Proposal for a Northwest Atlantic Zonal Monitoring Program

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PROPOSAL FOR A NORTHWEST ATLANTIC ZONAL MONITORING PROGRAM

J.-C. Therriault[1], B. Petrie[2], P. Pepin[3], J. Gagnon[4], D. Gregory[2], J. Helbig[3], A. Herman[2], D. Lefaivre[1], M. Mitchell[2], B. Pelchat[1], J. Runge[1], and D. Sameoto[2]

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A comprehensive monitoring program has been designed for the northwestern Atlantic with the aim of increasing the Department of Fisheries and Ocean's capacity to understand, describe, and forecast the state of the marine ecosystem and to quantify the changes in the oceans and the predator–prey relationships of marine resources. In this report we present an overview of the current monitoring activities and identify what we consider to be the fundamental elements of a zonal monitoring program, which include (1) in situ multidisciplinary monitoring of biological, chemical, and physical variables at fixed stations and along transects; (2) remote sensing of sea-surface temperature and ocean colour; (3) measurements of sea level; (4) groundfish surveys in all regions; and (5) continuous plankton recorder (CPR) lines on the Newfoundland and Scotian shelves. We discuss the necessity for coordinated and standardised sampling protocols and data management activities. The importance of data analysis and interpretation is addressed as well as the need to designate committees that will be responsible for the management and coordination of the zonal monitoring activities.

RÉSUMÉ

Therriault, J.-C., B. Petrie, P. Pepin, J. Gagnon, D. Gregory, J. Helbig, A. Herman, D. Lefaivre, M. Mitchell, B. Pelchat, J. Runge, and D. Sameoto. 1998. Proposal for a northwest Atlantic zonal monitoring program. Can. Tech. Rep. Hydrogr. Ocean Sci. 194: vii+57 p.

Un programme de monitorage exhaustif a été conçu pour le nord-ouest Atlantique afin d'accroître la capacité du Ministère des Pêches et des Océans à comprendre, décrire et prévoir l'état de l'écosystème marin et à mesurer les changements qui se produisent dans le milieu océanique, et en particulier dans les relations prédateurs–proies des ressources marines. Ce rapport présente d'abord une vue d'ensemble des activités de monitorage actuelles et identifie ce que nous considérons comme des éléments fondamentaux d'un programme de monitorage zonal. Ceux-ci incluent : (1) la surveillance multidisciplinaire in situ des variables biologiques, chimiques et physiques à des stations fixes et le long de transects; (2) la télédétection de la température de surface et de la couleur de l'océan; (3) la mesure du niveau de la mer; (4) les relevés de poisson de fond dans toutes les régions; et (5) l'échantillonnage par CPR («Continuous Plankton Recorder») le long des plateaux de Terre-Neuve et de la Nouvelle-Ecosse. Nous discutons ensuite de la nécessité de coordonner et standardiser les activités d'échantillonnage et de gestion des données. Finalement, l'importance de l'analyse et de l'interprétation des données est discutée et nous proposons la formation de comités qui seront responsables de la gestion et de la coordination du programme de monitorage zonal.

PREFACE

This proposal was prepared by the Ocean Monitoring Working Group (OMWG), which was formed following the specific request of the Atlantic Zone Science Management Committee for the design and implementation of an integrated zonal monitoring program that would fulfil the environmental surveillance mandate of the Department of Fisheries and Oceans for the Atlantic coast (including the Gulf of St. Lawrence and the Bay of Fundy). The OMWG is comprised of a number of specialists from all ocean science and fisheries disciplines who were nominated by the three Atlantic regions (Laurentian, Maritimes, and Newfoundland) and by Ottawa (MEDS and HQ). This final version of the zonal monitoring proposal includes adjustments that respond to comments and suggestions made during the extensive review exercises in each region, during a meeting with the Fisheries Oceanography Committee, and after a preliminary presentation to the Atlantic Zone Science Management Committee.

The Chairman of the OMWG (J.-C. Therriault, Laurentian Region) would like to take this opportunity to address many thanks to all OMWG members who participated in this important exercise and, in particular, who were able to put aside their regional bias to produce a monitoring proposal that brings the most objective zonal perspective possible. The chairman would also like to acknowledge the contributions of M. Chadwick, J. Gagné, S. Gosselin, P. Hally, L. Kinney, S. Narayanan, and K. Zwanenburg. It is hoped that the views of the majority are accurately represented in this final draft of the monitoring proposal, within the limit of the committee's scientific integrity and personal and professional biases.

1. INTRODUCTION

1.1 CONTEXT

Past experience has taught us that fluctuations in the marine environment, either natural or man-induced, can have drastic socio-economic implications for the Canadian population living in coastal areas. One evident example is the potential economic impact of the sea level rise on the inhabited coastal zones. Another is the relationship between environmental variability and the production of marine organisms, which suggests that changes in climate cannot be ignored as an explanation for fluctuations in marine resources.

Faced with the specific problem of estimating fisheries resources in a changing environment, the Fisheries Resources Conservation Council (FRCC; see Annex I for a list of acronyms used in this report) identified in its 1993 report the need to tackle environmental fisheries management issues using a more global or ecosystem approach. The FRCC report particularly pointed out that, in the short term, many of the interactions in the oceans should be characterised in a more comprehensive fashion. To do this, the FRCC recommended that the Department of Fisheries and Oceans (DFO) should increase considerably its monitoring capacity of the physical and, particularly, of the biological environment, until an empirical knowledge of the marine ecosystem is well developed. In response to this report, DFO has included the development of a better global understanding of the marine ecosystem as one of its six major national priorities in 1994-95. The intent was to increase DFO's capacity to understand, describe, and forecast the state of the marine ecosystem, and to quantify the impact of changes in the oceans and predator–prey relationships on marine resources.

In a recent report (DFO, Ocean Sciences Strategy Document), DFO specifically recognised that understanding the ocean—its variability, trends, and regime shifts—is fundamentally important for providing clients with the basic information required for a sound management of renewable marine resources and for supporting operational use (e.g., transportation, recreation), development (e.g., hydrocarbons), and protection (various Environmental Protection Acts) of the ocean. To achieve this, we support the idea of establishing a systematic and integrated monitoring program based on field sampling and remote sensing of various *in situ* biological, chemical, and physical variables to ensure the general surveillance of the marine environment. However, in the context of the present financial constraints, DFO has not yet determined the relative priority it should give to its monitoring program. The problem DFO is facing is the necessity for a long-term commitment of resources to ensure the maintenance of a useful monitoring program. DFO must also ensure effective coordination among DFO regions and stakeholders.

With these considerations in mind, the Ocean Monitoring Working Group (OMWG) has been formed by DFO to respond to the need to develop an integrated monitoring program for the northwest Atlantic region. The participants and specific mandate of this working group are summarised in Annex II. The present proposal represents the first step of the OMWG's response to this mandate.

1.2 THE ZONAL MONITORING PROPOSAL

In the present context, zonal or environmental monitoring is defined as the minimal, 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 a particular region. Environmental monitoring should provide the data sets that are necessary to: (1) track and predict changes in productivity and ocean state; (2) respond to immediate questions posed by clients; (3) alert clients to short- and long-term environmental/ecosystem changes; and (4) provide adequate historical databases to address future issues. For example, environmental monitoring is needed to understand environment–fisheries interactions; to detect trends in climate changes as a basis for rational predictions; to validate oceanographic models; and to provide historical and on-line data for development and exploitation activities in fisheries, oil and gas, and marine transportation.

Environmental monitoring can be divided into three general categories: (1) monitoring for compliance purposes (e.g., Canadian Oceans Act), (2) monitoring to detect patterns and trends, and (3) monitoring for research purposes. These categories are not mutually exclusive and a specific program might be designed to meet the objectives of more than one category. However, as indicated below, the present proposal can only address the second category, which aims at the detection of relatively long-term or climate changes in the marine environment. The monitoring activities associated with more specific issues (e.g., a particular fish stock problem or marine development) should be addressed through regular research programming, although some coordination could be ensured with the long-term Zonal Monitoring Program. The real challenge of the Zonal Monitoring Program is to identify key ecosystem variables (indicators) and to develop protocols that are financially and logistically feasible and that will endure for the next several decades.

The main objectives of the proposed monitoring program are twofold: (1) 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; 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.

The OMWG program proposal is based on the model illustrated in Figure 1.

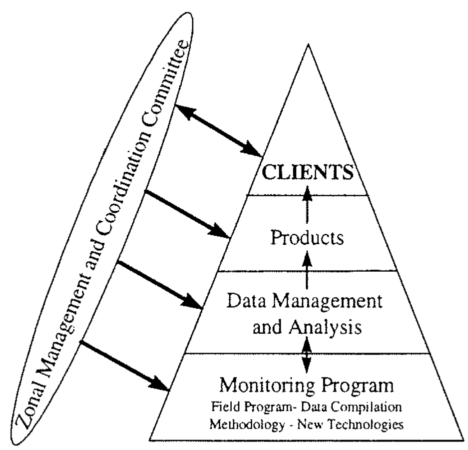

Figure 1. Schematic Overview of the zonal monitoring program.

A monitoring program collects and provides data to data management and analysis groups who are in turn responsible for the development of products that serve client needs and are also responsible for continuously assessing the effectiveness of the monitoring program. A permanent Zonal Management and Coordination Committee interacts directly with the clients to ensure that their needs are being properly met as well as to provide feedback to the scientific (field program and analysis) components of the Zonal Monitoring Program. The individual components of the model will be expanded upon in subsequent sections.

2. CLIENT NEEDS

The potential clients of the Zonal Monitoring Program are numerous and varied. The nature of the requests also varies widely, from simple queries for general information to more complicated questions that can involve additional analyses of data, to a heavy demand of real-time data for operational purposes. Internally, most requests come from the Science programs, Fisheries Management, Canadian Hydrographic Service, Canadian Coast Guard, and Inspection. Externally, the clients include fishers' associations; the Fisheries Resources Conservation Council; other federal and provincial departments; the scientific communities in Canada and the U.S.; universities; the private sector, including the transportation and petroleum industries and environmental and engineering consultants; the international scientific community; foreign countries; environmental groups; and the general public.

As an example, a very limited survey of requests to DFO for data and data products of a monitoring nature over a five-year period identified an average of about 100 external requests per year. In general, they can be categorised as 65% coming from the private sector, 20% from government agencies, and 15% from universities. The private sector and government agencies usually require an analysis or product; the academic sector generally requires complete data sets. Requests can further be categorised by location. Approximately 40% require near-shore information. These clients are generally involved in aquaculture assessment, engineering issues (bridge construction, underwater repairs, cooling plants, coastal pollution), fisheries (saltwater source for holding pens), and health and safety (water survival, hypothermia, pathogens). Requests for offshore information account for about 60% of all requests. These clients include fisheries (e.g., interdecadal cod growth studies, silver hake relationship to climate, general temperature climate), climate research (e.g., modelling, mean-state, long-term variability, instrument development), and engineering (e.g., energy project assessment, shipping, telecommunications cables, drilling operations, instrument applications).

After an analysis of the information provided by the three regions, the OMWG has identified the following current and anticipated client needs (non-prioritised) for the Zonal Monitoring Program:

- Sufficient data that when merged with data of opportunity can provide (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, and (2) environmental links to fish distributions;

- Coastal temperature data that will characterise the coastal zone over broad areas. Distinct oceanographic regimes should be sampled, such as the Bay of Fundy; southwest Nova Scotia; the southern coast of Nova Scotia; Sydney Bight; the northwestern, northeastern, and southern Gulf of St. Lawrence and the St. Lawrence Estuary; the Labrador coast; and the eastern, western, and southern coasts of Newfoundland;
- Coastal temperature (T), salinity (S), dissolved oxygen, nutrient, phytoplankton, and zooplankton data from a limited number of sites representing broad areas to describe the temporal evolution of these variables;
- Coastal sea level data over representative areas of the eastern coast of Canada that will resolve meteorological, seasonal, interannual, and decadal variability;
- East coast satellite data for synoptic views of remote sensing variables of oceanographic interest;
- A coordinated effort to examine, quantify, and understand seasonal, interannual, and decadal variability of biological, chemical, and physical observations, and supported efforts to incorporate primary and secondary production into circulation models;
- A permanent zonal group or committee to coordinate the monitoring activities for the whole Atlantic zone, to ensure that the needs of the clients are answered in a timely fashion, to foster continued reassessment and adjustment of the zonal monitoring program in light of new technological developments and analysis of data, and to develop and offer new products when necessary. In addition, this Zonal Monitoring Group should foster the ongoing development of databases in all disciplines, particularly encouraging the incorporation of existing data into the central database.

The recent development of multiple databases of T, S, currents, and other time series and the associated software for data extraction, statistical summaries, and reporting has made the provision of information easier. We anticipate improvements in the quality and efficiency of the responses through the development and implementation of the Zonal Monitoring Program, especially with the associated data management component.

In summary, there is an urgent need for DFO to identify long-term resources that will fully support the coordination and management of monitoring activities on the Atlantic coast, to ensure the collection, processing, quality control, and maintenance of long-term environmental databases, and to analyse this information to provide data and data products to internal and external clients in a timely fashion. It is expected that responding to many client requests will be greatly simplified with the development of WWW-based climatologies and databases.

3. OVERVIEW OF CURRENT MONITORING ACTIVITIES

From a survey of past and current monitoring activities, it is evident that DFO has until now concentrated its monitoring efforts on fish and physics (see Annexes III and IV for details). Some examples of monitoring programs that have been carried out by Ocean Science in the different DFO regions over the last two decades to respond to specific or perceived needs in support of biological oceanography, or other activities such as fisheries or operational oceanography, include hydrographic sections on the Newfoundland, Labrador, and Scotian shelves; monitoring currents at Hamilton Bank, Cape Sable, and off the Gaspé Peninsula; multi-purpose monitoring at

Station 27 in the Avalon Channel, Prince 5 in the Bay of Fundy, and a plankton monitoring station off Rimouski; ice forecast cruises in the Gulf of St. Lawrence; long-term coastal temperature monitoring programs; open-ocean baseline surveys; continuous plankton recorder (CPR) lines; water levels and waves; and remote sensing images. Another very significant monitoring effort in the different DFO regions is the various fish surveys that have been carried out annually over the last two decades to collect data on fish distribution and abundance. Most of these fish surveys also collect temperature, salinity, and, occasionally, dissolved oxygen data (see Annex III). These activities have produced a wealth of information that has been used to interpret environmental trends and influences for the benefit of DFO's clients. However, recent events like the cod crisis have demonstrated that we still require more complete and integrated information, particularly in the form of long time series of environmental and biological data, to be able to explain the changes that take place in the marine environment.

The data sets described above, because of a lack of spatio-temporal coverage and especially because of an acute lack of biological data, cannot constitute a complete monitoring program by themselves. However, the OMWG has identified the following programs that should be considered essential and fundamental elements of a zonal monitoring program: (1) *in situ* multi-disciplinary monitoring (biological, chemical, and physical variables) at Station 27, Prince 5, the Gaspé Current and Anticosti Gyre sites, and the ice forecast, long-term coastal temperature, and toxic algae monitoring programs; (2) remote sensing of sea surface temperature (SST) and, more recently, of ocean colour at IML, BIO, and NWAFC; (3) the sea level network, with stations in the St. Lawrence Estuary, the Gulf of St. Lawrence, and the open Atlantic coast; (4) groundfish surveys (and possibly pelagic and invertebrate surveys) in all regions; and (5) CPR lines on the Newfoundland and Scotian shelves. The approach that was adopted by the OMWG for the Zonal Monitoring Proposal is thus based on maintaining these activities and on supplementing them with new sampling initiatives in areas where significant gaps have been identified. The data will be more readily available because of improvements in the data management systems in each region (e.g., the St. Lawrence Observatory in the Laurentian Region) and following the development of a coordinated data management system for the participants consistent with national guidelines. There will also be a centralised web site maintained by MEDS for the provision of data and data products collected and generated by the Zonal Monitoring Program.

4. THE ZONAL MONITORING APPROACH

The main goal of the Zonal Monitoring Program is to provide a quantitative description of the ocean environment in the northwest Atlantic. With such a large area of the Atlantic Ocean characterised by complex and variable circulation patterns (see the general description in Annex V), the problem of determining representative sampling locations and the frequency of sampling at these locations represents a crucial element of a zonal monitoring strategy to obtain data that will meet this goal. In that context, the OMWG has conducted an analysis of the variability on the Scotian Shelf (see Annex VI), which 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;
- 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 above-mentioned analysis led the OMWG to propose a Zonal Monitoring Program approach 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; and (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), complemented by (4) 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. Figure 2 shows the location of the chosen sections and fixed stations. The rationale for these choices is provided in Annex VII.

In the past decade there has been an increasing demand for oceanographic information and advice on the near-shore zone. These requests have originated mainly from the accelerating development of aquaculture and the environmental concerns arising from human pressures on near-shore habitats. Therefore, the acquisition of information for the near-shore zone should also be a fundamental element of the overall strategy of the Zonal Monitoring Program, and the inclusion of existing near-shore biological, physical, and chemical monitoring programs in the zonal monitoring strategy (e.g., sea level, long-term temperature, and toxic algae monitoring programs; Bedford Basin station) should continue to provide a solid database that will be valuable for addressing near-shore issues.

Finally, the OMWG has also examined the possibility of using automatic moored systems. The group concluded that, at the present time, it would be too difficult (if not impossible) and too costly to obtain the biological information that is necessary to fulfil our monitoring needs using automatic sampling devices. However, because of the important research and development effort in this field, the OMWG recommends the reexamination of this problem at regular intervals to optimise the monitoring strategy when possible.

Even with sections and fixed stations, large areas of the Atlantic zone will not be sampled adequately. That is why the Zonal Monitoring Program proposes to use satellite imagery, initially of sea surface temperature distribution and later of chlorophyll distribution, to provide a broader-scale spatial coverage and also to allow for some temporal interpolation of these variables. In this context, the fixed stations are essential for obtaining critical measurements to ground-truth satellite images.

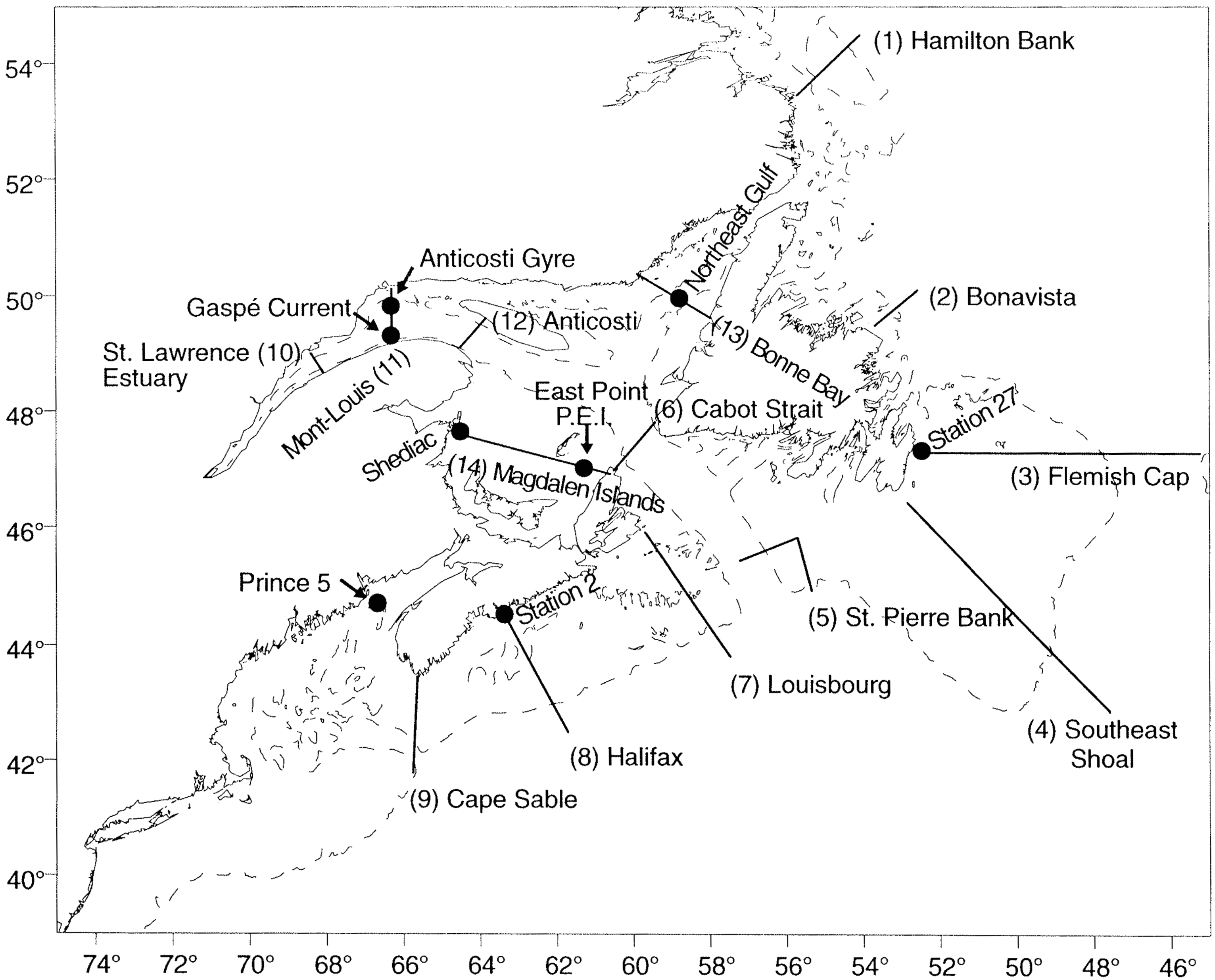

Figure 2. Location of sections (—) and fixed stations (●). See Annex VII for section and fixed station descriptions.

In a similar fashion, continuous plankton recorder lines can provide monthly, broad-scale sampling of the ocean's upper layer plankton. There is already a time series of CPR data of about 20 years (1961-76, 1991-present) for the Newfoundland to Scotian Shelf line and about 30 years for the line from Iceland to Newfoundland.

5. THE ZONAL MONITORING PROPOSAL (ZMP)

The OMWG proposes the use the existing fish surveys and other ship-of-opportunity cruises to acquire data over broad areas of the continental shelf and slope at a minimal increased cost for the monitoring program. To address the spatial representativity of the fixed stations, the OMWG proposes that an important and essential component of the ZMP in its initial stage should be the examination of existing biological and physical data sets (section 5.3) to estimate the spatial and temporal scales of variability for phytoplankton, zooplankton, chlorophyll, and related physical variables in the different regions of the northwest Atlantic, as was done for temperature and salinity on the Scotian Shelf. Until this analysis is completed, the OMWG proposes the minimal monitoring effort described in section 5.2, which makes extensive use of existing monitoring programs (supplemented by additional program components where there are obvious inadequacies) and which reinforces zonal coordination. After a period of three to five years, the Zonal Monitoring Program should be reexamined to optimise the sampling strategy.

Another important aspect of the initial program is the examination of the ongoing development of new technology (section 5.4) that should enable more rapid sampling of stations and/or transects. Underway sampling using non-specialised ships and remote sensing offer the promise of reduced costs, a critical factor in the sustainability of the ZMP.

Other key components of the initial program provide for the choice of key variables to monitor (section 5.1), standard protocols and methods (section 5.5), which are essential for a zonal effort involving three regions, and a data archaeology component (section 5.6), which will ensure that data are available for retrospective analyses.

5.1 KEY VARIABLES

5.1.1 Biological Variables. The key biological variables are those that describe important changes in ecosystem productivity or shifts in ecosystem structure over time. They include bulk variables (e.g., chlorophyll *a*, zooplankton biomass) and those that indicate changes in community structure (e.g., species composition).

a) Primary production.
Chlorophyll a concentrations (Chl a): Chlorophyll *a* is an index of phytoplankton biomass. It is a universal pigment found in all photosynthetic plankton. Seasonal patterns in Chl *a* concentrations indicate the timing and magnitude of phytoplankton blooms. Size-fractionated chlorophyll *a* gives an idea of the size structure of primary producers. This property will not differentiate species characteristics of population and is thus considered a bulk property, i.e., it is an indicator of the mass of the entire autotrophic community. Chl *a* measurements are also needed to ground truth remote sensing images.

Phytoplankton—dominant species composition: Identification of dominant taxa characterises both size and species structure at the base of the pelagic food web. To the extent that the higher trophic levels are species-selective in their feeding, bulk chlorophyll *a* is not a sufficient index of food source. Species counts (even limited to only the major taxonomic groups) reveal long-term changes in community structure that would be more indicative of regime shifts. For the ZMP, the analysis would be limited to the most abundant species.

Secchi disk and water transparency: Water transparency, except in highly coloured coastal waters, is governed largely by the abundance of suspended particles (principally phytoplankton). Secchi depth is a simple, inexpensive, and rapid means of determining water transparency, which can sometimes be used as a rough index of phytoplankton abundance and primary productivity or potentially as an index of the penetration of UV-B radiation in the water column. These measurements may also be of some utility for remote sensing validation studies.

b) Secondary production.

Zooplankton biomass (dry wt m^{-2}): An index of food availability that reveals fluctuations at intermediate levels of the marine ecosystem.

Zooplankton—dominant species composition, abundance, and size structure: Characterises zooplankton community structure. Seasonal and interannual variability in species composition indicate a different water mass source for the community, changes in environmental conditions (e.g., species-specific effects of temperature shifts on growth and reproduction) or shifts in predator fields. This provides an index of the favourability of the biological environment. For the ZMP, the analysis would be limited to the most abundant species.

c) *Fish and invertebrate species composition, distribution, and abundance.* Trawl surveys give standardised information on the abundance and distribution of the fish and large invertebrate components of a marine ecosystem. The protocols and data structures for these surveys have long been established and documented. These data provide the major fishery-independent source of information on fish population abundance. These surveys will continue to acquire the above-mentioned information using regular A-base funding while providing the bulk of the ongoing information on physical variables.

5.1.2 Chemical Variables. Key chemical variables must meet several criteria. First, for retrospective analysis, there must be an extensive archive of data. Second, the variable must measure some important component of the environmental conditions that could or does show variability on seasonal to decadal time scales and is not measured by some other more easily collected variable. Third, it must be logistically feasible to collect the data, i.e., the time, effort, and cost of sampling and analysis must be manageable. Two chemical variables meet these criteria: nutrients (phosphate, nitrate, and silicate) and oxygen.

a) Nutrient concentration. Relative surface nutrient concentrations characterise the interaction between biological activity and physical processes. When measured in winter-spring, nutrient levels (nitrates, phosphates, and silicates) are indicative of interannual variations in nutrient supply to the euphotic zone, which in turn influence the spring-summer structure of the autotrophic and heterotrophic communities (Plourde and Therriault, in prep.).

b) Dissolved oxygen. Dissolved oxygen is a measure of the trophic status of the waters, i.e., high concentrations are indicative of autotrophic systems, where primary production exceeds respiration, and low concentrations are indicative of heterotrophic systems, where breakdown and respiration processes exceed production processes. Oxygen concentration is also an index for the metabolic scope of fish; it is important because low oxygen concentrations within the range that is observed in coastal waters can determine the suitability of bottom waters as fish habitat.

5.1.3 Physical Variables. The key physical variables proposed for the monitoring program will allow for a quantitative description of the water mass structure in the Atlantic region on seasonal to decadal time scales. The fundamental measurements of temperature and salinity coupled with sea level will allow derivation of currents and transport through standard techniques and numerical modeling. Variables from allied fields, such as meteorology, will permit the examination of cause and effect.

a) Temperature and salinity provide a fundamental description of seasonal and interannual water mass variability as well as estimates of ocean currents and fluxes.

b) Sea level data provide a long-term measure of ocean climate change; seasonal and interannual variability provide fundamental input to ocean models.

c) Associated variables include ice and freshwater runoff, which primarily affect ocean stratification and salinity, and meteorological variables, which affect current, stratification, and water properties.

5.2 THE OBSERVATION PROGRAM

Initially, the OMWG proposes to base the Zonal Monitoring Program on: (1) high-frequency temporal sampling at the six most accessible fixed sites to monitor finer time scale dynamics in representative areas, (2) limited section sampling on the Scotian Shelf and Grand Banks, and (3) fish surveys and other ship-of-opportunity sampling to acquire seasonal data on proposed sections in the whole Atlantic region and particularly in the Gulf of St. Lawrence (Figure 2). This basic sampling pattern should be complemented by CPR surveys and remote sensing information as well as by other types of available data (e.g., meteorological data) to provide a broader spatial coverage and to increase our capacity to interpret ocean data. Near-shore data should also be acquired from existing near-shore monitoring programs. Thus, the initial Zonal Monitoring Program has been designed to make extensive use of existing monitoring programs, which in some cases will be extended to meet the overall objectives of the programs.

The different components of this initial Zonal Monitoring Program are the following:

— ***Fixed Sites.*** Six fixed stations are immediately proposed for measurements of the high frequency variations of the biological, chemical, and physical variables at time scales shorter than seasonal (see Figure 2 for locations). Sampling of these stations is to be conducted at least on a biweekly basis from February to October and on a monthly basis at other times to accurately characterise the fluctuations of organisms with higher turnover rates. The proposed stations are:

- Prince 5 (Bay of Fundy/Maritimes Region) –The longest times series of T–S profiles on the Atlantic coast going back about 70 years, Prince 5 is sampled biweekly for temperature and salinity. Under another program, the data are presently being made available in near real-time on a DFO web site.
- Station 2 (Emerald Basin/Maritimes Region) –Biweekly sampling of chlorophyll, nutrients, and plankton is proposed at Station 2 to allow the assessment of temporal variability and the intercomparison with CPR and ocean colour data. Rapid sampling methodology consisting of CTD/OPC/fluorometer/bongo nets would be used. The feasibility of using Coast Guard vessels to sample Station 2 will be addressed.
- Station 27 (Grand Banks/Newfoundland Region) –Another long time series of almost 50 years, this station is presently sampled by government ships-of-opportunity. Station sampling would be biweekly and consist of CTD, chlorophyll, zooplankton net hauls, nutrients, and currents (moored ADCP).
- Anticosti Gyre and Gaspé Current (Gulf of St. Lawrence/Laurentian Region) –These two stations in the western Gulf will be sampled biweekly for chlorophyll, zooplankton, nutrients, and associated physical variables. These stations provide information on the two major hydrological regimes in the Gulf of St. Lawrence: the output waters from the Gaspé Current and the more oceanic waters from the Anticosti Gyre. The stations are located near IML and sampling is manageable from small fishing vessels and Coast Guard icebreakers during the ice season.
- Shediac (Shippegan/Moncton/Maritimes Region) –This station is located in the Shédiac Valley, one of the most productive marine areas in Canada, and is accessible from the port of Shippegan. Chlorophyll, zooplankton, nutrients, temperature, and salinity will be sampled at least monthly from April to December. The station will be occupied by the snow crab biomass survey in August, the groundfish survey in September, and by a charter vessel, the *Opilio*, during the other months. The station will provide a seasonal view of productivity and will be integrated into the synoptic views of ocean physics inside the Gulf provided by the September groundfish survey.

Besides these six relatively offshore fixed sites, the OMWG proposes to continue the sampling of an existing near-shore station in Bedford Basin, where a multidisciplinary time series of data coming from various research programs has been collected over the last 30 years. Measurements of temperature, salinity, chlorophyll, and nutrients are currently carried out on a weekly basis at this station using a small boat.

— ***Section Sampling.*** Regular sampling of a number of sections throughout the whole Atlantic region is proposed using existing fish surveys and other ship-of-opportunity cruises. Of these, four are part of an existing sampling program (NAFO) and one is a new section (Halifax Line).

- Southeast Shoal, Hamilton Bank, Bonavista, Flemish Cap (Newfoundland Region) – Part of the current NAFO transects, these are sampled on a dedicated cruise once a year in July. Opportunity cruises typically should provide at least one additional cruise. Sampling protocol consists of currents, CTD, chlorophyll, vertical zooplankton hauls, and nutrients.
- Halifax Line (Maritimes Region) –There is a considerable amount of historical data of a physical and biological nature already available. The proposed line consists of sampling seven stations twice a year during spring and fall. Sampling protocol would consist of CTD, chlorophyll, vertical net hauls, dissolved oxygen, and nutrients. Groundfish trawl surveys, which presently sample approximately 200 stations on the Scotian Shelf during July and again in March, may be used to occupy the stations of the line on a regular basis. Other ship-of-opportunity cruises will provide additional coverage. The line crosses the cold intermediate layer (CIL), samples the shelf and slope waters, and is the minimum sampling required for the assessment of zooplankton on the Scotian Shelf. The possibility of sampling other sections along the shelf (Figure 2) using fish surveys and other ships-of-opportunity will be examined.
- Sections in the Gulf of St. Lawrence (Laurentian Region) –Fish surveys and other opportunity cruises will be used to acquire data from four to five sections in the Gulf of St. Lawrence (Figure 2). Data on physical variables will be collected, sometimes accompanied by limited biological or chemical sampling. The possibility of sampling the Gulf's sections using the late fall ice forecast cruise and the late winter/early spring helicopter survey will also be examined. The data from the late winter cruise are necessary to measure the depth of the winter mixed layer, a parameter that is essential for the estimation of nutrient availability and to forecast the global productivity of the Gulf.

— ***Remote Sensing***. The OMWG is of the opinion that remote sensing will not replace the need for sampling platforms, particularly for the biological variables. Remote sensing should be considered as an essential complement to other types of data acquisition to aid the interpretation of site-specific field data. Remote sensing capability exists in all three Atlantic regions. The remote sensing groups of the Maritimes and Laurentian regions are planning projects to issue maps of chlorophyll and primary productivity distributions on the whole east coast every two weeks using SeaWiFS data. SeaWiFS became fully operational on September 18, 1997. The remote sensing group at BIO has already downloaded a number of these images and should soon be able to do this routinely. The group also processes AVHRR SST images regularly. Surface chlorophyll maps should be available for operational purposes shortly. Another area where remote sensing can be clearly used with economic advantage is for sea-surface temperature measurements where specific products can be developed for applications at the zonal level. For example, this information could be used to study frontal processes and to monitor the Gulf Stream, the Labrador Current, and coastal upwelling areas. The Maritimes Region has completed a comparison of in situ temperature measurements with a data set from the Jet Propulsion Laboratory in California consisting of 18x18 km SST maps from 1982 to the present. Their results are very promising for the development of regional temperature climatology and anomaly fields. Another example comes from the Maurice Lamontagne

Institute, who regularly provides sea surface temperature maps for the Gulf of St. Lawrence. These maps are made using an automatic processing system that is being developed as part of the St. Lawrence Vision 2000 initiative. The system is able to receive, archive, and process NOAA AVHRR satellite images and to produce geometrically-corrected SST maps without human intervention. Some of the Gulf's data are already available on the Internet. This system can be easily upgraded to cover the whole northwest Atlantic region. Another important use of remote sensing is for the detection of ice cover, thickness, and drift, which are also important parameters to monitor climate changes on the east coast.

Until now, remote sensing activities have mainly been maintained using A-base funding for FTEs and B-base funding for O&M in the Maritimes and Laurentian regions. Because B-base funding is very volatile and variable, and because remote sensing is considered such an important component of the ZMP, DFO should ensure that adequate funding is available on a continuous basis for development and operational use of the remote sensing images in all regions.

— ***Continuous Plankton Recorder and Net Sampling.*** The CPR program dates back to 1957 in the western North Atlantic and is the only long-term data series for phytoplankton and zooplankton in the Atlantic zone that measures decadal scale changes. The monthly samples provide data on the species composition and abundance along two sections, one between Iceland and Newfoundland and the other between Newfoundland, Nova Scotia, and Georges Bank (see Annex VIII for location). The CPR phytoplankton colour index and species data are the only means of measuring ocean basin scale geographic changes in phytoplankton species, chlorophyll levels, and seasonal shifts in species abundance with time. The CPR colour index data can also be used to help calibrate the satellite ocean colour data. A new CPR vehicle should provide continuous temperature data in addition to the phytoplankton and zooplankton information. CPR zooplankton will complement the data obtained from the zooplankton net sampling on the fixed and section stations. The station net sampling data will measure changes in biomass and size spectrum of the micro-, meso-, and macrozooplankton in regions known to be important for fish spawning and larval retention that are not sampled by the CPR. The net samples will provide information for the entire water column and sample organisms missed by the shallow samples taken with the CPR. For these reasons, the OMWG recommends maintenance of the existing CPR lines Z and E on the shelf. Increased costs and uncertainty in ongoing funding are putting this valuable program in jeopardy.

— ***Fish Surveys.*** In the context of the Zonal Monitoring Proposal, current marine fish surveys are considered as a vital part of the monitoring program. These surveys provide standardised time series of fish and large invertebrate abundance and distribution as well as conductivity and temperature profiles since at least 1970, and in some cases since 1950. They provide the baseline data for fish stock assessments and also contribute a significant proportion of the physical oceanographic data contained in MEDS. For the zone, these represent more than 35,000 complete observations ranging from Georges Bank to Cape Chidley, Labrador (including the Gulf of St. Lawrence). Their continued operation must be ensured by adequate A-base funding allocations since the biological and physical data collected by these surveys (see Annex IV) are a vital part of the monitoring program. These surveys provide large sea-going platforms that operate reliably at fixed times of the year, occupy hundreds of stations within each region, and could be augmented (with appropriate resources) to collect other biological and chemical oceanographic information as an integral part of their operations. It is proposed that initially 10-20% of the trawl survey stations be augmented with vertical net hauls for zooplankton and possibly other types of biological or chemical data.

The surveys that are of particular interest for the Zonal Monitoring Program are:

- The Groundfish Surveys –About 10 surveys in the Maritimes, Newfoundland, and Laurentian regions. On the Scotian Shelf, current trawl surveys occupy several hundred stations at various times of the year. It is proposed that zooplankton net hauls (as a minimum) be carried out at a subset of these stations (10-20% initially) as an integrated part of the overall sampling program.
- The Southern Gulf Mackerel Survey –This survey collects mackerel eggs and zooplankton on alternate years during late June/early July. Sampling consists of CTD and zooplankton biomass with limited species composition analysis. It is proposed that this program be revised to make it annual at a small incremental cost.
- Other fish survey cruises –Other fish surveys that could be used on an opportunistic basis include the herring hydroacoustic survey off the west coast of Newfoundland and many other invertebrate surveys throughout the whole North Atlantic region. The sentinel fishery cruises could also become a significant source of physical data if they were maintained on a continuous basis. The possible use of these surveys should be examined.

— ***Other Ship-of-Opportunity Cruises.*** Oceanographic cruises also provide an opportunity to obtain additional data for the monitoring program and, in the past, these data have formed the backbone of ocean climate studies. Therefore, where needed, appropriate steps can be taken to make this information available to the Zonal Monitoring Program. In addition to purely opportunistic cruises, the annual ice forecast cruise in the Gulf of St. Lawrence can be use to provide full coverage of this area in the fall. Sampling is carried out at 65 stations and includes CTD, chlorophyll, vertical zooplankton hauls, and nutrients. Also of interest is the Gulf's helicopter survey, a 10-day survey that takes place during late winter/early spring and occupies 40-50 stations over all of the Gulf. It was started three years ago and consists of CTD, chlorophyll, vertical zooplankton hauls, and nutrient measurements. This survey is essential to assess the importance of winter mixing in the Gulf (cold intermediate layer formation) and to obtain pre-bloom information on nutrient levels. It is expected that these data can be used to detect the interannual variability of the global productivity in the Gulf.

— ***Near-shore Long Term Temperature Monitoring.*** The current DFO program at more than 50 sites throughout the Atlantic region (see Annex IX) will provide a significant database to address a number of near-shore issues. For example, this high frequency sampling is required for critical issues such as the frequency and duration of lethal temperatures for finfish aquaculture. In the past decade, there has been increasing demand for oceanographic information and advice concerning the near-shore zone. These requests have originated mainly from the accelerating development of aquaculture and the environmental concerns arising from human pressures on near-shore habitats. The growth of client needs for this oceanographic service makes this monitoring an essential component for the near-shore zone and a fundamental part of our overall monitoring strategy. This program should continue to be supported by A-base funding.

— ***Toxic Algae.*** This program is currently active in the Maritimes and Laurentian regions. It provides multidisciplinary data (temperature, salinity, dissolved oxygen, Secchi disk, chlorophyll, nutrients, phytoplankton identification and enumeration), collected biweekly on average, for the near-shore zone. It will complement similar types of data proposed for the open shelf. The OMWG strongly endorses the maintenance of the program and proposes including its data as a part of the monitoring program.

— ***Sea Level.*** This current CHS program should be maintained and the data acquired should be considered as a fundamental element of the monitoring program (see Annex X for current water level gauge locations). A review of the existing network has concluded that it is at the minimum level necessary to support national and international goals in operational oceanography, interannual variability, and long-term sea level rise. For the Zonal Monitoring Proposal, the OMWG endorses the maintenance of six sites (Rimouski-Est (QC), Charlottetown (PEI), Halifax (NS), Saint John (NB), St. John's (NF), and the Labrador coast (NF) that have been identified for long-term monitoring in a DFO review. At present, CHS-Maritimes has dropped one of these sites (Labrador Coast) and plans to remove two others (Charlottetown and Saint John) from service. However, the proposed reduction of the sea level network to two sites (Halifax and St. John's) for the entire Atlantic coast should be seen as a major concern for both the Department and the oceanographic science community. CHS-Laurentian, on the other hand, has plans to transfer the water level network management and maintenance responsibility (SINECO network between Montréal and Sept-Îles) to the private sector, but will retain its responsibility for quality control. In the meantime, CHS-Laurentian will maintain its funding at the same level at least for 1998-99.

— ***Freshwater Inflow.*** The annual cycle of freshwater runoff into the waters off Atlantic Canada profoundly affects water properties, stratification, and circulation (see Annex V). As part of the monitoring program, it will be necessary to regularly acquire the freshwater runoff data currently collected by Environment Canada for the entire region.

— ***Meteorological Data.*** Meteorological forcing on very short and long time scales has a major influence on ocean circulation and water properties. These data must be acquired from shore sites and meteorological buoys throughout the Atlantic region each year as part of the monitoring program.

— ***Ice Cover.*** Ice cover affects the ocean climate in two major ways in the Atlantic region: (1) dense ice cover can dramatically affect air-sea heat and momentum transfer and (2) the freeze-thaw cycle considerably modifies the temperature and salinity distribution and, consequently, the circulation. The ice charts, currently available from Ice Central, are digitised through A-base and PERD programs. The OMWG proposes to maintain this arrangement but to acquire the digitised data for monitoring purposes.

— ***Ship Weather Reports.*** Sea-surface temperature data are currently archived as part of weather reporting from ships. These data should be acquired for use in the monitoring program but maintained as a separate data archive from the hydrographic database. The data can provide another source of climatological information and could supplement satellite data during cloudy periods.

— ***Other Ship-of-Opportunity Sampling.*** Other sampling possibilities for monitoring purposes, including Coast Guard ships, ferries, and fishermen (sentinel), should be explored in coming years.

5.3 RETROSPECTIVE ANALYSES OF SAMPLING VARIABILITY

As was done for the physical variables on the Scotian Shelf, the OMWG proposes that, while already implementing a limited sampling program, a study also be initiated to assess the spatial representativeness of the biological variables at the different fixed sites using existing data sets that have been collected for different purposes. This analysis should determine the possibility of detecting climate variations in the biological variables with the sampling strategy used.

5.3.1 SCOTIAN SHELF.

a) Zooplankton. A retrospective analysis of zooplankton data would be performed looking at vertical and horizontal scales of variability. It would provide a basic design for a future sampling program as well as CPR data assessment. The following data sets will be used:

1) CPR data - existing 1961-93
2) SSIP data
3) BIONESS Tows -offshore/onshore variability
4) Batfish data -providing fine-scale vertical/horizontal resolution from CTD/OPC data.

b) Primary Productivity. Analyses of CZCS remotely-sensed data from Georges Bank, the Scotian Shelf, and the Gulf of St. Lawrence can provide 2x2 km scale variability of temperature, chlorophyll, and estimated productivity. However, ground truth measurements for biological variables are practically non-existent, which makes these remotely-acquired biological indices difficult to interpret. If the CZCS imagery does not give absolute measures of productivity but only relative ones, then the observations could be used to examine the different timings of the blooms within the region, the strength of the spring bloom relative to the fall bloom, the interannual variability of the blooms, and the spatial variability of bloom strength. Moreover, when coupled with temperature, these ocean colour indices can be used to identify and follow the major features of the circulation of the water masses in the whole area. Additional information of a similar nature can be derived from the analysis of the colour index from the CPR data set.

c) Bedford Basin. A 30-year data series consisting of T-S, chlorophyll, and nutrients will be analysed to assess temporal variability at an inshore site. In addition, where possible, this data series will be compared to offshore measurements to determine if the inshore time series bears any relationship to the biological variability in shelf waters.

d) _Prince 5 and Station 27_. Funding from the Ocean Climate Program was obtained to assess the spatial representativity of Stations 27 and Prince 5. The results from this study will be relevant to ocean monitoring.

5.3.2 Grand Banks/Labrador Shelf. The CPR data will be analysed to assess the spatial and temporal variability of primary and secondary production on the Newfoundland Shelf. Hydrographic sections and moored temperature and salinity data will be examined to determine the spatial and temporal scales of variability over the shelf. There are a number of arrays of instruments located primarily from Hamilton Bank to the Grand Bank that would lend themselves to this analysis. In addition, the year-long biological, chemical, and physical observations collected by Mobil Oil Corp. in the early 1980s from the Grand Banks provides an interdisciplinary data set to address questions of scale.

5.3.3 Gulf of St. Lawrence.

a) _Historic Drift and Anchor Stations_. Historic data from 24-48 hour drift and anchor stations over a number of years (mainly during July-August) and from other sources (e.g., V-fin transects) will be analysed for spatial and horizontal variability and to assess the representativeness of the two fixed stations in the Gulf. Sampling consisted of CTD, Chl *a*, primary production, and nutrients as well as zooplankton and ichthyoplankton in some cases.

b) _Rimouski Station_. A six-year time series of CTD and plankton collected on a weekly basis off Rimouski (from May to October) will be analysed to assess the temporal variability of species composition in the lower estuary.

c) _Historical Zooplankton Data_. A two-year spatial survey of zooplankton and phytoplankton samples in the lower estuary on a monthly basis from February to December will be analysed for spatial variability. Other survey samples and data sets in the estuary and the northwestern and southern Gulf should also be examined for information on the representativeness of the Gulf stations.

d) _Gaspé Current and Anticosti Gyre Fixed Stations_. Seasonal sampling of biological, chemical, and physical variables at these two fixed stations started two years ago and is complemented by the occasional sampling of a number of stations along a section comprising these two fixed stations. Analysis of these data will be carried out as well.

5.4 NEW TECHNOLOGY FOR MONITORING

5.4.1 Moving Vessel Profile. With the current reductions in DFO vessels and the high cost of overtime on cruises, there is a definite need for methodology that acquires oceanographic data in considerably shorter time. A high percentage of DFO cruises are occupied by sampling on stations. One could foresee examples of ship-time savings through the use of underway samplers. For example, shelf-wide surveys ranging from Cabot Strait to Brown's Bank require 10 days for CTD surveys and 15 days if biological sampling is included. Ideally, if all samples could be taken from a vessel while underway, ship time could be reduced to only four days, resulting in a considerable reduction.

New technology is currently being investigated at DFO-Maritimes that will allow physical and biological profiling on vessels of all sizes while underway. Based on technology developed at DFO-Maritimes and licensed to Canadian industry, DFO is working on a moving vessel profiler (MVP) designed to sample temperature, salinity, pressure, chlorophyll fluorescence, and zooplankton (optical plankton counter) to a depth of 200 m at 12-15 kts. The 200 m MVP would enable shelf-wide coverage at these speeds. The MVP is being developed in partnership with two local companies in Dartmouth, NS.

5.4.2 Other Technologies for Sampling Reduction. It is currently impossible to eliminate time-consuming stations taking biological samples and net hauls as these are used to ground truth other sampling. Our goal is to reduce stations and station time as much as possible. One DFO sampling objective is to develop zooplankton biomass indices from rapid profiling using a plankton counter thereby reducing the number of net hauls and station time.

Current profiling on station requires separate wire time for bongo net hauls and CTDs. DFO-Maritimes is developing an instrumented bongo net consisting of a CTD–fluorometer–optical plankton counter with bongo nets mounted on the outside wings, thereby combining two profiling activities into one. CTD and sensor profiles are taken on the 'down profile' while the representative zooplankton are sampled by the bongo nets on the 'up profile'. Total wire time is approximately 5 minutes for each shelf station. Costs currently consist of zooplankton sample analyses. Analyses of data from the instrumented bongo net will be focused on assessing the feasibility of using the plankton counter for obtaining zooplankton biomass indices thereby reducing zooplankton sample analyses.

5.5 Standard Protocols and Methods

Sampling protocols and analytical methods must be standardised among the three regions. This implies the development, adaptation, and use of common sampling gear and other logistics, and the attribution of common external contracts for specialised analyses that are not performed by DFO laboratories (e.g., phytoplankton and zooplankton species identification). This also means that it will be necessary to look at ways to avoid unnecessary duplication and to ensure comparability of data (e.g., by attributing a specialised analytical responsibility to a particular laboratory in one region while another laboratory will assume another responsibility). For these reasons it is important that each of the regions use the same types of sampling equipment and instruments; samples for each of the variables should be analysed in a central location when possible to avoid unnecessary duplication of equipment and effort as well as to reduce variance in the results. To ensure this standardisation, the OMWG proposes the creation of a permanent Zonal Management and Coordination Committee as described in section 8.

5.6 Data Archaeology

Rapid archiving of the acquired monitoring data will be an important element of the Zonal Monitoring Program. The OMWG also views the identification and incorporation of historic data sets into the monitoring databases as an important priority. Most of this effort should be supported by A-base funding as part of existing and ongoing programs, particularly with respect to physical oceanographic data. However, a particularly determined effort will have to be made to assemble and consolidate existing biological data sets that have traditionally not been managed as a regional or national resource to the extent of the physical data. Additional monitoring program funding will be required to initiate and support this effort. The recent departmental initiative to create a working group to develop a strategy for the archival of biological data sets through the Ocean Climate Program may provide solutions to the problem of biological archival. Some of the members of the OMWG will also be participating in this new initiative.

6. DATA MANAGEMENT

The OMWG data management objectives follow the National Data Management Working Group (NDMWG) objectives to coordinate and standardise procedures for quality control, processing, archiving, and dissemination of physical, chemical, and biological data from DFO's Science Branch. The OMWG objectives promote on-line access to distributed databases and related analysis products via an Internet web site to meet outside client needs.

The scope of the OMWG data management plan is limited to the area of interest in the Atlantic zone and to the specific variables and information identified by the participants. The emphasis is on rapid and easy access to the data and information collected and generated under the program. This will require close collaboration and cooperation between the data managers and scientists on regional and national levels.

The model proposes to build onto existing infrastructure for data management of physical and chemical data and to develop new infrastructure for the management of biological data based on recommendations from the NDMWG.

6.1 DATA MANAGEMENT OBJECTIVES

The OMWG data management objectives are:

- To centralise access to the data, data products, and derived information collected and generated by the monitoring program via an Internet web site to meet client needs;
- To facilitate data and information exchange and ensure that data sets collected during the current and prior year of operation are made available on-line among the monitoring program participants (Newfoundland, Maritimes, and Laurentian regions and MEDS);
- To ensure the safekeeping and long-term multiple re-use of the data and information collected and generated by the monitoring program;
- To ensure that all physical, chemical, and biological data are collected, processed, quality controlled, and documented to national data management standards.

6.2 DATA AND DATA PRODUCT DISTRIBUTION

An Internet WWW server will be established at MEDS to provide a single-window access to physical, chemical, and biological data as well as to information and products generated under the monitoring program. This site will respond to the needs identified earlier in the proposal of the many outside clients. Capabilities to search data directories and inventories as well as access to derived analysis products will be provided. Direct links to hardware servers and other established regional web sites maintained in the regions and at MEDS will also be provided to download relevant data sets and information.

All data and information collected and generated under the monitoring program during the current and prior year of operation will be made available on-line via this web site. As well, links to other regional and MEDS databases will be made as required to access relevant historical data sets. File transfer protocol (FTP) capabilities to download data, information, and products on-line via the web site will be developed where appropriate.

The success of this program is dependent upon the prompt availability of data sets from the primary investigators to the regional and national servers. It is incumbent on regional and MEDS management to ensure that the flow of data to these servers is maintained.

Most of the data collected under this program will be freely accessible to the public via the Internet web site. The web site will help fulfil national and international commitments to other global programs (e.g., GLOBEC, JGOFS) However, access restrictions to certain proprietary data sets may have to be applied (e.g., CPR data) at the local server level.

6.3 DATA EXCHANGE AND SAFEKEEPING

The OMWG proposes to use a data management model of continuously updated and distributed servers to provide access to derived analysis products and data collected for the program participants, consistent with NDMWG guidelines. This system is analogous to the recently-implemented National Contaminants Information System, whereby existing servers distributed regionally and at MEDS were interconnected to provide common access to data and information. This model provides for continuous updates of relevant data and information independent of individual progress as well as adherence to standards for data processing, quality control, and common data dictionaries required to link the data sets.

Data management of physical and chemical oceanographic data collected within DFO Science has an established infrastructure with centres of expertise for specialised data sets distributed regionally and nationally. The OMWG proposes to build on this existing infrastructure in order to improve access to distributed physical oceanographic databases and analysis products maintained regionally and at MEDS. To ensure safekeeping of OMWG key variables collected under the program, the archival responsibilities are distributed as follows:

- MEDS: Oceanographic profile data (e.g., T, S, nutrients, oxygen)
- MEDS: Sea level data;
- Ocean Sciences, Maritimes Region: Time series data (thermographs, ocean currents)

The OMWG recognises that there is no existing infrastructure, regionally or nationally, to archive biological data in an agreed-upon fashion and therefore intends to adhere to the recommendations of the National Ocean Climate Coordinating Committee on this issue. Laurentian Region has agreed to take the lead in the development of a common infrastructure for the OMWG biological data sets of interest to its participants, consistent with the NDMWG recommendations. To ensure safekeeping of OMWG data sets, archival responsibilities for biological variables will be coordinated between MEDS and Ocean Sciences, Laurentian Region.

6.4 Data Quality and Information Standards

It is the ultimate responsibility of the chief scientist to ensure the quality and integrity of the data collected under the monitoring program. The National Data Management Working Group will provide guidelines and standards for the processing, quality control, and archival of physical, chemical, and biological data that the OMWG will adhere to. All data will be quality controlled to NDMWG standards in consultation with the chief scientist.

Cruise Summary Reports, data inventories and summaries, documentation on sampling protocols, descriptions of quality control procedures, and other information as deemed pertinent to all participants and outside clients will be available via the WWW site maintained by MEDS. Guidelines for this information will also adhere to the NDMWG recommendations.

7. DATA ANALYSIS AND INTERPRETATION

Data Analysis is a critical component for ensuring the successful development and delivery of data products to the clients of the monitoring program. The OMWG foresees the necessity to create a permanent Data Analysis Working Group to ensure that the Zonal Monitoring Program will produce meaningful results. Unless this is done, the data will pile up and no one will be responsible for interpreting what is acquired. Moreover, with the development of new technologies (strongly encouraged by the OMWG) and with the continuously shrinking DFO resources, it will be essential to continuously reassess the validity of our Zonal Monitoring Program and to propose and implement changes when necessary. Another role of the permanent data analysis group would be to develop and produce adequate climatological indices or other specific products that can be used to answer client requests for the detection of changes in the environment.

In brief, the Zonal Monitoring Program must be able to use the data it collects to assess the biological, chemical, and physical environment from year to year as well as to compare the existing state to conditions in the past. The OMWG sees the program as complementary to the environmental assessments that are now presented to the Fisheries Oceanographic Committee, the Fisheries Resource Conservation Council, and NAFO. Many of the same people will be involved. New products should be developed to meet the needs of these groups as well as to answer inquiries from a broader base of clients.

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. Some of the products will be the same as those produced in the environmental reviews that currently take place. In addition, we anticipate some new products aimed at a broader assessment of environmental change. These products would include section plots of temperature, salinity, currents derived from the density field, oxygen, nutrients, and biological variables. For the physical and chemical variables, it will be possible to compare the current state of the environment with the long-term mean. Moreover, it will be possible to estimate the transport of heat, salt, and nutrients into and through the region. The synoptic, broad-scale nature of the section sampling will allow for overall assessment of regions with, for example, volumetric analysis of the temperature and salinity structure. From this we could derive the amount of near-bottom waters that fall into temperature ranges preferred by cod or other fish species. In addition, the nutrient pool available for primary production could be estimated for the shelf region. The OMWG also anticipates a greater use of sea level and satellite data. Sea level in particular has shown some very long-term trends in the region, with an increase of some 40 cm in the last century. In the Bay of Fundy region, the amplitude of the semidiurnal constituents may be changing either because of this long-term trend or because of varying dissipation changes in the bay itself. The CPR data and the fixed station data could be exploited in similar ways. Changes in overall abundance and species composition could be derived from these data series and could provide independent measures of interannual variability and long-term trends in plankton.

To evaluate the existing ocean climate we must know the mean state. Some variables, such as temperature and salinity, have existing climatologies and data retrieval tools that are available at the DFO web site. This capability has proven to be very valuable in responding to client requests. The OMWG would like to establish similar climatologies for other variables where possible. For example, there is an extensive nutrient and dissolved oxygen database development under way at BIO and IML. This could be used to create climatologies for limited portions of the region and could be made readily available through publication in hard copy and at the web site. In its analysis for scales of variability, the OMWG has relied heavily on the physical data sets. However, there are biological data that could be exploited in similar ways. For example, the CPR data could be used to derive spatial scales of variability in one dimension (y), the Sameoto-Herman (BIO) tows in two dimensions (y,z), the SSIP program in two dimensions (primarily x, y), the near-shore toxic algal data and Bedford Basin study (chemical as well as biological) in two dimensions (z, t). These are a few examples of work that the permanent data analysis group could consider to evaluate their sampling scheme, develop climatologies, and create products.

To synthesise the information and to test different hypotheses, the OMWG strongly supports the development (external to the monitoring program) of regional numerical models in each region. The development and use of numerical prognostic circulation models is a complement to the monitoring program. As results of these models become available, they will help to identify the sensitive areas in each region as well as their critical frequencies. The data analysis group will then be in a good position to evaluate the sampling strategy and to propose adjustments to the Zonal Monitoring Program. Moreover, data collected by the monitoring program and cruises of opportunity can be assimilated into models and used to constrain their solutions. Circulation models can also incorporate nutrients and estimate primary production. In addition, problems involving the advection of zooplankton and fish larvae can be addressed.

Examples of specific products coming from the monitoring program that could be delivered at the appropriate time scale include (1) the primary databases of fundamental variables describing the biological, chemical, and physical environment and (2) the value-added products that will be developed by the data analysis group. The annual State of the Ocean Report and other environmental indices developed for specific purposes (e.g., the W_I index [Therriault, J.-C. and J. Plourde. 1996. Development of an environmental index for the detection of climate changes in the Gulf of St. Lawrence: ecological interpretation of results and implication for future monitoring programs. Climate variability and climate change in Atlantic Canada, workshop report. Halifax, NS, 3-6 Dec. 1996]) will represent the most important value-added products that are produced by the permanent data analysis group, but other specific examples of existing and potential added value products could include:

In physics:

- Sections plots of temperature and salinity;
- Comparison with climatological mean sections (creation of mean section climatologies);
- Calculation of geostrophic currents on sections;
- Comparison with climatological mean geostrophic currents (creation of mean section climatologies);
- Plan view maps for particular times, depth levels, and bottom (includes the merger with other data collected on the shelf and Magdalen Shallows);
- Volumetric T–S assessment versus long-term mean, assessment of bottom areas in temperature bins, and comparison of both of these with the long-term mean;
- Time series for areas on sections including the southern Gulf, Cabot Strait, Louisbourg section, Halifax section, Cape Sable section, XBT section over Georges Bank, Prince 5, and other standard stations.

In chemistry:

- Nutrients distribution maps;
- Dissolved oxygen distribution maps.

In biology:

- Graphical index of seasonal chlorophyll levels at the fixed stations plus an areal map of the chlorophyll colour field from remote sensing;
- Graphical index of the mesozooplankton biomass in four to five subregions of the zone to detect fluctuations at order-of-magnitude levels;
- Graphs of the micro- and mesozooplankton species community structure from the subregions showing seasonal changes and long-term trends in composition that indicate regime shifts;
- CPR graphs for a number of different taxa showing seasonal cycles, decadal abundance changes, and the present year's data for each month. These will be produced for four areas: eastern Grand Banks, western Grand Banks, Scotian Shelf, and Georges Bank;
- Graphs of the levels of acoustic backscattering for different seasons along the three sections of the Scotian Shelf to be used as an index of macrozooplankton biomass (primarily krill).

Remote sensing:

- Satellite images processed by JPL (18 km x 18 km) to develop climatologies for different areas in the Scotian Shelf–Gulf of Maine and the Gulf of St. Lawrence atlases. The maps would consist of time series from the regions as well as monthly anomaly maps;
- Bimonthly SST maps for the Gulf of St. Lawrence;

- Consideration over the longer term should also be given to the use of the incoming tapes from AES to analyse for shelf–slope and slope–Gulf Stream fronts, eddies, coastal upwelling, Cabot Strait outflow, mixing zones and so on;
- Development of bimonthly chlorophyll maps for the whole Atlantic region in future years.

Coastal data:

- LTTMP (climatologies must be created initially and time series and anomalies produced);
- Sea level (climatologies must be created initially, time series and anomalies produced);
- Inlet monitoring sites (Sambro (NS), Mahone Bay (NS), Passamaquoddy (NB); again climatologies must be created initially and time series and anomalies produced).

Related data sets:

- This will consist of data series such as ice cover (charts must be digitised), winds (data purchased from AES), runoff (from AES), NAO, air temperatures;
- Graphs of the year class strengths of various species of fish;
- Distribution maps of toxic algae.

8. PERMANENT MANAGEMENT AND COORDINATION

To take advantage of the various data sets that have been or will be collected, and to suggest new collection activities or adjustment in the Zonal Monitoring Program (i.e., only in areas where crucial information is missing or where a coordinated zonal effort is necessary), the OMWG sees the necessity of maintaining permanent working groups or committees to ensure good coordination and integration of DFO's ocean science monitoring activities throughout the whole Atlantic region. These would include:

- *A Permanent Management and Coordination Committee* composed of designated management and technical personnel in the three regions and MEDS. It would be responsible for ensuring the general coordination of zonal monitoring activities, standardisation of methods, development of relationships with clients, data management aspects, and so on;
- *A Permanent Data Analysis Working Group* composed of designated research personnel from the Ocean Sciences and Fisheries Research branches of each region, with coordination ensured through the zonal coordination committee in association with the Fisheries Oceanographic Committee. This data analysis committee will assume the responsibility of producing the annual report on the state of the environment as well as the environmental indices that are required by clients. Other products to answer specific needs of clients will also be developed as suggested in section 7. Finally, this committee will be responsible for analysing the acquired monitoring data in order to recommend adjustments to the monitoring program as needed.

Finally, the OMWG proposes that regular workshops be held (every four to five years) to reexamine the Zonal Monitoring Program jointly with other organisations (e.g., FOC, fisher's associations, universities).

Annex I. List of acronyms used in this publication.

ADCP	Acoustic Doppler Current Profiler
AES	Atmospheric Environmental Service
AVHRR	Advanced Very High Resolution Radiometer
BIO	Bedford Institute of Oceanography
CHS	Canadian Hydrographic Service
CIL	Cold Intermediate Layer
CPR	Continuous Plankton Recorder
CTD	Conductivity, Temperature, Depth
CZCS	Coastal Zone Color Scanner
DFO	Department of Fisheries and Oceans
DOE	Department of Energy
FEP	Fisheries Ecology Program
FOC	Fisheries Oceanography Committee
FTE	Full-Time Equivalent
GLOBEC	Global Ocean Ecosystem Dynamics
GSL	Gulf of St Lawrence
IDM	Îles de la Madeleine
IML	Institut Maurice-Lamontagne
JGOFS	Joint Global Ocean Flux Study
JPL	Jet Propulsion Laboratory
LTTMP	Long Term Temperature Monitoring Program
MEDS	Marine Environmental Data Service
MVP	Moving Vessel Profiler
NAFO	North Atlantic Fisheries Organisation
NOA	North Atlantic Oscillation
NAOINDEX	North Atlantic Oscillation Index
NAQUADAT	National Aquatic Database
NDMWG	National Data Management Working Group
NOAA	National Oceanic and Atmospheric Administration
NWAFC	Northwest Atlantic Fisheries Center
OMWG	Ocean Management Working Group
OPC	Optical Plankton Counter
OPEN	Ocean Productivity and Enhancement Network
OPTEST	Optimally Estimated
PAR	Photosynthetically Available Radiation
PERD	Panel of Energy Research and Development
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SINECO	Système d'Information sur les Niveaux des Eaux Côtières et Océaniques
SPM	Suspended Particulate Matter
SSIP	Scotian Shelf Icthyoplankton Program
SST	Sea Surface Temperature
ZMP	Zonal Monitoring Program

Annex II. Mandate of the Ocean Monitoring Working Group.

TERMS OF REFERENCE

Environmental monitoring is defined as the collection of data on an ongoing basis to obtain a quantitative description of the variability of key physical, chemical, and biological characteristics of a particular region. Environmental monitoring is needed to understand environment–fisheries interactions, to detect and quantify climate changes, to make predictions, to validate models, and to provide historical and on-line data in support of marine activities (e.g., fisheries, energy, transportation).

MANDATE

In view of the above considerations, the specific mandate of the Ocean Monitoring Working Group (OMWG) is to develop and design an efficient and effective environmental monitoring program for the northwest Atlantic zone. This program will provide the reference and long time series data sets that are necessary:

1) to track and predict changes in ocean and ecosystem state and productivity;
2) to respond to immediate questions posed by clients;
3) to alert clients to short- and long-term changes; and
4) to provide an adequate database to meet future needs.

MEMBERSHIP

Membership is composed of the following representatives from the three Atlantic regions and from HQ:

Nominated participants:		Invited participants:	
Bellemare, Paul	(Maritimes)	Chadwick, Mike	(Maritimes)
D'Amours, Denis	(HQ-Ottawa)	Gagné, Jacques	(Laurentian)
Gagnon, Jean	(MEDS-Ottawa)	Gosselin, Serge	(HQ-Ottawa)
Gregory, Doug	(Maritimes)	Herman, Alex	(Maritimes)
Helbig, Jim	(Newfoundland)	Kinney, Laureen	(Maritimes)
Lefaivre, Denis	(Laurentian)†	Mitchell, Michel	(Maritimes)
Pelchat, Bernard	(Laurentian)	Zwanenburg, Kees	(Maritimes)
Pepin, Pierre	(Newfoundland)		
Petrie, Brian	(Maritimes)		
Runge, Jeff	(Laurentian)		
Sameoto, Doug	(Maritimes)		† rapporteur
Therriault, J.-Claude	(Laurentian)‡		‡ chairman

Annex III. Inventory of past and current monitoring activities in the different regions.

MARITIMES REGION

Inventory of Climate Indices Files. These files are maintained in an archive and are updated regularly.

- *Air Pressure Time Series:* NAOINDEX 1895-1997; OPTEST covers air pressure for approx. 20-90°N, 5°E-90°W;
- *Annual Air Temperatures:* 13 data series primarily from northern Europe starting as early as 1816;
- *Monthly Air Temperatures:* 83 time series covering the Arctic, east coast of Canada and the U.S., some European and some inland Canada starting as early as 1757;
- *Geostrophic Wind (6 h):* 25 time series for the AES standard east coast sites 1946-1991;
- *Freshwater Inflow (monthly):* 24 time series for NS and NB rivers plus a Hudson Bay index from as early as 1914;
- *Ocean Features:* Eddies, Gulf Stream, and shelf–slope boundary positions from as early as 1966 on monthly and chart frequency basis;
- *Ice/Icebergs:* Ice area seaward of Cabot Strait (1970-1994), south of 55°N (1963-1994), and number of bergs (1983-1994);
- *Monthly SST by area:* 24 time series for geographic areas (1971-1993);
- *Coastal/Lightship SST:* 13 time series from Woods Hole (MA, USA) to Grande Rivière (QC) beginning as early as 1906 (some have been discontinued);
- *Bay of Fundy SST:* 41 time series for the period of 1980-1990;
- *Monthly T–S Series:* 3 series for Emerald Basin (1947-1995), Prince 5 (1924-1995), and Station 27 (1946-1995);
- *Zooplankton (Doug Sameoto):* Years covered - 1984-1995; areas - primarily Scotian Shelf and Gulf of Maine, some from Arctic, northern Atlantic, eastern tropical Pacific. Tables include cruise, space, and time information; counts, weights, and species. The data in the database are almost exclusively from the Biological Oceanography Section;
- *Marine Fish Division (Bob Branton):* SSIP database - includes fish larvae, zooplankton, and nutrients on Scotian Shelf between 1977 and 1982;
- *Fish Database*: 1970-1996 abundance and distribution in Scotia-Fundy region;
- *Foreign and domestic observer programs*: 1977-present; catch, time, and location;
- *Ports Landing Program*: decades, species, size, and age of landed fish.

Other Time Series

- *Sea Level:* Approximately 20 sea level gauges have made up the permanent tide gauge network of eastern Canada, though the number has been decreasing over the past several years. Data have been collected since the late 1800s;
- *LTTMP (Long-Term Temperature Monitoring Program):* Eleven coastal temperature sites are sampled with recording instruments year-round at 1 to 3 depths. Program began in 1978. Data are maintained in a regularly-updated database;

- *Ice Forecast Cruise:* Late fall–early winter hydrographic survey (more recently including oxygen and nutrients) of the Gulf of St. Lawrence. Started in the early 1960s and ongoing. Temperature of the 200-300 m layer at Cabot Strait has been used as a climate index;
- *Hydrographic Sections:* The Cabot Strait, Louisbourg, Halifax, and Cape Sable sections were sampled irregularly beginning in the early 1950s and continuing until the late 1970s. Of these, the Halifax Section has the largest number of occupations followed by the Cabot Strait Section. Interest in sampling these sections has been revived in the last few years;
- *Current Meter Data:* While current meter moorings have not generally been occupied for long periods of time, the Cape Sable region had instruments in place from 1978-85 and 1995-96. The Cape Sable and Hamilton Bank moorings have the longest current meter time series;
- *Pte. Lapreau Environmental Monitoring Program:* Ongoing since 1978, this monitoring project collected oceanographic data on a yearly basis at first but has now dropped to one cruise every 5 years. A total of about 10 oceanographic cruises have been completed. A wide suite of radioactive tracers is sampled in the atmosphere, on land, and in the ocean. The land program is in cooperation with New Brunswick and provides some monthly series;
- *Bedford Basin Station:* A multidisciplinary time series spanning 30 years, this data set is the result of various research programs. Measurements of T–S, chlorophyll, and nutrients are currently being collected on a weekly basis from a small boat.
- *Contaminants in Cod and Lobster:* Chemistry has an extensive collection of contaminants in cod (livers and muscle tissue) from the southern Gulf of St. Lawrence stocks. The data, which extend from 1976 to 1994, are sporadic in time and space. A similar series (1980-92) was collected annually for lobster from the Belledune area;
- *Cores:* The contaminant records from a number of cores from various sites (e.g., Saguenay, Halifax Harbour) have been compiled and provide long time series;
- *NAQUADAT:* DOE has compiled an extensive database of contaminant concentrations in rivers;
- *Mussel Watch:* DOE, with some involvement from DFO, has monitored contaminants in mussels from coastal waters. There is broad spatial coverage, but the sampling sites have changed (e.g., intertidal in the early years, lately subtidal);
- *Archived General Data:* Hydrographic observations and data collected by moored instruments (current meters, temperature recorders, ADCPs, pressure gauges) are maintained in an archive. Tools are available for data extraction, analysis (e.g., creation of time series, spatial series), and display. Data from drifting buoys are also archived. Nutrient (nitrate, nitrite, silicate, ammonium) and dissolved oxygen observations are maintained in a database that supports data extract procedures to create temporal or spatial distributions;
- *Satellite SST:* For 1981-95 and continuing thereafter, 18x18 km monthly-resolution satellite SST data are available. We have the raw tapes of daily passes from 1984-present.

Current Programs (i.e., regular monitoring)

- The hydrographic, chemical, and moored instrument databases are being maintained and updated regularly. The climatological database is also revised regularly;
- The groundfish surveys typically cover a broad area, sometimes acquire data during seasons when there is generally the least number of observations, and thus serve as an extremely important source of oceanographic as well as fisheries data;

- The LTTMP, the Prince 5 monthly sampling, sea level sampling at Saint John (NB), Yarmouth (NS), Halifax (NS), North Sydney (NS), Charlottetown (PEI), and Escouminac (NB) are being maintained;
- Following the phytoplankton monitoring program (1989-91), a long-term monitoring program is being carried out at Indian Point (Mahone Bay, NS) and Sambro (NS) and at four sites in southern New Brunswick (Passamaquoddy Bay). There are no sites in the southern Gulf of St. Lawrence, but at least one site is being considered. Sampling is carried out about 26 times per year for temperature, salinity, dissolved oxygen, PAR, nutrients, chlorophyll, SPM, and phytoplankton analyses. Thermographs are maintained and plankton tows are carried out. All data are maintained in a database.

LAURENTIAN REGION
Monitoring activities 1996-97

- *Long Term Thermograph Monitoring Program:* Initiated for the GSL by BIO in 1978 and transferred to IML in 1992; stations on wharves and channel buoys, most of them during the ice-free season;
- *Fixed Stations Monitoring:* Initiated in the fall of 1995. Two stations, one in the northwest GSL and one in the Gaspé Current are occupied every two weeks for profiles of temperature, salinity, dissolved oxygen, nutrients, light (Secchi disk), fluorescence, and chlorophyll;
- *Toxic Algae Monitoring:* Initiated in 1989, 11 stations in the estuary and GSL (Québec shoreline) are sampled weekly from May to October. Measurements include phytoplankton identification and enumeration, surface temperature and salinity, nutrients, Secchi disk, vertical net cast, meteorology, and one station with chlorophyll (IML);
- *Fall Standard Sections Survey:* Initiated in 1981 as the ice-forecast cruise by BIO (G. Bugden) and transferred to IML in 1995. Profiles of temperature, salinity, dissolved oxygen, nutrients, and chlorophyll at the sections in the estuary, Anticosti, Bonne Bay, IDM–Cape Breton, and Cabot Strait;
- *Zooplankton Survey:* Initiated in 1994 as part of the krill assessment program: BIONESS tows in the estuary and GSL;
- *Winter Standard Sections Survey:* Initiated in 1996, ice floes are accessed in March by helicopter. Profiles of temperature and salinity at the sections in the estuary, Anticosti, Bonne Bay, IDM–Cape Breton, and Cabot Strait (ice conditions permitting);
- *Data Archiving and Distribution:* Initiated in 1986, on a continuous basis since 1994. Data format standardisation, common data acquisition programs, cataloguing and archiving system, historical data inventory and quality control;
- *Groundfish Survey:* Initiated in 1983 (temperature only), since 1990 with CTD, in August of every year, Gulf-wide;
- *Gaspé Current Monitoring:* Initiated in 1995, year-round mooring, replaced twice a year. Recordings of current, temperature (chain), salinity, and water level;
- *Meteorological Buoy in the Northwestern GSL:* Initiated in 1990, hourly recordings of meteorological data from April to November, jointly with AES, DOE (Québec Region).

Funded by St. Lawrence Action Plan, Vision 2000

- *Water Level Recordings in the Strait of Belle-Isle:* Initiated in 1995, year-round recordings on both sides of the strait for transport monitoring, jointly with CHS (Laurentian and Maritimes regions). Recordings of water level, surface temperature, and salinity;
- *Satellite Remote Sensing of Sea-Surface Temperature:* Since March 1994 a NOAA meteorological and SeaWiFS satellite receiving station has been in operation at IML.

Funded by the Fisheries Adjustment Plan

- *Sentinel Fisheries in the GSL:* Initiated in 1995, temperature and salinity profiles (CTD) on stations, Gulf-wide, in January and February.

NEWFOUNDLAND REGION
Monitoring activities 1996-97 (A-base funded)

- *Long-Term Thermograph Program:* Coastal temperature sites (25 marine, 20 riverine) sampled around the Newfoundland and Labrador coasts at depth of 1 to 30 m;
- *Station 27:* Ship-of-opportunity occupations of sites to obtain vertical profiles of temperature and salinity (since 1948). In 1996–97, a program of biological oceanographic monitoring was initiated;
- *Current Meter Moorings:* Archive of current meter data from coastal and shelf locations data back as early as 1970;
- *Acoustic Doppler Current Profiles:* On all major research cruises, current information obtained with ADCPs are collected, filtered, and archived. On-going since the early 1990s;
- *Summer Standard Survey:* July oceanographic cruises that sample along standard oceanographic transects from 47°N to Hamilton Bank;
- *Ship-of-Opportunity CTD:* On all major research cruises, profiles of temperature and salinity are obtained from all stations, processed, and archived. All information is used in the assessment of the State of the Ocean;
- *AVHRR Archive:* An average of four NOAA AVHRR (5 channels) full-resolution images have been archived daily since 1994.

Annex IV. List of fish and invertebrate surveys in 1997-1998. (GFC: Gulf Fisheries Center–Moncton; SSGOM: Scotian Shelf, Gulf of Maine).

Survey type	Area	Dates
GFC		
Bottom trawl	Southern GSL	Sept 3-26
Herring	Eastern PEI	Aug 14-Sept 10
Scallop	Bay of Fundy	June 2-18
Snow crab	Chaleur Bay	May 20-27
Scallop	Chaleur Bay	June 4-24
Lobster	NE NB	June 26-July 11
Snow crab	Chaleur Bay	July 14-Aug 1
Herring	Eastern PEI	Aug 18-Sept 21
Lobster	NE NB	Sept 22-Oct 3
Lobster	NE NB	Oct 14-28
Snow crab	Shediac Valley	Nov 3-11
SSGOM		
Groundfish	Scotian Shelf–GOM	July
Herring	Bay of Fundy–GOM	Nov
Groundfish	Georges Bank	Feb-March
Groundfish	Eastern Scotian Shelf	March (discontinued)
Groundfish	Sydney Bight	Jan
Laurentian		
Groundfish, shrimp	Northern GSL	Aug 5-Sept 2
Herring	West coast NF	Oct 13-31 (2 yrs)
Mackerel	Southern GSL	June 98 (2 yrs)
Snow crab	St. Lawrence Estuary	July 28-Aug 11
Scallop	Îles-de-la-Madeleine	Aug17-Sept 3
Lobster	Îles-de-la-Madeleine	Sept 4-20
Newfoundland	(NAFO areas)	
Groundfish	3LNO	May-June
Groundfish	3Ps	April
Groundfish	2J3KL	Oct-Nov-Dec
Groundfish	3NO	Oct-Nov-Dec
Pelagic juvenile	2J3KLNO	Aug-Sept
Redfish	3P, 4R	July-Aug
Capelin	3KL	May
Herring	Inshore bays east	Nov
Herring	Inshore bays south	Jan
Scallops	Grand Banks	April-May
Shrimp	2J3KL	Oct-Dec
Crab	Avalon	June
Crab	Bonavista Bay	Aug
Crab	White Bay	Aug-Sept
Crab	Conception Bay	Sept-Oct

Annex V. General circulation processes in the northwest Atlantic region.

ADVECTION

The flow of subpolar water toward the equator has a major influence on the entire northeastern North American seaboard. Relatively cool freshwater is transported from the north to the Labrador and Newfoundland shelves and then onward to the Gulf of St. Lawrence, Scotian Shelf, and the Gulf of Maine. Loder *et al.* (1997) have summarised the major current and transport features of the region (Figure 3). The figure consists of estimates of the annual mean transport of shelf water drawing on published values and their calculations from available observational data using salinity < 34.8 as a working criterion for shelf water (Mertz *et al.* 1993). The principal subpolar water sources for the Labrador Shelf are (i) a branch of the east-west Greenland Current system that flows westward across the northern Labrador Sea, (ii) most of the Baffin Island Current flowing south through western Davis Strait (except for a small branch entering Hudson Strait), and (iii) outflow from Hudson Strait. These combine to form the Labrador Current (Lazier and Wright 1993), which is concentrated over the break and upper slope of the Labrador Shelf but also has a small branch on the inner shelf (e.g., Smith *et al.* 1937). Loder *et al.* (1997) estimated a transport of 7.5 Sv (1 Sv = 1×10^6 m^3 s^{-1}) for the Hamilton Bank section.

Most of the Labrador Current flows onto the northeast Newfoundland Shelf and southward into the Grand Banks region (Colbourne *et al.* 1996; Narayanan *et al.* 1996). There is a small net inflow through the Strait of Belle Isle to the Gulf of St. Lawrence (Petrie *et al.* 1988) and a poorly-known eastward transport north of Flemish Cap (Figure 3). Off eastern Newfoundland at 47°N, the current has two distinct branches: a low-transport inshore branch that flows around the Avalon Peninsula onto the southern Newfoundland Shelf, and a high-transport, shelf-break branch that flows south through Flemish Pass towards the Tail of the Bank (e.g., Petrie and Anderson 1983). Some of the latter branch flows around the Tail and along the southern Newfoundland Shelf break while some turns offshore into the Newfoundland Basin; however, the magnitude and temporal variability of the branches that flow westward along the break and offshore into the basin are poorly known.

About 0.5 Sv of water from the southern Newfoundland Shelf enters the Gulf of St. Lawrence on the eastern side of Cabot Strait and, in combination with the Strait of Belle Isle inflow and runoff from the greater St. Lawrence drainage basin, contributes to a large-scale cyclonic circulation in the Gulf with outflow on the western side of Cabot Strait (Koutitonsky and Bugden 1991). This circulation includes the Gaspé Current in the northwestern Gulf (e.g., Benoit *et al.* 1985) that feeds low-salinity water from the St. Lawrence Estuary to the central Gulf and, subsequently, to the open shelf.

As a result, the Scotian Shelf has two partially-interconnected sources of subpolar water: (i) Cabot Strait outflow, which bifurcates to supply the Nova Scotian Current on the inner shelf and a shelf-break flow on the western side of Laurentian Channel and the outer Scotian Shelf; and (ii) the direct flow of Labrador Current water across the Laurentian Channel from the southern Newfoundland Shelf, primarily on the outer shelf (Figure 3). Thus, the flow is generally toward the equator on the Scotian Shelf (e.g., Smith and Schwing 1991; Loder *et al.* 1996), but with some cross-shelf meandering of the current branches and with a large reduction in net transport (<1 Sv) compared to the Labrador and Newfoundland shelves (3-8 Sv).

There are further reductions in the net transport as Scotian Shelf and slope waters enter the Gulf of Maine, again with inshore and offshore (Northeast Channel) branches, and subsequently move into the Middle Atlantic. The circulation in the Gulf of Maine is strongly directed by topography, with cyclonic flow around the Gulf's inner basins and anticyclonic flow around its outer banks (e.g., Brooks 1985; Naimie *et al.* 1994).

EXCHANGE

While transport toward the equator is the dominant flow feature of the northwestern Atlantic shelf, there are also important cross-shelf transports. The most important shelf–ocean exchange feature is the onshore flow of dense slope water at depth in several major cross-shelf channels. The best-documented cases are Laurentian Channel, the Scotian Gulf, and Northeast Channel, which are conduits for the supply (to the Scotian Shelf and adjacent regions) of nutrient-rich slope water (e.g., Bugden 1991; Loder *et al.* 1996; Ramp *et al.* 1986).

ANNUAL VARIATION

The circulation outlined above generally persists year-round, but there is an annual cycle of transport strength at most locations associated with the annual variation of water mass properties. For the along-shelf flow, annual transport variations have ranges of about 4 Sv for the traditional Labrador Current (Lazier and Wright 1993), 0.5 Sv for Cabot Strait outflow (El Sabh 1977), 0.6 Sv for the Nova Scotian Current (Anderson and Smith 1989), and 0.4 Sv for Scotian Shelf inflow to the Gulf of Maine (Smith 1983). The annual variation of deep slope water inflow is less well known, but, at least in the Northeast Channel case (Ramp *et al.* 1986), includes a summertime maximum associated with the annual cycle of shelf-water density.

INTERANNUAL AND DECADAL VARIABILITY

Quantitative information on interannual transport is more limited, but there are clear indications that it is significant. Petrie and Drinkwater (1993) have reported decadal-scale variations in geostrophic transport on the Newfoundland Shelf, which result in large changes in the hydrographic properties of slope water intruding onto the Scotian Shelf. Smith (1989) and Mountain (1991) have found year-to-year variations of transport into the Gulf of Maine that affect hydrographic conditions downstream to the Middle Atlantic Bight.

STRUCTURE OF SALINITY AND TEMPERATURE

The strong influence of along-shelf advection is apparent in the large-scale salinity and temperature distributions. Surface salinity (Figure 4a and 4b) has a persistent cross-shelf structure with values increasing offshore and along-shelf variations reflecting localised freshwater sources, particularly at the northern end of the Labrador Shelf and in the Gulf of St. Lawrence. Averaged across the shelf, the annual salinity range is typically 1-2 with a summertime minimum in many locations following the spring increases in coastal run-off and sea-ice melt. The range and phase of the annual cycle vary with distance downstream from the major sources (e.g., Sutcliffe *et al.* 1976; Petrie *et al.* 1991).

Surface temperature (Figure 4c, and 4d) shows influences from advection, but it has a strong annual variation associated with local air-sea interactions (e.g., Umoh and Thompson 1994). In winter, the large-scale pattern resembles that of salinity, with values ranging from near 0°C in northern regions to 6°C over Georges Bank. The summer values are typically 5-20°C warmer, with advective influences apparent in northern regions while other factors dominate the pattern elsewhere (e.g., tidal mixing of surface heat input in the Gulf of Maine; Garrett *et al.* 1978). Advection is particularly strong on the outer Labrador and Newfoundland shelves, consistent with the Labrador Current's properties and cross-shelf structure, but the surface hydrographic distributions over the entire area generally indicate flow toward the equator flow.

The vertical structure of temperature and salinity is illustrated by the winter and summer distributions on selected sections (Figure 5): the Bonavista section across the relatively deep northeast Newfoundland Shelf, the Halifax section across the topographically variable Scotian Shelf, and the Cape Sable section extending across the tidally energetic Georges Bank. The year-round salinity increases with depth throughout the region, with relatively fresh shelf water overlying saltier slope water in the deeper areas. Winter temperature has a similar structure, with cool (shelf) water overlying warmer water. In contrast, surface heating results in a warm and shallow near-surface layer from spring to fall, overlying a cool intermediate layer persisting at mid-depth, with warmer slope water below in the deeper areas. This basic structure is modified by shallow topography and enhanced tidal mixing. In shallow areas (e.g., the inner shelf and the Grand Bank), slope water influences are generally small and the temperature profile typically varies from a well-mixed structure in winter to a stratified structure in summer. However, in shallow areas with strong tidal currents (e.g., Georges Bank, Browns Bank), vertically-uniform hydrographic conditions are maintained year-round.

FRESHWATER SOURCES

The three primary sources of freshwater to the northeastern North American shelf are (in order of decreasing magnitude; see Loder *et al.* 1997 for details): (i) ocean transport of relatively fresh subpolar water onto the northern Labrador Shelf; (ii) continental run-off that is greatest in the St. Lawrence River system but also significant on the Labrador Shelf and in the Middle Atlantic Bight; and (iii) sea-ice melting, which is of local (but secondary) importance on the Labrador and northeast Newfoundland shelves and in the Gulf of St. Lawrence (Figure 6). The estimates suggest that the main source of the low-salinity, subpolar water is the Baffin Island Current out of Baffin Bay. The freshwater transport generally decreases downstream, in spite of the clear influence of the St. Lawrence discharge on the salinity distribution (Figure 4). The limited spatial extent of the sea-ice influence is indicated by the median seasonal peak in the extent of ice cover in Figure 6. These freshwater sources, along with the high-salinity offshore waters, the general circulation, and mixing processes, are the primary determinants of the observed salinity distributions (the net moisture fluxes across the sea surface are relatively small).

HEAT INPUT

In contrast, the primary heat source (and sink) for the shelf waters is the seasonally-varying flux across the sea surface. Summertime surface heating is dominated by solar radiation that generally has a broad latitudinal variation. On the other hand, winter cooling is dominated by latent and sensible heat losses (e.g., Umoh and Thompson 1994; Umoh *et al.* 1995). There is a net mean annual heat input to the ocean over most of the shelf region that must be balanced by the advection of cold water (Isemer and Hasse 1987; Battisti *et al.* 1995). Finally, the overall consistency of salinity and temperature as indices for shelf-water extent, particularly relative to the shelf break in the southern regions, is indicated by the mean surface position of the shelf-water / slope-water front inferred from satellite thermal imagery (Figure 6), which compares well with the surface position of the 34 isohaline (Figure 4).

OTHER FORCINGS

Two additional forcing mechanisms, wind stress and the Gulf Stream, can strongly influence the regional circulation and exchange. The large-scale mean wind stress pattern and its seasonal variation over the North Atlantic Ocean are important direct contributors to the circulation in the region, particularly for the Newfoundland–Labrador area. The variability of the large-scale meteorological forcing is often represented by the North Atlantic Oscillation (NAO) index, the difference in sea level barometric pressure between Iceland (the Icelandic Low) and the Azores (the Azores High). Enhanced wind stress from the northwest (high positive NAO index) can increase the southward advection of subpolar water. The Gulf Stream's influences on the southern shelf regions are generally indirect via slope water and transient rings. This results from the Gulf Stream's position (Figure 6) being several hundred kilometers from the shelf (except in the southern Middle Atlantic Bight).

SUMMARY OF LARGE SCALE DESCRIPTION

The quantitative estimates of volume and freshwater transports presented above (Figures 3 and 6) support the conceptual model that the northeastern North American shelf is dominated by a continuous but leaky current system originating at northern latitudes and flowing southward through the region. The net transports across six approximately equally-spaced sections are summarised in Table 1. Large decreases in volume transport occur between the eastern Newfoundland (47°N) and Halifax sections with smaller decreases elsewhere. Most of these decreases are attributable to off-shelf flows, such as the branch of the traditional Labrador Current near Flemish Cap and the Tail of the Bank directed towards the deep ocean (Figure 3). These transport decreases occur in spite of the known on-shelf intrusions of slope water in deep channels (e.g., Ramp *et al.* 1986; Petrie and Drinkwater 1993), which have relatively small volume transports but are important as salinity and nutrient sources. There is also a loss of transport caused by the inflow of water between Hamilton Bank and the 47°N sections, estimated as 0.22 Sv, to the Gulf of St. Lawrence.

Table1. Annual mean volume and freshwater transports.

Section Location	Volume Transport (Sv)	Freshwater Transport (10^{-3}Sv)
Cape Chidley	7.6	210
Hamilton Bank	7.5	190
47°N	6.2	150
Tail of the Bank	3.6	66
Halifax Section	0.6	49
Nantucket Shoals	0.38	13

The freshwater transports also show a general decrease with downstream distance, supporting a leaky current system. However, the detailed along-shelf variation of this decrease differs from that of the volume transport, apparently reflecting the increased importance of coastal run-off (e.g., Gulf of St. Lawrence) and slope water intrusions (e.g., Gulf of Maine) to the freshwater budgets.

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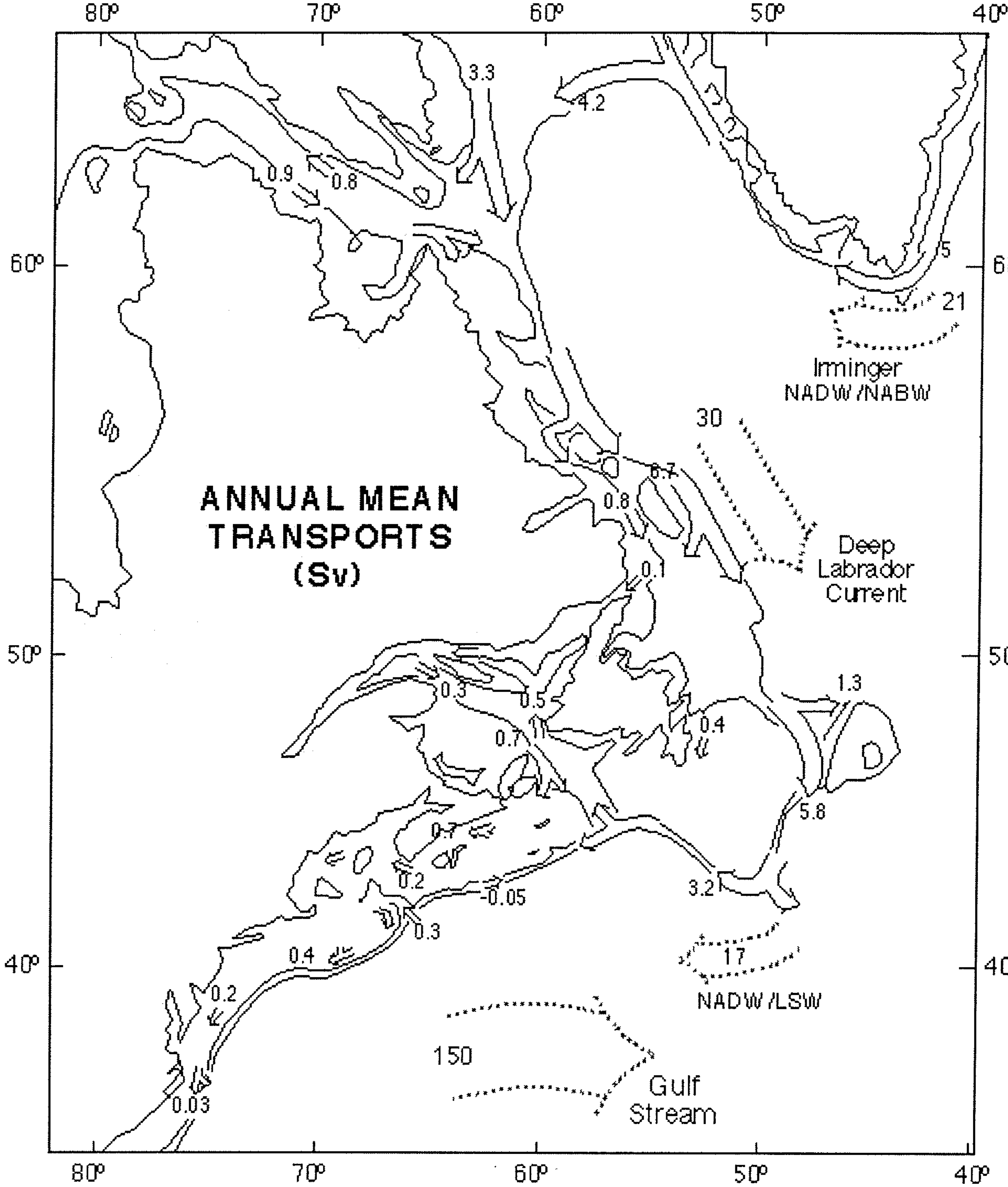

Figure 3. Schematic representation of the major transport features in the northeastern North American coastal ocean. Numbers indicate the mean annual transport in Sverdrups (Sv). Solid-line arrows represent shelf and slope currents with mean annual transport estimates taken from Table 1. Dashed-line arrows represent transports in adjacent parts of the deep North Atlantic. Irminger Sea / Current; NAD(B)W: North Atlantic Deep (Bottom) Water; LSW: Labrador Sea Water. The 200 and 1000 m isobaths are included. Figure from Loder *et al.* (1997).

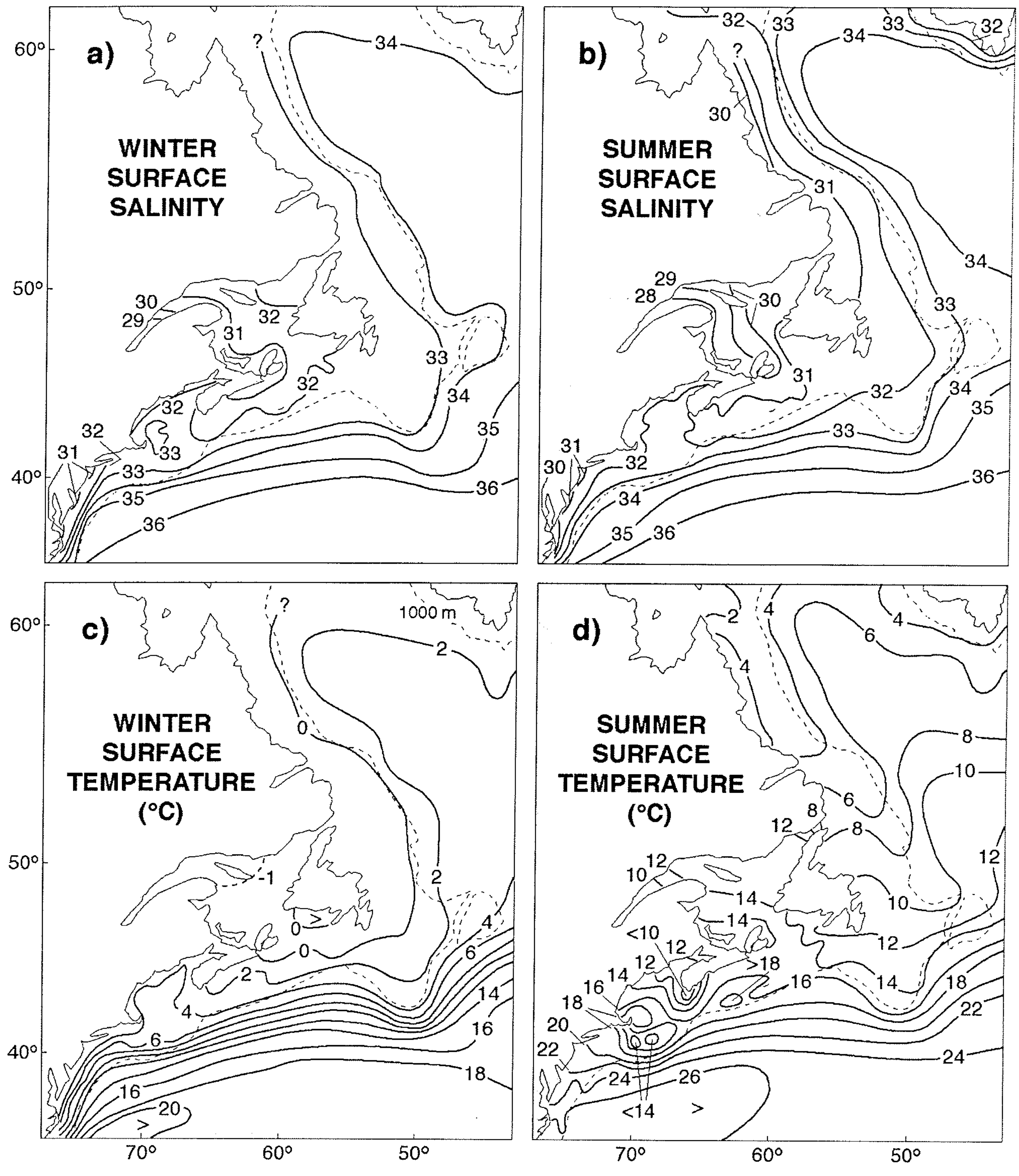

Figure 4. The climatological mean surface distributions off northeastern North America of (a) salinity in winter (nominally 1 February), (b) salinity in summer (nominally 1 August), (c) temperature in winter, and (d) temperature in summer. The distributions are composites based on published summaries and historical databases. Figure from Loder *et al.* (1997).

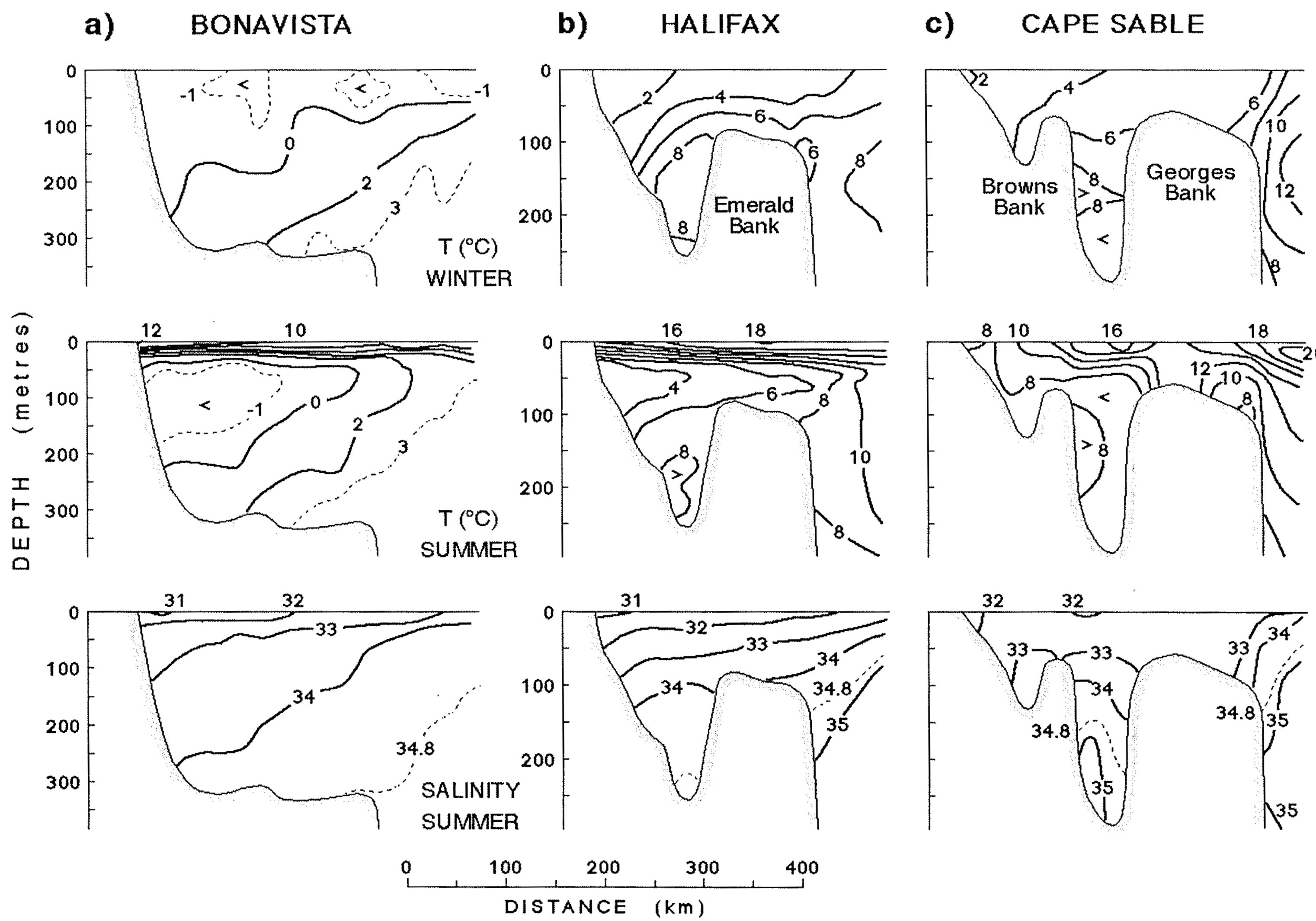

Figure 5. Climatological mean distributions of temperature in winter (upper panels) and summer (middle panels), and salinity in summer (lower panels) from the representative sections of (a) Bonavista, (b) Halifax, and (c) Cape Sable. The distributions were estimated from historical data following Loder *et al.* (1996). Note the different vertical scale in (a). Figure from Loder *et al.* (1997).

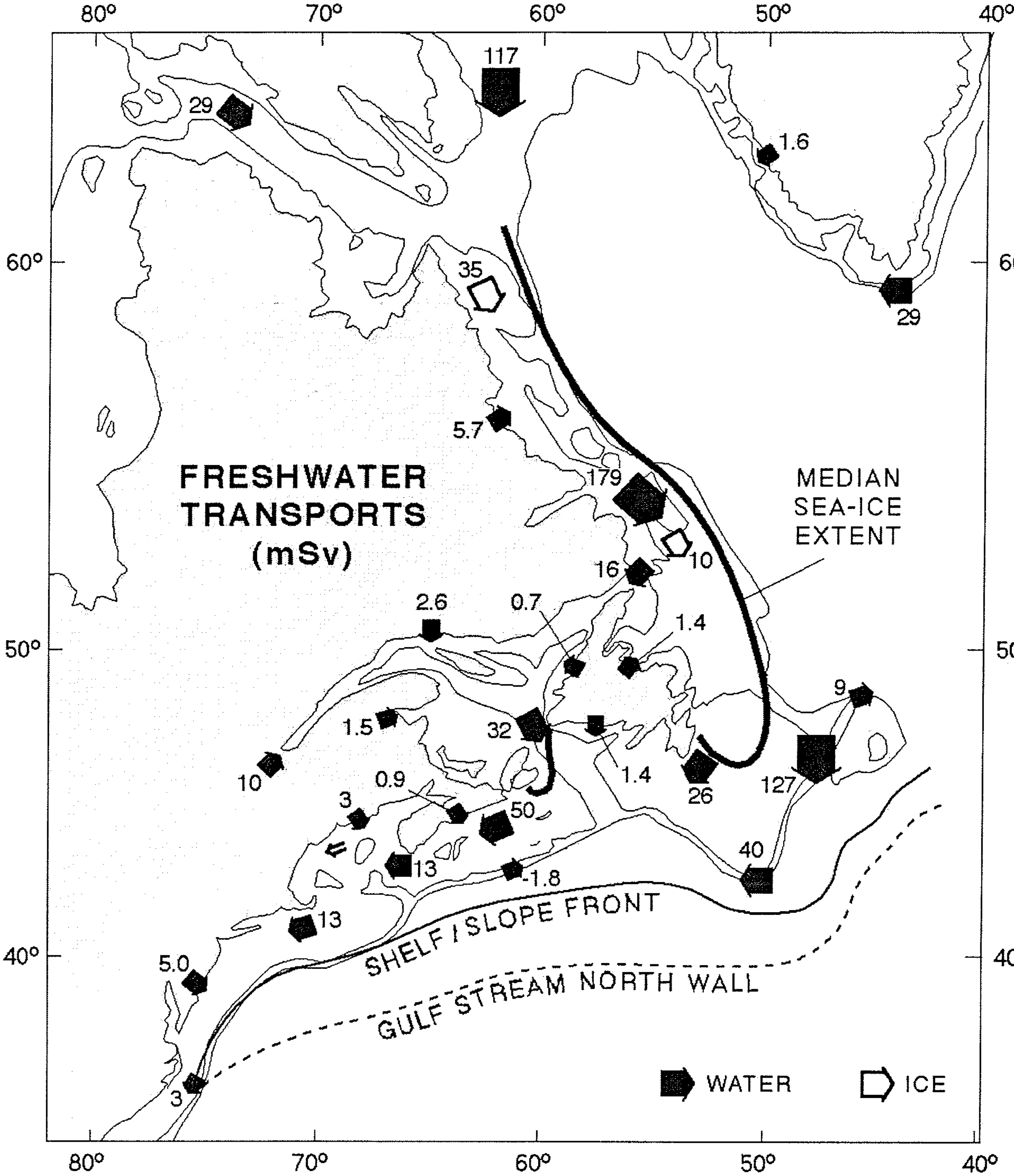

Figure 6. Summary of freshwater transports in milli-Sverdrups in the northeastern North American coastal ocean associated with continental run-off and ocean currents (filled arrows) and sea-ice drift (open arrows). The climatological mean positions of the shelf-water / slope-water front and the northern edge of the Gulf Stream are also shown, together with the median seasonal peak in the extent of sea ice. Figure from Loder *et al.* (1997).

Annex VI. An analysis of the frequency distribution of spatial and temporal variability for the Scotian Shelf.

THE SCOTIAN SHELF EXAMPLE

The temperature and salinity of Scotian Shelf waters vary over a broad range of temporal and spatial scales. Table 2 presents a brief summary of the range of temperature variability for different temporal scales. This table also indicates in a broad sense where that range is found. The largest decadal scale variability is observed in the deeper waters of the central Scotian Shelf. The annual cycle of temperature is generally greatest for the eastern portion of the shelf. The amplitude of the annual cycle decreases with depth so that by 75-100 m it is about 1°C; however, in the Bay of Fundy and the western shelf, the amplitudes do not increase as rapidly with depth because of the strong vertical mixing. Salinity generally varies in much the same way as temperature, i.e., the largest annual cycle is found near sources of freshwater, notably, at Cabot Strait and in the Bay of Fundy near the Saint John River.

Table 2. Distribution of temperature variability for the Scotian Shelf.

Time Scale	Range (°C)	Location (lower-upper range value)
Decadal	2-5	Eastern-Central shelf
Interannual	3-5	broadly distributed
Annual (surface)	4.7-9.1	Western shelf / Bay of Fundy-Eastern shelf
Day-Month	1-3	broadly distributed

The dominant spatial and temporal scales of oceanic variability for temperature and salinity have been calculated using data from instrumented arrays on the Scotian Shelf (Petrie and Dean-Moore 1996). These arrays covered the inner shelf, outer banks (Western and Browns), and the outer shelf–slope region. The scales represent the distance or time required for the squared correlation to fall to 0.5 (i.e., given one series of data, the distance or time separation where one could describe 50% of the variance in another data series). The values in Table 3 represent the minimum scales found for temperature. Scales generally vary with depth and season and are usually smaller for salinity.

Table 3. Scales of variability for the Scotian Shelf.

Area	Vertical	Along-bathymetry	Across-bathymetry	Temporal
Banks	13 m	17 km	17 km	56 h
Inner Shelf	43 m	59 km	63 km	52 h
Shelf–Slope	42 m	20 km	5 km	19 h

These results indicate that the empirical determination of the water temperature over the Scotian Shelf to within 50% of the variability would require a very dense set of moored instruments. A typical bank, for example, would require that every sampling location be located within 13 km horizontally and 10 m vertically of an instrument sampling every 44 hours if the reduction of the correlation coefficient squared is spread equally over all variables. Otherwise, the high frequency (periods less than 30 days) variability could induce errors of typically about 1-3°C (the magnitude of high frequency variability on the Scotian Shelf), depending on location and season. Such a dense array of instruments for the entire Canadian Atlantic shelf region is not possible logistically or economically. If such accurate resolution of ocean climate were required, it could only be attained for smaller, site-specific studies, such as those that have been conducted in the past (e.g., the FEP program on Browns Bank, OPEN on Western Bank). We expect that similar conclusions would hold for other areas, although one might anticipate that the scales of variability would be smaller (i.e., requiring more instrumentation) in the southern Gulf of St. Lawrence or larger on the Newfoundland Shelf. These considerations preclude empirical resolution of higher frequency variability of ocean temperature and like variables over broad areas.

On the other hand, the annual cycles of temperature and salinity have large amplitudes over most of the region. The temperature (salinity) amplitude at the surface varies from 10 to 7°C (salinity 1.7 to 0.15) from the southern to the western Scotian Shelf. From Cape Sable to the Bay of Fundy, vertical mixing reduces the surface amplitude to from 7 to 4.7°C (salintiy 0.05 to 0.45). These annual amplitudes generally decrease with increasing depth so that they are at noise levels by about 100 m. The exception is most of the area from Cape Sable to Bay of Fundy, where vertical mixing spreads the annual cycle almost uniformly over the entire depth. Given its amplitude throughout the region, it is possible to describe the annual cycle of temperature and salinity with limited sampling. A broad seasonal monitoring program, complemented by observations from other oceanographic projects, could provide the empirical data to characterise the annual cycle of these physical variables.

The situation is similar for the annual temperature cycle in the Newfoundland–Labrador shelf waters, with surface amplitudes of 3.2 (Labrador) to 7.7°C (SW Grand Bank shelf and slope). In the Gulf of St. Lawrence, the range is 4.75 (in the estuary) to 9.96°C (Northumberland Strait) for the annual surface temperature amplitudes (Petrie 1990, Petrie *et al.* 1991). On the Labrador–Newfoundland shelf, the salinity has an annual amplitude of 0.2-1.1 with the larger values in the more northern regions. In the Gulf, the range is 0.4 (Cabot Strait) to 2.2 (St. Lawrence Estuary).

In addition to annual variations, temperature and salinity vary over periods of years and decades. Recent studies for the Scotian Shelf and Gulf of Maine have documented interannual (decadal) changes of about 2°C (decadal 5°C) for temperature and 1 (decadal 1) for salinity. These changes can be detected by a seasonal monitoring program complemented by data from other projects. Interannual and decadal variability in the southern Gulf of St. Lawrence are smaller and spatially less coherent than the changes on the Scotian Shelf. This perhaps reflects the smaller amplitudes of the low frequency variability relative to the higher frequency changes. The hydrographic sampling there has not been sufficiently dense in space or time to separate the interannual or decadal variability from the higher frequency components. In the Laurentian Channel and northern areas of the Gulf, Gilbert and Pettigrew (1997) report a range of low frequency variability of the temperature of the cold intermediate layer of about 2°C. For Station 27 off St. John's, Petrie *et al.* (1992) found a range of about 5°C (1.5 for salinity) in the 0-20 m layer and nearly 2.5°C (0.8 for salinity) in the 75-150 m depth interval.

The nutrients and dissolved oxygen databases have not been analysed for high frequency variability or annual variations using an analytic approach as was applied to the temperature and salinity data. One would expect considerable variance at these frequencies, given the known variability of primary productivity (see, e.g., Fournier *et al.* 1977). The dissolved oxygen does show significant interannual variability. In the mid-60s, when deep shelf waters were dominated by Labrador slope water, the percent saturation levels in Emerald Basin (z>149 m) were about 70%. In the mid-70s, when warm slope water dominated, the percent saturation levels were about 45%. The situation for nutrients is less clear because there are less data. However, the indication is that during periods of Labrador slope water dominance, nitrate was one half to one third of the concentrations found when warm slope water prevailed. This indicates that interannual and decadal variations of the nutrient and dissolved oxygen pool can be resolved.

LOW- VERSUS HIGH-FREQUENCY SAMPLING

The existing data and their analyses indicate that it is possible to provide an empirical description of the seasonal, interannual, and decadal variability of hydrographic properties in the Canadian east coast region with limited sampling. Thus the primary objectives of the monitoring program should be to provide that description. Parallel collection of physical, chemical, biological, and fisheries data should provide the opportunity to explore the interrelationships between these variables. The use of complementary oceanographic, meteorological, and hydrological data should permit us to investigate the causes of these low-frequency changes at the climate scale.

On the other hand, it appears that it is not logistically or economically feasible to address questions that involve processes governed by higher frequency or finer spatial scale dynamics over the entire Atlantic region unless we rely on a modeling approach where the broad spatial scale sampling, complemented by higher frequency site specific temporal studies, are taken as input for validation of the model results. The OMWG strongly supports the modeling initiatives in each DFO region, which open the door for a whole suite of new clients or partners for the Zonal Monitoring Program. Sampling to support modeling programs imposes a new set of criteria for the choice of sampling sites and frequency of sampling, especially for some physical variables since the needs for validation of the circulation models must be satisfied. However, the potential return is very high: availability of information in the 5 to 10 km range horizontally, 20 meters range vertically, and every 20 to 60 minutes temporally, which are all within the observed scale of variability for some existing physical measurements (e.g., T, S, current measurements, water levels, winds).

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Annex VII. Justification for the choice of sampling sections and fixed stations

Why did the OMWG settle on time scales of seasonal duration and longer when it is known that there is considerable variability at shorter time periods? The OMWG approached this question by analysing temperature and salinity data from a number of instruments covering the Scotian Shelf (see details in Annex VI). These physical variables were selected because equivalent biological and chemical data do not exist. The instruments were located in the Bay of Fundy, the inner shelf, at a number of banks, and at the shelf break. These locations represented a variety of shelf regimes. The OMWG compared the high frequency variance to the annual cycle (seasonal variability) and interannual and decadal variability, and reached the conclusion that it is only possible to extract the longer time scale variability from a limited sampling of the ocean environment that would be logistically and financially acceptable for DFO. To examine higher frequency variability would require moored instruments, in which case only the physical variables could be monitored. The OMWG considers that the costs to monitor this physical variability, including the currents, on the shelf with moored instruments would be too high for permanent monitoring.

How far apart would moored instruments have to be to adequately sample the variability on all time scales? Again, the OMWG selected arrays of instruments covering all the topographic regimes on the Scotian Shelf and analysed the data for the spatial scales of variability. Depending on the location, the horizontal scales ranged from 5-60 km and the vertical scales from 10-40 m. This puts a very stringent requirement on the spacing of moored sensors to examine temperature and salinity variability at all time scales. Again, the OMWG reached the conclusion that the array of instruments that would be needed to monitor the physical environment alone would be too costly to contemplate (Annex VI).

Why did the OMWG select sections (see Table 4 for location of the sections) as a major component of the proposal? Let us again consider the Scotian Shelf as an example. The eastern end of the Scotian Shelf is dominated by the outflow from the Gulf of St. Lawrence with characteristic physical, chemical, and biological properties. The strength of this outflow (and, in fact, the inflow to the Gulf as well) is best measured at Cabot Strait, where the currents are confined to a small area. On the eastern portion of the shelf, the waters spread out more and some influence of offshore slope waters are felt, particularly over the outer banks. In the central shelf area, there is a very strong influence from slope water that has moved onshore and filled the inner basins. To the west, near the entrance to the Gulf of Maine–Bay of Fundy, tidal mixing is dominant and profoundly affects the vertical distribution of water properties. Thus, to cover these different oceanographic regimes of the Scotian Shelf, the OMWG proposes sampling four sections located: (1) at Cabot Strait, a major source of shelf water; (2) at the eastern end of the shelf, where St. Lawrence water dominates but slope water is exerting a significant influence; (3) at the central shelf, where slope water plays a greater, if not dominant, role; and (4) at the western end of the shelf, where tidal mixing fundamentally alters water mass structure.

Similar considerations were the basis of choosing the sections in other areas (see Annex V and Table 4). The sections provide broad coverage of each region and of the entire area. The broad coverage allows for an assessment of the ocean environment beyond presenting a time series from one or several locations. For example, it can provide the means of estimating the area of bottom water temperatures that were favourable or unfavourable for cod. Moreover, the Atlantic region is dominated by the advection of relatively cold and fresh water from the north (see Annex V for details). The flow moves southward through the region but with its transport of mass and freshwater generally decreasing because of losses to the offshore. Section data provide the means to calculate the transports of mass, heat, and salt. With complementary nutrient and biological measurements, the transports of these variables may be estimated as well.

The advective nature of the flow allows for some limited projections of environmental changes from one area to another, as it takes about a year for particular water masses to move through the region. We also foresee trying to connect the variability that is being experienced within the region with broader-scale forcing, particularly atmospheric. This may allow for estimates of the duration of cold/warm, fresh/salty conditions.

Why have fixed stations? (see Table 5 for the locations of the fixed stations) The biological and chemical variables cannot be measured in the same way that we can sample many of the physical variables. At present, there are not any sensors for measuring phytoplankton or zooplankton biomass or nutrient levels that can be moored for 6 to 12 months and sampled hourly to give long time series at a number of locations. We must still rely on sampling from ships. However, opportunistic sampling of the sections as proposed will not provide sufficient temporal resolution of the biological variability, and possibly for some of the chemical processes as well. Therefore, the OMWG proposes the occupation of eight fixed stations in different regions of the Northwest Atlantic (see Figure 2) on a biweekly basis from February to October and monthly from November to January to collect sufficient data to obtain the seasonal, annual, and decadal temporal scale information that is necessary to detect climate changes.

Table 4. Justification for the choice of sampling sections (see Figure 2 for locations).

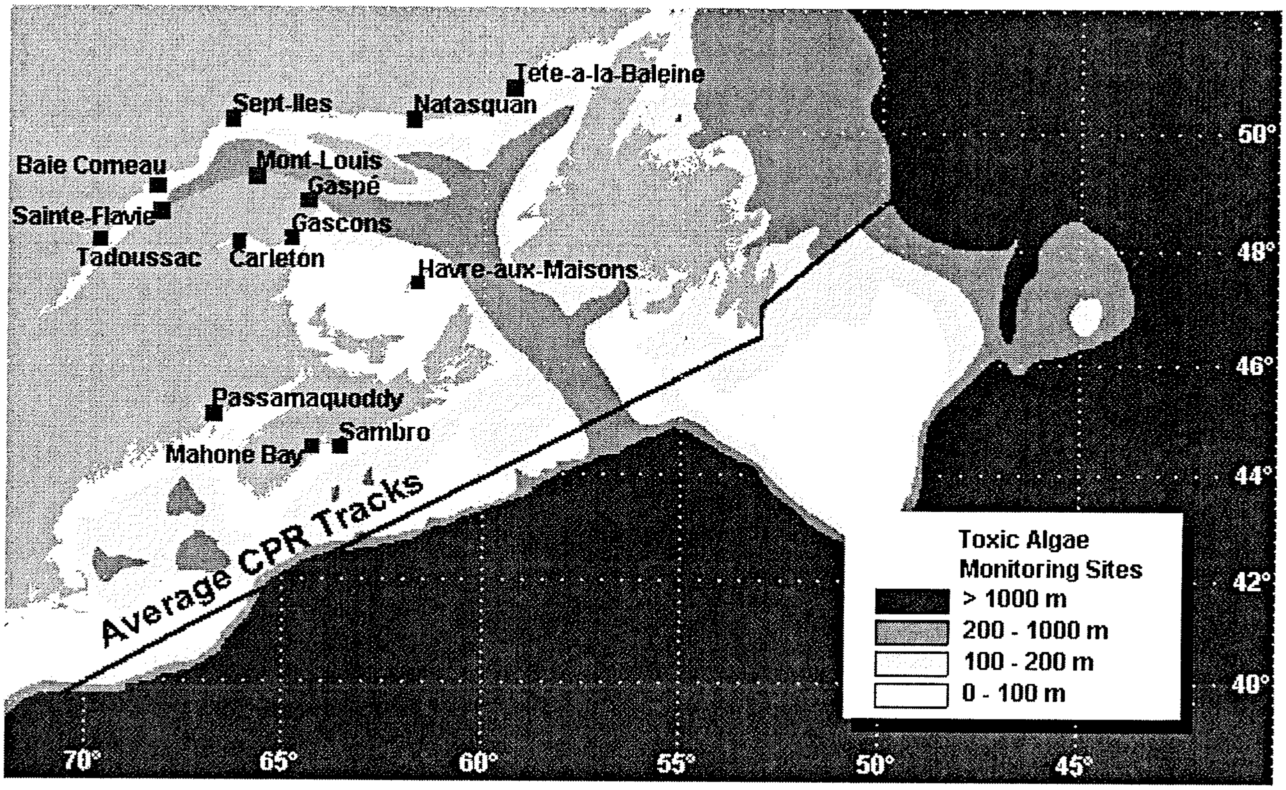
1) Hamilton Bank (Newfoundland)	This represents the northern boundary of the region where it is possible to contemplate acquiring data from several seasons. Just south of Hamilton Bank the flow splits, part entering the Gulf of St. Lawrence through the Strait of Belle Isle and part moving onto the northeast Newfoundland Shelf. A considerable climatological data series has been collected along this section.
2) Bonavista (Newfoundland)	This section can provide an unequivocal assessment of the cold intermediate layer for the Newfoundland region. The cross-sectional area and temperature of this layer has been a useful climate index for the region. There is also an extensive database to build on for this section.
3) Flemish Cap (Newfoundland)	This long-standing section provides data for both the inner and outer branches of the Labrador Current. It can also provide a measure of the strength of the baroclinic flow of the offshore branch before it undergoes a major loss of volume and freshwater transport.
4) Southeast Shoal (Newfoundland)	A region of weak current with no definite direction. Monitoring would document the slope water intrusions forced by the Gulf Stream meanders that dominate the water mass exchanges; its influence upon the capelin spawning grounds and the flatfish nursery grounds in the area is important.

5) St. Pierre Bank (Newfoundland)	This will provide data for the western Grand Banks, which has not been sampled as much as the rest of the Newfoundland Shelf in the past. It will also give an indication of the transport of Labrador slope water westward to the Gulf of St. Lawrence and the Scotian Shelf. The section should be across St. Pierre Bank rather than farther east in order to pick up the outflow of shelf water from Halibut and Haddock Channels.
6) Cabot Strait (Maritimes)	This long-standing section provides the information to assess the inflow and outflow of the major passage connecting the Gulf of St. Lawrence to the Atlantic Ocean.
7) Louisbourg (Maritimes)	Located so that the climate of the eastern Scotian Shelf can be assessed (at present this area has a climate that is distinct from the rest of the shelf). In addition, the inshore branch of the Nova Scotia Current can be estimated and the influence of Labrador slope water and Gulf outflow on the outer shelf and upper slope can be assessed.
8) Halifax (Maritimes)	This section provides a measure of the central shelf climate and the deep inner basin climate that is so important to decadal scale variability on the shelf as well as a measure of the strength of the Nova Scotia Current.
9) Cape Sable (Maritimes)	Provides an assessment of the western shelf climate, particularly in some of the tidally-mixed zones, and the inflow into the Bay of Fundy and the Gulf of Maine.
10) St. Lawrence Estuary (Laurentian)	Unique area of the Gulf with the smallest (largest) annual cycle amplitude for temperature (salinity).
11) Mont-Louis (Laurentian)	This northwest Gulf of St. Lawrence section runs through the two high-frequency stations and will be useful to bridge the two sets of data.
12) Anticosti (Laurentian)	This is the historical Gaspé section. A section between Anticosti Island and the south shore is necessary for monitoring the temperature and salinity fluctuations in the Gulf waters as well as in the Gaspé Current itself.
13) Bonne Bay (Laurentian)	Provides a measure of the climate of the northeast Gulf (an under-sampled area in the past), an assessment of the inflow of slope water into the Esquiman Channel, and the inflow of Labrador Shelf water to the Gulf through the Strait of Belle Isle.
14) Magdalen Islands (Laurentian)	Provides a measure of the climate in a lightly sampled area and gives an indication of the outflow from the Gaspé Current and the Magdalen Shallows towards Cabot Strait.

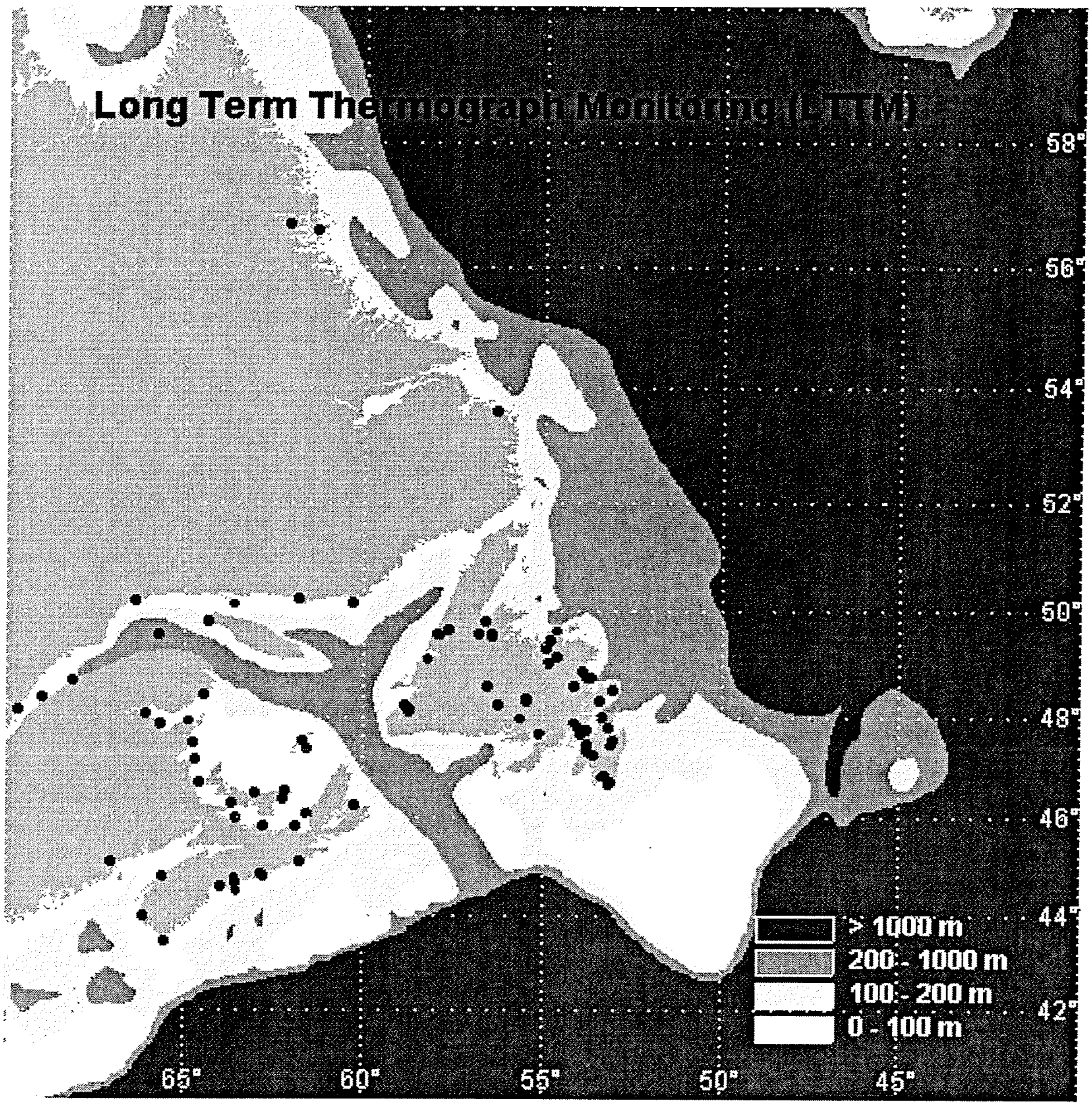
Table 5. Justification for the choice of fixed stations (see Figure 2 for locations).

1) Prince 5 (*DFO staff,* Maritimes)	Station representative of the Bay of Fundy environment.
2) Station 2 off the Halifax Section (*DFO staff,* Maritimes)	Station representative of the Scotian Shelf environment.
3) Shediac (DFO, Maritimes)	Station representative of the southern Gulf of St. Lawrence environment. It is the region where one branch of the Gaspé Current drifts towards Cabot Strait.
4) East Point PEI (*Trained fisherman,* Maritimes)	Station representative of the southern Gulf of St. Lawrence environment. This station is needed, particularly if one takes into account that it is the region where the annual variations in temperature are the largest.
5) Mont-Louis–Gaspé Current (49° 14.5'N, 66°.12.00'W) (*DFO staff,* Laurentian)	Station representative of the Gaspé Current and its drift region along the Gaspé Peninsula. The Gaspé Current by itself deserves particular attention since this is the most dynamic feature of the Gulf. It meanders further down the Gulf.
6) Northwestern Gulf of St. Lawrence gyre (49° 43.00'N, 66° 15.00'W) (*DFO staff,* Laurentian)	This station is representative of the northwest region of the Gulf.
7) Northeastern Gulf of St. Lawrence (49° 42.00'N, 59° 20.00'W) (*Trained fisherman,* Laurentian)	To monitor the deep layers of the Laurentian Channel, measurements once a year on a section at Cabot Strait or closer to the shelf break would be the bare minimum. Measurements a few times a year would be highly advisable. Measurements at the Gaspé section would enable us to follow the evolution of the variations observed 3 to 4 years earlier at Cabot Strait. On the other hand, there is a definite lack of data in the northeast Gulf, where data are needed to understand the dynamics of the Esquiman Channel. This station would complement the Bonne Bay section for which we anticipate a very low return of data due to a lack of opportunity to sample as noted in the past years. This is a station where we envisage automatic sampling from a moored sampling buoy.
8) Station 27 (47° 32.8'N, 52° 35.2'W) (*DFO staff,* Newfoundland)	Station representative of the Newfoundland shelf environment. This site was chosen because of the extensive physical and limited biological data already collected throughout the seasonal cycle. The site is easily sampled on a regular basis using either dedicated sampling or ship-of-opportunity.

Annex VIII. Location of the CPR lines and the toxic algae monitoring stations.



Annex IX. Locations of long term temperature monitoring stations.



Annex X. Location of water level gauges on the east coast. Numbers indicate CHS designations.