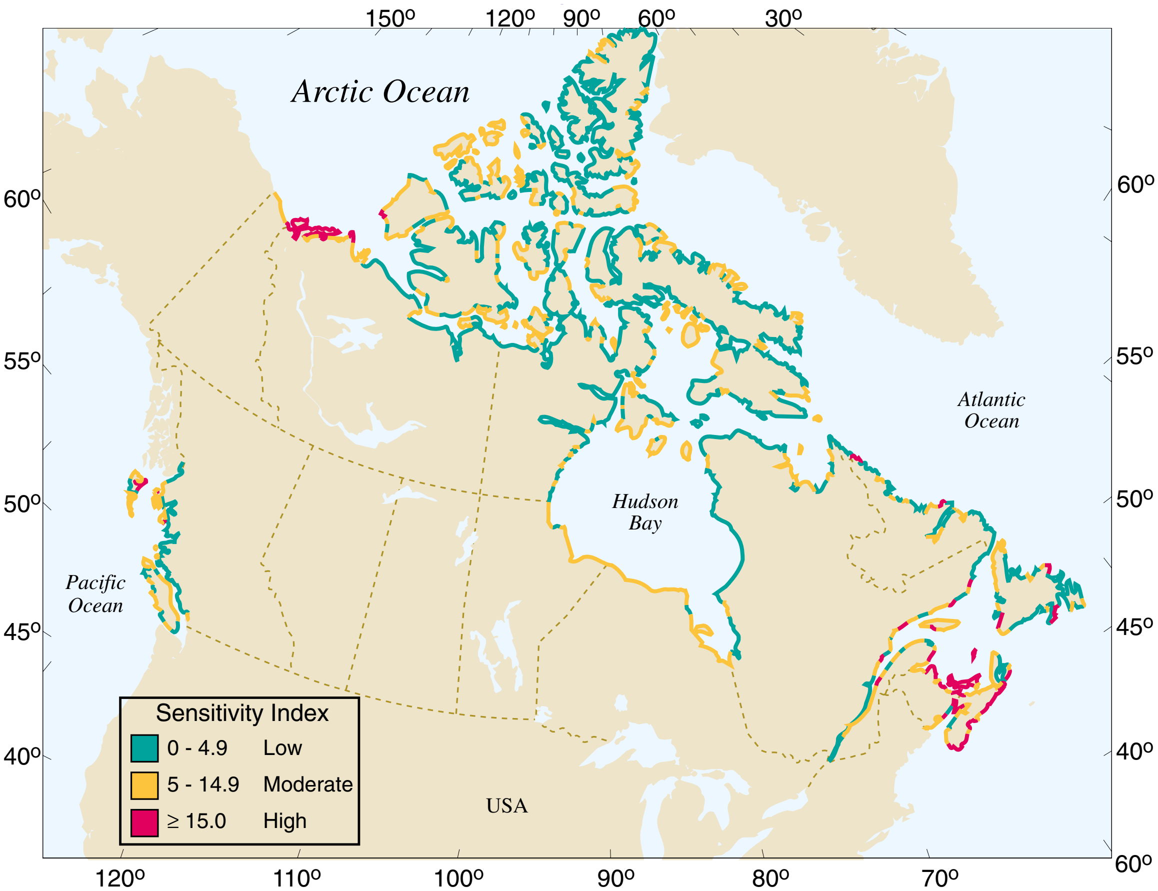

Figure 3: Sensitivity of Canadian coasts to global sea-level rise.

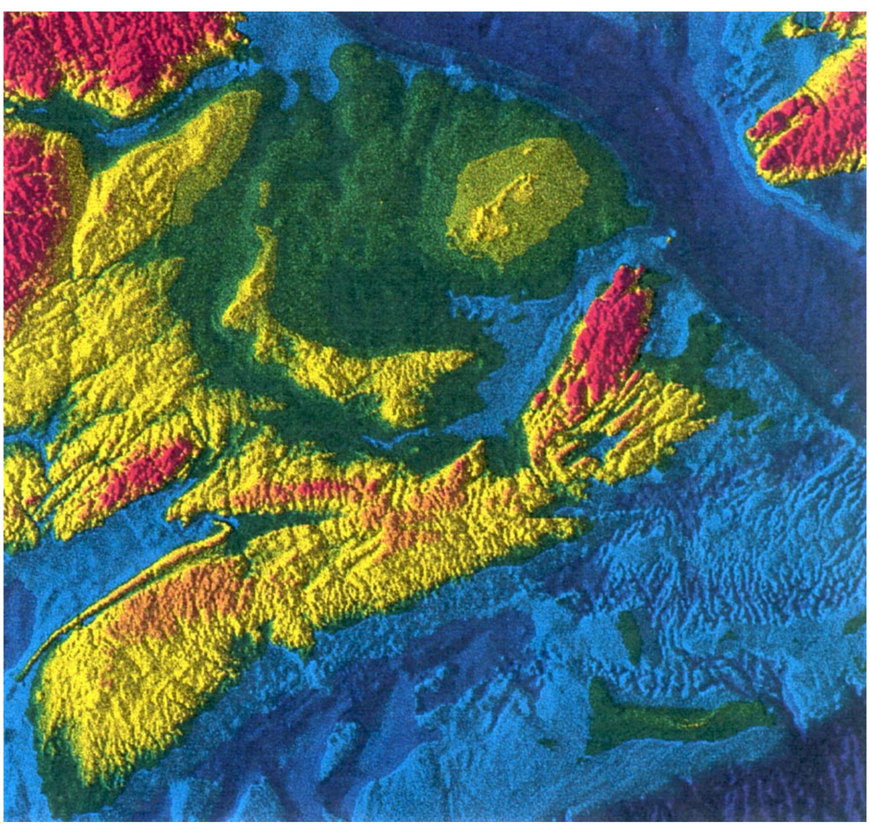

Figure 4: Geography of part of Atlantic Canada at 9000 radiocarbon years BP (which is about 10,000 sidereal years ago).

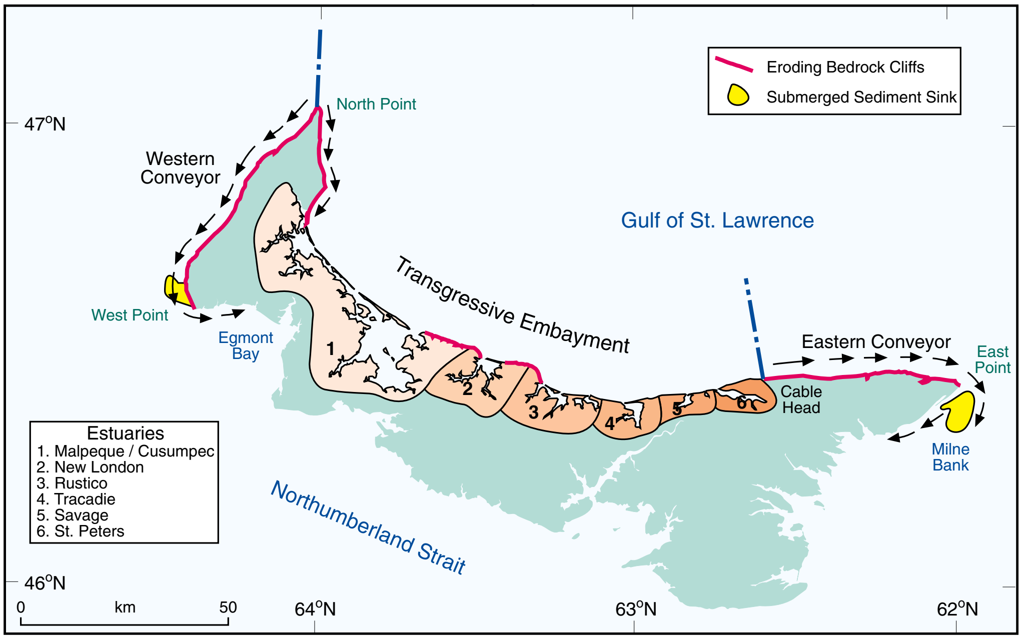

Figure 5: Coastal processes on the north coast of Prince Edward Island.

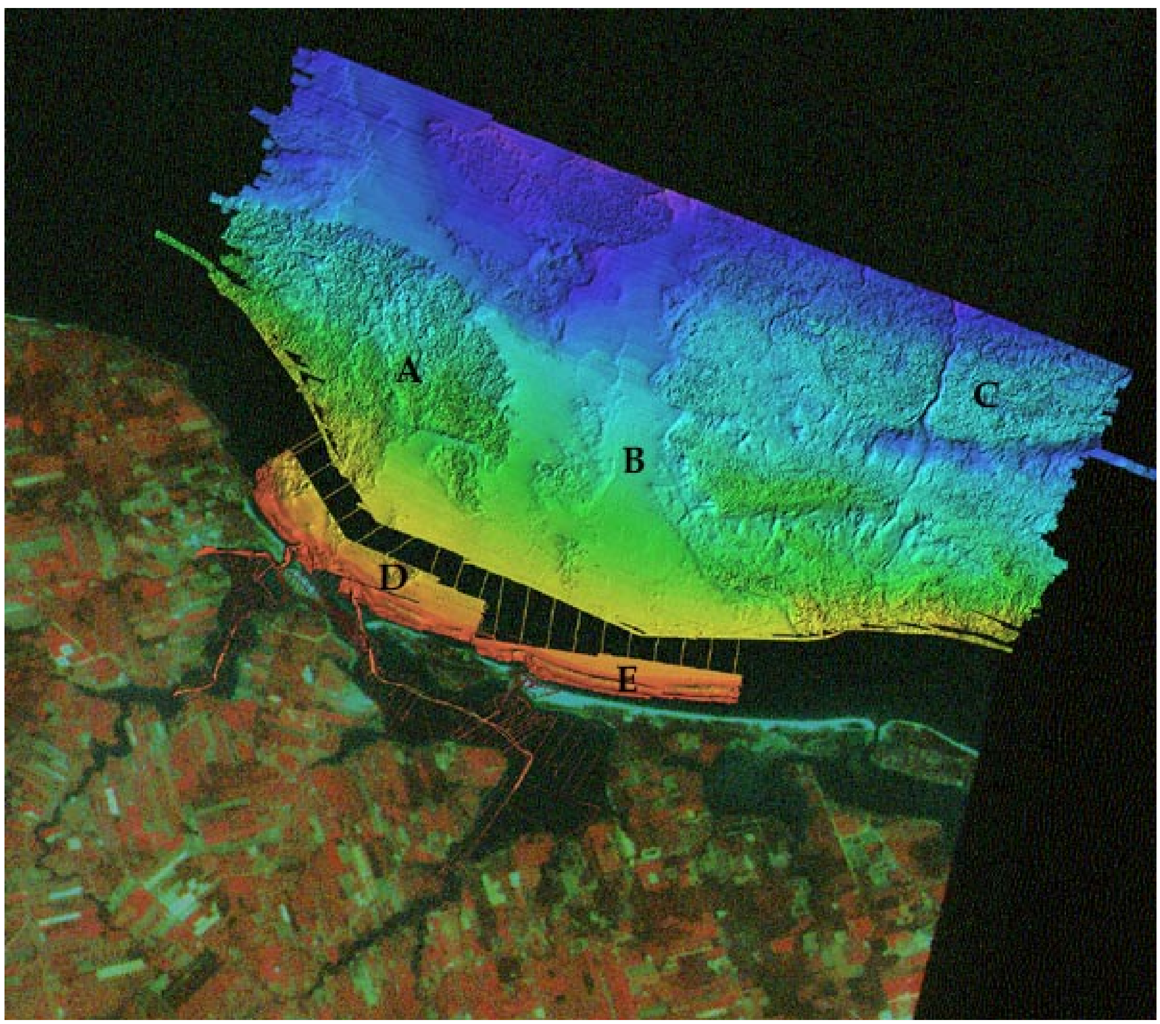

Figure 6: Shaded relief multibeam bathymetry of the Rustico area derived from EM-1000 and sweep data. Annotations described in text.

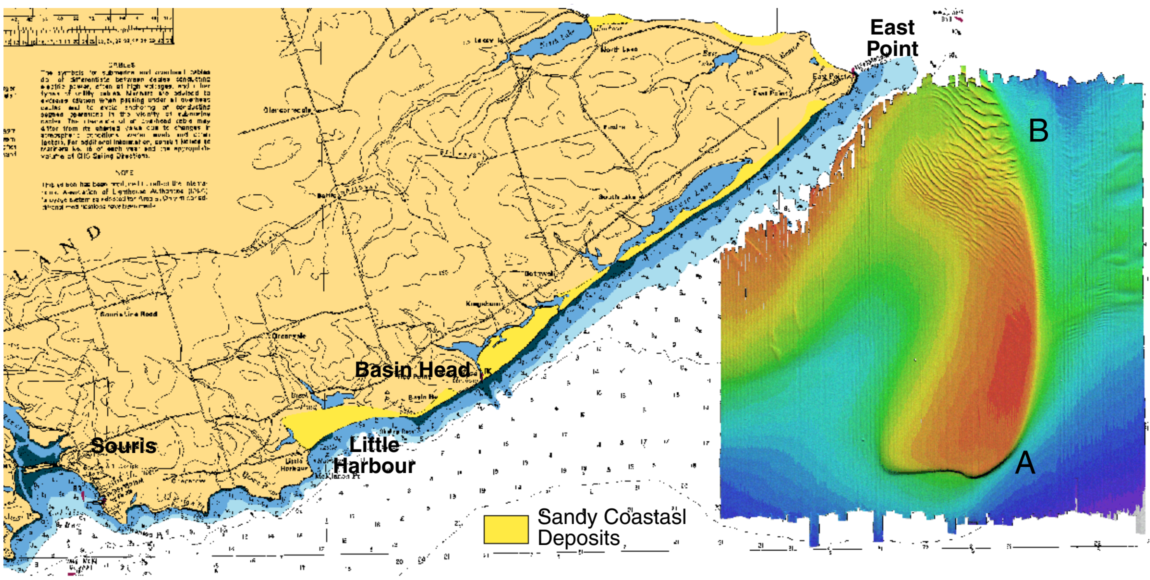

Figure 7: Shaded relief multibeam bathymetry of Milne Bank derived from EM-1000 data. Also showing coastal sand deposits.

Shaded-relief imagery (Fig. 6) produced from multibeam bathymetry collected in the Rustico Bay area shows that sand has moved landward with coastal retreat, leaving behind an eroded bedrock surface (A). Sand and estuarine mud have been trapped in the larger drowned valleys (B), completely filling them, whereas smaller drowned valleys are not completely filled (C). Close to the coast we observe a wedge of sand (D) connected to the beaches and the inlet (E), and marked by shore-parallel nearshore bars (F). This nearshore sediment body forms a littoral corridor in which sand is moved alongshore, but it is discontinuous at rocky shoals between drowned valleys.

The future of the Transgressive Embayment to 2100 AD includes ongoing retreat of barrier beaches by 25-50 m, flooding of low-lying estuary shorelines, and erosion of bedrock cliffs. This could be accompanied by tidal inlet switching and infilling of existing navigation channels as barriers evolve due to washover and spit re-orientation. Estuaries may shallow as well. On the rocky coast extending southeast from North Point, coastal cliffs could retreat 60-150 m.

In the Eastern Conveyor (Fig. 5), sand moves in the littoral corridor towards East Point, where it is accumulates in a submarine sediment sink - Milne Bank (Frobel, 1990; Kranck, 1971) - containing at least 1 x 10^9 m^3 of sand. A proportion of sand 'leaks' from Milne Bank into the littoral corridor, and is transported to the southwest. It has been estimated that 38,000 m^3 of sand annually moves from the north coast to the south coast. Over the past several millennia, embayments on the south coast have become successively filled with sand, sometimes forming very large aeolian deposits (Fig. 7) such as the Basin Head complex. In a cascade effect, as each embayment filled up, the corridor has then extended to the next embayment downdrift. The end of the conveyor today is at Little Harbour.

In the multibeam image of Milne Bank (Fig. 7) the steep faces in the south and east (A) indicate progradation in those directions, in agreement with seismic data. Large-scale, asymmetric sandy bedforms (B) are suggestive of sand transport southward on the bank. Smaller bedform that are visible on this data at 5-m resolution and on sidescan sonar images indicate active sediment movement across most of the bank.

The future for the Eastern Conveyor over the next century includes 100-200 m of erosion on the north coast, slight erosion on the sandy beach-dune systems that stretch southwest from East Point, and flooding of the lagoons and wetlands behind the dunes. The cascade effect will continue, so that Little Harbour will be infilled with sand, allowing the littoral conveyor to extend towards the southwest, eventually transporting sand into Souris Bay.

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Ongoing studies on larval lobster dispersal in the Canadian sector of the Gulf of Maine.

ToC

By Gareth Harding, Ken Drinkwater, Peter Vass, Dwight Reimer, John Pringle, Angus Fraser and Jens Prena.

Most people know that the lobster is a marine organism that lives on the sea bottom and that the female carries her eggs adhering to her swimming legs underneath her tail. However, few are aware that these eggs, which are laid and fertilized in late summer, hatch almost a year later in mid-summer and that these freshly hatched larvae swim directly towards the sea surface, where they spend the summer as a free-swimming or planktonic phase in the warmer water that develops seasonally at the ocean surface. Crustaceans, such as the lobster, have an external skeleton or shell which means that they must first shed their shell, or moult, before growing into a newly formed larger shell. The planktonic larvae moult three times before descending to the ocean bottom as a late fourth stage lobster. This planktonic phase of the life cycle lasts anywhere from one to two months depending on the local temperature and the food available. Higher temperatures and a sufficient supply of food favour faster development.

There is a long history of research on the possible connection between inshore and offshore lobster populations along the northeastern coast of North America. Rogers et al. (1968) were the first to suggest that some coastal lobster populations may originate from larvae released offshore and carried shoreward where onshore surface currents exist. This hypothesis was based on observations off Rhode Island where first stage larvae were more abundant offshore toward the continental margin, whereas the final planktonic fourth stage larvae were far more common within Rhode Island Sound in water generally less than 30 metres depth. Further south off southern New England, other biologists did not find any evidence that offshore "seeding" of larvae inshore was occurring although they did find unusually high concentrations of the fourth settling stage in Long Island Sound.

Lobster larvae initially were considered to be sparse in Canadian offshore waters (Stasko 1977). Surveys for the Scotian Shelf Ichthyoplankton Program in the 1970s located aggregations of larvae near German and Browns Bank, with a scattering of larvae along the continental margin as far west as Emerald Basin and the Western Bank (Watson & Miller 1991). Stasko speculated that larvae originating on Georges Bank could settle as far "downstream" as Browns Bank, based on the general surface circulation and a larval developmental duration of approximately one month at local temperatures. Larvae from Browns Bank, in turn, could settle as far inshore as southwestern Nova Scotia. Stasko (1978) expanded this hypothesis to include a return movement of adult lobsters along the bottom to the deeper waters off Georges, Browns and German Banks and off Grand Manan Island, which would complete their life cycle. Stasko and coworkers then conducted larval surveys in inshore and offshore waters off southwestern Nova Scotia in 1977 and 1978, mainly sampling the ocean surface (1.3 metres)with nets. They confirmed a widespread presence of lobster larvae, with the first stage hatching and appearing in the surface waters by early July, increasing to maximum abundance in the first two weeks of August, and disappearing by mid September (Stasko & Gordon 1983). However, they failed to find their anticipated temporal gradient of developmental stages from the offshore banks to the coast off southwestern Nova Scotia. This was due to their collections being inexplicably, at the time, overwhelmed with fourth stage lobster larvae (66%). Stage I lobster made up the remainder of the catch (29%) and second and third moult stages were rarely captured. Neither did they find an increase in the relative abundance of the fourth and final planktonic stage over time toward the coast, but this could reflect the differences in spawning time and development rates between Browns Bank and the inshore areas. Reanalysis of these surveys showed that approximately 2.5 times as many larvae were caught per tow offshore as inshore in both years These calculations were based on an inshore definition of shallower than the 20m contour, which would include the Trinity Ledge area. Offshore concentrations of first stage larvae generally occur in waters with bottom depths greater than 80 metres. Campbell and Pezzack (1986), on the other hand, estimated that 23 to 53% of the larvae produced off southwestern Nova Scotia would come from inshore sources based on the known abundance of egg bearing or "berried" females, but they almost certainly included deep-water migrants from the Gulf of

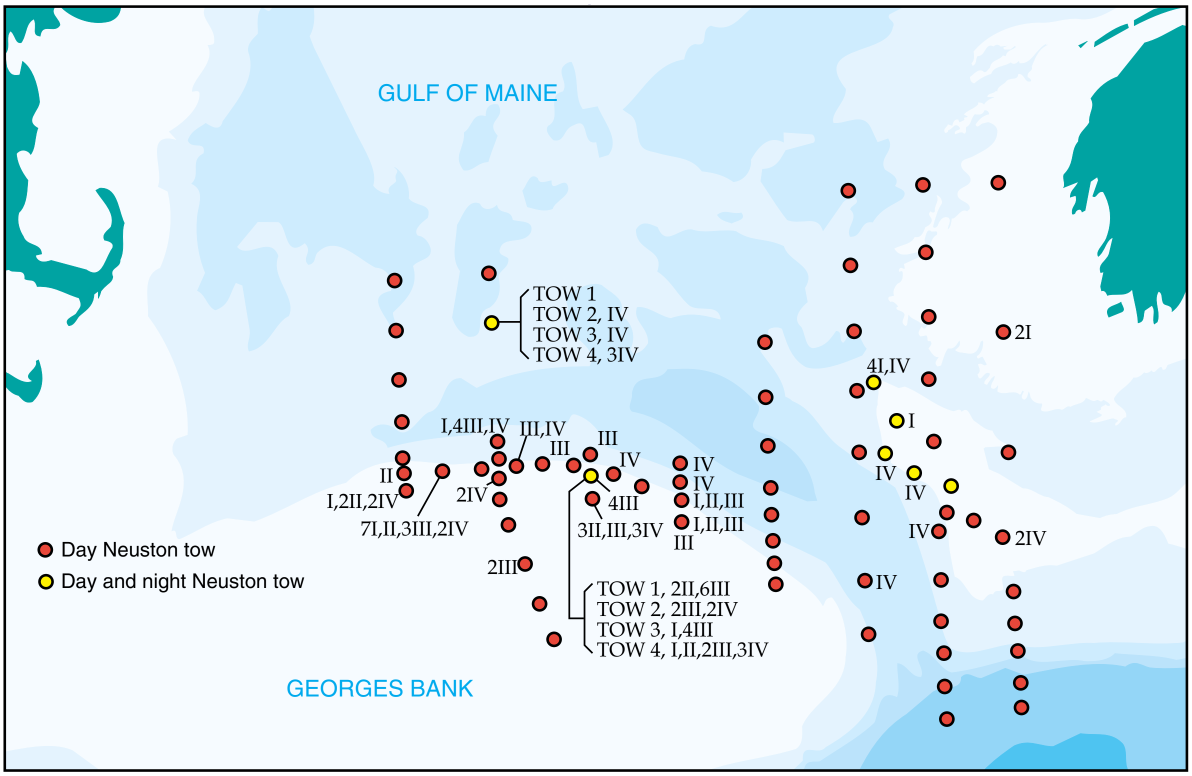

Figure 1. Distribution of larval lobster abundance (#s/ 30 min. tow) by developmental stage (I to IV) in a July 12 to 21, 1983, survey of the upper 1 m surface layer of the German, Browns and Georges Bank region of the Gulf of Maine.

Maine on German Bank to Lurcher Shoal and Grand Manan in their calculations. Watson and Miller (1991) examination of the Scotian Shelf Ichthyoplankton Program surveys from 1978 to 1981 established that most of the offshore lobster larvae were located near Browns and Georges Banks. It was particularly interesting that they found a plume-like distribution of fourth stage lobsters with their abundance diminishing from Browns Bank toward the northeast. The authors conclude that this distribution pattern could be explained by larval dispersion with the prevailing currents and/or surface forcing of waters by summer winds.

We estimated that, in general, there was not enough time available at local temperatures in inshore areas off southwestern Nova Scotia for larval development to reach the settling stage before winter. It was concluded that successful inshore recruitment should be largely confined to small bays where surface temperatures are higher. We calculated that recruitment in southwestern Nova Scotia based on laboratory-determined development rates, local sea-surface temperatures and the prevailing current speeds and directions could be derived primarily from offshore lobsters releasing larvae on the northern face of Georges Bank. In addition, Lawrence and Trites (1983) predicted from models based on the prevailing currents and wind vectors that surface oil from the Georges-Browns Bank region in summer would frequently impact the coastline of southwestern Nova Scotia and the Bay of Fundy with a drift time of more than 20 days. Harding et al. (1983) concluded that the Gulf of Maine could be considered a single lobster recruitment system because larval would be expected to be carried downstream in the counter-clockwise gyre. This conclusion was supported further by the similarity of the commercial lobster landing patterns found around the Gulf suggesting a common environmental control of lobster abundance.

We reinterpreted the earlier 1977/78 larval surveys with the unpublished drift-bottle results of the 1977 surveys, to project larval dispersion from Browns Bank at first hatch (early July) and maximum Stage I abundance (early August)(Harding & Trites 1988). It was concluded that offshore larvae could make an important contribution to recruitment not only to southwestern Nova Scotia but the entire eastern sector of the Gulf of Maine to Casco Bay. Off southwestern Nova Scotia it was calculated that 3.6 million fourth stage lobster larvae were produced inshore compared to 100 million offshore; and, if dispersion predictions were correct, a large part of this inshore production could have been derived from females on Browns and German Banks

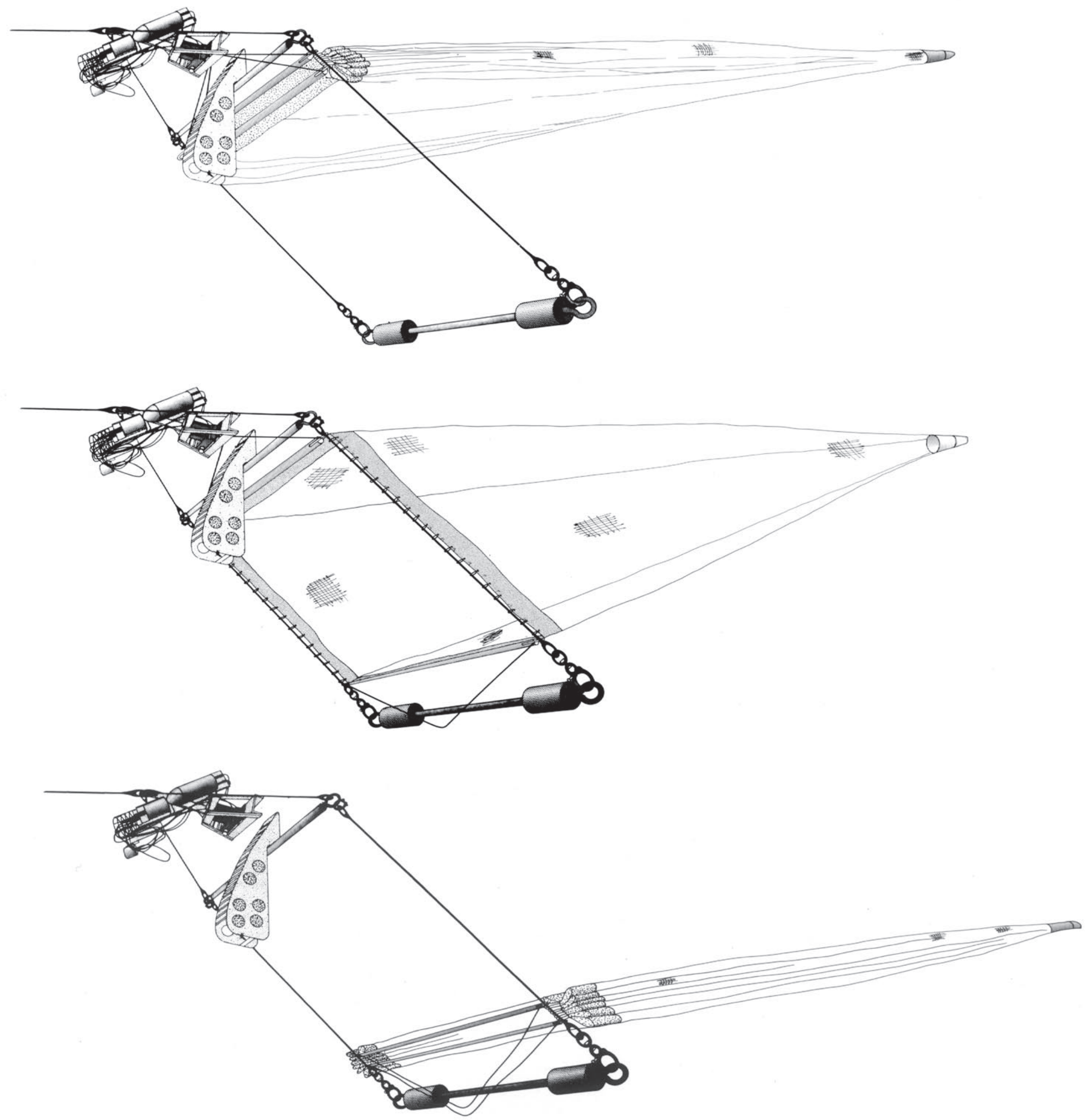

Figure 2. Vass-Tucker trawl designed for larval lobster work, showing deployment (upper), fishing (middle) and closed (lower) positions.

In 1983 we undertook a larval survey of the surface layer (1.3m) to assess the larval hatching areas at Georges and Browns Bank, as a potential "upstream" source of larvae for inshore southwest Nova Scotia. The results reaffirmed that the larval lobster planktonic cycle begins over Browns and German Banks between the second and third week of July and confirmed predictions that the northern flank of Georges Bank could be a prolific source of larvae downstream. All developmental stages were abundant in mid to late July on Georges Bank in surface waters of 14 to 21^0 C (Figure 1). However, the presence of scattered stage IV lobster over Browns Bank and Northeast Channel at temperatures of less than 11^0 C strongly suggests that these larvae were advected into the area from warmer areas "upstream", such as the shelf break east of Northeast Channel or Georges Bank (Figure 1). No lobster larvae were captured at the mouth of Northeast Channel which seems to eliminate this area as a possible source for the larvae. A turning point in our investigations was the finding that the fourth stage lobster larvae were absent in surface waters of the Gulf of Maine proper during daylight but were consistently present if towing was continued after dusk. Stasko & Gordon (1983) reported a lesser but significant vertical movement of stage IV lobsters out of the upper 0.15m during daylight to the 0.3 to 1.3m depths off southwestern Nova Scotia. This inference of deeper larval distributions lead us to the development of the Vass-Tucker trawl for the dis-

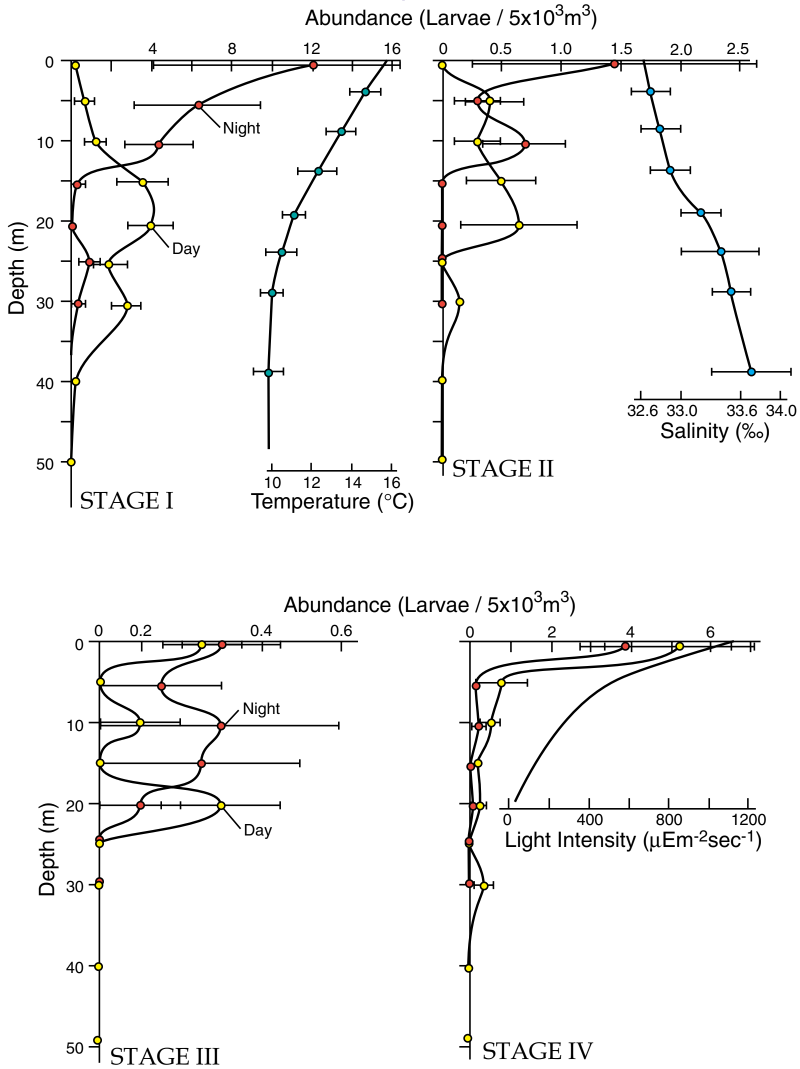

Figure 3. Diurnal vertical distributions of the four planktonic lobster stages found over Browns Bank in August , 1984. Also shown are average temperature, salinity and the mid-day light profiles (Means and standard deviation indicated).

crete subsurface sampling of lobster larvae (Figure 2). The next year our operations were directed to describing the vertical distributions of lobster larvae over Browns Bank. First stage lobster larvae were found to migrate from 15 to 30 metres depth during daylight to the upper 10 metres at night, although a small proportion of the population was present at any one time in the upper metre during the day (Figure 3). Stages II and III larvae were caught too infrequently to establish vertical migration patterns but the results were suggestive of less vertical movement than stage I. Earlier experimental work suggests that immediately after moulting stage I larvae are attracted to the light but this is reversed by the second day. This would explain why there are always some early stage larvae near the surface during daylight. Also the vertical restriction of lobster larvae to the upper mixed layer was confirmed by laboratory studies with vertical temperature gradients (Boudreau et al. 1992). Fourth stage larvae were caught almost entirely at the surface metre over Browns Bank, with no significant difference between day and night abundances.The predominance of the fourth stage lobster in previous offshore surface surveys off southwest Nova Scotia could now be explained by their continuous presence in the surface metre day and night, though occasionally individuals were found throughout the upper mixed layer during daytime. This surface distribution conflicts with our earlier observations in the clear waters of the Gulf of Maine where stage IVs descended below the upper metre in daylight. No such phenomenon was observed at a Georges Bank station with stages III and IVs being equally common in day and night surface samples.

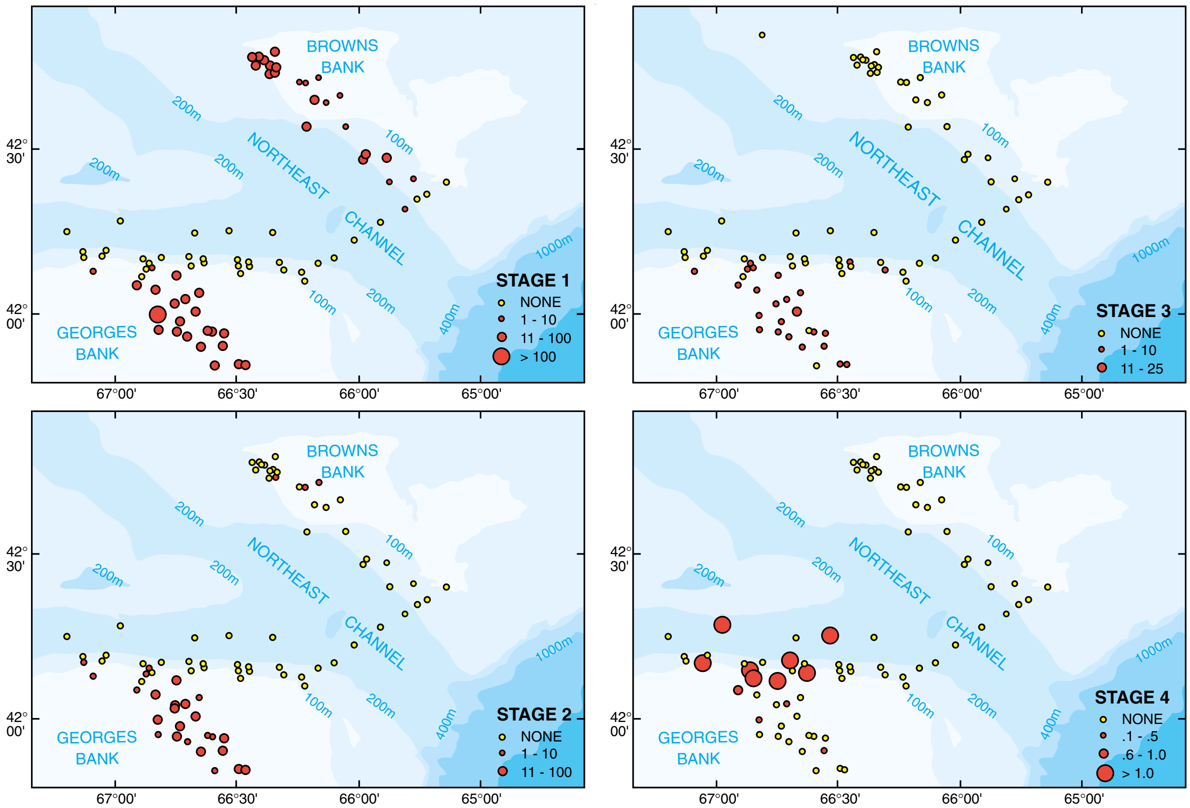

Figure 4. Distribution of larval lobster abundance by developmental stage (#s / 1000 m²) in a July 14 to 28, 1987, study with amalgamated results of horizontal Vass-tucker trawl from 50m depth or the bottom to the sea surface (horizontal tows were taken at 5 m depth intervals in the upper 30 m and 10 m depth intervals below 30m).

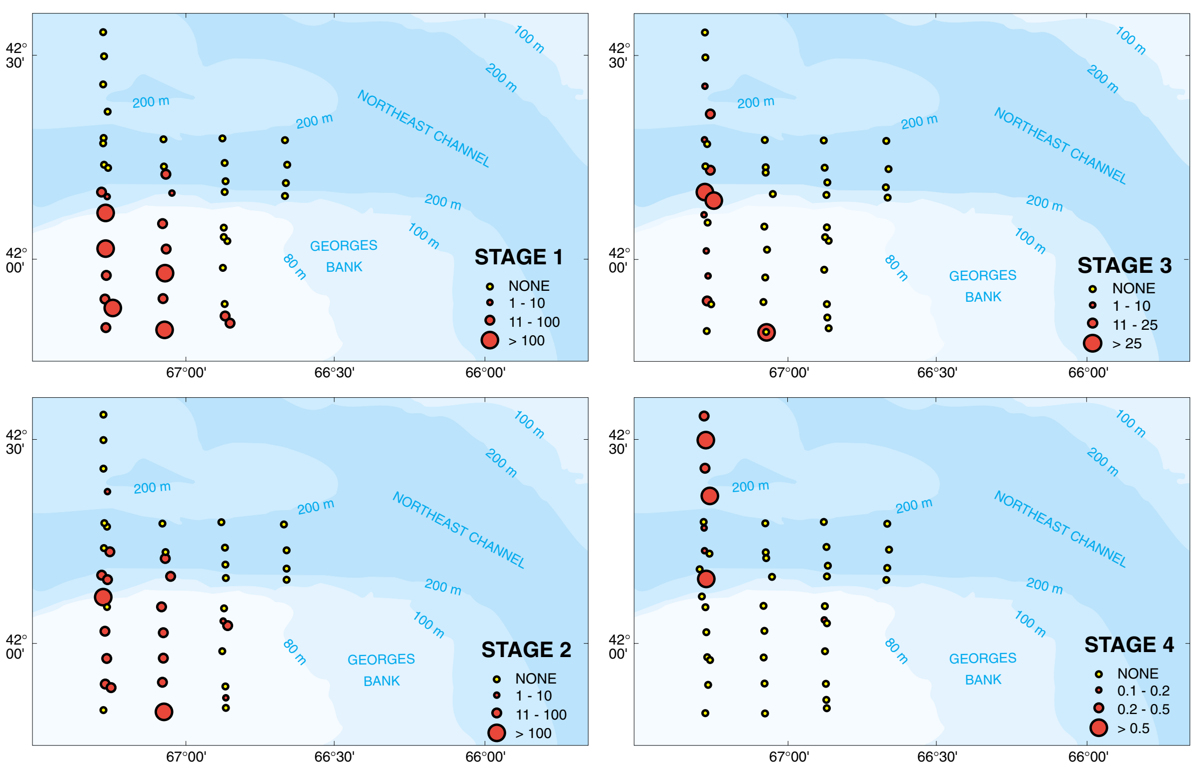

Figure 5. Distribution of larval lobster abundance by developmental stage (#s/ 1000 m²) in the July 14 to 30, 1989, frontal study with stepped oblique Vass-Tucker trawls from 50 m or near bottom to the ocean surface.

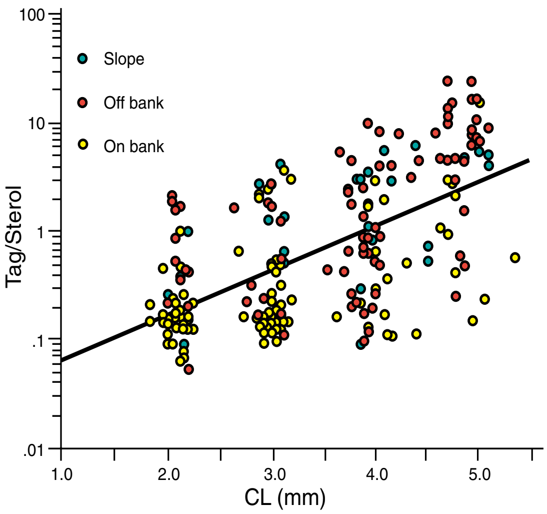

Figure 6. The lipid condition index (triacylglycerol [TAG] to sterol weight ratio) of larval lobsters collected on Georges Bank, along the bank edge and in Gulf of Maine waters adjacent to Georges Bank, in July, 1989.

The subsequent 1987 survey of lobster larvae between Browns and Georges Banks does not have the limitations of previous offshore studies which may have missed substantial portions of the population beneath the surface metre. Stages I and II lobsters were observed over or near Browns Bank (at locations <200m depth) and over Georges Bank (<100m depth) in mid to late July (Figure 4). Very few stage II and no stages III and IV lobster were present over Browns Bank, consistent with previous accounts of the timing of the seasonal cycle there. Stages III and IV lobster were present near Georges Bank at expected higher abundances considering the more advanced hatching time to the south. The distribution of the fourth stage lobsters, however, was centred along the northern slope of Georges Bank with some individuals present in the Gulf of Maine proper. The 1989 frontal study over Georges Bank support these results with stages I and II lobster caught almost entirely over the bank whereas stage IIIs were located on and near the periphery of the bank and stage IVs were mainly off the bank (Figure 5). Directional swimming first occurs in the fourth stage larvae. Either stage IV lobster swim actively through the northern tidal front, are carried off the bank in an eddy or by the action of winds on the surface waters, or are transported "downstrean" from the Cape Cod area where thermal conditions favour more rapid development. Tidal forces near Georges Bank and the seasonal surface circulation of the Gulf of Maine contribute to an eastward, along-bank current or "jet" of up to 50 cm per second during the summer months (Loder et al. 1993).

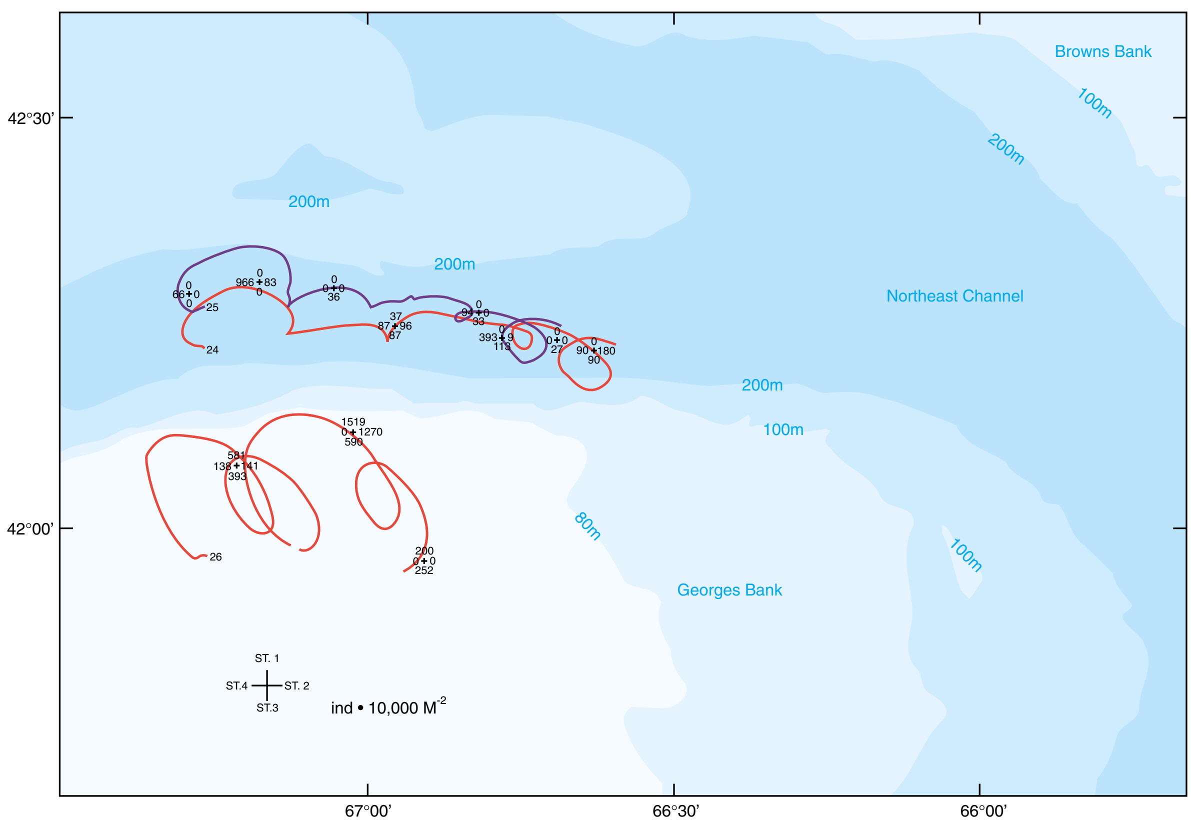

Figure 7. Movement of Loran-C drifters with drogues at 10 m depth and the average larval lobster abundance by developmental stage from three replicate trawls at various locations along their drift track, July 27 to 29, 1989.

There is strong circumstantial evidence that at least the fourth and last planktonic stage may be able to determine to some extent where they settle. It has been shown that lobster larvae orientate into a current in the laboratory (Ennis 1986) and field evidence from around the Magdallen Islands indicates that stages I-III lobster have different centres of distribution from the natatory fourth stage lobster, similar to our findings off Georges Bank (Hudon et al. 1986). Cobb et al. (1989) observed fourth stage lobster swimming in a northerly direction (NW to NE; mean of 37 degrees) at an average speed of 18 cm per second (7-24 cm per second) in the inshore waters of Block Island Sound off Rhode Island. Sasaki (1984) estimates that energy reserves of wild stage IV lobsters would allow continuous swimming for up to 5 days. However, fourth stage lobsters do not swim continuously in flume tanks and field observations indicate food in their guts both day and night (Juinio & Cobb 1992). Fourth stage lobster have been observed to stop and feed on floating insects at sea (Cobb et al. 1989). Katz et al. (1994) have incorporated swimming of stage IV lobsters into an offshore-inshore dispersion model off the coast of Rhode Island.

The lipid content of our lobster larvae was identified and quantified to assess the health and presumed viability of individuals caught over and in the proximity of Georges Bank in 1988 and 1989. Triacylglycerols are the predominant storage lipid in lobster embryos and larvae and their levels subsequently reflect the feeding history of the organism as they are utilized under starvation conditions(Sasaki 1984). Sterols, conversely, are largely structural components of cell membranes which have been found to remain essentially unchanged in larvae after 5 to 6 d starvation. The ratio of the storage triacylglycerols to the structural sterols of the individual has been used successfully as a condition index for larval lobsters in order to avoid the dependency of triacylglycerol content on larval size. The triacylglycerol /sterol ratios of larvae residing on Georges Bank were compared to those collected either on the periphery of the bank or in the Gulf of Maine (Figure 6). Stages III and IV lobster larvae residing off the bank had significantly higher triacylglycerol /sterol ratios than their counterparts caught over Georges Bank in both 1988 and 1989. Stages I and II larvae were not found off the bank in 1988, but the few larvae collected on the periphery of the bank in 1989 had significantly higher triacylglycerol /sterol ratios than the vast majority of the population collected over the bank. This suggests that either the larval feeding conditions were better off the bank or that predator avoidance caused the larvae to use up more energy on the bank. The latter appears more plausible at this time of year because the bank is swarming with sea fleas (Gammarus annulatus), arrow worms (Sagitta elegans), etc., and planktivorous fishes such as billfish (Scomberesox saurus), sandlance (Ammodytes americanus), etc., whereas biological production has slowed considerably in the central Gulf of Maine in the lower trophic levels following the establishment of a strong summer stratification of the surface waters (Sissenwine et al. 1984).

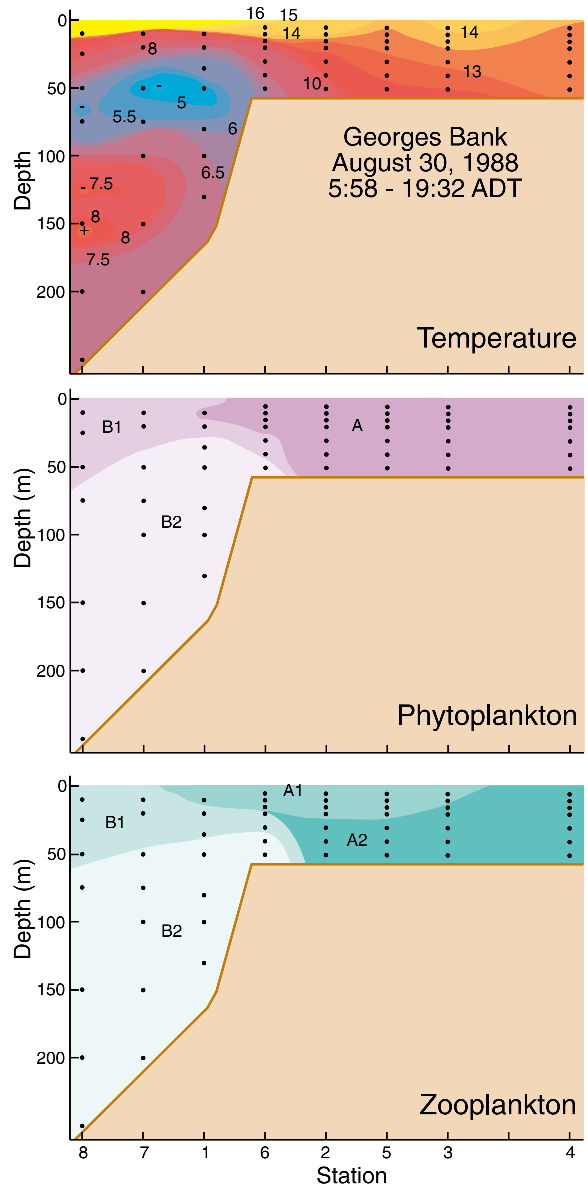

Figure 8. The distributions of temperature, phytoplankton and zooplankton communities across the northern edge of Georges Bank, August 30, 1988.

Currents may also help to transport larvae off Georges Bank. For example, satellite imagery shows plumes of water sometimes escaping off the northern edge of Georges Bank into the Gulf of Maine. Strong winds can push water and larvae off the bank as evident from the tracks of drifting buoys. For example, on August 23, 1988, four buoys deployed on the northern edge of the Bank were tracked for 3 days during which easterly winds blew at speeds of up to 12 m per second. Three of the four moved northward off the Bank as well as upwind in the direction of the prevailing current. While eddies and winds may transport lobster larvae northward it must be remembered that these processes are not continual but only occur occasionally. For example, surface drifters were not observed to leave the bank in July and August of 1988 during five other deployments of 2 to 4 buoys each that were tracked for several days. Between July 14 and 29, 1989, 28 Loran-C drifters drogued at 10 m and 14 surface ARGOS drifters were found to maintain their position either on or off the bank or occasionally to move from near the northern edge onto the bank. During two buoy deployments the abundance of lobster larvae from the immediate vicinity of six Loran-C drifters was analyzed for change over the three to four sampling intervals (Figure 7). A significant alteration of the larval lobster population occurred during the drift time of the three on-bank drifters whereas no difference was observed in the immediate vicinity of the three drifters located in the Gulf of Maine. The latter population was dominated by the more advanced stages whereas the on-bank population consisted mainly of first and second stage lobsters. One plausible reason why the off-bank drifters were more successful in following the larval population is that the latter stage larvae do not undergo such a marked daily vertical migration and therefore their drift was approximated better by the 10m drogue. On the other hand, first stage lobster are known to reside chiefly between 15 and 30m depth during daylight and above a depth of 10m during the night on nearby Browns Bank. It is less likely, therefore, that their movement would be expected to approximate that of the 10m drogued drifters.

Insight can be gained also from the plankton assemblages that exist across the frontal zone on Georges Bank as illustrated by a transect run in August of 1988 (Figure 8). In the upper panel the strong summer stratification in the Gulf of Maine, portrayed by the sharp temperature gradient in the upper 30 to 50 m, gradually dissipates over the bank through tidally induced turbulence in the frontal zone on Georges Bank. The front was located close to Station 4 during this transect. The distribution of the phytoplankton and zooplankton was similar, indicating that the greater vertical mobility of the larger organisms was not altering substantially the species distribution. A bank association existed (designated pattern A), which can be subdivided into a near-surface (A1) and deeper-water component (A2) in the case of the zooplankton, that extends from the tidally well-mixed area to near the edge of the bank along the bottom but out over the edge of the bank in the more surface waters. The Gulf of Maine association can likewise be divided into a shallow- (B1) and deep-water component (B2). This bank plankton pattern (A) corresponds to our observations of the distribution of first and second stages lobsters, but not the more plentiful presence of Stages III and IVs in the B1 area off the bank

Most recently, from 1996 to the present, a concentrated effort has been directed towards larval drift experiments with satellite-tracked drogues and larval sampling at different locations between Georges, Browns and German Banks and inshore southwest Nova Scotia. This phase will culminate in the modelling of larval drift using a Gulf of Maine circulation model to account for density-driven and tidally induced currents and the average summer wind field (speed and direction). This, combined together with information on larval release, larval development, subsequent drift and swimming will be used to predict lobster settlement areas in the Gulf of Maine. The settlement predictions of model runs will be evaluated by 1). comparison with observed drifter paths 2). known distributions of the final planktonic fourth stage and 3). correspondence to the major lobster grounds.

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Organization and Staff

ToC

The Bedford Institute of Oceanography (BIO), the Gulf Fisheries Centre (GFC), 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 the names and managers of the science divisions of DFO/Maritimes Region, research groups of NRCan and EC at BIO, and other DFO units that have staff at BIO as at the time of compilation (September 1998). The location of the manager is indicated in the bracket following the telephone number (MC - Maritime Centre in Halifax; QS - Queen Square in Dartmouth). A staff list follows, in which the group for which an individual works is given in abbreviated form following his/her name: the abbreviations used are defined in the list of groups below.

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Staff List

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Amos	Carl	L	(GSC.2)
Anderson	Bruce		(SCI.2)
Anderson	Debbie	L	(SCI.6)
Anderson	Judy	CR	(SCI.3)
Anderson	Leroy	A	(SCI.3)
Anstey	Carol	M	(SCI.6)
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Black	Jerry	AP	(SCI.7)
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Brown	Carolyn	G	(GSC.4)
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Burke	Garry	P	(CCG.2)
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Campbell	Robert	E	(SCI.5)
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Colford	Brian		(FIN.1)
Colford	Brian		(FIN.1)
Coll	Rhonda		(FIN.2)
Coll	Rhonda		(FIN.2)
Collette	Phyllis		(SCI.4)
Collier	Katherine	J	(SCI.8)
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Collins	Lori		(FIN.2)
Collins	Lori		(FIN.2)
Collins	Mike	B	(SCI.2)
Comeau	Michel		(SCI.5)
Comeau	Peter	A	(SCI.7)
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Conrod	John	M	(SCI.8)
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Coolen	Christopher		(SCI.2)
Cormier-Murphy	Paryse		(SCI.1)
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Covey	Michele	D	(SCI.5)
Craft	Andrew		(SCI.2)
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Cranford	Peter	J	(SCI.6)
Cranston	Ray	E	(GSC.2)
Crilley	Bernie	J	(GSC.1)
Crowell	Victor	E	(SCI.3)
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Cunningham	John		(SCI.2)
Currie	Claudia	G	(GSC.3)
Currie	David	A	(SCI.3)
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Currie	Randy	J	(GSC.3)
Currie	Ted		(SCI.4)
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Doiron	Adele		(SCI.8)
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Drinkwater	Ken	F	(SCI.8)
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Duggan	Dave	R	(SCI.5)
Duggan	Ron	E	(SCI.5)
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Fanning	Paul	L	(SCI.7)
Farrell	Wanda	M	(SCI.7)
Faulkner	Russell		(FIN.1)
Fennell	Janice	M	(SCI.7)
Fennell	Jim		(SCI.7)
Fensome	Rob	A	(GSC.1)
Ferguson	Ernest		(SCI.4)
Fiander	Anna	R	(FIN.2)
Fiander	Anna	R	(FIN.2)
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Frizzle	Doug		(SCI.2)
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Gale	Jim		(INF.1)
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Gorveatt	Mike	E	(GSC.2)
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Hébert	Marcel		(SCI.5)
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Hebert-Sellars	Joan	S	(FIN.1)
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Hellou	Jocelyne		(SCI.6)
Hemphill	Marc	J	(INF.2)
Henderson	Joni	M	(SCI)
Henderson	Terry	H	(GSC.4)
Hendry	Chris		(SCI.1)
Hendry	Ross	M	(SCI.8)
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Hepworth	Debbie	L	(SCI.2)
Herman	Alex	W	(SCI.8)
Hopkins	Jon		(CCG.2)
Horne	Edward	PW	(SCI.8)
Howes	Ken	G	(SCI.1)
Hubley	Phil	D	(SCI.3)
Hughes	Mike	D	(GSC.2)
Hunt	Joe	J	(SCI.7)
Hurlbut	Tom	R	(SCI.7)
Hurley	Peter	CF	(SCI.7)
Irwin	Brian	D	(SCI.8)
Isenor	Anthony	W	(SCI.8)
Jackson	Arthur	E	(GSC.1)
Jackson	Jeff	W	(SCI.8)
Jackson	Ruth	H	(GSC.3)
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Jodrey	Fred	D	(GSC.2)
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Johnston	Larry	B	(GSC.2)
Jollymore	Brian	H	(SCI.4)
Jones	E	Peter	(SCI.8)
Jones	Roger	N	(SCI.2)
Jones	Ross		(SCI.3)
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Kenchington	Ellen	L	(SCI.5)
Kennedy	Eddy		(SCI.1)
Kennedy	Mary	K	(SCI.8)
Kepkay	Paul	E	(SCI.8)
Kew	Andrea		(SCI.1)
King	Graham		(SCI.2)
King	Thomas	L	(SCI.6)
Knox	Derek	J	(SCI.6)
Koeller	Peter	A	(SCI.5)
Koziel	Nelly		(GSC.1)
Léger	Claude	E	(SCI.6)
Lévesque	Maurice	R	(SCI.4)
LaCroix	Gilles	L	(SCI.6)
Lake	Paul	B	(GSC.1)
Lambert	Tim	C	(SCI.7)
Lamplugh	Mike	J	(SCI.2)
Landry	Marilyn	A	(SCI.8)
Landry	Thomas		(SCI.1)
Landsburg	Wade		(SCI.4)
Landsburg	Wade	A	(SCI.5)
Lanteigne	Marc		(SCI.5)
Lapierre	Richard		(CCG.3)
LaViolette	Glenda	E	(FIN.1)
Lavoie	René	E	(SCI)
Lawrence	Don	J	(SCI.8)
Lawrence	Kerry	B	(CCG.2)
Lawton	Peter		(SCI.5)
Lazier	John	RN	(SCI.8)

LAST NAME	FIRST NAME	INITIAL	AFFILIATION
Leadbetter	Jim	C	(SCI.4)
LeBlanc	Andrée		(SCI.1)
LeBlanc	Christopher		(SCI.2)
LeBlanc	Claude	H	(SCI.7)
LeBlanc	JoAnne		(FIN.1)
LeBlanc	Neil		(SCI.1)
LeBlanc	Paul		(SCI.3)
LeBlanc	Paul	H	(SCI.3)
LeBlanc	Rita	M	(SCI.7)
LeBlanc	Tommie	D	(SCI.1)
LeBlanc	William	H	(GSC.2)
Lee	Ken		(SCI.6)
Legault	John	A	(SCI.9)
LeGresley	Murielle		(SCI.6)
LeJeune	Dianne		(CCG.3)
Leonard	B(Bernie)	M	(CCG.2)
Leonard	Jim	D	(SCI.6)
Levac	Carol	M	(INF.2)
Lewis	Mike	CF	(GSC.2)
Li	Michael		(GSC.2)
Li	William	K	(SCI.8)
Lively	Bob		(SCI.8)
Lively	Robert	R	(SCI.8)
Loch	John	S	(SCI)
Locke	Andrea		(SCI.3)
Loder	John	W	(SCI.8)
Loewen	Lois		(FIN.2)
Loewen	Lois		(FIN.2)
Longard	David	A	(SCI.3)
Longmire	Robbie		(SCI.1)
Loring	Doug	H	(SCI.6)
Losier	Randy	J	(SCI.8)
Lundy	Mark	J	(SCI.5)
Lutzac	Tim	G	(SCI.3)
Lux	Muriel		(SCI.8)
Macdonald	Alastair		(SCI.8)
MacDonald	Barry		(SCI.5)
Macdonald	Barry		(SCI.1)
MacDonald	Bill	M	(SCI.3)
MacDonald	Kirk	A	(SCI.2)
MacDonald	Maureen		(GSC.2)
MacDonald	Melissa	A	(SCI)
MacDonald	Theresa	M	(CCG.2)
MacDougall	Colin	J	(SCI.7)
MacDougall	William		(CCG.2)
MacEachern	Bill	J	(SCI.7)
MacGowan	Bruce	W	(SCI.2)

LAST NAME	FIRST NAME	INITIAL	AFFILIATION
MacHattie	George		(CCG.3)
MacInnis	Charles		(SCI.4)
MacIntosh	Troy		(SCI.2)
MacIsaac	Kevin	G	(SCI.6)
MacKeigan	Kenneth	G	(SCI.6)
MacKinnon	Ann-Margaret	F	(SCI.1)
MacKinnon	William	G	(GSC.2)
MacLean	Brian		(GSC.2)
MacLean	Melanie	A	(SCI.4)
MacLeod	Grant	NJ	(SCI.2)
MacMillian	William	C	(GSC.1)
Macnab	Ron	F	(GSC.3)
MacNeil	Nancy	E	(INF.2)
MacNeill	Allan		(CCG.3)
Maillet	Andre		(CCG.1)
Mallet	Pierre		(SCI.5)
Manchester	Keith	S.	(GSC.2)
Mann	Kenneth	H	(SCI.6)
Marks	Linda	J	(SCI.7)
Marshall	Larry	T	(SCI.3)
Martell	Jim	H	(INF)
Martell	John	D	(SCI.1)
Martin	Jennifer	L	(SCI.6)
Martin	Jim	D	(SCI.1)
Martin	Maureen	A	(FIN.2)
Martin	Maureen	A	(FIN.2)
Martin-Robichaud	Debbie	J	(SCI.1)
Mason	Clive	S	(SCI.8)
Maxwell	Grace		(SCI.6)
Mazerall	Anne		(FIN.2)
Mazerall	Anne		(FIN.2)
Mazerall	Anne		(GSC.1)
McAlpine	Donald	K.	(GSC.1)
McCarthy	Clare		(SCI.2)
McCarthy	Dave	P	(SCI.2)
McCarthy	Paul	L	(SCI.2)
McClelland	Gary		(SCI.1)
McGladdery	Sharon	E	(SCI.1)
McGormack	George	M	(GSC.4)
McGregor	Rita		(CCG.3)
McKeown	David	L	(SCI.8)
McMillan	Jim	I	(SCI.7)
McNeil	Lisa	A	(SCI.8)
McQuaid	Shayne	L	(SCI.4)
McRae	Tara		(INF.2)
McRuer	Jeff	K	(SCI.7)
Melvin	Gary	D	(SCI.7)

LAST NAME	FIRST NAME	INITIAL	AFFILIATION
Merchant	Susan		(GSC.1)
Michele	LeBlanc		(SCI.4)
Middleton	Cecilia		(GSC.4)
Miller	Anne		(CCG.2)
Miller	Robert	O.	(GSC.4)
Miller	Robert	J	(SCI.5)
Milligan	Timothy	G	(SCI.6)
Mitchell	Michel	R	(SCI.8)
Moeller	Dag		(SCI.1)
Moffatt	John	D	(SCI.6)
Mohn	Bob	K	(SCI.7)
Moir	Phil	N	(GSC.1)
Moody	Scott		(SCI.2)
Moore	David	S	(SCI.3)
Moran	Kathryn		(GSC.2)
Morgan	Sharon	P	(SCI.10)
Morin	Roderick		(SCI.7)
Moriyasu	Mikio		(SCI.5)
Morris	Pat		(FIN.1)
Morris	Richard	J	(INF)
Morrison	Carol		(SCI.1)
Morse	David		(CCG.3)
Mowbray	Fran	K	(SCI.3)
Mudie	Peta	J	(GSC.2)
Murphy	Jim	P	(SCI.7)
Murphy	Leaming		(SCI.4)
Murphy	Robert	J	(GSC.2)
Murphy	Dena	E	(SCI.9)
Murray	Michael		(SCI.3)
Myers	Carl		(COM)
Myers	Darlene		(FIN.1)
Myra	Valerie	M	(SCI.11)
Myres	Stanley		(CCG.3)
Myres	Steven		(CCG.3)
Needler	George	T	(SCI.8)
Neil	Steven		(SCI.1)
Neilson	Brian	S	(CCG.2)
Neilson	John	D	(SCI.7)
Nelson	Cecil	W	(SCI.7)
Nelson	Rick	WP	(SCI.6)
Nicholson	Dale		(SCI.2)
Nickerson	Bruce	M	(SCI.8)
Nielsen	Jess	A.	(GSC.2)
Niven	Sherry	EH	(SCI.6)
Nolan	Steve	C	(SCI.5)
Norton	Larry	G	(SCI.2)
Nowlan	Robert	J	(SCI.7)

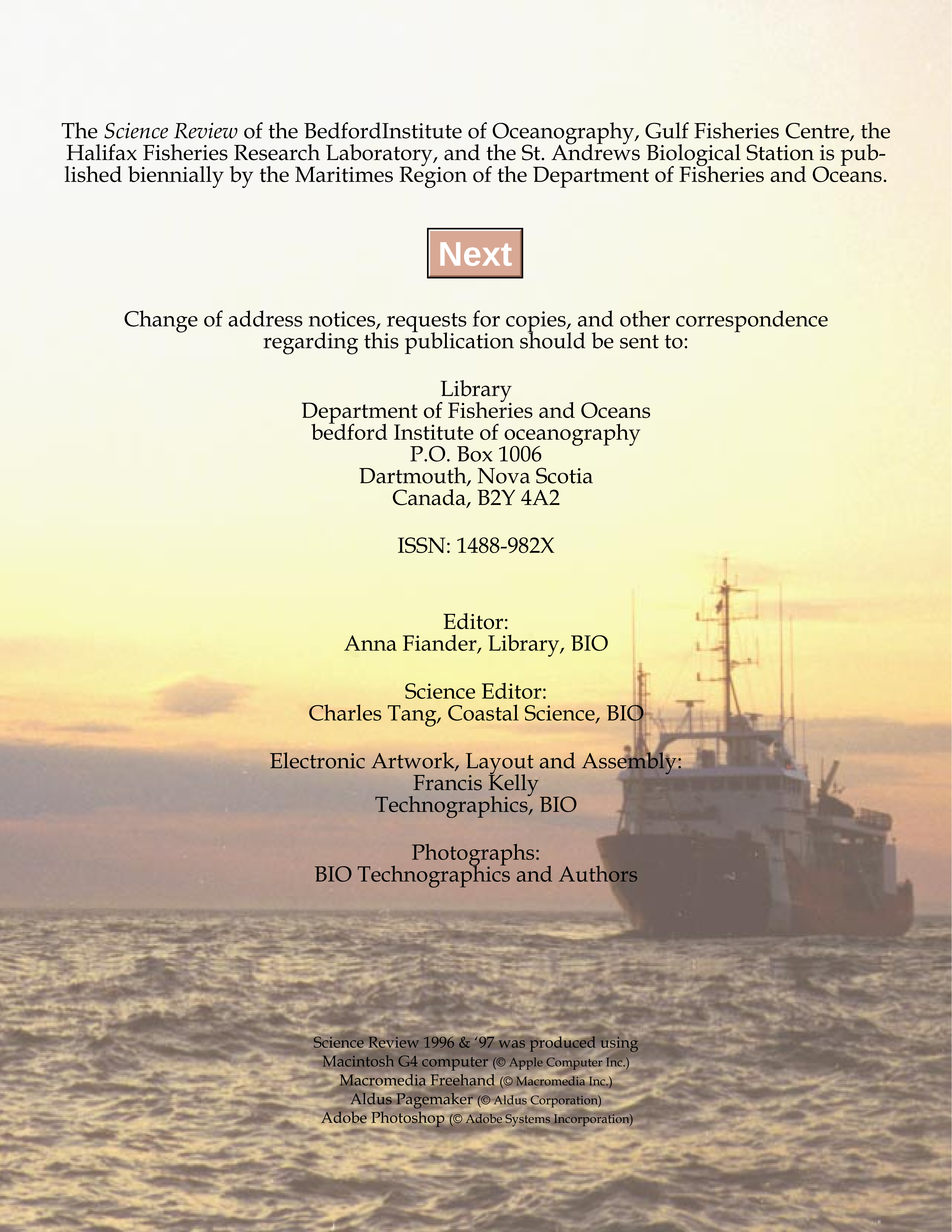
LAST NAME	FIRST NAME	INITIAL	AFFILIATION
Nunn	Steven	G	(SCI.2)
O'Boyle	Robert	N	(SCI.11)
O'Keefe	Cathy		(SCI.2)
O'Neil	Shane	F	(SCI.3)
O'Neill	John	T	(INF.1)
O'Reilly	Charles	T	(SCI.2)
O'Reilly-Shrum	Rose Anne		(CCG.1)
O'Rourke	Michael		(CCG.3)
Oakey	Gordon	N	(GSC.3)
Oakey	Neil	S	(SCI.8)
Ochieng-Mitula	John		(SCI.1)
Oickle	Lloyd		(CCG.3)
Ouellette	Marc		(SCI.1)
Page	Fred	H	(SCI.8)
Palmer	Nick	J	(SCI.2)
Palmer	Richard		(SCI.2)
Parks	Paul		(SCI.2)
Parrott	Russell	D	(GSC.2)
Parsons	Stephen		(SCI.2)
Paterson	Sue	P	(INF.2)
Paul	Kenneth	D	(SCI.2)
Payzant	Linda	A	(SCI.8)
Pelkey	Robert	W	(SCI.3)
Perley	Greg		(SCI.3)
Perley	Peter	D	(SCI.7)
Perrie	William	A	(SCI.8)
Perry	Stephen	W	(GSC.3)
Peterson	Ingrid	K	(SCI.8)
Peterson	Richard		(SCI.1)
Petrie	Brian	D	(SCI.8)
Petrie	Liam	M	(SCI.8)
Pettipas	Roger		(SCI.8)
Pezzack	Doug	S	(SCI.5)
Phillips	Georgina	A	(SCI.6)
Phillips	Ted	F	(SCI.8)
Pickard	Russell	P	(SCI.3)
Pickrill	Richard (Dick)	A	(GSC.2)
Pietrzak	Bob	C	(SCI.2)
Piper	David	JW	(GSC.2)
Platt	Trevor	C	(SCI.8)
Poirier	Gloria	A	(SCI.7)
Poirier	Martina		(SCI.7)
Porteous	David	M	(INF.2)
Porter	Catherine		(SCI.8)
Porter	Julie	M	(SCI.7)
Power	Mike	J	(SCI.7)
Preston	William		(CCG.3)

LAST NAME	FIRST NAME	INITIAL	AFFILIATION
Price	Roderick	A	(SCI.3)
Prime	Wayne	A	(GSC.3)
Prinsenberg	Simon	J	(SCI.8)
Prouse	Nick	J	(SCI.6)
Quick	Holly	A	(CCG.2)
Quon	Charlie		(SCI.8)
Randhawa	Vicki		(SCI.2)
Reid	Carmen		(CCG.3)
Reid	Jim	GG	(SCI.7)
Reid	Joan	P	(SCI.4)
Reid	John	C	(SCI.1)
Rhyno	Kevin	P	(CCG.2)
Richard	Gisèle	M	(SCI.5)
Richard	Bernard		(EC)
Ricketts	Troy		(SCI.2)
Ritchie	William	B	(SCI.4)
Ritter	John	A	(SCI.3)
Robert	Ginette		(SCI.5)
Robertson	Kevin	R	(GSC.2)
Robichaud	David	A	(SCI.5)
Robichaud	Guy		(SCI.5)
Robichaud	Louise	M	(SCI.5)
Robichaud /LeBlanc	Kim		(SCI.3)
Robinson	Shawn	MC	(SCI.1)
Rockett	Paula		(FIN.1)
Rockwell	Gary		(SCI.2)
Roddick	Dale	L	(SCI.5)
Rodger	Glenn	A	(SCI.2)
Rollin	Jeannine	M	(GSC.4)
Rommens	Melissa		(SCI.1)
Roop	Dave	M	(SCI.2)
Ross	Charlie	K	(SCI.8)
Ross	Jim	B	(SCI.4)
Rosse	Raymond	J	(FIN.1)
Rowell	Terrence	W	(SCI.6)
Rowsell	Tom	G	(SCI.2)
Roy	André		(SCI.2)
Rozon	Chris	F	(SCI.2)
Rumley	Betty	C	(SCI.2)
Rutherford	Karen		(SCI.3)
Rutherford	Robert	J	(SCI.9)
Ruxton	Mike	A	(SCI.2)
Ryan	Robert	F	(SCI.8)
Ryan	Stephen	R	(SCI.8)
Salisbury	Matt	H	(GSC.3)
Sameoto	Doug	D	(SCI.8)
Sampson	Carol	J	(SCI.4)

LAST NAME	FIRST NAME	INITIAL	AFFILIATION
Samson	Robert	G	(FIN.1)
Sandstrom	Halmuth		(SCI.8)
Saunders	Karen	S	(SCI.6)
Saunders	Richard		(SCI.1)
Savoie	Fernand		(SCI.5)
Scattolon	Faith	G	(SCI.9)
Schafer	Chales	T	(GSC.2)
Schell	Trecia	M	(SCI.6)
Schipilow	Cathy	M	(SCI.2)
Scotney	Murray	D	(SCI.8)
Semple	Robert	E	(SCI.5)
Senay	June		(SCI.2)
Sephton	Tom	W	(SCI.1)
Sharp	Glyn	J	(SCI.5)
Shaw	John		(GSC.2)
Shellnutt	Sheila	E	(SCI.6)
Shen	Yingshuo		(SCI.8)
Sherin	Andy	G	(GSC.2)
Shore	Jennifer		(SCI.8)
Showell	Mark	A	(SCI.7)
Silvert	William	L	(SCI.6)
Simmons	Carol Ann	R	(SCI.4)
Simms	Judy	B	(SCI.6)
Simon	Jim	E	(SCI.7)
Sinclair	Alan	F	(SCI.7)
Sinclair	Michael		(SCI.7)
Smith	Alan	S	(SCI.2)
Smith	Andrew		(SCI.2)
Smith	Don	C	(FIN.1)
Smith	John	N	(SCI.6)
Smith	Kathi	L	(CCG.2)
Smith	Marion	TE	(SCI.8)
Smith	Peter	C	(SCI.8)
Smith	Stephen	J	(SCI.5)
Smith	Stuart	D	(SCI.8)
Solomon	Frank		(SCI.3)
Solomon	Steve	M	(GSC.2)
Sonnichsen	Gary	V	(GSC.2)
Spears	Tobias		(INF.1)
Spry	Jacqueline		(SCI.8)
Spry	Jeff		(SCI.8)
Srivastava	Shiri	P	(GSC.3)
Steeves	George		(CCG.3)
Stepanczak	Mike		(INF.2)
Stepanczak	Mike		(SCI.8)
Stephenson	Mary	F	(SCI.1)
Stephenson	Robert	L	(SCI.7)

LAST NAME	FIRST NAME	INITIAL	AFFILIATION
Stewart	Debbie	A	(SCI.3)
Stewart	Diane		(FIN.2)
Stewart	James	E	(SCI.6)
Stewart	Diane		(FIN.2)
Stirrat	J	Bruce	(CCG.2)
Stobo	Nancy	J	(SCI.7)
Stobo	Wayne	T	(SCI.7)
Stone	Heath	H	(SCI.7)
Strain	Peter	M	(SCI.6)
Strong	Mike	B	(SCI.5)
Stuifbergen	Nick	HJ	(SCI.2)
Sutherland	Danielle		(SCI.3)
Swain	Doug	P	(SCI.7)
Swan	Perry	G	(SCI.1)
Sweeney	Reg	K	(SCI.4)
Swetnam	Dave		(INF.2)
Tang	Charles	CL	(SCI.8)
Taylor	Robert	B	(GSC.2)
Taylor	Tom		(SCI.1)
Terrien	Michel	C	(SCI.2)
Thomas	Frank	C	(GSC.1)
Thompson	Brian	D	(SCI.4)
Topliss	Brenda	J	(SCI.8)
Toulany	Bechara	J	(SCI.8)
Tremblay	John	M	(SCI.5)
Tremblay	Diane		(EC)
Trippel	Ed	A	(SCI.1)
Trudeau	Maureen		(FIN.1)
Trynor	John	D	(SCI.1)
Tvedt	Harald		(SCI.1)
Van Eeckhaute	Lou	AM	(SCI.7)
Varma	Herman	P	(SCI.2)
Vass	Peter	W	(SCI.6)
Vasseur	Jeff		(SCI.2)
Verhoef	Jacob		(GSC.4)
Vetese	Barbara	T	(GSC.4)
Vienneau	Réjean		(SCI.5)
Vromans	Albert	H	(SCI.8)
Vromans	Albert		(SCI.6)
Waddy	Susan	L	(SCI.1)
Wade	Elmer	J	(SCI.5)
Wade	John	A.	(GSC.1)
Waite	Linda	E	(SCI.8)
Waiwood	Brenda	A	(SCI.1)
Wallace	Valerie		(FIN.1)
Wang	Chou	K	(SCI.8)
Webb	Malcolm	A	(SCI.3)

LAST NAME	FIRST NAME	INITIAL	AFFILIATION
Wentzell	Cathy	A	(SCI.7)
Westhead	Maxine		(SCI.9)
White	George	N	(SCI.8)
White	Wesley	J	(SCI.4)
Wiele	Heinz	F	(CCG.3)
Wildish	David	J	(SCI.6)
Wile	Bruce	D	(GSC.2)
Williams	Charlene		(INF.2)
Williams	Graham	L.	(GSC.1)
Williams	Patricia	M	(SCI.8)
Williamson	Marie-Claude		(GSC.3)
Williamson	Mark	A	(GSC.3)
Willis	Doug	E	(SCI.6)
Wilson	Scott	J	(SCI.7)
Winchester	Peter	J	(SCI.4)
Winters	Gary	V	(GSC.2)
Wong	Paddy	W	(INF.2)
Wright	Dan	G	(SCI.8)
Wright	Morley		(CCG.3)
Xu	Zhigang		(SCI.8)
Yao	Tom		(SCI.8)
Yashayaev	Igor		(SCI.8)
Yeats	Phillip	A	(SCI.6)
Youle	Gordon	D	(SCI.8)
Young	Gerry	A	(SCI.7)
Young	Scott	W	(SCI.8)
Young	Jamie		(EC)
Young-Lai	Wilfred	W	(SCI.1)
Zamora	Phil	J	(SCI.4)
Zemlyak	Frank		(SCI.8)
Zhang	Sheng		(SCI.8)
Zitko	Vlado	E	(SCI.6)
Zwanenburg	Kees	CT	(SCI.7)



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