The Atlantic Zone Monitoring Program (AZMP): Review of 1998-2003

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THE ATLANTIC ZONE MONITORING PROGRAM (AZMP): REVIEW OF 1998-2003

By

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ABSTRACT

Pepin, P., Petrie, B., Therriault, J.-C., Narayanan, S., Harrison, G., Chassé, J., Colbourne, E., Gilbert, D., Gregory, D., Harvey, M., Maillet, G., Mitchel, M., and Starr, M. 2005. The Atlantic Zone Monitoring Program (AZMP): Review of 1998-2003. Can. Tech. Rep. Hydrogr. Ocean Sci. 242: v + 87 p.

We outline the results of the self-assessment by the Atlantic Zone Monitoring Program (AZMP) based on the milestones set out in the original proposal and on a series of key issues identified during the Fifth Annual General Meeting of the Atlantic Zone Monitoring Program and supported by the Atlantic Science Directors. The report is divided into 12 sections which aim at providing an overview of the program's accomplishments, progress to date as well as identifying key concerns about maintaining current program activities and future developments. The report is capped with four sections that outline some of the benefits in the understanding and predictability of marine systems that have been derived from continued long-term monitoring activities.

RÉSUMÉ

Pepin, P., Petrie, B., Therriault, J.-C., Narayanan, S., Harrison, G., Chassé, J., Colbourne, E., Gilbert, D., Gregory, D., Harvey, M., Maillet, G., Mitchel, M., and Starr, M. 2005. The Atlantic Zone Monitoring Program (AZMP): Review of 1998-2003. Can. Tech. Rep. Hydrogr. Ocean Sci. 242: v + 87 p.

Ce rapport présente les résultats de l'auto-évaluation du Programme de Monitorage de la Zone Atlantique (PMZA) basée sur les échéances précisées dans la proposition originale et sur une séries sujets identifies durand la Cinquième Réunion Générale du Programme de Monitorage de la Zone Atlantique et appuyer par les Directeurs des Sciences Atlantique. Ce rapport est divisé en 12 sections qui presentment un apercu des accomplisments du programme, du progress, ainsi que l'identification des soucis concernant le maintient des activitées courantes du programme et des futures developments. Ce rapport se termine avec quatres sections qui démontrents certains des benefices acquis par la compréhension et de la prévisions des systèmes marins qui ont été obtenus au cours des activitées de monitorage a long terme.

EXECUTIVE SUMMARY

The Atlantic Zone Monitoring Program (AZMP) has met the objectives of developing and implementing an observational program but the degree to which seasonal and interannual variations can be characterized varies among the variables being monitored;

AZMP meets the international standards needed to contribute to a sustained, systematic, and long-term observation system that provides end products and services about the state of marine ecosystem;

The current operational structure is effective for the operational activities of the program but we recommend that global reporting of AZMP activities and issues should be presented to the National Science Directors Committee (NSDC) rather than the Atlantic Science Directors Committee (ASDC);

The minimum observation system covered by AZMP activities have resulted in a significantly enhanced and coordinated monitoring of the marine ecosystem but demands on personnel and vulnerability of A-base resources could compromise our ability to continue to meet AZMP objectives;

There are resources that could make the program more effective, including greater use of new technologies (e.g. satellite and in situ sensors), databases and modelling. These would enhance aspects of the monitoring program and increase long term efficiency. However, current resources within AZMP for development and operationalization are modest and would require initial capital investment and infrastructure support;

The ability of AZMP to resolve seasonal and inter-annual variability in the variables is greatest for physical variables and weakest for biological variables, due in part to the limited time series available for the latter (see Section 1). Winter sampling remains limited and even a moderate increase in observations would be of great benefit to establishing the state of marine ecosystems; Regions with limited coverage include the northern Gulf of St. Lawrence, the Labrador and NE Newfoundland shelves, the south coast of Newfoundland; Nowhere is sampling excessive.

There is no duplication of effort in data collection: conventional sampling is essential to calibrate remote sensing while the latter provides greater spatial and temporal coverage over a limited portion of the water column (in the case of satellites) or of the region (in the case of Continuous Plankton Recorder (CPR);

AZMP provides multidisciplinary assessment of environmental status and draws on other monitoring activities to provide a more thorough perspective. While enhancements to existing databases (e.g. through archival sources) are continuing in order to improve understanding and broaden the scope of the program greater progress would be achieved if more scientific effort could be directed at synthesis and interpretation;

AZMP cannot sustain its present level of activities with present resources. AZMP relies heavily on A-base resources, which are subject to changing priorities, and has limited capacity to address emerging issues or renewal of resources; there is growing imbalance between collection and interpretation because of increasing demands for advice;

AZMP data management requirements have resulted in significant advancement in the way Fisheries and Oceans Canada (DFO) manages, safeguards and provides access to its data; there has been a heavy reliance on A-base resources for data management; more effort will be required to deliver truly integrated data sets from the multi-disciplinary AZMP analyses;

AZMP has developed and implemented a standard reporting format (e.g. Ecosystem Status Report (ESR), Research documents, AZMP bulletin) presented annually for peer review; AZMP has also responded to client needs as they arose; data are readily available and improvements for better access and interpretation are underway;

We recommend that greater efforts need to be directed at the comprehensive analysis and modelling of biological, chemical and physical variables (together and separately) to provide greater understanding of the dynamics of the components of the marine ecosystem monitored by AZMP. This can only be achieved through the identification and support of science priorities identified during peer-review evaluations of AZMP activities and reports;

THE KEY SUCCESSES OF THE PROGRAM ARE:

There has been a major increase in biological and chemical sampling leading to a greatly enhanced description and understanding of the ecosystem;

A strong, cooperative, coordinated and consistent effort among the regions to provide a thorough assessment of environmental conditions across the Atlantic Zone;

The AZMP program has identified and addressed specific issues:

- *invasion of Pacific phytoplankton species, Neodenticula seminae, into the Gulf of St Lawrence;*
- *long-term plankton changes in the Scotian Shelf-southern Newfoundland Shelf region through CPR program;*
- *relationship between year class success for haddock in Southwest Nova Scotia (SWNS) and the timing of the spring phytoplankton bloom;*
- *major input into the eastern Scotian Shelf ecosystem review;*
- *will be providing the foundation for Canadian contributions to Global Ocean Observing System (GOOS) and related national and international ecosystem observation and monitoring networks.*

INTRODUCTION

The Atlantic Zone Monitoring Program (AZMP) represents the minimum requirement to adequately detect and measure inter-annual variability over the Atlantic Canadian shelves and slopes. The Atlantic DFO regions are collectively responsible for the delivery of this Zonal Program. AZMP involves the multidisciplinary monitoring of biological (abundance and/or biomasses), chemical (nutrients) and physical (temperature, salinity) variables; both in situ and by use of remote sensing. AZMP was built largely on existing field and monitoring programs, and enjoys close links with other research and monitoring programs (e.g. fish surveys, remote sensing). It attempts to use new technologies and methodologies to improve the efficiency of the sampling program and the quality of data sets but these efforts are not supported by the existing AZMP funding.

The AZMP observation component consists of:

- Six time series from fixed stations (approximately biweekly sampling frequency) to observe the seasonal cycle of temperature, salinity, nutrients, phytoplankton and zooplankton in key locations throughout the zone;

- Semi-monthly composite maps of Sea Surface Temperature (SST), chlorophyll and phytoplankton biomass from satellite observations;

- Monthly CPR transect across the Gulf of Maine, Scotian Shelf and Grand Banks;

- Two to three surveys annually consisting of fixed transects of temperature, salinity, nutrients, oxygen, chlorophyll and plankton across the entire zone with some use of ships-of-opportunity (SOOP) to provide more extensive seasonal coverage over a limited portion of the Zone;

- Compilation of related meteorological, river runoff and sea level data sets at Marine Environmental Data Services (MEDS) website; and,

- Web based access to all of the data and data products through a single site.

The AZMP provides peer-reviewed environmental status reports describing the physical, chemical and biological oceanographic conditions to national and international audiences (clients, stakeholders). The annual reporting consists of assessing the current state of the ecosystem, its evolution from past conditions and, where possible, its causal relationships.

The AZMP was developed around international standards for environmental monitoring and serves as a linchpin in the development and implementation of the Canadian Ocean Observing System (COOS) which is directly tied to the Global Ocean Observing System (GOOS) and the Canada's contribution to the Earth Observation System (EOS) for the Atlantic region.

In addition to the normal peer review of activities and information, the AZMP intends to provide a critical assessment of the progress against objectives on a regular basis. In the original development of the proposal (Therriault et al. 1998), the scientific leaders identified a five-year time horizon for the self-evaluation. In the following report, we outline the program's self-assessment based on the milestones set out in the original proposal and on a series of key issues identified during the Fifth Annual General Meeting of the AZMP and supported by the Atlantic Science Directors. The report is divided into 12 sections which aim at providing an overview of the program's accomplishments, progress to date as well as identifying key concerns about maintaining current program activities and future developments.

The report is capped with four sections that outline some of the benefits in the understanding and predictability of marine systems that have been derived from continued long-term monitoring activities.

***THE KEY SUCCESSES OF THE PROGRAM ARE*:**

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- *major input into the eastern Scotian Shelf ecosystem review;*
- *will be providing the foundation for Canadian contributions to GOOS and related national and international ecosystem observation and monitoring networks.*

***THE MOST SIGNIFICANT ISSUES FACING THE SCIENTISTS WORKING IN THE PROGRAM ARE*:**

Workload: The AZMP program is already working beyond its capacity and cannot, with present resources, maintain the current program or entertain an expanded one;

Ship time availability is a critical and long standing issue which has been raised on several occasions with senior management but for which a resolution has yet to be implemented across all regions;

Increased access to automated sampling devices, or the opportunity to apply them, could ultimately reduce workloads and improve the quality of advice provide by AZMP;

There has been considerable emphasis on the collection and description of data as part of AZMP but there needs to be greater efforts dedicated to more comprehensive analysis and modelling;

Lack of feedback from Atlantic science directors from year-to-year reviews: workload and resource allocation issues have been presented repeatedly yet the reply and actions are generally indirect.

SECTION 1. HAS THE AZMP ACCOMPLISHED THE OBJECTIVES OUTLINED IN THE ORIGINAL PROPOSAL (THERRIAULT ET AL. 1998)?

Conclusion: The AZMP has met the objectives of developing and implementing an observational program but the degree to which seasonal and interannual variations can be characterized varies among the variables being monitored.

Recommendation: Greater efforts need to be directed at the comprehensive analysis and modelling of biological, chemical and physical variables (together and separately) to provide greater understanding of the dynamics of the components of the marine ecosystem monitored by AZMP. This can only be achieved through the identification and support of science priorities identified during peer-review evaluations of AZMP activities and reports.

Variables resolved on three times scales

	Seasonal	Interannual[1]	Decadal
Biological (chlorophyll, plankton, optical properties)	surface chlorophyll everywhere; chlorophyll, plankton at fixed sites (except Shediac), along CPR lines and their representative areas	along AZMP sections; Southern Gulf of St. Lawrence (SGSL), Scotian Shelf and Gulf of Maine (SSGoM), Georges Bank	everywhere[2]
Chemical nutrients, oxygen	fixed station and their representative areas, Eastern Scotian Shelf (ESS)	along AZMP sections; SGSL, SSGoM, Georges Bank	everywhere[2]
Physical temperature, salinity	SST everywhere, fixed stations and their representative areas, ESS, other limited areas, year-round Long- term Temperature Monitoring Program (LTTMP) stations	everywhere[2]	everywhere[2]

[1] All areas under seasonal carry over to longer time scales.
[2] In some cases interannual or decadal variability is resolved for a particular season but only that season.

RATIONALE:

The main objectives of the proposed monitoring program are twofold: (1) to collect and analyze biological, chemical, and physical data to characterize and understand the causes of oceanic variability at the seasonal, interannual, and decadal scales; and (2) to provide the multidisciplinary data sets that can be used to establish relationships among the biological, chemical, and physical variability. An additional but no less important objective is to ensure the protection of the marine environment by providing adequate data to support the sound development of ocean activities. With such a large area of the Atlantic Ocean characterized by complex and variable circulation patterns, the problem of determining representative sampling locations and the frequency of sampling represents a crucial element of a zonal monitoring strategy to obtain data that will meet this goal. In that context, an analysis of the variability on the Scotian Shelf led to the following conclusions:

- It is impracticable and too costly to provide a zonal coverage of the physical climate with moorings;
- With a limited sampling program, variance of temperature and salinity at the seasonal scales and longer can be measured despite the presence of high frequency background variability;
- Seasonal and interannual fluctuations of nutrient and dissolved oxygen in the upper layers should be detectable as well;
- Hydrographic sections can provide quantitative assessments of water mass variability, transport, and fluxes of heat, salt, and possibly nutrients for major current features;
- Large-scale coherence in the variability of planktonic organisms exists, but significant short-term fluctuations in abundance at time scales shorter than seasonal are also important.

The analysis led to the proposal that a Zonal Monitoring Program approach be based on:

1. Seasonal and/or opportunistic sampling along sections (with individual stations spaced from 20 to 40 km apart) to obtain information on the variability of the physical environment for the whole northwest Atlantic region;
2. Higher frequency temporal sampling (biological, chemical, and physical variables) at accessible fixed sites to monitor the smaller time scale dynamics in representative areas;
3. Remote sensing of physical and biological variables to provide a broader spatial coverage and to increase our capacity to interpret ocean data (e.g. interpolation or synoptic capacity of site-specific field data) is to be used whenever possible;
4. All collections and interpretations will be completed by data coming from other existing monitoring programs (e.g. CPR) and other types of available data (e.g. meteorological data) that bear direct relevance to ocean climate;
5. The program would be based on the development of standardized protocols and methods to ensure comparability of information across regions. This implies not only the use of common approaches but also the need to avoid unnecessary duplication. All activities were to be coordinated by a logistic subcommittee;
6. Rapid archiving of the acquired monitoring data will be an important element of the AZMP. This aspect of the program is to be coordinated through a data management subcommittee. The emphasis is on rapid and easy access to the data and information collected and generated under the program;
7. Data Analysis is a critical component for ensuring the successful development and delivery of data products to the clients of the monitoring program. The Ocean Monitoring Working Group (OMWG) foresees the necessity to create a

permanent Data Analysis Working Group to ensure that the Zonal Monitoring Program will produce meaningful results. The products of the monitoring program will change and evolve over time to meet new demands and as products are identified as useful or not;

8. Regular workshops to be held (every four to five years) to re-examine the Zonal Monitoring Program jointly with other organizations (e.g. Fisheries Oceanography Committee (FOC), fishers' associations, universities).

Under this element of the review of the AZMP, we provide a general overview of the accomplishments of the program based on the initial objectives set forth by Therriault et al. (1998):

1. There were 14 sections listed as essential for AZMP activities in the original proposal. Of those, only five are regularly sampled three times during the year, with 12 being sampled at least twice (spring and fall) and only one is sampled only during the summer months (Table 1.1). Dedicated ship time has been allocated twice a year in the Maritimes and Quebec regions whereas three trips have been allocated in the Newfoundland and Labrador (NL) region. In no instance has it been feasible to perform regular sampling during the winter period (January-March) throughout the region due in part to availability of ships as well as limitations due to ice and inclement weather. However, the Maritimes region provides one AZMP technician on the February groundfish cruise to Georges Bank and on the March groundfish cruise to the eastern Scotian Shelf to collect hydrographic, nutrient, chlorophyll and zooplankton data. Summer sampling on the Scotian Shelf and the Northeastern Gulf of St. Lawrence has been accomplished using ships of opportunity based on other survey programs. The St. Pierre bank transect has never been occupied as part of the regular oceanographic cruises but a synthetic view of hydrographic variables along the transect in spring is available from ship-of-opportunity sampling. SOOP significantly supplemented the directed AZMP observations, permitting realistic assessments of long-term variability in hydrographic variables.
2. Six fixed stations have been sampled regularly throughout the program (Table 1.2). Seasonal and interannual variability in biological, chemical and hydrographic variables are captured in all cases. Sampling is generally conducted throughout the year at all fixed stations although gaps of several weeks are not infrequent due to unavailability of platforms for sampling. In most instances, regional solutions have been attempted but sampling frequency remains unreliable. At Shediac, sampling is limited to the period April-December due to ice conditions, and thus misses the spring phytoplankton bloom or captures it while underway. The only major difference between the original proposal and the current implementation program is that there is no fixed station located in the northern Gulf of St. Lawrence due to insufficient resources.
3. Remote sensing activities have been carried out throughout the program. SST and surface chlorophyll (SeaWiFS) data have been archived in two week composite images throughout the Western North Atlantic by staff at the Bedford Institute of Oceanography (BIO) and more recently the implementation of an automated SST

archive at Institut Maurice Lamontagne (IML) covering the same territory as well as the more northern latitudes (through a receiving station at Resolute) has been carried out. Weekly SST observations at 9 km resolution are archived in a public relational database at BIO.

4. Use of SOOP and other monitoring activities have been extensive during the course of the AZMP.
   a. Trawl mounted conductivity-temperature-depth (CTD) on all multispecies surveys in NL region allows the construction of transect information of physical variables for the south coast of Newfoundland (St. Pierre Bank) in the spring.
   b. Ship of opportunity sampling on Scotian Shelf (3 times per year), Georges Bank and southern Gulf of St. Lawrence trawl surveys provides temperature, salinity, surface and bottom nutrients, dissolved oxygen, chlorophyll and zooplankton at selected sites.
   c. Annual zooplankton surveys in St. Lawrence Estuary have been used to monitor changes in macro- and mesozooplankton composition and biomass in the region.
   d. Weekly sampling of a fixed station at Rimouski (ice out-Dec) has provided a more complete view of the seasonal cycle of production in the region.
5. Standardized protocols for sampling were developed early on in the program but certain analytical procedures had to be compared before arriving at a final and consistent approach across all regions. These are outlined by Mitchell et al. (2002). Despite the research needed to reach consensus, all data collected during the first five years of the AZMP are directly comparable.
6. The data management committee has worked to ensure consistent archiving of all collections of physical oceanographic data (temperature, salinity, density, and oxygen) collected throughout the AZMP. In addition, the data management committee has spearheaded the development of a biological and chemical data archive (BioChem) that will provide a common platform and format for the archiving of all chemical and biological data collected as part of AZMP. Currently, all chemical and biological data are archived in regional databases. In addition, the dissemination of information, data and data products has been coordinated through the development of the AZMP website, hosted at MEDS. The site displays hydrographic data, climate indices, sea level, links to remote sensing and meteorological data as well as plankton data from the CPR and phytoplankton collections. There has been a lag in displaying zooplankton data collections because of sample processing times within each region. The development of a relational database for the SeaWiFS observations has not occurred because of changing algorithms for chlorophyll estimation and regional modifications to the algorithms.
7. There were two primary tasks of the Data Analysis subcommittee: (1) develop effective data products which meet client needs, and (2) undertake analyses in support of requirements for the interpretation of multidisciplinary data. With respect to the first of these objectives, the AZMP has effectively accomplished the objective. Annual presentation on zonally consistent data products to the FOC

has led to the production of ESR for physical, chemical and biological oceanographic conditions across all regions of the Zone. Furthermore, a zonal environmental summary is presented in the Annual Bulletin of the AZMP. In terms of the second objective, research surrounding in-depth analysis of AZMP collections as well as the interpretation of the processes which affect inter-annual and inter-regional differences in environmental conditions has been limited due to workload demands on the primary scientists in charge of the program and the lack of resources to address some of the fundamental questions arising from the annual ESRs. Data from AZMP collections have been used by a number of researchers inside and outside the department. Although the data collected directly by the monitoring program were used in the provision of advice early in the implementation program, the incorporation of additional sources of monitoring information (e.g. toxic algae, Long Term Thermosalinograph Monitoring, some data from remote sensing sources) are lagging due to limited time available to the researchers involved with the program. However, data from Station Rimouski, the Bedford Basin Monitoring Program and the Labrador Sea time series are actively being used in our assessments of the state of marine ecosystems.

8. Since the inception of the program, scientists from AZMP have been providing the FOC with annual reports on the state of physical, chemical and biological oceanographic variables. In addition, scientists from the program have been responding to client requests in the development and provision of assessment-related indices as requested by individual Regional Assessment Programs (RAP). In the Fall of 2002, the department sponsored a joint FOC-AZMP workshop with the principal objectives to discuss how stock assessment might benefit from ecosystem information and in particular to identify data products from the AZMP that could improve our capability to foresee and to understand the causes of variation in the distribution, abundance, and productivity of fish and shellfish resources. A report of the recommendations was presented to the ASDC in February 2003, and the recommendations will be addressed as part of this review and assessment of AZMP.

Closing remarks: The AZMP has provided a substantial increase in the sampling of the continental shelf and slope waters of Atlantic Canada compared with observations made prior to the implementation of AZMP. The greatest gains have been made in biological and chemical oceanography. Only a limited description of the long-term variability of nutrients and oxygen could be made before AZMP (Petrie and Yeats 2000). Outside of the CPR transect from Iceland to Newfoundland to Nova Scotia and long-term sampling in Bedford Basin, biological data were spotty and only a sparse picture of the variability of lower trophic levels could be fashioned (Longhurst 1980). There are of course a number of gaps (e.g. winter sampling in the SGSL) and deficiencies (no benthic sampling) in the sampling.

Table 1.1. Overview of sampling frequency of the 14 basic AZMP transects, as identified in Therriault et al. (1998).

Transect	Winter	Spring	Summer	Fall
Hamilton Bank			July	
Bonavista Bay		May	July	November
Flemish Cap		May	July	November
Southeast Shoal		May		November
St. Pierre Bank				
Cabot Strait		April-May	August	Oct-Nov
Louisbourg		April-May		Oct-Nov
Halifax		April-May	May-July	Oct-Nov
Cape Sable		April-May		Oct-Nov
St. Lawrence Estuary		May-June		Nov-Dec
Mont Louis		May-June		Nov-Dec
Anticosti		May-June		Nov-Dec
Bonne Bay		May-June	August	Nov-Dec
Magdalen Island		May-June		Nov-Dec

Table 1.2. Overview of the sampling periods of the six fixed sites of the AZMP.

Site	Sampling period	Comments
Station 27	January-December	Gaps in winter
Halifax 2	January-December	
Prince 5	January-December	
Shediac	April-December	Sampling starts after ice-out
Gaspé Current	January-December	Gaps in winter and summer
Anticosti Gyre	January-December	Gaps in winter and summer

SECTION 2. DOES THE AZMP MEET INTERNATIONAL PRINCIPLES FOR LONG-TERM MONITORING (E.G. GOOS PRINCIPLES OF DESIGN AND IMPLEMENTATION)?

Conclusion: AZMP meets the international standards needed to contribute to a sustained, systematic, and long-term observation system that provides end products and services about the state of marine ecosystem.

Recommendation: The development of value added products for more complete interpretation of the changes in the state of marine ecosystems requires greater emphasis on research that will provide a more comprehensive analysis of data collected as part of AZMP.

RATIONALE:

In the fall of 2002, the World Summit on Sustainable Development, meeting in South Africa, made a number of pronouncements in support of the need for coordinated global observation strategies in support of sustainable development and highlighted GOOS for the oceans component of the earth system. More recently, a Canadian interdepartmental delegation, lead by the Minister of Environment David Anderson, attended the Earth Observations Summit in Washington, D.C. and participated in the inaugural Group on Earth Observations (GEO) meeting that followed. At a press conference that followed, Minister Anderson stated that Canada needs to make new (substantial) investments for climate observations if it is to be a global player. Clearly, earth system observations addressing climate and sustainable development issues are “on the radar” both at the national and international levels and DFO’s ocean observation programs, including AZMP, are poised to play an important role in meeting Canadian needs as well as fulfilling its international commitments through participation in GOOS.

The principles upon which AZMP was developed and implemented align well with the design principles and principles of involvement defined for GOOS (see below). Important among those are commitment to a sustained, systematic, long-term, “end-to-end” observation system that is cost-effective, employs standardized methodologies, quality assurance and an open data policy, and one that is subject to periodic review and is flexible, adaptable and responsive to end-user needs. Similar design principles have been identified recently in DFO’s plan for a broader network of ocean monitoring in Canadian waters, the Canadian Ocean Observation System (COOS), where the importance of compatibility with international objectives and standards, as outlined for GOOS, are emphasized (DFO 2002).

Data and data products generated by AZMP are relevant to the observational requirements for both the climate (Ocean Observations Panel for Climate, OOPC) and coastal (Coastal Ocean Observations Panel, COOP) modules of GOOS. AZMP currently measures most of the common variables identified by OOPC and COOP for the initial global ocean observing system (UNESCO 2003). With regard to “end-to-end” information flow, AZMP is fully operational in data capture, reporting and generation of generic and client-requested data products (see below). Capabilities for nowcast and forecast of oceanographic and ecosystem conditions, however, have not yet been achieved but would not be expected at this early stage (5 yrs) in AZMP operation.

The GOOS implementation strategy calls for the development of regional pilot studies that provide “proof in concept and practice”. Canada (DFO), in cooperation with the National Marine Fisheries Service (NMFS), is currently developing a regional GOOS pilot project for the Gulf of Maine (Gulf of Maine Area (GOMA)-GOOS) to develop an end-to-end ocean observation system with the following objectives:

- Evaluate the observation and monitoring system, and its coordination, of the GOMA (NAFO Div. 4X-5) in relation to diverse indicators required for 'integrated management', with particular emphasis on fisheries,
- Develop an information support system for data management,
- Undertake research on the inter-relationships of indicators of diversity, productivity and habitat,
- Develop a seasonal forecast model of the Gulf of Maine and adjacent marine areas. Incorporate oceanographic models for the GOMA into climate change models of the North Atlantic.

Oceanographic observations and data products routinely generated by AZMP will be critical to the success of GOMA-GOOS and projects such as GOMA-GOOS will help AZMP achieve its “end-to-end” commitments.

GOOS Design Principles:

- D1. GOOS is based on a plan designed to meet defined objectives on the basis of *user needs*.
- D2. The design assumes that contributions to GOOS are *long term*.
- D3. The design will be *reviewed regularly*.
- D4. The design allows for *flexibility of technique*.
- D5. GOOS is directed towards *global problems* and/or those ubiquitous problems benefiting from global observing systems.
- D6. The design covers the range from *data capture to end products and servic*es.
- D7. The management, processing and distribution of data will follow a specified *data policy*.
- D8. The design takes into account the existence of systems outside GOOS that can contribute to and/or benefit from GOOS.
- D9. The design takes into account *quality assurance proce*dures.

GOOS Principles of Involvement:

- P1. Contributions to GOOS will be compliant with plans developed and agreed on the basis of the above design principles.
- P2. Contributions will be compliant with a defined GOOS data policy.
- P3. Contributions should reflect intent for sustained observations.
- P4. Standards of quality will apply to GOOS contributions.

- P5. Implementation will be effected using existing national and international systems and organisations where appropriate.
- P6. Implementation will be incremental and progressive, whilst bearing in mind the long term goals.
- P7. Participation in GOOS implies an undertaking to help less-developed countries to participate and benefit.
- P8. Participants will have full autonomy in the management of their contributions to GOOS.
- P9. Contributing nations and organisations will reserve the right to determine and limit their contributions to GOOS.
- P10. Use of the GOOS 'label' implies conformity with the relevant principles of GOOS.

SECTION 3. IS THE CURRENT MANAGEMENT STRUCTURE THE MOST EFFECTIVE METHOD TO ACHIEVE THE GOALS OF THE PROGRAM?

> *Conclusion: The current management structure is effective for the operational activities of the program.*
>
> *Recommendation: Reporting of AZMP activities and issues should be presented to NSDC instead of ASDC. Members of AZMP feel that the program is part of national activities. Furthermore, issues of concern (ship time, coordinated capital allocation of resources, national coordination of monitoring activities) can only be dealt with at the national level.*

RATIONALE:

The current structure of the program involves a Steering Committee (SC) with one representative from each region, and three subcommittees (Logistics, Data Management and Data Analysis) which are tasked to address particular areas of coordination and comparability in order to maintain maximal efficiency. The AZMP currently reports to the ASDC which has the Regional Directors of Science for the four Atlantic regions as well as the Director General Atlantic Headquarters (HQ).

After discussion during the fifth Annual General meeting, the group felt that the current structure was an effective tool for the coordination of the program. The Logistic Subcommittee has achieved the development of standardized protocols and e-discussions continue to deal with issues of comparability among regions. Much of the activity of the Data Management Committee has focused on consolidating regional data sets and making them available through various media, particularly over the web. Since there did not exist a national data base for the archival of biological and chemical data, considerable effort was made to develop an ORACLE database for this purpose. Most of the Maritimes regions data are already in this database, and efforts are underway to include the data from other regions. BioChem will be hosted by MEDS, but all regions will be able to enter data and extract them. A few challenges, such as metadata standards, Quebec (QC) and archival standards, still remain, though they are currently being addressed. Activities of the Data Analysis subcommittee have been limited because of time constraints of the members. There are a variety of issues that can only be addressed as directed research initiatives (e.g. decorrelation scales) and that require substantial time and/or financial investments to address the issues with the scientific excellence required. Scientists involved with the Data Analysis subcommittee have faced increasing demands from other research initiatives and thus the subcommittee has never held a meeting independent of the Annual AZMP meeting and the FOC. However, through discussions the group has achieved a standardized presentation of information across regions, with regional additions of specific data sets and surveys.

Members of AZMP feel that the program is considered to be part of a larger national program of environmental monitoring. As such, committee members felt that AZMP should report to the NSDC rather than the ASDC. The rationale for this recommendation stems from the nature of the issues which AZMP feels need to be addressed in order to maintain the effectiveness of the program. After the initial influx of funding and personnel, most of the issues surrounding the implementation and operation of the program have been addressed through the SC. The current operation of the program involves regional implementation and planning with zonal coordination through the SC. However, issues concerning the continued effective implementation of the program that surface regularly in the previous year's report have focussed on aspects of which can only be dealt with through discussion at the NSDC level. The first of the issues involves the renewal of capital resources for the program. AZMP owns relatively little of the equipment it currently uses: most resources have been derived from A-base programs. Currently, capital resources are requested and allocated on a regional basis. There has been no avenue for the regionally coordinated request of equipment, particularly remote sensing tools or large analytical systems, which would be accessed directly by all regional users. As a result, renewal of equipment for coordinated monitoring across regions has been subject to regional constraints that do not address zonal issues. Each region effectively relies on their own resources to satisfy national objectives with limited discussion among regions about the possible allocation or development of a common equipment pool which is maintained and operated through a regional agreement on costs and protocols.

The second issue relates to the availability of platforms for sampling and observations. The AZMP relies on effective observational collections of information over a broad geographic range. Currently, the coverage of the program varies considerably among regions and the involvement and participation of A-base funded collections program is currently being reviewed regionally. Each year, the SC has been faced with the concerns that ship time availability would be uncertain in one region or another because of regional concerns for research and observations that are separate from those of the zonal program. Both past and current Chairs have raised the issue repeatedly with the ASDC. Up to the end of 2002, there has been consistency in the level of coverage for the program but at the start of 2003 there were concerns in at least two of the three operational regions about the possible loss of sampling opportunities. Because the issue of platform availability was being addressed at the national level, the concerns of the program were carefully noted by ASDC but no direct feedback about possible ramifications to the program's operation was obtained. Members of the AZMP feel strongly that in order to voice our concerns about this national program, direct representation to the decisional body (NSDC) is needed. Finally, members of the AZMP felt that by reporting to a national rather than regional body maintains awareness of the issues facing the environmental monitoring program and of the changes that are taking place in the environment.

SECTION 4. ARE WE MEETING OUR OBJECTIVES IN AN EFFECTIVE MANNER?

<u>Conclusion</u>*: The minimum observation system covered by AZMP activities have resulted in a significantly enhanced and coordinated monitoring of the marine ecosystem but demands on personnel and vulnerability of A-base resources could compromise our ability to meet AZMP objectives.*

<u>Recommendation</u>*: The growing pains of starting a monitoring program still linger. The right balance among data analysis collection and synthesis has not yet been achieved. More attention must be focused on effective use of the data leading to better understanding of ecosystem variability.*

RATIONALE:

The fundamental purpose of the AZMP is to: (a) provide the environmental datasets that are necessary to track and predict changes in ocean state and productivity, (b) to respond to questions posed by end-users, (c) to alert them to short and long-term environmental/ecosystem changes, and (d) to provide adequate historical databases to address future issues. It is important to emphasize that AZMP represents the minimum, ongoing collection and analysis of ocean data required to obtain a quantitative description leading to an understanding of the variability of the biological, chemical and physical characteristics of the NW Atlantic. It does not explicitly have the responsibility for the associated “cause-effect and forecasting” Research and Development (R&D) (Therriault et al. 1998).

As part of the implementation of AZMP, the program was supplied with $400K in Operational and Management (O&M) funds and nine new positions were created (three in each of Maritimes, Québec and Newfoundland and Labrador regions). With the objectives of the program to provide seasonal coverage of environmental state along 13 oceanographic transects and at six fixed stations across the entire Atlantic zone, it is clear that the additional funds and personnel were intended to supplement existing resources. The current basic program across the entire zone involves a substantial increase in the collection and analysis of nutrient, chlorophyll, phytoplankton and zooplankton samples in addition to processing, calibration and archiving of enhanced CTD observations relative to activities prior to the implementation of the program and provides $80K to fund CPR operations, which is supplemented by $35K from Maritimes region.

The operation of monitoring activities prior to the inception of AZMP varied considerably among regions. Much of the information was collected from SOOP with a limited number of dedicated surveys aimed at collecting biological, chemical and hydrographic observations on the state of the ocean. In all regions, scientists provide an overview of ecosystem and environment tracking through regular reports and generic data productions, as well as in some instances provide custom data productions where specific requests arise from RAP. However, to meet the objectives of the AZMP, the nine new staff provided in response to the original proposal are insufficient to meet all the sampling, processing and data analysis required by the program. As a result, the additional needs of AZMP are being carried out by scientific staff that performs AZMP-related tasks in addition to the program requirements they had prior to the implementation of the monitoring program.

The large time commitment to in situ sampling and processing affects the analysis of data by limiting the time AZMP staff has to conduct basic, retrospective and new analyses. Current AZMP activities rely heavily on personnel, funds and ship time allocated from regional resources to collect, process, analyze, interpret and manage program activities that are essential to meet program objectives. The program relies presently on researchers outside the program to make progress on understanding causal relationships as well as in the development of models to assist in the interpretation and extension of the data and on the critical assessment of the sampling scheme. Technological advances to allow more economical and efficient data collection or processing are limited by the amount of resources that AZMP can provide. Any development in this area relies almost entirely on grants from other sources.

The seed funding provided by the program has resulted in obtaining significant additional funds for data management, particularly to build the BioChem database and to migrate to ‘managed’ databases, many historical data sets that are at risk of loss. Such activities have greatly helped the AZMP scientists to conform to the DFO data policy for the management of scientific data.

Program efficiency and accuracy has been achieved through a combined use of dedicated and opportunistic platforms. The latter has been particularly useful in the collection of hydrographic information but has been less effective for collection of chemical and biological variables because of the personnel requirements needed to support the activities. Scientific productivity of the program has been primarily restricted to the regular provision of environmental overviews and a limited amount of innovation (AZMP Bulletin 2001; 2002). The time requirement to research personnel with the responsibilities of the program in addition to other Departmental priorities has limited efficiency in pursuing new avenues of understanding.

Any change in resource allocation will result in direct impacts to the quality, accuracy and extent of information provided to the advisory process. Currently, some activities in the Maritime region based on SOOP will likely be dropped because of excessive demands on non-AZMP personnel. As outlined in section 6 of this report, sampling of hydrographic variables, through dedicated and opportunistic collections, provides good measures of seasonal, interannual and decadal variations in environmental conditions but further analyses are required to determine the underlying accuracy of chemical and biological collections in resolving the spatial and temporal scales of variability.

SECTION 5. ARE THERE OTHER RESOURCES (E.G. REMOTE SENSING) THAT COULD SERVE TO MAKE PROGRAM MORE EFFECTIVE?

Conclusion: There are resources that could make the program more effective, including greater use of new technologies (e.g. satellite and in situ sensors), databases and modelling. These would enhance aspects of the monitoring program and increase long term efficiency. Current resources within AZMP for development and operationalization are modest and would require initial capital investment and infrastructure support.

Recommendation: The AZMP needs to identify the resources and define an implementation plan needed to enhance the use of new technologies to make the program more effective at meeting its objectives.

RATIONALE:

New technological advances in satellite-based observations of SST and ocean colour are being fully exploited by AZMP. Centres at BIO and IML have operationalized the collection, processing and production of a variety of standard and specialized (user-requested) data products that provide small scale (kilometres) to synoptic regional to zonal scale information on ocean physical and biological properties. Satellites can provide useful information on other ocean properties that are currently being exploited by AZMP (e.g. sea-ice) or are being considered, (e.g. wind fields).

Advances in ship-based towed instrument payload vehicles (e.g. Moving Vessel Profiler (MPV)), ship-mounted thermosalinographs, trawl-mounted instrument packages, moorings (e.g. Seahorse, bio-optical moorings, and new biological (Laser Optical Plankton Counter (LOPC)) and chemical (Nitrate) sensors are also being tested and evaluated with support from AZMP. These new technologies when proven and operationalized will help somewhat to rationalize AZMP ship time resources and at the same time give AZMP access to important remote locations that are inaccessible in the present context. This should result in a substantial increase in data quantity and quality per unit effort. This new instrumentation will not, however, totally replace conventional ship-based observations since: (1) “ground-truthing” will still be required for most of the new technologies and (2) a number of important ecosystem properties comprising the suite of AZMP observations, primarily related to systematic, community structure and biodiversity, are not yet quantifiable by the new technologies. It would probably be better to think that new technologies will complement conventional ship-based observation by filling in the gaps (temporal and spatial) and by providing information helpful for designing more intelligent (and efficient) use of expensive ship-time.

New technology may also provide alternate methods of measuring key AZMP variables. The current AZMP protocol is based on traditional methodology which provides poor spatial and temporal information. The AZMP field effort as well as the level of uncertainty of some products might benefit from moving from traditional to new methods (e.g. net tows and microscope measurements vs. MVP plankton counter measurements).

Substantial benefits could also be achieved through enhanced use of buoy systems to provide better coverage of the fixed stations. Systems could include profilers to measure physical, biological and chemical variables. There would still be a need for vessels to provide servicing of the sites and equipment, as well as to collect some biological variables that cannot be effectively sampled using such systems. Even with a limited set of sensors, moored buoy systems could serve to monitor remote sites such as the northern Gulf of St. Lawrence, the coast of Labrador, as well as all current fixed stations or allow a reallocation of resources to provide more widespread coverage. This would also avoid current limitations whereby gaps in the availability of dedicated or opportunistic platforms have resulted in substantial periods during which observations are not available. Although there would be a substantial initial outlay of funds to acquire systems, the reduced reliance on vessels could serve to decrease overall costs to the Department and optimize sampling of fixed sites. To reduce demands on existing resources, the implementation of fixed buoy systems could be phased in through the purchase of one or two annually.

The resources available within AZMP for technology development, however, are modest at present and timely advances in development and operationalization of these technologies will require substantial investment; start-up capital costs will be high and system maintenance costs will have to be maintained on a long term basis. The frequency of servicing would require careful assessment. Furthermore, due to the anticipated substantial increase in data flow, a new or modified data management infrastructure will be required which has non-trivial associated costs (hardware, software, technically-trained personnel). Nevertheless, the inclusion of these new technologies into AZMP will benefit the program by the higher quality of the data set as well as by information not previously available, much like including remote sensing data has done, and by potentially increasing the efficiency of our field operations.

SECTION6. ARE ALL REGIONS/VARIABLES RECEIVING ADEQUATE, EXCESSIVE OR INSUFFICIENT COVERAGE?

Conclusions:

- *The development of climatologies is a critical element in determining the state of marine ecosystems: within AZMP physical variables have well established climatolologies whereas they are currently being developed for chemical variables, while there are just beginning for biological variables;*
- *The ability of AZMP to resolve seasonal and inter-annual variability in the variables is greatest for physical variables and weakest for biological variables, due in part to the limited time series available for the latter (see Section 1). Winter sampling remains limited and even a moderate increase in observations would be of great benefit to establishing the state of marine ecosystems;*
- *Through a combination of dedicated surveys and the use of SOOP, many areas are sampled with sufficient frequency to provide good resolution of inter-annual variations in the state of some elements of the marine ecosystem. However, regions with limited coverage include the northern Gulf of St. Lawrence, the Labrador and NE Newfoundland Shelves, the south coast of Newfoundland;*
- *Nowhere is there excessive sampling.*

Recommendation: ASDC or NSDC identify new or reallocated resources that could be made available to provide enhanced sampling and analysis of Atlantic regions with limited coverage.

RATIONALE:

The AZMP monitoring proposal is explicit about the time scales it hopes to resolve:

To collect and analyse biological, chemical, and physical data to characterise and understand the causes of oceanic variability at the seasonal, interannual, and decadal scales; …

but is not as explicit about the spatial scales:

(1) a seasonal, interannual, and decadal quantitative description of the temperature, salinity, dissolved oxygen, nutrients, phytoplankton, and zooplankton for the continental shelf and upper slope and the Gulf of St. Lawrence system…

We shall approach this by considering the most sampled data in space and time that are available to the AZMP, viz., ocean temperature. Consider first the distribution of variance as a function of frequency. For Halifax SST we have:

Table 6.1. Halifax SST variance for several bandwidths.

High Frequency Limit(d^{-1})	Low Frequency Limit(d^{-1})	Period Range	Variance ($^oC^2$)
24	1	1h-1d	0.15
1	0.1	1-10d	0.51
0.033	0.011	1-3m	0.37[1]
0.011	0.0026	3m-1y	0.38[1]
0.0026	0.00007	>1y	0.43[1]

[1]SST anomaly variance (i.e. after removal of the first three annual harmonics)

The distribution of variance will differ throughout the region for SST and the amount of variance contained in the annual cycle will decrease with depth, nonetheless, this should give us a sense of what the AZMP sampling captures and what it misses. Also, we might expect the highest frequency variance to have a subsurface maximum because of the presence of internal waves.

We would ideally measure temperature using fixed sensors with a high sampling rate (upper panel, Fig. 6.1). The variance of this record is about 27 $^oC^2$. None of our sampling has this temporal resolution. At best we sample every two weeks at the fixed stations. The middle panel of Figure 6.1 shows the high frequency variability that would be noise if the sampling were every two weeks. The noise has an annual cycle, with a standard deviation of 0.5^{o}C in winter increasing to 1.14^{o}C in summer, and an overall standard deviation of about 1^{o}C. The lower panel of Figure 6.1 shows the signal that we are actually after, namely, the monthly temperature anomaly. The spikiness in this record is due in part to undersampling (the very high frequency contamination) and because there is variability at periods of 1-13 months (see Table 6.1). We are fortunate that there is significant variability at the lower frequencies that is detectable by our sampling regimen.

As our sampling frequency decreases, e.g. with the AZMP shelf surveys, more of the low frequency becomes noise and it is increasingly difficult to extract interannual and decadal variability from the data series. There has been considerable work with the physical data sets to indicate that interannual variability is resolved within reasonable statistical uncertainty by combining the AZMP data and opportunistic sampling in the Atlantic region.

Spatial scales of variability have also received attention. Again we illustrate this with the SST data. Figure 6.2 shows a map of the spatial scales, defined as the distance where the correlation between weekly SST time series falls to 0.7 (Ouellet et al., 2003). Scales vary from about 50 to 250 km over the grid, with the largest scales in the Grand Banks region. From this plot, we can conclude that in order to characterize the SST variability at weekly time scales and longer, we need stations ~100 km apart. Clearly this cannot be done.

Figure 6.3 shows the correlations between pairs of annual time series of SST anomalies within three regions and a fit to all of the correlations within and across regions. The overall scale is ~500 km (r=0.7 criterion) and varies little from region to region although again it appears to be larger for the Newfoundland-Labrador area. AZMP and opportunistic sampling combined will generally resolve these spatial scales of variability at the annual time scale.

An analysis similar to that shown in Figure 6.2 for the temporal decrease of the weekly SST anomalies gave an e-folding scale (time it takes the correlation to = 0.37) of two to three weeks throughout the region. Using the monthly Halifax SST anomaly (bottom panel, Fig. 6.1), we found that the e-folding time was slightly less than two months for the monthly variability, and 27 months for the annual anomalies. The correlation was equal to 0.7 for the annual anomalies for a lag of 8.5 months.

The seasonal distribution of hydrographic data for 2002 (Fig. 6.4) indicates the sampling deficiencies: the Labrador Shelf in three of four seasons; the NE Newfoundland Shelf and the Grand Banks in winter, the Scotian Shelf in spring and fall, the eastern Gulf of Maine and Bay of Fundy in winter, spring and fall. Clearly seasonal resolution of hydrographic variability will only be possible at the year round fixed stations, their representative areas and in limited areas of the Canadian east coast. Given the length scale of 500 km and the temporal scale of 8.5 months (r=0.7 criterion), it should be possible to resolve interannual variability with long time series. However, we should qualify this by indicating that in some areas consistent measurements are made only at specified times of the year and that phase shifts of hydrographic variability could introduce additional uncertainty. For example, an early or late snow/ice melt on land could bias a measure of the salinity always and only made on a specific date.

CHEMICAL AND BIOLOGICAL TIME SERIES

Chemical data. Little comparable analysis has been done for chemical and biological data series. The chemical dataset, specifically nitrate, silicate and phosphate, are only at the point where initial atlases of long-term averages have been published for the Scotian Shelf and the Gulf of Maine (1999), and for the Gulf of St. Lawrence (2003). These atlases show that for some areas there are not enough data to form a statistically reliable monthly mean let alone address the scales of variability. However, interannual variability is considerable for areas such as the central Scotian Shelf where there are more complete data series. Peak-to-peak annual variations of nitrate are as much as 10 μM for the deeper waters of the Shelf; this is about the same magnitude as the upper layer concentrations just before the spring bloom and therefore is very significant. Newly acquired and deployed nitrate sensors will allow the assessment of the distribution of nitrate variance with frequency.

Prior to the AZMP, in an average year about 700 nitrate samples were collected in the Scotian Shelf-Gulf of Maine region. This includes the western Gulf as well so the number for the Canadian section of this area would be roughly half of the total. Figure 6.5 shows the distribution of nitrate samples for 2001. In the Canadian section of the Scotian Shelf-Gulf of Maine, nearly 2600 nitrate samples were processed. Despite this increase in sampling, it is evident that there are still deficiencies. For example, only the eastern Scotian Shelf, the NE sector of Georges Bank and some of the fixed stations measure the nutrient store in winter before the initiation of the spring bloom. The Labrador Shelf is sampled only in the summer and the northern Gulf of St. Lawrence only in spring and fall. The dense summer sampling on the Scotian Shelf and in the southern Gulf of St. Lawrence should provide sufficient data to examine spatial scales associated with the nutrient fields.

An initial role of the AZMP then is to provide the basic observations for regional climatologies, a fundamental step before spatial and temporal scales of anomalies can be described. Year-to-year comparisons for most of the region and quantitative evaluation of interannual variability for limited areas are done. There are two other attainable goals that can be achieved during the building phase of the data set: evaluation of the nutricline gradients that contribute to the vertical fluxes and consequently the new production throughout the year; and, determination of the winter inventories of nutrients in the upper layers that drive the spring blooms. The latter will require some increased winter sampling effort.

Biological data. The seasonal distributions of chlorophyll, phytoplankton and zooplankton stations for 2001 are shown in Figure 6.6-6.8. The magnitude of the overall effort to collect these data is evident from the number of stations. On the other hand, there are areas which receive little sampling throughout the year. In the ten years before AZMP a typical year would collect chlorophyll on about 400 stations. In 2001, chlorophyll was collected on about 900 stations providing a more complete overall picture throughout the year. The most consistent year-to-year sampling of phyto- and zooplankton is from the monthly CPR survey (Fig. 6.7, 6.8). This collection is complemented by spring and fall phytoplankton surveys in the Gulf and area limited spring, summer and fall surveys on the Newfoundland-Labrador Shelf. The spring and fall surveys and the summer Halifax section on the Scotian Shelf have not been processed yet. A similar picture prevails for the zooplankton. It is not possible to compare the number of non-CPR plankton stations prior to the AZMP with 2001 because much of the earlier data are not yet in the BIOCHEM database. However, a reasonable estimate is that the AZMP: pre-AZMP ratio is greater than that for nutrients which was ~7:1.

The six year long SeaWiFS data set is comparable to the SST time series in spatial and temporal resolution but not in length. These data have been examined for spatial differences in the timing and intensity of the annual spring bloom and for its interannual variability. The annual cycles are found to be quite robust from region to region and particularly in their latitudinal variation. Annual cycles of chlorophyll estimated from the satellite data are shown for 3 of the AZMP sections across the Scotian Shelf (Fig. 6.9). All show well-defined spring blooms and weaker, but in some cases longer, fall blooms. Some spatial analysis has been conducted for the Scotian Shelf on the daily images. An e-folding scale of 82 km has been estimated for the central Scotian Shelf based on the raw data (i.e. not on anomalies). Semi-monthly time series from pre-defined areas throughout the entire region have also been used to estimate spatial scales (Fig. 6.10). The 0 distance intercept is 0.61, a measure of the "noise" in the data; the e-folding distance is nearly 400 km about five times that for the central Scotian Shelf from the daily imagery. This indicates that semi-monthly averaging reduces the variability/noise appreciably. As longer time series develop, we can examine the frequency dependence of the scales of variability. As with the hydrographic variables, we expect the spatial scales to increase with increasing period; our ability to address year-to-year differences will thus be better than our ability to detect month-to-month differences. As a general rule, it requires ~10 years of data to resolve scales with one year period. However, the six year data set has already proven useful in studies of year class success of haddock in SWNS.

Similar analysis can be carried out with the CPR observations but we must remember that those data are quite unlike most we encounter (Fig. 6.11-6.13). Counts are not continuous (e.g. 1, 2, 3, … of species A) but rather have major jumps (e.g. for diatoms and dinoflagellates the counts go 0, 15,000, 35,000, 65,000, 95,000, 130,000, 170,000, 225,000, 300,000, 420,000, 750,000; *Calanus finmarchicus* as 0, 1, 2, 3, 6, 17, 35, 75, 160, 310, 640…). Conventional statistics may not apply so the scales derived should be interpreted as a guide to appreciating the distances over which plankton variability may be coherent. Other confounding factors include whether the sampling was done in day or night, the changing position of the tracks, the day of the month the sampling occurred, and changing expertise counting the plankton. These will be addressed more fully in issue seven. Table 6.2 below summarizes the results as 0 km distance correlation (the intercept) and the e-folding distance (where the correlation = 0.368, i.e. e^{-1}, a standard scale parameter).

Table 6.2. Parameters derived from CPR Line E counts for the Scotian Shelf 57-66^{o} W

Variable	Intercept	e-folding Distance (km)
Diatoms	0.74	580
Dinoflagellates	0.366	0
Calanus finmarchicus	0.58	240

The best correlation and largest scale are for diatoms but even in this case a single site would only capture 50% of the variance at short distances. The worst results are for dinoflagellates where the intercept is less than e^{-1}. Overall we conclude that the CPR data do not provide sufficient spatial resolution to describe the variability at frequencies that cover the entire band (0.5 month^{-1} to ~O(10 y^{-1})). However, as with the hydrographic variables and chlorophyll, the scale appears to increase as the higher frequencies are filtered from the data. AZMP Bulletin 1 featured an article on the CPR data that indicated reasonably coherent decadal temporal and shelf spatial scale variations of *Calanus finmarchicu*s and the greenness index (a measure of chlorophyll concentrations). The greenness index was higher in the 1990s on Lines E and Z west of 45^{o}W; the timing of the peak greenness was earlier. On the other hand, the abundance of young stages of *Calanus finmarchicus* was lower in the 1990s compared to the 60s and 70s. We conclude, subject to some provisos, the CPR data can be used to examine the very low frequency (O(decadal)) variability of a limited number of planktonic species.

FINAL COMMENTS

Where is our data collection insufficient to provide an assessment of the oceanic variability at seasonal periods and longer?

Physical Properties

The least sampled area are the Labrador Shelf and the northern Gulf of St. Lawrence (including the Belle Isle Strait); seasonal variability is out of the question over the entire shelf, interannual variability for particular seasons is only possible for the Hamilton Bank area for summer and fall. Interannual variability for particular seasons is attainable for the Grand Banks, Laurentian Channel, the western Scotian Shelf, eastern Gulf of Maine and Bay of Fundy. The Slope Water regions off Newfoundland and Nova Scotia are poorly sampled; Slope water is a major contributor to the deeper waters of the shelf and Gulf of St. Lawrence. Seasonal variability can be resolved elsewhere. Remotely-sensed SST should allow seasonal resolution everywhere.

Currents are important and are missing everywhere. It is not only the temperature and salinity that are important but also the rate at which they are moved into, within and out of our region. Current meter moorings are very expensive to run and maintain and are beyond the resources of the current AZMP. The alternatives are:

- Using the broad scale Temperature- Salinity (T-S) surveys to evaluate the quantities of water types within a smaller part of the region, assessing its change with time and thereby providing some indication of the influences of current transport. We have some examples of this already with indexes such as the Cold-intermediate Layer (CIL) areas on the Newfoundland Shelf and in the Gulf of St. Lawrence. More could be done and some ongoing analyses show promise.
- Geostrophic computations for selected large current features. This would be useful for the Labrador Current given the results of earlier studies; would not be useful for the Nova Scotian Current, also given recent results; may be useful but has not been tried for the Gaspé Current and the Cabot Strait outflow.
- Remotely sensed sea level. This is likely only useful for the Labrador Current; a pilot project is underway at the NWAFC.
- Numerical models. Models are run for the Gulf of St. Lawrence and the Newfoundland and Labrador region within DFO labs. The latter model is being extended to the Scotian Shelf. AZMP does not extract any information from these models now but could initiate a project.
- There should be a general increase in the development and use of numerical models, including coupled biological-physical models, in the interpretation of data collected as part of AZMP field activities.

However, these solutions would be useful on the Shelves but would not provide adequate information for the northern Gulf of St. Lawrence. In this region, deployment of a moored instrumented buoy or mooring off western Newfoundland and increased sampling/mooring of instruments could provide monitoring of some critical variables that are important tools in predicting the dynamics throughout the Gulf. One approach to address the issue while minimizing costs would be to eliminate collections at the fixed station in the Gaspé Current while focussing on sampling at the Rimouski station, which shows considerable correlation in environmental variability with conditions along the downstream portion of the estuarine flow.

Where is our data collection excessive? **Nowhere**.

Overall the physical sampling currently provides the best data set to resolve the temporal and spatial variability of the ocean as specified in the AZMP proposal.

Chemical Properties

A major initial role of AZMP is to build on the existing database so that statistical meaningful climatologies can be constructed. This is a fundamental and crucial step towards describing the variability at any time scale. The program also provides a broad-scale, quantitative measure of the nutricline vertical gradient, which is essential in the determination of nutrient fluxes during periods when upper layer concentrations are depleted. A realistic, short-term goal of AZMP would be to address the lack of winter data in all areas except for the eastern Scotian Shelf, NE Georges Bank and at the fixed stations excepting Shediac Valley. Winter sampling provides the inventory of upper layer nutrients, a primary factor determining the limits of new production during the spring bloom. The only broad area where seasonal nutrient variability can be resolved is the eastern Scotian Shelf. In all other areas, interannual variability of seasonal nutrients is possible. Winter nutrient distributions are critical to establishing the potential productivity of the spring phytoplankton bloom, yet this is one of the elements for which AZMP has the least amount of information. To obtain even moderate sampling of conditions would provide a substantially stronger base for the application of regional bio-physical models of ecosystem processes. This would entail the implementation of winter surveys, which could be coordinated across all regions through joint efforts. At the moment the Quebec region has plans to sample the Gulf of St. Lawrence in March of every year using a combination of icebreaker and helicopter sampling, given an appropriate allocation of resources.

In addition to the necessary building of regional climatologies, there are a number of analyses that could be carried out for nutrients that could extend the applicability and determine the effectiveness of current sampling including:

- An examination of the relationship of deeper nutrient and T-S characteristics. This could help define the nutrient gradient below the generally nutrient depleted mixed layer and, with appropriate and attainable mixing models, specify the vertical nutrient flux into the euphotic zone. Consequently, new production throughout the year could be estimated. Some preliminary work indicates that within years this approach can be quite useful but that the relationship between nutrients and T-S varies from year to year.

- The intense sampling that occurs on groundfish surveys could be used to address spatial scales of nutrient variability. This is fundamental in the determination of whether too many or too few samples are being collected.
- Development of a basic nutrient atlas for the Newfoundland-Labrador region. The statistics will be poor for most areas and times however the exercise will identify deficiencies and help direct sampling efforts.

Where is our data collection excessive? **Nowhere**.

For nutrients, the AZMP is at the basic phase of building on archived data to attain regional climatologies. In some limited areas, it is already possible to examine interannual variability. Overall, the long-term means and variations about the means are still statistically poor for most areas. The AZMP will remedy this situation if the current sampling, with some adjustment, continues.

Biological Properties

The remotely-sensed SeaWiFS surface chlorophyll data when combined with the in situ samples provide the means of determining the seasonal and longer period variability throughout the region much like is done with SST. These data also provide the opportunity to determine the temporal distribution of variance and the spatial scales of variability. There has been work done within AZMP on both of these issues. The data have been used to address year class success of haddock in SWNS and are also being similarly applied to Bay of Fundy scallop studies. More effective use of these data to address sampling and other issues would come when these observations are incorporated into a database. These data hold considerable promise.

Consistent plankton sampling has occurred on the CPR lines through the Newfoundland Shelf and the Scotian Shelf, at the fixed stations, on spring and fall surveys in the Gulf of St. Lawrence, the Scotian Shelf and Grand Bank, and on the summer survey on the NE Newfoundland Shelf, the southern Labrador Shelf and the Halifax Section. Interpretation of the CPR data is difficult because of changing collection routes, timing (day-night, time of the month), and processing variations at Sir Alister Hardy Foundation for Ocean Science (SAHFOS) (e.g. different taxonomists from year to year). Nonetheless, in addition to the potential to examine low frequency variability, these data offer an opportunity to address species richness issues across the open ocean portion of the region but there is no corresponding information available for the Gulf of St. Lawrence. Similar opportunities, perhaps with greater potential because of AZMP's capacity to control sampling, are presented with the biweekly fixed station data and seasonal cruises.

We have examined the scales of variability from the high frequency sampled surface chlorophyll (SeaWiFS, biweekly) and plankton (CPR, monthly). These analyses indicate that the AZMP is undersampling plankton when high frequency variability is part of the time series. The prospect of collecting additional samples more often to resolve the high frequency variability cannot be entertained within the present program. The AZMP cannot keep up with current data collection and make them quickly available. However, like the hydrographic data, we anticipate being able to resolve the lower frequency scales provided that they contain more variance than the high frequencies and therefore not be badly aliased. The AZMP observations will then be able to provide quantitative assessments of ecosystem variability within the region at these longer time scales.

The AZMP provides a data set that has standard, constant protocols. Ongoing sampling began in 1999. It is still building towards defining the dominant species and species richness, leading towards a description of interannual variability. These observations, when coupled with SeaWiFS data, will allow better interpretation of the long CPR time series. There is considerable potential to define basic species compositions, the biological ground state, variability of species composition (similarity and dissimilarity) as well as interannual variations in the concentrations of dominant species. The data become more useful as the series lengthen, as demonstrated already by the six year SeaWiFS time series. The potential is there in this data set to examine temporal and spatial scales of variability and some of this work has been done.

One of the greatest gaps in AZMP sampling of biological variables comes from the general lack of information concerning macrozooplankton. Only the Québec region has maintained prolonged sampling of the Estuary and northwest region of the Gulf of St. Lawrence. These data have already shown clear evidence of the influence of Labrador waters on the macrozooplankton community within the region, which serve as important elements in the diets of top predators. The need for information throughout the Atlantic Zone was highlighted in recommendations from the FOC-AZMP workshop held in 2002. It is important to note that information on macrozooplankton is considered as important to obtain an overview of ecosystem status but that this should not occur at the expense of other elements of the current AZMP activities as they too present essential elements needed to monitor interannual variations in ecosystem status. However, greater collections cannot be entertained in the current program and there is currently a risk that the only ongoing program may be lost due to budgetary restrictions.

The basic building phase of developing climatologies as a precursor of quantifying interannual variability was recognised in the original proposal and is well underway. This effort requires time and patience. As the database grows and the appropriate scales are examined, adjustments could be made to the program with the overall aim to provide a quantitative description of ecosystem variability.

Where is our data collection excessive? **Nowhere**.

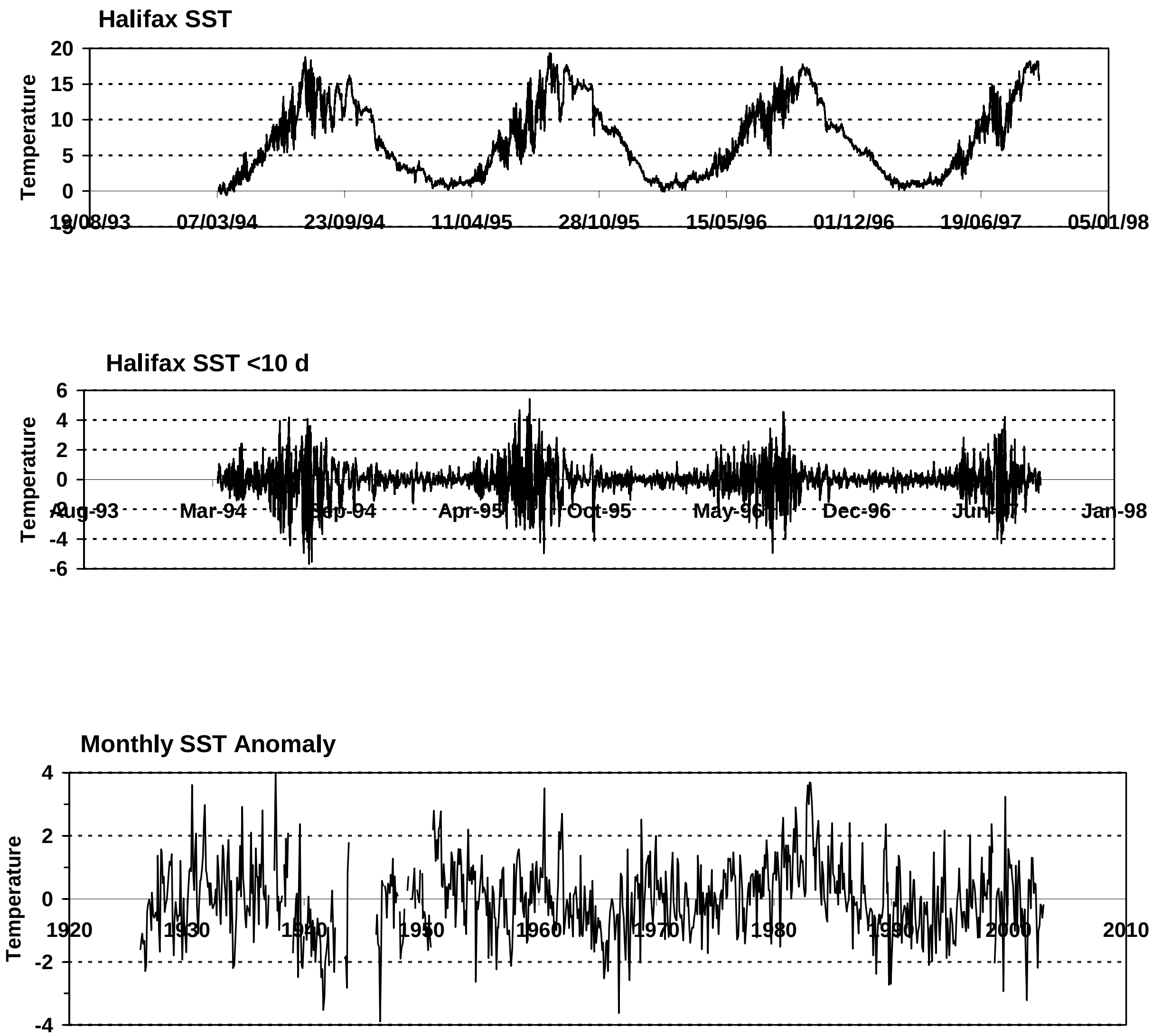


Figure 6.1. SST from Halifax sampled every 30 minutes. The top panel is the complete series; the middle panel is the variability with periods less than 10 day, i.e. the very high frequency variability. In AZMP sampling, the middle panel represents noise. The bottom panel is the monthly SST anomaly, the variable that we are trying to measure with the AZMP sampling.

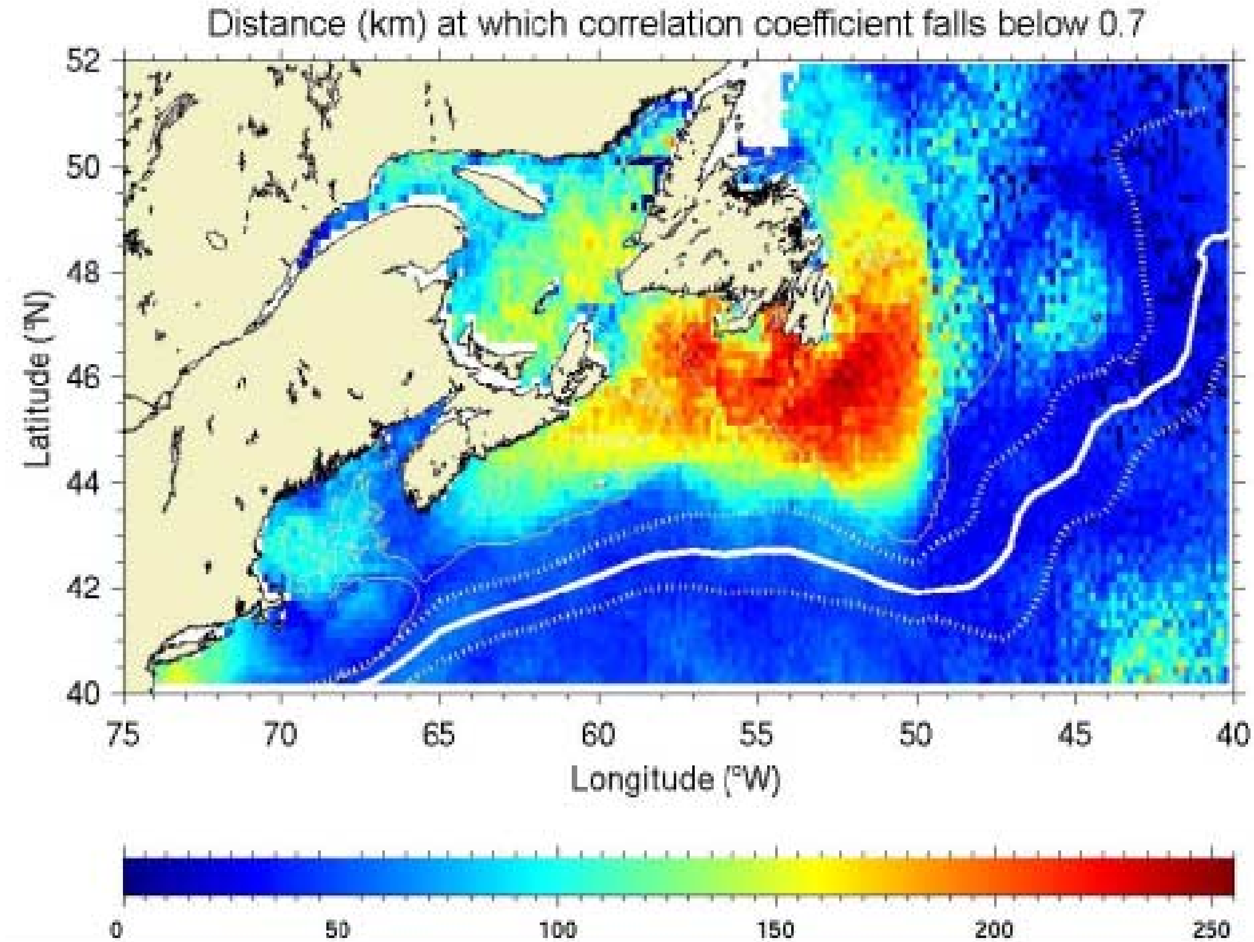


Figure 6.2. Spatial scales of variability of weekly sampled SST anomalies defined by the distance to the 0.7 correlation value from a linear fit to correlations versus distance from each pixel.

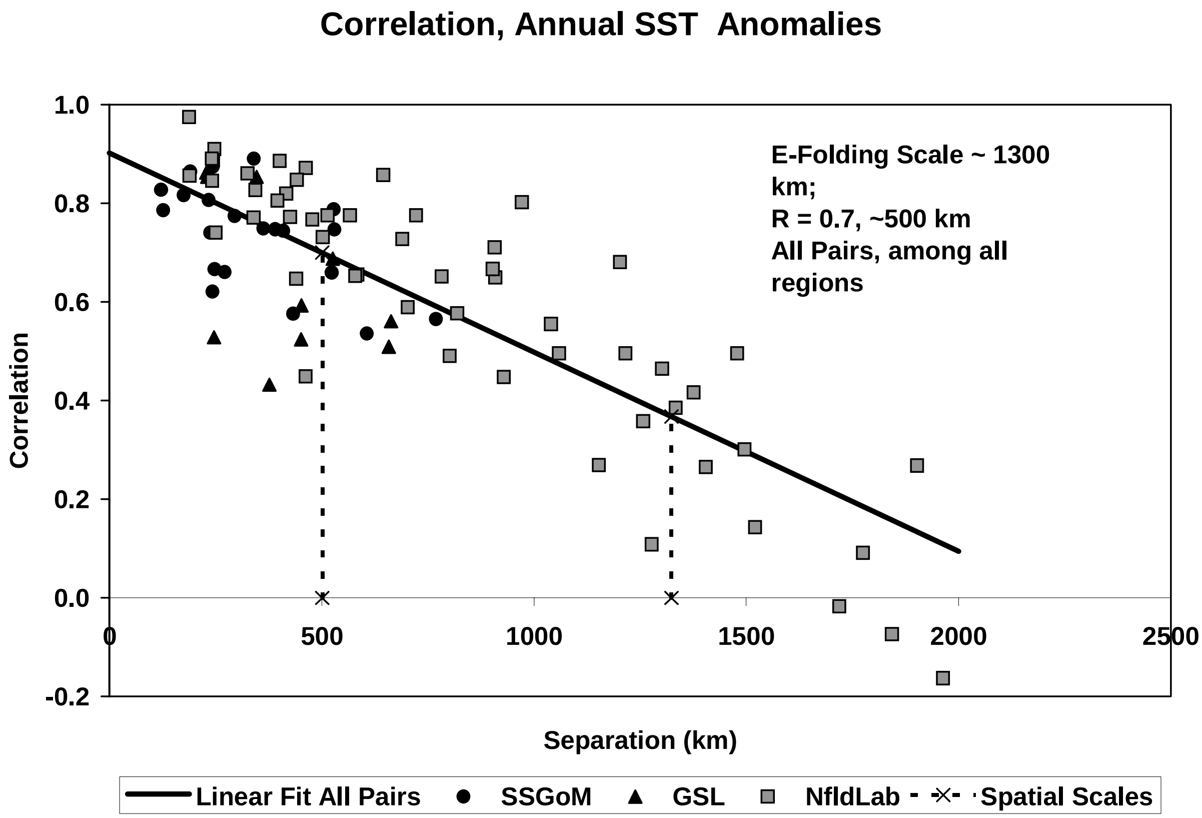


Figure 6.3. Correlation between pairs of annual temperature anomaly time series in the Atlantic region. The linear fit is based on all pairs; the dots show the correlations within regions.

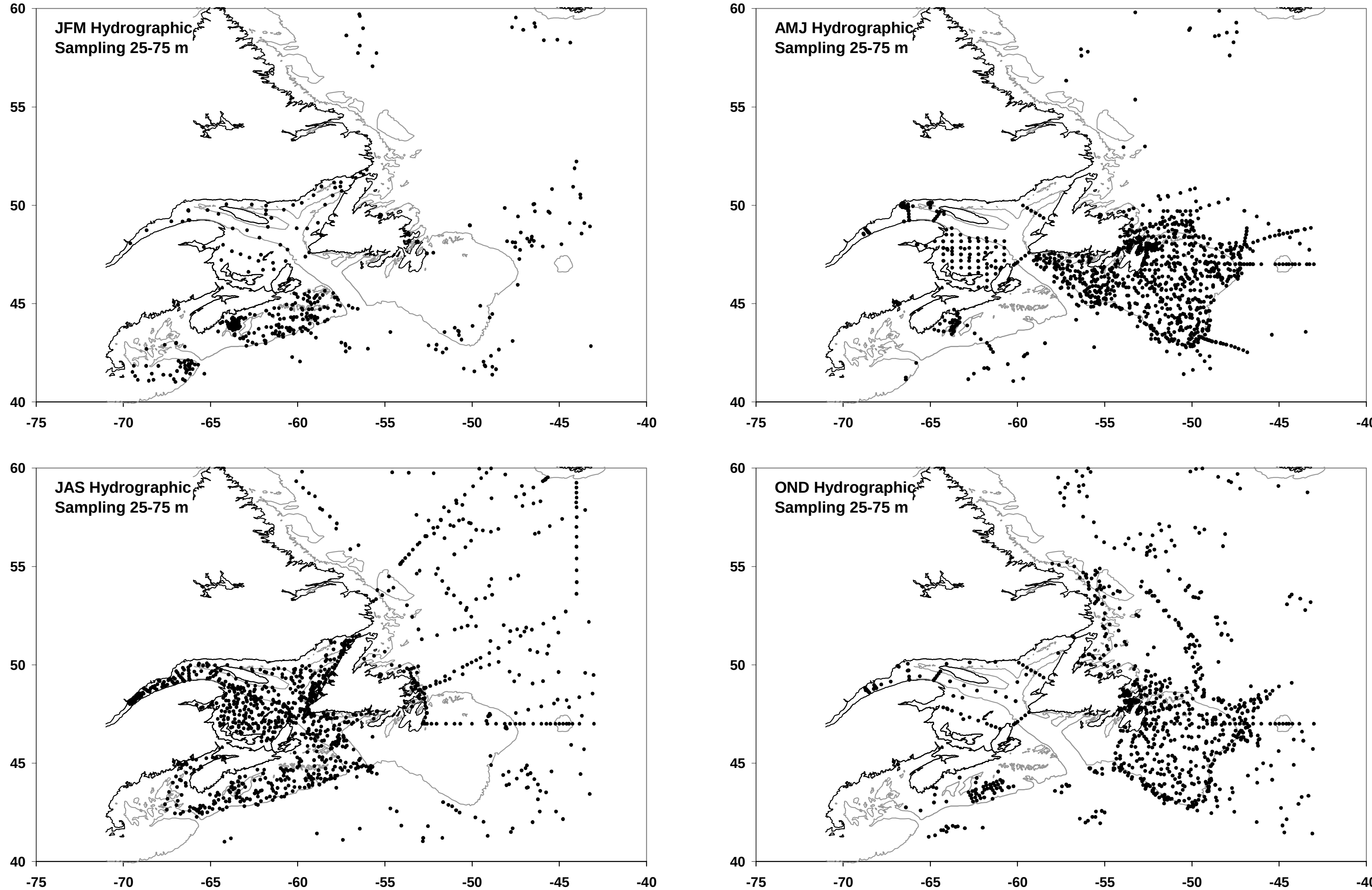


Figure 6.4. Distribution of hydrographic stations (based on data between 25-75 m) by season for 2002.

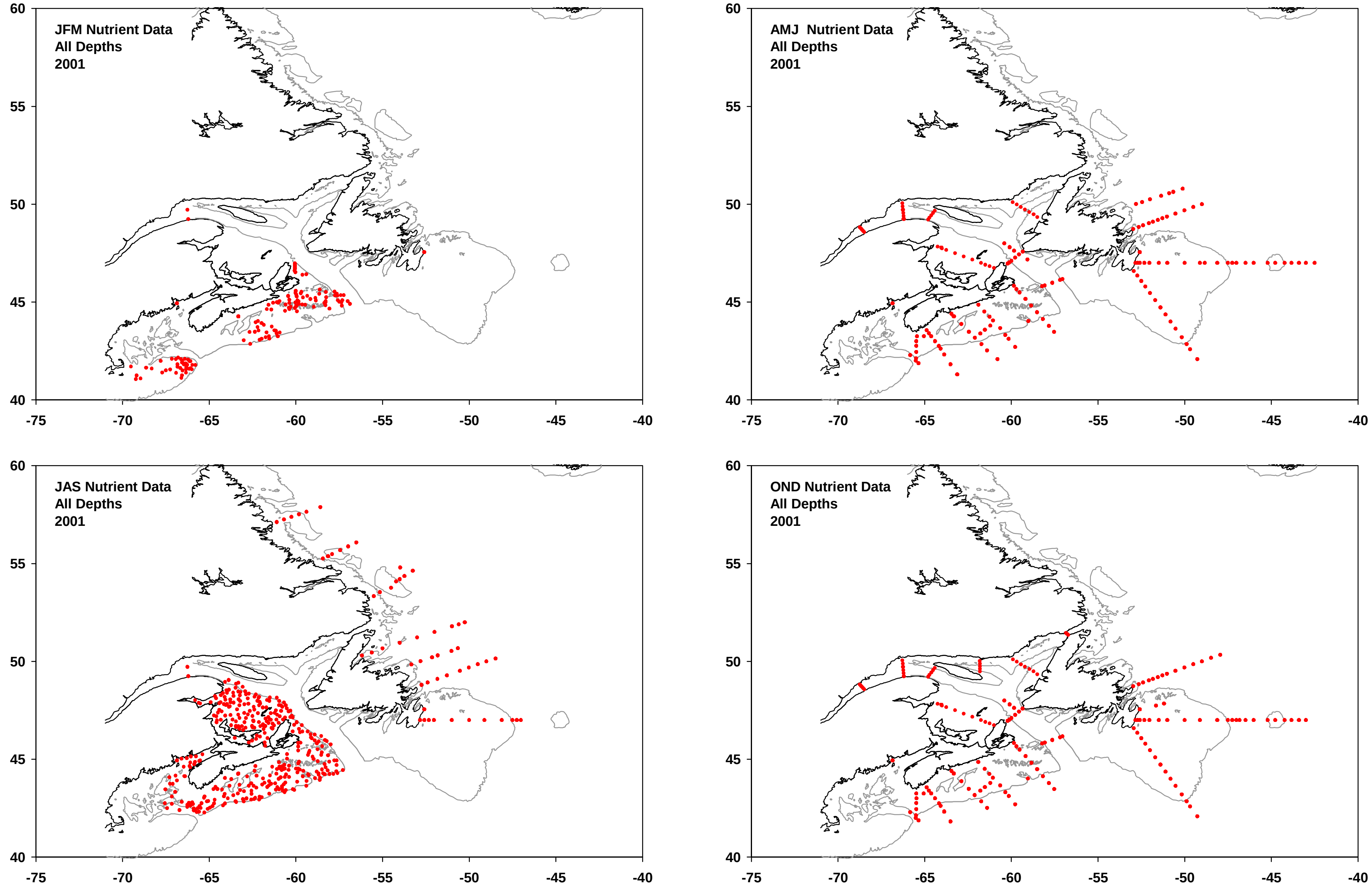


Figure 6.5. Distribution of nutrient stations (based on data from all depths) by season for 2001.

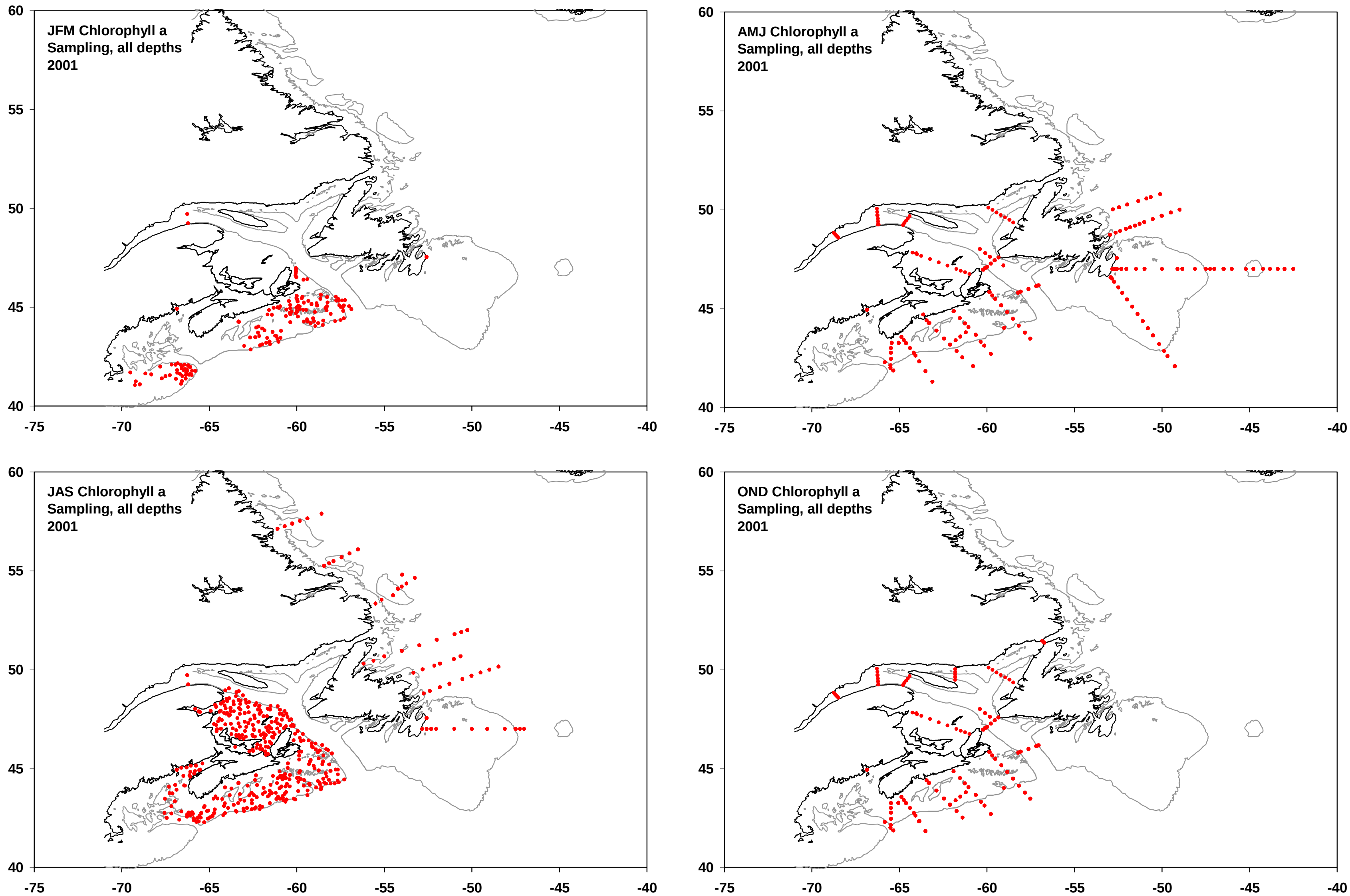


Figure 6.6. Distribution of chlorophyll stations (based on data from all depths) by season for 2001.

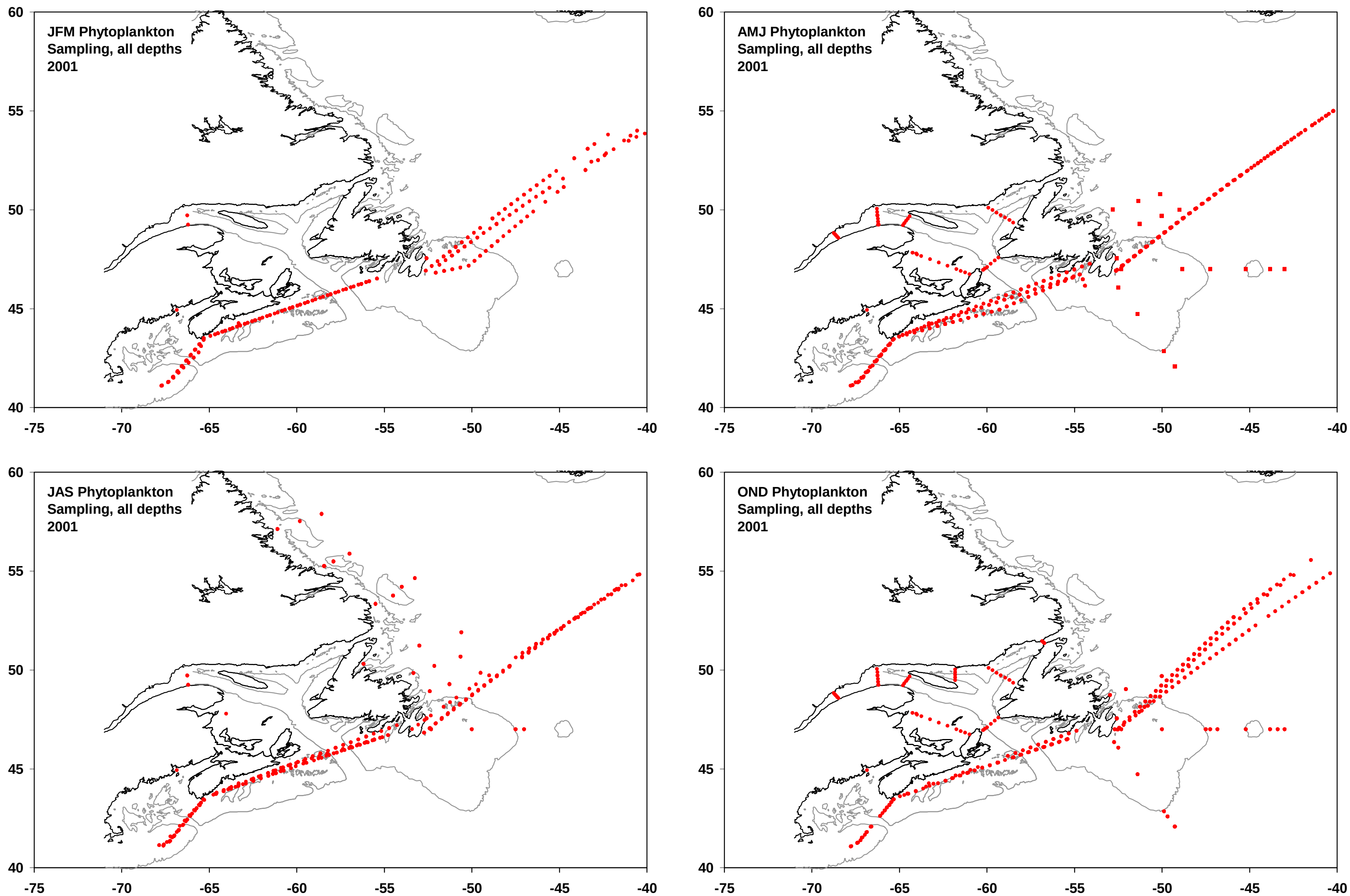


Figure 6.7. Distribution of phytoplankton stations (based on data from all depths) by season for 2001.

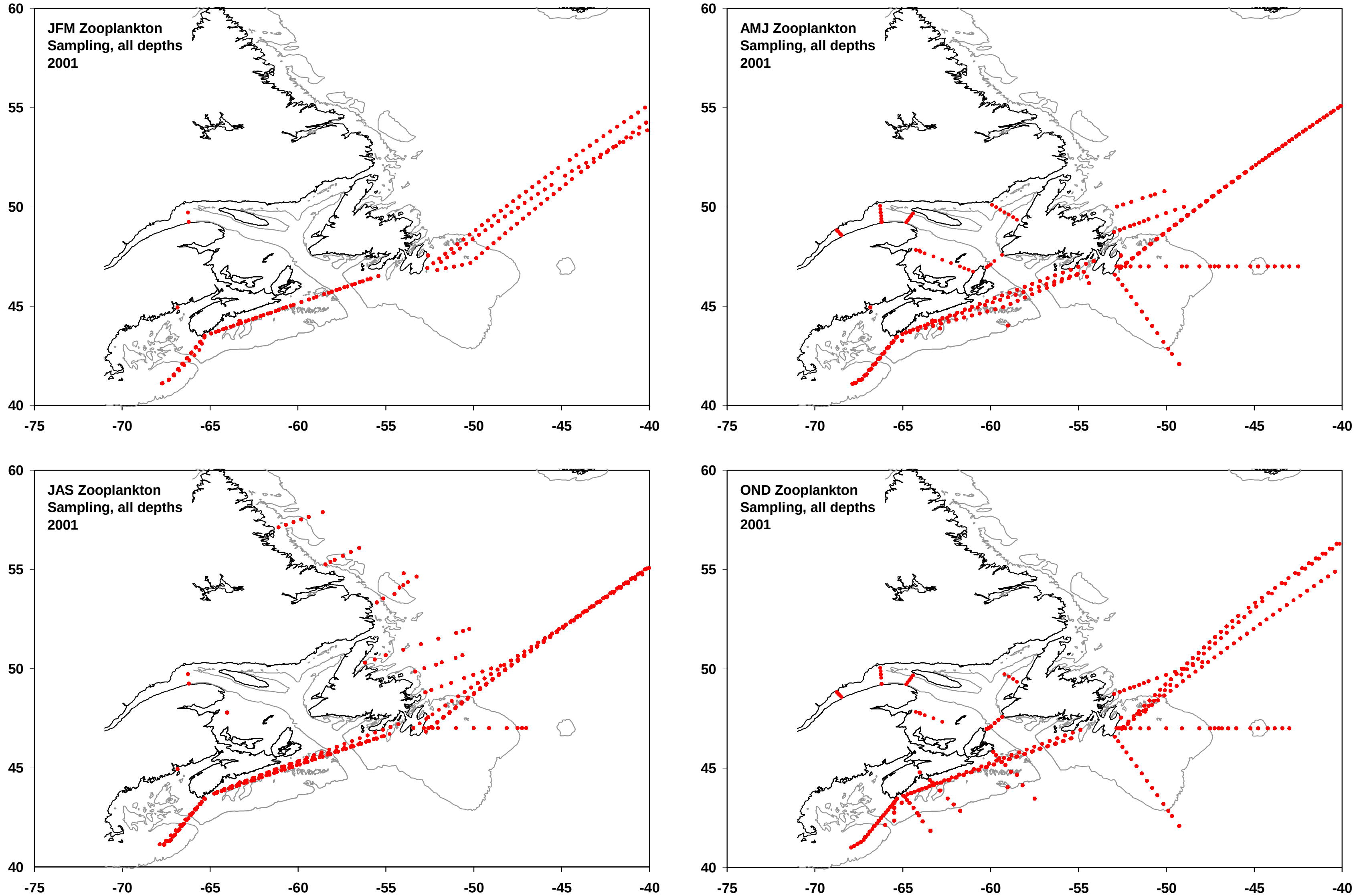


Figure 6.8. Distribution of zooplankton stations (based on data from all depths) by season for 2001.

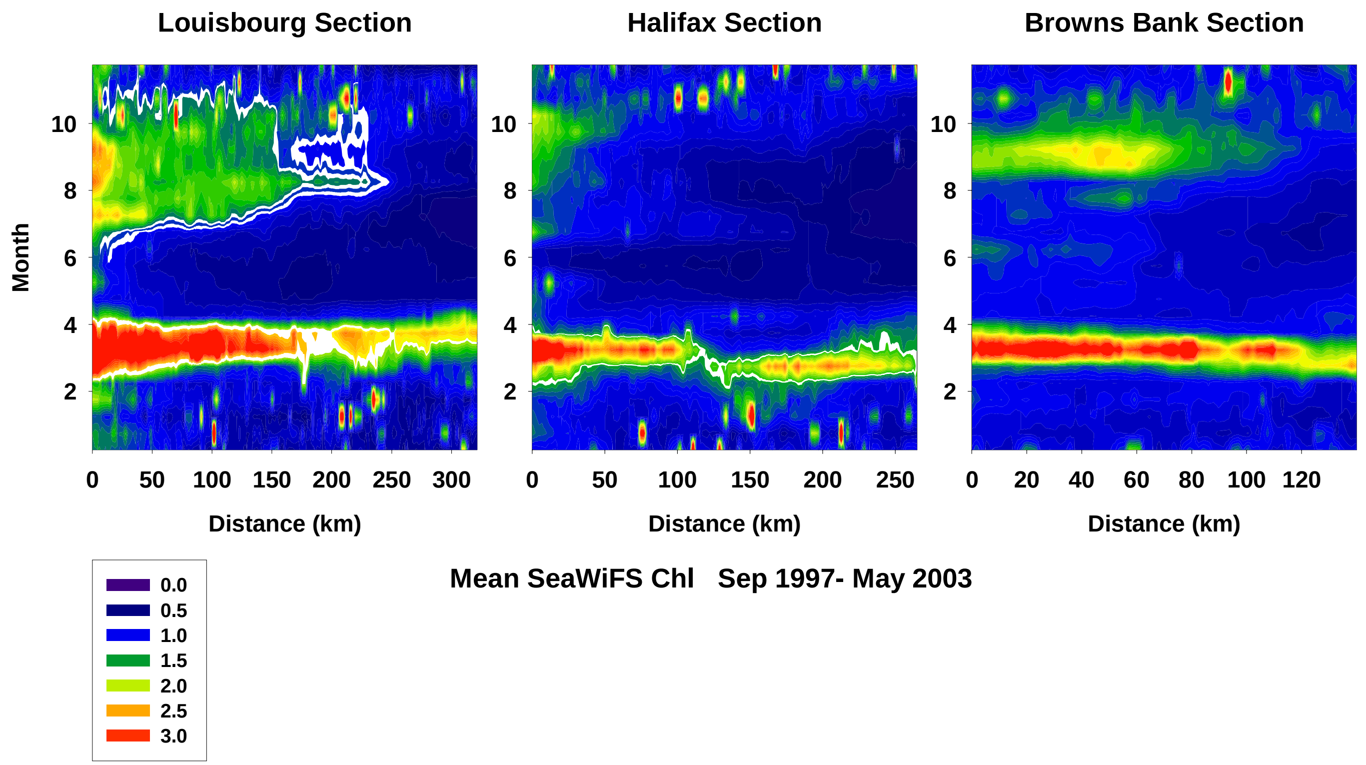


Figure 6.9. Mean chlorophyll (mg m^3) along the Louisbourg, Halifax and Browns Bank AZMP Sections based on SeaWiFS observations.

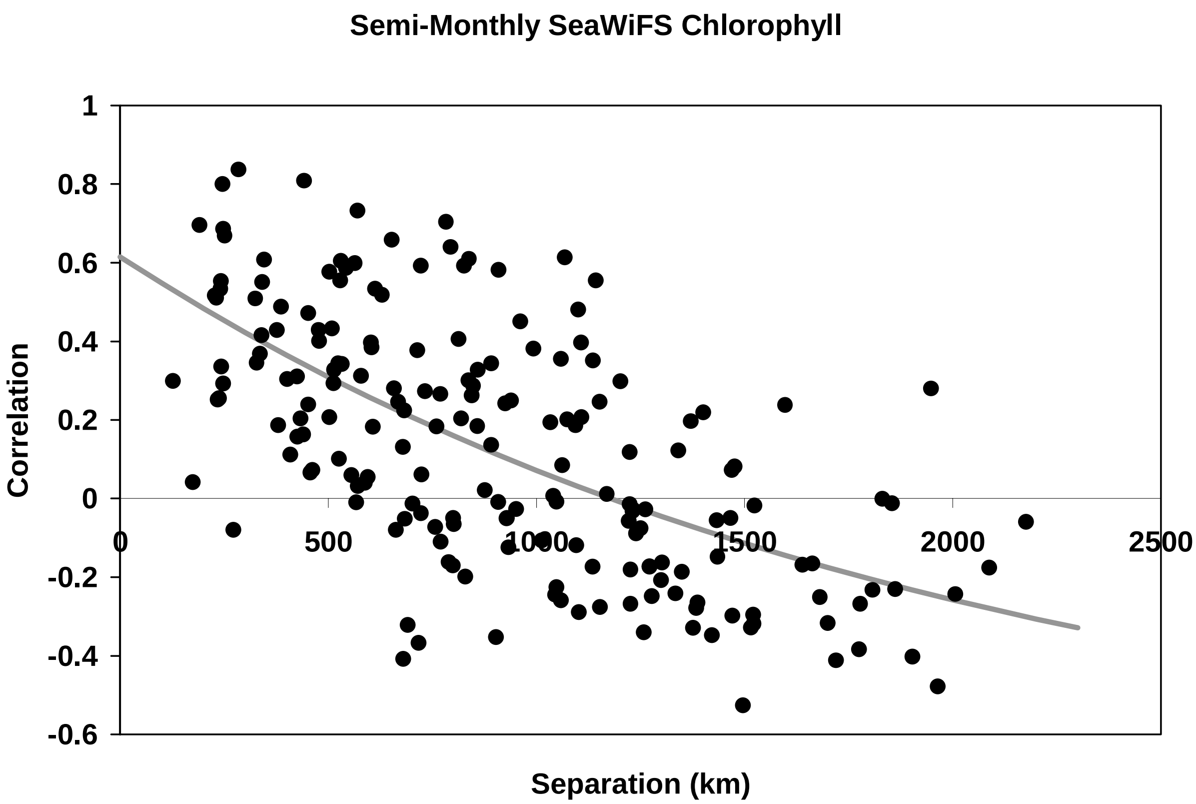


Figure 6.10. Correlation versus distance for semi-monthly chlorophyll estimated from the SeaWiFS imagery.

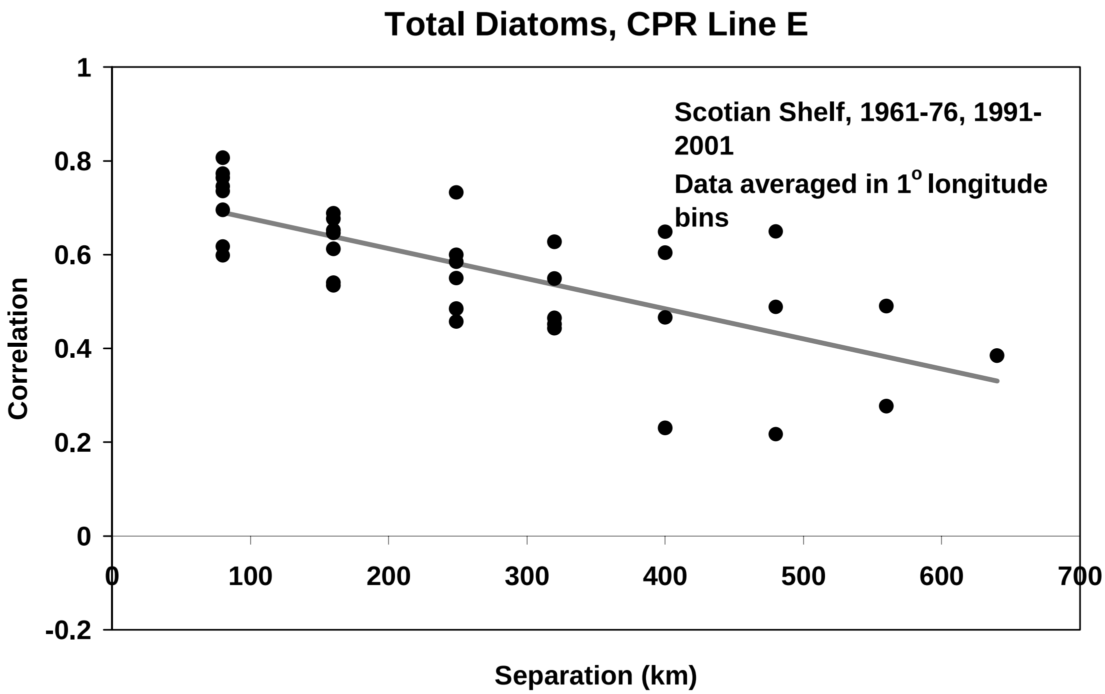


Figure 6.11. Correlation versus distance for monthly diatom counts estimated from the CPR Line E on the Scotian Shelf, 57-66° W.

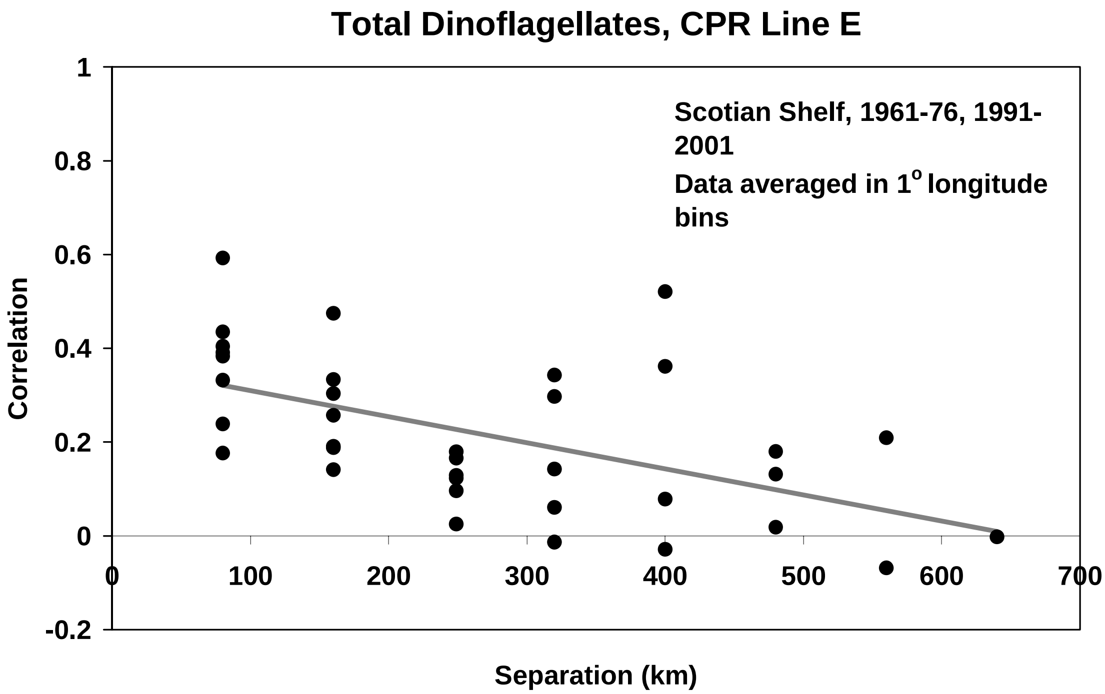


Figure 6.12. Correlation versus distance for monthly dinoflagellate counts estimated from the CPR Line E on the Scotian Shelf, 57-66^{o} W.

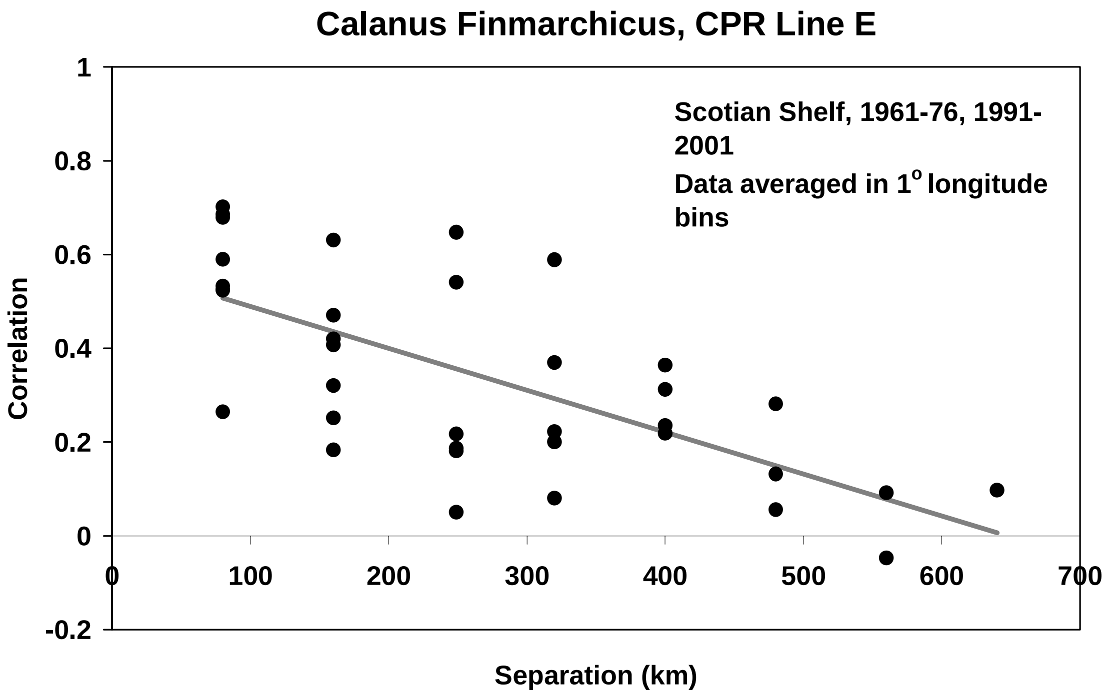


Figure 6.13. Correlation versus distance for monthly *Calanus finmarchicus* counts estimated from the CPR Line E on the Scotian Shelf, 57-66^o W.

SECTION 7. IS THERE A DUPLICATION OF EFFORT IN DATA COLLECTION?

<u>Conclusion</u>**:** *There is no duplication of effort in data collection: conventional sampling is essential to calibrate remote sensing while the latter provides greater spatial and temporal coverage over a limited portion of the water column (in the case of satellites) or of the region (in the case of CPR).*

<u>Recommendation</u>: *AZMP is to continue the inter-comparison of remote and field collected data to determine sampling and analytical requirements to maintain optimum coverage and efficiency throughout the Atlantic zone. AZMP should also explore the potential application of new technologies as they become available.*

RATIONALE:

There are two major areas of data gathering where one could perceive duplication of effort: [1] phytoplankton biomass monitoring versus satellite remote sensing, and [2] zooplankton sampling versus the CPR. In both these instances, each collection program has monetary and personnel costs to the Program. However, as with other monitoring programs, the collection of numerous indices is intended to ensure comparability among region as well as provide alternate measurements of environmental state because each sampling method has inherent bias and variability that can lead to inaccuracies when observations are limited due to unforeseen events.

With respect to item [1], the continued collection of both satellite and section/station profiles of chlorophyll biomass are fundamentally linked. Satellite collections provide high spatial (~1.5 km) and temporal (daily) resolution information of the surface layer (top 10-20 m, i.e. one optical depth) but after major blooms (spring, fall) the greatest fraction of the biomass is located at depth (generally > 20 m) and cannot be assessed by direct remote sensing of optical properties. The vertical distribution of phytoplankton biomass, its proximity to nutrient sources, and the dynamics in relation to changes in ocean climate can only be assessed through the collection of vertical profiles. Also, in coastal waters where freshwater influence is strong, optical properties are much more complex due to the presence of coloured dissolved organic matter (yellow substances) and sediment loads, leading to an increased uncertainty in the satellite derived phytoplankton biomass, thus necessitating a continuous in situ validation effort. The two approaches are complementary in developing regional models of ecosystem dynamics.

Item [2] may appear on the surface to represent a duplication of effort but in terms of the objectives of the program, both current elements are essential to the development of an understanding of the current state of the environment and how it relates to the long term. In the planning of AZMP, a critical element was to ensure that data across all Atlantic regions would be directly comparable through development of common protocols that optimize collections of dominant species of zooplankton (Mitchell et al. 2002). Seasonal observations along standard transects and fixed stations are collected to ensure detailed characterization of the zooplankton community so that changes in population dynamics can be ascertained (e.g. staging of key copepod species). The current CPR program covers the northern Grand Banks (47-49°N) and Scotian Shelf, with extensive sampling in deep waters between Iceland and Newfoundland. There are no collections on the NE Newfoundland or Labrador Shelves, or in the Gulf of St. Lawrence, thus limiting the basis for comparison among regions. Many of the smaller species, which are numerically dominant in most regions, have a high rate of extrusion in the CPR towed body which can potentially limit the index. There are no concurrent collections to physical, chemical or biological variables, other than indices of large phytoplankton. Furthermore, interpretation of the CPR data is difficult because of changing collection routes, timing (day-night, time of the month), and processing variations at SAHFOS (e.g. different taxonomists from year to year). In addition, the data are presented as relative values rather than absolute abundance estimates.

Despite these limitations, the CPR program does provide a long term perspective of changes in relative abundance of many zooplankton taxa that can be useful in the interpretation of changes observed in net collections currently carried out by AZMP, which is not available in most regions. However, for this comparison to be effective, research will have to be carried out to develop an assessment of the comparability of the two indices where sampling does overlap. The analysis will require careful consideration of spatial and temporal aspects of the two sampling programs in order to provide a valid comparison. Some of the current limitations to this comparison include the limited data available from the Newfoundland Shelf prior to the inception of the AZMP, the extensive gap in CPR collections on the Scotian Shelf between 1976 and 1992 (during which much of BIO's activities were carried out), and differences in net collection methods used as part of the various environmental study programs carried out by DFO.

Evaluation of CPR

The response to Issue 6 concludes that AZMP is not over-sampling for biological, chemical or physical variables as best we can determine. The SeaWiFS and CPR data provide the only broad scale biological information to evaluate spatial scales of variability readily. These scales are certainly smaller than the distances between fixed stations, the only other dataset that provides frequent temporal resolution.

Of particular concern is the CPR program. The impact of this sampling compared to the fixed station and shelf surveys conducted in the AZMP region is seen in the seasonal distributions of chlorophyll, phytoplankton and zooplankton stations for 2001 (Fig. 7.1-7.3). The CPR variable "greenness" is plotted on the chlorophyll plot (Fig. 7.1). The value of the CPR data set lies in: its intended monthly coverage along the lines shown in Figure 7.1; this complements the conventional chlorophyll sampling by filling data gaps (temporal and spatial), by providing better temporal resolution at all sites for in situ observations except the year-round fixed stations; and by continuing a long (1961-76; 1991-present) data series. On the other hand, the greenness index offers only four values: 0 (no greenness), 1 (very pale green), 2 (pale green) and 6.5 (green). The silk is compared to a colour chart. This is a subjective analysis, with arbitrary values returned, but it can be the first indication of phytoplankton blooms on the samples provided the blooms occur during the monthly transect. Given the extensive (and quantitative) chlorophyll sampling underway and provided SeaWiFS-like sampling which began in 1997 continues to be available (e.g. Fig. 7.4), the only ongoing value of the CPR greennness index is in the length of the time series. Indeed, interdecadal variability of the greenness index has been reported in AZMP Bulletin 1. A version of this interdecadal variability is shown in Figure 7.5 where it is clear that the index is considerably higher in the 90s than any of the other decades. Within the 90s there was year to year variability as well. These years formed two groups: 1991-1994 and 1995 to 1999 (Fig. 7.6, where 2000/01 is also shown). Clearly there are amplitude and timing differences among the 3 curves. The 1995-99 period features an earlier spring bloom than the two other periods. However, there was a change in sampling among the three periods. Figure 7.7 shows the CPR tracks in the 90s. There are two main paths: one confined to the inner shelf, within the Nova Scotian Current; the second towards the outer shelf about 100 km south of the inner track. The inner track was the main path of the CPR surveys from 1991-94 and 2000/01. The 1995-99 surveys mainly followed the outer track. Fuentes-Yaco and Platt have used SeaWiFS data from 1998-2001 to define the timing of the spring bloom (Fig. 7.8). There is about a four week difference between the timing of the bloom on the outer (earlier) versus inner eastern Scotian Shelf. A strong alternative hypothesis to the interpretation that the change of the greenness index was temporal during the last decade is that it occurred because of the change in the survey track.

Other sampling conditions could affect the interpretation of the CPR surveys: the distribution of the number of samples in time, day versus night tracks, timing during the month, and the changing expertise at SAHFOS. The sampling has been quite irregular until the last decade (Fig. 7.9), there is interdecadal variability of day versus night sampling and timing during the month. SAHFOS responded to our request concerning the history of the reading protocols and analysts by assuring us that “As regards analysis protocols… These have not changed…. So, I believe your concerns, about changing protocols or analysts, should be dismissed.” Yet in a follow-up comment: “One other thing that occurred to me is that some taxa have been recorded differently as years have progressed. The usual change is that instead of recording presence/absence we have started to count. For instance in 1993 we started to count tintinnids and in 1996 we separated and recorded some genera (e.g., *Dictyocysta, Favella*).”

We conclude that:

1) CPR data provide broad spatial and temporal coverage and are the only plankton data available at certain times of the year;
2) The length of the time series is important and allows long-term variability to be addressed;
3) Current value for assessing chlorophyll is very limited;
4) Use of the data on the Canadian sections of the Z and E lines has been limited (see section 15, Sameoto);
5) Interpretation of the data is confounded by sampling rate, timing (day-night, time of month), track changes and counting protocols;

6) The CPR data do not provide sufficient spatial resolution to describe the variability at frequencies that cover the entire band (0.5 months to ~O(10) years) but with care may be able to examine the very low frequency (O(decadal)) variability of a limited number of plankton;
7) We are not fully assured by the SAHFOS response that protocols have remained constant. In addition to the issues raised above, this would affect simple biodiversity measures such as the cumulative number of species in the region;
8) Comparison of CPR observations with other in situ and remotely-sensed data is needed.

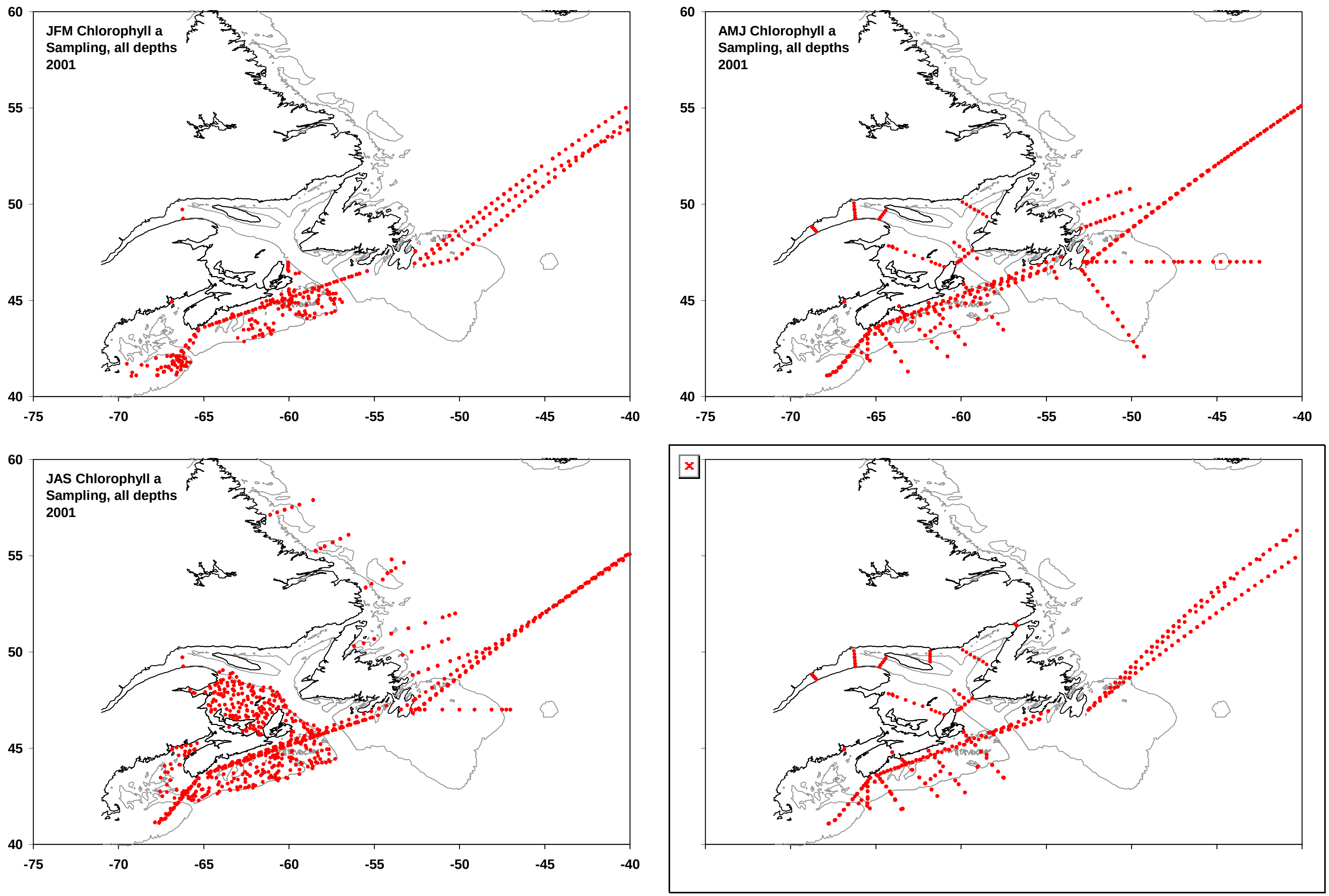


Figure 7.1. Distribution of chlorophyll stations (based on data from all depths) and CPR sites by season for 2001.

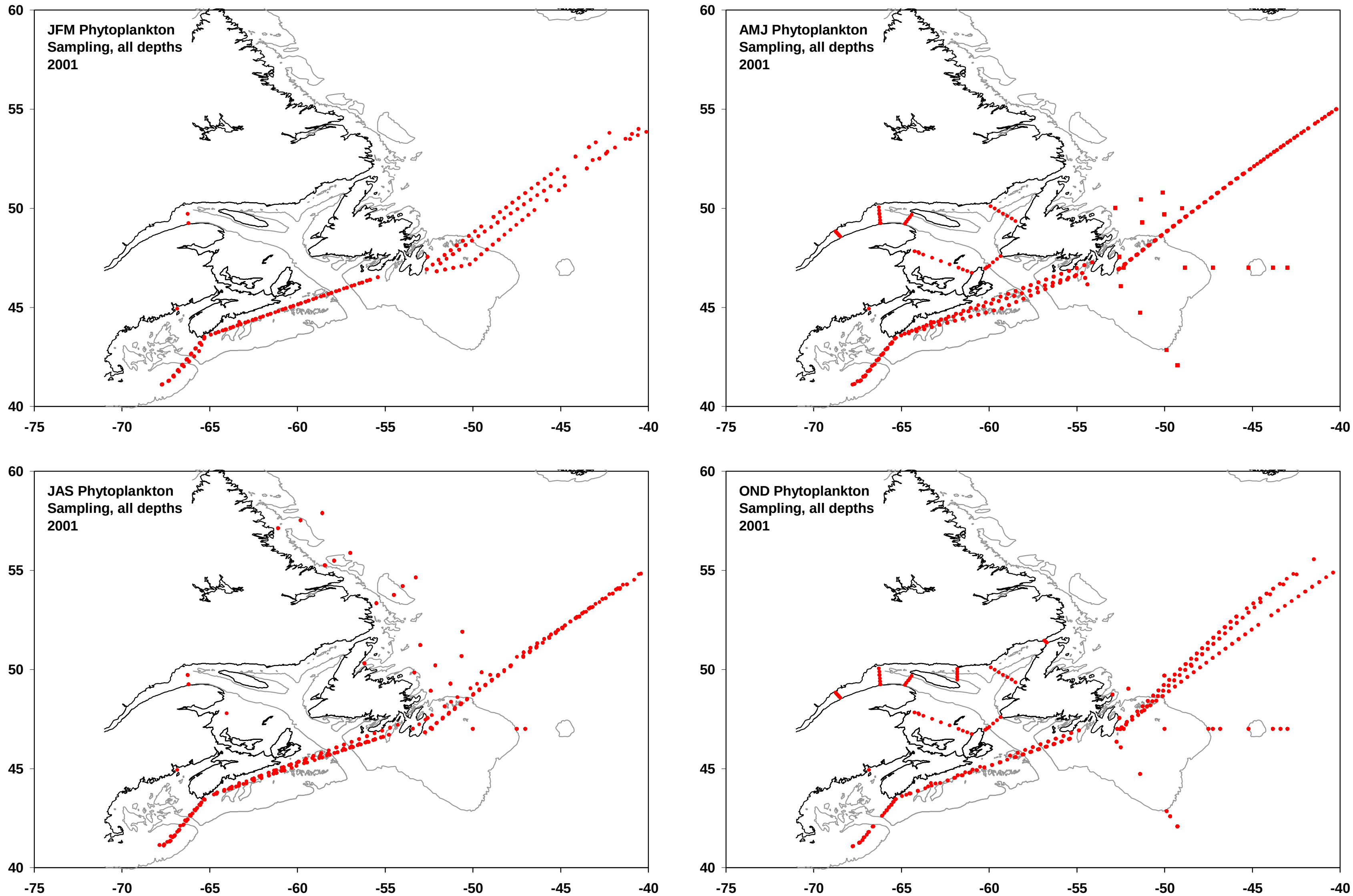


Figure 7.2. Distribution of phytoplankton stations (based on data from all depths) by season for 2001.

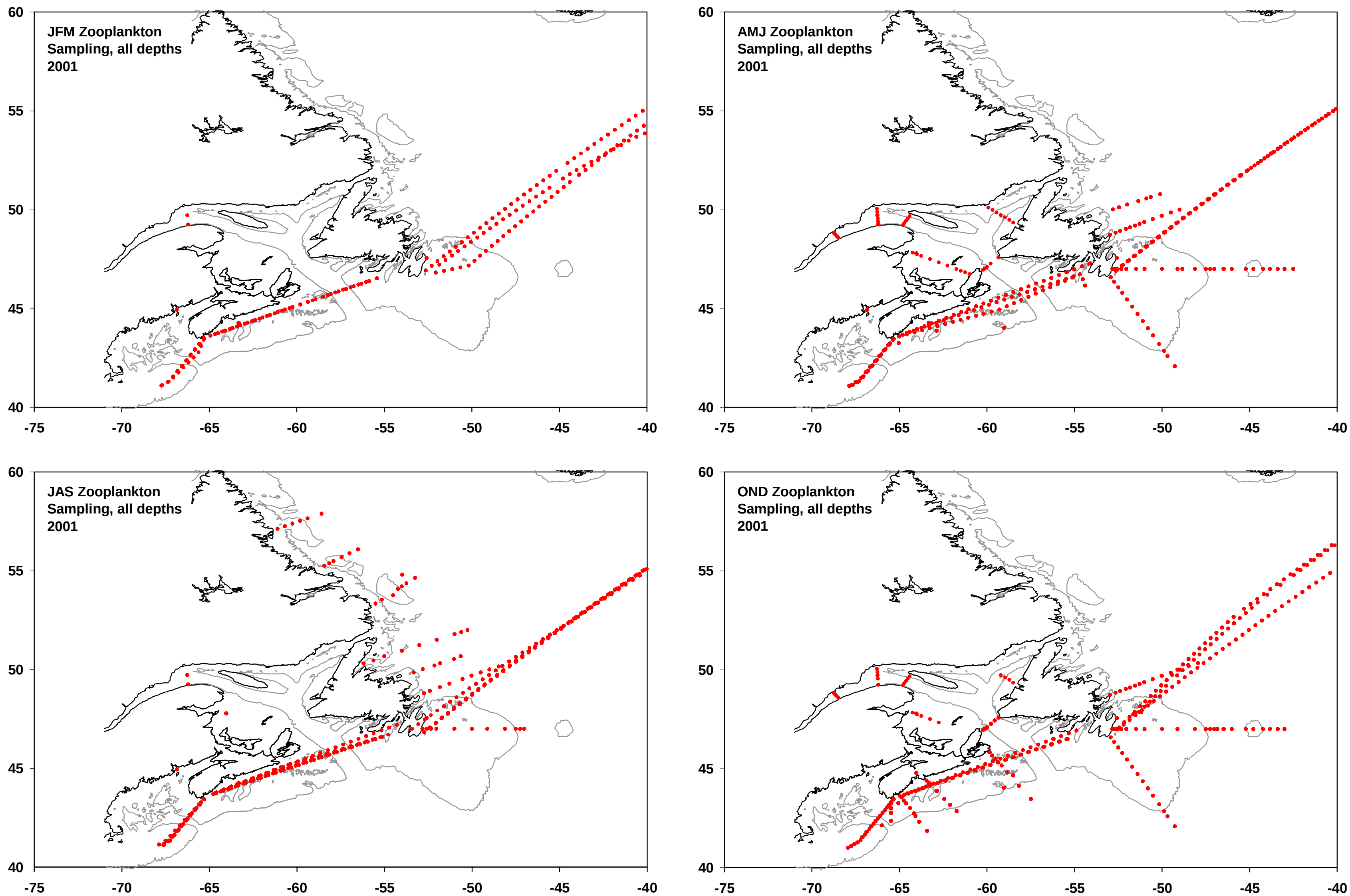


Figure 7.3. Distribution of zooplankton stations (based on data from all depths) by season for 2001.

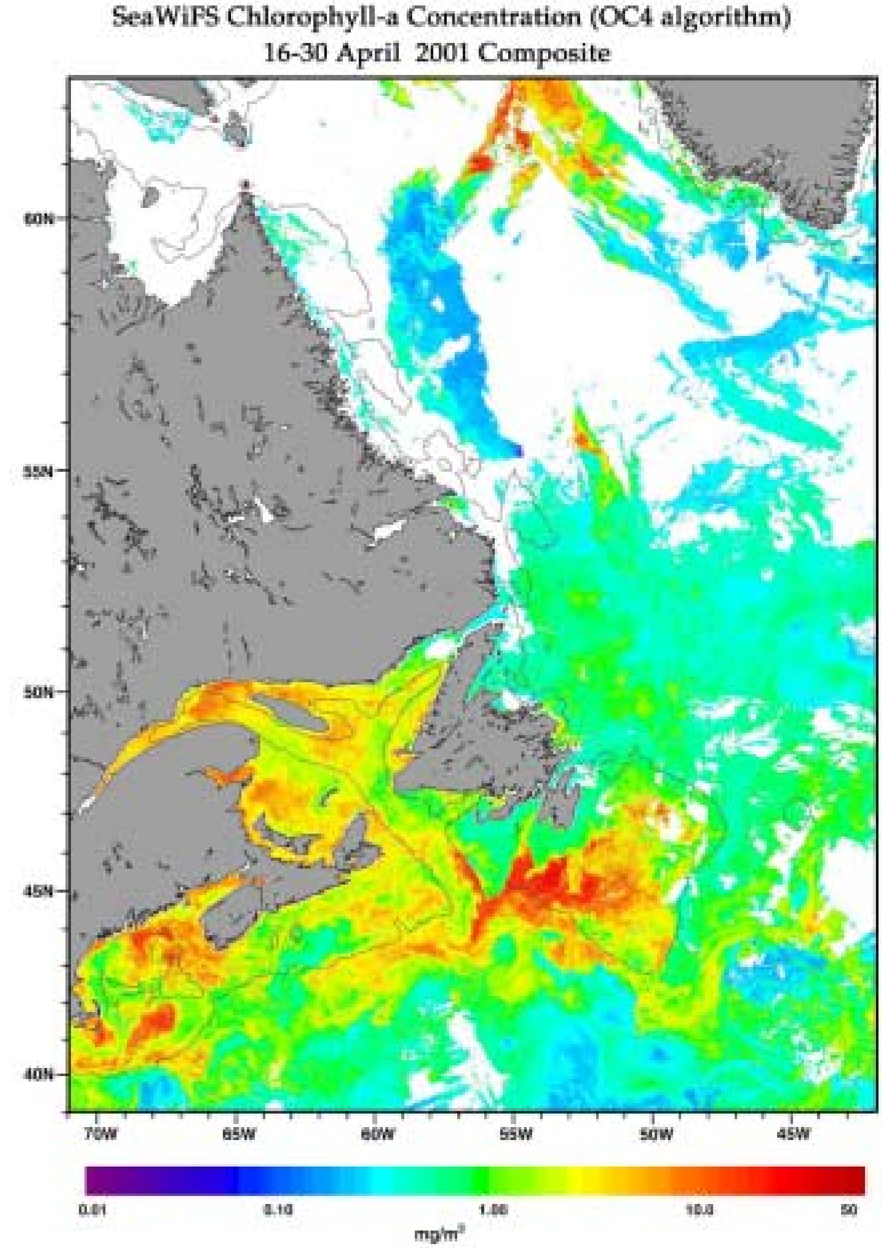


Figure 7.4. SeaWiFS ocean colour composite image for April 16-30, 2001.

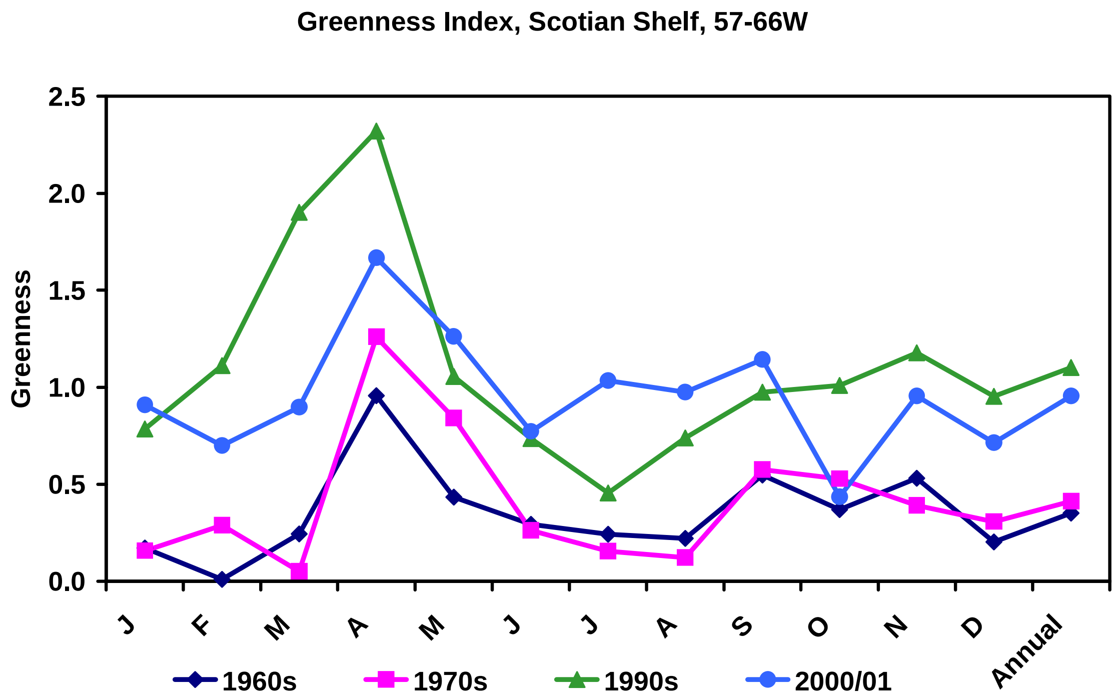


Figure 7.5. Monthly greenness index for the Scotian Shelf for the 60s, 70s, 90s and 2000-01.

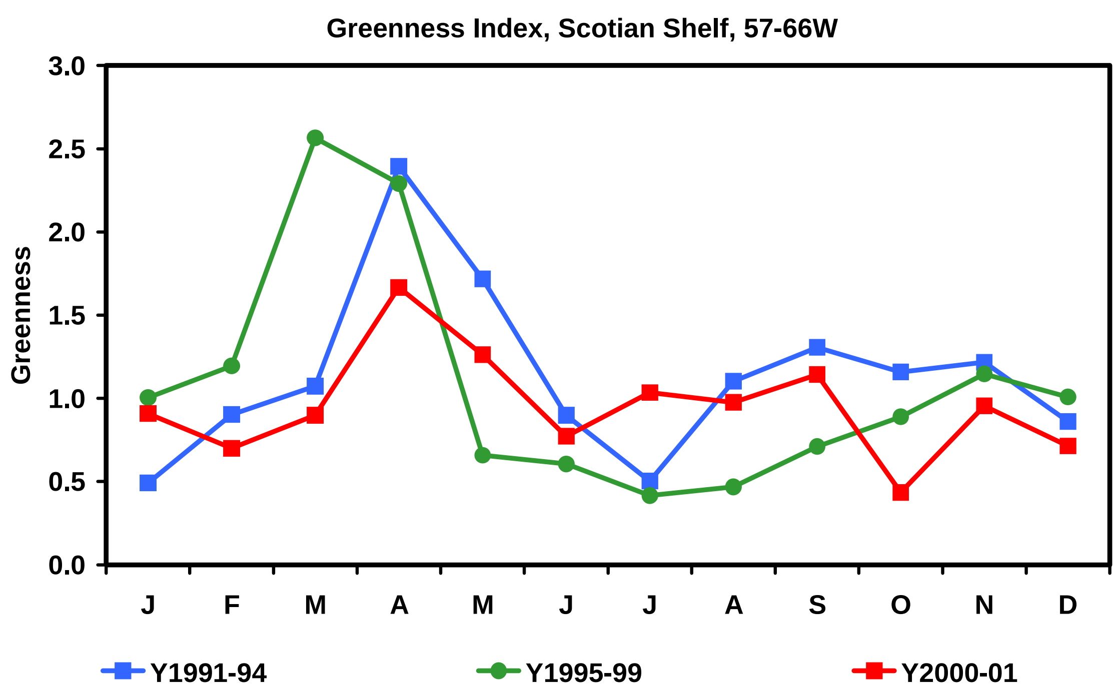


Figure 7.6. Monthly greenness index for the Scotian Shelf for 1991-94, 1995-99 and 2000-01.

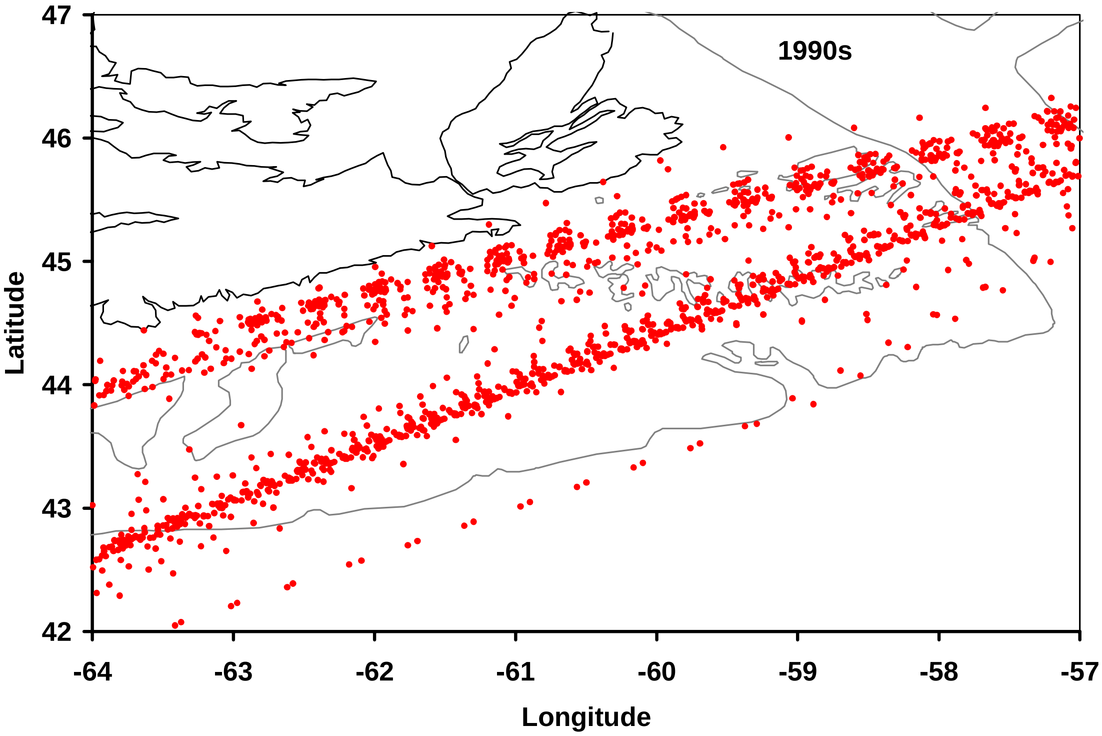


Figure 7.7. CPR tracks 1991-99.

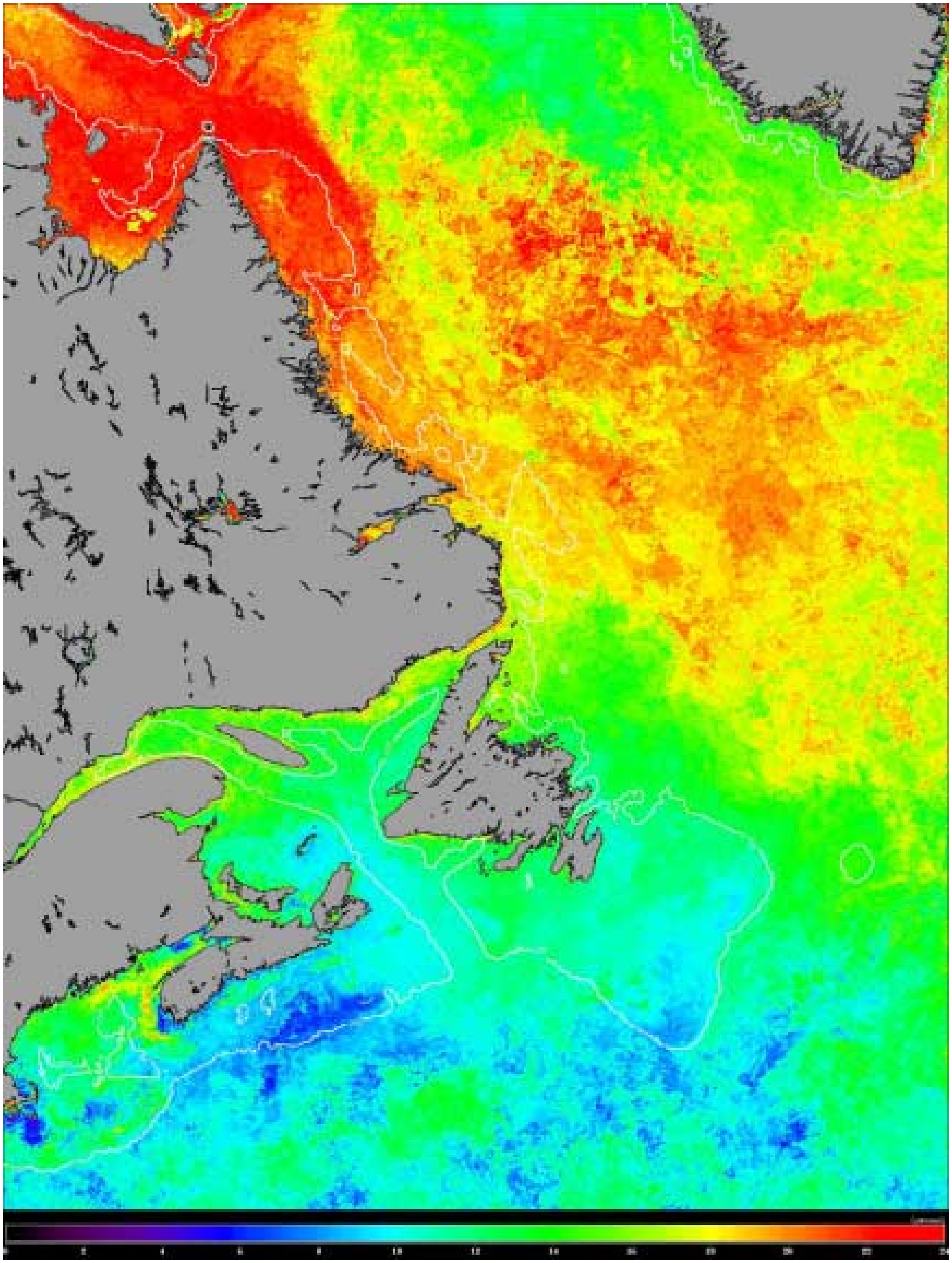


Figure 7.8. Timing of spring bloom maxima for the NW Atlantic. The 24 week scale begins in February and runs to July.

	Month												
Year	1	2	3	4	5	6	7	8	9	10	11	12	Grand Total
1961							15	15	1	14		4	49
1962		13	15		15	15	13		15	15			101
1963		12	12	10		8	13	13		11			79
1964	13	8	11		11	13			14	13			83
1965	4	10	11	2	11		13	12	15			13	91
1966	8		13		4		13	10	8	5	11	13	85
1967	13		9	12		13		10			14		71
1968		11		2	13	3	8			12	21	11	81
1969	9	12	23	11		13	14	29	8	20		14	153
1970	9		14	11	8		15	10		14	9		90
1971	12	9	5	13		10		11	10		10		80
1972		13	12				12		7		12		56
1973	15	2		4	6	13		10		9			59
1974				1	7					13			21
1975												7	7
1976		14		13	10								37
1991			15		15		15		12	13	14		84
1992	13	10	14	17		14	14	14	9	15	19	10	149
1993	14	9	26		15	27	14	13	13	15	15	15	176
1994	14		14	15	14	17	15	16	14	31	14	17	181
1995		14	17	16	14	16	16	16	16	17	16	16	174
1996	16	15	17	17	17	16	16		16	16	16	16	178
1997	15	16	9	25	2	17	17	17	17	17	16	16	184
1998	16	17	20	17	16	16	15	16	16	2	17		168
1999	17	15	29	17	15		15	15	15	16	15	15	184
2000	21	9	31	15			15	15	15	15	15		151
2001	15	15		15	15	15	31	15	15	15	16	15	182
Grand Total	224	224	317	233	208	226	299	257	236	298	250	182	2954

Figure 7.9. Number of full length tracks of the CPR for the eastern Scotian Shelf, 57-66W.

SECTION 8. IS AZMP MAKING EFFECTIVE USE OF ALL MONITORING DATA BEING COLLECTED FROM VARIOUS GROUPS?

Conclusion: AZMP provides multidisciplinary assessment of environmental status and draws on other monitoring activities to provide a more thorough perspective. While enhancements to existing databases (e.g. through archival sources) are continuing in order to improve understanding and broaden the scope of the program greater progress would be achieved if more scientific effort could be directed at synthesis and interpretation.

Recommendation: No new action required. AZMP Scientists will continue to participate and collaborate with other members of the marine science community as ideas and resources become available.

RATIONALE:

The AZMP makes extensive use of physical oceanographic data collected from SOOP, as well as chemical and biological data collected at fixed stations from those same platforms. This requires regular servicing of equipment and substantial investments in gear and data processing. Maritimes regions has made use of similar platforms to collect limited chemical and biological data but at the cost of maintaining staff aboard those vessels for extended periods, as well as obtaining assistance from other programs. In addition, data collected during the annual mackerel egg surveys in the Gulf off St. Lawrence, have been used by scientists in the Québec region but the cost of processing has been covered entirely outside the auspices of AZMP, because of current limitations.

Although the data collected directly by the monitoring program were used in the provision of advice early in the implementation program, in some areas the incorporation of additional sources of monitoring information (e.g. toxic algae, Long Term Thermosalinograph Monitoring, some data from remote sensing sources) is lagging due to limited time available to the researchers involved with the program. On the other hand, sea level observations (part of the GOOS), global solar radiation (a primary driving force of primary productivity), and Labrador Sea physical and biological assessments are now part of the AZMP reporting.

The AZMP has not made use of data beyond the elements outlined in the original proposal by Therriault et al. (1998). As such, information on human activities (e.g. fishery landings, oil and gas exploration and exploitation), fish abundance and distribution and life history characteristics, and marine mammals have not been used in the development of ESRs. Many of the activities surrounding AZMP deal specifically with the logistics of collecting, processing and interpreting extensive multidisciplinary data sets that leaves little time for the scientific leaders to deal with more extensive syntheses of information from other sources. Members of the AZMP feel that elements such as those outlined above are outside the purview of the program and that synthesis of the information provided by the program in addition to other sources of information on the status of marine ecosystems should fall under the auspices of the FOC.

SECTION 9. IS THE MONITORING PROGRAM UNDERTAKING WORK THAT SHOULD BE CONSIDERED AS A RESEARCH ACTIVITY? (E.G. DEVELOPMENT OF STOCK-SPECIFIC DATA PRODUCTS)

Conclusion: AZMP does not draw in research initiatives for resources; AZMP currently provides standardized reporting and makes only a modest effort at data integration; AZMP has fostered new research initiatives throughout the Department; in the least AZMP needs a mechanism to identify and prioritise R&D directed at the interpretation of AZMP observations.

Recommendation: No action required.

RATIONALE:

To date, AZMP has produced largely descriptive information producing standardized reporting and data products. A suite of generic physical "indices" have been generated; comparable biological-chemical indices have been the subject of discussion but have not been produced. AZMP has responded to various client requests for custom data products but the fundamental research to identify the data products is done by those requesting the information, not AZMP staff. However, AZMP leaders *are also DFO scientists* and therefore have an important role in R&D.

It could be argued that scientists involved in AZMP spend an inordinate amount of time on routine chores (standard reporting) instead of in-depth analysis and interpretation of AZMP results. However, AZMP has provided great stimulus for research (see sections 13-16). At the regional level, AZMP has enhanced the profile of FOC. At the international level, it has begun to make significant contributions to Northwest Atlantic Fisheries Organization (NAFO), International Council for the Exploration of the Sea (ICES) working groups and new international research initiatives such as Census of Marine Life (COML), Gulf of Maine Biogeographic Information System (GMBIS) project, D. Keifer University of California San Diego (UCSD).

AZMP currently makes only a modest effort at data integration (modelling) and cause-effect research but this could be enhanced – there is a human resources/workload issue for AZMP scientists, however as mentioned above. Some modelling activities within regions have been making use of AZMP data but considerably more needs to be undertaken to assist in the interpretation of observations.

In the least, AZMP needs a mechanism to advise on (identify and prioritise) R&D directed at the interpretation of AZMP observations. This is done formally through the AZMP chair's annual reporting to the NSDC but the direct impact on research appears to have been modest. Identification of research projects that would support AZMP is a standard agenda item for AZMP annual meetings.

SECTION 10. IS THE PROGRAM SUSTAINABLE GIVEN CURRENT RELIANCE ON THE COMBINATION OF AZMP AND A-BASE RESOURCES?

> *Conclusion: AZMP cannot sustain its present level of activities with present resources. AZMP relies heavily on A-base resources, which are subject to changing priorities, and has limited capacity to address emerging issues or renewal of resources; there is growing imbalance between collection and interpretation because of increasing demands for advice.*
>
> *Recommendation: stabilize A-base support.*

RATIONALE:

The answer to this question is somewhat region dependent but the fundamental point is that most of the AZMP activities are largely supported by A-base resources, in terms of ship time allocations, personnel (salaries, overtime and compensatory time), and infrastructure. There is an approximately equal or greater contribution of A-based O&M dollars assigned to AZMP as there is in terms of funds transferred from HQ. The reliance on A-base funds, as well as the maintenance, reduction or expansion of current AZMP activities will also depend on the national and regional decisions pertaining to the Departmental Assessment and Alignment Project (DAAP). The Newfoundland-Labrador region has managed to maintain activities at consistent levels throughout the program and if resources remain at existing levels, AZMP activities are likely to be maintained for the most part. For the Maritimes, there is entirely too much reliance on A-base resources/personnel (with short-term/uncertain goals & funding providing significant resources). A regional assessment is underway to identify which program activities are to be maintained in order to meet objectives while remaining within budgetary constraints. In the Québec region, the situation is much the same as in the Newfoundland-Labrador region whereby existing resources have enabled the region to maintain a good level of activity without reliance on short-term funding. However, there has been mounting pressure on available resources in all regions to maintain both monitoring and basic research activities, which has pushed to the limit demands on equipment and personnel (salaries, overtime and compensatory time) which has had an impact on both research and AZMP activities.

In terms of data management, the AZMP funding levels are significantly lower than the A-base, while the effort required to establish the databases and manage the multidisciplinary data is high. Though in the last few years AZMP was successful in obtaining significant sunset funding, and consequently major advances were made, 2003 has seen many cutbacks in A-base support for data management in most regions. The net result is that, the ground we gained in data archaeology is being lost by not being able to analyse and migrate current data sets, thus increasing the backlog.

Ship costs and availability are continuing pressures on AZMP sustainability. Dedicated surveys require the assignment of vessels for oceanographic research to make the most effective use of personnel and sampling resources while ensuring an accurate and quasi-synoptic view of ecosystem and environmental conditions. Any reductions in platform availability will have a direct impact on the sustainability of program quality. In addition, workload/overtime costs are issues for all AZMP regions.

AZMP has a fixed annual budget but costs are increasing for (a) basic operational costs of sample collection and processing (b) CPR contract, (c) equipment maintenance/replacement, (d) computer software licenses and hardware upgrades. Any new technology support and development cannot be supported by the program. Furthermore, the current allocation of capital resources remains largely based on a regional model. However, AZMP represents a zonal program which must compete with regional pressures to obtain capital funding. This effectively prevents a coordinated effort for the provision, maintenance and replacement of costly equipment. Shared use, particularly of the more expensive resources, could allow a more streamlined, efficient and coordinated use of equipment dedicated to AZMP activities that would not impact on other programs.

There is a growing imbalance between data collection-reporting and synthesis-interpretation (the latter under-represented). As indicated above, many of the lead researchers involved with AZMP have had limited time available to carry out in-depth analyses or modelling of the information collected as part of the program. In addition, there are new demands on the horizon (e.g. support of the Canadian contribution to the international GOOS program). This may require adjustments in the AZMP observational program. In addition, FOC has identified benthic and macrozooplankton monitoring as areas of priority that AZMP should investigate further.

SECTION 11. IS THE DATA MANAGEMENT MEETING THE REQUIREMENTS FOR PROGRAM?

Conclusion: *AZMP data management requirements have resulted in significant advancement in the way DFO manages, safeguards and provides access to its data; there has been a heavy reliance on A-base resources for data management; more effort will be required to deliver truly integrated data sets from the multi-disciplinary AZMP analyses.*

Recommendation: *A significant national commitment is required to provide the resources needed to develop and deliver integrated data sets. Although it must involve AZMP, this activity is beyond the scope of responsibilities of the program.*

RATIONALE:

The answer to this question is variable. According to the AZMP data management plan (1999), *all* data should be made available in a *timely* manner. At the onset of the program, it was agreed that the data management will be a shared responsibility among the Atlantic regions and MEDS, and will aim to implement a web-based dissemination system of distributed data bases.

The data management was designed to take into account (a) the diverse data types of the AZMP, and (b) the level of effort required for each data type to be transformed from what was collected at sea into electronic data and products with relevant metadata. For example, there was an established procedure for data management of the physical data, particularly for the CTD and water level data. The AZMP data management was built on this existing infrastructure. In this process, each region sends to MEDS the profiles (T, S, Oxygen and fluorescence) in low-resolution format almost immediately after the cruise is completed, for distribution on the Global Temperature-Salinity Profile Project (GTS), for archival and for dissemination through the AZMP web-site. Any data that are not received at MEDS within 30 days of its collection are not placed on the GTS, but they are archived and available on the web. In 2003, the percentage of data successfully distributed through the GTS within 30 days varied between 50% and 100% according to station.

The high-resolution data of the continuous type are sent by the regions to MEDS within one year (on average) of acquisition. Upon reception, MEDS replaces the low-resolution version previously received, updates the archive and disseminates them through the AZMP website. As of October 2003, MEDS had received data from the May, June, July and September 2003 sections, and from all AZMP cruises of the previous years. At stations, the average percentage of high-resolution profile/total number of 2001 and 2002 profiles (low-resolution + high-resolution) was 89% on average.

MEDS also has a data archive of discrete data (mainly from bottle analyses: nutrients, O_2, chlorophyll-*a*) used to be submitted directly by the regions to MEDS. However, with the development of an ORACLE based data base for the biochemical data, BioChem, it was decided that the focus will be to make BioChem a national data base accessible from all regions, and migrate all AZMP data into this data base. In the first few years, BioChem received considerable funding support from other sources at BIO, and limited support from national climate funding, and consequently, under the leadership of the Informatics Group in the Maritimes region, the data base was built and most of the current AZMP Maritimes data are migrated into it. The recognition that data are a national capital asset and that the development of data bases and maintenance of the content should be treated as capital projects resulted in BioChem receiving much needed funding in the recent years, thus allowing the data management group to ‘nationalise’ the data base to be managed by MEDS. By the end of the fiscal year 2003-04, all regions will be able to upload data into BioChem, and there will not be a need to ‘copy’ and ‘send’ data to MEDS.

Fundamental to implementing a national archive is the need to agree on standards for metadata, quality control and procedures and protocols. Concurrent with the development of the data base, the data management group is addressing these challenges.

While waiting for the upload software to be ready for all regions, the regions have processed their own data, archived regionally, and generated products. Many of these products, such as the plankton abundance, are available from the AZMP website.

AZMP is built on existing programs, which includes satellite based observations. However, the management of this data is carried out by the remote sensing groups of BIO and IML, but the data and products may be accessed through the AZMP website.

The AZMP website also displays the climate indices and selected products including the annual state-of-the-ocean reports and the AZMP Bulletin.

Thus one could say that the data management has resulted in significant advancement in the way DFO manages its data, and safeguarding and providing access to all AZMP data. However, to deliver truly integrated data sets from the multi-variate multi-disciplinary AZMP data, considerably more effort will be required. The realignment process that is taking place in the department will hopefully recognise the importance of data and information management and modelling, and assign a high priority with funding to such activities.

SECTION 12. ARE DATA PRODUCTS CLEARLY IDENTIFIED AND READILY AVAILABLE?

Conclusion: AZMP has developed and implemented a standard reporting format (e.g. ESR, Research documents, AZMP bulletin) presented annually for peer review; AZMP has also responded to client needs as they arose; data are readily available and improvements for better access and interpretation are underway.

Recommendation: AZMP should continue to direct efforts to provide greater ease of access of AZMP data sets and interpretations.

RATIONALE:

Data products produced by AZMP fall into two classes, (1) routinely produced "generic" data products, and (2) custom data products generated expressly for end-users on a "one off" or continuing basis.

Generic data products include annually produced Research Documents (Res. Doc.) describing annual trends in physical (meteorological as well as oceanographic), chemical and biological properties of the four AZMP regions. These documents are produced for the annual spring FOC meeting and are presented/reviewed at that venue. In addition to Res. Doc., regional Ecosystem Status Reports (ESRs) are produced and reviewed at the FOC meeting. Both Res. Doc. and ESRs are made available on DFO's Canadian Science Advisory Secretariat (CSAS) website (http://www.dfo-mpo.gc.ca/csas/Csas/English/Publications/Index_Pub_e.htm) sometime during the year following the reporting year. In addition, AZMP publishes an annual Bulletin containing English, French, and bilingual articles to provide oceanographers and fisheries scientists, habitat and environment managers as well as the general public with the latest monitoring information from the AZMP (AZMP). The Bulletin presents an annual review of the general oceanographic conditions in the Northwest Atlantic region, including the Gulf of St. Lawrence, as well as AZMP-related information concerning particular events, studies, or activities that took place during the previous year. The bulletin is distributed to all DFO and Canadian university libraries, as well as to some other department libraries. It is also distributed to higher level management people in the three Atlantic regions and in Ottawa, as well as to a number of interested people from different disciplines. Last year around 600-700 copies of the Bulletin were distributed.

Finally, MEDS maintains a public-access internet website for AZMP (http://www.meds-sdmm.dfo-mpo.gc.ca/zmp/main_zmp_e.html) which so far has been used mainly to provide access to data and showcase products. Data collected during AZMP cruises (profiles and continuous recordings of physical, biological and chemical variables) are available to download by sections and fixed stations. Data from other sources and of relevance to the oceanography of the Atlantic zone are also presented and made available. This includes water levels from nine (9) Atlantic and St. Lawrence stations, and meteorological data (air temperature, wind, solar radiation, rainfall, cloud coverage), provided by Environment Canada, and recorded at stations in northern Québec and the Atlantic provinces. Products include climate indices, time-series, contour plots, depth profiles, sea level monthly and yearly means, phytoplankton and zooplankton abundance and links for access to remote sensing. In addition, the website hosts the AZMP bulletins, useful links, and a publication section with links to the documents on the CSAS website. AZMP data products are also generated for the international community, e.g. NAFO and ICES working groups reports (e.g. http://www.ices.dk/marineworld/oceanclimate.asp; http://www.ices.dk/marineworld/zooplanktonindex.asp).

The development of larger scale/longer term generic oceanographic "indices" for atmospheric and physical properties of the Atlantic Zone is well-advanced (Colbourne et al. 2002); climate indices (including climatologies and anomalies) relevant to the Atlantic Zone are routinely produced/updated on the AZMP website. Chemical/biological indices development has progressed more slowly although a number have been suggested (Harrison et al. 2002) but not yet implemented. AZMP scientists are also involved in the development of more sophisticated data integration methodologies and integrated data indices with the goal of routinely producing regional state-of-the-ecosystem reports (Frank, 2003).

AZMP also contributes data for value added products in the St. Lawrence Observatory (OSL) portal (http://www.osl.gc.ca) AZMP scientists are also actively involved in the development of physical/chemical/ biological indicators in support of the GOOS. Under action 17 of the 5th meeting of the GOOS steering committee in 2003, an international group of scientists (including an AZMP rep.) were given the task of reviewing the status of indicator development and operational use, and to develop requirements for indicators, identify user groups, and develop a plan for identifying and incorporating indicators as GOOS products and report back to the GOOS Steering Committee-VI (GSC) in 2004. It was also agreed that the scope of the indicators should address the following categories:

- Physical oceanographic properties such as El Niño/Southern Oscillation (ENSO) events, basin scale oscillations (e.g. North Atlantic Oscillation (NAO), North Pacific Decadal Oscillation (NPDO)), thermohaline circulations, Arctic sea ice and sea level;
- Susceptibility of coastal populations, habitats and living resources to extreme weather events;
- Condition (status, health) of marine and estuarine ecosystems, including the health of marine organisms (both as an indication of the health of marine communities and as indicators of human health risks);
- Sustainability of living marine resources and the carrying capacity of marine ecosystems for living resources.

A draft report has been produced and submitted to the GOOS Steering Committee for review.

A more formal request for the feedback on custom data products from the stock assessment community was discussed at a joint FOC-AZMP workshop held in Montreal in winter, 2002 (Ouellet 2002).

SECTION 13 GENERAL DISCUSSION

The implementation of the AZMP has greatly enhanced the level of knowledge of the variability in many of the physical, chemical and biological oceanographic variables important for the determination of the state of the pelagic marine planktonic ecosystem. In most instances, the current sampling program can identify interannual variability in the state of many of the variables that are sampled by the program. However, it is clear from our assessment of the observations and interpretation of the program's results that in several instances, there is considerable unresolved variability that contributes to uncertainty in our evaluation of the state of Atlantic Ecosystems. Furthermore, our consultations with various client groups, in collaboration with the FOC, showed that many aspects of the marine ecosystem are not effectively sampled by the program, nor can they be given current resource availability.

Implementation and operation of the program came as an additional task for many of the researchers involved with the program. The addition of nine new positions (three per region, excluding MEDS) was key to allowing the program to proceed but the reality is that there were considerable additional requirements to existing staff that has lead to significant workload issues. There is currently insufficient research activity within the program to warrant full time dedication of research scientists to the ongoing activities but there is still the need for these scientists to maintain an overview of the program's activities as well as provide the primary assessment of the observations. Field collections and laboratory processing of data represent a major demand on the few staff that are available to carry out the work. As a result, the continued implementation of the program has required a general reallocation of time commitments on the part of a large number of personnel within each region, resulting in a significant strain on our capability to provide the dedication necessary to ensure that there is sufficient comprehensive analysis and modelling of AZMP data to provide a greater understanding of the dynamics of the lower trophic levels of the pelagic food web. In some instances, the limitations are due to issues surrounding available time while in others is it a question of having the skills necessary to carry out the research needed to achieve greater understanding (e.g. modelling).

Key to the interpretation of the data collected as part of the program is the development of coupled biological-chemical-physical models of the Atlantic regions. There have been significant research efforts dedicated to modelling ocean circulation in the different regions of the Atlantic zone, and further work is required for issues pertaining to operational oceanography, but there has not been a concomitant effort of equal magnitude to model the biogeochemical cycle in tandem with these efforts. In order to interpret the dynamics which lead to the fluctuations in environmental conditions observed as part of AZMP, the use of coupled models is essential because of the sparseness of the chemical and biological observations currently being collected as part of the program. There is an urgent need to support a dedicated effort in all regions of the Atlantic zone to fill this gap.

When first implemented, the program's originators and developers clearly stated that the current program represented the minimal required to provide an overview of the state of marine environmental conditions. However, it has become clear during this review that there exist some very major gaps in the coverage being afforded of the Atlantic zone.

Fiscal constraints must be faced realistically but it is important to start the planning for the development of a more effective and widespread observation system if the Department is to meet future requirements of a Global Observations System. The program should build on the knowledge and experience achieved from existing observation systems used throughout the world. The greatest accuracies and efficiencies would likely be obtained by combining ongoing field programs with the development of remote sensing tools that could be deployed in both near-field and remote locations of the Atlantic zone. This would necessarily involve capital investment but it would also require investment in the personnel needed to maintain operations as well as the field activities required to service and calibrate such systems. The return on investment would be achieved through decreased uncertainty in our knowledge and understanding of environmental changes taking place in the Atlantic zone.

SECTION 14. STATION 27 OCEANOGRAPHIC TIME SERIES- A BRIEF HISTORY, E. B. COLBOURNE

Oceanographic observations on the Grand Banks of Newfoundland began as early as 1894 and were presented in the annual report of the Newfoundland Department of Fisheries for the year 1895. However, no systematic, regular oceanographic observations were conducted until 1931, when the Newfoundland Fisheries Research Commission opened the Biological Laboratory at Bay Bulls, Newfoundland. This laboratory was destroyed by fire in 1937 and it was not until the commissioning of the *Investigator II* as a full time research vessel in 1946 that hydrographic work resumed under the directorship of Dr. Wilfred Templeman. During the late 1940s and early 1950s, hydrographic monitoring along several sections crossing the Newfoundland and Labrador Shelf was initiated. The section beginning immediately off St. John's Harbour with Station 27 (*Latitude* 47^o $32.8'$ *N*, 52^o $35.2'$ *W*) proceeded to the southeast Grand Bank, ending with Station 32. The second station on this line, Station 28 was the first monitoring station on the Flemish Cap section (47^o *N)* with stations numbering 28-42. The southeast Grand Bank section was not sampled regularly but Station 27 was often included as part of the Flemish Cap section. The site is located about 7 km off St. John's Harbour in a water depth of 176 metres and was intentionally located in the Avalon Channel to monitor the water properties of the inshore branch of the Labrador Current (Fig. 14.1). In this area, the cold $<0^oC$ water that forms the CIL on the continental shelf is present year-round, and variations in water properties are representative of conditions across a broad area of the Newfoundland Shelf.

The first data from Station 27 were collected in June of 1947 and during the remainder of that year, the station was sampled 14 times. In subsequent years, sampling increased to include all months; there were 15-30 occupations per year up to the late 1970s. In recent years, the station has been sampled about two to four times per month on average. Historically, most of the data at Station 27 were collected at standard oceanographic depths (0, 10, 20, 30, 50, 75, 100, 125, 150 and 175 m) using bottles fitted with reversing thermometers. Since the mid-1960s, a considerable amount of data was also collected using mechanical and electronic bathythermographs. More recently, CTD recorders have been the instrument of choice. The monthly distribution of the number of temperature profiles collected at Station 27 shows a bias towards sampling in spring and early summer and to some extent during the fall with minimum sampling in winter (Fig. 14.2, top panel). The number of temperature profiles collected from 1946 to 1979 accounted for about 40% of the data (Fig. 14.2, bottom panel). Since the mid-1980s, there has been a large increase in data collection at Station 27, with an average of 45 to 55 profiles per year. In fact, the 1990s accounts for about 36% of the data collected at Station 27 in its 55-year history. The maximum number (>70) occupations occurred in 1991 and 1992 during the collapse of the northern cod stock. The complete data set contains over 1800 temperature and over 1500 salinity profiles, making it the most frequently sampled site in Newfoundland and Labrador waters.

USE OF DATA

In the 1950s, Station 27 data mainly provided annual descriptions of the hydrographic conditions and occasionally these were related to changes in local fisheries. The annual report of the Fisheries Research Board of Canada for the year 1950 contains the first detailed description of oceanographic conditions using Station 27 data (Templeman 1951). He described seasonal variations in temperature with depth and attributed unusually large catches of cod and lobsters in shallow water and the greatest abundance of squid for many years in the Newfoundland area to warmer-than-usual surface waters. By the mid-1950s, enough data had accumulated to allow Templeman and Fleming (1956) to compute the first temperature climatology for inshore Newfoundland waters which was used to describe the thermal habitat of cod during the longlining experiments of 1950-53 along the east coast of Newfoundland. Beginning in 1954, summaries of temperature and salinity variations at Station 27 were routinely included in the annual proceedings of the International Commission for the Northwest Atlantic Fisheries (ICNAF) (Templeman 1955). As more data accumulated, ICNAF initiated a series of special symposiums describing environmental conditions in the Northwest Atlantic on decadal time scales (ICNAF 1965).

Beginning in the 1960s, use of the Station 27 data was extended beyond annual descriptions of the physical environment. Bailey (1961), using data collected from 1946-1958, completed a detailed study of the oceanographic variability in the inshore waters of Newfoundland. He used harmonic analysis to construct annual and seasonal cycles of temperature and salinity at several depths and subsequently computed time series of temperature and salinity anomalies. Shortly afterwards, Templeman (1965a) published a report relating anomalies in sea temperature at Station 27 with air temperatures at St. John's. In the same year, he attributed the mass fish mortalities in the Newfoundland area to cold ocean temperatures (Templeman 1965b).

A series of climatologies of temperature, salinity and density measured at Station 27 were published that were based on progressively longer time series. Huyer and Verney (1975) produced the first analysis using data from 1950-59; Keeley (1981) extended it to include data from 1946-77. More recently, Colbourne and Fitzpatrick (1994) presented an analysis of the Station 27 data for the years 1978-93 and Fitzpatrick and Colbourne (2000) produced an updated temperature, salinity and density climatology for Station 27 using data from 1946-99. Currently these data sets are used to construct temperature and salinity anomaly time series for the inner Newfoundland Shelf using standard harmonic analysis and reference periods consistent with the World Meteorological Organisation (WMO) (Fig. 14.3).

Petrie et al. (1988) using Station 27 data along with other environmental observations presented a comprehensive description of the Newfoundland Shelf temperature variability, specifically the CIL, and concluded from correlation analysis that the spatial scales of variability are coherent over large areas of the Newfoundland Shelf. They then went on to describe in detail the phase and amplitude characteristics of the annual cycle in temperature and salinity (Petrie et al. 1991) and examined the spatial and temporal scales of variability in the residual field (Petrie et al. 1992) on the eastern Newfoundland Shelf. In these studies, the data were used to parameterize vertical diffusion coefficients and kinematic models were employed to interpret the observations. A follow up to these studies by Umoh et al. (1995) used a vertical diffusion model with a horizontal advection adjustment to quantify the annual variations in the temperature cycle and partition the effects of local air-sea heat flux and advection on the Newfoundland Shelf. Mathieu and deYoung (1995) used temperature and salinity data from Station 27 to examine the influence of vertical diffusion and the importance of salinity in constraining a mixed layer model for the inner Newfoundland Shelf.

Symonds (1986) used the data to model seasonal sea-ice extent on the Newfoundland Shelf and Myers et al. (1990) concluded that ice-melt over Labrador and the northern Newfoundland Shelf was primarily responsible for the salinity minimum observed during late summer over much of the Newfoundland Shelf. Colbourne et al. (1994) and Drinkwater (1996) examined inter-decadal climate changes in the Northwest Atlantic using data from Station 27. Numerous other studies have used Station 27 data to examine environmental influences on growth, recruitment and distribution of many marine organisms in Newfoundland waters (e. g. Myers et al. 1993; Parsons and Lear 2001; Colbourne and Anderson 2003). Stein and Lloret (2001) used the data in statistical models to forecast ocean temperatures for up to one year for fisheries assessment applications. These and other studies have contributed greatly to our understanding of the oceanography on the Newfoundland Shelf and the linkages between ocean climate and the marine ecosystem.

The climatology and year-to-year descriptions dominated the use of the Station 27 data until the mid-1980s. Moreover, annual descriptions of ocean climate that began in 1954 for ICNAF and presently for the Northwest Atlantic Fisheries Organization (NAFO) are still a primary focus and are perhaps one of the longest time series of documentation available anywhere pertaining to ocean climate conditions in the North Atlantic (Colbourne and Fitzpatrick 2002). Beginning in the mid 1980s, there has been increasing use of the data to address issues related to scales of variability, long-term climate changes, vertical mixing, local upwelling and circulation. During the mid-1990s oceanographers from Canada began active participation in the ICES Oceanography Committee and its working groups and, using the Station 27 time series, have contributed to the annual ocean climate status summary for the North Atlantic (ICES 2003). National and zonal groups, such as the FOC of Fisheries and Oceans and the RAP remain a primary user of the Station 27 data (Colbourne 2003).

STATION 27 AND THE AZMP ERA

In 1992 under the northern cod science program, limited biological sampling was initiated at Station 27 but essentially ended with the termination of the program in 1995. Since 1998 as part of the AZMP, biological and chemical sampling was resumed and oceanographic conditions based on these observations are now routinely published (Pepin et al. 2003). With over five years of continuous biological and chemical observations at Station 27 investigators are now beginning to construct short-term mean conditions, much like was done with hydrographic observations throughout the 1950s. Continued monitoring at this site will greatly increase our understanding of physical processes and long-term trends in ocean climate. It is in our understanding of ecosystem processes however, through ongoing biological and chemical monitoring, that the most significant contribution to ocean science will likely be made in the near future.

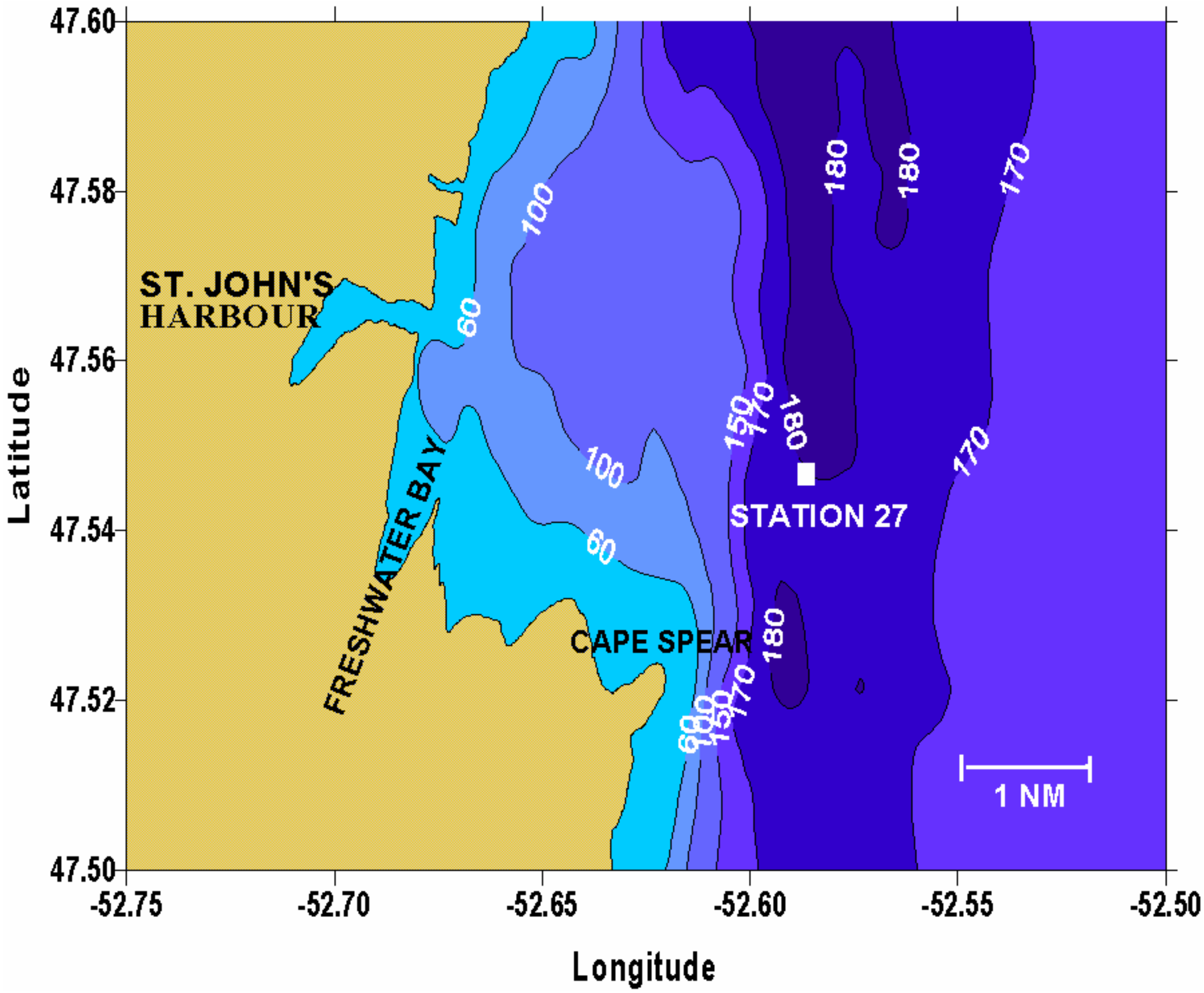


Figure 14.1. Map showing the bathymetry (m) and location of Station 27 off St. John's Harbour.

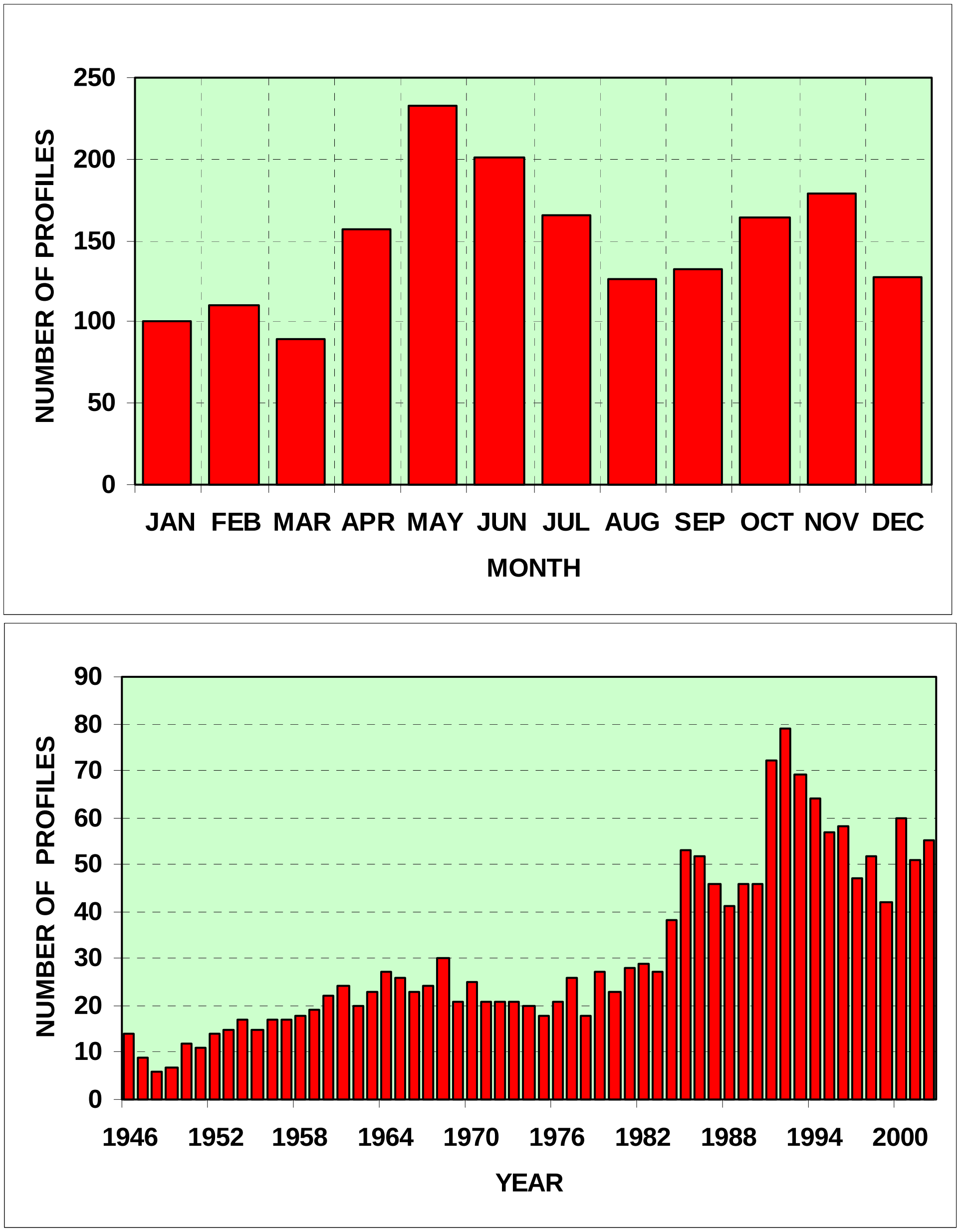


Figure 14.2. The total number of temperature profiles collected at Station 27 by month (top panel) and by year (bottom panel).

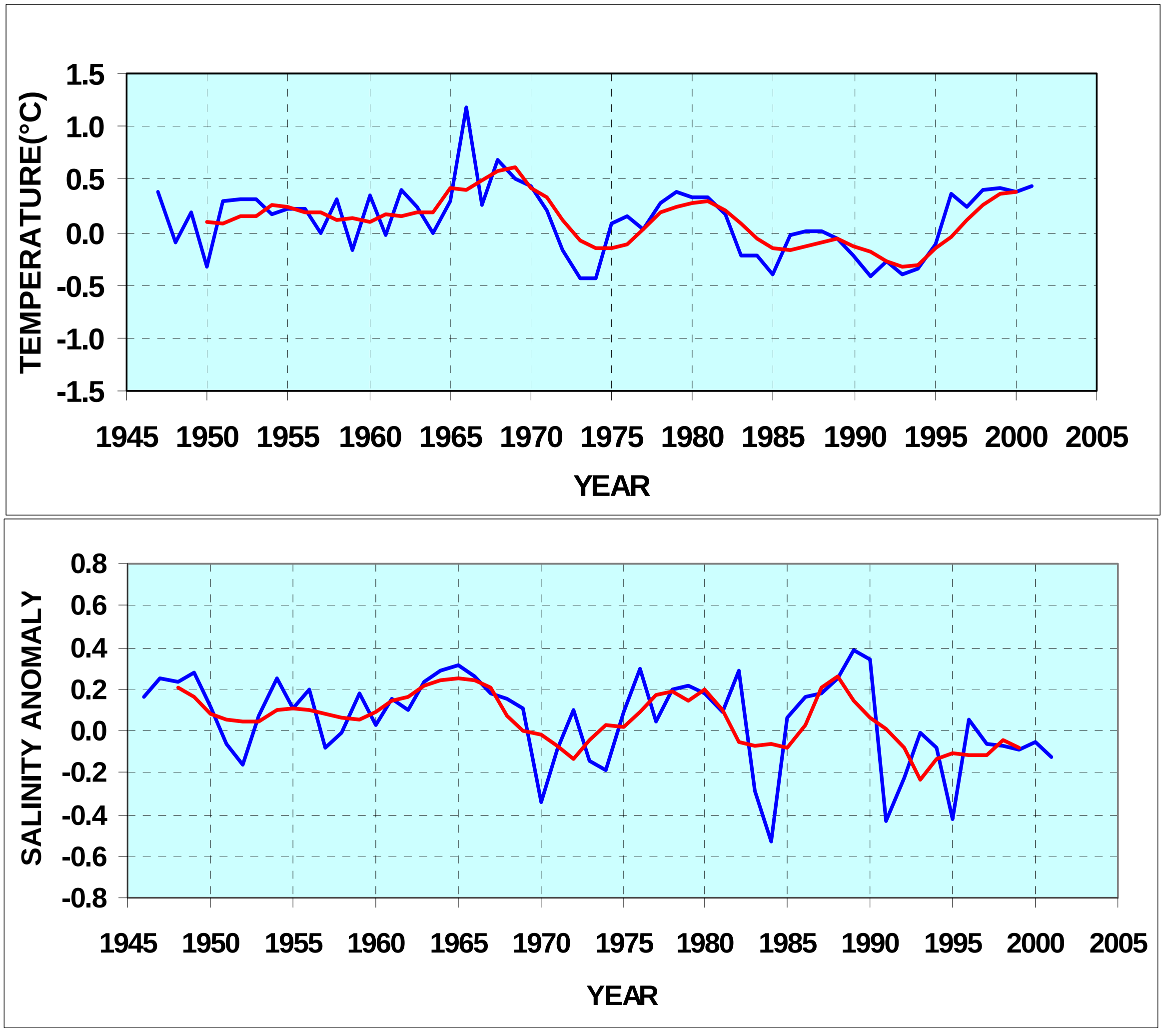


Figure 14.3. Station 27 annual bottom temperature anomalies (top panel) and surface salinity anomalies with their 5-year averages (red lines). The reference period is from 1971-2000.

SECTION 15. HALIFAX SECTION, B. PETRIE

A series of seasonal cruises on the Scotian Shelf covering the Halifax Section from the coast southward through Emerald Basin, over Emerald Bank to the 2500 m isobath on the continental slope began in 1950 (Fig.15.1). The section was occupied irregularly until the late 1970s. Sampling resumed in the early to mid 1990s and is ongoing. The Halifax Section was established in part because earlier, quasi-systematic sampling across the shelf, mainly in the 1930s, had built up a core hydrographic and limited dynamic picture of the physical oceanography along the transect (Hachey 1938).

In the pre-1950 era, a significant amount of progress was made, particularly by Harry Hachey, towards the understanding of water mass structure and movement on the Scotian Shelf. For example, Hachey (1938) addressed the issue of the origin of the "cold water layer", later known as the cold intermediate layer or CIL (Fig. 15.2). He concluded that the layer was not formed in situ but originated outside the Scotian Shelf region to the northeast of the Halifax Section and was advected into the area. Hachey (1947) described the 3-layer hydrographic structure and its seasonal changes. From five years of hydrographic data, he made geostrophic current and transport estimates over the shelf, including some estimates of seasonal variability (Hachey 1947).

Sampling on the current Halifax Section was re-established in 1950. As the time series increased, oceanographers began to address scientific issues dealing with shelf mixing, circulation, biological coupling, variability and long-term climate changes.

McLellan (1954) examined alongshelf mixing from Banquereau to the Halifax Section. He quantified the changes in the proportions of five core water masses as they moved from east to west over the shelf using Halifax Section data as his anchor. Intrusions of offshore Slope Waters into the deep basin along the Halifax Line were observed to occur frequently, sometimes driven by horizontal density gradients and at other times by atmospheric storms (Hachey 1953; McLellan et al. 1953). Taylor (1961) presented the first 10 years of Halifax Section data as individual transects and updated this report in Taylor (1966); the next addition was by de la Ronde (1972), followed by Dobson (1975, 1977, 1978). Neither Taylor nor de la Ronde nor Dobson produced long-term means for the section. That was left to Drinkwater and Taylor (1982) who published the first section climatology, a collection of graphs and tables of the monthly mean temperatures, salinities and densities.

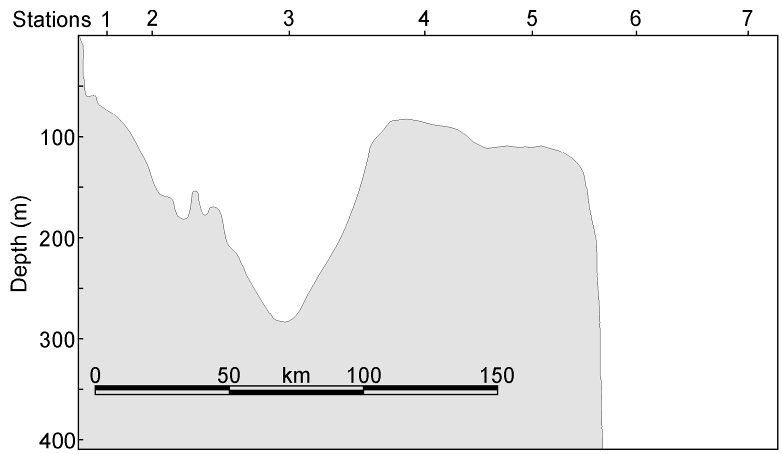
As data were compiled and climatologies derived, understanding of the oceanography was growing but some caveats were part of the story as well. Lauzier (1965) used section data to quantify a cooling trend on the Scotian Shelf that began in the early 1950s. He noted that the trend was stronger on the outer shelf and suggested a balance between Labrador Slope Water (LSW) and Warm Slope Water (WSW) was the cause of the low frequency climate variability. However, Mann and Needler (1967) concluded that seasonal sampling of the Halifax Section was inadequate to determine interannual variability. Mann (1969) used the data from 19 section occupations from February 1961 to April 1963 to describe the variability of LSW and WSW at the shelf edge. He re-iterated the earlier warnings of Mann and Needler (1967) about aliasing arising from the infrequent sampling. The aliasing issue was a major factor in the abandonment of Halifax Section sampling in the late 1970s.

Nonetheless, considerable progress, resting on the foundation of the Halifax Section observations, was made in the 1970s on shelf processes: Sutcliffe et al. (1976) tracked the freshwater outflow from the Gulf of St. Lawrence, quantified advection rates and patterns, and connected the CIL area to freshwater discharge; Fournier et al. (1977) estimated that cross shelf exchange could supply enough nutrients to account for 20% of the annual primary production on the shelf; in addition, they tied the observed biological variability to physical property distributions on the section; Smith et al. (1978) linked wind forcing to slope water intrusions and inner shelf flushing; Houghton et al. (1978) quantified cross shelf mixing of T, S and nitrate and related the mixing parameters to shelf edge eddy fluxes; finally, Drinkwater et al. (1979) produced long-term monthly estimates of the alongshelf geostrophic transports and related them to seasonal outflows from the Gulf of St. Lawrence.

A renaissance of Halifax Section data analysis and sampling emerged in the 1990s largely driven by biological issues. Petrie and Drinkwater (1993) examined long-term variability in the Scotian Shelf-Gulf of Maine region for 1945-90. They addressed the aliasing issue raised by Mann and Needler (1967) and found that the Halifax Section sampling was indeed sufficient to observe the longer-term hydrographic trends, revived and modified the Lauzier hypothesis, and connected the hydrographic variability to cause through observations and modelling. Loder et al. (2001) used the section observations and a circulation model to contrast the cold and warm periods in the Scotian Shelf-Gulf of Maine region. Most recently, Loder et al. (2003) have addressed the nature of the ocean climate variability, episodic rather than continuous, on the Scotian Shelf and indeed have in part redeemed the concerns of Mann and Needler (1967) by showing that individual transport estimates from the section are aliased.

Year-to-year descriptions and comparisons are still a part of the Halifax Section. The observations are used to describe the current oceanographic conditions for the international community (Drinkwater et al. 2003b) and for the Fisheries Oceanography Committee Workshops (Drinkwater et al. 2002). The AZMP monitoring documented the flushing of Emerald Basin by an intrusion of Labrador Slope Water in 1998, one of the most dramatic changes in the hydrography of the Scotian Shelf throughout the 1990s (Drinkwater et al., 2003a).

The history of the Halifax Section has been one of progress in the understanding of short and long-term oceanography variability. Imaginative oceanographers, Hachey, McLellan and Lauzier, made use of limited amounts of data to address mixing processes, water mass formation and interannual variability. As the data set grew, hypotheses were refined, firmer connections to cause were made and our knowledge of the Scotian Shelf increased, especially of the interannual variability. While there is more to learn about the physical oceanography and the ocean climate of the Scotian Shelf from continuing monitoring of the Halifax Section, our greatest gains are likely to come in biology and chemistry, which have seen limited sampling in the past.



Halifax Section 1950-present.

Figure 15.1. Cross-sectional bathymetric profile of the Halifax section showing the location of AZMP sampling sites.

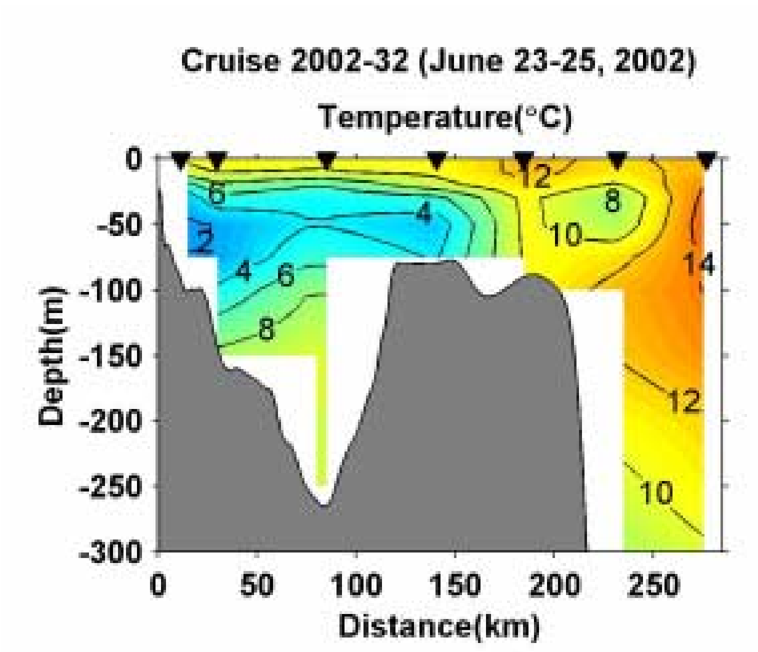


Figure 15.2. Interpolated temperature profile along the Halifax section during the erpiod 23-25 June 2002, showing the cold water layer in blue. Triangles indicate sampling locations.

SECTION 16. CPR TIME SERIES, D. SAMEOTO

To understand changes in populations with time we must sample at a frequency that is less than the time scale of interest. The highest frequency that can be resolved is half the sampling frequency (e. g., to measure monthly changes we must sample at least biweekly). Similar considerations apply to the spatial resolution. Variability at higher frequencies can appear in the analysis as lower frequency components, i.e., they are "aliased". Short-lived spring or fall blooms can be missed or be seen as monthly variations.

The longest data series of phytoplankton and zooplankton species concentrations in the northwestern Atlantic and on the Canadian eastern continental shelf is the CPR collected for The Sir Alister Hardy Foundation for Ocean Science of Plymouth, England. Collection began in 1959 and continues to the present, with a break of a number of years from 1976 to 1991, along two transect lines, the Z-line running between Iceland and Newfoundland and the E-line between Newfoundland and the east coast of the United States of America (Fig.16.1). The CPR is towed monthly at ~6 m along generally fixed shipping routes. The sample gauze is divided into 18.52 km sections corresponding to a sample volume of ~3 m^3; every second section is analyzed providing a spatial resolution of ~37 km. A subsample of 0.001 of the whole sample is analyses for phytoplankton species; Small zooplankton are identified from a 0.02 subsample of the entire sample. Zooplankton larger than 2 mm are counted from the whole sample.

Early analysis of the CPR data included contoured plots of annual and seasonal fluctuations of phytoplankton colour, total copepoda, *Calanus finmarchicus* stages I-VI and V-VI, *Euchaeta norvegica*, euphausiacea, *Sebastes* spp. and ammodytidae in annual commentaries for ICNAF area 3 (Robinson 1975). The results from a particular year were generally compared to those from previous years, e.g. "the spring outbreaks of phytoplankton and copepods were much later than usual in 1974". Similar discussions were presented as the time series built to decadal length (Robinson et al. 1975). Longhurst (1980) indicated that "a formal data analysis *(of the CPR data series)* has yet to be performed". Longhurst sub-divided the ICNAF areas into smaller components than previously considered in order to derive annual cycles and variability for phytoplankton and zooplankton in the Grand Banks region and adjacent areas.

As the length of the series increased, analyses have yielded understanding and insights into plankton population dynamics that could not be found other ways. Myers et al. (1994) examined the 1959-92 data for the Northwest Atlantic and presented seasonal cycles, and long-term trends for zooplankton and phytoplankton for different geographic sub-regions corresponding to the NAFO divisions which included the Scotian Shelf and Gulf of Maine. Sameoto et al. (1996) determined the monthly abundance and geographic distribution for 47 taxa of phytoplankton and zooplankton from the Grand Banks to Georges Bank. Planque et al (1997) mapped the distribution of zooplankton species in the North Atlantic in relation to the physical oceanography.

The phytoplankton colour index, total diatoms, *C. finmarchicus* stages 1 - 4, *C. glacialis, C. hyperboreus* and *Paracalanus/Pseudocalanus* collected from 1961 to 1998 in the Canadian Atlantic region were analyzed for geographic and temporal changes.

Significant differences on both geographic and temporal scales were found. After 1991, the phytoplankton colour index increased significantly (Reid et al. 1998; Sameoto 2001). A shift in the climatology occurred after 1991 as concentrations *of C. finmarchicus* and *Paracalanus/Pseudocalanus* became significantly higher in the first three months of the year compared to 1961-75 (Sameoto 2001). Over the period 1959 to 2000 in the region between Iceland and New England, significant changes occurred in the abundance and seasonal timing of the blooms of phytoplankton and zooplankton taxa: phytoplankton increased and zooplankton decreased. The changes occurred after 1991 in the region west of 45° W; changes were not observed east of 45° W. This suggests that the plankton changes may be related to changes in the physical climate related to the Labrador Current system.

Because of the long length of this time series, we were able to detect decadal change in the abundance of both zooplankton and phytoplankton in different geographical regions of the Atlantic zone. The most striking observations were the decline in *Calanus finmarchicus* and the dramatic increase in phytoplankton in the region west of the Labrador Current and on the Scotian Shelf after 1991 compared to the 1960 to1976 period.

There has been a major change in the timing and duration of the blooms of both phytoplankton and zooplankton in the western Atlantic. The phytoplankton are blooming earlier and longer and the main copepod population, *C. finmarchicus*, is also breeding earlier but its population decreases much earlier in the summer than in past decades.

The CPR time series has shown that there are significant differences in the abundance of both phytoplankton and zooplankton species in different geographical regions of the western Atlantic that show consistent patterns.

None of the major low frequency temporal or spatial changes in plankton population structure or dynamics would have been found if we had not had the broad spatial coverage and extended time series of CPR sampling. The consistent long-term sampling coupled with the persistent long-term variability has compensated for the less than ideal monthly sampling.

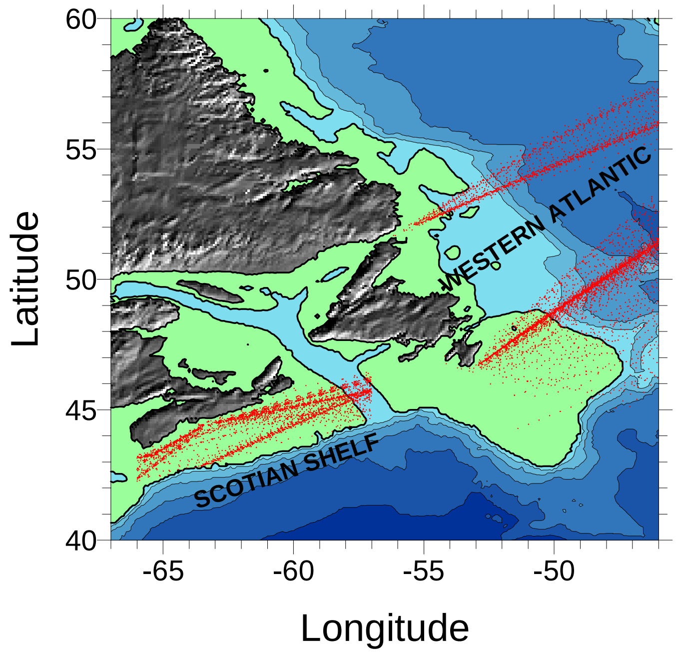


Figure 16.1. Map showing the distribution of collections from the Continuous Plankton Recorder along the Northwest Atlantic routes.

SECTION 17. SCOTIAN SHELF GROUNDFISH TRAWL SURVEY, K.T. FRANK

Annual, standardized groundfish surveys of the Scotian Shelf were first implemented in the summer of 1970 and have continued uninterrupted to present. The surveys have assumed a key role in the provision of scientific advice for fishery management due to the many shortcomings of commercial fishing data, such as occasional poor accuracy, weak indicators of stock abundance and generally no useful abundance estimates of incoming year-classes. The survey uses a random, stratified sampling design where the stratification is based on depth and the allocation of sets per stratum is proportional to stratum area (Fig.17.1). Set location is based on a random selection procedure. The Scotian Shelf summer survey contains forty- eight strata distributed among four depth zones (< 50 fathoms, 51-100 fathoms, > 100, mixed). The total number of sets per year has ranged from 115 to 212 and since 1992 set number has been increasing. Throughout the history of the survey the gear has changed only once in 1982 when the *Yankee 36* trawl was replaced by the *Western IIA* trawl. Both gear types contained a small mesh liner capable of retaining forage and small, non-commercial species and young-of-the-year groundfish. A vessel change also occurred in 1982 when the *A.T. Cameron* was replaced by the *Lady Hammond*. In 1983, the newly commissioned *Alfred Needler* became the principal survey vessel. Comparative fishing experiments were conducted at the time of the vessel conversions and correction factors exist for a few of the dominant groundfish species (Fanning 1985). Otherwise, the vast majority of species collected and their estimated abundances represent a continuous series from 1970 to present. Hydrographic sampling has also been conducted on the survey since its inception and has contributed significantly to the regional database for the Scotian Shelf.

The surveys generate valuable data on the abundance and distribution of groundfish species. For many of the commercially important species detailed biological sampling has been conducted for determination of age, maturity, feeding behaviour, and so on. Most of the survey information forms an important basis for analytical stock assessments where age-specific, survey abundance estimates are inter-calibrated with commercial fishery data through cohort analysis (Fig.17.2). The ability of the survey to track the progression of cohorts (or year-classes) has been repeatedly demonstrated (Frank et al. 2000) and the figure shows the progression of the 1999 year- class of haddock on the eastern Scotian Shelf from its birth year to age three. In those instances where commercial fishery data are poorly resolved to the species levels (such as for flatfish and skates) and analytical assessments are not possible, the survey data provides the main foundation for fishery management advice. The same has been true for newly developing fisheries where biomass estimates derived from the survey alone provide a baseline for management decisions.

One of the first ancillary uses of the survey data for purposes not directly related to stock assessment was the delineation of the haddock closed area that was established in 1987 on the central Scotian Shelf. The objective of closure was to protect juvenile haddock from excessive discarding that typified the fishery during the early to mid-1980s and thereby allow the stock to rebuild. This industry supported initiative used survey information on the distribution of juvenile haddock that existed at the time. Shown in the adjacent figure is the average abundance of age 1 + 2 haddock in 10 minute squares during the pre-closure period (1970-86). The high concentrations of juveniles in the Emerald/Western Banks region led to the establishment of the closed area in this region (Fig17.3). The survey data has also figured prominently in the evaluation of this management measure (Frank et al. 2000).

The apparent colonization of capelin on the eastern Scotian Shelf was fully documented through the use of the groundfish survey database (Fig.17.4). The surge of capelin coincided with the occurrence of cold-water conditions that persisted for nearly a decade beginning in the mid-1980s. Prior to that time few or no capelin were recorded from the area. In addition, several other cold-water species became abundant in the area coincident with capelin (Frank et al. 1996). The above figures show the composite distribution of capelin from 1975-85 – a time when almost no capelin were encountered during the summer surveys and 1990 to 2000. During this latter period, maximum catch rates of capelin were four orders of magnitude higher than those recorded in the previous period. Recent data indicate a dramatic decline in capelin abundance coincident with an amelioration of water temperature conditions in the area.

The survey data are proving to be a useful tool for the quantification of spatial and temporal patterns of species diversity and other related community level analyses (Fig.17.5). This is possible because all of the species captured have been identified and enumerated since the inception of the survey. In only a few cases can resolution to the species level not be attained at sea (e.g. redfish). Groundfish species assemblages from the survey database were first examined by Mahon and Smith (1989) who used clustering methods of the catch-weighted species composition (for abundant species only) at the stratum level during four time periods to identify species associations in space and their persistence in time. Nine species-groups and 10 site groups were defined which showed strong associations with depth and temperature gradients. More recently, Mahon et al. (1998) used survey data combined from several government laboratories to examine biogeographic patterns in species assemblages from Cape Hatteras to Cape Chidley. Many nations are now creating policy to conserve marine biodiversity and diversity indices are much needed to monitor change and assess compliance with policy. Recent research (Shackell and Frank 2003) has been aimed at determining whether or not the groundfish survey could be used to monitor fish diversity and to determine the spatial patterns of diversity. The latter objective was based on an analysis of the cumulative number of species or species list, from 1970 to present, at a grid scale smaller than the strata as well as the stratum scale. The above picture shows the species richness on the Scotian Shelf at a 300 km^2 scale. Highly diverse areas include the Bay of Fundy, the eastern Gully, the slopes, Western Bank and the northeastern Shelf. Until now, the northeastern shelf has been under-appreciated as a highly diverse area, because previous analyses were based on the number of species per tow rather than the cumulative number of species over time.

The survey data time series continue to be a basic research tool within DFO and for collaborators from several other research groups. Because of its scope and length, it is among the best data series in existence for addressing questions dealing with the testing and development of ecological theory, issues beyond its original intended use – providing timely fisheries management advice. This overview has provided just a few past and recent examples of the variety of ways this information has been used.

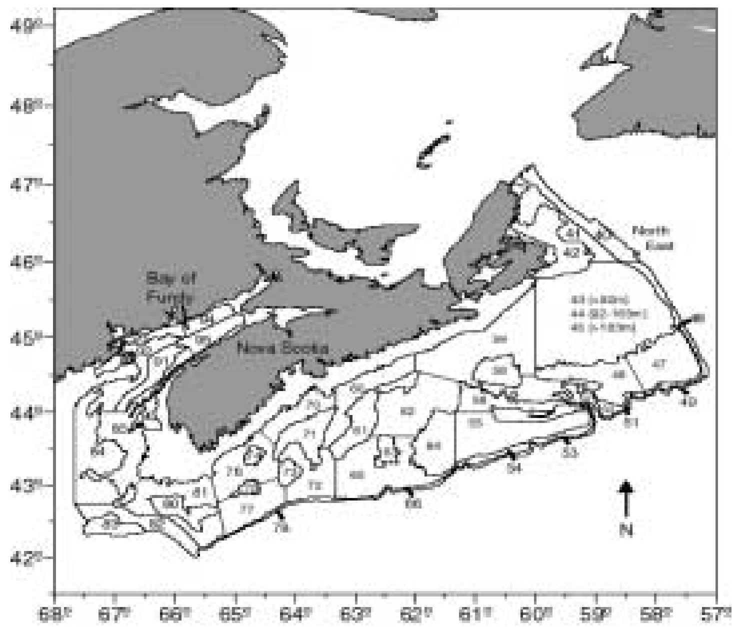


Figure 17.1. Stratification scheme of the Scotian Shelf groundfish surveys.

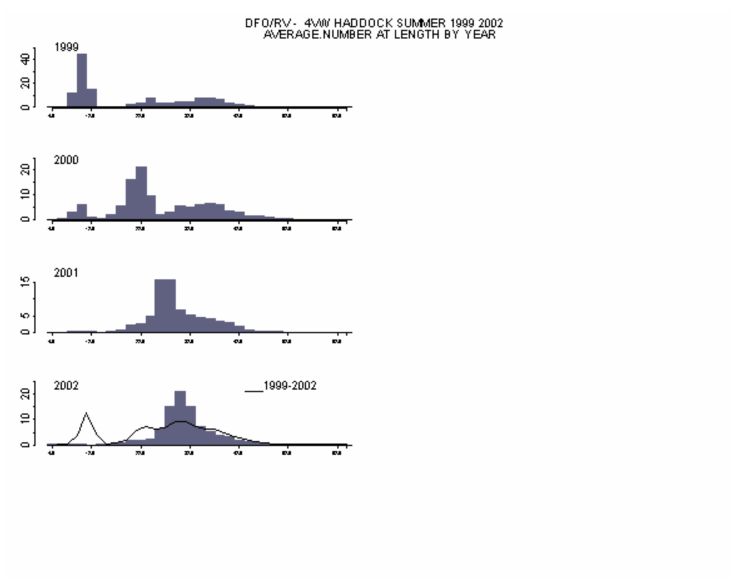


Figure 17.2. Research Vessel survey estimates of average number of 4VW haddock at year for the 1999-2002.

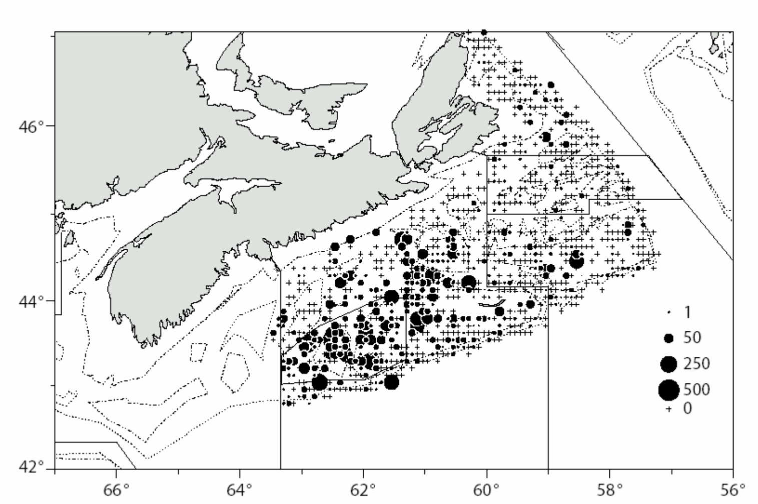


Figure 17.3. Distribution of juvenile haddock on the Eastern Scotian Shelf.

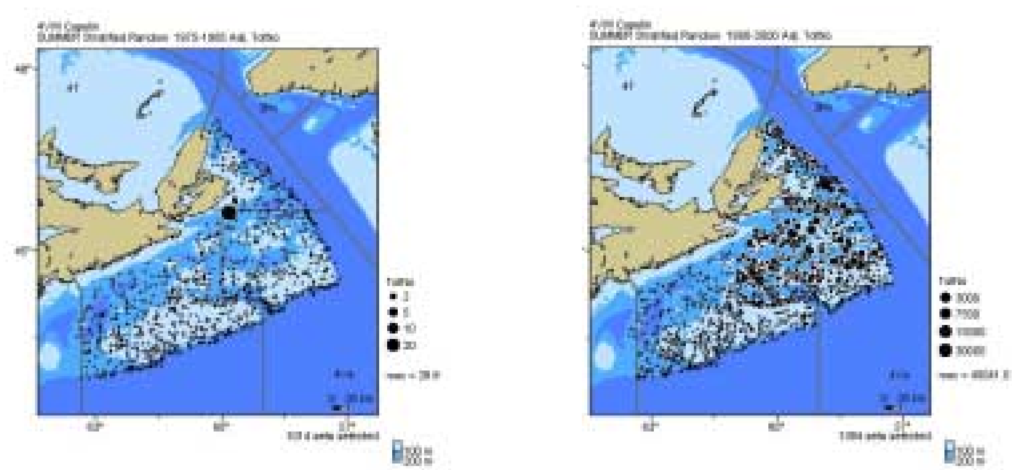


Figure 17.4. Distribution of capelin catches from the summer groundfish surveys for the periods 1975-1985 (left) and 1990-2000 (right).

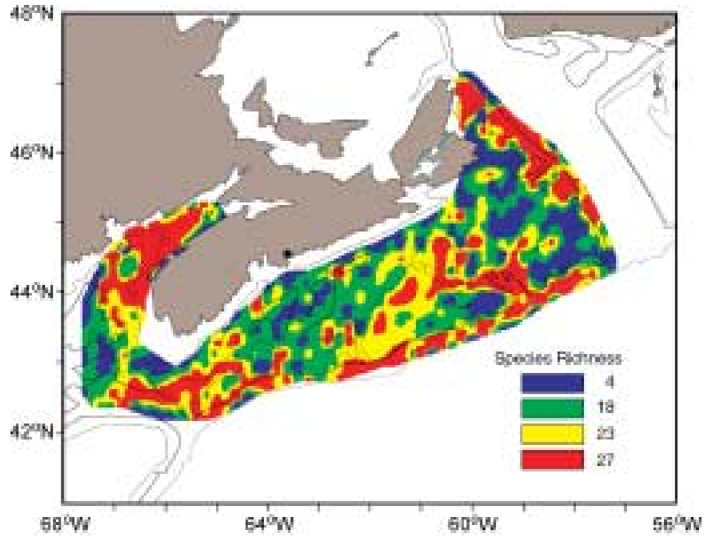


Figure 17.5. Distribution of species richness from the combined Scotian Shelf groundfish surveys.

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