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ATLANTIC ZONE MONITORING PROGRAM

# AZMP Bulletin PMZA

PROGRAMME DE MONITORAGE DE LA ZONE ATLANTIQUE

http://www.meds-sdmm.dfo-mpo.gc.ca/zmp/main_zmp_e.html

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## *Le Bulletin du PMZA*

Le Bulletin annuel du PMZA publie des articles anglais, français ou bilingues afin de fournir aux océanographes et aux chercheurs des pêches, aux gestionnaires de l'habitat et de l'environnement, ainsi qu'au public en général les plus récentes informations concernant le Programme de Monitorage de la Zone Atlantique (PMZA). Le bulletin présente une revue annuelle des conditions océanographiques générales pour la région nord-ouest de l'Atlantique, incluant le golfe du Saint-Laurent, ainsi que de l'information reliée au PMZA concernant des événements particuliers, des études ou des activités qui ont eu lieu au cours de l'année précédente.

## The AZMP Bulletin

The AZMP annual Bulletin publishes English, French, and bilingual articles to provide oceanographers and fisheries scientists, habitat and environment managers, and the general public with the latest information concerning the Atlantic Zone Monitoring Program (AZMP). The Bulletin presents an annual review of the general oceanographic conditions in the Northwest Atlantic region, including the Gulf of St. Lawrence, as well as AZMP-related information concerning particular events, studies, or activities that took place during the previous year.

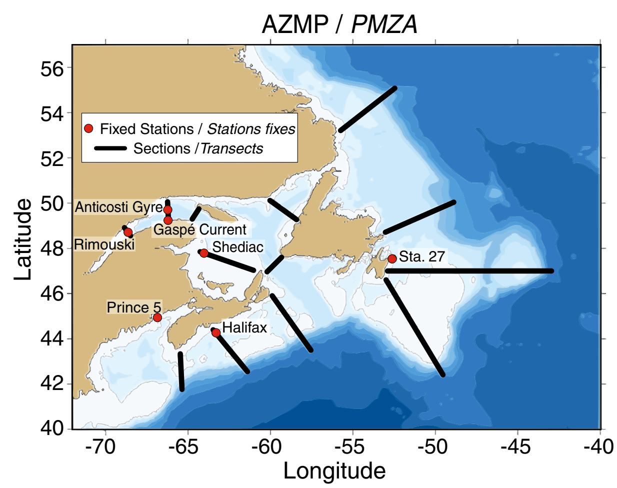


Fig. 1 Locations of sections and fixed stations.
*Position des transects et des stations fixes.*

## The Atlantic Zone Monitoring Program

The AZMP was implemented in 1998 with the aim of collecting and analyzing the biological, chemical, and physical field data that are necessary to (1) characterize and understand the causes of oceanic variability at the seasonal, interannual, and decadal scales, (2) provide multidisciplinary data sets that can be used to establish relationships among the biological, chemical, and physical variables, and (3) provide adequate data to support the sound development of ocean activities. AZMP involves the Gulf, Québec, Maritimes, and Newfoundland regions of DFO. Its sampling strategy is based on (1) seasonal and opportunistic sampling along "sections" to quantify the oceanographic variability in the Canadian NW Atlantic shelf region, (2) higher-frequency temporal sampling at more accessible "fixed sites" to monitor the shorter time scale dynamics in representative areas, (3) fish survey and remote sensing data to provide broader spatial coverage and a context to interpret other data, and (4) data from other existing monitoring programs such as CPR (Continuous Plankton Recorder) lines, Sea Level Network, nearshore Long-Term Temperature Monitoring, Toxic Algae monitoring, or from other external organizations (e.g., winds and air temperatures from Environment Canada) to complement AZMP data.

The key element of the AZMP sampling strategy is the oceanographic sampling at fixed stations and along sections. The fixed stations are occupied about every two weeks, conditions permitting, and the sections are sampled from one to three times during the year. The location of the regular sections and the fixed stations are shown in Figure 1. Temperature, salinity, fluorescence, oxygen, chl *a*, nitrates, silicates, and phosphates are measured, and phytoplankton and zooplankton samples are collected. These measurements are carried out following well-established common protocols.

## Le programme de monitorage de la zone atlantique

Le PMZA a été mis en œuvre en 1998 et vise à collecter et analyser l'information biologique, chimique et physique recueillie sur le terrain afin de (1) caractériser et comprendre les causes de la variabilité océanique aux échelles saisonnières, inter-annuelles et décadales, (2) fournir les ensembles de données pluridisciplinaires qui sont nécessaires pour établir des relations entre les variables biologiques, chimiques et physiques et (3) fournir les données pour le développement durable des activités océaniques. Le PMZA implique les régions du Golfe, du Québec, des Maritimes et de Terre-Neuve du MPO. Sa stratégie d'échantillonnage est fondée sur (1) l'échantillonnage saisonnier et opportuniste le long de «transects» afin de quantifier la variabilité biologique, chimique et physique de l'environnement, (2) l'échantillonnage à plus haute fréquence à des «stations fixes» plus accessibles pour monitorer la dynamique à plus fine échelle de temps dans des régions représentatives, (3) l'utilisation des données provenant des missions d'évaluation de stocks et de la télédétection pour fournir une couverture spatiale plus vaste et le contexte pour l'interprétation des autres données et (4) l'utilisation de données provenant d'autres programmes de monitorage comme les transects CPR (*Continuous Plankton Recorder*), les réseaux côtiers de niveau d'eau et de température, le monitorage des algues toxiques, ou provenant d'autres organismes externes (ex. vents et température de l'air de Environnement Canada) pour complémenter les données du PMZA.

L'élément clé de la stratégie d'échantillonnage est la collecte de mesures océanographiques aux stations fixes et le long de transects. Les stations fixes sont occupées à toutes les deux semaines, dépendant des conditions, et les sections sont échantillonnées de 1 à 3 fois durant l'année. La localisation des transects et des stations fixes est illustrée à la Figure 1. L'échantillonnage régulier comprend des mesures de température, salinité, fluorescence, oxygène, chl *a*, nitrates, silicates et phosphates, ainsi que la collecte d'échantillons de phytoplancton et de zooplancton. Ces mesures sont effectuées suivant des protocoles communs bien établis.

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## Physical and Biological Status of the Environment

## État de l'environnement physique et biologique

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### Physical Environment

Cold surface water over the Labrador and northeast Newfoundland shelves, the Gulf of St. Lawrence, and the inshore half of the Scotian Shelf prevailed in a satellite image from early spring 2005 (Fig. 1A). The offshore branch of the Labrador Current on the eastern edge of the Grand Banks is indicated by patches of cold water; the inshore branch is seen in Avalon Channel. Cold water and some ice from the Gulf of St. Lawrence mark the Nova Scotia Current from Cabot Strait to offshore of Halifax. Conditions are much the same for the early spring of 2006 (Fig. 1B); however, the Labrador Current is not as evident on the outer edge of Grand Bank nor is the Nova Scotia Current on the inner Scotian Shelf. Moreover, there is no ice in the southern Gulf of St. Lawrence in contrast to the previous year, when most of the Magdalen Shallows was ice covered. In 2005, mean annual sea surface temperatures (SST) were above normal in all shelf regions by 0.6 to 1.0°C; the lone exception was the area from Georges Bank to the Bay of Fundy, which was 0.6°C below normal. In all regions, SST

### Environnement physique

Une image satellitaire du début de printemps 2005 montre une vaste région d'eaux de surface froides couvrant les plateaux du Labrador et de Terre-Neuve (région nord-est), le golfe du Saint-Laurent ainsi que la région côtière du plateau Néo-Écossais (Fig. 1A). La branche hauturière du courant du Labrador se distingue par des parcelles d'eaux froides le long de la marge est des Grands Bancs; la branche côtière se situe au dessus du chenal Avalon. La présence d'eaux froides et d'un peu de glace provenant du golfe du Saint-Laurent identifient le courant de la Nouvelle-Écosse entre le Cap Breton et la région au large de Halifax. Les conditions sont à peu près semblables pour le début du printemps 2006 (Fig. 1B); cependant, le courant du Labrador n'est pas aussi évident le long de la marge externe du Grand Banc pas plus d'ailleurs que le courant de la Nouvelle-Écossse sur la marge interne du plateau Néo-Écossais. De plus, il n'y a pas de glace dans la partie sud du golfe du Saint-Laurent, en contraste avec l'année précédente lorsque la plus grande partie du plateau Madelinien était couverte de glace. En 2005, les températures moyennes en surface (SST) étaient de 0,6 à 1,0 °C au-dessus de la normale dans toutes les régions de la marge continentale; la seule exception étant la région s'étendant du banc Georges jusqu'à la baie de Fundy avec des SST de 0,6 °C au-dessous de la normale. Dans toutes les régions, SST montre une augmentation en 2006 en comparaison avec 2005, de 0,2 °C pour la région du Labrador jusqu'à 1.6 °C pour le golfe du Maine. Le couvert de glace entre décembre 2004 et juillet 2005 était bien au-dessous de la normale pour les plateaux du Labrador et de Terre-Neuve, et juste au-dessous de la normale pour le golfe du Saint-Laurent. L'analyse sommaire des données de glace pour 2006 n'est pas encore complétée.

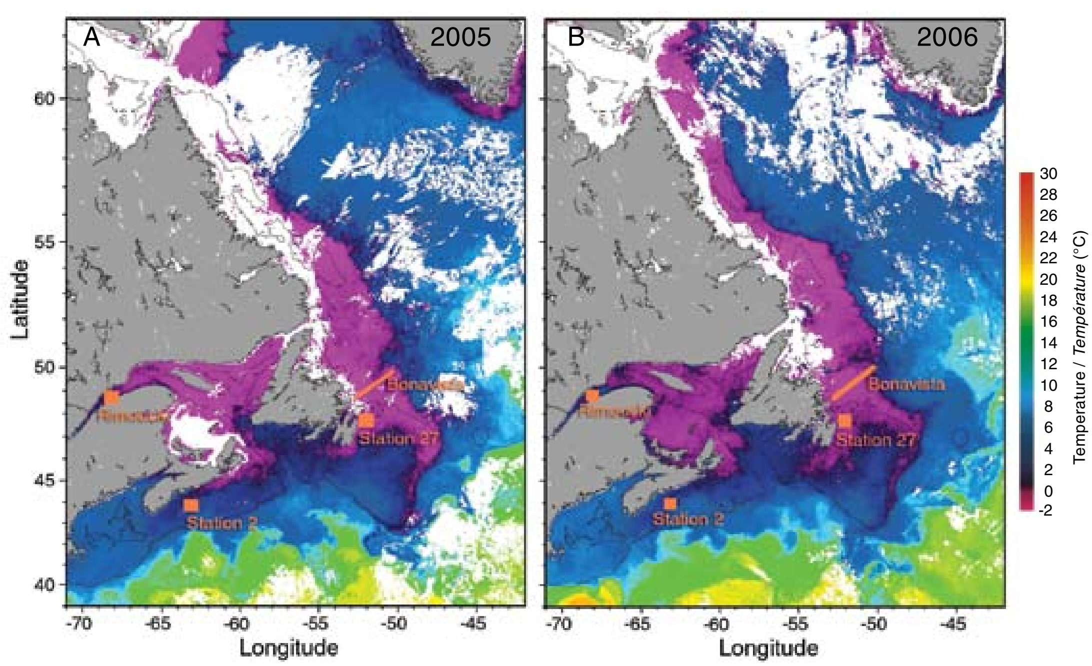


Fig. 1 Sea surface temperature in the AZMP region during spring 2005 (A) and 2006 (B). The locations of fixed stations (squares) and the Bonavista section (line) discussed in the article are shown. White areas indicate sea-ice or clouds.

*Température de surface de la mer dans la région couverte par le PMZA aux printemps 2005 (A) et 2006 (B). Les positions des stations fixes (carrés) et du transect de Bonavista (ligne) qui sont discutés dans cet article sont indiquées. Les régions blanches représentent de la glace à la surface de la mer ou des nuages.*

increased in 2006 relative to 2005 by 0.2 (Labrador) to 1.6°C (Gulf of Maine). Ice cover between December 2004 and July 2005 was well below normal for the Labrador–Newfoundland shelf and below normal for the Gulf of St. Lawrence. The summary analysis of the ice data for 2006 is not yet completed.

Air temperatures are an indication of the amount of heat that can be transferred from the atmosphere to the ocean. For the 5 stations (Fig. 2), only 13 of 120 months (5 stations × 12 months × 2 years) had below-normal temperatures, indicating generally warmer than normal conditions throughout the region. The average anomaly for all stations was 1.3°C in 2005 and 1.9°C in 2006. Cartwright had the largest annual anomalies in 2005 (1.8°C) and 2006 (2.9°C).

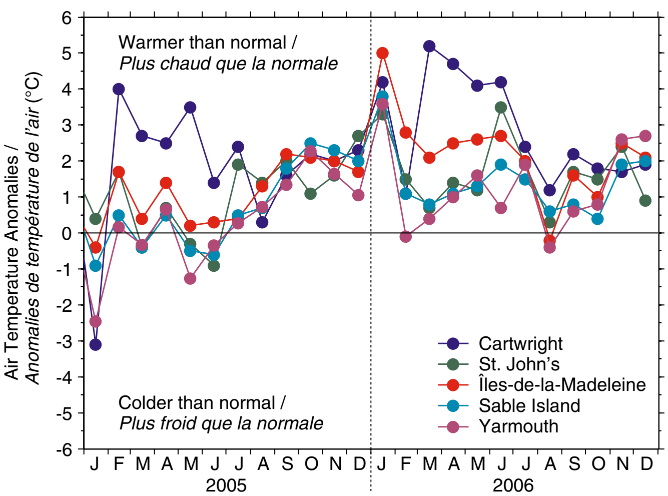


Fig. 2 Monthly air temperature anomalies in 2005–2006 based on the 1971–2000 average values for Cartwright, Labrador; St. John's, Newfoundland; Îles-de-la-Madeleine, Québec; and Sable Island and Yarmouth, Nova Scotia.

*Anomalies mensuelles de la température de l'air en 2005–2006 comparées aux valeurs moyennes 1971-2000 pour Cartwright au Labrador, St. John's Terre-Neuve, Îles-de-le-Madeleine au Québec, et Sable Island et Yarmouth en Nouvelle-Écosse.*

Station 27, Rimouski Station, and Halifax Station 2 are the focus of our discussion of the physical and biological oceanic variability. Data from other fixed stations will be presented in the research documents and environmental status reports available on the CSAS website (http://www.dfo-mpo.gc.ca/csas/).

In 2005, minimum water temperatures of less than -1.5°C were seen at Station 27 off St. John's in late April; maximum values of greater than 15°C were recorded near the surface in August and September (Fig. 3). The depth-averaged annual temperature decreased slightly from the record high in 2004 to just over 0.5°C above normal, the 7th highest since 1946. Anomalies were highest near the surface, ~1°C above normal, decreased to ~0.1°C above normal at 100 m, and rose to ~0.8°C at 175 m. In 2006, the depth-averaged annual anomaly reached a new high in the 61-year record, 0.9°C above normal, about 0.2°C higher than in 2004. The anomalies were highest in January and February, fell to minimum values in July, and finished the year with a December anomaly of about 0.45°C above normal.

La température de l'air est une indication de la quantité de chaleur qui peut être transférée de l'atmosphère vers l'océan. Pour les 5 stations (Fig. 2), des températures de l'air sous la normale se retrouvent seulement pour 13 des 120 mois (5 stations × 12 mois × 2 ans), ce qui indique des conditions généralement plus chaudes que la normale pour toute la zone. L'anomalie moyenne pour toutes les stations était de 1,3 °C en 2005 et de 1,9 °C en 2006. La région de Cartwright a montré les plus grandes anomalies en 2005 (1,8 °C) et 2006 (2,9 °C).

Notre discussion sur la variabilité océanique biologique et physique est centrée sur la Station 27, la station de Rimouski et la Station 2 de Halifax. Les données pour les autres stations fixes sont présentées dans les documents de recherche et les rapports sur l'état de l'environnement qui sont accessibles sur le site web du SCCS (http://www.dfo-mpo.gc.ca/csas/).

En 2005, des températures minimales plus basses que -1,5 °C ont été observées à la Station 27 au large de St. John's vers la fin avril; des valeurs maximales de plus de 15 °C ont été enregistrées près de la surface en août et septembre (Fig. 3). La température moyenne de la colonne d'eau a diminué légèrement par rapport au record de hautes températures de 2004 pour se situer à un peu plus de 0,5 °C au-dessus de la normale, la 7ième plus haute température moyenne observée depuis 1946. Les anomalies sont plus grandes près de la surface soit ~1 °C au-dessus de la normale, diminuent à ~0,1 °C au-dessus de la normale à 100 m, et augmentent à ~0,8 °C à 175 m. En 2006, l'anomalie moyenne sur la colonne d'eau a atteint un nouveau record au cours des 61 années de la série, soit 0,9 °C au-dessus de la normale, environ 0,2 °C plus haut qu'en 2004. Les anomalies sont plus grandes en janvier et février, tombent à des valeurs minimales en juillet, et l'année se termine avec des anomalies d'environ 0,45 °C au-dessus de la normale en décembre.

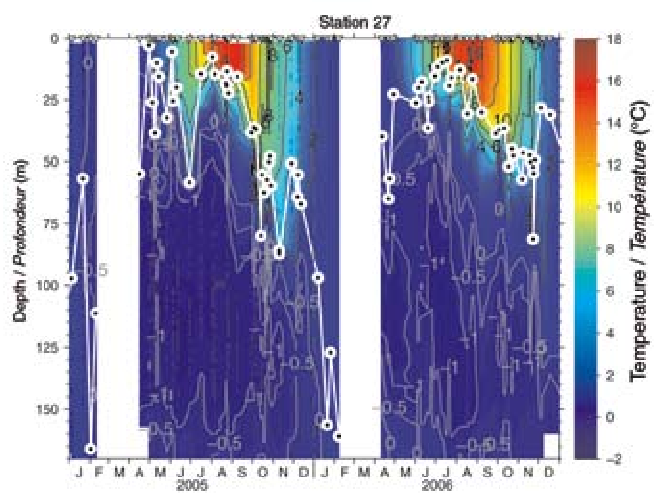


Fig. 3 Coloured, contoured plot of the vertical temperature profiles (gray triangles) in 2005–2006 for Station 27 off St. John's Newfoundland. The thick white line shows the depth of the mixed layer, derived from the density profiles. White areas are data gaps.

*Évolution du profil vertical de la température (triangles gris) en 2005-2006 pour la Station 27 au large de St. John's Terre-Neuve. La ligne blanche épaisse indique la profondeur de la couche de mélange, dérivée des profils de densité. Les zones blanches indiquent une absence de données.*

The temperatures from the surface to 100 m at Rimouski Station during 2005 were above normal until early June, generally below normal from June to the end of September, and above normal from September to mid-November (Fig. 4).

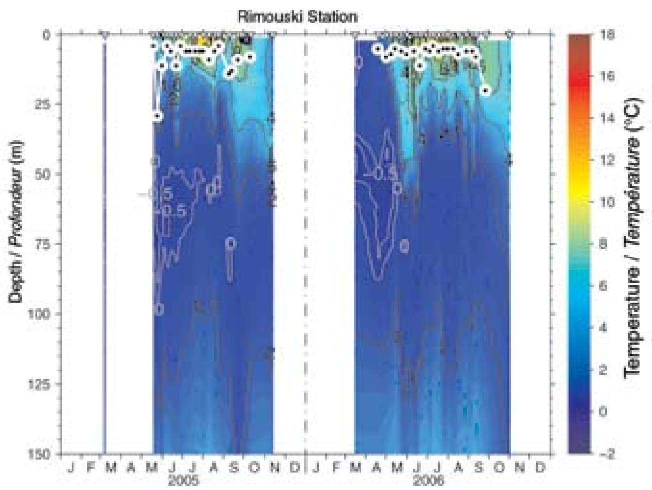


Fig. 4 Coloured, contoured plot of the vertical temperature profiles (gray triangles) in 2005–2006 at Rimouski Station in the Lower St. Lawrence Estuary. The thick white line shows the depth of the mixed layer, derived from the density profiles. White areas are data gaps.

*Évolution du profil vertical de la température (triangles gris) en 2005–2006 pour la station de Rimouski dans l'estuaire maritime du Saint-Laurent. La ligne blanche épaisse indique la profondeur de la couche de mélange, dérivée des profils de densité. Les zones blanches indiquent une absence de données.*

This variation led to typically weak, below-normal anomalies of about 0.3°C from 10 to 60 m and above-normal values of 0.2°C from 65 to 100 m over the May 1 to October 31 period. This contrasts with the temperatures in 2006, when 0–100 m anomalies were typically 0.8°C to 1.2°C above normal.

Temperatures were predominantly below normal in 2005 by about 0.3°C averaged over the year at all depths at Halifax Station 2 (Fig. 5). The dominant feature was a thick subsurface layer defined by the 4°C isotherm. This contrasts with 2006, when temperatures were about 0.5°C above normal at the surface and increased to 1°C warmer than normal at 150 m.

Time series of the cold intermediate layer (CIL, temperature ≤ 0°C) area from the Bonavista section, Newfoundland, as well as the volume of the CIL in the Gulf of St. Lawrence (T ≤ 0°C) and on the Scotian Shelf (T ≤ 4°C) can vary substantially from year to year (Fig. 6). In 2005 and 2006, the areas of the CIL on the Bonavista section were below normal for the 11th and 12th consecutive years; in the 53-year time series, the CIL was the 6th lowest in 2005 and 3rd lowest in 2006. This indicates ongoing warmer than normal conditions and agrees with the observations at Station 27. The CIL volume in the Gulf of St. Lawrence continued to decrease in 2005 and 2006, reaching its second lowest value in 22 years this past year. On the Scotian Shelf, the water volume of the CIL decreased from its all-time high in 2004 to an intermediate value in 2005 (17th smallest of 33 years) and to its 2nd lowest volume in 2006, roughly half of the 2004 observation. These measurements of the CIL on the Newfoundland and Scotian Shelves and in the

En 2005, les températures de la surface jusqu'à 100 m à la station de Rimouski étaient au-dessus de la normale jusqu'au début de juin, puis généralement au-dessous de la normale entre juin et la fin de septembre, et de nouveau au-dessus de la normale de septembre jusqu'à la mi-novembre (Fig. 4). Cette variation a conduit à des anomalies sous la normale typiquement faibles d'environ 0,3 °C entre 10 et 60 m, et des valeurs au-dessus de la normale de 0,2 °C entre 65 à 100 m pour la période du 1 mai au 31 octobre. Cette situation contraste avec les températures en 2006, lorsque les anomalies entre 0 et 100 m variaient typiquement entre 0,8 et 1,2 °C au-dessus de la normale.

Des températures moyennes sous la normale d'environ 0,3 °C ont prédominé à toutes les profondeurs pendant toute l'année en 2005 à la Station 2 de Halifax (Fig. 5). La caractéristique dominante était une épaisse couche sous la surface qui était définie par l'isotherme de 4 °C. Cette condition contraste avec

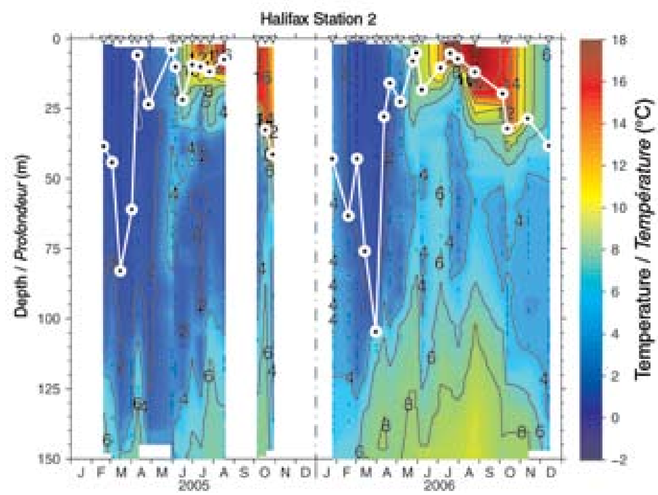


Fig. 5 Coloured, contoured plot of the vertical temperature profiles (gray triangles) in 2005–2006 at Halifax Station 2. The thick white line shows the depth of the mixed layer, derived from the density profiles. White areas are data gaps.

*Évolution du profil vertical de température (triangles gris) en 2005–2006 pour la Station 2 de Halifax. La ligne blanche épaisse indique la profondeur de la couche de mélange, dérivée des profils de densité. Les zones blanches indiquent une absence de données.*

l'année 2006, quand les températures étaient environ 0,5 °C au-dessus de la normale à la surface et augmentaient de 1 °C plus chaud que la normale à 150 m.

La série temporelle de l'aire couverte par la couche intermédiaire froide (CIF, avec des températures ≤ 0 °C) le long du transect de Bonavista à Terre-Neuve, aussi bien que le volume de la CIF dans le golfe du Saint-Laurent (T ≤ 0 °C) et celui de la masse d'eau du plateau Néo-Écossais (T ≤ 4 °C) peuvent montrer d'importantes variations interannuelles (Fig. 6). En 2005 et 2006, l'aire couverte par la CIF sur le transect de Bonavista était sous la moyenne à long terme pour les 11ième et 12ième années consécutives; les surfaces de la CIF pour 2005 et 2006 étaient respectivement les 6ième et 3ième plus faibles en 53 années d'observations. Ces données sont en accord avec les observations à la Station 27 et indiquent des conditions plus chaudes que la normale qui continuent de se maintenir.

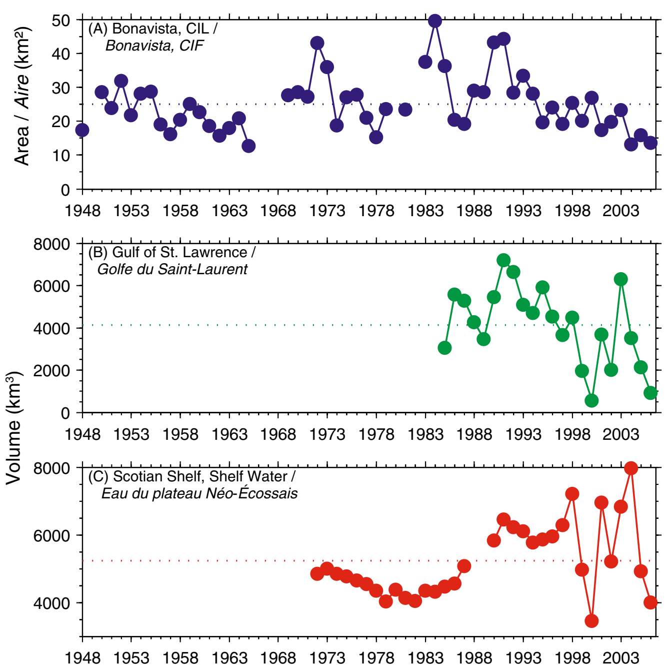


Fig. 6 Time series of (A) the CIL area on the Bonavista Section, (B) CIL volume in the Gulf of St. Lawrence, and (C) shelf water volume on the Scotian Shelf. Horizontal lines are the means of all points in each plot.

*Séries temporelles (A) de l'aire occupée par la CIF le long du transect de Bonavista, (B) du volume de la CIF dans le golfe du Saint-Laurent et (C) du volume d'eau du plateau Néo-Écossais. Les lignes horizontales représentent la moyenne de tous les points pour chaque graphique.*

Gulf of St. Lawrence indicate warmer than normal conditions throughout the region, particularly in 2006.

## Chemical and Biological Environment

At Station 27, surface nutrient inventories in 2005 and 2006 were notably lower than seen in previous years and bottom nutrient inventories continued to decline from the peak levels seen in 2000. There were indications in 2005 of a continued (since 2002) decrease in phytoplankton abundance, but the magnitude of the change was not significant (Fig. 7A). In 2006, an increase in the magnitude and duration of the spring phytoplankton bloom was observed. There was evidence of subsurface phytoplankton blooms during the summer (July–August) and weaker autumn blooms at Station 27 in 2006 compared to previous years.

In the southern and northeastern Gulf of St. Lawrence (GSL), surface nutrient levels in late winter 2005 were overall significantly lower compared to the 2001–2004 period while levels were not markedly different for the late spring–summer period. On the other hand, surface nutrient concentrations in 2006 at Rimouski Station remained high and at levels non-limiting for phytoplankton growth throughout the sampling period except in July. Freshwater runoff and water turbidity during the spring–summer of 2006 were not markedly different compared to recent years. As in 2004, no major phytoplankton bloom was observed in the Lower St. Lawrence Estuary (LSLE) in 2005 and 2006 (Fig. 7B). The average phytoplankton biomass during both years was ~2.3 times lower than the historical mean (1992–2004) and ~6 times lower compared

Le volume de la CIF dans le golfe du Saint-Laurent a aussi continué à diminuer en 2005 pour atteindre en 2006 sa 2ième plus faible valeur en 22 ans d'observations. Sur le plateau Néo-Écossais, le volume d'eau de la CIF a diminué de sa valeur record de 2004, à une valeur intermédiaire en 2005 (17ième plus petite en 33 années d'observations), jusqu'à sa 2ième plus faible valeur en 2006, soit approximativement la moitié de l'observation de 2004. Ces mesures de la CIF sur les plateaux de Terre-Neuve et de la Nouvelle-Écosse et dans le golfe du Saint-Laurent indiquent des conditions plus chaudes que la normale sur toute la région, particulièrement en 2006.

## Environnement chimique et biologique

À la Station 27, les concentrations en sels nutritifs en 2005 et 2006 étaient nettement inférieures aux niveaux observés au cours des années précédentes et les concentrations en sels nutritifs près du fond ont continué à diminuer en comparaison avec le maximum observé en 2000. En 2005, il y avait des indications d'une décroissance continue (depuis 2000) dans l'abondance du phytoplancton, mais l'amplitude du changement n'était pas significative (Fig. 7A). En 2006, une augmentation de l'amplitude et de la durée de la floraison printanière de phytoplancton a été observée. À la station 27 en 2006, il y avait aussi évidence de floraisons sous les eaux de surface durant l'été (juillet–août) et de floraisons plus faibles à l'automne en comparaison avec les années précédentes.

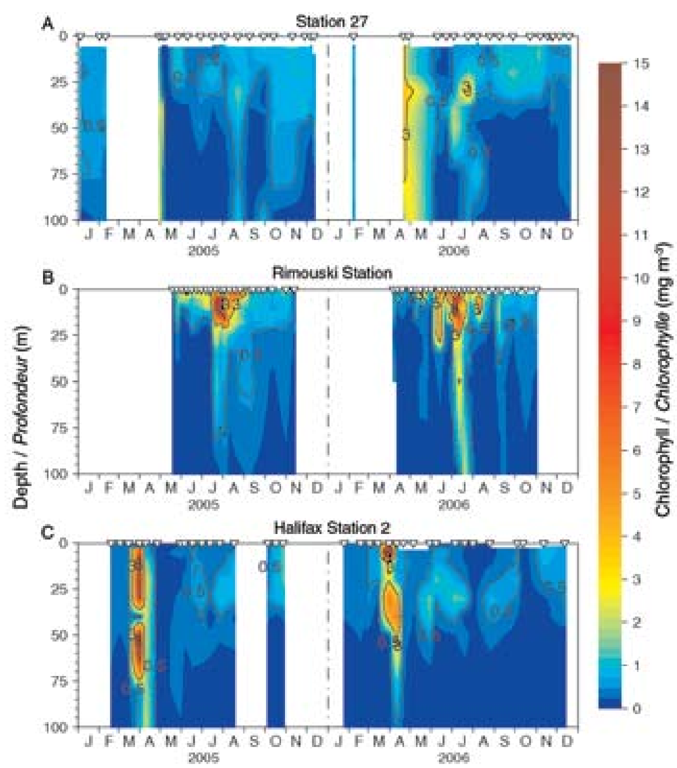


Fig. 7 Evolution of the vertical phytoplankton chlorophyll concentration for the fixed stations: (A) Station 27, (B) Rimouski Station, and (C) Halifax Station 2. The gray triangles indicate sampling points. White areas are data gaps

*Évolution des concentrations en chlorophylle du phytoplancton pour les stations fixes : (A) Station 27, (B) station de Rimouski et (C) Station 2 de Halifax. Les triangles gris indiquent les moments d'échantillonnage. Les zones blanches indiquent une absence de données.*

to 1999. Only a small diatom bloom was observed in July of 2006. For the fifth (2005) and sixth (2006) consecutive years, the North Pacific diatom *Neodenticula seminae* was found in the GSL. The abundances of this invasive species, however, were much lower compared to previous observations.

Surface nutrient inventories, particularly in winter, continued to decline at Halifax Station 2 in 2005 and 2006 while deep nutrient inventories, particularly in summer, continued to increase. This is in marked contrast to declining deep nutrient concentrations seen at Station 27. The spring phytoplankton bloom off Halifax in 2005 was early and of short duration but of relatively high magnitude compared to the blooms seen in the previous two years (Fig. 7C). In 2006, however, the bloom was later, of shorter duration, and the lowest magnitude seen since AZMP observations began in 1999.

Large calanoid copepods continue to make up the bulk of the mesozooplankton biomass at the three fixed stations, but smaller species (*Para-* and *Pseudocalanus* spp. and *Oithona* spp.) represent ~20% of the biomass at Station 27 and off Halifax; their contribution to the total biomass in the LSLE is minor (Fig. 8). Deep, cold-water species (*Calanus glacialis* and *Calanus hyperboreus*) make up a significant part of the total biomass at all of the fixed stations as well and largely account for the seasonal biomass peaks. At all sites, *Calanus finmarchicus* is a key species, representing almost half of the biomass over the year.

In 2005, the overall abundance of zooplankton at Station 27 was low relative to the long-term average for 5 of the 12 dominant species groups. *C. finmarchicus* and other associated calanoids were at the lowest levels seen since 1999, as were the abundances of euphausiids and larvaceans. In 2006, the overall biomass of the dominant copepods was similar to that observed in previous years, although significantly lower (60%) than the 2002 peak. The numerical abundance of *Calanus finmarchicus* increased by 50% over the previous year, when it had been at record low levels, while the abundance of other associated calanoids reached the lowest levels since 1999. The abundances of both larvaceans and pteropods, organisms commonly known as slub and blackberries, were also at very low levels.

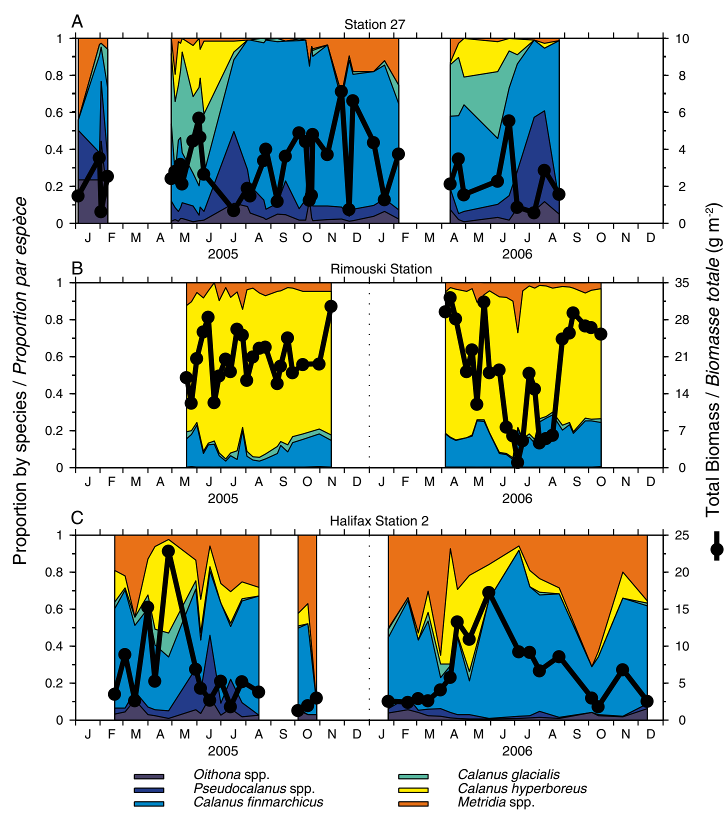


Fig. 8 Relative importance of the dominant copepod species for the fixed stations: (A) Station 27, (B) Rimouski Station, and (C) Halifax Station 2. The solid line shows the total integrated (surface–bottom) biomass of the dominant copepods. White areas are data gaps

*Importance relative de quelques espèces dominantes de copépodes pour les stations fixes : (A) Station 27, (B) station de Rimouski et (C) Station 2 de Halifax. La ligne noire épaisse indique la biomasse intégrée (surface–fond) de copépodes. Les zones blanches indiquent une absence de données.*

Dans les régions sud et nord-est du golfe du Saint-Laurent (GSL), les concentrations globales en sels nutritifs en surface à la fin de l'hiver 2005 étaient significativement plus basses que pour la période de 2001 à 2004, tandis que les niveaux n'étaient pas très différents pour la période fin de printemps–été. Par ailleurs, les concentrations en sels nutritifs en surface en 2006 à la station Rimouski sont demeurées élevées et à des niveaux non-limitants pour la croissance du phytoplancton durant toute la période d'échantillonnage, excepté pour juillet. Les débits d'eau douce et la turbidité durant la période de printemps–été 2006 n'étaient pas très différents des valeurs pour les années précédentes. Comme pour 2004, aucune floraison majeure de phytoplancton n'a été observée dans l'estuaire maritime du Saint-Laurent (EMSL) en 2005 et en 2006 (Fig. 7B). La biomasse moyenne du phytoplancton pour les deux années était 2,3 fois plus basse que les moyennes historiques (1992–2004) et 6 fois plus basse que celle de 1999. Seulement une petite floraison de diatomées a été observée en juillet 2006. Pour les $5^{\text{ième}}$ (2005) et $6^{\text{ième}}$ (2006) années consécutives, la diatomée originaire du Pacific nord, *Neodenticula seminae*, a été trouvée dans le GSL. Les abondances de cette espèce invasive étaient cependant beaucoup plus faibles qu'au cours des années précédentes.

Les concentrations en éléments nutritifs à la Station 2 de Halifax en 2005 et 2006 ont continué à diminuer tandis que les concentrations en eaux profondes ont continué à augmenter, particulièrement durant l'été. Cette observation contraste fortement avec les diminutions de sels nutritifs en profondeur observées à la Station 27. La floraison printanière de phytoplancton au large de Halifax en 2005 était hâtive et de courte durée, mais d'amplitude comparable aux floraisons observées lors des deux années précédentes (Fig.7C). Cependant, en 2006, la floraison était plus tardive, de plus courte durée, et avait la plus faible amplitude depuis le début des observations du PMZA en 1999.

Les gros copépodes de type calanoides forment la majeure partie de la biomasse de mésozooplancton aux trois stations fixes, mais les plus petites espèces comme *Para-* et *Pseudocalanus* spp. and *Oithona* spp. représentent ~20 % de la biomasse à la Station 27 et au large de Halifax; leur contribution à la biomasse totale dans l'ESML est triviale (Fig. 8). Les espèces d'eaux froides

Mesozooplankton biomass in November 2005 in the LSLE and in the NWGSL was higher than in 2004 and was the third highest observed over the last 12 years. The mean abundance of the euphausiid *Thysanoessa raschii* corresponded to the third highest value observed in the last 12 years and to the highest increase in abundance observed over two consecutive years. On the other hand, the mean abundance of the hyperiid amphipod *Themisto libellula* was lower than in 2004 and corresponded to the third lowest values observed in 12 years. In contrast to the previous year, mesozooplankton biomass in the LSLE and in the NWGSL in November 2006 was lower and was the third lowest value observed in the previous 13 years. Macrozooplankton biomass was the lowest observed over the same period. The mean abundance of the euphausiid *Thysanoessa raschii* in 2006 was the lowest observed over the previous 13 years and represented the second largest decrease in abundance observed over two consecutive years. The mean abundance of the hyperiid amphipod *Themisto libellula* was near zero and corresponded to the lowest value observed over the past 13 years.

Zooplankton biomass in 2005 and in 2006 at Halifax Station 2 was comparable to levels seen previously. *C. finmarchicus* abundance in 2005 was also similar to numbers seen in earlier years, but numbers in 2006 were the lowest seen since the record minimum numbers observed in 2002. The year 2006 was also notable for record low numbers of early developmental stages of *C. finmarchicus* (stages CI-CIII). The years 2005 and 2006 were notable by the near absence or very low biomass of *C. glacialis*, *Metridia* spp., and *Oithona* spp. off Halifax when compared with previous years (Fig. 8C).

Time series from the Continuous Plankton Recorder showed that phytoplankton abundance, as estimated by the phytoplankton colour index, was well above levels observed in the 1960s and 1970s on both the Grand Banks and the Scotian Shelf (Fig. 9A). On the other hand, zooplankton (*Para- / Pseudocalanus* spp., *C. finmarchicus*, total euphausiids), particularly the larger species (*C. finmarchicus* and euphausiids) that make up the bulk of the biomass, were generally less abundant during the 1990s and early 2000s relative to the early part of the time series in both regions (Fig. 9B, C, D). Over the past few years, however, some of these zooplankton species appear to be recovering to long-term mean levels.

### Highlight 2005–2006

In 2005-06, the outstanding feature of the physical environment was the persistence of above-normal water temperatures on the Newfoundland Shelf. For the 8$^{th}$ year in succession, the annual, depth-averaged temperatures observed at Sta. 27 were warmer than normal, with 2006 the warmest year in the 61-year time series. In addition, the area of the CIL, an indicator of the quantity of cold water on the eastern Newfoundland and Labrador Shelf, was the 3$^{rd}$ lowest in the 53-year record, nearly matching the record low year of 1965.

While local air temperatures and winds play the major role in the annual cycle of water temperatures throughout the region, Canadian east coast waters are also strongly influenced by flow from the arctic. Currents from the north bring not only cold water but also northern species of plankton. For example,

et profondes (*Calanus glacialis* et *Calanus hyperboreus*) représentent aussi une partie significative de la biomasse totale à toutes les stations fixes et expliquent en grande partie le pic saisonnier. À toutes les stations, *Calanus finmarchicus* est une espèce clé représentant presque la moitié de la biomasse totale au cours de l'année.

En 2005, l'abondance globale du zooplancton à la Station 27 était faible relativement à la moyenne à long terme pour 5 des 12 groupes d'espèces dominantes. *Calanus finmarchicus* et les autres espèces associées de calanoides étaient à leurs plus bas niveaux depuis 1999, comme l'étaient également les abondances d'euphausiacés et de larvacés. En 2006, la biomasse totale des copépodes dominants était similaire à celle observée au cours des années précédentes, quoiqu'à des niveaux significativement plus bas (60 %) que le pic de 2002. L'abondance numérique de *Calanus finmarchicus* a augmenté de 50 % par rapport à l'année précédente, alors qu'elle atteignait ses niveaux record les plus bas, tandis que l'abondance des autres espèces de calanoides associées a atteint son plus bas niveaux depuis 1999. L'abondance des larvacés et des ptéropodes était également très basse.

La biomasse du mésozooplancton en novembre 2005 dans l'EMSL et dans le nord-ouest du GSL était plus élevée qu'en 2004 et représentait la troisième plus haute valeur observée au cours des 12 dernières années. L'abondance moyenne de l'euphausiacé *Thysanoessa raschii* correspond à la troisième plus haute valeur observée au cours des 12 dernières années et à la plus forte augmentation d'abondance observée sur deux années consécutives. Par ailleurs, l'abondance moyenne de l'amphipode hypéridé *Themisto libellula* était plus basse qu'en 2004 et correspondait à la troisième plus basse valeur en 12 ans. Contrairement aux années précédentes, la biomasse du mésozooplancton dans l'EMSL et le GSL en novembre 2006 était plus basse, correspondant à la troisième plus basse valeur observée au cours des 13 dernières années. La biomasse du macrozooplancton était également la plus basse observée durant la même période. L'abondance moyenne de l'euphausiacé *Thysanoessa raschii* en 2006 était aussi la plus basse observée au cours des 13 dernières années et représentait la deuxième plus grande décroissance en abondance observée pour deux années consécutives. L'abondance moyenne de l'amphipode hypéridé *Themisto libellula* était presque nulle et correspondait aux plus basses valeurs observées au cours des 13 dernières années.

La biomasse du zooplancton en 2005 et 2006 à la Station 2 de Halifax était comparable aux niveaux observés précédemment. L'abondance de *Calanus finmarchicus* en 2005 était aussi similaire aux nombres observés au cours des années précédentes; les nombres observés en 2006 étaient les plus bas depuis les valeurs minimales record de 2002. L'année 2006 était aussi remarquable pour ses faibles nombres record de stades de développement de *C. finmarchicus* (stades CI-CIII). En comparaison avec les années précédentes, les années 2005 et 2006 ont été remarquables pour leur quasi absence ou très faible biomasse de *C. glacialis*, *Metridia* spp. et *Oithona* spp. au large de Halifax (Fig. 8C).

Les séries temporelles de données CPR (*Continuous Plankton Recorder*) montrent que l'abondance du phytoplancton,

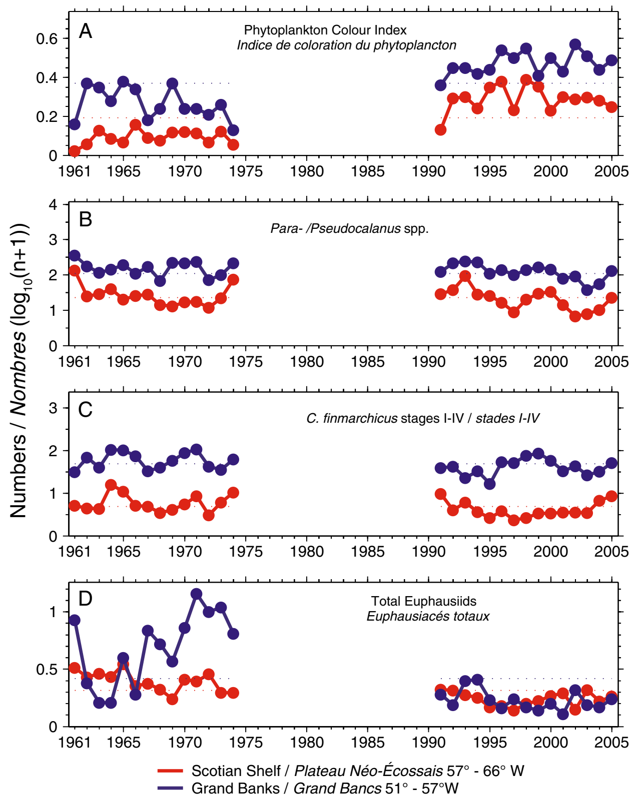


Fig. 9 Data from the Continuous Plankton Recorder (CPR) showing the annual average phytoplankton colour index (A) and annual average abundances of dominant zooplankton taxa (B,C,D) from the Scotian Shelf (red) and Grand Banks (blue) regions.

*Données CPR (*Continuous Plankton Recorder*) montrant l'indice annuel de coloration du phytoplancton (A) et les abondances annuelles moyennes de certains taxons dominants du zooplancton (B, C, D) pour les régions du plateau Néo-Écossais (rouge) et des Grands Bancs (bleu).*

we continue to observe cold-water copepods such as *C. glacialis* and *C. hyperboreus* in all regions. In addition, the arctic hyperiid amphipod *T. libellula* has continued to be a component of the macrozooplankton of the Gulf of St. Lawrence. In the last couple of years, however, the relative importance of some of these cold water species (e.g., *C. glacialis* off Halifax and *T. libellula* in the GSL) has diminished, presumably due to the warming ocean conditions and reduction in the CIL. Other species have been changing in their relative abundance as well but environmental linkages are less clear.

déterminée par un indice de coloration, était bien au-dessus des niveaux observés durant les années 1960 et 1970 autant sur les Grands Bancs que sur le plateau Néo-Écossais (Fig. 9A). Par ailleurs, le zooplancton (*Para- / Pseudocalanus* spp., *C. finmarchicus* et les euphausiacés totaux) et particulièrement les grosses espèces (*C. finmarchicus* et les euphausiacés) qui forment la majeure partie de la biomasse, étaient généralement moins abondants durant les années 1990 et le début des années 2000 en comparaison avec la première partie de la série temporelle dans ces deux régions (Fig. 9B, C, D). Cependant, au cours des dernières années, certaines de ces espèces semblent revenir vers les niveaux d'abondance moyens historiques.

### Faits saillants en 2005–2006

En 2005 et 2006, le fait saillant de l'environnement physique était la persistance de températures d'eau au-dessus de la normale sur le plateau de Terre-Neuve. Pour la 8$^{ième}$ année consécutive, la moyenne annuelle de la température intégrée sur la colonne d'eau à la Station 27 était plus chaude que la normale, consacrant notamment l'année 2006 comme étant la plus chaude au cours des 61 années de la série d'observations. De plus, la surface de la CIF, un indicateur de la quantité d'eaux froides sur les plateaux est de Terre-Neuve et du Labrador, était la 3$^{ième}$ plus faible au cours des 53 années d'observation, tout près de la valeur record observée en 1965.

Quoique les températures de l'air et les vents jouent un rôle majeur dans le cycle annuel de la température de l'eau dans toute la région, les eaux de la côte est canadienne sont aussi fortement influencées par les influx d'eaux de l'arctique. Les courants provenant du nord amènent non seulement des eaux froides mais aussi des espèces nordiques de plancton. Par exemple, on a continué à observer des copépodes d'eaux froides tels que *C. glacialis* et *C. hyperboreus* dans toutes les régions. De plus, l'amphipode arctique hypéridé *Themisto libellula* a continué a être une composante du macrozooplancton du golfe du Saint-Laurent. Cependant, au cours des deux dernières années, l'importance relative de ces espèces d'eaux froides (e.g., *C. glacialis* au large de Halifax et *T. libellula* dans le GSL) a diminué, vraisemblablement à cause des conditions de réchauffement des océans et la réduction de la CIF. D'autres espèces ont aussi changé leur abondance relative mais le lien de cause à effet avec l'environnement est beaucoup moins clair.

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# *Status of the Labrador Sea*

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**Sommaire**

Le secteur des sciences de la région des Maritimes de Pêches et Océans à l'institut océanographique de Bedford effectue le monitorage des conditions physiques, chimiques et biologiques dans la mer du Labrador au moyen d'une occupation annuelle du transect AR7W qui s'étend du banc de Hamilton sur le plateau du Labrador jusqu'au cap Désolation sur la côte du Groenland. Cette région de l'Atlantique nord subit une grande variabilité de conditions atmosphériques à des échelles de temps interannuelles et décennales et les propriétés de la colonne d'eau et la profondeur de la convection hivernale changent donc en réponse au forçage atmosphérique. La convection profonde détermine les propriétés de température et de salinité des eaux de la mer du Labrador et permettent aux gaz atmosphériques tel que le dioxyde de carbone de passer de la zone de mélange de surface jusqu'à des niveaux plus profond. La production primaire et la biomasse planctonique subissent une variabilité spatiale et temporelle à large échelle qui est liée aux changements de l'environnement physique. Ces changements dans l'écosystème de la mer du Labrador jouent un rôle important dans l'évolution à grande échelle des écosystèmes du plateau et de la pente continentale de l'Est du Canada. Pour cette raison, la région des Maritimes de Pêches et Océans a incorporé le programme de monitorage du transect AR7W dans son effort global de surveillance régionale des océans. La Mission AR7W contribue également aux efforts nationaux et internationaux visant à modéliser et prédire la variabilité du climat et les changements climatiques en supportant la recherche scientifique sur les processus physiques et biologiques et leurs interactions qui affectent le système climatique. Les températures de l'air et de la surface de l'eau dans la mer du Labrador étaient notablement plus chaudes que la normale en 2006, perpétuant ainsi le patron de réchauffement qui dure depuis plusieurs années. Un patron décennal de conditions plus chaudes et salées dans les 2 km supérieurs de la colonne d'eau a également persisté en 2006. Les concentrations en carbone inorganique dans la couche ventilée ont augmenté régulièrement durant la dernière décennie. La grande variabilité des propriétés biologiques ne permet pas d'interpréter facilement les patrons sur plusieurs couches, mais les sels nutritifs, la chlorophylle, le carbone organique total et les bactéries ont tous montré des patrons temporels régionalement distincts. La biomasse zooplanctonique a été particulièrement variable dans l'espace et le temps en 2006. Par exemple, des nombres extraordinairement élevés de jeunes stades de *Calanus finmarchicus* ont été observés dans la partie est de la mer du Labrador.

## Introduction

Convection driven by winter cooling and wind mixing can create deep surface mixed layers in the Labrador Sea, directly linking the atmosphere and the deep ocean. In severe winters, convective overturning can mix surface waters to depths as great as 2 km. Milder winters lead to lower heat losses and shallower mixed layers. Energetic interannual variability in North Atlantic atmospheric conditions drives decadal timescale changes in the volume and properties of this convectively formed Labrador Sea Water (LSW).

After seasonal restratification removes the newly formed LSW from contact with the overlying atmosphere, its temperature and salinity properties change only slowly as it is exported out of the Labrador Sea to other regions of the North Atlantic. One of several subsurface export paths leads to the Slope Water south of Nova Scotia. Interannual changes in the volume and properties of exported LSW can have a notable influence on deep Slope Water properties.

Deep convection in the Labrador Sea provides an important pathway for atmospheric gases such as oxygen, carbon dioxide ($CO_2$), and chlorofluorocarbons (CFCs) to pass from the surface mixed layer to intermediate depths. Convection also transports biogenic carbon (dissolved and particulate organic matter) produced in the surface waters to the deep ocean. Some of the sequestered $CO_2$ and biogenic carbon in the Labrador Sea is incorporated into the meridional overturning circulation and stored in the deep ocean over century to millennial time scales. These physical and biological processes make the Labrador Sea an important oceanic sink for atmospheric $CO_2$.

Interannual variability in water properties and changes in the balance of inflows of fresh water from northern sources and warm and saline waters from more southerly latitudes impact the marine ecosystems of the region. Changes in phytoplankton, zooplankton, and bacterial components of the food web drive changes in fish stocks, seabirds, and marine mammals. Local changes in physical properties and biological production in the Labrador Sea can influence downstream ecosystems.

## The AR7W Section

Since 1990, DFO Science Branch at the Bedford Institute of Oceanography in the Maritimes Region has carried out annual spring or early summer (May–July) occupations of a hydrographic section across the Labrador Sea. Figure 1 shows a map of the Labrador Sea and the locations of the standard hydrographic stations, selected meteorological stations discussed below, and Ocean Weather Station (OWS) Bravo, which operated in the area until 1974. The section was designated AR7W (Atlantic Repeat Hydrography Line 7) in the World Ocean Circulation Experiment (WOCE). Ice conditions permitting, 28 stations are sampled between Hamilton Bank on the Labrador Shelf and Cape Desolation on the Greenland Shelf. The surveys measure temperature, salinity, and a comprehensive suite of chemical variables including dissolved

[1]The Labrador Sea Monitoring Group includes scientists and technicians from Ocean Sciences Division http://www.mar.dfo-mpo.gc.ca/science/ocean/osd/osd-e.html and Ecosystem Research Division http://www.mar.dfo-mpo.gc.ca/science/ocean/erd/erd-e.html. For further information, please contact Ross Hendry (OSD) HendryR@dfo-mpo.gc.ca or Glen Harrison (ERD) HarrisonG@dfo-mpo.gc.ca.

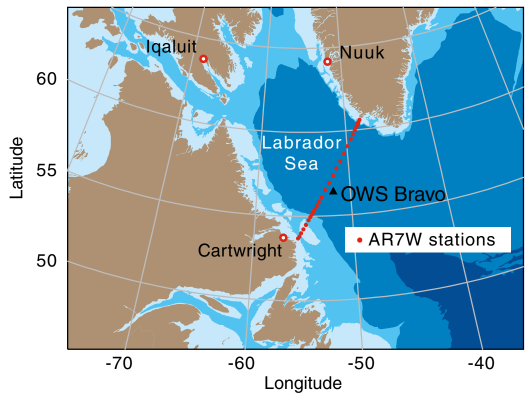


Fig. 1 Map of the Labrador Sea showing the AR7W section, selected meteorological stations, and OWS Bravo.

*Carte de la mer du Labrador montrant le transect AR7W, quelques stations météorologiques, ainsi que la station OWS Bravo.*

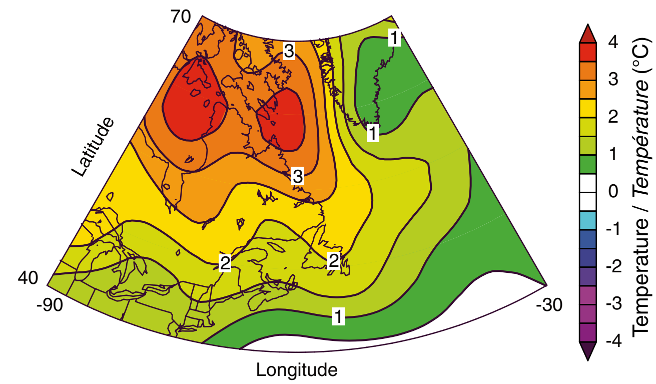


Fig. 2 Annual mean 1000 mb air temperature anomalies for 2006 relative to 1971–2000 from NCEP Reanalysis data.

*Anomalies annuelles moyennes de la température de l'air à 1000 mb pour 2006 par rapport aux années 1971 à 2000 provenant de la réanalyse des données de NCEP.*

oxygen, nutrients, and dissolved inorganic carbon. Since 1994, biological variables such as dissolved and particulate biogenic (organic) carbon, bacteria, phytoplankton, and zooplankton have been an integral part of the measurement program.

This effort serves national and international priorities, contributing to ocean monitoring, modelling, and forecasting as part of the Global Ocean Observing System (GOOS). It also contributes to the climate monitoring goals of the Global Climate Observing System (GCOS) established in 1992 to ensure that physical, chemical, and biological observations and information needed to address climate-related issues are obtained and made available to all potential users. The AR7W data are used by DFO and international scientists in studies of ocean processes related to the variability and predictability of global climate that contribute to the international Climate Variability (CLIVAR) project of the World Climate Research Program (WCRP). The oceanic carbon cycle has been a principal focus of the chemistry and biology programs. The Canadian Panel on Energy Research and Development (PERD) program on the Enhancement of Greenhouse Gas Sinks supported this work because the ocean sequesters part of the increasing anthropogenic production of $CO_2$ implicated in global climate change. The chemical and biological programs also contributed to the international Joint Global Ocean Flux (JGOFS) research program in the 1990s and the more recent Surface Ocean–Lower Atmosphere Study (SOLAS).

The Atlantic Zone Monitoring Program (AZMP) implemented in 1998 is committed to collecting and analyzing the biological, chemical, and physical field data needed to detect and measure interannual variability in ecosystems of the Atlantic Canadian shelves and slopes. Recognizing that climate variability influences the ecology of many species and can play an important role in ecosystem dynamics, and that changes in the Labrador Sea can influence conditions in Atlantic Canadian waters, Maritimes Region of DFO has designated the AR7W surveys as a core element of its regional ocean monitoring network. These annual surveys will continue to add both to DFO's ecosystem monitoring mandate and to Canadian and international scientific efforts to understand the processes responsible for climate variability and global climate change.

## Physical Environment

### *Air Temperature*

Air temperatures in 2006 were more than 3.5°C above normal in the eastern Canadian Arctic and 2–3°C above normal over the western Labrador Sea (Fig. 2). Station data available to date show 2006 mean temperatures 3.0°C warmer than normal at Cartwright (Labrador), 3.7°C warmer than normal at Iqaluit (Nunavut), and 1.6°C warmer than normal at Nuuk (Greenland).

### *Sea Surface Temperature*

Sea surface temperatures (SST) in 2006 were more than 1°C above normal over much of the western Labrador Sea and more than 1.8°C above normal over the southernmost Labrador Sea (Fig. 3).

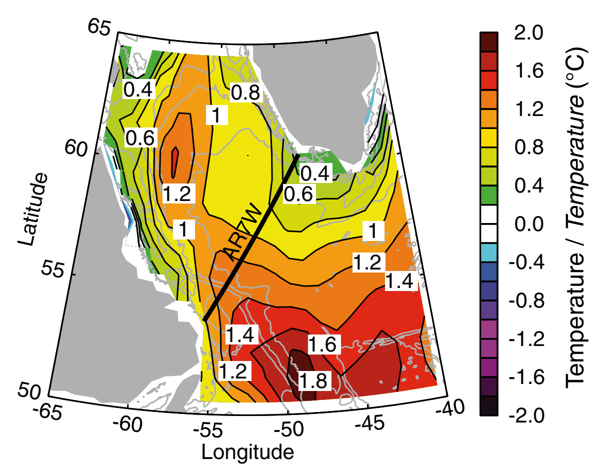


Fig. 3 Sea surface temperature anomalies for January–October 2006 relative to the years 1971–2000 (from the U.K. Hadley Centre HadISST climatology). The AR7W section is shown.

*Anomalies annuelles moyennes de la température de surface océanique pour la période de janvier à octobre 2006 par rapport aux années 1971 à 2000 (provenant de la climatologie HadISST du Hadley Centre, Royaume-Uni). La position du transect AR7W est montrée.*

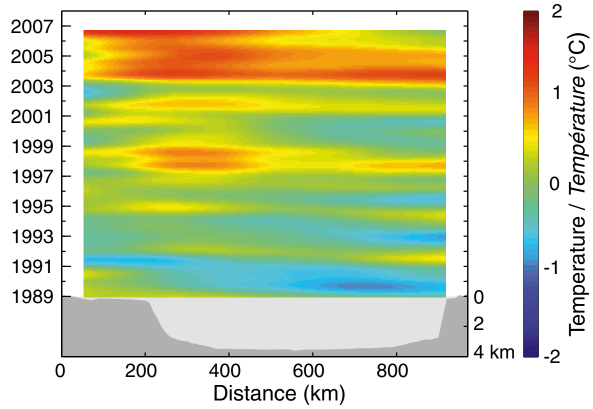


Fig. 4 Low-pass filtered January 1989–October 2006 HadISST sea surface temperature anomalies relative to 1971–2000 interpolated to the AR7W line. The bathymetry along the AR7W line is shown at the bottom of the figure.

*Anomalies de la température de surface océaniques (HadISST) observées pour la période janvier 1989 à octobre 2006 par rapport aux années 1971 à 2000. Ces données ont été filtrées à l'aide d'un filtre passe-bas et interpolées au transect AR7W. Le bas de la figure montre le profil bathymétrique du transect.*

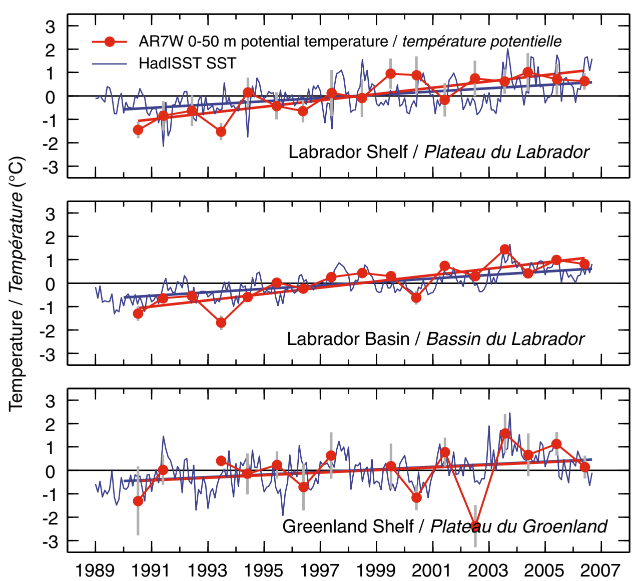


Fig. 5 Deseasonalized 0–50 m AR7W potential temperature anomalies and regression lines for the Labrador Shelf (top), Labrador Basin (middle), and western Greenland Shelf (bottom). Reference seasonal cycles were derived from U.S. National Oceanographic Data Center climatological hydrographic data. Corresponding HadISST SST monthly anomalies from 1989- 2006 are also shown. Reference means and trend lines for both fields are based on 1990–2006 data. The error bars indicate standard error of the mean.

*Anomalies corrigées des fluctuations saisonnières de la température potentielle observée entre 0 et 50 m à AR7W et les droites de régression correspondantes pour le plateau continental du Labrador (haut), le bassin du Labrador (milieu) et le plateau continental de l'ouest du Groenland (bas). Les cycles saisonniers de références ont été calculés à partir des données hydrographiques climatologiques obtenues du U.S. National Oceanographic Data Center. Les anomalies mensuelles correspondantes de la température de la surface de la mer tirées de HadISST sont présentées pour 1989 à 2006. Les valeurs de références moyennes et les lignes de tendances pour tous les champs sont basées sur les données de 1990 à 2006. Les barres d'erreur montrent l'erreur-type de la moyenne.*

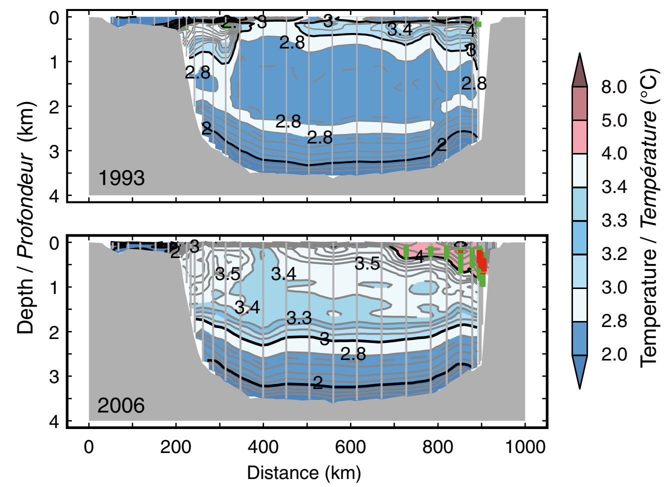


Fig. 6 Section plots of potential temperature from the 1993 (top) and 2006 (bottom) occupations of AR7W. Station positions are marked by vertical lines. Waters with potential temperatures in the range 4–6°C are highlighted for salinities in the range 34.95–35.10 (red) or 34.85–34.95 (green).

*Profils verticaux de la température potentielle au cours des campagnes AR7W 1993 (haut) et 2006 (bas). Les lignes verticales montrent la position des stations. Les régions colorées indiquent des eaux avec températures potentielles dans l'intervalle de 4 à 6 °C dont l'intervalle de salinité varie de 34,95 à 35,10 (rouge) ou de 34,85 à 34,95 (vert).*

SST along the AR7W transect has varied noticeably on interannual time scales since 1989, beginning with below-normal values in the early 1990s (Fig. 4). Severe winters in that period led to exceptionally deep convection in the Labrador Sea. Recent years have been warm: the section-averaged SST in each of the past four years is warmer than any other time during the post-1960 period. The most recent SST data indicate that West Greenland waters returned to near-normal conditions in 2006.

### *AR7W Hydrography*

Record high 0–50 m AR7W potential temperatures were observed in the early 2000s on the Labrador Shelf, in the Labrador Sea, and on the Greenland Shelf (Fig. 5). The decadal-scale trends are upward for 0–50 m potential temperature and SST in all three areas, although both fields decreased to near-normal values on the West Greenland Shelf in 2006.

Intermediate-depth waters show marked warming between the 1993 and 2006 AR7W surveys (Fig. 6). In 1993, a pool of newly formed cool (~2.8°C) Labrador Sea Water extended to 2000 m depths. By 2006, following a series of mild winters with relatively shallow convection, waters in this depth range had warmed to 3.3°C and greater. Waters warmer than 4°C were almost absent in the 1993 survey but were abundant in the upper 500 m on the West Greenland side in 2006. Figure 6 highlights the warm and saline Irminger waters that enter the Labrador Sea in the West Greenland Current and play an important role in the regional heat and salt balance.

The upper 2 km of the water column warmed by about 0.7°C between 1900 and 2006; salinity has also generally increased (Fig. 7). The upper 1-km layer warmed by almost 0.4°C from 2002 to 2003. The past four years show relatively little change

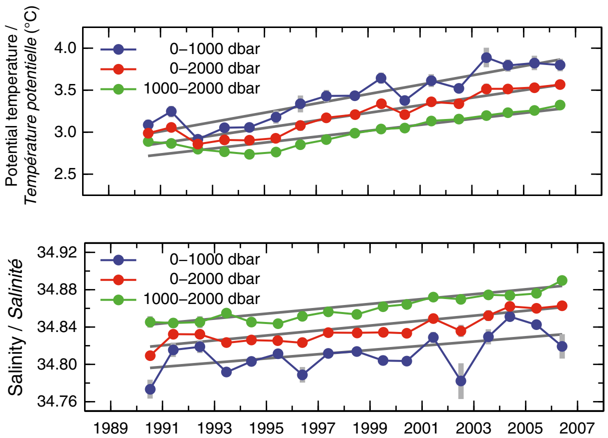


Fig. 7 Section-averaged deseasonalized AR7W fields and corresponding regression lines for potential temperature (top) and salinity (bottom) for the indicated depth ranges. The error bars indicate standard error of the mean.

*Moyennes de température potentielle (haut) et de salinité (bas) corrigées des fluctuations saisonnières pour le transect AR7W et les droites de régression correspondantes pour les intervalles de profondeur indiquées. Les barres d'erreur indiquent l'erreur-type de la moyenne.*

and are the warmest of the AR7W record. Salinity is more variable than temperature in the upper 1-km layer but also shows relatively high values during the past four years. In the 1–2 km depth range, the section-averaged potential temperature and salinity increased steadily from 1994 to 2006. The deep convection that peaked in 1993 and 1994 filled this layer with relatively cool and fresh water that has gradually been replaced by increasing fractions of warmer and saltier waters.

## Chemical Environment

The upper layers of the Labrador Sea are brought into equilibrium with atmospheric gases when exposed to the overlying atmosphere by winter convection. Since 1996, total inorganic carbon concentrations in the recently ventilated 100–500 m layer in the central Labrador Sea have increased at an average rate of 1.2 µmol kg$^{-1}$ per year (Fig. 8).

Nutrients in the 60–200 m depth range reflect the surface water concentrations after winter mixing and drive the annual plankton growth. Section averages for silicate (Si) and

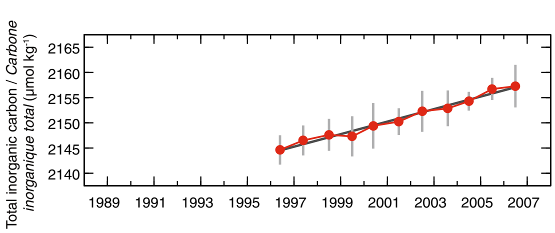


Fig. 8 Total inorganic carbon for 100–500 m depths in the central part of the Labrador Basin for 1996–2006 and a corresponding regression line. The error bars indicate the standard deviation.

*Concentrations en carbone inorganique total dans l'intervalle de profondeur 100 à 500 m au centre du bassin du Labrador pour la période de 1996 à 2006 et la droite de régression correspondante. Les barres d'erreurs indiquent l'écart-type.*

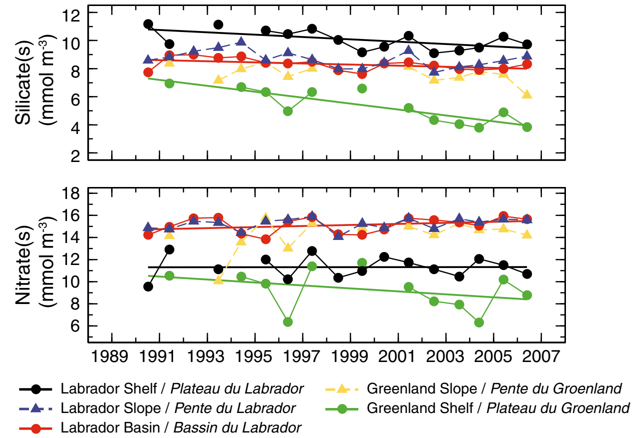


Fig. 9 Concentration of silicate (top) and nitrate (bottom) for 60–200 m depths averaged within specified areas on the AR7W line and corresponding regression lines.

*Concentrations moyennes sur tout le transect AR7W en silicates (haut) et en nitrates (bas) dans l'intervalle de profondeur 60 à 200 m ainsi que les droites de régression correspondantes.*

nitrate (N) in this depth range are shown for the Labrador Shelf, Labrador Slope, Labrador Basin, Greenland Slope, and Greenland Shelf (Fig. 9). Concentrations in the two shelf regions (depths less than 500 m) are quite distinct from the slope areas (bottom depths between 500 and 3300 m) and deeper central basin. Silicate concentrations are highest on the Labrador Shelf and lowest on the Greenland Shelf, while the highest nitrate levels are found in the Labrador Basin. Silicate shows a downward trend with time, especially on the Greenland Shelf, while nitrates show weak positive trends for the Labrador Basin. Silicate on the Labrador Shelf is influenced by water transported from Baffin Bay. The main source of nitrate is in oceanic waters transported into the Labrador Sea from the North Atlantic. Changes in the relative importance of Arctic and Atlantic source waters could account for some of the differences in the trends in nutrient concentrations. Resulting changes in the N:Si ratio could influence phytoplankton growth and community structure.

## Biological Environment

Time series of chlorophyll concentration, bacterial abundance, and total organic carbon (mainly dissolved material) for station groups on the Labrador Shelf, the central Labrador Basin, and the Greenland Shelf show large scatter (Fig. 10). However, all three of these biogenic carbon pools have negative trends in the central Labrador Basin. This might be a broad indication that changes in primary production, in particulate and dissolved forms, are transmitted to secondary production levels at multi-year time scales, even though direct microbial interactions occur more rapidly.

The copepod *Calanus finmarchicus* makes up a large proportion of the total mesozooplankton biomass sampled on AR7W surveys, especially in the eastern Labrador Sea/Greenland Slope region (Fig. 11). Trend lines are included in Figure 11, but their significance is doubtful because of the great variability. The eastern Labrador Sea shows the most variable biomass and the highest peak values. Our surveys take place at different stages of the April–June reproduction

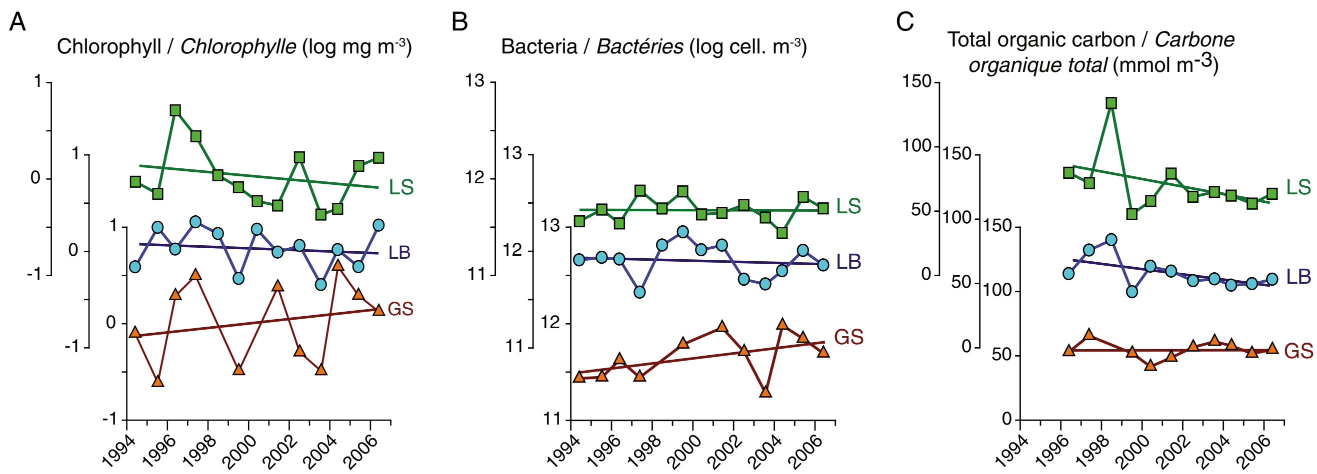


Fig. 10 (A) Chlorophyll concentration (0–100 m), (B) bacterial abundance (0–100 m), (C) total organic carbon concentration (water column), and corresponding regression lines for groups of stations for the Labrador Shelf (LS), the central Labrador Basin (LB), and the Greenland Shelf (GS).

*(A) Concentration en chlorophylle (0 à 100 m), (B) nombres de bactéries (0 à 100 m), (C) concentration en carbone organique total (colonne d'eau totale) ainsi que les droites de régression correspondantes pour des groupes de stations situées sur le plateau continental du Labrador (LS), dans le bassin du Labrador (LB) et sur le plateau continental de l'ouest du Groenland (GS).*

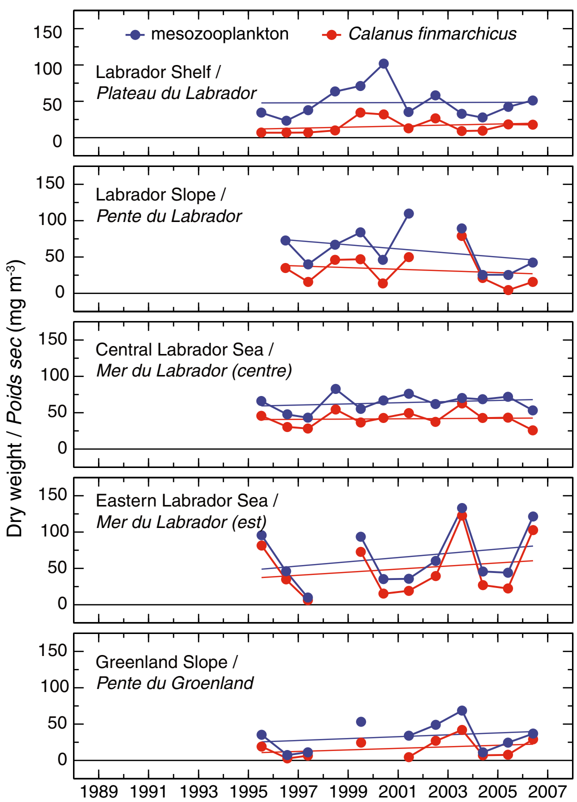


Fig. 11 Total mesozooplankton and *Calanus finmarchicus* biomass in the 0–100 m depth range and corresponding regression lines for selected regions on the AR7W transect.

*Biomasse totale de mésozooplancton et de* Calanus finmarchicus *dans l'intervalle de profondeur 0 à 100 m, ainsi que les droites de régression correspondantes pour des régions précises au long du transect AR7W.*

period. Members of the new generation encountered on May surveys tend to be from earlier stages and smaller than those encountered on July surveys. The three pre-2006 peaks in the eastern Labrador Sea were in fact from July surveys, but the 2006 peak corresponds to a survey in late May. The high biomass in May 2006 included exceptionally high numbers of early copepodite stages. The average abundance of *C. finmarchicus* (0–100 m) for the eastern Labrador Sea was 8,940 m$^{-3}$, at least four times higher than found previously and, to our knowledge, the highest ever reported.

## Highlights 2006

The year 2006 continued a four-year period of exceptionally warm conditions in the Labrador Sea. Surface air temperatures averaged 2–4°C warmer than normal. Sea surface temperatures were ~1°C warmer than normal in the west-central Labrador Sea and Labrador Slope. The upper layers of the Labrador Sea remained warm and saline, with 2006 giving 17-year highs in 0–2000 m heat and salt content. Total inorganic carbon concentrations continued to increase. Nutrient conditions followed recent trends, downward in silicate in all regions and upward in nitrate in basin and slope waters, with increasing nitrate: silicate ratios. High variability in all biological properties makes multi-year trends uncertain, but total organic carbon has been relatively stable over the past 5–6 years and generally lower than in previous years. Labrador Slope and deep Labrador Sea chlorophyll increased slightly in 2006 against a weak long-term decline while Greenland Shelf chlorophyll decreased slightly against a weak long-term increase. High copepod biomass characterized by extraordinarily high numbers of young *Calanus finmarchicus* was observed in the eastern Labrador Sea.

## Acknowledgements

Figure 2 was provided by the NOAA/ESRL Physical Sciences Division from their Web site at http://www.cdc.noaa.gov. The HadISST 1.1 Global Sea Surface Temperature data were provided by the Hadley Centre for Climate Prediction and Research http://www.metoffice.com. Climatological hydrographic data were provided by the U.S. National Oceanographic Data Center http://www.nodc.noaa.gov. Many staff and associates of Ocean Sciences Division and Ecosystem Research Division at BIO have contributed to the Labrador Sea program. The efforts of the officers and crew of CCGS *Hudson* in support of this work in recent years are gratefully acknowledged.

# *Changing Chemical Environment in the Labrador Sea: Consequences for Climate and Ecosystem Studies*

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**Sommaire**

Des séries temporelles de mesures de traceurs transitoires, de carbone organique total et de sels nutritifs obtenues au cours des 16 ans de monitorage des variables océanographiques physiques, chimiques et biologiques sur le transect AR7W dans la mer du Labrador ont révélé un environnement chimique changeant. Les traceurs transitoires fournissent un outil puissant pour comprendre les échelles de variation des processus physiques dans les océans que la salinité et la température seuls ne peuvent résoudre. La concentration en sels nutritifs de la surface jusqu'au fond ont montré une variabilité spatiale inattendue dans la mer du Labrador. Dans la couche de surface, un très fort gradient des silicates à la marge externe du plateau du Labrador a été observé. Ce gradient détermine une frontière entre les eaux du plateau et les eaux riches en nitrates du bassin du Labrador. À des profondeurs plus grandes, les concentrations en nitrates reflètent la structure de la masse d'eau, incluant les variations spatiales et interannuelles. Des patrons à long terme de la concentration aussi bien que des rapports de sels nutritifs ont été observés dans différentes masses d'eau. Les concentrations en carbone inorganique total (CIT) ont augmentés dans toute la colonne d'eau depuis le début du programme de monitorage du CIT en 1993. La mer du Labrador constitue une porte d'entrée majeure pour le stockage à long terme du $CO_2$ atmosphérique et notre programme de monitorage joue donc un rôle important pour comprendre le cycle global du carbone. L'invasion du $CO_2$ anthropogénique de l'atmosphère a conduit à une acidification des eaux nouvellement ventilées de la mer du Labrador durant la même période. Les changements observés dans l'environnement chimique de la mer du Labrador influencent donc non seulement le climat et la santé de l'écosystème dans l'Atlantique canadien mais aussi, à cause du volume importance des eaux du Labrador, le climat à l'échelle globale.

## Introduction

The Labrador Sea is one of two sites in the North Atlantic that produce intermediate and deep water by winter convection. Labrador Sea Water (LSW) formed during the winter convection is a well-ventilated water mass. Sequestered atmospheric gases in LSW, including carbon dioxide and transient tracers such as chlorofluorocarbons (CFCs), are subsequently incorporated into the meridional overturning circulation and partly transported to the south as the Deep Western Boundary Current, while some spread at intermediate depths into the North Atlantic sub-polar gyre (Fig. 1). Depths of winter convection vary from 200 m to over 2000 m during the severe winters such as those observed in early 1990s (Hendry 2006, Yashayaev and Clarke 2006). Variable physical conditions influence chemical and biological environments. Ongoing studies are essential to distinguish the change caused by human activities from natural variability. The information obtained from the monitoring program will provide the foundation for the prediction of future climate and associated marine ecosystem responses. The Ocean Sciences Division and Ecosystem Research Division of the Bedford Institute of Oceanography have participated in the annual occupation of a hydrographic section across the Labrador Sea (Fig. 1), measuring transient tracers (CFCs and carbon tetrachloride), carbonate system variables (total inorganic carbon, total alkalinity), dissolved oxygen, and nutrients (nitrate, silicate, and phosphate) since the early 1990s. The information helps in understanding the physical processes in the ocean and also contributes to ecosystem studies.

*Transient Tracers (CFCs)*

Chlorofluorocarbons (CFCs, including CFC-12, CFC-11, and CFC-113) are anthropogenic gases whose sources and concentration histories in the atmosphere are well known. Surface ocean concentrations reflect the changing atmospheric concentrations, thus making CFCs some of the most widely used transient tracers for studying the ventilation and transport processes in the ocean. They give a direct measure of the ventilation age, which is a measure of the time since a water mass was last in contact with the atmosphere, at the ocean surface. Further, knowing the location of this outcrop region and the assumed pathway to the sampling location, the speed of the flow can be calculated (Fine 1995). Therefore, CFCs can provide important information on the temporal history

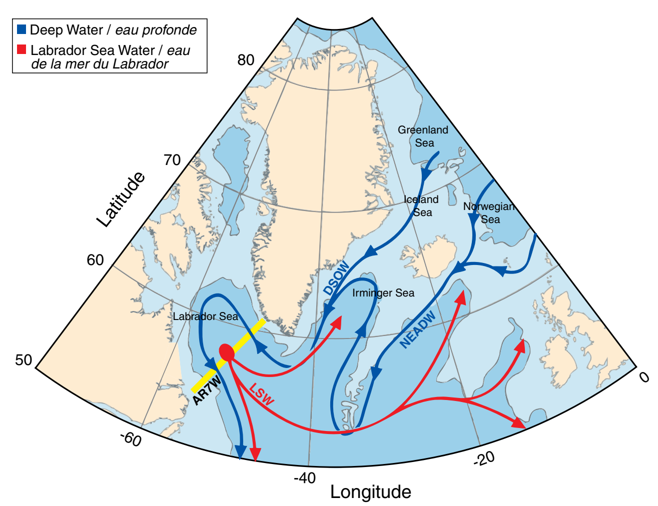


Fig. 1 Map of the Labrador Sea and the northern North Atlantic. AR7W is the standard monitoring line (yellow) in the Labrador Sea. Blue lines indicate deep currents and red lines indicate spreading of Labrador Sea Water.

*Carte de la mer du Labrador et de la partie nord de l'Atlantique Nord. AR7W identifie le transect de monitorage standard dans la mer du Labrador (en jaune). Les lignes bleues indiquent les courants profonds et les lignes rouges montrent la dispersion des eaux de la mer du Labrador.*

of water masses that cannot be resolved by conventional physical measurements such as salinity and temperature. CFCs have been widely applied to calibrate and to validate ocean circulation models (Zhao et al. 2006; see England and Maier-Reimer 2001 for an overview). An understanding of CFC uptake processes and the variability of boundary conditions in the Labrador Sea source region are fundamental for understanding the transport of LSW away from its source (Azetsu-Scott et al. 2003, 2005).

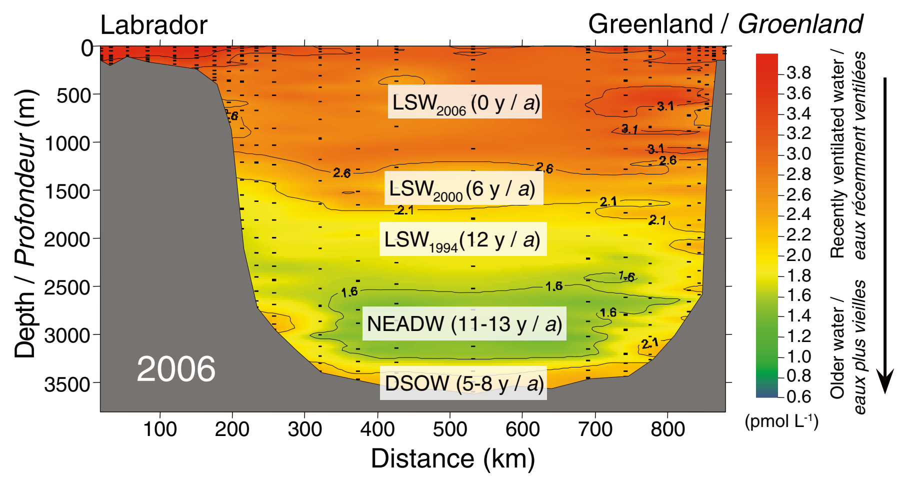


Fig. 2 Distribution of CFC-12 along section AR7W. Ventilation ages were calculated for each water mass. $LSW_{2006}$, $LSW_{2000}$, and $LSW_{1994}$ indicate Labrador Sea Water formed in 2006, 2000, and 1994, respectively. Northeast Atlantic Deep Water (NEADW) and Denmark Strait Overflow Water (DSOW) were formed in the Nordic Seas and flow into the Labrador Sea by different paths.

*Répartition des CFC-12 le long du transect AR7W. Les temps de ventilation ont été calculés pour chaque masse d'eau. $LSW_{2006}$, $LSW_{2000}$ et $LSW_{1994}$ indiquent respectivement des eaux de la mer du Labrador formés en 2006, 2000 et 1994. Les eaux profondes de l'Atlantique nord-est (NEADW) et les débordements du détroit du Danemark ont été formés dans les mers nordiques et s'écoulent dans la mer du Labrador par différents passages.*

Figure 2 shows the distribution of CFC-12 concentrations in the 2006 AR7W survey. Red indicates recently ventilated water with higher CFC concentrations while green indicates older water with lower CFC concentrations. Three different vintages of LSW were observed in 2006: LSW formed in winter 2006 ($LSW_{2006}$), LSW produced in 2000 ($LSW_{2000}$), and the oldest LSW, produced in the extreme deep convection year of 1994 ($LSW_{1994}$). Underneath these LSW types, Northeast Atlantic Deep Water (NEADW), the oldest water in the Labrador Sea at 11–13 years old, extends from 2200 to 3400 m. The deepest part of the Labrador Sea is occupied by Denmark Strait Overflow Water (DSOW), with a ventilation age of 5–8 years. Both NEADW and DSOW were formed in the Nordic Seas and flow into the Labrador Sea through different paths (Fig. 1).

*Nutrients*

Nutrient concentrations in the central part of the Labrador Sea show vertical structures that reflect both biological and physical processes. Figure 3 shows the vertical profiles for silicate (Si) and nitrate (N) for a station in the centre of the Labrador Sea (58.2° N, 50.9° W) in 1993, when deep convection of the LSW was strong, and a more recent year, 2005, when convection was much reduced. All four profiles show a very shallow surface layer (<60 m) where concentrations were depleted by phytoplankton growth. In the intermediate and deep waters, concentrations vary in ways that reflect the contributions of the different water masses as described above. The profiles for silicate and nitrate are clearly different and concentration changes between 1993 and 2005 are evident. Temporal trends in each of these water masses have been assessed using all the data collected over the 17 years of nutrient measurements. Statistically significant trends ($P<0.05$) for silicate were found for recently formed LSW, $LSW_{1994}$, NEADW, and DSOW. The arrows in Figure 3 indicate the direction of the trends. For nitrate and phosphate, only the increase for the deep LSW ($LSW_{1994}$) is significant. Though the concentrations of nitrate in the DSOW decrease with time, the trend is not significant. However, the concentrations of both nitrate ($r=0.66$) and silicate ($r=0.38$) in the DSOW are correlated with the magnitude of the North Atlantic Oscillation if the nutrient data are lagged by two years to allow for transit time to the Labrador Sea. This observation, along with the fact that increases in nutrient concentrations in the LSW, NEADW, and DSOW are associated with increases in oxygen concentrations, indicates that physical processes, and not the biological regeneration of nutrients, are responsible for the temporal trends. The only exception is the deep LSW ($LSW_{1994}$), where nutrient concentrations increase with time while oxygen concentrations decrease; but even here, the nitrate/phosphate and nutrient/oxygen ratios are not consistent with biological regeneration.

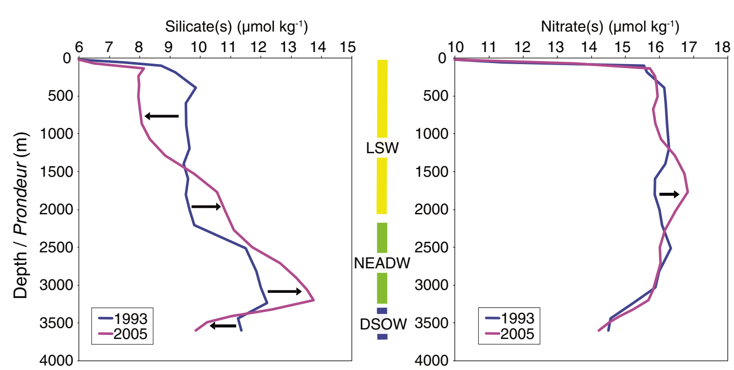


Fig. 3 Vertical profiles of silicate and nitrate at 58.2°N, 50.9°W in 1993 and 2005. The arrows on the plots indicate statistically significant ($P<0.05$) trends in concentration vs. time for individual water masses.

*Profils verticaux des silicates et des nitrates à 58,2°N, 50,9°W en 1993 et 2005. Les flèches indiquent les patrons statistiquement significatifs (P<0,05) des concentrations en fonction du temps pour des masses d'eau individuelles.*

The structure of the nutrient distributions described above is illustrated in a different way in the section plots shown in Figure 4. It shows that the maximum in nitrate concentration in the LSW in 1993 near 1000 m associated

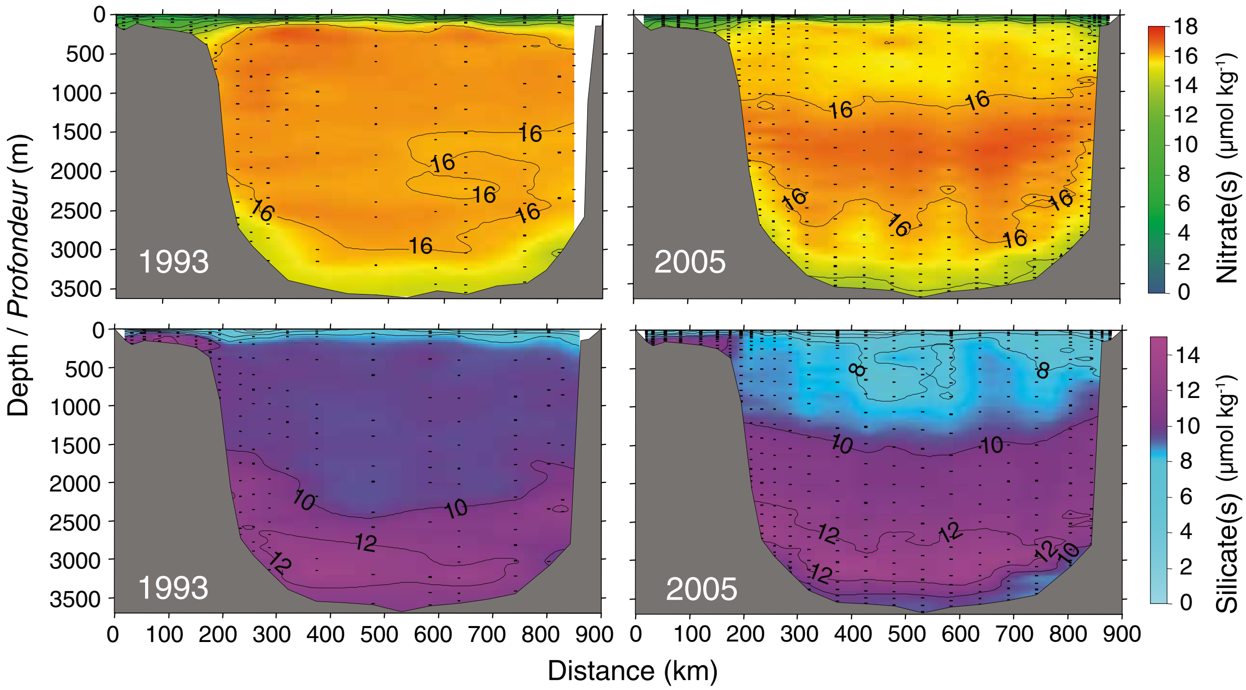


Fig. 4 Distributions of nitrate and silicate concentrations along the AR7W section for 1993 and 2005.

*Répartitions des concentrations en nitrates et en silicates le long du transect AR7W en 1993 et 2005.*

with the Irminger Current is more intense and shallower on the stations to the southwest. This and many of the other smaller-scale features in the nutrient distributions are also evident in the temperature and salinity section plots such as those presented in Yashayaev and Clarke (2006). One interesting feature is the cross-sectional gradient in silicate concentrations in DSOW that gives on average 1.2 µmol $kg^{-1}$ higher concentrations on the Labrador side of the section. Fifteen of 16 years (one cruise did not sample the Greenland side of the section) have higher concentrations on the Labrador side of the section, and for 12 of the 15, the correlation with the distance from the Labrador Shelf is significant ($P<0.05$). The DSOW enters the Labrador Sea as a deep bottom flow on the Greenland side of the section, follows the topography around the Labrador Sea, and exits at depth on the Labrador side. Salinity increases slightly during this transit, suggesting that some overlying NEADW has been incorporated into the flow; however, this would not increase the Si concentrations by the observed 1.2 µmol $kg^{-1}$. The likely explanation for the difference is the dissolution of silicate from diatom frustules raining down from primary production along the Labrador shelf/slope region. Inputs of silicate to this region are large and productivity in the area is mostly dominated by diatoms.

Both Si section plots show high concentrations on the Labrador Shelf and a strong silicate front at the shelf edge. Nitrate concentrations in the same areas are low. The source for the elevated Si concentrations is the transport of water from Baffin Bay to the Labrador Shelf in the Baffin Island/Labrador Current system. Some of this water has its origin in the Pacific Ocean and brings to the Labrador Shelf water with both high Si concentrations and unusually low (for the Atlantic) nitrate to phosphate ratios. Another component of this inflow gets its high Si concentrations from silicate dissolution in the deep waters of Baffin Bay. These nutrient inputs will have an obvious effect on productivity on the Labrador Shelf but will also influence the productivity of the broader Labrador Sea because of the interaction along the shelf edge front between the Arctic waters with high silicate and phosphate but low nitrate concentrations and the Atlantic waters of relatively higher nitrate concentrations. The nitrate:silicate balance has been changing with time (see *Status of the Labrador Sea* article, this volume).

*Total Inorganic Carbon*

During the formation of LSW, atmospheric $CO_2$ is taken up and transported to depth. Therefore, the Labrador Sea provides an efficient conduit of atmospheric $CO_2$ to the long-term storage in the ocean. Ongoing monitoring of TIC is crucial to understand the magnitude and variability of this carbon storage in a changing climate.

Figure 5 demonstrates the increasing total inorganic carbon (TIC) concentrations in all water masses from 1993 to 2005 in the Labrador Sea. This concentration increase corresponds to a change in the carbon inventory in the Labrador Sea by 0.5 gigatons of carbon (Gt C, $0.5\times10^{15}$ grams of carbon) from 1993 to 2005. The Labrador Sea contained about 106.8 Gt C in 2005. Over 95% of the carbon in the atmosphere–ocean system is stored in the ocean. Because the ocean carbon reservoir is so large, small changes in circulation, convection, or pH in the Labrador Sea can have a major impact on the carbon concentration in the atmosphere and therefore, on global climate.

An emerging issue related to the increase of atmospheric $CO_2$ is acidification of the ocean. The invasion of anthropogenic $CO_2$ into the ocean is pushing the pH balance in the ocean

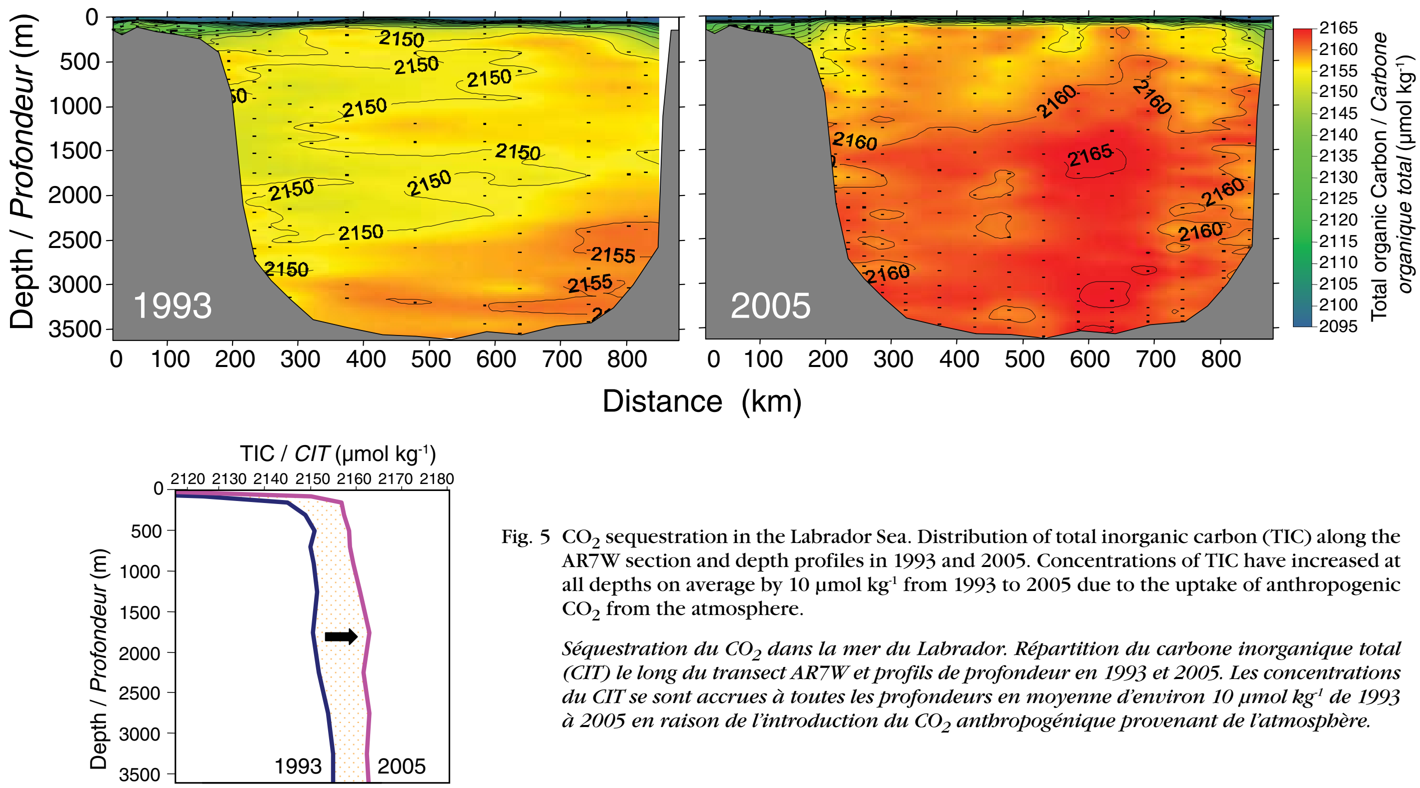


Fig. 5 $CO_2$ sequestration in the Labrador Sea. Distribution of total inorganic carbon (TIC) along the AR7W section and depth profiles in 1993 and 2005. Concentrations of TIC have increased at all depths on average by 10 µmol kg-1 from 1993 to 2005 due to the uptake of anthropogenic $CO_2$ from the atmosphere.

*Séquestration du $CO_2$ dans la mer du Labrador. Répartition du carbone inorganique total (CIT) le long du transect AR7W et profils de profondeur en 1993 et 2005. Les concentrations du CIT se sont accrues à toutes les profondeurs en moyenne d'environ 10 µmol kg-1 de 1993 à 2005 en raison de l'introduction du $CO_2$ anthropogénique provenant de l'atmosphère.*

lower. This will have a negative impact on various processes in the marine ecosystem. Calcareous shell-forming organisms (e.g., coccolithophores, foraminifera, pteropods, and corals) will have more difficulty forming shells in low pH environments. Speciation of $NH_3$ and $PO_4^{3-}$ is also sensitive to small variations in pH. One of the impacts of decreasing $NH_3$ is the inhibition of pelagic nitrification (The Royal Society 2005). These changes in $CO_2$ and nutrient speciation can lead to changes in marine ecosystem structure; therefore, monitoring pH change is an important activity that has recently been added to our program. A preliminary look at the pH change calculated from measured TIC and total alkalinity indicates a decrease in the newly ventilated LSW from 1993 to 2005 that is similar to or slightly greater than the global pH decrease expected from the anthropogenic $CO_2$ increase in the atmosphere (The Royal Society 2005).

## Concluding Remarks

Chemical measurements contribute to both the physical and biological components of the Labrador Sea monitoring program. Measurements of CFCs, chemical oceanographic tracers that come with built-in clocks, allow the determination of the ventilation ages of water masses, and changes in deep-water nutrient concentrations mostly reflect changes in the physical oceanographic environment. It is hard at the moment to determine what the oceanographic or ecological significance of these temporal changes in deep-water nutrients might be, but we know that the TIC measurements give a direct measure of the increasing storage of anthropogenic $CO_2$ sequestered from the atmosphere over the past 12 years. These changes in the carbon inventory in the Labrador Sea are directly related to global increases in atmospheric $CO_2$ and are having a direct impact on biological oceanographic processes. In addition, total inorganic carbon measurements in conjunction with measurements of alkalinity give an estimate of changes in ocean pH that is consistent with estimated global pH change. Increases in nitrate in conjunction with decreases in silicate on the Labrador Shelf reflect a significant change in the relative inputs of Arctic water compared to Atlantic source waters to the Labrador Current. The ecosystem impacts of changing TIC, nutrients, and pH will be a focus for the monitoring program in the future.

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# Seasonal Nutrient Cycles and "New" Primary Production in the Labrador Sea Derived From Satellite (SST and Ocean Colour) Data

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**Sommaire**
Un ensemble d'équations de régression multiples a été développé pour relier les sels nutritifs en surface (nitrates et silicates) à la température et la chlorophylle dans la mer du Labrador. Ces équations ont été appliquées sur des données satellitaires bimensuelles de la température de surface (SST) et de la couleur de l'océan (chlorophylle) afin de générer des cycles saisonniers de sels nutritifs pour le plateau et la partie centrale de la mer du Labrador pour la période s'étendant de 1998 à 2004. Ces cycles dérivés de sels nutritifs se comparent bien avec les concentrations de surface printanières-estivales des sels nutritifs et les concentrations prédites pour l'hiver. La diminution hiver–été des concentrations en nitrates et silicates dérivée de ces cycles saisonniers peut être utilisée pour fournir un estimé minimal de la production primaire « nouvelle » pour la composante totale de la communauté phytoplanctonique dans le cas des nitrates, et pour la composante diatomées dans le cas des silicates. Cette méthode exploite la nature synoptique des données satellites afin de fournir de l'information cruciale sur les échelles de variabilité temporelle et spatiale des sels nutritifs qui sont une information clef pour lier la variabilité du climat aux changements des écosystèmes.

## Introduction

The Labrador Sea Monitoring Program (LSMP) is DFO's Atlantic contribution to long-term studies of the variability and change in climate and its impact on ecosystems (Hendry 2006). Physical observations emphasize winter convective mixing, water mass properties, and large-scale circulation. Chemical observations emphasize the natural and anthropogenic carbon cycles, dissolved gases, and inorganic nutrients. Biological observations emphasize the plankton constituents at the base of the food chain and their productivity. One of the key biogeochemical processes that connects biology and the carbon system to climate change is the so-called "new" primary production ($P_{new}$)—that fraction of total system productivity fuelled by newly available nutrients supplied to the surface ocean largely by mixing from deep ocean reserves, but in principle also from other sources such as nitrogen fixation and atmospheric deposition. $P_{new}$ has been equated with the biogenic carbon exported to the ocean interior where it is sequestered for decades to millennia, representing one of the major oceanic sinks for atmospheric $CO_2$. Quantifying $P_{new}$ in the Labrador Sea is therefore an important element of the climate component of the LSMP.

$P_{new}$ can be measured directly using isotope tracer incubation techniques, but the procedures are impractical for characterizing large spatial–temporal scales. Seasonal nutrient depletion (particularly nitrate and silicate) in surface waters has been suggested as an alternative method for providing estimates (minimum) of $P_{new}$, but it requires data of sufficient temporal duration and resolution to resolve winter maximum nutrient conditions and summer minimum conditions—the difference being $P_{new}$. The LSMP annual spring–summer missions measure seasonal nutrient concentrations but not winter maximums nor summer minimums for the most part, which are critical for $P_{new}$ estimation (Koeve 2001).

A number of studies in the North Pacific (Goes et al. 1999, 2000) and more recently in the Irminger Basin (Henson et al. 2006) have exploited established empirical relationships between seasonal changes in surface ocean temperature, nutrients, and chlorophyll to derive nutrient fields from satellite-based SST and ocean colour. We have adapted this method to the Labrador Sea using our extensive (1994 – present) temperature, nutrient, and chlorophyll database from the LSMP and regional satellite SST (AVHRR) and ocean colour (SeaWiFS) data to see if we could produce realistic seasonal cycles of surface nitrate and silicate, and from those, calculate $P_{new}$ for the years for which we have satellite data (i.e., 1998–2004).

## Data and Analyses

Goes, Henson, and co-workers (1999, 2000, 2006) used their analyses to produce spatial nutrient maps for their regions of interest. For our analysis, we have concentrated instead on temporal changes in nutrient fields and have aggregated our data into two spatial domains, the Labrador Shelf and the central Labrador Basin (Fig. 1). Also, we have assumed that the basic temperature–nutrient–chlorophyll relationships do not vary significantly by year and have combined data over several years to produce a single set of regression equations to yield surface nitrate and silicate concentrations for each sub-region. We have chosen to focus on nitrate and silicate because their consumption represents $P_{new}$ of the total phytoplankton community and the diatom component, respectively (Henson et al. 2006).

Henson et al. (2006) derived their empirical relationships between surface nitrate (or silicate) and temperature and chlorophyll using broad spatial distributions of these variables at 5 m depth collected on four missions between November 2001 and December 2002 in the Irminger Basin. Reasonable descriptions of these relationships require data from winter through spring to summer in order to capture the major chemical–biological interactions. Relationships based on data collected in only one season would, therefore, not adequately describe the seasonality in the relationship.

For the Labrador Sea, we have collected data on only one mission per year during the spring–summer period. We have combined results from adjacent (in time) missions that have spring (May–June) and summer (July) dates to get a measure of the spring–summer distributions. In addition, we have esti-

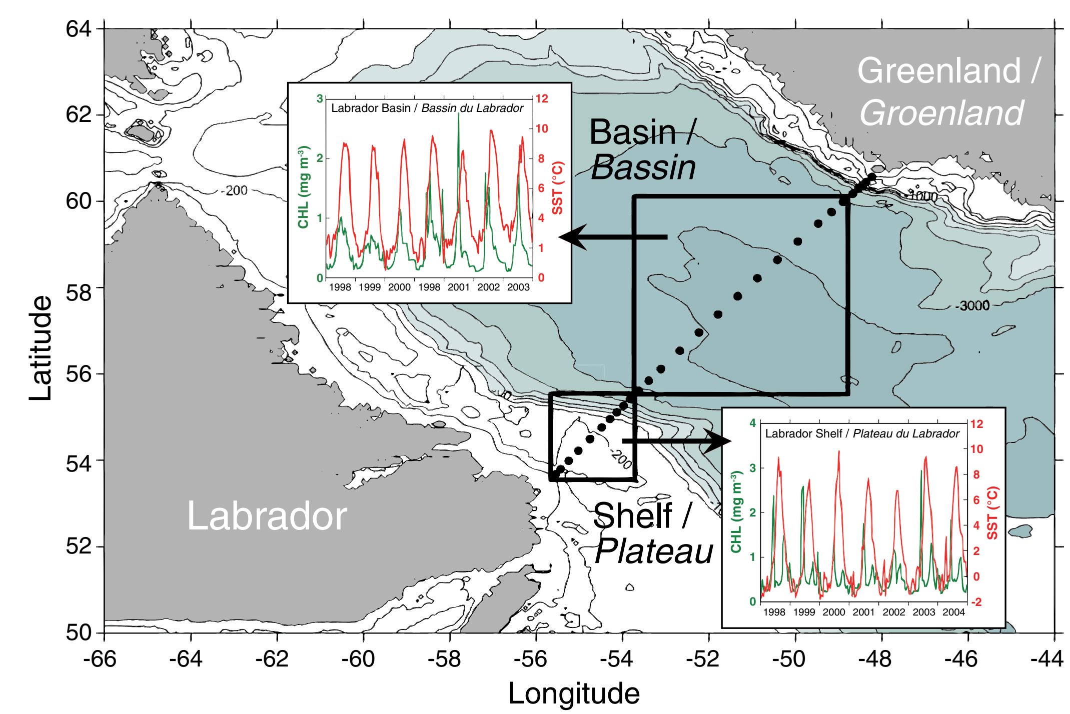


Fig. 1 Labrador Sea Monitoring Program: Study area showing hydrographic stations along the AR7W line and statistical boxes delineating the Labrador Shelf and central Labrador Basin sub-regions. The inserts show time series (1998-2004) of satellite SST and ocean colour (chlorophyll) from twice-monthly composites for the two sub-regions.

*Programme de monitorage de la mer du Labrador : Région d'étude montrant les stations hydrographiques le long de la ligne AR7W. Les boites noires délimitent les sous-régions utilisées statistiquement pour représenter le plateau et le bassin central de la mer du Labrador. Les encarts présentent les séries temporelles (1998 à 2004) de données de température (SST) et de la couleur (chlorophylle) de la surface de l'océan obtenues à partir des données satellitaires composites bimensuelles pour ces deux sous-régions.*

spring and summer samples deviated from this relationship, showing lower nutrient concentrations for a given temperature. But the dominant impression from their plots of nutrient vs. temperature is a fairly linear relationship between winter conditions of high nutrient concentrations and low temperature and summer conditions with low nutrients and high temperature. In the Labrador Basin, we see a qualitatively similar picture, but one with fewer data on the linear portion of the plot and more that deviate to lower temperature and nutrient concentrations (Fig. 2). The earliest season mission (2004) shows substantial reduction in nutrient concentrations associated with very little increase in temperature, suggesting that there is substantial biological activity in the spring before any appreciable increase in surface temperature. It is more difficult to describe shelf nutrient concentrations using temperature and chlorophyll because the hydrography will generally be more complex. Henson et al. (2006) were unable to extend their analysis to the east Greenland Shelf for this reason. On the Labrador Shelf, we see seasonal warming of surface waters overlying a fairly consistent layer of cold water (CIL, cold intermediate layer) that can be used for an analysis similar to that for the Labrador Basin. Plots of nutrient vs. temperature for the Labrador Shelf show features similar to the Labrador Basin plots.

mated the winter distributions by assuming that subsurface concentrations from immediately below the seasonal mixed layer and seasonal nutricline represent the previous winter's conditions. For the Labrador Basin, "winter" temperatures (3.0-3.5°C) extend to considerable depths, so any waters from below the surface mixed layer can be used to represent the winter conditions. We have used samples from 60–200 m. On the Labrador Shelf, a temperature minimum (~-1.5°C) is found at between 50 and 100 m. We have only used data from the nutricline to -1.5°C to represent the winter conditions on the shelf. Seasonal warming of Greenland Shelf waters is not really evident in our data and the relationship between nutrients and temperature has a positive slope because the deeper waters are warmer than the surface ones. We can generate results for the Greenland Shelf, but it is not clear how meaningful they would actually be. For this reason, we have chosen not to consider the Greenland Shelf in the present analysis.

*Annual Nutrient Cycles*

For the Irminger Basin, Henson and co-workers (2006) found a strong covariance of nitrate (and to a lesser extent silicate) with temperature; some of the

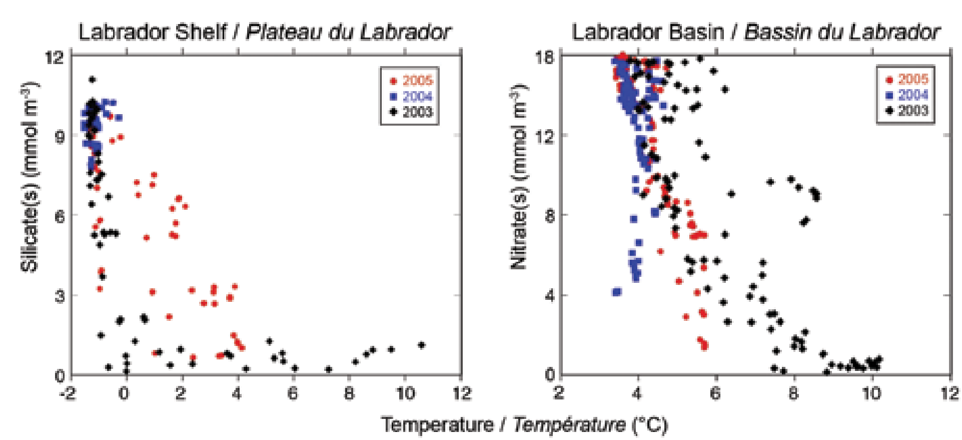


Fig. 2 Scatterplots of temperature versus silicate and nitrate concentrations (surface–200 m) observed during spring–summer Labrador Sea missions, 2003–2005.

*Graphiques de la température versus les concentrations en silicates et en nitrates (surface à 200 m) pour les données récoltées au cours des missions de printemps-été 2003 à 2005.*

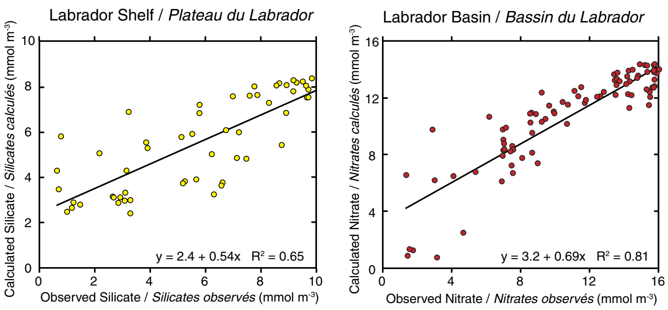


Fig. 3 Predicted (see Data and Analyses section in text) versus observed surface silicate and nitrate concentrations on the Labrador Shelf and in the central Labrador Basin, 2005.

*Concentrations en silicates et en nitrates en surface prédites (voir section* Data and Analyses *dans le texte) versus les concentrations observées sur le plateau et le basin de la mer du Labrador en 2005.*

Table 1 Multiple regression equations from composite (1999-2005) temperature, chlorophyll, and nutrient data (surface–200 m) for the Labrador Shelf and central Labrador Basin.

*Équations de regression multiples pour l'ensemble des données (de la surface jusqu'à 200 m) de température, chlorophylle et sels nutritifs (1999-2005) pour le plateau et le bassin central du Labrador.*

| Shelf / *Plateau* | Basin / *Bassin* |
|---|---|
| Silicate(s) = 8.35-1.14T-0.563CHL  $R^2$=0.61 | Silicate(s) = 13.2-1.50T-0.832CHL  $R^2$=0.69 |
| Nitrate(s) = 7.11-1.17T-0.586CHL  $R^2$=0.66 | Nitrate(s) = 22.0-2.21T-1.57CHL  $R^2$=0.71 |

The fits of the nutrient concentrations predicted from the multiple linear regressions to the observed data are illustrated for the 2005 mission data (Fig. 3). The results for other missions are qualitatively similar but the goodness of fit varies. The fits are generally better for nitrate than silicate, with the silicate plots showing substantial numbers of near-surface samples for which the predicted silicate concentration is considerably higher than the observed concentration. Henson et al. (2006) made similar observations.

The multiple regressions (Table 1) of nutrients on temperature and chlorophyll for the Labrador Shelf and Labrador Basin can be combined with satellite SST and ocean colour data to generate seasonal surface nutrient cycles.

Using satellite data from 1998-2004 and the 1999-2005 composite regressions, we can produce graphs of predicted surface nitrate and silicate concentrations vs. time for both the Labrador Shelf and Labrador Basin (Fig. 4). The plots show consistency, with average surface mixed-layer nutrient concentrations measured on each of the LSMP missions as well as with estimated mean nutrient concentrations for the previous winter based on sub mixed layer (60-200 m) concentrations.

All four panels in Figure 4 show the expected seasonal nutrient cycles for the temperate zone; the fit of the observed surface layer data to the predicted curves is good. For the shelf waters, the winter observed data also fit well, but the winter observations are slightly lower than the predicted ones for the Labrador Basin. Temperatures for the mixed layer waters on our missions never fall below about 3°C, yet the satellite indicates surface layer temperatures as low as 1°C in mid winter. If the source waters resupplying nutrients to the surface waters in winter have temperatures of ~3°C and

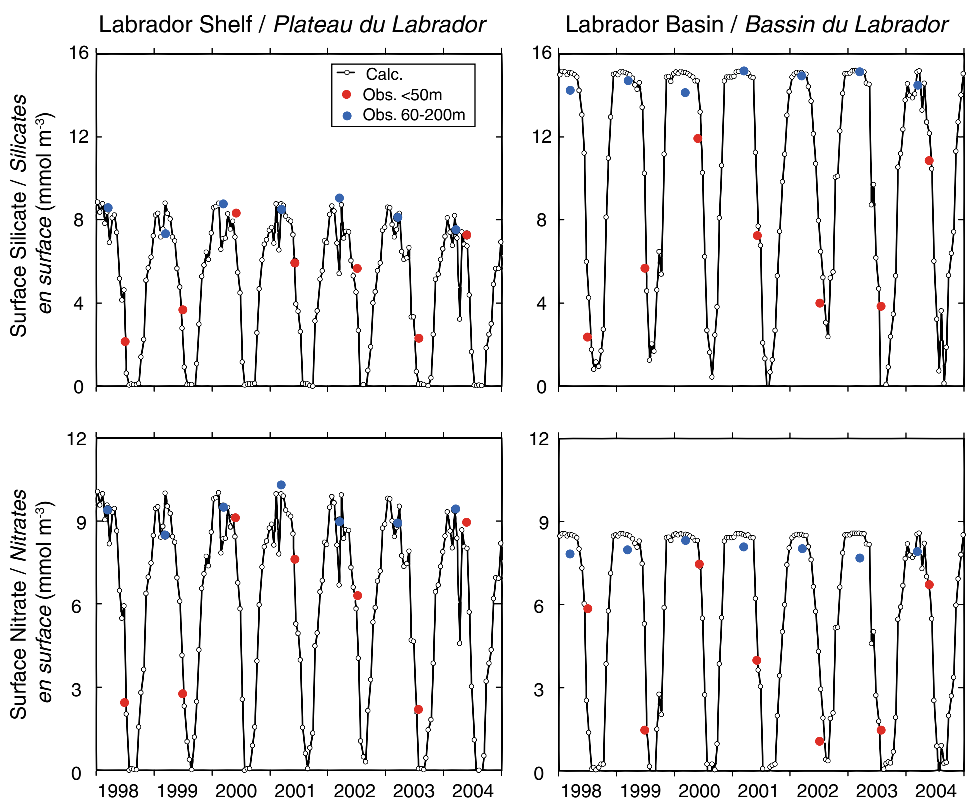


Fig. 4 Time series (1998-2004) of surface silicate and nitrate concentrations on the Labrador Shelf and in the central Labrador Basin derived from twice-monthly satellite SST and ocean colour data. Red circles are observed average spring–summer surface concentrations (plotted on the mean date samples were collected). Blue circles are estimated winter concentrations (average spring-summer concentrations from 60-200 m depth plotted back in time to 15 March, assumed to be the date of seasonal maximum nutrient concentrations).

*Séries temporelles (1998-2004) des concentrations de surface en nitrates et silicates sur le plateau et dans le bassin central de la mer du Labrador dérivées à partir des données satellites bimensuelles de la température de surface et de la couleur des océans. Les cercles rouges indiquent les concentrations de surface moyennes pour la période de printemps–été (les points rouges sont placés à la date moyenne de collecte d'échantillons pour la période considérée). Les cercles bleus représentent les concentrations hivernales estimées (concentrations moyennes pour la période de printemps–été pour les profondeurs de 60 à 200 m en date du 15 mars qui est la date assumée pour le maximum saisonnier des sels nutritifs).*

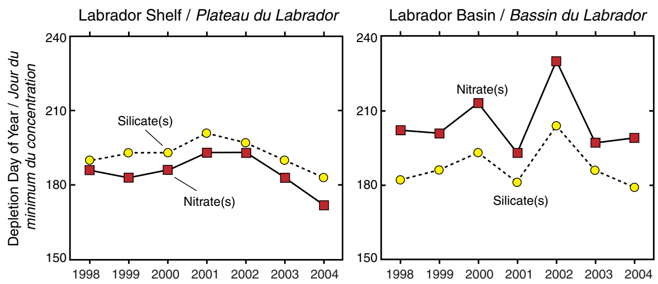


Fig. 5 Date of surface nutrient depletion (concentrations <2 mmol m$^{-3}$) on the Labrador Shelf and in the central Labrador Basin calculated from satellite-derived nutrient cycles (Fig. 4).

*Moment d'apparition du minimum de concentration des sels nutritifs (concentrations <2 mmol m$^{-3}$) sur le plateau et le bassin central de la mer du Labrador, dérivé à partir des cycles de sels nutritifs détectés par satellite (Fig. 4).*

Table 2 Total ($P_{total}$) and new ($P_{new}$) primary production in the Labrador Sea derived from ($^{13}C$–$^{15}N$) tracer measurements compared with $P_{new}$ from satellite-based estimates of nitrate ($P_{new}$ – dep$NO_3$) and silicate ($P_{new}$ – dep$SiO_3$) depletion in surface waters.

*Production primaire totale ($P_{total}$) et nouvelle ($P_{new}$) dans la mer du Labrador dérivées des mesures de traceurs ($^{13}C$–$^{15}N$) et comparées avec $P_{new}$ estimé à partir des mesures satellites d'utilisation des nitrates ($P_{new}$-dep$NO_3$) et des silicates ($P_{new}$-dep$SiO_3$) dans les eaux de surface.*

| Region / *Région* | $P_{total}$ (mg C m$^{-2}$ d$^{-1}$) | $P_{new}$ (mg C m$^{-2}$ d$^{-1}$) | $P_{new}$ - dep$NO_3$ (mg C m$^{-2}$ d$^{-1}$)† | $P_{new}$ - dep$SiO_3$ (mg C m$^{-2}$ d$^{-1}$)† |
|---|---|---|---|---|
| Shelf / *Plateau* | 948 | 569 | 262 | 278 |
| Basin / *Bassin* | 1050 | 508 | 573 | 374 |

†$P_{new}$ converted to carbon units using the Redfield molar ratio times the molecular weight of carbon (C:N = 6.625:12) and assuming C:Si conversion using same factor.
† *$P_{new}$ convertie en unités de carbone en utilisant le rapport de Redfield (C:N = 6.625:12) et assumant une conversion C:Si utilisant le même facteur.*

nitrate and silicate concentrations of ~15 and ~8 mmol m$^{-3}$, respectively, and thermal cooling subsequently lowers the water temperatures to 1°C, then the model will predict an increase in nutrients that is not real. The actual observations of nutrient concentrations at depths sufficiently deeper than the surface mixed layer to eliminate any in situ uptake (i.e., the blue circles in the plots) should give us a better estimate of winter concentrations. Similar arguments can be used to explain predictions of summer nutrient concentrations that are <0. In the Labrador Basin, by the time summer temperatures have increased to ~8.5 and ~9.5°C, silicate and nitrate concentrations have decreased to 0, respectively. The corresponding temperatures at which silicate and nitrate decrease to 0 on the Labrador Shelf are ~7 and ~6°C. Further warming cannot result in the further reductions in nutrient concentrations that the model predicts. The computations, therefore, were done using truncated temperature ranges as described above. Some tuning of the fits gave a 3°C minimum temperature for the Labrador Sea and 8.3 and 9.5°C as the temperatures at which silicate and nitrate disappear, respectively. For the Labrador Shelf, we have set the temperature limits at -1.6, 7.1, and 5.8°C.

These representations of the seasonal cycles in silicate and nitrate for the Labrador Shelf and Labrador Basin can be used to estimate several features related to the seasonal biological productivity cycle, such as (1) nutrient depletion times, i.e., when nutrient concentrations decrease below some critical minimum value—here taken to be 2 mmol m$^{-3}$ (Henson et al. 2006), (2) net seasonal biological consumption of nutrients (minimum $P_{new}$), and (3) nutrient consumption ratios (e.g., N:Si).

On the Labrador Shelf, the depletion time for nitrate precedes that for silicate by approximately one week, which is consistent with a lower initial inventory of nitrate if biological comsumption rates of nitrate and silicate are comparable, as assumed here (Fig. 5). There may be a temporal trend in depletion dates for both nitrate and silicate, i.e., depletion dates appear to be occurring progressively earlier over the last 3-4 years of the data record. In the Labrador Basin, the silicate depletion date is earlier than that of nitrate, again reflecting differences in initial inventories. There is one year (2002) for which nitrate concentrations did not get below 2 mmol m$^{-3}$. For the other years, silicate depletion precedes nitrate depletion by 11 to 20 days, but no discernible temporal trend is evident.

### *"New" Primary Production and N:Si Consumption Ratios*

More nutrient depletion (winter maximum minus summer minimum) of silicate than nitrate is seen for the shelf and considerably more depletion of nitrate than silicate is seen for the basin. This mostly reflects the relatively greater inputs of Si on the shelf and greater inputs of N in the basin. On the shelf, complete summertime depletion of both Si and N occurs in all years, but for the Labrador Basin, some residual summer nitrate is seen in most years, perhaps with a trend to less residual in more recent years. The trend for silicate may be the opposite, i.e., there is some suggestion of increasing residual Si in recent years.

$P_{new}$ can be computed from these nutrient depletion estimates by applying appropriate elemental conversion factors (i.e., the canonical "Redfield Ratio") to produce carbon-equivalent consumption rates, or N-based and Si-based primary productivity. For these calculations, the Redfield C:N consumption ratio of 106:16 (molar) is used and the N:Si consumption is assumed to be typical for coastal temperate phytoplankton (i.e., 1:1). These calculations will represent minimum estimates of $P_{new}$ since they are based on the initial nutrient inventory and "net" changes over time and do not take into account nutrients that are continuously being supplied to the surface layer by mixing. N consumption will represent $P_{new}$ of the total phytoplankton population whereas Si consumption will represent $P_{new}$ of only the diatoms and silicoflagellates when present. $P_{new}$ calculations based on nutrient consumption are compared with independent estimates of total and N-based new primary production from tracer experiments carried out during some of the LSMP missions (Table 2). N-based $P_{new}$ from the tracer experiments represents ~50% of the total production on both the Labrador Shelf and in the central Labrador Basin. $P_{new}$ based on nitrate depletion was similar to the tracer estimate of $P_{new}$ in the Labrador Basin but only about half of the tracer estimate on the Labrador Shelf. $P_{new}$ based on silicate depletion was

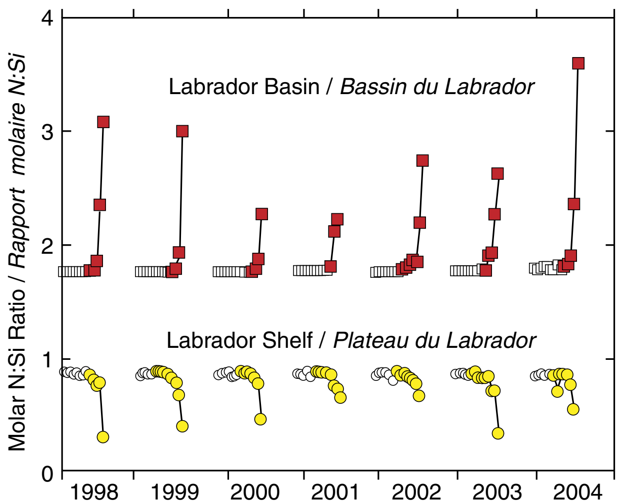


Fig. 6 Time-series of N:Si concentration ratios in surface waters on the Labrador Shelf and in the central Labrador Basin in winter (open symbols) and through the spring–summer period when surface concentrations are rapidly depleted by biological consumption (filled symbols) calculated from satellite-derived nutrient cycles (Fig. 4).

*Séries temporelles des rapports de concentration N:Si dans les eaux de surface sur le plateau et le bassin central de la mer du Labrador en hiver (symboles ouverts) et pour la période de printemps-été quand les concentrations en sels nutritifs sont rapidement diminuées dû à la consommation biologique (symboles pleins). Les calculs sont effectués à partir des cycles de sels nutritifs dérivés des mesures satellitaires (Fig. 4).*

equivalent to $P_{new}$ based on nitrate depletion on the Labrador Shelf but only two-thirds of the nitrate depletion estimate in the Labrador Basin. These preliminary results suggest that nutrient depletion may provide a reasonable estimate of $P_{new}$ in the Labrador Sea. From these calculations, it appears from the comparative nitrate and silicate consumption rates that silicate-requiring phytoplankton account for virtually all of the $P_{new}$ on the Labrador Shelf and two-thirds of the $P_{new}$ in the central Basin. The observation that $P_{new}$ based on nitrate consumption is only about half that based on tracer-N measurements on the Labrador Shelf suggests that other sources of N besides the initial inventory are fueling $P_{new}$ there.

N:Si ratios are relatively constant (~1.8) in the Labrador Basin in winter and increase into the spring–summer as silicate becomes depleted more rapidly than nitrate (Fig. 6). On the Labrador Shelf, N:Si ratios are also constant in winter–spring but lower (~0.9) than in the Basin. Ratios decrease into the summer as nitrate is more rapidly depleted. It appears that the deviations from the winter ratios occur earlier in the Labrador Basin than on the Labrador Shelf. The fundamental differences in N and Si sources, inventories, and depletion patterns between the Labrador Shelf and central Basin may be important factors in structuring the phytoplankton communities in this region.

## Concluding Remarks

From the information above, it would appear that satellite temperature and ocean colour data can be used to predict surface nutrient concentrations for both the Labrador Shelf and Labrador Basin. While some care has to be taken as to how the model is applied, the fit of observed and predicted concentrations seen in this preliminary analysis suggests that the model works reasonably well. The results can be used to more completely describe the seasonal cycle of surface nutrients for regions such as the Arctic, where we have limited temporal data coverage. Moreover, results can be used to describe features of nutrient distributions (e.g., supply, timing of depletion, net consumption, and consumption ratios) that are of considerable value in understanding nutrient controls on regional biology dynamics and climate-related biogeochemistry.

Although we have established the general utility of this model, there are a number of refinements we must consider. The empirical equations relating nutrients to temperature and chlorophyll are clearly region-specific based on the differences we observed between the Labrador Shelf and central Labrador Basin and compared with those developed by Henson et al. (2006) for an adjacent ocean region, the Irminger Basin. Moreover, there is evidence that the relationships may vary from year to year within a region, i.e., the composite (1999-2005) regression equations may not be appropriate for all years. It may also be determined that a non-linear model will provide a better overall fit to the data than the linear model used here. The hydrodynamics and biological growth cycles on the Greenland Shelf appear to differ considerably from those in the Labrador Shelf–Basin regions; adjustments to our assumptions and procedures may be required to be able to derive nutrient fields from satellite data for this region. We therefore need to explore more broadly the relationships between temperature, chlorophyll, and nutrients with a view of developing a suite of region-specific equations that would permit us to map nutrient fields using satellite data for the entire NW Atlantic. Another consideration for further analysis is to develop twice–monthly spatial maps of surface nutrients for the Labrador Sea (and adjacent regions), similar to the km-resolution composite images of SST and ocean colour that AZMP routinely produces for the entire NW Atlantic. The potential for a more comprehensive understanding of the temporal and spatial scales of nutrient variability offered by this method will be key to elucidating the links between climate variability and change and regional ecosystems.

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# History of Annual Multi-Species Trawl Surveys on the Atlantic Coast of Canada

# Historique des relevés de chalut multi-spécifiques annuels sur la côte Atlantique du Canada

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**Abstract**

The department of Fisheries and Oceans has conducted annual multi-species fisheries surveys for nearly four decades in the four Atlantic coast regions to provide an assessment of the state of marine resources and environmental conditions throughout the major shelf areas of eastern Canada. Over the years, there have been significant modifications to survey design, vessels, gear type, tow speed, time of survey, biological sampling protocols, and oceanographic observations. An awareness of these changes is essential to interpret the data properly.

**Sommaire**

Le ministère des Pêches et des Océans a effectué des relevés de pêches plurispécifiques chaque année depuis tout près de quarante ans dans les quatre régions côtières de l'Atlantique afin de fournir un aperçu de l'état des ressources marines et des conditions environnementales sur les principaux plateaux marins de l'Est du Canada. Au fil des ans, la conception des relevés, les navires, les types d'engins, la vitesse des traits de chalut, la période des relevés, les protocoles d'échantillonnage biologique ainsi que les observations océanographiques ont beaucoup évolué. La connaissance de ces changements est donc essentielle pour une interprétation correcte des données.

## Introduction

The multi-species trawl surveys on Canada's east coast are one of the world's largest investments in monitoring the state of the marine environment. For almost six months each year since the early 1970s, large research vessels have been randomly sampling (nearly 2,000 stations since the 1990s) in well-defined strata throughout the major shelf areas of Atlantic Canada. Information from these surveys is the source for much of our knowledge on the status of commercial and non-commercial fish stocks and, recently, on the physical and chemical properties of seawater.

The surveys are led by four regions: Newfoundland and Labrador Region (Labrador Shelf, Hamilton Bank, Grand Banks, St. Pierre Bank), Maritimes Region (Scotian Shelf, Bay of Fundy), Gulf Region (southern Gulf of St. Lawrence), and Québec Region (northern Gulf of St. Lawrence, Rose Blanche Bank). The surveys in all regions have the same objectives but have different constraints, such as bottom topography, bathymetry, size of area, and vessel availability. Thus, although regional protocols are similar, there are important differences that must be considered before conducting any large-scale analyses of the combined data sets. In addition, over the years there have been significant modifications within each region to survey design, vessels, gear type, tow speed, time of survey, biological sampling protocols, and oceanographic observations. An awareness of these changes is important for data interpretation. The regional summaries presented below provide an outline of where and when these changes occurred.

## Newfoundland and Labrador Region

*A. History*

Research vessels, operated by the Canadian government, have conducted multi-species trawl surveys in the Newfoundland and Labrador (N.L.) area since 1949; earlier surveys were conducted by other agencies. Prior to 1971, the surveys' purposes as well as the nature and detail of the data gathered varied.

## Introduction

Les relevés plurispécifiques annuels effectués sur la côte est du Canada comptent parmi les plus importantes sources de données sur l'état du milieu marin. Pour une période de six mois à chaque année depuis le début des années 1970, des spécialistes à bord de grands navires de recherche prélèvent des échantillons aléatoires stratifiés (quelques 2,000 stations depuis 1990) éparpillées sur les principaux plateaux de la côte Atlantique Canadienne. Nos connaissances sur l'état des espèces halieutiques commerciales et non commerciales et, plus récemment, sur les propriétés physiques et chimiques de l'eau de mer, proviennent principalement des résultats de ces relevés.

Les relevés sont effectués par quatre régions : Région de Terre-Neuve et du Labrador (plateau continental du Labrador, banc Hamilton, Grands Bancs et banc de Saint-Pierre), Région des Maritimes (plateau Néo-Écossais et baie de Fundy), Région du Golfe (sud du golfe du Saint-Laurent) et Région du Québec (nord du golfe du Saint-Laurent et banc de la Rose Blanche). L'objectif est le même dans chaque région, mais les contraintes varient, notamment en raison de la topographie du fond marin, la bathymétrie, la taille des secteurs et la disponibilité des navires. Par conséquent, quoique semblables, les protocoles régionaux comportent des divergences importantes dont il faut tenir compte avant de mener des analyses à grande échelle des ensembles de données combinés. Par ailleurs, au fil des ans, la conception des relevés, les navires, le type d'engins, la vitesse des traits de chalut, la période des relevés, les protocoles d'échantillonnage biologique et les observations océanographiques ont beaucoup évolué dans chaque région. La connaissance de ces changements est donc essentielle pour une interprétation correcte des données. Les sommaires régionaux ci-dessous donnent un aperçu de ces changements et du moment où ils se sont produits.

## Région du Terre-Neuve et du Labrador

*A. Historique*

Le gouvernement du Canada effectue des relevés au chalut d'espèces multiples au moyen de navires de recherche dans les eaux de Terre-Neuve et du Labrador (T.-N.-L.) depuis 1949; des relevés ont été effectués par d'autres organisations même avant cette date. Avant 1971, les objectifs des relevés ainsi que la nature et le niveau de détail des données recueillies étaient variables.

Standardized, stratified random bottom-trawl surveys were initiated on the Grand Banks (NAFO Divisions 3LNO, Fig. 1) in the spring of 1971 to provide indices of abundance and biomass for demersal fish stocks on the Grand Banks using methods that were adopted and approved by ICNAF (International Commission of Northwest Atlantic Fisheries) and later by NAFO (Northwest Atlantic Fisheries Organization).

The spring survey was expanded in 1973 to include St. Pierre Bank and the surrounding areas (NAFO Division 3P). Beginning in 1977, autumn surveys were carried out in Division 2J, later expanding to include 3K (1978), 3L (1981), and 3NO (1990). Divisions 2G and 2H have been surveyed in some years in the autumn, and some deeper sets in the Flemish Pass area of 3M were also added to the survey design in 1997. Documentation of the early spring surveys can be found in Pitt et al. (1981); Brodie (1996, 2005) describes the autumn surveys. Many stock assessment documents, which make use of the spring and autumn data series, provide extensive descriptions of the survey series (e.g., Walsh et al. 2006).

Data from these surveys have been the foundation for the majority of the stock assessments of commercially important marine finfish and shellfish species in the N.L. area. They have also become critical for addressing questions concerning species-at-risk and for understanding the structure and function of the ecosystems in the N.L. area.

*B. Survey Design*

Beginning in 1971, a stratified random survey design, with stations allocated in proportion to stratum surface area (i.e., proportional allocation) has been employed. Stations are chosen randomly, within each stratum prior to the start of each survey and are fished around the clock. There have been changes to the stratification scheme over time as new and more accurate charts became available and as strata were added in the inshore areas (3K, 3L, and 3Ps), as well as in the deep slope areas (deeper than 400 fm/731 m in 3LMNOP and deeper than 750 m north of 3L). At present, a complete autumn survey of 2HJ and 3KLMNO consists of about 800 fishing stations (Fig. 1) and is carried out by two vessels, the CCGS *Teleost* and the CCGS *Wilfred Templeman*, from late September to mid-December (often into January, although not as part of the original design). The spring survey of 3P and 3LNO currently consists of about 480 fishing stations and is generally conducted from April to June on board the CCGS *Wilfred Templeman*. On several occasions, the CCGS *Alfred Needler*, the *Wilfred Templeman*'s sister ship, has been used in the spring and fall surveys. Maximum station depth in the fall survey is 1500 m compared to 731 m during the spring.

*C. Fishing Protocols*

Fishing protocols were documented by Pinhorn (1971). Prior to the adoption of the Campelen 1800 trawl in 1995, a standard fishing tow was 30 minutes in duration

Les relevés aléatoires stratifiés et normalisés de chalut de fond sur les Grands Bancs (divisions 3LNO de l'OPANO, Fig. 1) ont débuté au printemps de 1971 pour fournir des indices d'abondance et de biomasse des stocks de poissons démersaux sur les Grands Bancs à l'aide de méthodes adoptées et approuvées par la CIPANO (Commission internationale pour les pêcheries de l'Atlantique Nord-Ouest) et plus tard par l'OPANO (Organisation des pêches de l'Atlantique Nord-Ouest).

Le relevé printanier a été élargi en 1973 pour inclure le banc de Saint-Pierre et la zone avoisinante (division 3P de l'OPANO). Depuis 1977, des relevés automnaux ont été effectués dans la division 2J, qui ont, plus tard, été étendus aux divisions 3K (1978), 3L (1981) et 3NO (1990). Certaines années, les relevés d'automne incluaient également les divisions 2G et 2H, et en 1997, se sont ajoutés des traits de chalut en eau profonde dans le secteur du chenal du Bonnet Flamand de la division 3M. Les premiers relevés du printemps sont documentés dans un ouvrage de Pitt et al. (1981); Brodie (1996, 2005) décrit les relevés d'automne. De nombreux rapports d'évaluation des stocks, qui utilisent à la fois les données des relevés d'automne et de printemps, fournissent une description exhaustive des séries de relevés (ex., Walsh et al. 2006).

Jusqu'à maintenant, les données tirées de ces relevés ont servi de fondement à la majorité des évaluations des stocks d'espèces de poissons marins et de mollusques et crustacés de la région de T.-N.-L. Elles sont également devenues indispensables pour répondre à des questions sur les espèces en péril et pour comprendre la structure et la fonction des écosystèmes de la région de T.-N.-L.

*B. Conception du relevé*

Depuis 1971, on utilise un plan de relevé aléatoire stratifié, avec des stations réparties proportionnellement à la superficie des strates (répartition proportionnelle). Les stations sont choisies au hasard à l'intérieur de chaque strate avant le début de chaque relevé et sont échantillonnées sur 24 heures. Au fil des ans, on a apporté quelques changements dans la méthode de stratification, à mesure que l'on obtenait de nouvelles cartes plus précises et que l'on ajoutait des strates dans les zones plus côtières (3K et 3L et 3Ps), ainsi que dans les parties profondes du talus continental (profondeurs supérieures à 400 brasses/731 m dans 3LMNOP et plus profond que 750 m au nord de 3L). À l'heure actuelle, un relevé automnal complet dans 2HJ + 3KLMNO comprend quelques 800 stations de pêche (Fig. 1) et s'effectue en utilisant deux navires (NGCC *Teleost* et NGCC *Wilfred Templeman*) entre la fin de septembre et la mi-décembre. Le relevé se prolonge souvent en janvier, quoique cela ne fasse pas partie du plan initial. Le relevé de printemps dans 3P et 3LNO comprend actuellement quelques 480 stations de pêche, et a généralement lieu entre avril et juin à bord du NGCC *Wilfred Templeman*. On a utilisé plusieurs fois le NGCC *Alfred Needler*, navire jumeau du *Wilfred Templeman*, pour les relevés de printemps et d'automne. La profondeur maximale pour le relevé d'automne est de 1500 m, comparativement à 731 m dans le cas des relevés de printemps.

*C. Protocoles de pêche*

Les protocoles de pêche utilisés ont été documentés par Pinhorn (1971). Avant l'apparition du chalut Campelen 1800 en 1995, un trait de chalut standard durait 30 minutes à une vitesse de 3,5 at a speed of 3.5 knots (measured from the time when all of the warp has been "shot" and the brakes on the winch drum applied until the beginning of haulback). Tow duration may be shortened if rough bottom is encountered, but tows lasting less than 20 minutes were generally not considered valid. When the Campelen trawl came into use in autumn 1995, a standard fishing tow was 15 minutes in duration at a speed of 3.0 knots, with Scanmar net-monitoring equipment used to determine touchdown and lift-off of the net from the ocean bottom. A tow of less than 10 minutes was generally not considered valid. Actual tow time (net-on-bottom) in the Campelen surveys has been determined from post-survey analysis of the trawl-mounted CTD (conductivity, temperature, depth) data, which give an accurate trace of the net depth for each tow.

Alternate fishing stations may be substituted depending on circumstances (e.g., presence of fixed fishing gear, untrawlable bottom at a station, time constraints). Two alternate sites per stratum are generally chosen at the same time as the other randomly chosen stations.

Prior to 1995, the amount of warp shot was determined from a standard warp-to-depth ratio table. This was revised for the Campelen trawl (McCallum and Walsh 1996). Scanmar trawl geometry has been recorded via computer since the early 1990s.

There have been changes to the survey vessel and survey gear, all of which have been shown to affect the catchability of organisms by the survey gear. As a result, corrections based on comparative fishing are required to maintain a consistent time series for many species (Gavaris and Brodie 1984, Warren 1997, Warren et al. 1997, Morgan et al. 1998). McCallum and Walsh (1996) give a detailed description of the trawls that have been used in the various survey time series. An extensive trawl mensuration program has been in place since the early 1990s to ensure trawl standardization on the surveys.

Since 1994, data on sea bottom type, using a ship-mounted system known as RoxAnn, has been collected regularly during the surveys.

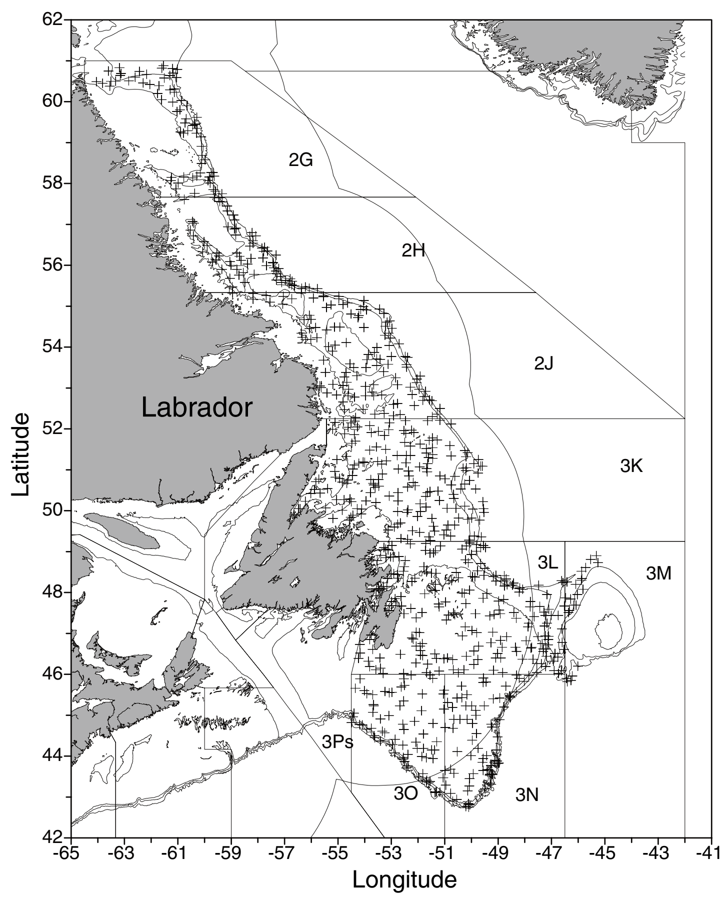


Fig. 1 Set locations for the multi-species 1997 fall survey of the Newfoundland and Labrador region.

*Position des stations pour le relevé multi-spécifique d'évaluation d'automne 1997 dans la région de Terre-Neuve et du Labrador.*

nœuds (durée calculée à partir du moment où toutes les funes ont été mouillées et que les freins ont été appliqués sur le tambour du treuil jusqu'au début de la remontée). La durée du trait pouvait être raccourcie en présence d'un fond accidenté, mais un trait de moins de 20 minutes est généralement considéré comme non valide. Lorsque le chalut Campelen a été introduit à l'automne 1995, un trait de pêche standard avait une durée de 15 minutes à la vitesse de 3,0 nœuds et le système de surveillance de filets Scanmar était utilisé pour déterminer le moment où le filet touchait et quittait le fond. En général, un trait de moins de dix minutes n'était pas considéré comme étant valide. La durée actuelle (filet sur le fond) des relevés au chalut Campelen est déterminée à partir d'une analyse postérieure des données obtenues par une sonde CTD (conductivité, température, profondeur) installée sur le chalut, ce qui permet de déterminer la profondeur exacte du filet pour chaque trait.

Selon les circonstances (ex., présence d'un engin de pêche fixe ou d'un fond non chalutable, ou en cas de contraintes de temps), certaines stations sont remplacées par d'autres stations. Deux stations de rechange par stratum sont généralement choisies avant le relevé, en même temps que se fait le choix aléatoire des stations.

Avant 1995, la longueur du cable d'amarrage à mouiller était déterminée à partir de la table des ratios cable : profondeur. On a modifié cette façon de faire avec l'arrivée du chalut Campelen (McCallum et Walsh 1996). Depuis le début des années 1990, les données géométriques du chalut Scanmar sont enregistrées par ordinateur.

Des changements de navire et d'engin de pêche ont été apportés au cours des ans qui se sont tous avérés des éléments pouvant influencer la capture des organismes par l'engin de pêche utilisé pour le relevé. Pour conserver une série chronologique cohérente, il a fallu apporter des corrections sur les captures de beaucoup d'espèces (Gavaris et Brodie 1984, Warren 1997, Warren et al. 1997, Morgan et al. 1998). McCallum et Walsh (1996) décrivent en détail les chaluts qui ont été utilisés pour les diverses séries chronologiques de chalutage. Un programme intensif de mensuration des chaluts est en place depuis le début des années 1990 afin de veiller à la standardisation des chaluts utilisés pour les relevés.

Depuis 1994, des données sur le type de fond sont régulièrement collectées en utilisant le système RoxAnn installé à l'intérieur du navire.

*D. Fish and Invertebrate Sampling Protocols*

Sampling protocols from earlier surveys have been documented in a number of places, mainly in departmental trip reports. The minimum requirements of the current fish sampling protocol are to determine the total numbers and total weight for almost every fish species caught; almost all fish caught must be identified to the species level. Exceptions include redfish, which are identified as beaked or deep-sea redfish (*Sebastes mentella* and *S. fasciatus*), because of logistical difficulties in identifying these to species level during survey conditions, and myctophids, which are often indistinguishable in the condition they are in when removed from the trawl. Unidentified specimens are preserved and returned to the Northwest Atlantic Fisheries Centre for positive identification.

Many fish species are sampled at sea, and some others (e.g., capelin) are frozen and returned to the lab for further measurement and sampling. Sampling protocols vary among species but often include length, sex, and maturity (LSM) measurements, otolith (stratified samples by length), stomach content sampling, and detailed individual weight analyses. Since 1995, all catch, weight, and length data have been recorded at sea using the computerized data collection system known as FFS (Fisheries Forms System).

Whenever possible, the total catch is processed, but subsampling is necessary for large catches. Different methodologies may be employed for this subsampling, depending on the species and size compositions involved. Generally, a known (weighed) fraction of the catch is chosen at random. For many catches, all of the fish are measured to obtain a detailed biological sampling.

Invertebrate species have not been consistently identified and enumerated in the surveys since 1971, although records usually show the species composition and catch weights of major commercial invertebrates (e.g., scallop, squid, crabs, lobster). The sorting, identification, and sampling of macroinvertebrate catches did not become part of the standard survey protocol until autumn 1995, with the adoption of the Campelen trawl.

The current protocol for invertebrates is that they should always be identified to the species or to the lowest species group possible (e.g., brittle stars, sea urchins, polychaete worms). To minimize the sorting workload for mixed catches of “problematic” small invertebrate species, they can be weighed together and a weight allocated to each species group in proportion to their contribution to the mixture. For every set in which snow crab or shrimp (any species) are caught, detailed biological sampling (e.g., size, sex, maturity, shell condition) is conducted at sea.

*E. Oceanographic Sampling Protocols*

The collection of hydrographic data on fisheries research surveys was initiated as early as May 3, 1894, in waters

*D. Protocoles d’échantillonnage des poissons et des invertébrés*

Les protocoles d’échantillonnage des premiers relevés sont documentés à plusieurs endroits, notamment dans les rapports de mission du Ministère. Les exigences minimales du protocole actuel d’échantillonnage de poissons sont de déterminer les nombres et poids totaux pour presque chaque espèce de poissons capturés; presque tous les poissons capturés doivent être identifiés à l’espèce. Les exceptions incluent le sébaste qui sont identifiés comme un sébaste atlantique ou comme un sébaste des profondeurs (*Sebastes mentella* et *S. fasciatus*) puisqu’il est difficile logistiquement de différencier ces deux espèces dans les conditions des relevés, ainsi que les myctophidés qui sont souvent impossibles à identifier dans l’état où ils se trouvent lorsque retirés du chalut. Les spécimens non identifiés sont conservés et ramenés au Centre des pêches de l’Atlantique Nord-Ouest, pour une meilleure identification.

Plusieurs espèces de poisson sont échantillonnées en mer, alors que d’autres (ex., le capelan) sont congelées puis retournées au laboratoire pour y être mesurées et échantillonnées. Les protocoles d’échantillonnage varient selon l’espèce mais incluent souvent la mesure de longueur, la détermination du sexe et du degré de maturité, les prélèvements des otolithes (échantillons stratifiés par longueur) et du contenu stomacal, et une analyse détaillée du poids des individus. Depuis 1995, toutes les données de poids et de longueur sont enregistrées en mer, à l’aide du système de collecte de données informatiques FFS (Fisheries Forms System).

Dans la mesure du possible, les captures totales sont traitées mais un sous-échantillonnage doit souvent être effectué pour les grosses captures. Différentes méthodes sont alors utilisées, en fonction de l’espèce visée et de la composition par taille de l’échantillon. En général, une fraction connue (pesée) de la prise est choisie au hazard pour représenter le total. Dans plusieurs cas, tout le poisson est mesuré pour obtenir un échantillonnage biologique détaillé.

Les espèces d’invertébrés n’ont pas été identifiées et mesurées de façon constante depuis 1971, bien que les registres indiquent habituellement la composition par espèce et le poids de la capture pour les grandes espèces d’invertébrés à valeur commerciale (ex., pétoncle, calmar, crabe, homard). Le tri, l’identification et l’échantillonnage des prises des captures de macroinvertébrés n’ont été intégrés au protocole de relevé standard qu’à l’automne de 1995, avec l’adoption du chalut Campelen.

Le protocole actuel pour les invertébrés consiste à toujours identifier les invertébrés à l’espèce ou jusqu’au niveau le plus bas du groupe (ex., les ophiures, les oursins, les vers polychètes). Pour minimiser la charge de travail du tri des prises comportant plusieurs espèces de petits invertébrés dits « problématiques », ceux-ci sont pesés ensemble et un poids proportionnel à leur contribution dans le mélange d’espèces leur est attribué. Pour chaque trait où le crabe des neiges ou la crevette (peu importe l’espèce) sont présents, un échantillonnage biologique détaillé (ex., taille, sexe, maturité, condition des carapace) est effectué en mer.

*E. Protocoles d’échantillonnage océanographique*

La cueillette de données hydrographiques sur les relevés de recherches halieutiques remonte au 3 mai 1894 dans les eaux entourant Terre-Neuve au moyen de thermomètres à renversement Negretti et around Newfoundland using Negretti and Zambra deep-sea reversing thermometers; it has remained an integral part of fisheries resource assessment surveys. However, there have been numerous changes to the oceanographic sampling protocols and technology that were not documented in any great detail.

Systematic hydrographic sampling in support of fisheries research was initiated on August 5, 1931, by the Newfoundland Fisheries Research Commission operating from its research laboratory at Bay Bulls Newfoundland. Temperature and salinity measurements were made at several discrete depths using Nansen bottles fitted with deep-sea reversing thermometers for a five-year period from 1931-1935. Bottle salinity samples were determined by chemical titrations.

Throughout the late 1940s and 1950s, hydrographic data were collected using Nansen and later Knudsen bottles fitted with protected or unprotected reversing thermometers. Beginning on May 20, 1954, bottle samples were supplemented with mechanical bathythermograph (MBT) deployments that provided a continuous depth-temperature profile to 270 m. At selected stations, surface bucket samples and bottles equipped with reversing thermometers were used for temperature and salinity measurements to verify and calibrate MBT measurements.

Beginning on January 28, 1979, MBT and bottle casts were gradually replaced by expendable bathythermographs (XBT) with an occasional bottle cast at selected stations mainly to determine salinity. Initially these were analogue systems with a paper chart recorder, but these were gradually phased out and replaced with modern digital XBT systems beginning in June 1982.

Towards the end of the 1980s, with the formation of the oceanography section at the Northwest Atlantic Fisheries Centre, an effort was made to enhance oceanographic data collections on fisheries surveys. In 1988, a trawl-mounted CTD probe was tested and in the fall of 1989 a trawl-mounted Sea-Bird™ model SBE-19 CTD system became operational; it has been the primary instrument used to collect oceanographic data during fisheries assessments since then. Expendable bathythermographs are still used occasionally as a backup to the trawl CTD.

## Maritimes Region

*A. History*

Research surveys using a bottom trawl have been conducted on the Scotian Shelf and in the Bay of Fundy since the mid-1950s. Prior to 1970, these surveys were conducted for a variety of purposes and the type of data collected varied. In 1958, standard recording formats were adopted and the data were computerized.

Annual surveys began in July 1970 using methods that were adopted and approved by the International Commission of Northwest Atlantic Fisheries (ICNAF) and later by the Northwest Atlantic Fisheries Organization

Zambra; depuis ce temps, la collecte de ces données est demeurée une partie intégrale des relevés d'évaluation des ressources halieutiques. Cependant, les nombreux changements qui ont été apportés aux protocoles d'échantillonnage océanographique et à la technologie au cours des ans n'ont pas été documentés en détail.

L'échantillonnage hydrographique systématique à l'appui de la recherche halieutique a été initié le 5 août 1931 par la Newfoundland Fisheries Research Commission qui opérait à partir de son laboratoire de recherche dans la baie Bulls, à Terre-Neuve. Des mesures de température et salinité ont été effectuées à plusieurs profondeurs discrètes au moyen de bouteilles Nansen équippées de thermomètres à renversement pour une période de cinq ans, soit entre 1931 et 1935. La salinité des échantillons recueillis était déterminée par titrage chimique.

De la fin des années 1940 jusqu'aux années 1950, les données hydrographiques étaient collectées au moyen de bouteilles Nansen et plus tard de bouteilles Knudsen, munies de thermomètres à renversement protégés ou non protégés. À partir du 20 mai 1954, le déploiement de bathythermographes mécaniques (BTM) fournissant un profil continu de profondeur-température jusqu'à 270 m a été ajouté à l'échantillonnage par bouteilles. Pour certaines stations, de l'eau de surface était recueillie à l'aide d'un seau et des bouteilles munies de thermomètres à renversement pour mesurer la température et la salinité étaient déployés afin de vérifier et calibrer les mesures du BTM.

À compter du 28 janvier 1979, les BTM et les bouteilles ont été graduellement remplacées par des déploiements de bathythermographes non récupérables (XBT), accompagnés d'un déploiement de bouteilles à certaines stations, surtout pour déterminer la salinité. Au début, ces systèmes analogiques enregistraient sur papier graphique; ils ont été progressivement remplacés par des systèmes XBT numériques modernes à partir de juin 1982.

Vers la fin des années 1980, avec la création de la section océanographie au Centre des pêches de l'Atlantique Nord-Ouest, un effort a été fait pour améliorer la collecte des données océanographiques sur les relevés halieutiques. En 1988, une sonde CTD attachée au chalut a alors été testée et, à l'automne 1989, l'utilisation d'un CTD Sea-Bird[MD], modèle SBE-19, monté sur le chalut est devenue opérationnelle; ce CTD est alors devenu l'instrument primaire pour la collecte de données océanographiques sur les relevés d'évaluation. Les bathythermographes non récupérables sont encore utilisés occasionnellement comme système de secours en cas de bris du CTD.

## Région des Maritimes

*A. Historique*

Des relevés scientifiques par chalut de fond sont effectués sur le plateau Néo-Écossais et dans la baie de Fundy depuis le milieu des années 1950. Avant 1970, les relevés avaient plusieurs buts et le genre de données recueillies dépendait du but visé. En 1958, on a adopté des présentations normalisées pour les relevés et on a commencé à saisir les données sur ordinateur.

Les relevés annuels ont débuté en juillet 1970 utilisant les méthodes adoptées et approuvées par la Commission internationale pour les pêcheries de l'Atlantique Nord Ouest, devenue plus tard l'Organisation des pêches de l'Atlantique Nord-Ouest (OPANO). Basés sur un échantillonnage aléatoire stratifié, ces relevés avaient

(NAFO). These surveys used a stratified random design and were intended to provide unbiased, fishery-independent indices of groundfish abundance and recruitment for the Scotian Shelf and Bay of Fundy (Fig. 2).

From 1978 to 1984, additional fall and spring surveys were conducted in the Scotia-Fundy area. Coverage, station allocation, and methods for these surveys were the same as for the summer survey. The spring survey was redesigned in 1986 to cover only the Eastern Scotian Shelf, with new strata and set allocations, and has continued to the present with only two years missed. In 1987, a stratified random survey was designed for Georges Bank as part of a US/Canada co-management agreement (Fig. 3).

The introduction of standardized survey protocols in 1970 was accompanied by a revision of data formats, the introduction of at-sea standing orders or protocols, and a revision of computer methods and formats. These methods, protocols, and formats, described by Halliday and Koeller (1981) and Koeller (1981), were applied to all groundfish surveys including special purpose surveys conducted in what was then referred to as the Maritimes Region (Scotian Shelf, Bay of Fundy, and southern Gulf of St. Lawrence).

The introduction of electronic balances in the early 1990s allowed greater precision in the determination of fish weights. The catch from each fish set was sorted by species into baskets, the total catch was weighed in baskets, and then biological data were collected on individual fish. From 1970 to 1990, spring scales were used to weigh individual fish. These scales were accurate to ± 25 g and any weight less than 25 g was not recorded. In 1990, electronic scales accurate to ± 5 g were introduced and were replaced by a scale accurate to ± 2 g in 1992. Finally, a scale accurate to ± 0.1 g was used in 1996 for individual specimens less than 5 g. From 1970 to 1994, baskets were weighed on a dial face scale in 1 kg increments. Total catches of a species that were less than 0.5 kg were recorded as zero. In 1995, an electronic platform scale replaced the old scale; this scale is accurate to ± 0.01 kg.

With the evolution of microcomputers, data formats and at-sea protocols have evolved since 1995, when the Scotia-Fundy region implemented an onboard data entry system (GSE). All data are now

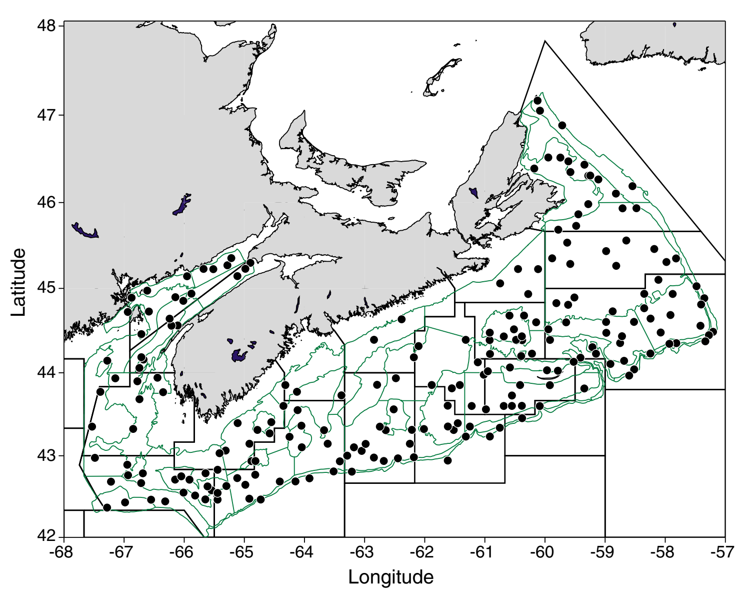


Fig. 2 Station locations for the Scotian Shelf and Bay of Fundy summer survey in 2006 (Maritimes Region).

*Position des stations pour le relevé d'évaluation d'été 2006 sur le plateau Néo-Écossais et dans la baie de Fundy en 2006 (région des Maritimes).*

pour but de fournir des indices indépendants et non biaisés de la pêche et de l'abondance et du recrutement du poisson de fond sur le plateau Néo-Écossais et dans la baie de Fundy (Fig. 2).

De 1978 à 1984, des relevés additionnels d'automne et de printemps ont été effectués dans le secteur Scotia-Fundy. La superficie visée, la répartition des stations et les méthodes d'échantillonnage étaient les mêmes que pour le relevé d'été. Le relevé du printemps a été modifié en 1986 par l'ajout de nouvelles strates et de nouveaux traits de chalut afin de couvrir uniquement la partie est du plateau Néo-Écossais. Ce relevé a été effectué jusqu'à aujourd'hui avec seulement deux années manquantes. En 1987, un relevé aléatoire stratifié a été conçu pour le banc Georges dans le cadre d'une entente de cogestion Canada / États-Unis (Fig. 3).

L'introduction de protocoles de relevé normalisés en 1970 a été accompagnée d'une révision des formats de données, de l'adoption de procédures ou de protocoles en mer et d'une révision des présentations et méthodes informatiques. Ces méthodes, protocoles et formats, décrits par Halliday et Koeller (1981) et par Koeller (1981), ont été appliqués à tous les relevés du poisson de fond, y compris les relevés à objectif particulier menés dans la région que l'on désignait alors comme la Région des Maritimes (plateau Néo-Écossais, baie de Fundy et sud du golfe du Saint-Laurent).

L'arrivée de balances électroniques au début des années 1990 a permis de peser les poissons capturés de façon plus précise. Les captures de chaque trait de chalut étaient triées par espèce dans de grands paniers et pesés. Les données biologiques étaient ensuite prélevées sur certains individus. De 1970 à 1990, des balances à ressort étaient utilisées pour peser les poissons individuels. Ces balances étaient précises à ± 25 g et le poids de tout poisson pesant moins de 25 g n'était pas enregistré. En 1990, des balances électroniques avec une précision de ± 5 g ont été introduites et remplacées par des balances d'une précision de ± 2 g en 1992. Finalement, une balance avec une précision de ± 0,1 g a été introduite en 1996 pour les individus pesant moins de 5 g. De 1970 à 1994, les paniers étaient pesés sur des balances à cadran gradué par unités de 1 kg. On inscrivait 0 pour les prises totales d'une espèce pesant moins de 0,5 kg. En 1995, cette balance a été remplacée par une balance électronique à bascule d'une précision de ± 0,01 kg.

Avec le perfectionnement des microordinateurs, les formats de données et les protocoles en mer ont évolué dans la région de Scotia-Fundy où, depuis 1995, un système de saisie des données du relevé à bord du navire (GSE) est utilisé. Toutes les données sont maintenant saisies directement dans une base de données et des contrôles entered directly into a database, and error checks are built in to assist in detecting erroneous data. A survey manual was updated to describe the new procedures (M. Strong and S. Gavaris, DFO Maritimes Region, unpublished), and a guide for using the GSE was developed to describe standard procedures and to assist in troubleshooting when computer problems were encountered (J. Gale, DFO Maritimes Region, unpublished).

*B. Survey Design*

The surveys employ a stratified random design. The survey area was divided into strata based on the biogeography of fish stocks and depth zones, with strata described by depth ranges of <50 fm, 50–100 fm, or 100–200 fm. In 1970, the number of stations allocated to each stratum was roughly proportional to stratum surface area, with larger strata receiving more stations. Additional stations were added between 1984 and 1990 and again in 1999 to increase sampling in areas of high commercial fish abundance. Three new strata (496, 497 and 498) were added in 1995 on the edge of the Scotian Shelf to extend the coverage down to 400 fm, with the primary objective of including areas where redfish were abundant.

There have been changes to the vessel and gear over the span of the time series. In 1982, the side trawler *A. T. Cameron* was replaced by a stern trawler and at the same time the Yankee 41 trawl was replaced by the Western IIA box trawl. The *Lady Hammond* was used in 1982, but the *Alfred Needler* has been the primary survey vessel since 1983. Comparative fishing studies were conducted to determine conversion factors for these gear and vessel changes, but conversion factors have only been derived for a small set of commercial species (Fanning 1985).

*C. Fishing Protocols*

Fishing protocols were documented by Koeller (1981). A standard set is 30 minutes long at a speed of 3.5 knots, timed from when all warp is out to the start of the haulback. Tows of less than 20 minutes or greater than 40 minutes are not considered to be valid sets. Alternate stations may be substituted depending on circumstances (e.g., presence of fixed fishing gear, untrawlable bottom at a station, time constraints). Set positions may be moved by up to a maximum of 1.75 nautical miles to avoid untrawlable bottoms.

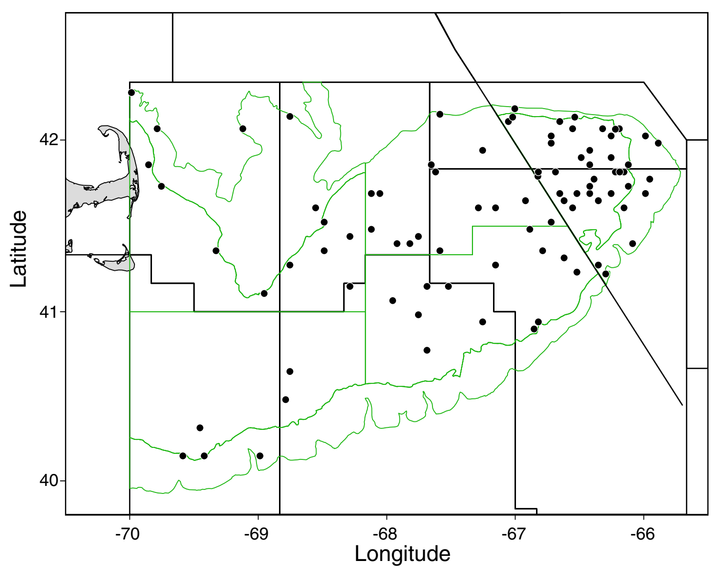


Fig. 3 Station locations for the Georges Bank winter survey in 2007 (Maritimes Region).

*Position des stations pour le relevé d'évaluation d'hiver 2007 sur le banc Georges (région des Maritimes).*

sont intégrés dans le système afin de déceler les erreurs. Le guide du relevé a été mis à jour pour décrire les nouvelles procédures (M. Strong et S. Gavaris, MPO région des Maritimes, non publié) et un guide d'utilisation du GSE décrit les procédures normalisées et donne des conseils sur la façon de régler d'éventuels problèmes informatiques (J. Gale, MPO région des Maritimes, non publié).

*B. Conception du relevé*

La conception du relevé se fait selon une approche aléatoire stratifiée. La zone du relevé a été répartie en strates selon la biogéographie des stocks de poisson et des différentes profondeurs d'eau. Les strates sont divisées en trois couches distinctes : moins de 50 brasses, de 50 à 100 brasses et de 100 à 200 brasses. En 1970, le nombre de stations par strate était plus ou moins proportionnel à la superficie des strates, les plus grandes ayant droit à plus de stations. Des stations ont été ajoutées entre 1984 et 1990 ainsi qu'en 1999 afin d'accroître l'échantillonnage dans des zones à forte abondance de poissons commerciaux. Trois nouvelles strates (496, 497 et 498) ont été ajoutées en 1995 sur la marge du plateau Néo-Écossais afin d'étendre la couverture jusqu'à 400 brasses, avec comme objectif d'inclure les zones d'abondance du sébaste.

Plusieurs changements de navire et d'engin de pêche sont survenus depuis le début de la série temporelle. En 1982, le chalutier à pêche latérale *A. T. Cameron* a été remplacé par un chalutier à pêche arrière, en même temps que le chalut Yankee 41 était supplanté par le chalut à boîte Western IIA. Le relevé de 1982 s'est effectué sur le *Lady Hammond*, mais le *Alfred Needle*r est devenu le navire de recherche principal depuis 1983. Des études de pêches comparatives ont été effectuées afin de déterminer des facteurs de conversion tenant compte de ces changements d'engins et de navires, mais des facteurs de conversion n'ont été déterminés que pour un choix limité d'espèces commerciales (Fanning 1985).

*C. Protocoles de pêche*

Les protocoles de pêche ont été documentés par Koeller (1981). Un trait de chalut normalisé dure 30 minutes à la vitesse de 3,5 nœuds, à partir du moment où toutes les funes ont été mouillées jusqu'au début de la remontée. Des traits de chalut de moins de 20 minutes ou de plus de 40 minutes sont non valides. Les stations peuvent être remplacées par d'autres selon les circonstances (ex., présence d'un engin de pêche fixe ou d'un fond non chalutable ou encore en cas de contraintes de temps). La position du trait peut être déplacée d'une distance maximale de 1,75 mille marin pour éviter un fond non chalutable.

During most surveys, the amount of warp deployed was determined by the officer on the bridge, based on fishing experience. In general, a warp-to-depth ratio of about 3 : 1 was used in shallow water, with a lower ratio used in deeper water or on rough bottom. This pattern began to change around 1996, with higher ratios used in some surveys, and since 2005, a warp-to-depth ratio table for the Western IIA trawl has been used to determine the amount of warp deployed.

Scanmar trawl geometry data were collected from 1990 to 1994 and since 2005. Data are logged every 15 seconds but are not used to adjust net performance after the net begins to tow on the bottom or to determine duration of the tow.

*D. Fish and Invertebrate Sampling Protocols*

Protocols for sampling fish and invertebrates were documented by Koeller (1981). They were updated in 1995 to record increased sampling details (M. Strong and S. Gavaris, DFO Maritimes Region. Manual bottom trawl surveys marine Scotia-Fundy region, unpublished). The Georges Bank survey continued to follow this protocol until 2006, while the number of species for which detailed sampling has been conducted on the Scotian Shelf has increased over time.

Whenever possible, the total catch is processed, but subsampling may occasionally be necessary for large catches. For most catches, all of the fish can be measured for detailed biological sampling.

All fish caught must be identified to the species level. The only exceptions are redfish, which are identified as unspecified redfish because of uncertainties concerning their taxonomy, and myctophids (lanternfishes). If identification is impossible at sea, unidentified specimens must be frozen and brought ashore for positive identification. For every fish species, total number, total weight, and length-frequency data have been collected in all years.

From 1970 to 1985, length-stratified samples were required from three fish per 3-cm length group for cod, pollock, white hake, all skates, and dogfish, two per 2-cm group for haddock, and one per 1-cm group for all other species. Length-stratified sampling was conducted by sex for silver hake; redfish; plaice; yellowtail; witch and winter flounder; halibut; all skates; and dogfish. Detailed sampling for selected species included observations of length, weight, sex, maturity, and collection of otoliths.

For the period 1986 to 1994, detailed observations were collected only for cod, pollock, haddock, silver hake, and plaice, with data on maturity collected only for silver hake. During this period, only length frequencies were required for all other fish species. From 1995 to 1997, maturity stages were again recorded for species where detailed observations were made, but since 1998

Pendant la plupart des relevés, l'officier de quart déterminait la longueur des funes déployées, selon son expérience de pêche. En général, on utilisait un rapport fune-profondeur d'environ 3 : 1 en eau peu profonde, et un rapport plus faible dans des zones plus profondes ou sur un fond rugueux. À partir de 1996, les choses ont commencé à changer et des rapports plus élevés ont été utilisés dans certains relevés et, depuis 2005, on utilise un tableau de rapports longueur-profondeur pour déterminer la longueur des funes pour pour le chalut Western IIA.

Des données sur la géométrie du chalut Scanmar ont été prélevées de 1990 à 1994 et depuis 2005. Les données sont enregistrées aux 15 secondes, mais ne sont pas utilisées pour ajuster la performance du filet quand ce dernier commence à traîner sur le fond, ni pour déterminer la durée du trait.

*D. Protocoles d'échantillonnage des poissons et des invertébrés*

Les protocoles d'échantillonnage des poissons et des invertébrés ont été documentés par Koeller (1981). Ils ont été mis à jour en 1995 pour inclure des données plus détaillées (M. Strong et S. Gavaris, MPO région des Maritimes. Manual bottom trawl surveys marine Scotia-Fundy region, unpublished). Ce protocole a continué d'être utilisé pour le relevé sur le banc Georges jusqu'en 2006, tandis que le nombre d'espèces pour lesquelles un échantillonnage détaillé a été effectué sur le plateau Néo-Écossais n'a cessé d'augmenter.

Dans la mesure du possible, la capture totale est traitée mais un sous-échantillonnage doit être effectué pour les grosses captures. La plupart du temps, tout le poisson capturé est mesuré afin d'obtenir un échantillonnage biologique détaillé.

Tous les poissons capturés sont identifiés jusqu'au niveau de l'espèce. Les seules exceptions sont les myctophidés ou poissons-lanternes, et le sébaste, que l'on identifie comme étant du sébaste non identifié, en raison des incertitudes au sujet de sa taxonomie. S'il est impossible d'identifier un spécimen en mer, il faut le congeler et le ramener à terre pour procéder à l'identification positive. Tout au long de la série temporelle, on a recueilli pour toutes les espèces des données sur les poids et les nombres totaux et sur les fréquences de longueur.

De 1970 à 1985, trois échantillons stratifiés étaient requis pour chaque unité de 3 cm de longueur pour la morue, la goberge, la merluche blanche et toutes les espèces de raies et d'aiguillats, pour deux individus par unité de 2 cm pour l'aiglefin, et pour un individu par unité de 1 cm pour toutes les autres espèces. Des échantillons stratifiés selon la longueur par sexe ont aussi été prélevés pour le merlu argenté, le sébaste, la plie lisse, la limande à queue jaune, la plie grise, la plie rouge, le flétan, et toutes les raies et aiguillats. L'échantillonnage détaillé pour certaines espèces comprenait des données sur la longueur, le poids, le sexe et la maturité, avec prélèvement d'otolithes.

De 1986 à 1994, des observations détaillées ont été faites seulement pour la morue, la goberge, l'aiglefin, le merlu argenté et la plie lisse, et des données sur la maturité n'ont été prélevées que pour le merlu argenté. Au cours de cette période, uniquement les données sur les fréquences de tailles étaient requises pour toutes les autres espèces. De 1995 à 1997, les stades de maturité ont de nouveau été consignés pour les espèces ayant fait l'objet d'observations détail-only silver hake maturities have been required due to the difficulty in differentiating immature and resting stages in summer.

The only invertebrate species that have been consistently identified and enumerated in this survey since 1970 are squid and lobster. Although there are periodic records for other invertebrates, it has only been since 1999 that the sorting and sampling of invertebrates has become standard protocol in the Bay of Fundy and on the Scotian Shelf surveys.

The same data requirements have been consistently adhered to on Georges Bank, except that detailed observations have only been taken for cod, haddock, pollock, and yellowtail flounder, and invertebrate sampling was not enhanced in 1999.

While the sampling protocols for the Georges Bank survey have remained static, there have been changes to the detailed sampling of fish and increases in sampling of invertebrates on the Scotian Shelf and Bay of Fundy surveys. Length stratification for detailed sampling was changed to one fish per 1 cm length grouping in 1995, and this protocol has been followed since then. Enhanced sampling of crustaceans, bivalves, and corals was instituted in 1999. Most common invertebrates have been sorted and identified since 1999, though not always to species level, and total weight and total number have been recorded. Individual carapace lengths are recorded for lobsters and most crab species, and shell height is recorded for sea scallops. Total weight has been recorded for corals and samples retained for detailed work onshore. Starting in 2006, all corals have been sorted and weighed by species, and identifications have been corroborated onshore. Many other taxa, including sponges, brittle stars, basket stars, bryozoans, tunicates, and a variety of zooplankton, are encountered but not sorted or sampled.

*E. Oceanographic Sampling Protocols*

Since 1970, there have been numerous changes to the oceanographic sampling protocols that have accompanied the changes in the technology used. Unfortunately, these changes have not been well documented (see Koeller 1981 and Hurlbut and Clay 1990).

From 1970 to 1989, minimum hydrographic observations, consisting of surface and bottom water samples and a temperature profile, were collected with a mechanical bathythermograph (MBT). At a number of selected stations, a full series of hydrographic observations were made; these consisted of an MBT cast and water samples taken at specific depths. In addition, XBT casts were made between widely spaced stations. Beginning in 1990, profiles of temperature, conductivity (salinity), and oxygen concentration have been obtained with a Sea-Bird CTD. Since 1999, VEMCO™ depth/temperature Minilogs have been attached to the trawl during each set to monitor the temperature and to provide a back-up to the bottom temperatures measured by the CTD.

lées, mais depuis 1998, seulement les stades de maturité du merlu argenté ont été utilisés en raison de la difficulté à distinguer les stades immatures et les stades de repos durant l'été.

Depuis 1970, le calmar et le homard sont les seules espèces d'invertébrés qui ont été systématiquement identifiées et recensées dans le cadre de ce relevé. Malgré la présence de données périodiques pour les autres invertébrés, ce n'est que depuis 1999 que le tri et l'échantillonnage des invertébrés font partie du protocole standard des relevés de la baie de Fundy et du plateau Néo-Écossais.

Les exigences en matière de données ont toujours été respectées pour le banc Georges, sauf que les observations détaillées se sont limitées à la morue, l'aiglefin, la goberge et la limande à queue jaune, et que l'échantillonnage d'invertébrés n'a pas été amélioré en 1999.

Même si les protocoles d'échantillonnage pour le relevé du banc Georges n'ont pas changé, une augmentation des prélèvements d'invertébrés et des changements dans l'échantillonnage détaillé des poissons se sont produits pour les relevés du plateau Néo-Écossais et de la baie de Fundy. En 1995, la stratification de longueurs pour l'échantillonnage détaillé a été changée à un individu par unité de 1 cm. Ce protocole est en vigueur depuis ce temps. Un échantillonnage amélioré des crustacés, bivalves et coraux a été mis en place en 1999. Le tri et l'identification des invertébrés les plus communs ont été effectués depuis 1999, quoique pas toujours au niveau de l'espèce, et les poids et nombres totaux ont aussi été enregistrés. Les longueurs de carapace pour tous les homards et de la plupart des espèces de crabes ont été mesurées, ainsi que l'épaisseur de la coquille des pétoncles géants. Le poids total des coraux a été enregistré et des échantillons ont été conservés pour fins d'analyse détaillée à terre. Depuis 2006, tous les coraux sont triés et pesés par espèce, et chaque identification est vérifiée à terre. De nombreux autres taxons, comprenant les éponges, les ophiures, les fausses étoiles de mer, les bryozoaires, les tuniciers et une variété de zooplancton sont observés mais n'ont pas fait l'objet de tri ou d'échantillonnage.

*E. Protocoles d'échantillonnage océanographique*

Depuis 1970, de nombreux changements ont été apportés aux protocoles d'échantillonnage océanographique qui ont été occasionnés par les changements technologiques. Malheureusement, ces changements n'ont pas été bien documentés (voir Koeller 1981 et Hurlbut et Clay 1990).

De 1970 à 1989, un minimum d'observations hydrographiques a été effectué, comprenant des échantillons d'eaux de surface et de fond ainsi qu'un profil de température, au moyen d'un bathythermographe mécanique (BTM). À certaines stations, une série complète d'observations hydrographiques a été effectuée qui comprenait un déploiement de BTM et des prélèvements d'échantillons d'eau à partir de profondeurs distinctes dans la colonne d'eau. En outre, des lancements de XBT ont eu lieu entre les stations très espacées les unes des autres. À compter de 1990, on a enregistré des profils de température, de conductivité (salinité) et de concentration en oxygène au moyen d'une sonde CTD Sea-Bird. Depuis 1999, on attache au chalut des enregistreurs de profondeur et de température VEMCO[MD] (Minilog) afin de monitorer la température et de confirmer les mesures de température au fond enregistrées par le CTD.

Oceanographic data collection was expanded starting with the 1999 Scotian Shelf and Bay of Fundy survey. In addition to CTD profiles and water sampling previously conducted at all successfully fished stations, additional water samples have been collected from specific depths for salinity, nutrient, chlorophyll, and oxygen determination. The expanded sampling has also included vertical zooplankton net tows from bottom to surface and the collection of phytoplankton samples from surface and bottom water. These samples are collected at the Halifax section, Station 2, and at a number of stations distributed throughout the survey as part of the Atlantic Zone Monitoring Program (AZMP).

*F. Future Plans*

Enhancements to sampling details are continuing and there has been movement away from a focus solely on commercial groundfish towards surveys that provide broad information on ecosystem status. Detailed data collection from all fish species and invertebrates will begin on Georges Bank in 2007, following the protocols used on the Scotian Shelf. Additional sorting and identification of invertebrates are also planned for this trip, and a finer level of taxonomic resolution is planned for many species that are currently included in broad groupings, particularly in deep water where taxonomic resolution has been poor. Additional fixed stations for detailed hydrographic sampling are being considered, and the seasonal and geographic coverage of the surveys is being reviewed. Meeting the increasing demands for long-term monitoring, a requirement for achieving the goal of managing ecosystems, will be the challenge for future surveys.

## Gulf Region

*A. History*

Research vessels, operated by the Canadian government (Fig. 4), have conducted multi-species trawl surveys in the southern Gulf of St. Lawrence since the mid-1950s. Prior to 1970, these surveys were conducted for a variety of purposes, and the nature and detail of the data gathered varied.

Standardized, stratified random, bottom-trawl surveys were initiated in the southern Gulf of St. Lawrence in September 1971. This survey was designed to provide indices of abundance and biomass for demersal fish stocks in the southern Gulf using methods that were adopted and approved by ICNAF (International Commission of Northwest Atlantic Fisheries) and later by NAFO (Northwest Atlantic Fisheries Organization).

The introduction of standardized survey protocols in 1971 was accompanied by a revision of data formats, the introduction of at-sea standing orders or protocols, and a revision of computer methods and formats. These methods, protocols, and formats were applied to all demersal fish surveys conducted in what was then referred to as the Maritimes Region (Scotian Shelf, Bay of Fundy, and southern Gulf of St. Lawrence); these protocols,

La collecte de données océanographiques a pris plus d'ampleur avec le relevé de 1999 sur le plateau Néo-Écossais et dans la baie de Fundy. Outre le profil CTD et le prélèvement d'échantillons d'eau effectués à toutes les stations pêchées avec succès, d'autres échantillons d'eau ont été prélevés à partir de profondeurs distinctes, pour déterminer la salinité, les concentrations en sels nutritifs, chlorophylle et oxygène dissous. Cet échantillonnage élargi incluait également des traits verticaux de filet à zooplancton (du fond à la surface), et des prélèvements d'échantillons d'eau de surface et de fond pour le phytoplancton. Ces échantillons sont prélevés à la station fixe 2 du transect de Halifax ainsi qu'à plusieurs autres stations réparties dans le relevé qui font partie du Programme de monitorage de la zone atlantique (PMZA).

*F. Plans futurs*

Les améliorations de l'échantillonnage détaillé se poursuivent et un mouvement a été amorcé pour s'éloigner de la concentration unique sur les pêches commerciales pour s'en aller vers des relevés qui fournissent des renseignements généraux sur l'état de l'écosystème. En 2007, une collecte de données détaillées sur toutes les espèces de poissons et d'invertébrés du banc Georges sera effectuée en suivant les protocoles utilisés pour le plateau Néo-Écossais. On prévoit également augmenter les activités de tri et d'identification des invertébrés pour se rendre à un niveau taxonomique plus précis dans le cas de plusieurs espèces qui sont actuellement regroupées dans des catégories trop larges. Les espèces en eaux profondes sont particulièrement visées, puisque leur résolution taxonomique a donné de piètres résultats jusqu'à présent. Il est également envisagé d'ajouter des stations fixes pour l'échantillonnage hydrographique détaillé, et le choix de la saison pour effectuer les relevés ainsi que leur superficie géographique est également examiné. Le défi à relever pour l'avenir consiste à répondre au besoin d'une surveillance accrue à long terme qui est nécessaire pour une gestion efficace des écosystèmes.

## Région du Golfe

*A. Historique*

Des navires de recherche, exploités par le gouvernement canadien (Fig. 4), effectuent des relevés pluri-spécifiques au chalut dans le sud du golfe du Saint Laurent depuis le milieu des années 1950. Avant 1970, on effectuait ces relevés à différentes fins, et la nature ainsi que le niveau de détail des données collectées pouvaient varier.

Des relevés aléatoires stratifiés et normalisés au chalut de fond dans le sud du golfe du Saint Laurent sont effectués depuis septembre 1971. Ce genre de relevé est conçu pour fournir des indices d'abondance et de biomasse des stocks de poissons de fond dans le sud du Golfe en utilisant les méthodes adoptées et approuvées par la CIPANO (Commission internationale pour les pêcheries de l'Atlantique Nord Ouest) et plus tard par l'OPANO (l'Organisation des pêches de l'Atlantique Nord-Ouest).

L'entrée en vigueur de protocoles de relevé normalisés en 1971 s'est accompagnée d'une révision des formats des données, de l'établissement de protocoles ou d'ordres permanents en mer et d'une révision également des méthodes et des formats informatiques. Ces méthodes, protocoles et formats ont été appliqués à tous les relevés de poissons de fond effectués dans ce qu'on appelait alors la Région des Maritimes (le plateau Néo-Écossais, la baie de Fundy et le sud du golfe du Saint Laurent); ces protocoles, méthodes methods and formats were described by Halliday and Koeller (1981) and Koeller (1981).

The reorganization of the regional structure of the Department of Fisheries and Oceans in Atlantic Canada in the early 1980s coincided with the rapid evolution of microcomputers and further revisions to data formats, methods, and at-sea survey protocols by the Gulf Region. These revisions were described by Hurlbut and Clay (1990), who also documented the survey protocols that were in use from 1970 to 1983. More recently, Benoît et al. (2003) and Benoît and Swain (2003) provided additional information on the survey of the southern Gulf of St. Lawrence that was not documented in Hurlbut and Clay (1990).

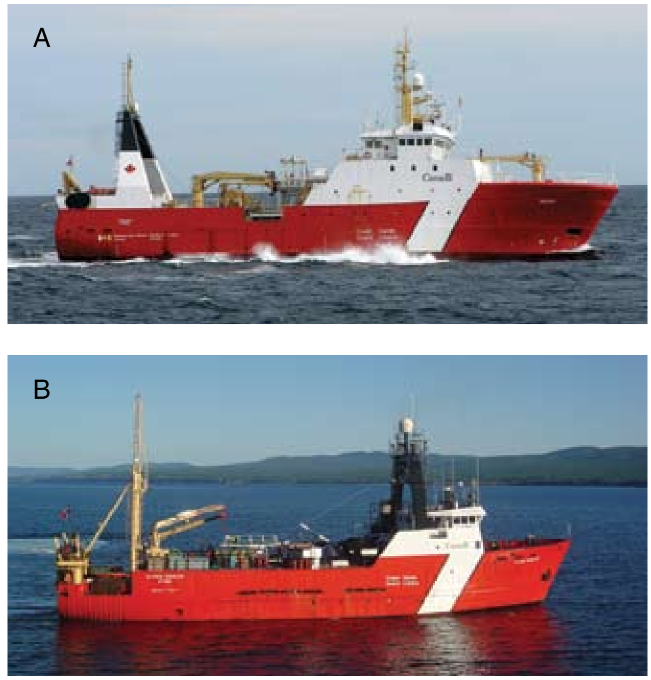


Fig. 4 Survey vessels: CCGS *Teleost* (A) and CCGS *Alfred Needler* (B).

*Navires d'échantillonnage : NGCC* Teleost *(A) et NGCC* Alfred Needler *(B).*

et formats ont été décrits par Halliday et Koeller (1981) et par Koeller (1981).

La réorganisation de la structure régionale du ministère des Pêches et des Océans sur la côte atlantique du Canada au début des années 1980 a coïncidé avec l'évolution rapide de la micro informatique et avec d'autres révisions qui ont été apportées par la Région du Golfe aux formats des données, aux méthodes et aux protocoles des relevés en mer. Ces révisions ont été décrites par Hurlbut et Clay (1990), qui ont aussi documenté les protocoles de relevé utilisés de 1970 à 1983. Plus récemment, Benoît et al. (2003) et Benoît et Swain (2003) ont fourni de l'information additionnelle sur le relevé du sud du golfe du Saint Laurent qui n'avait pas été documentée dans le rapport de Hurlbut et Clay (1990).

Data from this survey have been the foundation for the majority of the stock assessments of commercially important marine fish species in the southern Gulf. They have also become critical for addressing questions concerning species-at-risk and for understanding the structure and function of the southern Gulf ecosystem.

Les données tirées de ce relevé ont jusqu'à présent servi de fondement à la majorité des évaluations des stocks d'espèces de poissons marins commercialement importantes du sud du Golfe. Elles sont également devenues indispensables pour répondre à des questions sur les espèces en péril et pour comprendre la structure et la fonction de l'écosystème du sud du Golfe.

*B. Survey Design*

Since 1971, a stratified random survey design, with stations allocated in proportion to stratum surface area, has been maintained. Three inshore strata (401, 402, and 403) were added to the southern Gulf survey area in 1984. With the exception of this addition, both the survey timing (September) and survey area have remained constant since 1971. However, there have been changes to the survey vessel, survey gear, and the time of day at which fishing occurs, all of which have been shown to affect the catchability of organisms by the survey gear. As a result, corrections are required to maintain a consistent time series for

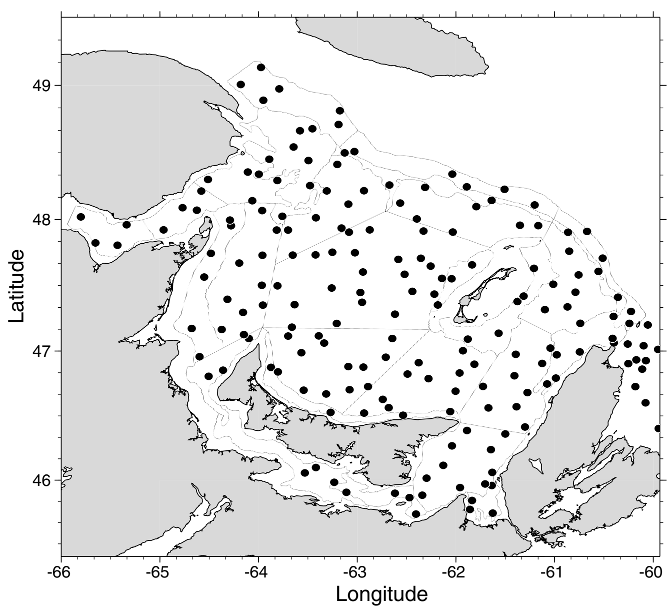


Fig. 5 Location of fishing sets in the Southern Gulf of St. Lawrence for the September multi-species survey in 2006.

*Positions des stations de pêches dans le sud du golfe du Saint-Laurent pour le relevé multi-spécifique d'évaluation de septembre 2006.*

*B. Conception du relevé*

Depuis 1971, un plan de relevé aléatoire stratifié avec répartition des stations proportionnellement à la superficie des strates a été maintenu. Trois strates côtières (401, 402 et 403) ont été ajoutées à la zone du relevé du sud du Golfe en 1984. À l'exception de cet ajout, le moment du relevé (septembre) et la surface de la zone du relevé sont demeurés constants depuis 1971. Cependant, il y a eu des changements concernant les navires et les engins de pêche utilisés, et le moment de la journée où est effectuée la pêche qui se sont tous avérés des éléments influençant la capture par les engins de pêche. Il a donc fallu apporter des many species (Benoît et al. 2003, Benoît and Swain 2003); for additional information, see Halliday and Koeller (1981), Koeller (1981), Hurlbut and Clay (1990), Benoît et al. (2003), and Benoît and Swain (2003). An example of the location of the fishing sets in September 2006 is presented in Figure 5 for the Southern Gulf of St. Lawrence.

*C. Fishing Protocols*

Fishing protocols were documented by Koeller (1981) and later by Hurlbut and Clay (1990). A standard fishing tow is 30-minutes in duration at a speed of 3.5 knots (measured from the time that all of the warp has been “shot” to the beginning of haul-back). Tow duration may be shortened if rough bottom is encountered, but tows of less than 20 minutes are not considered valid.

Alternate stations may be substituted depending on circumstances (e.g., presence of fixed fishing gear, untrawlable bottom at a station, time constraints). Set positions may be moved up to a maximum of 1.75 nautical miles to avoid untrawlable bottom.

The amount of warp shot is determined from Carrothers' (1989) warp-to-depth ratio table for the Western IIA trawl. The Auto-Trawl™ facility must be used during all survey sets. The amount of warp deployed on each side is recorded just before the end of the set on the station card. Scanmar trawl geometry data is also recorded (logged every 15 sec.) but must not be used to adjust net performance after the net begins to tow on the bottom.

*D. Fish and Invertebrate Sampling Protocols*

Protocols for sampling fish and invertebrates were documented by Koeller (1981) and Hurlbut and Clay (1990). The minimum requirements for every fish species caught are total number, total weight, and length frequency. All fish caught must be identified to the species level. The only exceptions are redfish, which are identified as unspecified redfish because of uncertainties concerning their taxonomy. Unidentified specimens must be preserved and returned to the Gulf Fisheries Centre for positive identification.

Whenever possible, the total catch should be processed, but subsampling may occasionally be necessary for large catches. If subsampling is necessary, all fish must be thoroughly mixed beforehand despite the practical difficulties of doing so. For most catches, all of the fish can be measured and stratified for detailed biological sampling. An example of the results obtained is presented in Figure 6.

The identification and sampling of invertebrate species have evolved considerably since 1971 and are described by Benoît et al. (2003). The only invertebrate species that have been consistently identified and enumerated in this survey since 1971 are squid and lobster. Although there are records for crabs (e.g., rock crab, toad crab,

corrections afin de conserver des séries temporelles cohérentes pour plusieurs espèces (Benoît et al. 2003, Benoît et Swain 2003); pour plus d'information, consulter également Halliday et Koeller (1981), Koeller (1981), Hurlbut et Clay (1990), Benoît et al. (2003) et Benoît et Swain (2003). La Figure 5 présente un exemple de localisation des stations de pêches pour septembre 2006 pour la région sud du Golfe.

*C. Protocoles de pêche*

Les protocoles de pêche ont été documentés par Koeller (1981) et plus tard par Hurlbut et Clay (1990). Un trait de chalut standard dure 30 minutes à une vitesse de 3,5 nœuds (durée qu'on calcule à partir du moment où toute les funes ont été mouillées jusqu'au début de la remontée). La durée du trait peut être diminuée lorsqu'un fond accidenté est rencontré mais les traits d'une durée de moins de 20 minutes ne sont pas considérés comme valides.

Certaines stations peuvent être remplacées par d'autres selon les circonstances (ex., présence d'un engin de pêche fixe, un fond non chalutable, contraintes de temps). Les stations peuvent également être déplacées d'une distance maximale de 1,75 mille marin pour éviter un fond non chalutable.

La longueur des funes est déterminée à partir de la table des rapports fune : profondeur de Carrothers (1989) pour le chalut Western IIA. Le mécanisme « Auto Trawl™ » doit être utilisé pour tous les relevés. La longueur des funes déployées de chaque côté du navire doit être enregistrée pour chaque station juste avant la fin du trait de chalut. Les données géométriques du chalut Scanmar (mesures à toutes les 15 sec.) doivent également être enregistrées; ces données ne doivent cependant pas être utilisées pour ajuster la performance du chalut une fois que le filet commence à traîner sur le fond.

*D. Protocoles d'échantillonnage des poissons et des invertébrés*

Les protocoles d'échantillonnage des poissons et des invertébrés ont été documentés par Koeller (1981) et par Hurlbut et Clay (1990). Les exigences minimales pour chaque espèce de poissons capturés sont le nombre et le poids total des poissons et leur fréquence de longueur. Tous les poissons capturés sont identifiés à l'espèce. La seule exception est le sébaste qui est identifié comme espèce non déterminée de sébaste en raison des incertitudes au sujet de sa taxonomie. Les spécimens non identifiés sont préservés et ramenés au Centre des pêches du Golfe pour identification ultérieure.

Dans la mesure du possible toutes les captures sont traitées mais on peut à l'occasion être obligé d'effectuer un sous-échantillonnage pour les grosses captures. S'il faut effectuer un sous-échantillonnage, on doit mélanger à fond à l'avance tous les poissons, en dépit des difficultés pratiques que cela pose. Pour la plupart des captures, tous les poissons peuvent être mesurés et stratifiés pour fin d'échantillonnage biologique détaillé. Un exemple des résultats obtenus est présenté à la Figure 6.

L'identification et l'échantillonnage des espèces d'invertébrés ont énormément évolué depuis 1971 et ont été décrits par Benoît et al. (2003). Les seules espèces d'invertébrés qui ont toujours été identifiées et dénombrées dans le relevé depuis 1971 sont le calmar et le homard. Même s'il existe des données sur le crabe (crabes snow crab), shrimp (Pandalidae and Crangonidae), and scallops extending back to 1971, these species were not consistently identified until 1980 (Benoît et al. 2003). The sorting, identification and sampling of catches of all other macroinvertebrates did not become part of the standard survey protocol until 1985 (Benoît et al. 2003). Benoît et al. (2003) also noted that while efforts have been made to identify species of macroinvertebrates to the lowest practical taxonomic level, a gradual refinement in the taxonomic identification of several of these taxa is evident from 1985 to the mid-1990s. Figure 7 shows examples of sample sorting (A) and taxonomic identification (B).

According to the current protocol, invertebrates should always be identified to the species or to the lowest species group possible. To minimize the sorting workload for mixed catches of “problematic” small invertebrate species (e.g., brittle stars, sea urchins, sand dollars), they can be weighed together, and a weight can be allocated to each species group in proportion to its contribution to the mixture. For every set in which shrimp (any species) are caught, a random sample of up to 1 kg is collected and frozen for species identification at the Gulf Fisheries Centre.

Since 1997, all station, catch, and sampling data have been recorded at sea using the computerized data collection system known as GSE (Groundfish Survey Entry).

communs, araignées et des neiges), la crevette (pandalidés et crangonidés) et le pétoncle qui remontent jusqu’à 1971, ces espèces n’ont pas été identifié systématiquement avant 1980 (Benoît et al. 2003). Le tri, l’identification et l’échantillonnage des prises de tous les autres macro invertébrés n’ont fait partie du protocole du relevé standard qu’à partir de 1985 (Benoît et al. 2003). Benoît et al. (2003) ont aussi noté que quoique des efforts pour identifier les macro invertébrés jusqu’au plus bas niveau taxonomique aient été faits, il est évident qu’un peaufinement graduel de l’identification taxonomique de plusieurs de ces taxa s’est produit entre 1985 et le milieu des années 1990. La figure 7 montre des exemples de tri (A) et d'identification taxonomique (B) des échantillons.

Le protocole actuel exige de toujours identifier les invertébrés jusqu’au niveau de l’espèce ou jusqu’au niveau du groupe le plus bas possible. Pour réduire au minimum la charge de travail du tri des captures mélangées des petits invertébrés dits « problématiques » (ex., ophiures, oursins, clypéastres), on peut les peser ensembles et leur attribuer un poids proportionnel à leur contribution dans le mélange. Pour chaque relevé où des crevettes (peu importe l’espèce) sont capturées, un échantillon aléatoire pesant jusqu’à 1 kg doit être prélevé et congelé pour fin d’identification au Centre des pêches du Golfe.

Depuis 1997, toutes les données sur les stations, les captures, et les échantillonages sont enregistrées en mer, à l’aide du système de collecte de données informatique GSE (Groundfish Survey Entry).

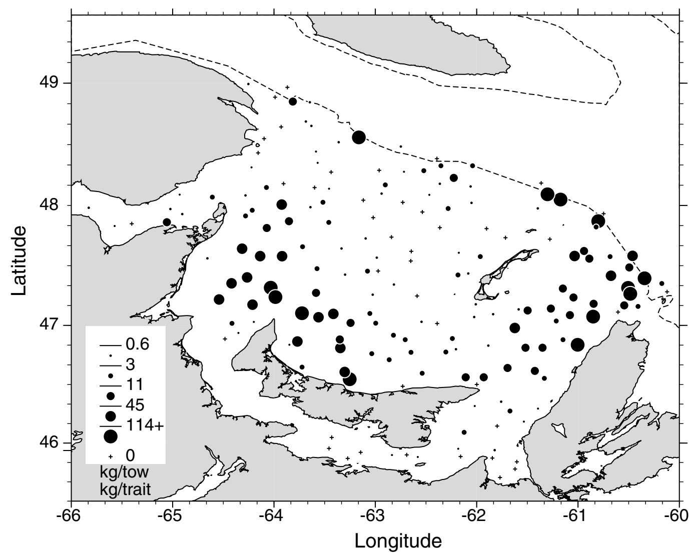


Fig. 6 Cod catch distribution in the southern Gulf of St. Lawrence from the September survey in 2002.

*Répartition spatiale des captures de morues à partir de la mission d’évaluation de septembre 2002.*

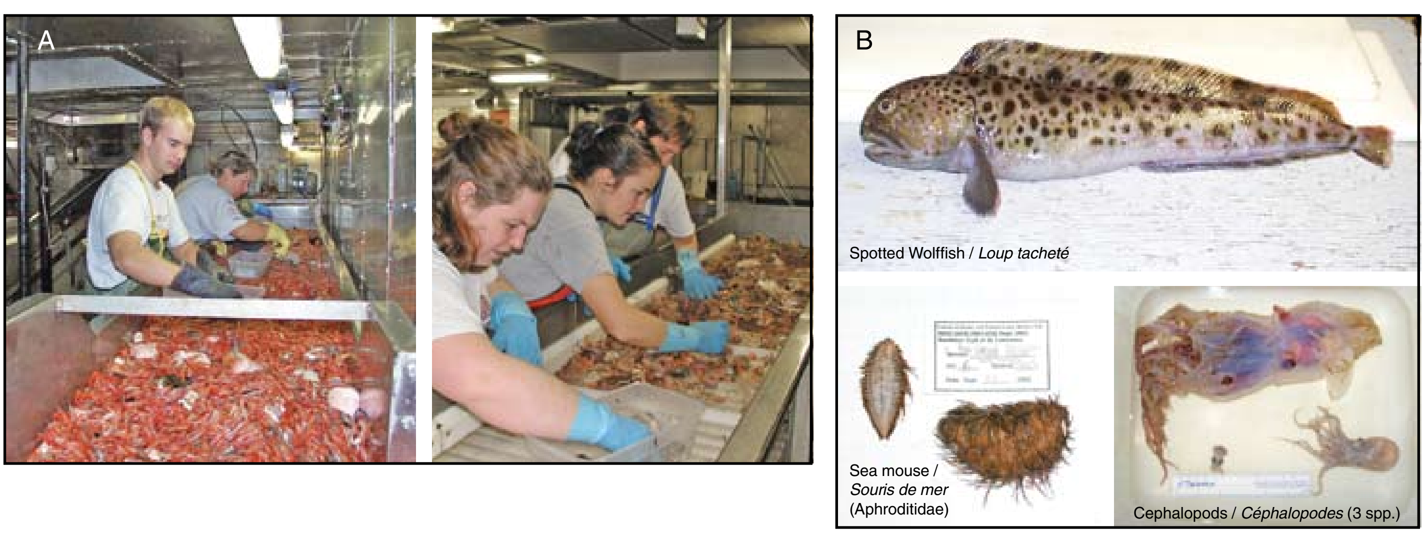


Fig. 7 Examples of sample sorting setup (A) and taxonomic identification effort (B).

*Exemples d'une installation de tri (A) et d'un effort identification taxonomique (B).*

*E. Oceanographic Sampling Protocols*

Since 1971, there have been numerous changes to the oceanographic sampling protocols that have accompanied the changes in the technology used. Unfortunately, these changes have not been well documented (see Koeller 1981 and Hurlbut and Clay 1990). From 1971 to 1982, the oceanographic sampling consisted of a temperature profile measured with a mechanical bathythermograph (MBT), surface temperature measurement, and surface salinity sample from specific fishing stations. At some stations, MBT casts were made and water samplers equipped with reversing thermometers were used to collect water from specific depths for salinity determination and to verify MBT temperature measurements. From 1983 to 1988, MBT casts were made to obtain temperature profiles and surface temperature was measured at each fishing station (the collection of salinity samples was discontinued during this time period).

From 1989 to 1990, temperature profiles were recorded with a custom-made, non-expendable electronic bathythermograph (NXBT) and surface temperatures were measured with a VEMCO™ thermometer at all successfully fished stations. When seas were too rough to deploy the NXBT, an expendable bathythermograph (XBT) cast was made. At each station sampled by the NXBT, water samplers equipped with reversing thermometers were used to collect water from specific depths for salinity determination and dissolved oxygen titrations.

Since 1991, profiles of temperature, conductivity (salinity), and oxygen concentration have been obtained with Sea-Bird™ CTDs. Water samples have also been collected from the surface and from specific depths for salinity, nutrient, chlorophyll, and oxygen determination. Since 2000, CTD profiles have also included measurements of fluorescence (chlorophyll) and irradiance (PAR).

Since about 1996, VEMCO depth/temperature Minilogs have been attached to the trawl during each set to monitor the temperature of the water filtered by the trawl and to provide a back-up to the bottom temperatures measured by the electronic probes.

Oceanographic data collection was expanded during the 1999 survey. In addition to the standard oceanographic sampling done at all successfully fished stations (i.e., CTD profile and the collection of water samples at specific depths for salinity, nutrient, chlorophyll, and oxygen determination), sampling at 15 fishing stations and at the Shediac Valley fixed hydrographic (AZMP) station now includes a vertical zooplankton net tow from bottom to surface and the collection of phytoplankton samples from surface and bottom water.

## Québec Region

*A. History*

The development of multi-species bottom trawl surveys in the northern Gulf of St. Lawrence followed a similar path

*E. Protocoles d'échantillonnage océanographique*

Depuis 1971, de nombreux changements ont été apportés aux protocoles d'échantillonnage océanographique accompagnant les améliorations technologiques. Ces changements n'ont malheureusement pas été bien documentés (voir Koeller 1981 et Hurlbut et Clay 1990). De 1971 à 1982, l'échantillonnage océanographique se composait d'un profil de températures mesuré avec un bathythermographe mécanique (BTM), d'une mesure de la température et d'une prise d'échantillon pour la salinité en surface à chaque station de pêche. À certaines stations des déploiements BTM et de bouteilles munies de thermomètres à renversement étaient utilisés pour prélever l'eau à des profondeurs distinctes, principalement afin de déterminer la salinité, permettant aussi de valider les mesures enregistrées par le BTM. De 1983 à 1988, des lancements de BTM ont été effectués à chaque station de pêche et les prélèvements d'échantillons pour la salinité ont été interrompus.

De 1989 à 1990, des profiles de température ont été effectués avec un bathythermographe électronique récupérable fabriqué sur mesure (NXBT) et la température de surface a été mesurée à l'aide d'un thermomètre VEMCO^MD à toutes les stations pêchées avec succès. Lorsque la mer était trop forte pour déployer le NXBT, un bathythermographe non récupérable (XBT) était lancé. Pour chacune des stations où un profilage NXBT a été effectué, des bouteilles munies de thermomètres à renversement ont été utilisées pour prélever des échantillons d'eau à des profondeurs distinctes pour la détermination de la salinité et la titration de l'oxygène dissous.

Depuis 1991, des profils de température, de conductivité (salinité) et de la concentration en oxygène dissous ont été obtenues à l'aide d'un CTD Sea-Bird^MD. Des échantillons d'eau ont également été collectés à la surface et à des profondeurs discrètes pour la détermination de la salinité, des sels nutritifs, de la chlorophylle et de l'oxygène dissous. Depuis 2000, les profils obtenus à l'aide de ce CTD incluent également des mesures de fluorescence (chloropylle) et d'irradiance (RPU).

Depuis 1996, des enregistreurs de profondeur/température VEMCO (Minilogs) sont attachés au chalut pour monitorer la température de l'eau filtrée par le filet et pour valider les températures de fond mesurées par les sondes électroniques.

La collecte de données océanographiques a été élargie a partir du relevé de 1999. En plus de l'échantillonnage océanographique standard effectué à toutes les stations pêchées avec succès (i.e., profils CTD et prélèvement d'échantillons d'eau à partir de profondeurs distinctes pour déterminer la salinité et les concentrations en sels nutritifs, chlorophylle et oxygène dissous), l'échantillonnage à 15 stations de pêche et à la station hydrographique fixe de la vallée de Shediac (PMZA) a été augmenté pour inclure un trait de filet à zooplancton vertical du fond à la surface et le prélèvement d'échantillons de phytoplancton en surface et au fond.

## Région du Québec

*A. Historique*

Le développement des relevés mutispécifiques au chalut de fond dans le nord du golfe du Saint-Laurent possède un historique to those in the other Atlantic regions. However, annual monitoring only began in 1977, with a survey done by the MV *Gadus Atlantica* in January. This monitoring program ended in 1994 once summer monitoring (see below) became well established. The winter season during which this mission had been carried out is an active migration period that is variable in time and space for many species. This introduced considerable variability and made the interpretation of the data difficult.

Following the reorganization of the Department's administrative region in the Atlantic area in the early 1980s, the winter survey was transferred to what is now the Québec Region, along with two other summer single-species bottom trawl surveys: the first targeting northern shrimp (1982-1989) and using commercial fishing vessels; the second targeting redfish (1983-1989) and using the *Lady Hammond*. These two summer surveys were combined in 1990 on the CCGS *Alfred Needler* (Fig. 4B) to establish a multi-species survey. In 1989, in cooperation with the Centre spécialisé des pêches de Grande-Rivière (CEGEP de la Gaspésie et des Îles), a wide-opening shrimp trawl, the University of Rhode Island (URI) 81'/114' Trawl (see Table 1 for trawl characteristics), was selected. Using a small-mesh trawl was necessary because the survey targeted both northern shrimp (*Pandalus borealis*) and groundfish species. It was tested during a mission conducted in September 1989, and the necessary adjustments were made (Boudreau et al. 1989).

The first mission was conducted in August 1990 and the program has continued since then. Comparative trawls were done in 1990 between the *Lady Hammond* and the CCGS *Alfred Needler*. Because of the large degree of difference in the selectivity of the URI 81'/114' trawl and that of the Western IIA trawl used on the *Lady Hammond*, no conversion factor was calculated at the time, due to the lack of appropriate statistical techniques for determining conversion factors for at length for the fish catches.

In preparation for the decommissioning of the CCGS *Alfred Needler*, the mission was transferred to the CCGS *Teleost* in 2004. Because of mechanical problems on the CCGS *Alfred Needler*, the comparative fishing test was only done in 2005 (instead of the two previous years) to obtain conversion factors (H. Bourdages and colleagues, DFO Québec Region, unpublished data). The fishing protocols used on the CCGS *Teleost* are the same as those used by the Newfoundland Region on this vessel (see above).

*B. Survey Design*

The sampling plan is based on the design described in Pitt et al. (1981), and an example illustrating the loca-

similaire à celui des autres régions de l'Atlantique. Par contre, le monitorage annuel n'a commencé qu'en 1977, avec un relevé effectué par le MV *Gadus Atlantica* au cours du mois de janvier. Ce programme de monitorage a pris fin en 1994 quand le monitorage estival (voir plus bas) a été bien établi. La période hivernale durant laquelle cette mission a été réalisée correspond à une période de migration active, variable dans le temps et l'espace pour de nombreuses espèces, ce qui a introduit une variabilité considérable et a rendu difficile l'interprétation des données.

Suite à la réorganisation des régions administratives du Ministère dans la zone Atlantique au début des années 1980, le relevé hivernal a été transféré à l'actuelle région du Québec, avec deux autres relevés estivaux monospécifiques au chalut de fond : le premier étant dirigé vers la crevette nordique (1982-1989) à partir de navires de pêche commerciaux et le second vers le sébaste (1983-1989) à partir du *Lady Hammond*. Ces deux relevés estivaux ont été regroupés en 1990 sur le NGCC *Alfred Needler* (Fig. 4B) pour en faire un relevé multispécifique. En 1989, en collaboration avec le Centre spécialisé des pêches de Grande-Rivière (CEGEP de la Gaspésie et des Îles), un chalut à crevette à grande ouverture, le University of Rhode Island (URI) 81'/114' Trawl (voir le Tableau 1 pour les caractéristiques de ce chalut) a été sélectionné. L'utilisation d'un chalut à maille fine était nécessaire parce que le relevé ciblait à la fois la crevette nordique (*Pandalus borealis*) et les espèces de poissons de fond. Une mission, réalisée en septembre 1989 a permis de le tester et d'y apporter les ajustements nécessaires (Boudreau et al. 1989).

La première mission a eu lieu en août 1990 et le programme se poursuit depuis. Des traits comparatifs ont été effectués en 1990 entre le *Lady Hammond* et le NGCC *Alfred Needler*. En raison de la très grande différence dans la sélectivité du chalut URI 81'/114' par rapport au chalut Western IIA en usage sur le *Lady Hammond*, aucun facteur de conversion n'a été calculé à l'époque en l'absence de techniques statistiques appropriées pour déterminer des facteurs de conversion en fonction de la longueur des poissons capturés.

En prévision de la mise au rancart du NGCC *Alfred Needler*, la mission a été transférée en 2004 sur le NGCC *Teleost*, mais des problèmes mécaniques sur le NGCC *Alfred Needler* ont fait que l'expérience de pêche comparative n'a été effectuée qu'en 2005 (au lieu des deux années précédentes) afin d'obtenir des facteurs de conversion (Bourdages et al., MPO région de Québec, données non publiées). Les protocoles de pêche utilisés sur le NGCC *Teleost* sont les mêmes que ceux utilisés par la région de Terre-Neuve sur ce navire (voir plus haut).

*B. Conception du relevé*

Le plan d'échantillonnage est basé sur le design décrit dans Pitt et al. (1981) et un exemple illustrant la position des stations de pêches

Table 1 Main characteristics of the URI 81'/114' trawl.
*Principales caractéristiques du chalut URI 81'/114'.*

| | | |
|---|---|---|
| Number of panels | *Nombre de panneaux* | 2 |
| Wing opening | *Ouverture des ailes* | 14-15 m |
| Vertical opening | *Ouverture verticale* | 5.5 m |
| Length of head-rope | *Longueur de la corde de dos* | 24.7 m (81 ft / *pi*) |
| Length of foot-rope | *Longueur de la corde de faux-bourrelet* | 34.7 m (114 ft / *pi*) |
| Doors | *Portes* | Morgère 950 kg |
| Number of floaters | *Nombre de flottes* | 88, plastic / *en plastique* |
| Length of legs | *Longueur des entremises* | 39.6 m |
| Trawl body mesh size | *Maillage du corps du chalut* | 44 mm |
| Mesh size of codend | *Maillage du cul* | 19 mm |

tion of fishing sets in 2006 is shown in Figure 8. Scanmar acoustic sensors were regularly used to monitor trawl characteristics (vertical net opening, distance between doors, net depth) at 15-s intervals during each tow, although this information was not used to modify operations during fishing.

*C. Fishing Protocol*

The change in fishing gear in 1990 led to some significant modifications, such as a reduced duration of tows, since it was expected (and this was confirmed by trials) that the number of small-sized organisms to be sorted and identified would be considerably greater than with a traditional bottom trawl. It had initially been planned to use Scanmar sensors to measure the duration of tows, which had been set at 20 minutes of operation on the bottom (Hurtubise and Gagnon 1993). Because of technical problems with the sensors, this approach had to be abandoned in 1993. The Scanmar data available and the profiles obtained from the STD attached to the upper side of the trawl enabled us to calculate the real distances trawled in 1990-1993 and set the duration of trawls at 24 minutes (1990-1993 average), measured between the stopping and starting of the winches, as of 1993. Towing speed was 3.0 knots. To be considered valid, a tow had to have a minimum duration of 16 minutes (2/3 of target time). The length of the warps to be unwound was based on a table of the ratio warp length : depth established for the MV *Gadus Atlantica.*

From 1993 to 2003, the sampling plan followed an optimal allocation approach with restrictions (Gagnon 1991) so as to minimize variances. However, the addition of restrictions and species in the optimization over the years considerably reduced the efficiency of this approach for reducing the variance. Optimal allocations were abandoned in 2004 and the use of allocations proportionate to the strata surface area was resumed. During the station selection, alternate stations were identified in advance in case of impediments to fishing such as the presence of fixed fishing gear and untrawlable bottom. A replacement tow had to be done within a range of 1.75 nautical miles from the coordinates initially set.

The surveys cover NAFO Divisions 4RS and the deep part (>100 fathoms) of Division 4T. Subdivision 3Pn was sampled from 1994 to 2003, but the very low abundance of the main species in summer led us to abandon the sampling there in favour of other divisions. Some sectors along the North Shore of Québec (strata 825 and 826)

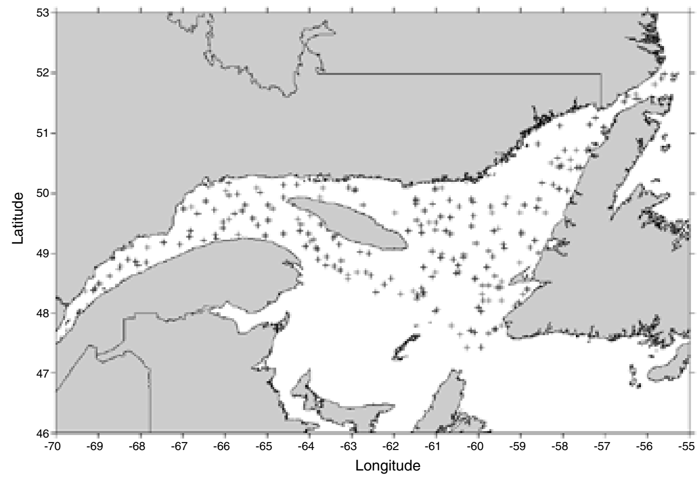


Fig. 8 Location of fishing sets for the Northern Gulf of St. Lawrence survey (CCGS *Teleost*) in 2006.

*Positions des stations de pêche pour le relevé d'évaluation du nord du golfe du Saint-Laurent (NGCC* Teleost*) en 2006.*

en 2006 est présenté à la figure 8. Des sondes hydroacoustiques Scanmar mesurant l'ouverture verticale, la distance entre les portes et la profondeur du chalut ont été utilisées sur une base régulière (fréquence aux 15 secondes) pour enregistrer le comportement du chalut à chacun des traits, sans toutefois utiliser cette information pour modifier les opérations en cours de pêche.

*C. Protocole de pêche*

Le changement d'engin de pêche en 1990 a entraîné quelques modifications significatives, dont la réduction de la durée des traits, puisqu'il était anticipé (et confirmé par des essais) que le nombre d'organismes de petites tailles à trier et à identifier serait considérablement plus important qu'avec un chalut à poisson de fond traditionnel. Initialement il avait été prévu d'utiliser les sondes Scanmar pour mesurer la durée des traits qui avait été fixée à 20 minutes d'opération sur le fond (Hurtubise et Gagnon 1993). Les difficultés techniques avec les sondes ont forcé l'abandon de cette approche dès 1993. Les données Scanmar disponibles, et les profils obtenus des STD attachés sur le dos du chalut, ont permis de calculer les distances réelles chalutées en 1990-1993 et de fixer la durée des traits à partir de 1993 à 24 minutes (moyenne 1990-1993) mesurée entre l'arrêt et le départ des treuils. La vitesse de touage était de 3,0 nœuds. Les traits considérés valides doivent avoir une durée minimale de 16 minutes (2/3 du temps visé). La longueur des funes à dérouler est basée sur un tableau de rapport de longueur de fune : profondeur établi pour le MV *Gadus Atlantica*.

De 1993 à 2003, le plan d'échantillonnage suivait une approche basée sur une allocation optimale avec contraintes (Gagnon 1991) dans le but de minimiser la variance. Cependant, l'ajout au fil des ans de contraintes et d'espèces dans l'optimisation a considérablement réduit l'efficacité de cette approche pour réduire la variance. L'allocation optimale a été abandonnée en 2004 pour revenir à une allocation proportionnelle à la surface des strates. Lors du processus de sélection des stations, des stations alternatives sont déterminées à l'avance au cas où il y aurait des empêchements comme par exemple la présence d'engins de pêche fixes et des fonds non chalutables. La position alternative d'un trait doit se situer dans un rayon de 1,75 milles marin des coordonnées initialement prévues.

Les relevés couvrent les divisions de l'OPANO 4RS et la zone profonde (>100 brasses) de la division 4T. La sous-division 3Pn a été échantillonnée entre 1994 et 2003, mais la très faible abondance des principales espèces en été nous a conduit à abandonner cet échantillonnage au profit d'autres divisions. Certain secteurs le long de la côte nord du Québec (strates 825 et 826) ne sont pas échantillonnés en raison de la topographie très accidentée des are not sampled because of the very uneven topography of the bottom. Finally, in 1991, eight coastal strata were added along the west coast of Newfoundland, the Strait of Belle Isle, and the St. Lawrence Estuary to cover the entire cod and Greenland halibut area of distribution.

*D. Fish and Invertebrate Sampling Protocols*

The biological sampling of catches has evolved over the years. The basic variables that have always been recorded are the identification of each taxon of fish and shellfish as well as the total weight of the catch of each species. Whenever possible, the total catch is processed, but subsampling is occasionally necessary for large catches. Detailed sampling was always done for commercial species and included, at minimum, information on length frequencies, age (otoliths), and maturity. The exact nature of the variables measured varied from one species to the other according to their specific characteristics.

A review of the data on the taxonomic composition of catches brought up chronic problems with the identification of species since the surveys began in 1977 (Dutil et al. 2006). Some groups, such as the Cottidae, Liparidae, and Zoarcidae, are problematic. Identification tools focussing on precise specific characteristics, combined with photographs, were developed to ensure better identification on the vessel. The current procedure is to identify all specimens collected to the species level and to photograph, freeze, and bring back any uncertain cases to ensure precise identification in the laboratory.

Through the years, the quantity of biological variables measured during catch sampling has increased considerably, with the aim of obtaining indications as to the biological condition of the organisms harvested. These measurements were integrated into the regular sampling protocols. Starting in 1995, individual weights of all sampled species were recorded. Additional detailed measurement of liver, stomach content, and gonad weights for the main commercial species (cod, Greenland halibut, redfish, and Atlantic halibut) were progressively introduced to establish condition factors for these species. Finally, starting in 2000, a computer data entry system, closely linked to our databases, was introduced. In addition, numerous discrete samples were collected throughout the years in support of various research projects.

*E. Oceanographic Sampling Protocols*

The number and nature of variables measuring environmental conditions have evolved considerably over the years according to the technology available and our ability to operate measurement devices without unduly disrupting fishing activities. Initially, only temperature profiles were collected using XBTs. Later, the use of CTD sensors attached to the head rope of the trawl (1990-1993) enabled us to include salinity measurements. This was changed in 1994 to standard oceanographic vertical profiles, but various instruments were then attached to the trawl to obtain the time/depth/temperature of the fished profiles.

fonds. Enfin, en 1991, 8 strates côtières furent ajoutées sur la côte ouest de Terre-Neuve, dans le détroit de Belle Isle et dans l'estuaire du Saint-Laurent pour inclure toute l'aire de distribution de la morue et du flétan du Groenland.

*D. Protocoles d'échantillonnage des poissons et des invertébrés*

L'échantillonnage biologique des captures a évolué au cours des ans. Les paramètres de base qui ont toujours été enregistrés sont l'identification de chacun des taxa de poissons et de crustacés et le poids total de la capture pour chaque espèce. En autant que possible, toute la capture est traitée mais des sous-échantillonnages sont parfois nécessaires pour les grosses captures. Les espèces commerciales ont toujours fait l'objet d'un échantillonnage détaillé, qui comprenait au minimum l'information sur les fréquences de longueur, l'âge (otolithes) et la maturité. La nature exacte des variables mesurées a varié d'une espèce à l'autre en fonction de leurs caractéristiques propres.

Un examen des données sur la composition taxonomique des captures a permis d'identifier des problèmes chroniques quant à l'identification des espèces depuis le début des relevés en 1977 (Dutil et al. 2006). Certains groupes sont problématiques comme les Cottidae, les Liparidae et les Zoarcidae. Des outils d'identification axés sur des caractères spécifiques précis, conjugués à des photos, ont été élaborés pour assurer une meilleure identification sur le navire. La procédure actuelle consiste à identifier à l'espèce tous les spécimens capturés, et de photographier, congeler et rapporter au laboratoire tout les cas incertains pour assurer une identification plus précise.

Au fil des ans, la quantité de variables biologiques mesurées lors de l'échantillonnage des captures s'est considérablement accrue pour obtenir des indices sur la condition biologique des organismes capturés. Ces mesures ont été intégrées aux protocoles d'échantillonnage réguliers. À partir de 1995, le poids individuel de toutes les espèces échantillonnées a été recueilli. Des mesures détaillées additionnelles de poids du foie, du contenu stomacal et des gonades ont été progressivement recueillies pour les principales espèces commerciales (morue, flétan du Groenland, sébaste et flétan Atlantique) afin de déterminer des indices de conditions pour ces espèces. Finalement à partir de 2000, un système de saisie électronique, étroitement lié à nos bases de données, a été introduit pour l'enregistrement des données. De plus, plusieurs échantillons spéciaux ont été recueillis au cours des ans pour répondre aux besoins spécifiques de nombreux projets de recherche.

*E. Protocole d'échantillonnage océanographique*

Le nombre et la nature des variables pour mesurer les conditions environnementales ont considérablement évolués au cour des années en fonction de la technologie disponible et notre capacité d'opérer les appareils de mesures sans perturber indument les activités de pêche. Initialement, seuls des profils de température étaient recueillis au moyen de XBT. Par après, l'utilisation de CTD attachés au dos du chalut (1990-1993) a permis d'ajouter des mesures de salinité. À partir de 1994, des profils océanographiques verticaux standards ont été effectués. Divers appareils furent alors attachés au dos du chalut pour obtenir les profils pêchés temps/profondeur/température.

After 1995, data gathering became systematic and increased considerably with the integration of the AZMP surveys (CTD vertical profiles for conductivity, temperature, dissolved oxygen, and fluorescence). Some twenty additional stations, corresponding to oceanographic transects, along with some stations outside the area sampled by trawling (owing to uneven bottoms) were systematically visited to ensure complete coverage of the Estuary and northern Gulf of St. Lawrence from an oceanographic point of view. Starting in 2004, a rosette sampler was used to collect water samples for measurements of dissolved oxygen (by titration), chlorophyll, and various nutrients (nitrites, nitrates, phosphates, and silicates). Finally, in 2006, we added surface to bottom vertical zooplankton net hauls (202 µm mesh size).

Depuis 1995, le cueillette des données s'est systématisée et considérablement accrue suite à l'intégration des missions au PZMA (profils verticaux de CTD pour conductivité, température, oxygène dissous et fluorescence). Une vingtaine de stations additionnelles, correspondant aux transects océanographiques, ainsi que certaines stations à l'extérieur de la zone échantillonnée par le chalutage (en raison des fonds non propices) ont été visitées systématiquement pour assurer une couverture complète de l'estuaire et du nord du golfe du Saint-Laurent au point de vue océanographique. À partir de 2004, l'utilisation d'un échantillonneur rosette a permis d'obtenir des échantillons d'eau pour mesurer l'oxygène dissous (par titration), la chlorophylle et plusieurs sels nutritifs (nitrites, nitrates, phosphates et silicates). Enfin en 2006, nous avons ajouté de traits verticaux (surface jusqu'au fond) de filet à zooplancton (mailles de 202 µm).

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# *Oceanographic Observations from Trawl-Mounted CTDs on Multi-Species Surveys in the Newfoundland and Labrador Region*

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## Sommaire

La récolte de données océanographiques sur les Grands-Bancs de Terre-Neuve a débuté vers la fin du 19ième siècle et fait intégralement partie des standards utilisés pour l'évaluation des ressources depuis le début des années 1970. Historiquement, les observations consistaient principalement en des mesures de profils verticaux de température obtenues à l'aide de bathythermographes déployés à la fin des traits de chalut de pêche. Souvent, ces mesures étaient également calibrées à l'aide d'échantillons d'eau recueillis à l'aide de bouteilles à des profondeurs et stations déterminées. Vers la fin des années 1980, pour faire face aux coûts croissants des sondes non-réutilisables (XBT) et du précieux temps de navire, et associé au besoin compétitif d'augmenter la collection de données océanographiques, on a alors initié un projet pour construire un système de mesures de conductivité-température-profondeur (CTD) pouvant être monté sur un chalut. Au cours de la mission d'échantillonnage de 1989, ce prototype de traineau sous-marin qui comprenait un CTD Sea-Bird modèle SBE-19 a été testé avec succès et est alors devenu opérationnel. Aujourd'hui, ce système est devenu le principal moyen de récolter des données océanographiques durant les missions d'évaluation des pêches. Ce système est normalement attaché aux câbles de tête du chalut et permet d'enregistrer le temps, la pression d'eau, la température et la conductivité pour la durée du trait de chalut, sans ajout de temps de navire à la mission. C'est là une considération importante pour la région de Terre-Neuve et du Labrador étant donné l'importance du nombre de traits de chaluts (~1400) et la surface échantillonnée chaque année (~900,000 km$^2$) sur les missions multi-spécifiques et de recherche. Depuis son implantation en 1989, approximativement 20,000 profils CTD (équivalent à environ $1.2 M en sondes XBT ou environ 1.5 années de temps de navire) ont été effectués sur les chalutiers de pêche. Les données obtenues sont utilisées pour une grande variété de produits et d'analyses qui sont utiles pour le monitorage du climat. Cet échantillonnage représente également une composante vitale du programme d'observation du PMZA. Les données de ces missions sont aussi utilisées pour la préparation des évaluations environnementales demandées par le comité national d'océanographie des pêches, le comité du PMZA, le CIEM (sommaire climatique annuel), et par l'Organisation des pêches de l'Atlantique Nord-Ouest (OPANO). Finalement, ces données représentent une contribution importante pour les études liant la variabilité du climat aux changements dans la répartition et l'abondance des espèces de poissons et d'invertébrés dans les eaux de la région de Terre-Neuve et du Labrador.

## Introduction

The collection of oceanographic data on the Grand Banks dates back to the late 19th century and has been an integral part of the standardized fisheries resource assessment surveys in Newfoundland and Labrador since the early 1970s. Historically, the observations consisted mainly of temperature profiles obtained from bathythermograph deployments at the completion of each fishing set. A standard bottle cast at selected depths and stations for calibration and salinity measurements often supplemented these measurements. These profiles were used to extract bottom temperatures for integration into the fishing set details and, at the end of the field season, the raw data were sent to the Marine Environmental Data Service in Ottawa for quality control and archiving.

Towards the end of the 1980s, faced with both the increasing cost of expendable probes and ship time as well as a competing requirement to enhance oceanographic data collections, a project to construct a trawl mount for a conductivity-temperature-depth (CTD) probe was initiated. During the fall survey of 1989, a prototype sled containing a Sea-Bird model SBE-19 CTD system was successfully tested and implemented. Today it is the primary instrument used to collect oceanographic data during fisheries assessment surveys. The package attached to the trawl head-ropes records time, water pressure, temperature, and conductivity for the duration of the fishing set without adding valuable ship time to the survey. This is an important consideration in the Newfoundland and Labrador region given the number of fishing sets (~1400) and the area surveyed (~900,000 km$^2$) annually on the multi-species and other research surveys (Brodie 2005).

Since its implementation in 1989, approximately 20,000 CTD deployments (equivalent to over $1 million in XBT probes or more than 1 year of ship time) on fishing trawls have been made in Newfoundland and Labrador waters. During 2005, 1331 trawl-mounted CTD profiles were archived: 283 from the spring 3P survey, 320 from the spring 3LNO survey, 685 from the fall 2J3KLNO survey, and 43 from other research surveys in the region. These surveys provide two large spatial-scale temperature and salinity data sets annually, one during the spring and one in the fall, that allow for the construction of a wide array of data products useful for ocean climate monitoring (Harrison et al. 2004). The surveys thus provide a significant component of the AZMP observational program that was initiated in the late 1990s (Therriault et al. 1998).

The data products are currently used in the environmental reviews prepared for the Fisheries Oceanography Committee (Colbourne et al. 2006), the AZMP Committee's Science Advisory Report for NL (DFO 2006), and in the report of Northwest Atlantic Fisheries Organization's (NAFO) standing committee on fisheries environment. In addition, the data provide valuable information to studies linking ocean climate variability to changes in the distribution and abundance of fish and invertebrate species in Newfoundland and Labrador waters (Colbourne and Kulka 2004).

## Trawl Mount Design and Instrumentation

Some of the obvious challenges and considerations associated with collecting reliable measurements of water properties during trawling operations include the protection of

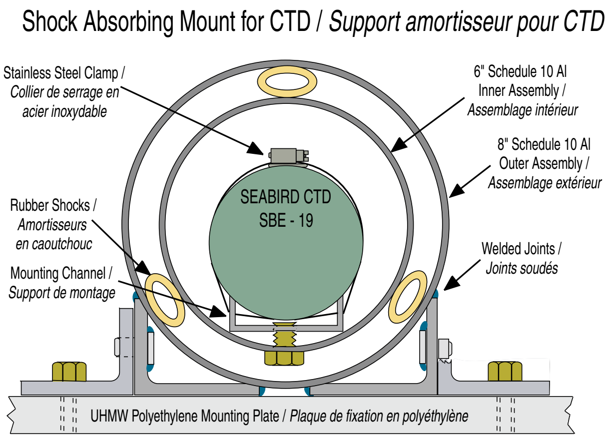


Fig. 1 A cross-section schematic of the shock-absorbing CTD sled showing its major components (Adapted from the original engineering drawings by T. Foulkes, DFO, 1989).

*Profil transversal montrant le montage du CTD sur son support permettant d'absorber les chocs (Adapté des dessins originaux de T. Foulkes, MPO, 1989).*

instrumentation, potential affects of additional hardware on trawl fishing performance, and possible effects on trawling operations from a deployment and recovery perspective. The biggest challenge is how to deal with the extreme vibrations to the instrument's electronics associated with trawling over rough bottom terrain. Therefore, the engineering design had to offer both acceptable hydrodynamic performance and very high shock-absorbing properties. To meet these requirements, a coaxial protective sled was designed for attachment to a flat buoyant plate (Fig. 1 & 2).

The shock-absorbing trawl mount consists of three sub-assemblies: (1) the headline mounting plate, which shackles directly to the headlines of the trawl, (2) the outer shock assembly that mounts directly to the mounting plate, and (3) the inner shock mount assembly that contains the CTD pressure case. The mounting plate measuring about 0.75" × 24" × 40" was made from ultra-high molecular weight polyethylene that is capable of absorbing high impacts and is positively buoyant in seawater. The inner and outer shock assemblies are 6" and 8" Schedule 10 aluminum industrial strength pipe separated by heavy-duty rubber tubing along the full length of the pipes to provide high shock absorption. The CTD pressure case attached to a 1.5" × 3" aluminum channel is bolted to the inner pipe. The combined weight of the sled assembly including the CTD is about 15 kg in seawater. When attached to the trawl headline, the hydrodynamic properties of the plate and pipes generate enough lift to negate the need for additional trawl floats. The shock mount assembly is also designed to be easily removed from the headline mounting plate for CTD servicing and data retrieval by two flexible T-handle draw latches.

After initial trials with an Applied Microsystems CTD, the Sea-Bird SBE-19 CTD recorder was chosen for the trawl-mounted system. The expected accuracy of this system under ideal deployment conditions is ±0.005°C for temperature and ±0.005 for salinity, compared to ±0.1–0.2°C in temperature from bathythermographs. The net-mounted CTDs are not field calibrated

Fig. 2 The trawl-mounted CTD package ready for deployment.

*Le système CTD monté sur son traîneau sous-marin et prêt pour le déploiement.*

but are checked periodically against known systems both in the field and in a laboratory test tank. If sensor problems are identified during the calibration check, the unit is sent to Sea-Bird Electronics, Inc., for factory calibration. During each survey, a minimum of two complete systems per vessel are normally available. Given the harsh environment encountered during bottom trawling, the conductivity cell operates without the usual pump and associated plumbing; however, since the trawl deployments are relatively slow, usually ≤0.5 m $s^{-1}$, the response time of the conductivity cell is generally adequate to achieve a reasonable accuracy in salinity, certainly sufficient to resolve ocean climate variability. Immediately before each trawl deployment, the CTD is initialized and at the end of each tow the data are downloaded, plotted, and checked for accuracy. If problems with the CTD data are obvious from a visual inspection of the graphs, resulting from either battery or electronic failures or debris in the conductivity cell, an XBT cast for that particular fishing set is acquired.

## Data and Quality Control

The CTD data collected consist of an oblique downcast corresponding to the trawl deployment, a portion at nearly constant depth corresponding to the fishing tow, and an oblique upcast corresponding to the trawl recovery. Early in the program, a scan of pressure, temperature, and conductivity data were digitalized at 10-second intervals, but on the newer CTD models, the scan rate has been increased to 1 or 2 scans per second. Typical descent rates are around 0.5 m $s^{-1}$, giving a vertical resolution of about 0.5 m at 1.0-second scan rates. Average tow speeds are around 2 knots, which corresponds to a horizontal distance of approximately 1.0 km during the downcast, assuming a 15-minute descent time to a depth of approximately 500 m. After download, the raw converted ASCII data are plotted against depth and time to highlight spikes caused by surface

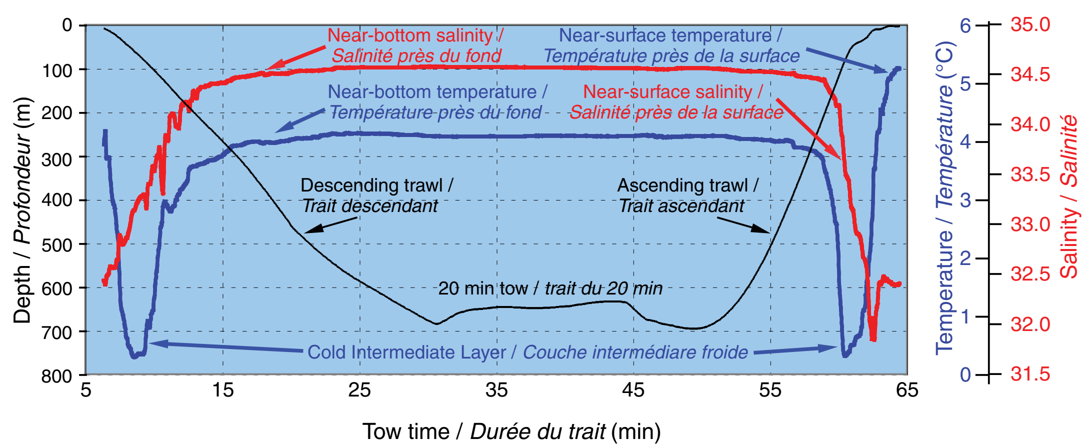


Fig. 3 A typical time series of depth, temperature, and salinity from a 20-minute fishing tow to approximately 700 m depth.

*Un profil typique d'échantillonnage de la profondeur, de la température et de la salinité provenant d'un trait de chalut de 20 minutes à une profondeur approximative de 700 m.*

and salinity maps are also produced for other depths, including the surface; however, extensive analysis is usually required to deal with temporal variability since the surveys can take up to three months to complete. Other related data products are time series of the area of the bottom covered by water in selected temperature ranges, sometimes referred to as the "Thermal Habitat Index." A time series of the spatially averaged temperature field for a particular management area or geographic feature, such as a major bank, is also generated from this analysis. These show long-term trends and yearly variations in the ocean environment that may influence growth or distribution of a particular species of fish or invertebrate or other aspects of marine productivity.

clutter, electronic failures, or other artifacts caused by the trawl deployment and recovery operations (Fig. 3). After the initial removal of redundant surface observations and de-spiking, the data are range-checked against the climatology and then median-filtered to smooth electronic noise. The final step in the quality control process compares the temperature and salinity values at standard depths against the climatological mean for the area. If the difference in the values at standard depths are >2.0 standard deviations from the mean, the profiles are flagged and re-checked.

## Data Products

The first requirement of the trawl-mounted CTD program is to satisfy the oceanographic data requirements for the fishing set details summary. In this regard, the CTD data corresponding to the bottom tow section of the fishing set are analyzed. The tow portion of the CTD data time series is selected either automatically by software or manually in most cases if the bathymetry encountered during the tow is uneven. Basic statistics of the temperature and salinity time series along the bottom are then computed, including minimum, maximum, median, and mean values, and the start and end values of depth, temperature, and salinity. This analysis has proven useful in monitoring trawl-fishing times in addition to providing an average temperature during the fishing set. The bottom temperature now entered into the fishing set details differs from that used prior to the implementation of the trawl CTD, when bottom temperatures were extracted from bathythermograph profiles usually at the end of the fishing tow.

The most common data products derived from the trawl-mounted CTDs are bottom temperature and salinity maps and their associated anomalies (Fig. 4). Temperature

A key component of the AZMP observational program is the sampling of several standard cross-shelf sections throughout Atlantic Canadian waters. Using data collected on the spring and fall multi-species surveys, it is possible to construct vertical cross-sections of temperature, salinity, and density fields and their associated anomalies over a wide geographical range, from 3Ps in the south to 2J in the north. Assuming the oblique

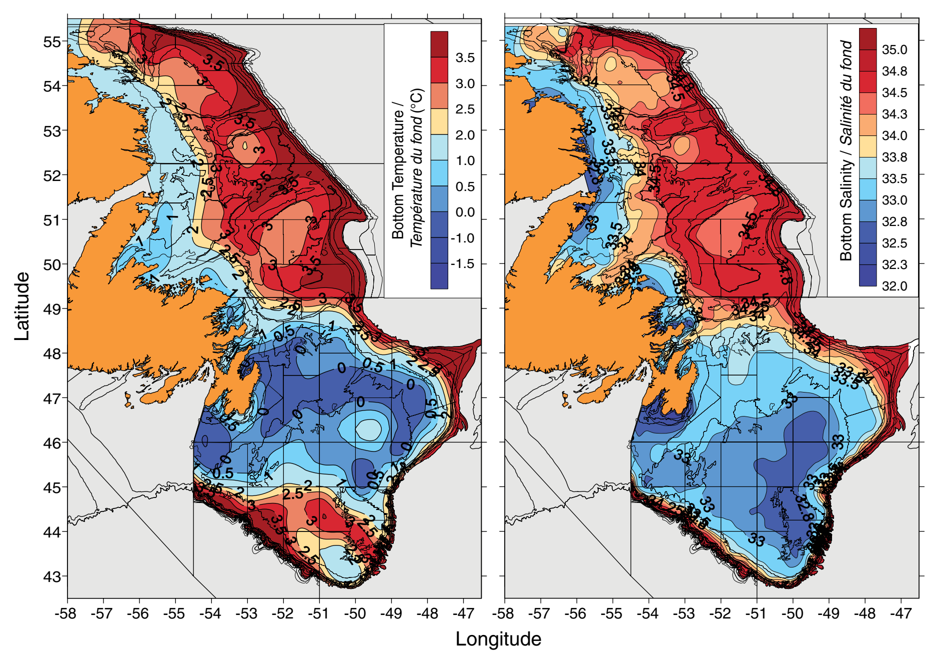


Fig. 4 Bottom temperature and salinity maps derived from the trawl-mounted CTD data from about 700 fishing tows in 2JsK3LNO during the fall 2005 multi-species survey.

*Carte de répartition des données de température et de salinité réalisées à partir des 700 traits de chalut équipé d'un système CTD monté sur un traîneau sous-marin durant la mission d'évaluation multi-spécifique en 2005 dans 2JsK3LNO.*

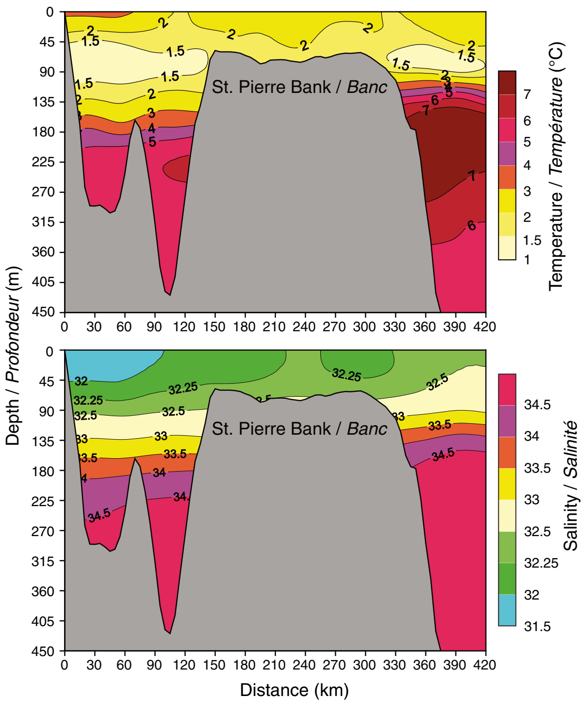


Fig. 5 Temperature (°C) and salinity cross-sections derived from the trawl-mounted CTD data during the April 2005 multi-species survey in NAFO Div. 3Pn.

*Profils transversaux de température (°C) et de salinité dérivés des résultats provenant du système CTD monté sur le chalut au cours de la mission d'évaluation multi-spécifique dans la division 3Pn de l'OPANO en avril 2005.*

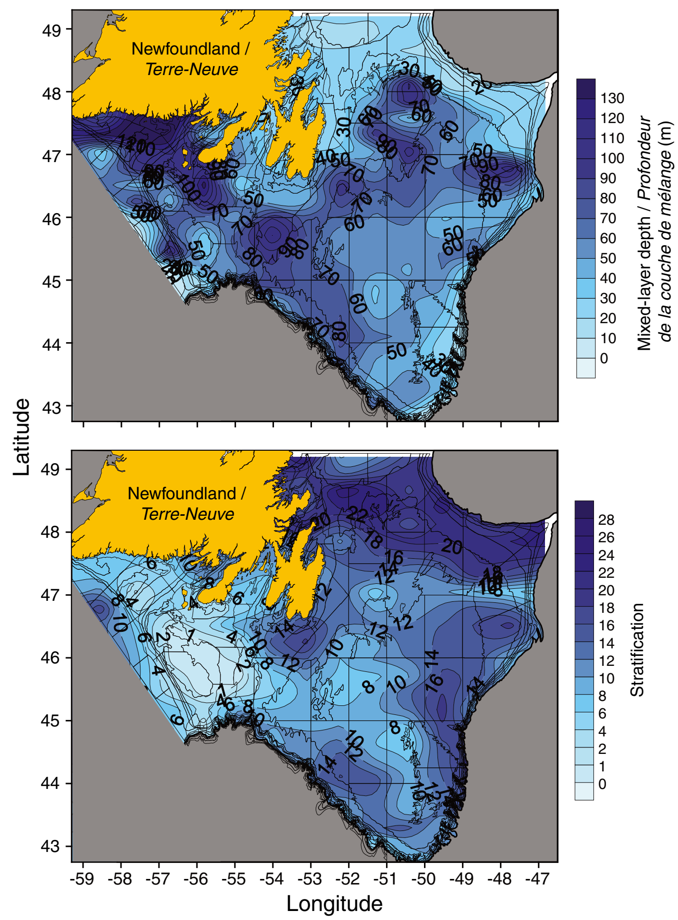


Fig. 6 Spatial maps of the mixed-layer depth (m) and stratification index ($10^{-3}$ kg m$^{-4}$) derived from the trawl-mounted CTD data during the spring 2005 multi-species survey in 3PNLO.

*Cartes de la répartition spatiale de la profondeur de mélange (m) et de l'indice de stratification ($10^{-3}$ kg m$^{-4}$) dérivées des données du CTD monté sur le chalut durant la mission multi-spécifique de printemps 2005 dans 3PLNO.*

downcast obtained from the trawl deployments approximates a vertical profile, the fishing set locations within a narrow corridor of the surveyed area are projected along a straight line and the water properties are contoured in the usual way (Fig. 5). Cross-sections of temperature and salinity using the multi-species CTD data from NAFO Division 3P during the spring are routinely used in the assessment of ocean climate conditions in the area (Colbourne and Murphy 2005).

In addition to time series and areal indices, it is also possible to compute volume-based data products such as the Cold Intermediate Layer (CIL) (defined as waters with temperatures <0°C) from these large-scale surveys. Spatial maps of the vertical extent or thickness of the CIL water mass on the NL shelf are computed from the spring and fall survey data. The temperature and salinity profiles are also used to compute and characterize the vertical density structure of the water column. Spatial maps from this analysis of both the mixed-layer depth (MLD; depth of maximum density gradient) and the stratification index (difference in density between surface and 50 m) are useful in linking physical dynamics to biological productivity, an important goal of the AZMP (Fig. 6). Although most of the spatial variability in the MLD and stratification can be attributed to temporal variability in the data collections, sub-areas show real inter-annual changes since the survey timing within NAFO divisions are consistent during most years.

## The Future

Standardized large-scale surveys of marine resources will continue to provide a principal source of data used by AZMP to characterize spatial variability of oceanographic properties in the Atlantic zone. Historically, hydrographic properties such as temperature and salinity were the only variables measured, but biological and chemical variables such as chlorophyll and nutrients have been recently added to some surveys in Atlantic Canada, although not on a trawl-mounted system. In the Newfoundland and Labrador Region, oceanographic data collections on the multi-species surveys so far have been restricted to physical measurements, except for some limited biological sampling at Station 27. As the Department of Fisheries and Oceans moves forward with ecosystem-based management of marine systems and a multi-disciplinary approach to fisheries science, there will be a pressing need to integrate data collections across several disciplines on broad-scale surveys.

With the continued development of new compact optical and chemical sensors, it should be possible to expand the data collections from in-flight trawl-mounted instrumentation packages to measures of the biological and chemical environment at spatial scales much larger than the "standard section" model currently used on AZMP surveys. The ability to compare the biological and chemical environment directly to the physical forcing over large spatial scales will add new insights to the integration of the physics, chemistry, and biology of complex marine ecosystems.

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# *Spring Oceanographic Conditions and Northern Shrimp (*Pandalus borealis*) Recruitment Success in the Northwestern Gulf of St. Lawrence*

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### Sommaire

Des séries temporelles de la température de surface (TS), de la profondeur de la couche mélangée (en température) et du taux de réchauffement de TS au printemps au moment de l'émergence des larves de crevettes ont été corrélées à des indices de recrutement de la crevette nordique (*Pandalus borealis*) entre 1994 et 2004 dans le nord-ouest du golfe du Saint-Laurent, Canada. L'indice de la survie larvaire était corrélé négativement avec la moyenne journalière de TS au moment de l'émergence des larves de crevettes. L'indice de la survie larvaire était corrélé positivement avec le taux de réchauffement de TS et la profondeur de la couche mélangée au moment de l'émergence des larves. Dans leur ensemble, les analyses ont révélé que l'émergence des larves de crevettes pendant une période de faibles stratifications de densité et de faibles TS au printemps, suivi d'un taux de réchauffement relativement élevé dans la couche supérieure de la colonne d'eau est favorable à la survie des larves. Notre étude montre aussi l'importance d'un monitorage des conditions océanographiques tôt au printemps dans l'écosystème du nord du golfe du Saint-Laurent.

## Introduction

The northern shrimp *Pandalus borealis* (Krøyer) is a dominant crustacean decapod species in the Estuary and the Gulf of St. Lawrence ecosystem and has been an important commercial fishery since the mid-1960s. Northern shrimp is particularly abundant in the northern Gulf, where depths and bottom temperatures are suitable for its establishment. The northwestern sector of the Gulf (NW GSL) holds the most abundant concentration and the most important shrimp fishery. This shrimp population is assumed to be self-sustaining and is managed as one stock. Long-term monitoring of the fishery has shown that individual cohorts can be followed for successive years in the population and biomass fluctuations through time are possibly a function of recruitment variations (Savard and Bouchard 2004). Moreover, small-mesh bottom trawl surveys conducted in October from 1998 to 2004 in the St. Lawrence Estuary revealed that post-larval abundance varies greatly between years, indicating that the strength of a year-class could be determined during the pelagic larval phase (L. Savard, unpubl. data).

Mature females spawn in late summer or early fall and carry the fertilized eggs on their pleopods until the larvae hatch eight to nine months later, in late April. The larvae are planktonic, and the complete sequence of larval development at sea—the pelagic phase of the life cycle—passes through five instars (four moults) and is estimated to last up to three months before the first juveniles descend to the bottom (Ouellet and Allard 2006). In the NW GSL, the first three larval stages are present in the upper layer of the stratified water column, where favourable feeding conditions are expected (Ouellet and Allard 2006).

Investigations carried out in different oceanic regions have suggested that variability in both the physical conditions and the spring biological production cycles influence *P. borealis* abundance and growth (Anderson 2000, Parsons and Colbourne 2000, Fuentes-Yaco et al. 2007). In addition, the notion that variability in larval survival arises from annual variations in the temporal and/or spatial overlap between larvae and prey is still a popular explanation for recruitment success in aquatic animal populations (Cushing 1990, Platt et al. 2003, Edwards and Richardson 2004). In most scenarios, it is the timing of the prey production cycle that varies most relative to the spawning and/or hatching time. However, monitoring of the Gulf of St. Lawrence fisheries showed that shrimp spawning and hatching dates can vary from one year to the next.

Our objective was to investigate fluctuations of northern shrimp recruitment in the Gulf of St. Lawrence. An examination of the spring oceanographic conditions, particularly the density and thermal structure of the upper waters, and shrimp recruitment variations combined with our knowledge of shrimp larvae ecology in this system led us to propose that the timing of larval emergence relative to the initiation and development of the biological production cycle is critical for northern shrimp recruitment success (Ouellet et al. 2007).

## Material and Methods

### *Oceanographic Data*

Time series of daily mean sea-surface temperature (SST) for the spring (March to end of June) in the NW GSL were constructed from three independent data sources: (1) all available conductivity–temperature–depth (CTD) profiles between

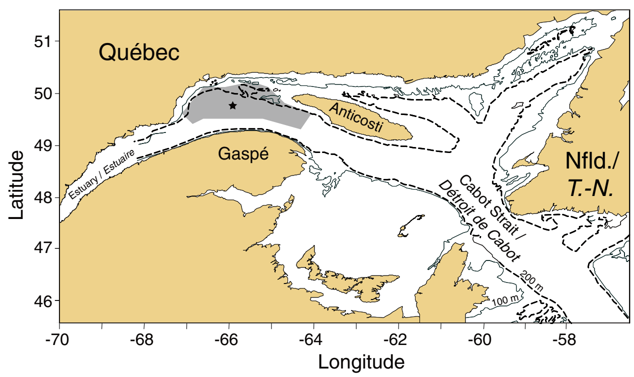


Fig. 1 Position of the fixed monitoring station for the annual sea-surface temperature time series (asterisk) and the general area where CTD profiles were retained for the analysis (shaded area).

*Position de la station fixe de monitorage pour la série annuelle des températures de surface (étoile) et présentation de l'aire générale où les profils de CTD ont été retenus pour l'analyse (surface ombragée).*

March and the end of June at stations with depths greater than 100 m but excluding the influence of the strong coastal current on the north shore of the Gaspé Peninsula (see Fig. 1); (2) data from a surface (0.5 m) temperature probe on a buoy at a fixed monitoring station located in the northwestern Gulf (49.53° N – 65.75° W); and, (3) sea-surface temperatures extracted from NOAA-AVHRR satellite images in a 3 × 3 pixel box (3 × 3 km) corresponding to the position of the fixed monitoring station. That station was selected because it represents well the SST variance over the entire NW GSL (Ouellet et al. 2003). The near-surface temperature series recorded at 30-min intervals at the monitoring station served as the reference time series from which daily mean SSTs were estimated for each year. However, in some years the buoy was moored late in spring (e.g., mid-May), so available CTD profiles and, especially, satellite data were then used to extend the daily mean SST series to earlier in spring (to the beginning of March). There was always a good agreement between the three SST data series (Fig. 2A). Therefore, all data were combined to obtain a daily mean SST time series from the end of March to the end of June for the 1994 to 2004 period. In addition, climatological daily mean SSTs for the 11-year period and standardized daily anomalies for each year were also estimated.

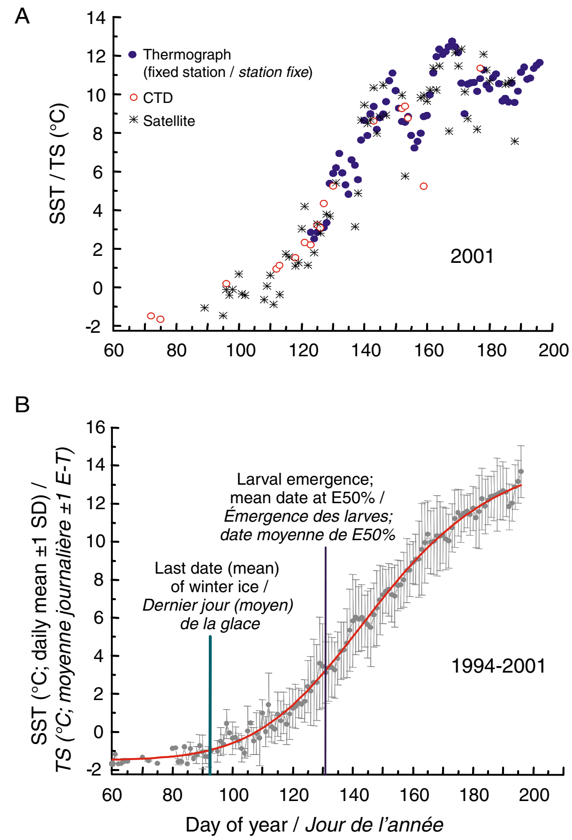


Fig. 2 (A) Daily mean SST estimated from three sources of data (CTD profiles, satellite, thermograph at fixed station) for 2001; (B) Evolution of the daily mean SST in spring between 1994 and 2004 in the NW GSL. In (B), dots indicate the daily mean, bars the standard deviation, and the red curve is a smoothed fit to the data.

*(A) Moyennes journalières des TS obtenues de trois sources de données (profils CTD, satellite, thermographe à la stations fixe) pour 2001; (B) Évolution des moyennes journalières de TS au printemps entre 1994 et 2004 dans le nord-ouest du Golfe. Dans (B), les points montrent la moyenne, les lignes montrent l'écart-type et la courbe en rouge montre la fonction ajustée aux données.*

Using the daily mean SST data series and the CTD profiles, we derived different indices of physical oceanographic conditions in reference to the date (day of the year, DOY) of 50% shrimp larval emergence (E50%) in spring (see below): (1) SST, (2) a mean SST warming rate for the 30 days following E50%, (3) the upper-layer density stratification index (density difference between 5 and 30 m divided by 25), (4) an index of the thermal mixed layer depth (MLD), and (5) the depth of the upper 1°C isotherm.

The thermal mixed layer depth (MLD, $Z_m$) was defined as the depth where water temperature difference from the surface was less than or equal to 1°C: $Z_m = (T_0 - T_z) \leq 1$°C (Doyon and Ingram 2000). Determination of the mixed layer depth is complex and often subjective; however, for the ice-free period in the Gulf, it was concluded that temperature was a robust indicator of the depth of the upper well-mixed layer (Doyon and Ingram 2000).

### *Sea-Surface Chlorophyll Data (SeaWiFS)*

SeaWiFS-derived chlorophyll images were used to calculate daily mean values in a 3 × 3 pixel box (3 × 3 km) centred on the location of the fixed monitoring station. By using information over the limited area of the monitoring station near the centre of the NW GSL, we minimize the problem of surface waters contaminated by coloured dissolved organic matter associated with freshwater runoff. The SeaWiFS images were processed using standard algorithms (SEADAS 4.8). These daily values were then further averaged into weekly means to derive a proxy for the timing of the spring bloom in the NW GSL.

*Sea-Ice Data*

The Gulf of St. Lawrence has a subarctic climate with sea ice present over most of the area from January to April. Local sea-ice dynamics are suspected to play an important role for the timing of the spring bloom (Le Fouest et al. 2005). The duration of the winter ice coverage in the NW GSL was estimated from digitized data (0.5° latitude by 1° longitude grid) from charts produced by the Canadian Ice Service of Environment Canada (Drinkwater et al. 1999; R. G. Pettipas, pers. comm., Fisheries and Oceans Canada, Bedford Institute of Oceanography, Dartmouth, NS). The day of the year (DOY) of last ice presence in the NW GSL was estimated as the time when no ice was recorded in any grid cell of the area retained for the analysis (Fig. 1).

*Shrimp Recruitment Index and Mean Date of Larval Emergence*

Northern shrimp samples were obtained from the commercial fishery in the NW GSL between 1993 and 2005. Thirty to seventy samples representing between 7,000 and 17,000 individuals were collected annually from April to October. Sex change occurs at about 21 mm (oblique carapace length) in the Gulf of St. Lawrence, when shrimp are 4 to 5 years old. The maturity stage of the females was determined by the presence (primiparous) or absence (multiparous) of sternal spines. The presence of eggs under the abdomen (ovigerous) was also noted.

Annual catch-at-length (in number) was obtained by summing monthly data then dividing by the annual standardized fishing effort to obtain a length–frequency distribution that was considered as an index of abundance (number caught per hour fishing) of shrimp by size classes (Savard and Bouchard 2004). Modal analyses were performed on the male component of the annual length–frequency distributions using the MIX 3.1 software (MacDonald and Pitcher 1979).

The proportion of each mode (five modes were identified each year, corresponding to ages 1 to 5) and the estimate of abundance for each age group were obtained from the modal analysis. Individuals of age group 1 were present in small numbers, but their abundance was not considered as a valuable index of the cohort strength because their capture by fishing gear is variable depending on the fishing pattern and the growth rate of the cohort. Therefore, the male shrimp abundance index estimated at age 2 was selected as the recruitment index for the NW GSL (1991 to 2004 year classes) because it allowed the inclusion of recent data in the series (Ouellet et al. 2007).

Samples collected at regular intervals from the beginning of the fishing season (ca. 1 April, when almost all females carry eggs) were also used to determine the larval emergence dates. The ratio of ovigerous females to the total number of multiparous females (females that still carry eggs or have just released larvae) was calculated for each sample and plotted against the catch date. A logistic curve was adjusted for each year, and the date at which 50% of the females were still ovigerous was used as an estimate of the DOY at 50% larval emergence (E50%).

Finally, an index of the spawning stock biomass (SSB) was obtained by calculating the catch rate of multiparous females in the fishery in the months of April and May. Multiparous females that are caught in spring are responsible for the production of larvae of the same year and their catch rate is considered as a reliable index of their abundance. Therefore, a larval survival index was estimated by dividing the recruitment index (abundance of age 2 shrimp) by the SSB index.

## Results

The DOY of larval emergence (E50%) varied among years, but there seems to be a tendency for later dates starting in 1999 (Fig. 3A). The time series of the shrimp recruitment index is characterized by large oscillations between high and low recruitment values among years (Fig. 3B). There have been two very strong shrimp year classes since 1991 (1997 and 1999) and a noticeable recruitment failure in 1998. Recently, with the exception of 2001, recruitment has been relatively low (Fig. 3B). The larval survival index shows similarities with the recruitment index series. There were high survival values in 1997 and 1999 but, interestingly, more contrast between the earlier years (before 1996) and the recent low survival index values estimated since 1998 (with the exception of 1999; Fig. 3C).

Since 1990, the NW GSL has been free of winter ice from ca. 1 April (mean DOY = 92.5). However, between 1996 and 2002, winter ice tended to disappear earlier than the average (Fig. 3D). Since 1994, there seem to be two distinct periods in the SST at E50% series: either SST was below average (1994 to 1997) or generally above average (1998 to 2003) (Fig. 3E). The upper-layer density stratification at E50% was below average between 1994 and 1997, above average from 1998 to 2001 with the exception of 2000, and remained below average since 2002 (Fig. 3F).

In general, the daily mean SST in the NW GSL remained cold (≤ 0°C) until mid-April but increased rapidly during the first half of May, at the time of shrimp larval emergence (Fig. 2B). Note that the error bars (± 1 SD) in the daily mean SST series also illustrate strong interannual variability during the period of vernal warming in the NW GSL.

Each series shows high interannual fluctuations and no apparent trends that would be indicative of significant auto-correlations, therefore Pearson's correlations were used to show the strength of the relationships between the environmental indices and the shrimp larval survival index. Despite the short time series, there appears to be a consistent negative relationship between the shrimp larval survival index and daily mean SST at E50% (Fig. 4A). The shrimp larval survival index was positively correlated with the SST warming rate (Fig. 4B). A positive relationship between the larval survival index and the depth of the 1°C isotherm was observed (Fig. 4C), but a

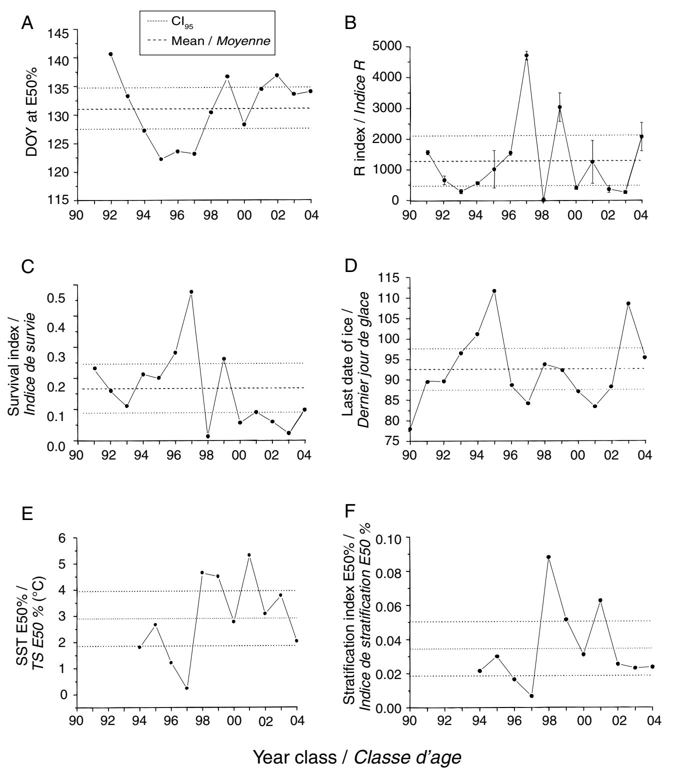


Fig. 3 (A) Mean day of the year (DOY) at 50% shrimp larval emergence (E50%) in the NW GSL between 1992 and 2004; (B) Annual index of shrimp recruitment, 1991 to 2004 year classes (the error bars represent the standard errors estimated by the modal analysis); (C) Annual index of larval survival, 1991 to 2004 year classes; (D) DOY of the last presence of winter ice in the NW GSL between 1990 and 2004; (E) Mean daily SST in the NW GSL at the time of E50%; and (F) Density stratification index at the time of E50%. For each graph, the horizontal lines illustrate the series mean and the upper and lower 95% confidence intervals.

*(A) Jour de l'année moyen (DOY) pour 50 % de l'émergence larvaire (E50 %) dans le nord-ouest du Golfe entre 1992 et 2004; (B) L'indice annuel de recrutement de la crevette pour les classes d'âge de 1991 à 2004, les lignes montrent l'erreur-type de l'estimation obtenue par l'analyse modale; (C) L'indice annuel de la survie larvaire pour les classes d'âge de 1991 à 2004; (D) Jour de l'année pour la dernière présence de la glace dans le nord-ouest du Golfe entre 1990 et 2004; (E) TS moyenne journalière dans le nord-ouest du Golfe au moment de E50 %; et (F) L'indice de stratification de densité au de moment de E50 %. Sur chaque graphique, les lignes horizontales montrent la moyenne de la série et les intervalles de confiance (95 %) supérieure et inférieure.*

stronger positive correlation was found between the larval survival index and the mixed layer depth (Fig. 4D).

Satellite-derived sea-surface chlorophyll concentrations (SSC) for the NW GSL are available from SeaWiFS satellite data since 1998 only. Weekly mean values, as proxies of the timing of the spring bloom, are shown for each year. It appears that the date of 50% larval emergence (corresponding to week 19 or 20) is generally coincident with the yearly period of maximum SSC (Fig. 5).

The different relationships observed are indications that spring oceanographic conditions in the upper layer can account for shrimp larval survival and recruitment success in the NW GSL. In an attempt to present a synoptic view of what conditions are more or less favourable to larval survival, for each series the values were transformed to z scores ($(x_i - \bar{x})/ SD_{\bar{x}}$) and compared as annual anomalies relative to the series mean (Table 1). From 1994 to 1998, a coherent pattern of early larval emergence and weak upper layer density stratification (low SST) but followed by a relatively high SST warming rate is associated with positive larval survival anomalies (Table 1). In contrast, in 1998, the year of the lowest shrimp recruitment, the pattern is reversed, with later larval emergence, strong stratification, and high SST associated with low larval survival. Since 2000, a pattern of late emergence date, higher SST (moderate upper layer density stratification), and lower SST warming rates is associated with negative larval survival anomalies (Table 1).

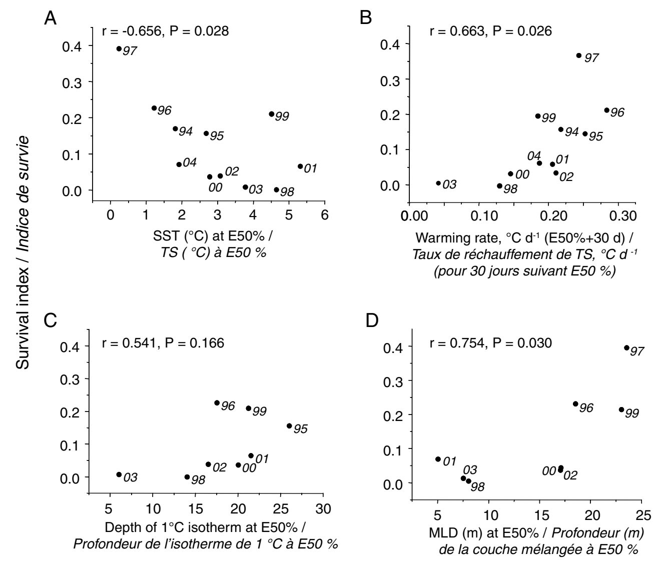


Fig. 4 (A) Correlation between SST at E50% and the larval survival index; (B) Correlation between the SST warming rate for 30 days following the E50% date and the larval survival index; (C) Correlation between the depth of the 1°C isotherm at E50% and the larval survival index; and (D) Correlation between the thermal mixed layer depth at E50% and the larval survival index.

*(A) Corrélation entre TS au moment de E50 % et l'indice de survie larvaire; (B) Corrélation entre le taux de réchauffement de TS pour les 30 jours suivant E50 % et l'indice de survie larvaire; (C) Corrélation entre la profondeur de l'isotherme de 1 °C au moment de E50 % et l'indice de survie larvaire; et (D) Corrélation entre la profondeur de la couche mélangée en température au moment de E50 % et l'indice de survie larvaire.*

## Discussion

The general pattern revealed by our analysis is that northern shrimp larval emergence in spring during a period of weak density stratification (low SST) and deep (thermal) mixed layer but followed by relatively high warming rates of the upper layer favours larval survival and recruitment success in the NW GSL. In early spring, the upper layer is rich in nitrate following strong vertical mixing during the previous fall/winter (Plourde and Therriault 2004). However, strong stratification and a shallow MLD will likely result in a rapid depletion of nutrients and reduce the potential for high and sustained phytoplankton production. We suggest that the combined observed relationships support the idea that oceanographic conditions affecting the initiation of the spring diatom bloom and that can sustain high levels of primary and secondary production at the time of larval emergence and development—the match/mismatch

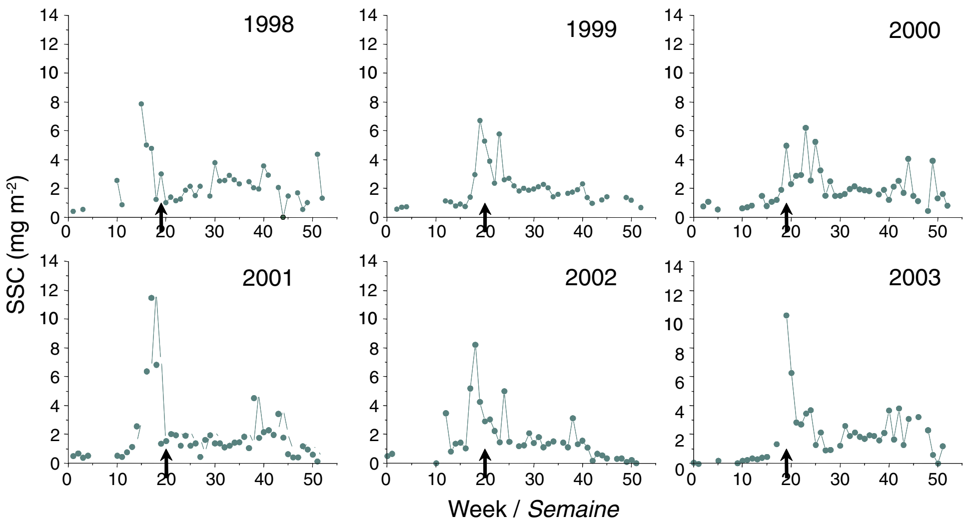


Fig. 5 Weekly mean time series of sea surface chlorophyll (SSC) concentrations (SeaWiFS) near the fixed monitoring station for each year between 1998 and 2003. The short vertical arrows on the x-axes indicate the week during which the 50% larval shrimp emergence occurred for each year.

*Séries temporelles des moyennes hebdomadaires des concentrations de surface de chlorophylle (SeaWiFS) à proximité de la station fixe de monitorage entre 1998 et 2003. Les flèches verticales sur l'axe des x montrent la semaine correspondent au moment de 50 % de l'émergence des larves de crevette à chaque année.*

Table 1 Synopsis of conditions for good and poor larval survival of northern shrimp in the NW GSL. For each series, values were transformed to z scores (($x_i$ – $\bar{x}$ )/ $SD_{\bar{x}}$ ) and colour-coded in terms of 0.5 SD units to be shown as annual anomalies relative to the series mean. The columns (variables), from left to right, are: year-class, day of the year at 50% larval emergence, density stratification in the upper layer and sea-surface temperature at E50%, warming rate of SST for the first 30 days following E50%, and the larval survival index.

*Résumé des conditions pour une bonne et une mauvaise survie larvaire de la crevette nordique dans le nord-ouest du golfe du Saint-Laurent. Pour chaque série, les valeurs ont été centrés-réduites (($x_i$ – $\bar{x}$ )/ $SD_{\bar{x}}$ ) et attribuées un code de couleur par intervalle de 0,5 de la valeur de l'écart-type afin de les présentées en termes d'anomalies par rapport à la moyenne de la série. Les colonnes (variables) sont, de gauche à droite : la classe d'âge, le jour de l'année au moment de 50 % de l'émergence des larves (E50 %), la densité de stratification dans la couche supérieure et la TS au moment de E50 %, le taux de réchauffement de la TS pour 30 jours suivant E50 % et l'indice de la survie larvaire.*

| Year / *Année* | Day of year / *Jour de l'année* | Stratification Index / *Indice de stratification* | SST / *TS* | Warming rate / *Taux de réchauffement* | Survival Index / *Indice de survie* |
|---|---|---|---|---|---|
| 1994 | -0.498 | -0.548 | -0.711 | 0.400 | 0.348 |
| 1995 | -1.410 | -0.192 | -0.150 | 0.924 | 0.299 |
| 1996 | -1.228 | -0.764 | -1.090 | 1.387 | 0.834 |
| 1997 | -1.228 | -1.180 | -1.721 | 0.789 | 2.242 |
| 1998 | 0.050 | 2.267 | 1.118 | -0.917 | -1.012 |
| 1999 | 1.145 | 0.719 | 1.021 | -0.094 | 0.736 |
| 2000 | -0.315 | 0.150 | -0.092 | -0.677 | -0.720 |
| 2001 | 0.780 | 1.186 | 1.543 | 0.220 | -0.477 |
| 2002 | 1.327 | -0.387 | 0.101 | 0.295 | -0.772 |
| 2003 | 0.597 | -0.489 | 0.551 | -2.233 | -0.963 |
| 2004 | 0.780 | -0.463 | -0.569 | -0.094 | -0.615 |

+ / - < 0.5 | 0.5 - 1.5 | > 1.5

hypothesis as proposed by Cushing (1990)—are favourable to northern shrimp recruitment success. Indeed, support for this conclusion can be found by a closer examination and comparison of the conditions associated with an average (2001) and the extreme (1997, 1998, 1999) recruitment years.

In 1997, the year of maximum recruitment for the time series, there were strong negative SST anomalies from early May to mid-June (Fig. 6), suggesting that the weak stratification and deep MLD present at E50% persisted for the period of development of the first two or three larval stages. In contrast, shrimp recruitment in 1998 was extremely low in conjunction with strong positive daily SST anomalies (Fig. 6) (i.e., strong upper layer stratification, shallow MLD; Fig. 5) following the date of 50% larval emergence. In 1999, the combination of late larval emergence, relatively strong stratification, and warm surface water should have resulted in average or low larval survival. However, 1999 was exceptional, with very strong positive temperature anomalies in late winter/early spring and early production (Drinkwater et al. 2000, Head et al. 2005), but the daily SST anomalies were about normal at the time of E50% (see Fig. 6). This indicates an important weakening of the stratification and deep vertical mixing in the upper layer in May and June—conditions that corresponded to enhanced larval survival. In 2001, conditions seemed similar to those in 1999, but the water column remained strongly stratified (shallow MLD; Fig. 5) following larval emergence as inferred by the strong positive SST anomaly (Fig. 6) and larval survival was only average. Moreover, according to our analysis, the DOY at 50% larval emergence coincides generally well with the period of high sea-surface chlorophyll concentrations.

The match/mismatch hypothesis of recruitment success in marine populations has been notoriously difficult to prove or disprove, and early larval feeding success is likely not the only factor affecting recruitment (e.g., Leggett and Deblois 1994). Nonetheless, many aspects of northern shrimp ecology in the NW GSL add additional support in favour of the hypothesis. Simple mathematical simulations of the match/mismatch scenario indicate that recruitment variability is dependent on the duration of spawning (larval emergence) in relation to the spring bloom (Mertz and Myers 1994). Contrary to many marine fish populations with sequential spawning and/or a protracted spawning season, northern shrimp larval emergence is of short duration (mean duration, between 25% and 75% larval emergence, is ca. 12 days). It is therefore possible that because of its short duration, an emergence can occur when the oceanographic conditions are not optimal for larval survival. In addition, as revealed by our analysis, the timing of larval emergence can also vary through the years, possibly due to interannual fluctuations in the deep-water temperature in the Gulf. Indeed, there is evidence that temperature fluctuations in the deep waters, where ovigerous females spend most of the egg incubation period, will affect egg development and survival as well as larval emergence time (Brillon et al. 2005).

What is much less known is what controls the initiation and the temporal evolution of the spring biological production

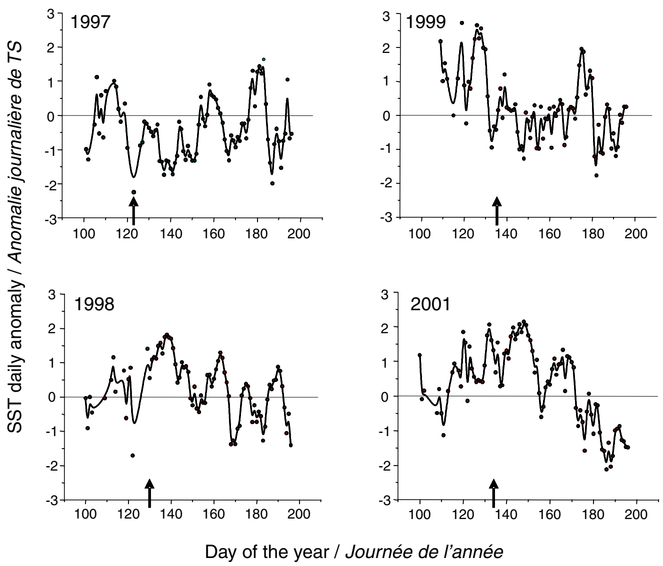


Fig. 6 Time series of the standardized daily mean SST anomaly ($[T_{ij} - T_i]/SD_{Ti}$) for the extreme (1997 and 1998) and "outlier" years (1999 and 2001), where $T_{ij}$ is the daily mean SST for day *i* in year *j*, $T_i$ is the daily mean SST for day *i* (for all years), and $SD_{Ti}$ is the standard deviation of $T_i$. The vertical arrows indicate the date at E50%.

*Séries temporelles des anomalies de moyennes journalières de TS ($[T_{ij} - T_i]/SD_{Ti}$) pour les années extrêmes (1997 et 1998) et « atypiques » (1999 et 2001), où $T_{ij}$ est la TS moyenne journalière pour le jour* i *de l'année* j, *$T_i$ est la TS moyenne journalière du jour* i *(pour toutes les années), et $SD_{Ti}$ l'écart-type de $T_i$. Les flèches verticales montrent le moment de E50 %.*

in this region of the Gulf. The assumption that the physical structure and dynamics at shallow depths determine the characteristics of biological production is critical to our interpretation. In early spring, increased photoperiod and stratification and high nutrient concentrations in the upper layer from the previous fall/winter deep convection are likely to influence the timing and amplitude of the spring bloom (Le Fouest et al. 2005). When strong stratification and a shallow MLD are established early, the upward flux of nutrients is inhibited and the bloom will likely be of short duration while, conversely, a situation of weaker stratification and moderate mixing (deeper MLD) replenishing the surface nutrient field will support enhanced phytoplankton and micro- and mesozooplankton growth (e.g., Kiørboe 1993).

Finally, we suggest that significant progress in our ability to anticipate northern shrimp recruitment fluctuations in the GSL, and the impacts of climate change on shrimp populations in the Northwest Atlantic in general, can be made by an approach that would integrate an atmosphere–ocean model of the seasonal oceanographic characteristics and their control of the initiation of the spring bloom, a shrimp population model of total egg production and development (emergence) time, and a bio-physical model of the development of the plankton community coupled to a model (IBM type) of shrimp early life stage dynamics.

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# Moored Observations of the 2002 Spring Bloom on the Scotian Shelf

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**Sommaire**
Cet article examine les données de variables biologiques, chimiques et physiques provenant de deux lignes d'instruments autonomes mouillées à la station 2 de la Section Halifax (HL2) sur le plateau Néo-Écossais pour une période couvrant la floraison printanière du phytoplancton en 2002. Ce programme de terrain porte sur la détermination de l'importance des phénomènes physiques à court terme sur le contrôle de la production primaire dans cet écosystème. Les résultats montrent que la floraison printanière du phytoplancton a débuté à la station HL2 plusieurs jours après la mise en place des mouillages (mi-mars) et a duré jusqu'à la mi-avril. Durant cette période, on a noté que les variations des propriétés physiques ont consisté principalement en des tendances à long terme reliées principalement au réchauffement des eaux de surface dû à une hausse de l'insolation. Par ailleurs, les mesures de la chlorophylle ont indiqué que la concentration de phytoplancton pouvait varier considérablement sur une période de plusieurs jours. Ceci est sans doute relié aux processus contrôlant la variabilité spatiale des variables biologiques dans la zone d'advection du plateau Néo-Écossais.

## Introduction
The AZMP sampling protocol for fixed stations such as the Halifax Line Station 2 (HL2) is intended to provide twice–montly measurements to complement the spring and fall surveys that cover a larger spatial area. One of the key assumptions of this sampling protocol is that it is sufficient to capture most of the temporal variability of the ecosystem while also representing a larger spatial area. However, Greenan et al. (2004) have demonstrated that meteorologically forced events on time scales of several days to a week are sufficient to produce a biological response at HL2 during the fall, when nutrients are depleted in the euphotic zone. This raises questions in regard to the response of the Scotian Shelf ecosystem to short-term physical forcing events during other periods of the year. While meteorological forcing plays a dominant role, other internally driven events such as advection and mixing are also very important in determining the biological response.

One of the critical periods for monitoring primary productivity is during the spring, when phytoplankton concentrations are at their highest and subsist for an extended period. Based on in situ data collected at HL2 for the period of 1999-2005, the typical duration of the spring bloom at HL2 is 46 days (Harrison et al. 2006). This estimate is based on the duration for which the 0-50 m integrated chlorophyll is above a baseline value of 50 mg m$^{-2}$. Based on the AZMP fixed station protocol, the HL2 spring bloom would be sampled three times on average in a given year. This article describes a high-resolution data set collected with a mooring array deployed for one month at HL2 that gives a detailed picture of the temporal evolution of the spring bloom.

## Methods
Two moorings were deployed at HL2 from 18 March to 18 April 2002 (Fig. 1). The first mooring consisted of a SeaHorse moored profiler (Hamilton et al. 1999) that cycled between 7 and 120 m every 2 h at an ascent rate of 0.5 m s$^{-1}$ and carried instruments that measured temperature, salinity, depth, fluorescence, and photosynthetically active radiation (PAR). The Sea-Bird Electronics (SBE) model 19plus CTD has a sampling rate of 4 Hz, giving a vertical resolution of 0.1 m. A WET Labs WETStar fluorometer provided estimates of chlorophyll biomass through the manufacturer's calibration and comparisons with extracted chlorophyll from AZMP in situ samples at the

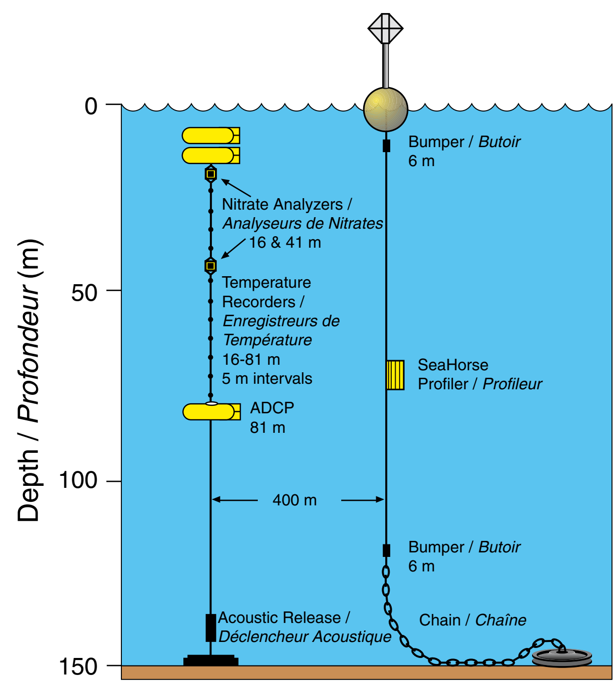


Fig. 1 Schematic diagram of moorings at HL2. The SeaHorse profiles betweens the lower and upper bumpers every two hours making CTD, fluorometer, and PAR measurements. The second mooring includes two in situ nitrate analyzers, 14 temperature recorders (black circles), and an upward-looking ADCP at mid-depth sampling every 15 minutes.

*Représentation schématique des deux mouillages d'instruments à la station HL2. Le profileur SeaHorse se déplaçait entre les butoirs supérieur et inférieur (cycle de deux heures) et mesurait la conductivité, la température, la profondeur, la fluorescence et le rayonnement photosynthétique utilisable. Le deuxième mouillage comprenait deux analyseurs de nitrates in situ, 14 thermographes (points noirs) ainsi qu'un profileur de courant à effet Doppler à vision orientée vers le haut qui était situé à mi profondeur et qui prenait des mesures à toutes les 15 minutes.*

site during the mooring period. A LI-COR spherical Quantum Sensor (model LI-193SA) provided PAR measurements in the 400-700 nm waveband.

The second mooring, ~400 m from the first, included an upward-looking RDI Workhorse acoustic Doppler current profiler (ADCP) at 81 m that measured currents in 2-m vertical bins every 15 minutes between 6 and 78 m. On the mooring above the ADCP were 14 Vemco Minilog temperature recorders that sampled every 10 minutes with 0.1°C resolution; the Minilogs were spaced 5 m apart from 16-81 m. In situ nitrate analyzers (WS Envirotech model NAS-2EN) at 16 and 41 m provided estimates of the nitrate concentration by measuring a diazo dye formed by the reaction between sulfanilamide and nitrite, which in turn was produced by the reduction of nitrate to nitrite on a copperized cadmium column (Grasshoff et al. 1999). An on-board standard was run after every five hourly samples. The frequent analysis of standards, and the stability of those standards, allows for the correction of the raw data for variations in the cadmium column efficiency. Since the standard replaces one sample, the final data record has a gap every six hours.

## Results

Vertical profiles of temperature, conductivity, chlorophyll fluorescence, and PAR were collected for the period 18 March – 18 April 2002, with a short interruption when the mooring was recovered and re-deployed on 29 March (Fig. 2). The mooring was designed for the SeaHorse to cycle between 7 and 120 m; however, during the servicing operation on 29 March, it was discovered that a knot had formed (likely during deployment) in the jacketed wire that limited the profiling to the upper 50 m. The wire was replaced, but mechanical wear of the SeaHorse clamp limited the maximum depth attained during the rest of the period. Calm sea conditions on 12 April did not provide sufficient energy for the SeaHorse to climb down the wire, causing a second data gap.

Water temperature is presented as a composite of SeaHorse and Minilog recorder data (Fig. 2A). This shows that well-mixed conditions to ~50 m prevailed in the latter half of March and that stratification at the surface developed in April. The near-surface layer temperature increased from ~0°C in mid-March to ~3°C by mid-April. The profiles deeper than 80 m indicated temperatures in excess of 3°C. This development of a cold intermediate layer is characteristic of the Scotian Shelf, where the near-surface waters largely originate from the Gulf of St. Lawrence and the deeper waters from the continental slope (Petrie et al. 1996, Loder et al. 2003).

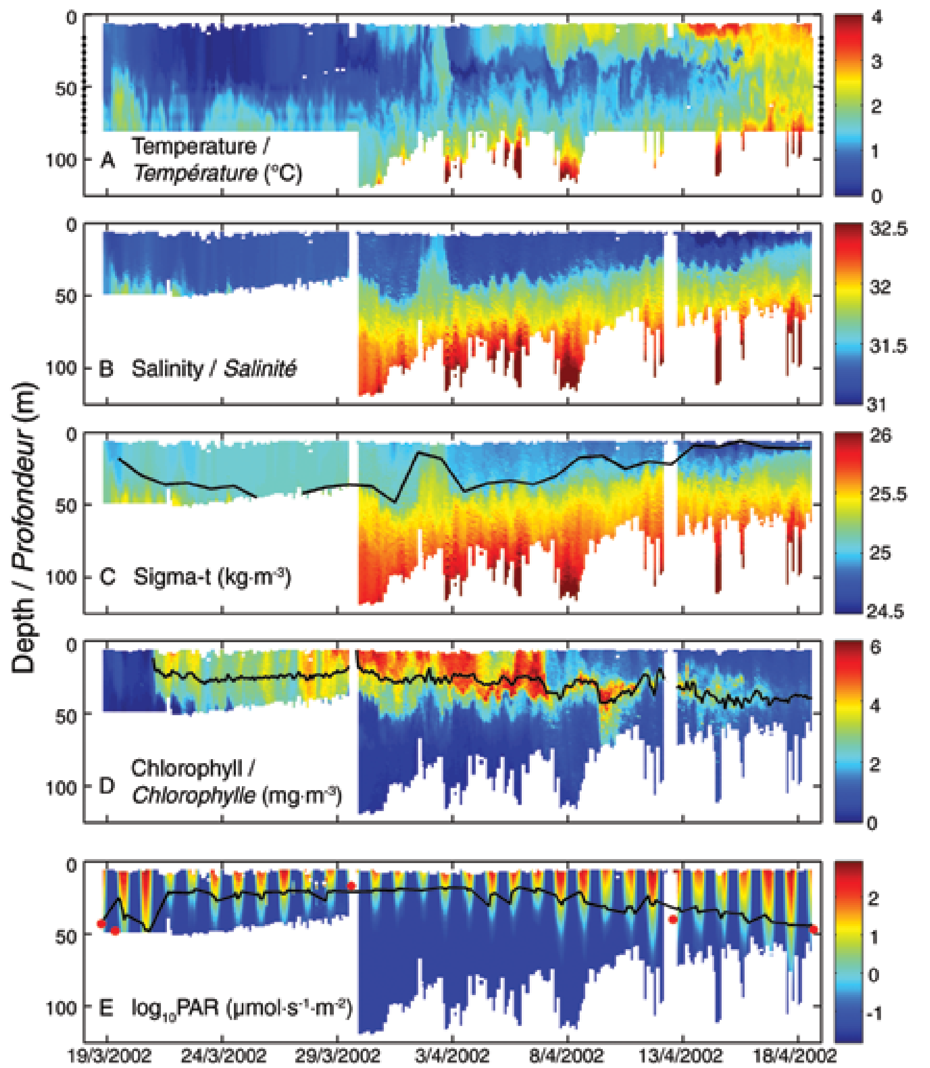


Fig. 2 (A) Temperature, (B) salinity, (C) density (sigma-t), (D) chlorophyll, and (E) photosynthetically active radiation (PAR) measured with the SeaHorse at station HL2, 18 March – 18 April 2002. In the upper panel, gaps in the SeaHorse temperature record were filled using the data from the Minilog recorders that were spaced 5 m apart starting at 16 m depth and ending at 81 m (indicated by dots on y-axis). The solid black line on the density panel indicates the depth of the ocean mixed layer. On the chlorophyll plot, the black line represents the depth of the chlorophyll centre of mass. The euphotic zone depth is presented as the black line on the PAR panel with the red dots indicating the depth of the euphotic zone estimated from Secchi disc measurements.

*(A) Mesures de la température, (B) de la salinité, (C) de la densité (sigma-t), (D) de la teneur en chlorophylle et (E) du rayonnement photosynthétique utilisable (RPU) par le profileur SeaHorse à la station HL2, du 18 mars au 18 avril 2002. Dans le panneau supérieur, le manque de données dans le profil de la température a été comblé à l'aide des données provenant des thermographes Minilog, placés à cinq mètres de distance les uns des autres entre 16 et 81 m de profondeur (représentés par des points noirs sur l'axe Y). La ligne noire continue sur le panneau de la densité indique la profondeur de la couche de mélange. Dans le panneau de la teneur en chlorophylle, la ligne noire représente la profondeur du centre de masse de la chlorophylle. Sur le panneau du RPU, la ligne noire représente la profondeur de la zone euphotique et les points rouges représentent la profondeur de la zone euphotique estimée à l'aide d'un disque de Secchi.*

Salinity (Fig. 2B) was ~31 near the surface and increased to ~32.5 at 120 m. Between 29 March and the end of the mooring period, the isohalines rose by about 25 m. The plot of density (Fig. 2C) indicates that salinity was the primary control of this variable during the mooring period. The mixed layer depth (indicated by the black line in Fig. 2C) was estimated from daily-averaged density profiles at the depth at which the density gradient was larger than 0.01 kg $m^{-4}$. The mixed layer quickly deepened from 20 to 40 m during the first two days of the mooring deployment and then remained near this depth until the end of March. The mixed layer shallowed to 15 m for a period of 2 days at the beginning of April as temperature and salinity changed significantly in the upper water column. This change is perhaps related to an advective movement of a different water mass past the mooring site. On 4 April, the mixed layer returned to 40 m and then gradually shallowed to 10 m by the end of the mooring period.

The fluorometer data (Fig. 2D) were calibrated using in situ chlorophyll measurements from AZMP ($r^2$ = 0.75, 31 observations). Low phytoplankton concentrations prevailed throughout the upper 50 m for the 18-20 March period. The chlorophyll concentration then increased throughout this layer and peaked in early April. In total, the intense period of the bloom lasted about 10 days in the near-surface layer. Just prior to the collapse of this bloom on 7 April, the chlorophyll concentration was reduced in the upper 25 m during 4-5 April. As the bloom subsided, a subsurface maximum developed below the base of the mixed layer and remained until 17 April at gradually reduced concentrations. The solid black line in this panel represents the chlorophyll centre of mass, which was at a relatively constant depth (25 m) for the first half of the mooring period, after which it slowly descended to ~40 m by mid-April. This variable has been calculated with the assumption that chlorophyll concentration in the upper 6-7 m of the water column is equal to the uppermost bin of the SeaHorse profile.

Photic zone depths were determined by fitting exponential curves to the daytime PAR profiles and calculating the depth at which 1% surface light levels would occur. PAR profiles (Fig. 2E) indicated an abrupt shallowing by 20-30 m of the photic zone depth after 21 March in conjunction with the development of the phytoplankton bloom. The photic depth remained close to 20 m until 4 April, after which it increased to 45 m toward the end of the deployment. The collapse of the surface chlorophyll bloom on 7 April resulted in an order of magnitude increase in PAR at 41 m, where the subsurface chlorophyll maximum develops. The red dots, indicating the depth of the euphotic zone as estimated using a Secchi disc on AZMP station occupations, are in good agreement with the SeaHorse PAR results.

Nitrate concentrations from the moored NAS sensors (Fig. 3A) were calibrated against values derived from water samples drawn during AZMP occupations of HL2. The standard AZMP bottle samples are drawn at 1, 5, 10, 20, 30, 40, 50, and 75 m. A linear interpolation was used to estimate the nitrate concentration at NAS depths of 16 and 41 m. There was one exception to this on 29 March, during which the bottle samples were not at the standard AZMP depths and the closest ones to the deep NAS were at 35 and 60 m. In this case, the NAS appeared to be in the nutricline while the 35 m sample was in the mixed layer and a linear interpolation did not provide a reasonable estimate. Hence, the 41 m concentration was calculated using an extrapolation of the 60 and 100 m nitrate samples. The shallow NAS calibration indicated a small positive offset of the instrument of 0.6 mmol $m^{-3}$ with an RMS difference of 0.7 mmol $m^{-3}$. No offset was apparent for the deep NAS, which had an RMS difference of 2.6 mmol $m^{-3}$.

During the mooring period, the initial nitrate concentration at 16 m was 4.5 mmol $m^{-3}$, increased over the first 48 hours to ~6 mmol $m^{-3}$, then decreased over the next 24 hours to 0.5 mmol $m^{-3}$ (Fig. 3A). The concentration increased to ~2 mmol $m^{-3}$ for 23-27 March and then decreased to zero on 29 March and remained negligible throughout the rest of the mooring period.

During the first two days, the nitrate concentration at 41 m increased from 2 to 6 mmol $m^{-3}$ and then decreased back to 4 mmol $m^{-3}$, but uncertainties were large. By 23 March, the concentration had decreased to 2 mmol $m^{-3}$ and remained constant until 27 March. During this period, the nitrate concentrations at the two NAS sensor depths were of similar magnitude. There were several periods when nitrate levels increased: 29-31 March, peak of ~7 mmol $m^{-3}$; 2 April, peak 4 mmol $m^{-3}$; and 7-19 April, a broad variable period with peak values of 8.5 mmol $m^{-3}$. The shallow and deep nitrate concentrations over the first three days of the record are broadly similar, with relatively high levels followed by a rapid decrease, suggesting that the onset of a growth period of the spring bloom occurred about two days after the start of the deployment. The e-folding time scale of this decay in nitrate concentration at 41 m was estimated to be 3.9 days.

The density stratification was weak at the depths of the two nitrate sensors for the first four days of the mooring period and was eliminated completely by 23 March (Fig. 3B). Nitrate

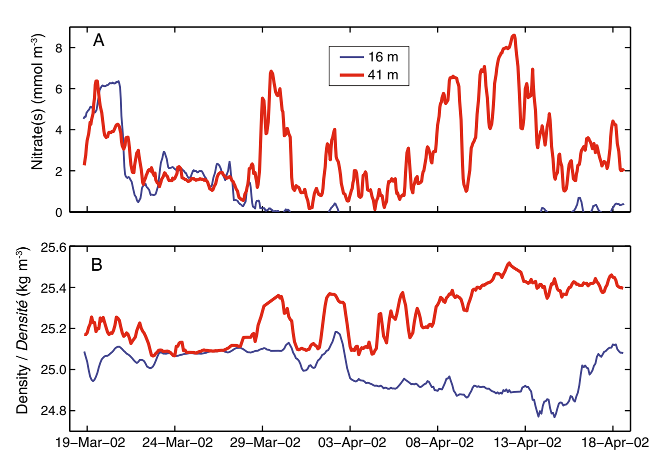


Fig. 3 (A) Nitrate concentrations measured by NAS-2EN instruments at the depths of 16 m (thin line) and 41 m (thick line) at HL2 for the period 18 March 2002 – 18 April 2002; (B) seawater density at depths of nitrate sensors (thin line: 16 m; thick line: 41 m).

*(A) Teneurs en nitrates mesurées à l'aide d'instruments NAS-2EN aux profondeurs de 16 m (ligne mince) et de 41 m (ligne épaisse), à la station HL2, pendant la période du 18 mars au 18 avril 2002; (B) Densité de l'eau de mer aux profondeurs où des analyseurs de nitrates ont été installés (ligne mince [16 m] et ligne épaisse [41 m]).*

concentrations declined significantly prior to the break-down of this stratification. A temperature–salinity plot for this time period indicates that the water mass at these two depths is of similar origin. After 28 March, the water column began to restratify and reached its maximum in mid-April.

Two short-term events in the density time series at 41 m were centred at 30 March and 2 April; the second event is apparent at the shallower depth as well. Nitrate at 41 m showed a similar pattern for these two events; however, the response at 16 m was very limited. The chlorophyll layer thickened and intensified in response to these events (Fig. 2D). Following 3 April, the density at 16 m decreased slightly as the water warmed. The nitrate concentration remained close to zero for the remainder of the mooring period. After 3 April, the density at 41 m gradually increased reaching a maximum on 12 April and then remained relatively constant at 25.4 until the end of the mooring period. The nitrate at this depth followed a similar trend although the concentration decreased rapidly after 12 April. This decline in concentration is probably related to the deepening of the photic zone and improved light conditions that allowed the phytoplankton to more efficiently use nitrate at this depth. The cross-correlation between the 41-m density and nitrate time series was 0.6 for the whole mooring period; if the period following 12 April is removed, then r = 0.7.

## Conclusion

Our results indicate that a phytoplankton bloom started at HL2 several days after the moorings were deployed. During this period, changes in the physical properties were dominated by longer-term trends such as surface warming through increased insolation. However, chlorophyll measurements indicate that phytoplankton concentration can change substantially over a period of several days and these changes are probably related to the processes controlling the spatial variability in the biological fields in this advective region of the Scotian Shelf.

There are a number of questions that arise from these data. The first one is, what precipitated the onset of the bloom? It does not appear to be the development of a stratified layer, which is the classic picture of the commencement of the spring bloom. Was it the lack of turbulence in the shallow near-surface layer that allowed the phytoplankton to proliferate, or production advected from upstream as HL2 is located in the core of the Nova Scotia Current? What role, if any, did upwelling play in the two events of late March and early April? Why didn't the long-term increase of nitrate from early to mid-April generate a stronger response? How do these short-term events modify the "normal" dynamics of the spring bloom, which are determined only by the winter inventory of surface nutrients? Could these events disrupt the growth cycle and result in "multiple bloomlets"? Could short-term processes increase the magnitude or extend of the growth period of the bloom by adding more nutrients? If so, these modified bloom dynamics might impact the stage development and survival of their grazers (e.g., *Calanus finmarchicus*). Some of these issues are being investigated further through the analyses of complementary datasets such as AZMP in situ sampling at HL2, 10 m winds from Sable Island, and SeaWiFS and NOAA AVHRR satellite imagery of ocean colour and temperature, respectively.

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# *Bottom Temperature Monitoring in the Coastal Zone: A Cooperative Effort of Lobster Fishermen, FSRS and DFO*


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### Sommaire

Depuis qu'une étude pilote a été réalisée en 1998, les pêcheurs de homard, la Fishermen and Scientists Research Society (FSRS) et des spécialistes de la biologie des populations du ministère des Pêches et des Océans collaborent à la mesure des variables physiques et biologiques liées à la pêche côtière. Ce programme a pris de l'expansion et comprend maintenant la collecte d'environ 15 000 jours de données de température chaque année à divers endroits dans la région s'étendant du nord de l'île du Cap-Breton jusqu'à la baie de Fundy. À l'heure actuelle, le jeu de données porte uniquement sur la saison de pêche du homard dans chaque zone de pêche. Les données ont été utilisées pour résoudre des problèmes liés à la croissance, la mue, la reproduction et la capturabilité du homard dans la région des Maritimes. En plus des registres de température, les pêcheurs recueillent des données démographiques qui sont utilisées comme indicateurs de l'abondance des stades de pré-recrues de homard.

## Introduction

The coastal waters less than 50 m deep off Nova Scotia are productive areas for several marine populations including commercially important species such as lobster. In 1998, the Ocean Monitoring Working Group designed the Atlantic Zonal Monitoring Program (AZMP) "to acquire data over broad areas of the continental shelf and slope" (Therriault et al. 1998). While the group acknowledged the importance of the nearshore zone, the AZMP did not add additional monitoring in the coastal region; the proposal stated that "near-shore data should also be acquired from existing near-shore monitoring programs." Long-term near-shore temperature monitoring by the Department of Fisheries and Oceans (DFO) is limited to 8 sites from Sydney Bight to the mouth of the Bay of Fundy. This coverage is quite limited compared to the extensive lobster fishery carried out along the coast.

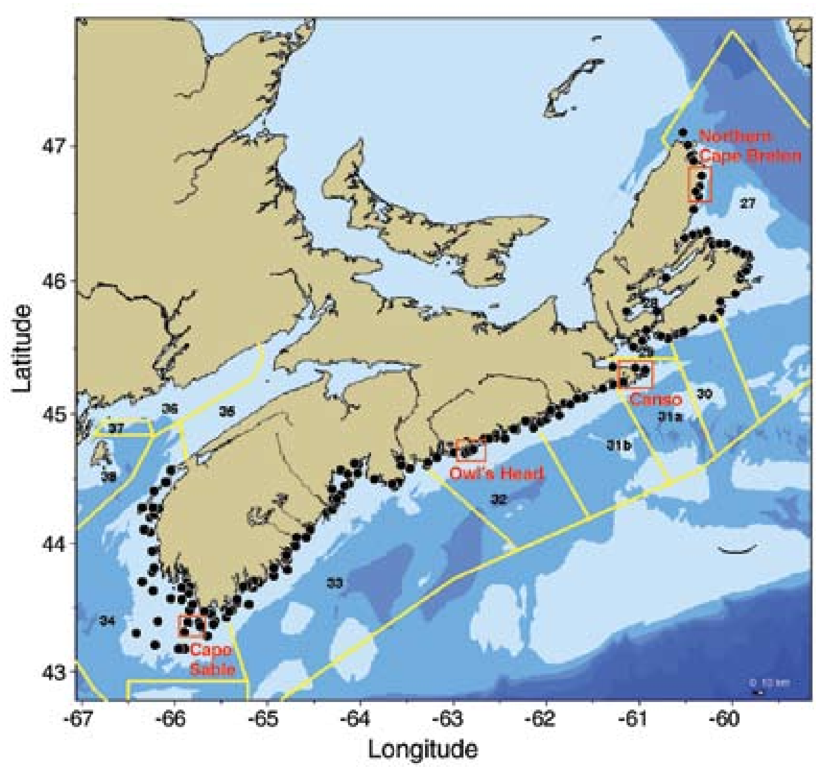


Fig. 1 Locations of FSRS traps with temperature recorders during commercial lobster fisheries in spring (black dots). Red boxes outline source areas for temperature data used in Figures 3 to 6. Also shown are Lobster Fishing Areas (LFAs, yellow polygons).

*Emplacements des casiers de la FSRS dotés de thermographes durant la pêche commerciale du homard au printemps (points noirs). Les zones encadrés en rouge représentent les zones sources des données de température utilisées dans les figures 3 à 6. Sont également illustrées les zones de pêche du homard (ZPH, polygones jaunes).*

Temperature has a pervasive effect on lobster biology, including such fundamental processes as growth and reproduction. As such, temperature has long been used in models to explain annual variation of lobster landings (Flowers and Saila 1972, Drinkwater et al. 1996). On a shorter time scale, daily fluctuations of temperature are correlated with daily changes in lobster catch rate in some areas (Drinkwater et al. 2006), likely due to temperature-induced changes in lobster catchability. Much of the daily variation in coastal bottom temperatures is driven by alongshore winds producing upwelling or downwelling. The links among wind, temperature, and catch rate help explain fishermen's observations of changes in catch rate associated with changes in wind direction.

During lobster seasons throughout Atlantic Canada, fishermen work daily in the coastal zone and are keenly interested in temperature and other oceanographic conditions. The setting and hauling of lobster traps provides a unique opportunity for monitoring ocean bottom temperatures. The lobster industry and scientists are cooperating to measure bottom temperatures as part of another project (see below - FSRS Lobster Recruitment Index Project). The program began as a pilot study in 1998, expanded significantly in 1999, and is ongoing (Fig. 1 & 2). During the lobster fishing season, lasting 2-6 months depending on the Lobster Fishing Area (LFA), small temperature recorders are attached to traps. This article provides some highlights of the project. Fishermen collect the data, the Fishermen and Scientists Research Society (FSRS) manages all aspects of the project, and DFO scientists provide data interpretation and advice on project improvement. The FSRS makes the data available to DFO scientists who incorporate them into the Coastal Time Series Database, a public database on the Maritimes internet website at the address http://www.mar.dfo-mpo.gc.ca/science/ocean/database/data_query.html.

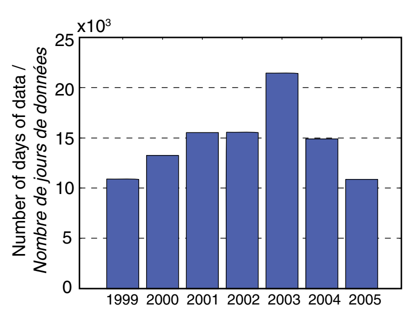


Fig. 2 Histogram of the number of data days for 1999 to 2005. Note that only the spring deployments are shown for 2005; the fall records are still being processed and quality controlled.

*Histogramme du nombre de jours de données pour la période de 1999 à 2005. À noter que seuls les casiers mis à l'eau au printemps sont pris en considération pour l'année 2005; les données d'automne sont encore au stade de traitement et de contrôle de qualité.*

### *Uses of the Temperature Data*

The temperature data from the FSRS traps have been used in a wide variety of issues associated with the near-shore lobster fishery such as: (1) annual updates to fishermen to better understand seasonal trends in landings, (2) context for periodic lobster assessments (e.g., Facey and Petrie 2005), (3) providing the data for temperature-corrected estimators of exploitation rate, and (4) evaluation of whether recent changes in the shell condition of lobsters during the commercial fishery are related to temperature (Claytor et al. in prep.). In addition to the uses associated with the lobster fishery, the data have been used for the assessment of the coastal ocean climate, complementing the year-round series at other sites and the very long records at Halifax and St. Andrews, and the determination of the spatial variability of the near-shore ocean climate.

As part of the Lobster Recruitment Index Project, the FSRS has worked with volunteer lobster fishermen to collect bottom temperature data since 1999. This project was initiated to develop an indicator of abundance of prerecruit lobsters and involves fishermen measuring and recording all lobsters collected in standard traps each day. These standard traps, distributed by the FSRS, have features that lead to greater retention of prerecruit lobsters: smaller openings in the wire mesh, relatively small entrance rings, and no escape slots (as is required on all commercial traps). As such, these standard traps provide a better indicator of the abundance of prerecruit lobsters than do commercial traps. Fishermen sex and measure all lobsters in the standard traps using an FSRS gauge that is marked in 5-10 mm increments.

For the temperature measurement part of the project, participating fishermen each get one Vemco Minilog temperature recorder and attach it to one of 2-5 standard traps. The traps with recorders are deployed all along the Atlantic coast of Nova Scotia (Fig. 1). In spring 2006, there were a total of 180 participants fishing a total of 508 traps.

Fishermen are asked to keep the traps (and thus the temperature recorder) in one location throughout the season. Most are able to do this, but commercial traps in some fishing areas are routinely moved significant distances over the course of the season. As a result, the standard traps with the temperature recorder must also be moved. In these cases, the location changes are noted and recorded in the database.

The temperature data from temperature recorders that are within a few tens of miles from one another show a high degree of synchrony (Fig. 3). All measure about the same winter cooling and spring warming; some measure essentially the same higher frequency variability as well. This is in spite of the fact that depths may differ by tens of metres.

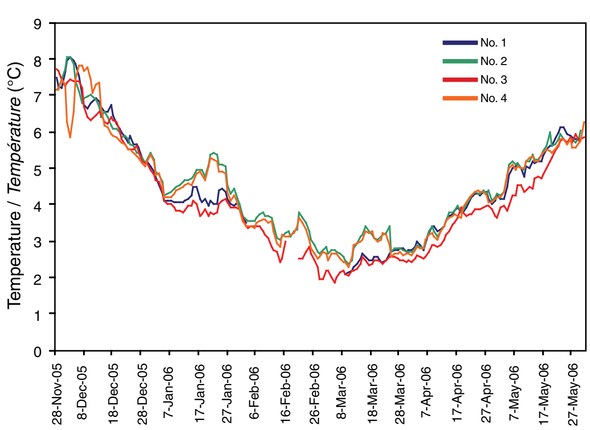


Fig. 3 Daily mean temperature for four temperature recorders in the Cape Sable area (see Fig. 1) during the 2005–2006 lobster fishing season. Depths ranged from 28 to 46 m.

*Température moyenne quotidienne pour quatre thermographes dans la zone du cap Sable (voir Fig. 1) durant la saison de pêche au homard 2005 – 2006. Les profondeurs variaient entre 28 et 46 mètres.*

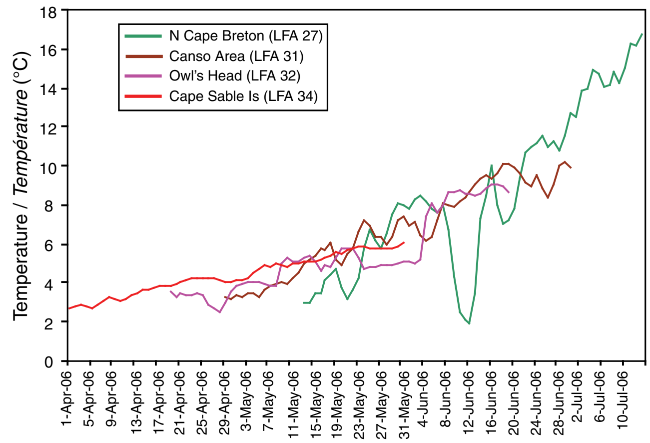


Fig. 4 Mean daily temperature in spring and early summer for the four areas delineated in Figure 1. Depths were 9–17 m for northern Cape Breton, 7–14 m for Canso, 9–18 m for Owl's Head, and 28–46 m for Cape Sable. The number of days for each area is different because of different lobster seasons: May 15–July 15 for LFA 27, Apr. 29–June 30 for LFA 31, Apr. 18–June 20 for LFA 32, and last Monday in November–May 31 for LFA 34.

*Température moyenne quotidienne au printemps et au début de l'été pour les quatre zones encadrées dans la figure 1. Les profondeurs variaient entre 9 et 17 m pour le nord de l'île du cap Breton, entre 7 et 14 m pour Canso, entre 9 et 18 m pour Owl's Head et entre 28 et 46 m pour cap Sable. Le nombre de jours pour chaque zone est différent en raison de différences dans les saisons de pêche : du 15 mai au 15 juillet pour la ZPH 27, du 29 avril au 30 juin pour la ZPH 31, du 18 avril au 20 juin pour la ZPH 32 et du dernier lundi de novembre au 31 mai pour la ZPH 34.*

The data can be used to characterize the spatial and temporal differences from northern Cape Breton to the mouth of the Bay of Fundy. Daily mean temperatures from April to early summer are shown for four widely separated areas of coastal Nova Scotia in Figure 4. LFA 34 in southwest Nova Scotia, an area dominated by the strong tides of the Gulf of Maine–Bay of Fundy region leading to vertically well-mixed conditions, has the highest temperatures in April–May; the tidal mixing, while keeping temperatures relatively high during winter and spring, tends to limit the temperatures in summer. On the other hand, temperatures in northern LFA 27, which are typically below 0°C in winter, can warm to above 15°C in July.

Strong interannual variability in bottom temperatures is apparent (Fig. 5). In LFA 34, for example, late fall temperatures differed by up to 2.5°C. In winter, the range increased to ~3°C. Finally in spring, the observed range was still about 3°C, with temperatures in 2003-04 about 3°C lower than spring temperatures in 2000-01 and 2001-02.

The FSRS project samples the physical environment during the lobster seasons only, not throughout the year. Temperature data during those parts of the year outside of the fishing seasons must be collected by other means. At present this is done at a few sites as part of another more modest long-term project. Providing the resolution obtained during the fishing season by the FSRS deployments is not possible with available resources. However, a modest increase of the number of year-round sites could greatly help with near-shore lobster issues such as the soft-shell problem.

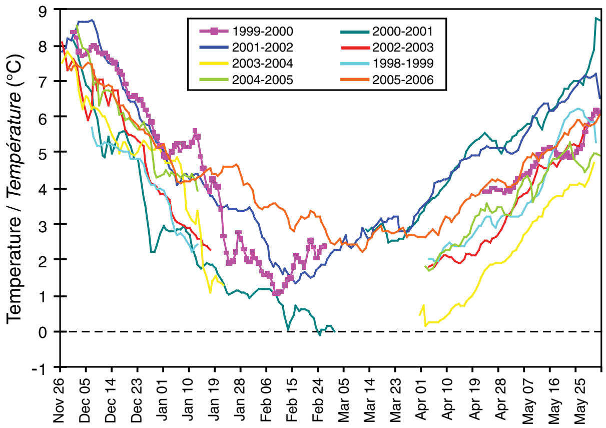


Fig. 5 The annual trends in temperature for the Cape Sable area (see Fig. 1) for the 1998–1999 season through to the 2005–2006 seasons. Shown is mean daily temperature for the 1–5 recorders maintained in each year over the period.

*Tendances annuelles de la température dans la région du cap Sable (voir la Fig. 1) pour la période allant de la saison 1998 –1999 à la saison 2005–2006. Les données illustrées représentent la température moyenne quotidienne pour les thermographes (de 1 à 5) mis à l'eau chaque année pendant la période mentionnée.*

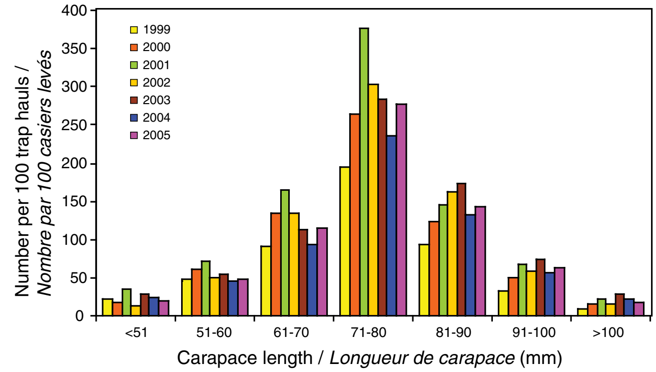


Fig. 6 Mean seasonal catch rate of lobsters of different sizes for all participants in LFA 34. Data for the fall component of the fishery are shown and correspond to the period late November to December 31. The minimum legal size in this LFA is 82.5 mm carapace length.

*Taux saisonnier moyen de capture de homards de différentes tailles pour tous les participants dans la ZPH 34. Les données entre la fin novembre et le 31 décembre sont illustrées et correspondent à la composante automnale de la pêche au homard. La longueur de carapace réglementaire dans cette ZPH est de 82,5 mm.*

The demographic data collected by fisherman on the catch rates by size and sex are proving to be very interesting and useful. While most areas have shown some stability in the last 7 years as shown by the relatively constant numbers in each length group across years (e.g., Fig. 6), the area around Chedabucto Bay (e.g., Canso area) shows a remarkable jump in the catch rate of prerecruit lobsters (those in the 71-80 mm carapace length group) beginning in 2003 (Fig. 7). This increase has continued to the present and has translated into a large increase in commercial landings that was predicted from the FSRS recruitment trap data.

*Lobster Shell Hardness*

Recently there has been an increased percentage of lobsters with soft shells in the December catch in southwest Nova Scotia. There are several hypotheses to explain this increase. One of the hypotheses is that lower temperature has caused a delay in the moult cycle such that lobster shells have had insufficient time to harden and fill with meat prior to the December start of the season. As shown in Figure 5, the interannual variability in bottom temperature during the lobster season can be considerable. However, lobster growth occurs throughout the year, and one of the challenges in evaluating this hypothesis is developing a complete seasonal temperature cycle for LFA 34. Combinations of satellite data, opportunistic in situ sampling, and limited mooring observations from the region can be used along with the FSRS series to build a year-round dataset (Facey and Petrie 2005). Results from a project to evaluate the relationship between temperature and shell hardness are documented in Retzlaf et al. 2007.

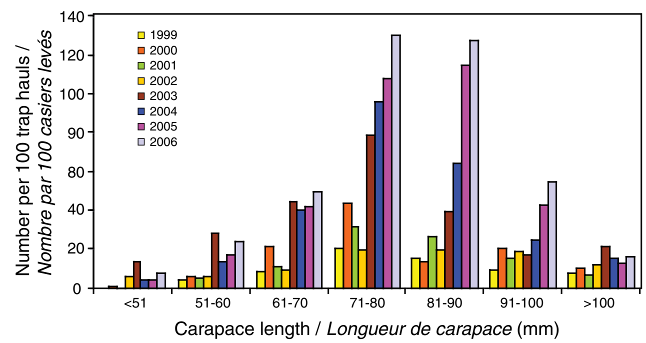


Fig. 7 Mean seasonal catch rate of lobsters of different sizes for all participants in LFA 31a; the season is Apr. 29–June 30. The minimum legal size in this LFA is 84 mm carapace length.

*Taux saisonnier moyen de capture de homards de différentes tailles pour tous les participants dans la ZPH 31a. La saison est ouverte du 29 avril au 30 juin. La longueur de carapace réglementaire dans cette ZPH est de 84 mm.*

## Conclusion

The FSRS project is a successful collaboration among lobster fishermen, the FSRS, and the Department of Fisheries and Oceans. It provides high spatial resolution data to understand the physical environment in which the lobsters live, grow, and reproduce, and is a significant source of near–coastal physical information for DFO's AZMP monitoring database. Some of the benefits of this project have emerged already, and securing long-term measurements will assist with ongoing issues such as lobster moulting, ongoing assessments of stock status, management of the fishery, and other types of advice needing coastal physical information.

## Acknowledgements


We thank the more than 200 lobster fishermen who have participated in the project since 1999. We also thank Shannon Scott-Tibbetts and all our other colleagues who have input and managed these data over the years.


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## Real-Time Monitoring of Nitrate With the Satlantic-ISUS Sensor

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**Sommaire**

Cet article décrit la performance d'un instrument optique conçu pour fournir des estimés de nitrates, le principal sel nutritif limitant pour les organismes phytoplanctoniques situés à la base de la chaîne trophique. Nous avons comparé les niveaux de nitrates déterminés par la méthode chimique traditionnelle avec les mesures optiques in situ obtenues à l'aide d'un spectrophotomètre ultraviolet (ISUS). La comparaison entre les deux méthodes confirme la validité de la méthode optique en ultraviolet afin d'obtenir des concentrations de nitrates in situ en temps réel dans le milieu marin.

### Introduction

The Satlantic ISUS (In Situ Ultraviolet Spectrophotometer) is a real-time, chemical-free ultraviolet spectrophotometer designed to overcome the traditional challenges associated with nitrate analyses in coastal, estuarine, and oceanic waters. The ISUS sensor was developed by the Monterey Bay Aquarium Research Institute (MBARI) in California and is based on the absorption characteristics of inorganic compounds in the UV light spectrum (Johnson and Coletti 2002). The ISUS uses the UV (200-400 nm) absorption characteristics of various chemical species to provide in situ measurements of their concentrations in solution. The system consists of four key components: a stable UV light source, a UV spectrophotometer, a bifurcated fibre optic sampling probe, and a processing microcomputer. All these components are housed within an anodized aluminium pressure case rated to 1000 m (Fig. 1).

Fig. 1 The ISUS in situ ultraviolet spectrophotometer measures dissolved chemical species to infer nitrate concentration. The sensor provides a chemical-free, real-time, continuous assessment of nitrate concentration and can be deployed in a variety of aquatic systems including freshwater, estuarine, and open-ocean areas. Battery pack not shown. Physical characteristics: length 608 mm; diameter 114 mm; weight in air 5.0 kg, in water 0.7 kg. The housing material is made of anodized aluminum and operating temperatures range from –1.8 to 40°C.

*Le spectrophotomètre ultraviolet de terrain ISUS mesure différents composés chimiques dissous afin de déterminer la concentration des nitrates. Ce senseur procure une estimation en temps réel et en continue, sans utilisation de produits chimiques, et peut être déployé dans plusieurs types d'environnements aquatiques incluant les systèmes estuariens et d'eaux douces et les systèmes océaniques. Le bloc de batteries n'est pas montré. Le système a une longueur de 608 mm, un diamètre de 114 mm, un poids dans hors de l'eau de 5.0 kg et dans l'eau de 0.7 kg. L'instrument est fabriqué en aluminium anodisé et peut être opéré à des températures variant entre -1.8 à 40°C.*

Few chemical species absorb light in the UV, and each has a unique absorption spectrum. In seawater, UV absorption spectra are dominated by nitrate and bromide. By using advanced UV absorption technology, the ISUS instrument measures the nitrate absorption spectrum and computes the concentration directly. A precision laboratory calibration generates instrument-specific coefficients for both nitrate and bromide over a range of concentrations and temperatures. The ISUS measures the in situ absorption spectrum and then uses the calibrated coefficients and a least-squares curve fitting routine to calculate an absorption spectrum matching the measured spectrum. It then calculates the concentrations of nitrate and bromide required to generate the matching spectrum.

The ISUS is designed to be a self-contained nitrate monitoring system that does not require chemicals or reagents to determine the nitrate concentration. The system provides continuous nitrate concentration measurements from a user-programmable schedule, logging to an internal 256 MB memory. These remotely obtained measurements of one of the ocean's most important nutrients are essential to the study of physical, chemical, and biological processes.

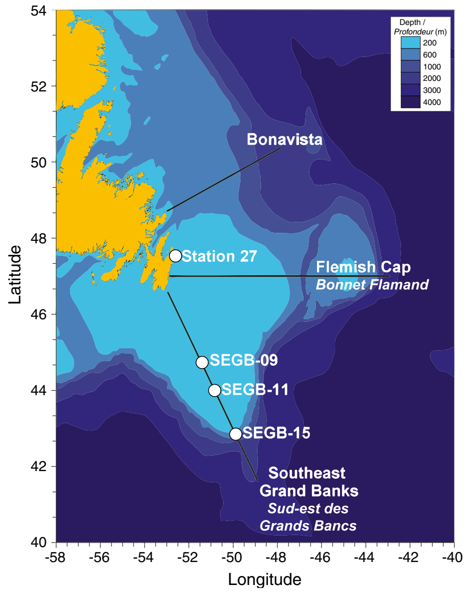


Fig. 2 Station locations for ISUS-CTD vertical deployments and collection of seawater at standard depths at Station 27 and along the southeast Grand Banks section. Locations of the Flemish Cap and Bonavista Bay sections are also provided.

*Positions des stations pour les profilages verticaux de la sonde ISUS-CTD et la collecte d'eau de mer aux profondeurs standards à la Station 27 et le long d'un transect au sud-est des Grands Bancs. La position des transects de Bonnet Flamand et de Bonavista est également illustrée.*

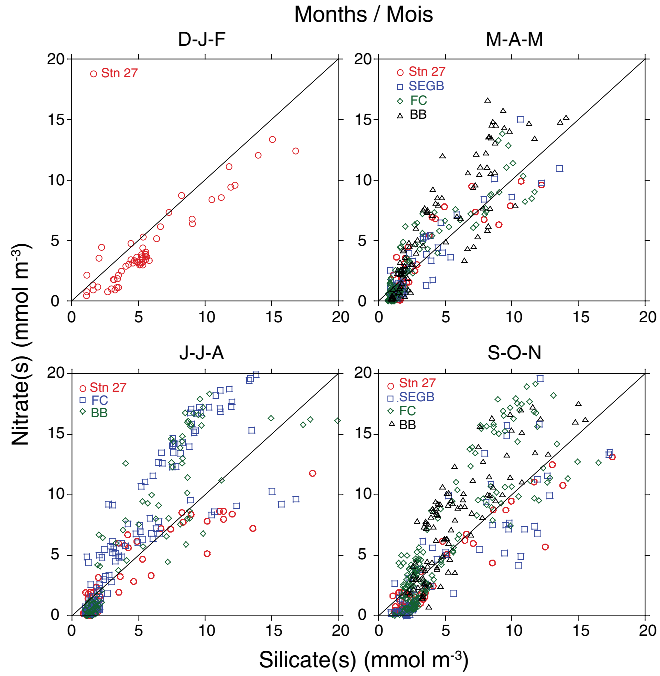


Fig. 3 Seasonal variations of silicate versus nitrate for an inshore coastal station (Station 27) and for three sections of the Atlantic Zone Monitoring Program (AZMP) collected in 2005 (SEGB: southeast Grand Banks; FC: Flemish Cap; BB: Bonavista Bay; see Fig. 2). Note that in all locations and seasons, nitrate is the principal limiting nutrient on the Newfoundland Grand Banks and Northeast Shelf.

*Variations saisonnières du rapport silicates/nitrates pour des stations situées près de la côte (Station 27) et le long de trois transects du programme de monitorage de la zone Atlantique (PMZA) en 2005 (SEGB : sud-est des Grands Bancs, FC : Bonnet Flamand, et BB : baie de Bonavista; voir Fig. 2). Noter qu'à toutes les stations et pour toutes les saisons, les nitrates représentent l'élément nutritif limitant dans la région des Grands Bancs de Terre-Neuve et dans la partie nord-est du plateau continental.*

We coupled the deployment of the Satlantic-ISUS nitrate sensor with a Sea-Bird 911 CTD at an inshore coastal station and at three stations along the southeast Grand Banks section (Fig. 2). We collected vertical profiles with both instruments and discrete seawater samples with a rosette sampler during the upcasts. Water samples were frozen and then analyzed on shore for nitrate determination with a Technicon II Autoanalyzer using the conventional cadmium reduction column to reduce nitrate to nitrite (combined nitrate+nitrite determination; Mitchell et al. 2002). Here, we report on the performance of the ISUS sensor in making high-resolution measurements of nitrate concentration during vertical profiling on the Newfoundland Shelf and Slope waters. We compare autoanalyzer determinations of nitrate with ISUS estimates using ultraviolet absorption spectra.

### *Seasonal Nutrient Distributions*

Biological production of phytoplankton is partly dependent on the accumulated inventories of nutrients. The potential for seasonal growth of phytoplankton is limited by the availability of nutrients that are replenished through advective and vertical mixing processes from deeper layers during late autumn and winter and through recycling at shallower depths. Results from the Atlantic Zone Monitoring Program (AZMP) indicate that nitrate is the principal limiting nutrient during much of the year in the northwest Atlantic (Pepin et al. 2005). Seasonal distributions of silicate and nitrate concentrations in the Newfoundland Shelf and Slope waters in 2005 support this observation, with the consistent depletion of nitrate prior to silicate along all oceanographic sections and at the inshore coastal station (Fig. 3).

### *Vertical Profiles of Nitrate*

The performance of the ISUS sensor was assessed by comparing nitrate concentrations from water samples collected by Niskin bottles at discrete depths and analyzed on a Technicon autoanalyzer with estimates derived from UV absorption spectra. Four ISUS-CTD vertical profiles were collected along with corresponding water samples at an inshore coastal site (Station 27) that is located within the Avalon Channel and three stations along the southeast Grand Banks section extending to the Slope waters (Fig. 2). We matched the timing of the ISUS absorption spectra with the corresponding time of collection of water samples. The vertical concentration profiles determined by ISUS and the autoanalyzer are shown in Figure 4. The optical estimates from ISUS spectra track the general shape of the vertical nitrate profile determined by conventional laboratory measurements. We note small differences in the vertical profiles of nitrate concentrations between ISUS and the autoanalyzer-derived values. The largest differences in nitrate concentrations tended to be associated with samples collected near the bottom (Fig. 4D) and at the surface of the water column (Fig. 4B). Differences can be attributed to non-linear instrument drift, fouling (long-term moored deployments), additional UV-absorbing chemical species (e.g., bromine, suspended particulates, and dissolved organics[CDOM]), and changes in temperature that modify

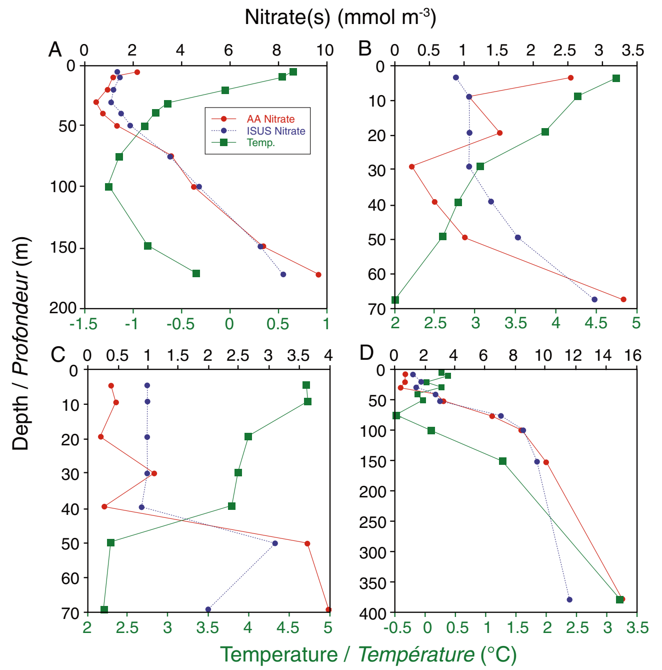


Fig. 4 Vertical profiles of nitrate concentration and temperature collected at Station 27 (A) and at three stations along the Southeast Grand Banks (SEGB) section. Station SEGB-09 (B) and SEGB-11 (C) are located on the Shelf while station SEGB-15 (D) is situated on the Continental Slope (see Fig. 2).

*Profils verticaux de la concentration en nitrates effectués (A) à la Station 27 et à trois stations le long du transect du sud-est des Grands Bancs. Les stations SEGB-09 (B) et SEGB-11 (C) sont localisées sur le plateau tandis que la station SEGB-15 (D) est située au dessus de la pente continentale.*

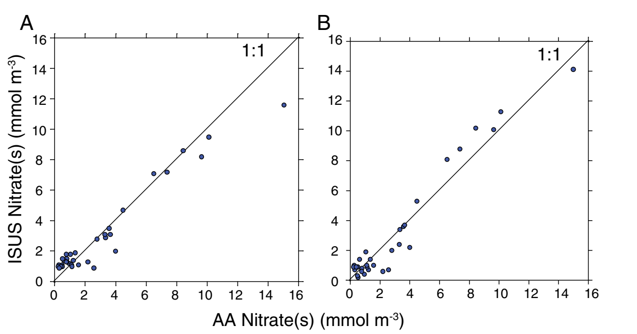


Fig. 5 Relationship between corrected ISUS optical estimates of nitrate concentration determined by UV spectrophotometry and conventional Technicon autoanalyzer (AA) measurements: (A) offset-corrected values and (B) temperature-corrected values made by increasing the ISUS nitrate values by the same proportion as the error in optical salinity. Both corrections of the optical estimates are highly correlated (r = 0.97) with laboratory measurements.

*Relation entre les estimés optiques (ISUS) de la concentration en nitrates mesurés par spectrophotométrie en ultraviolet et par la méthode conventionnelle de l'autoanalyseur Technicon (AA) : (A) valeurs corrigées pour le décalage et (B) valeurs corrigées pour la température obtenues en augmentant les valeurs optiques ISUS de nitrates en proportion égale à l'erreur optique associée à la salinité. Les deux corrections des estimés optiques sont fortement corrélées (r = 0,97) avec les mesures en laboratoire.*

instrument performance (Johnson and Coletti 2002). Our data lend support to the latter observation in that the largest differences in nitrate concentrations between the optical and chemical-based measurements were generally associated with the thermocline depth (rapid change in temperature with depth, see Fig. 4). The absolute difference in nitrate concentrations between the two methods was positively correlated with the change in temperature with depth ($r = 0.4$, $P < 0.05$). We compared the standard offset correction that was applied to the profile data with the percent difference between ISUS UV salinity estimates and CTD salinity values, as suggested by Johnson and Coletti (2002). Both correction methods indicated a high correlation ($r = 0.97$) between ISUS and conventional measurements (Fig. 5), although the additional temperature/salinity correction provided a slightly better fit when the residuals were evaluated (data not shown). The average absolute error in nitrate concentration values between ISUS and laboratory measurements was 0.7 mmol $m^{-3}$ (range 0.1 to 3.4 mmol $m^{-3}$; $n = 34$) for the entire data set.

## Conclusion

The Satlantic-ISUS sensor coupled with a conventional CTD-rosette system can be used to acquire high-resolution profiles and near real-time estimates of nitrate concentrations in conjunction with other environmental variables in temperate North Atlantic waters. The collection of UV absorption spectra to estimate nitrate concentrations offers a rapid, chemical-free method to evaluate the primary limiting nutrient influencing ocean productivity. The results we obtained with the ISUS instrument confirm the potential to make reliable in situ measurements of nitrate concentration using a robust optical method in conjunction with the collection of environmental data. The acquisition of real-time information of the vertical distribution of nitrate offers advantages over traditional wet chemistry methods: real-time information can be used to design enrichment experiments to infer the rate of primary productivity and provide high resolution maps over large oceanic areas. Although ISUS has been used extensively in profiling applications integrated with CTD systems, the instrument can also be utilized in undulating towed bodies, autonomous underwater vehicles, drifters, and long-term moorings deployed in coastal, estuarine, and deep-ocean environments.

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# *Expanding the Gathering of Real-Time In Situ Oceanographic Data With the DFO Marine Mammal Research Program*

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**Sommaire**

L'observation des océans est nécessaire afin de mieux comprendre, modéliser et prédire leur évolution. À cette fin le MPO a mis sur pied le Programme de Monitorage de la Zone Atlantique (PMZA) pour faciliter la collecte de données océanographiques physiques et biologiques pour la zone nord-ouest de l'Atlantique. Le PZMA est un important collaborateur et fournisseur de données pour l'océanographie opérationnelle, laquelle sert un bon nombre d'utilisateurs scientifiques et industriels, ainsi que la navigation de plaisance. Le rôle principal de l'océanographie opérationnelle est de fournir de l'information fiable sur les conditions océaniques aux échelles temporelles et spatiales désirées, dans un délai raisonnable, ce qui permet à l'utilisateur de prendre des décisions plus éclairées. Afin d'ajouter à la panoplie d'informations océanographiques recueillies par des méthodes classiques, nous proposons l'utilisation de « plateformes biologiques » telles que des capteurs ou balises attachés sur le dos de phoques afin de mieux échantillonner les eaux canadiennes de l'Atlantique. Cet article décrit la méthodologie utilisée et présente quelques résultats physiques et biologiques obtenus en 2004 et 2005. Une revue des enjeux et des avantages de cette méthodologie est finalement présentée pour mettre en lumière le potentiel de ce programme d'acquisition de données océanographiques basé sur l'utilisation de phoques.

## Introduction

The development of numerical ocean forecast models in Canada requires complementary data to statistically constrain and validate model results. In providing a state of the ocean analysis, whether it is a 10-year hindcast or an instantaneous assessment for forecasting, observations are of prime importance.

Ocean forecasting falls within the broader field of operational oceanography, which encompasses all systems that provide useful information about the past, present, and future states of the ocean for marine and scientific applications (Davidson et al. 2006). This information is typically a combination of observations and model results.

Good forcing fields are essential for estimating the state of the oceans. The most important is the wind, followed by surface and lateral boundary fluxes. Models do not resolve all the physical processes in the ocean; moreover, the forcing fields contain errors. To compensate for the missing physics and reduce errors, models often blend in or assimilate observations.

Here we examine the contribution of oceanographic data collected by marine mammals in the North Atlantic to increasing our biological understanding of these animals as well as to improving the description of the marine environment. In addition, with real-time dissemination, these data provide timely information for operational ocean forecast systems.

*Description of the Profiling Instrumentation for Marine Mammals*

The idea of using animals as oceanographic observation platforms is not new, but technological improvements in micro-electronics and programming have transformed these ideas into practice. As a result, the profiling instrumentation for marine mammals provides a cost-effective opportunity to gather biological and oceanographic data and transmit it to the researcher in near real time (Lydersen et al. 2002, 2004).

The principal components in the approach are the deployment of the basic sensor(s) coupled to a data storage/processing/transmitting device, the transmission of the data to orbiting satellites, and the subsequent relay to receiving ground stations. The deployment of instruments on marine mammals has many challenges, beginning with the capture—which often involves some type of net and physical or chemical immobilization—and the attachment of the package with a quick-setting epoxy (Fig. 1). Data are received by Argos instruments on various satellites.

Fig. 1 Harp seal fitted with a profiling instrument.

*Phoque du Groenland équipé d'un instrument du profilage.*

Transmitted data includes hand shaking information (communication establishment), the transmitter ID number, and sensor data. The Argos system also provides the mammal's location based on the Doppler shift in received frequencies, with an estimated accuracy of 150-1000 m, depending on the quality assessed by Argos (for more information see https://www.argos-system.org/).

The major instrument constraint is transmitter size. The package must be large enough to contain all of the necessary components but small and light enough to not significantly affect the animal's normal activities. Although smaller component size has allowed researchers to add more sensors, energy requirements mean that the battery remains the single largest and often most limiting component. Additional limitations include bandwidth constraints of the Argos system and the limited time that animals remain at the surface, when transmissions to the satellite must occur.

Within the Canadian Department of Fisheries and Oceans (DFO) Marine Mammal Program, we have deployed transmitters developed by the Sea Mammal Research Unit (SMRU: Gatty Laboratory, University of St. Andrews, United Kingdom), which have onboard oceanographic-quality conductivity–temperature (CT) sensors with accuracies of ±0.02 mS cm$^{-1}$ and ±0.02°C in addition to the basic pressure and velocity sensors (Fedak et al. 2002, Fedak 2004).

Given the limitations associated with the Argos system, the SMRU transmitters are designed to collect data at full resolution then run complex, flexible software to process and compress data while managing the transmitter energy budget (Fedak et al. 2002, Fedak 2004). In addition to general dive and swim velocity information, CTD upcasts are recorded, starting at the bottom of the first six dives of a 6-h period that are deeper than 45 m. Additional CTD data are collected in subsequent dives within the 6-h period that are deeper than these first records. Upon completion of each upcast, a "broken stick" compression algorithm (as used in XBT casts) is applied to identify and retain the 12 most important inflection points in the temperature, conductivity, and computed salinity profiles. At the end of the 6-h period, profiles from the six deepest dives of that period are put into a buffer from which they are chosen at random for transmission.

*Marine Mammal Program Deployment*

The DFO Marine Mammal Program has deployed satellite transmitters since the early 1990s (Stenson and Sjare 1997, Richard et al. 1998, Goulet et al. 1999). Initially, the transmitters provided the locations and diving behaviours of the mammals (Stenson and Sjare 1997); since 2004, support from the Atlantic Seal Research Program has allowed us to deploy satellite transmitters equipped with temperature–depth sensors on Northwest Atlantic harp (*Pagophilus groenlandicus*) and hooded seals (*Cystophora cristata*) seals.

*Distribution of Seals*

Forty satellite transmitters were deployed on harp seals and 59 on hooded seals between 1992 and 2006. Of these, 19 harp and 37 hooded seal tags, deployed from 2004 through 2006, recorded water temperatures in addition to the mammals' locations and diving behaviours. Adult harp seals were caught off the coast of Newfoundland in May 2004 during their annual moult and taken to the Ocean Science Centre in St. John's Newfoundland. Once the moult was completed, transmitters were attached to the fur just behind the head (Fig. 1). For hooded seals, transmitters were fitted on seals caught during the pupping period off the coast of Newfoundland and in the Gulf of St. Lawrence. Another 22 newly moulted adult hooded seals were caught off southeast Greenland during the summers of 2005 and 2006. Transmitters were deployed on all of the hooded seals at the site of capture and seals were released immediately. Data were collected throughout the year, with some transmitters remaining active for over 350 days.

Both harp and hooded seals undertook extensive seasonal migrations, wintering in southern Canadian waters and summering in Baffin Bay, west or southeast Greenland, and the eastern Canadian Arctic (Fig. 2). Although they did not appear to require the presence of ice outside of the pupping and moulting periods, they spent much of the year in areas where ice was present.

Harp seals were found primarily in continental shelf areas. However, in contrast to traditional belief, they spent a significant amount of time in offshore areas. The southern Labrador Shelf and Grand Banks appeared to be important feeding areas in both the winter and spring periods (Stenson and Sjare 1997). During the summer, harp seals were found mainly in southern Baffin Bay and Davis Strait. A few seals, however, inhabited the coastal waters of Greenland and Baffin Island. On average, harp seals migrated northward in late June and returned south in mid-November. Although most of their time was spent at shallow depths, harp seals routinely dove to depths of 100–200 m and remained underwater for 5–10 minutes. Maximum dive depths were greater than 700 m and maximum durations longer then 20 minutes.

Hooded seals give birth in March. In the Gulf of St. Lawrence, the majority of adults move into the northern Gulf, along the edge of the Laurentian Channel, where they remain for about 4–6 weeks before leaving the Gulf to move to southeast Greenland where moulting occurs in late June. A different pattern is observed among animals equipped with transmitters in March off Newfoundland. There, animals leave Canadian waters almost immediately after the pups are weaned and make their way to southeast Greenland. Following the moult, the majority of hooded seals moved around Cape Farwell and northward into Davis Strait and Baffin Bay. In the winter, breeding seals migrated southward to the pupping areas of Newfoundland and in the Gulf of St. Lawrence while non-breeding seals returned to southeast Greenland. Unlike harp seals, who remained on the continental shelves, hooded seals spent most of their time along the slope edges of the shelves and in areas such as the Flemish Cap and Reykjanes Ridge. Hooded seals dove deeper (>1500 m) and remained under the water longer (>50 min.) than harp seals. This is consistent with the presence of the deep-water species (e.g., Greenland halibut, redfish) in their diet.

The release of 100 tagged animals in 2004 is apparent in the number of profile locations. In the spring (March–May), the seal-based profiles stretch across the Labrador Sea between Iceland and Greenland and in the Gulf of St. Lawrence, with a few animals tracking on the west side of Greenland south of Baffin Bay. In the summer, the harp seals account for the Newfoundland Shelf data with the hooded seals sampling off the west coast of Greenland. In the fall, the seals are distributed on the shelves surrounding the Labrador Sea as well as the western and eastern sides of Baffin Bay.

The major change in the pattern of sampling between years is in the Labrador Sea. In 2004 and 2005, the hooded seals tended to move across the Labrador Sea in a straight line between Newfoundland and Greenland. However, there was more profiling done in 2005 by the hooded seals on the surrounding shelf break areas rather than across the Labrador Sea. In both cases, the seal data are a significant addition to the number of temperature profiles in the North Atlantic.

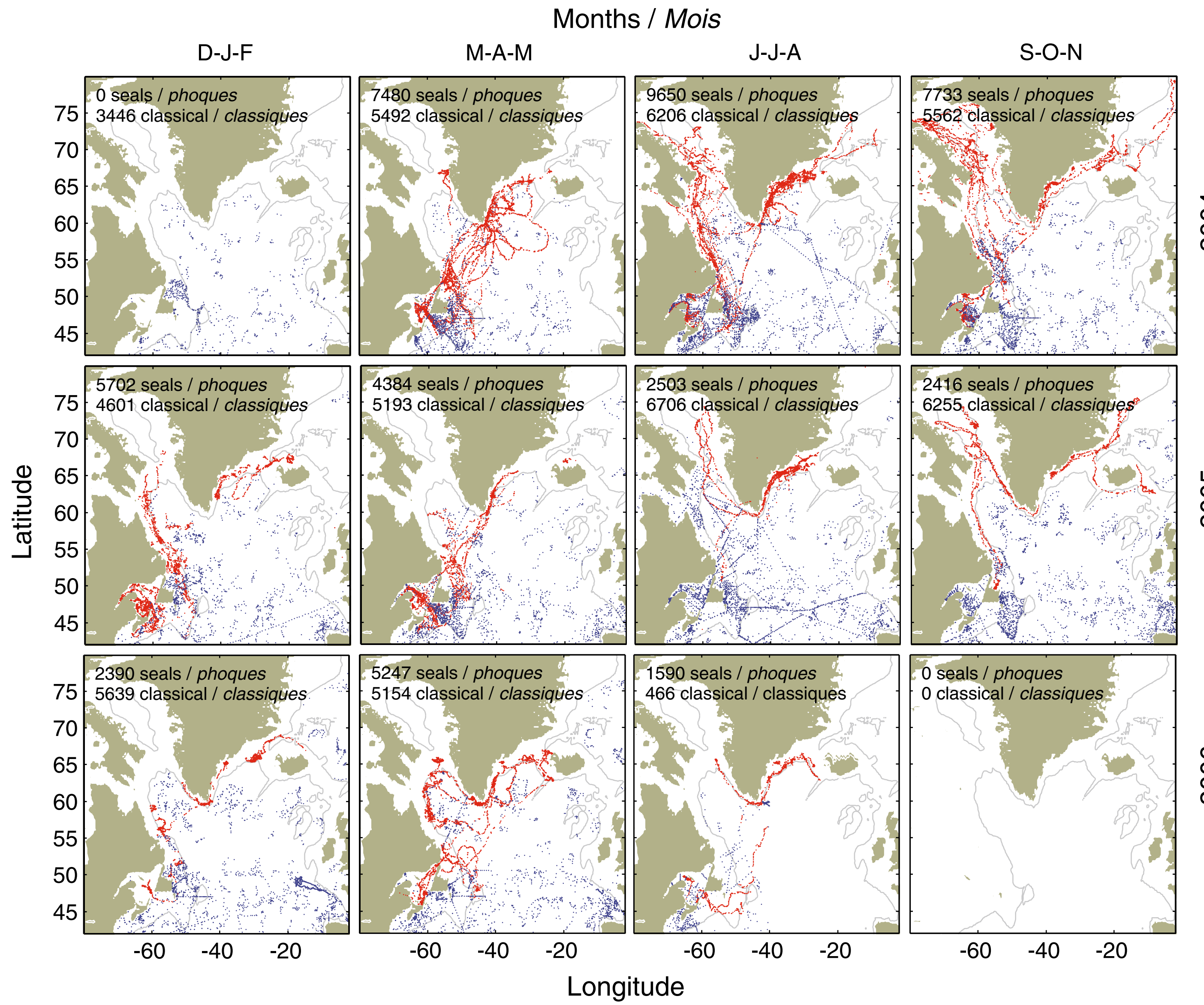


Fig. 2 Location of seal-based temperature profiles/tracks (red) and classically observed profiles (blue) for the North Atlantic (north of 40°N).

*Position des profils/tracés de température obtenus à l'aide des phoques (en rouge) et par des profileurs classiques (en bleu) dans l'Atlantique nord (au nord de 40°N).*

For the deployment throughout 2004, the volume of data available for the entire North Atlantic is at least doubled compared to data obtained using standard oceanographic methods; data collected by hooded seals doubled the available temperature profiles north of 40°N. Tagging ended in the summer of 2006, resulting in the decrease in the number of profiles from seals at that time (Fig. 2).

*Observation Characteristics*

The seal tag distribution for the 2004 deployment is shown in Figure 3 in the form of the number of temperature profile observations per one degree box in 2004 for the Northwest Atlantic. During this time, 55,000 seal profiles were collected, providing valuable additional data to the roughly 5000 observations from the Argo (distinct from the Argos satellite data acquisition system discussed earlier) floats and ship-based profile data. On average, individual seals collected profiles every 10 hours and every 9 kilometres. However, there is a broad spread in time and space for sampling frequency. Overall in a 10-day period, seals collected 24 profiles. In comparison, 10 days is the repeat period of a satellite measuring the sea surface height; during the same interval, an Argo float will collect one profile.

From our observations, hooded and harp seals repeatedly cross shelf break areas associated with strong currents and density gradients. This useful characteristic is unique to the seal-based data because it provides a snapshot of shelf break fronts. The seal-based profile density is highest on the continental shelf and near shelf breaks, providing temperature profiles over large areas of the ocean with seal tracks ranging up to 16,000 kilometres over the Labrador Sea, surrounding continental shelves, Baffin Bay, and the East Greenland Current (Fig. 3). In contrast, Argo float profiles are mainly confined to the deeper areas of the ocean. Thus the profiles collected by seals complement the Argo data.

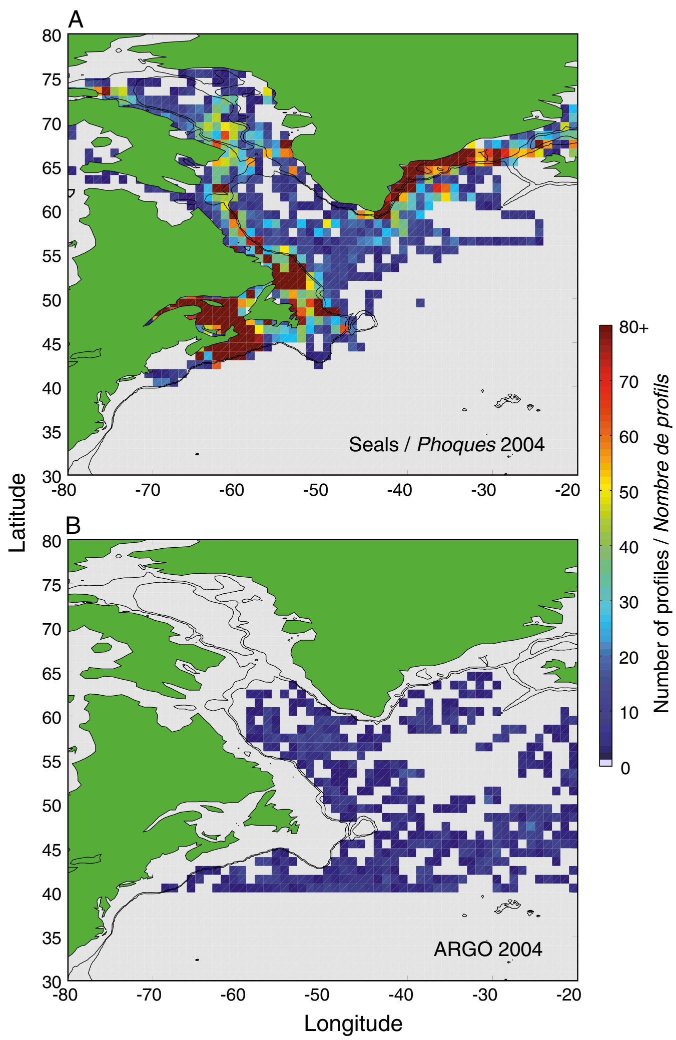


Fig. 3 Number of profiles obtained by seals (A) and Argo floats (B) per one-degree box in 2004 (March–December) indicated by the colour scale. Maximum sampling occurred in the Gulf of St. Lawrence, with 400 samples per one-degree box.

*Nombre de profils obtenus par les phoques (A) et les profileurs Argo (B) par boite de 1 degré en 2004 (mars–décembre) indiqué par l'échelle de couleur. La densité maximale des profils se retrouve dans le golfe du Saint-Laurent avec plus de 400 profils par boite.*

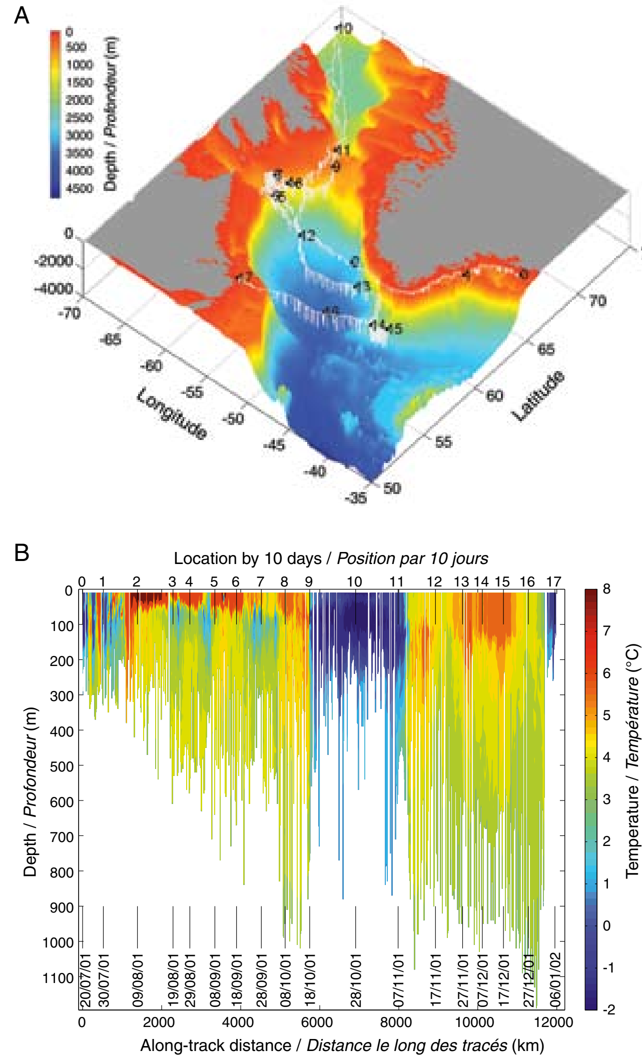


Fig. 4 Example of a hooded seal track (A) with corresponding along-track temperatures (B). The numbers on both panels indicate the seal's position for every 10-day period. Thus location 17 refers to the track position after 170 days of travel.

*Exemple de tracé de phoque à capuchon (A) et profils de température obtenus le long de ces tracés (B). Sur les deux panneaux, les chiffres indiquent la position du phoque tous les 10 jours. Ainsi le chiffre 17 indique la position du phoque 170 jours après départ.*

An example of along-track ocean temperatures obtained from a hooded seal off Greenland beginning in August of 2005 is shown in Figure 4. This seal provided profiles to depths of up to 1100 m in the Labrador Sea and to 900 m in Baffin Bay. The sharp contrast in water temperatures between the Labrador Sea and Baffin Bay water is evident. Of particular use are the in situ snapshot and positioning of fronts between the Labrador Sea, the adjacent shelves, and Baffin Basin. Sampling in these regions provides crucial information concerning the vertical variations of temperature that can be used as input for the ocean forecasting systems such as MERCATOR, which is being developed for application on the Canadian east coast.

In the Labrador Sea, the seal-based temperature transect shows relatively cold water (1°C) trapped at mid-depth with various thicknesses (Fig. 4; light blue patch around 100 m at 2500 km along the track from markers 3 to 8) on the northwest edge of the sea near the shelf break. This could be an extension of West Greenland Shelf Water. This cold mid-depth water is not seen by the seal as it crosses the Labrador Sea (Fig. 4, marker 2). For Baffin Bay, the track provides a transect up to 800 m deep through the centre of Baffin Bay, with waters varying from 0 to -1.6°C, characteristic of Baffin Island Current Water. A sharp temperature contrast is observed at the sill at Davis Strait separating Baffin Bay from the Labrador Sea.

The current AZMP transects are valuable for validating ocean models as well as providing consistent transects from year to year. The data from these shelf transects can be compared to results from various North Atlantic operational forecast systems as well as to present and developing regional systems in Canada. While these AZMP transects are short in comparison to seal-based transects, they are done regularly. In contrast, seals sample continuously for the year in various regions of the Northwest Atlantic, but not along fixed repeated transects. Compared with ship-based transects costing $30,000

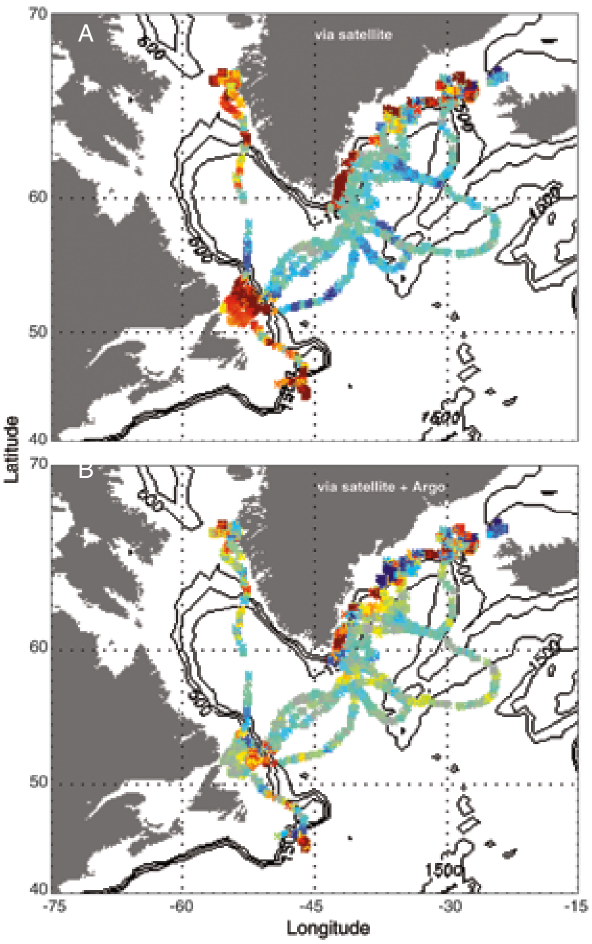


Fig. 5 Seal vs. model (MERCATOR) temperature comparison for assimilation of satellite altimetry only (A) and for combined satellite altimetry and in situ Argo float profilers (B).

*Comparaison des valeurs de température observées par les phoques et celles obtenues par le model de prévision océanique MERCATOR avec assimilation altimétrique seulement (A), et avec assimilation altimétrque et des données in situ Argo combinées (B).*

per day, seals provide inexpensive data for $13,000 per year, which includes tags, near real-time transmission, plus deployment costs; all this, depending on the number of transmitters deployed, works out to be on the order of 1-2 days of ship time. The near real-time reporting of data collection by the seals provides good week-to-week validation of ocean forecast systems.

Metrics are a series of defined outputs that allow model-to-model and model-to-data comparisons. Seals provide data for Class 2 and Class 4 metrics for operational oceanography development (Crosnier and Le Provost 2006). Class 2 metrics encompass high-resolution transects of temperature, salinity, and velocity for regions of the model domain that are of special dynamic interest. For the seal tracks, model output needs to be sampled as a seal would, for better inter-comparison. Class 4 metrics include inter-comparison of model output with available in situ profiles to provide a score for model performance.

During this past year, basin-scale operational ocean forecasting systems currently being run for the North Atlantic have advanced to include assimilation of both altimetry and in situ profiles; previously only altimeter data were used. While altimetric sea surface measurements provide a measure of the depth-integrated effect of density changes, it is impossible to accurately determine the vertical distribution of changes without in situ observations. Prior to assimilating in situ data, errors of 3-4°C occurred in the upper water column on the Newfoundland Shelf (Fig. 5). With the inclusion of in situ data in the assimilation scheme, the errors have been reduced by up to a factor of ten, i.e., to 0.3-0.4°C; the effect of assimilating in situ data with altimetry is thus significant. Further improvements in both shelf and deep-ocean regions are anticipated as the observations and assimilation methodologies are refined. Assimilation schemes are particularly crucial for shelf waters, where dynamics are complicated because strong fronts are coincident with abrupt topographic variations and because the altimetry data can be degraded in the near-shore region (Mourre et al. 2004). The AZMP will be providing valuable data for fine tuning assimilation schemes that are under development for the shelf.

## Conclusion

The AZMP operations are a good foundation for oceanographic observations in Canada. The Canadian Marine Mammal Program can add significant contributions in the form of a relatively high volume of real-time, in situ opportunistic profiles of temperature and salinity. While more needs to be done on the systematic validation of seal-based profiles, the work under way demonstrates reasonable inter-comparisons with other data sources. The seal data are currently useful for model validation purposes. In the near future, the seal data can be used for direct assimilation into operational ocean forecast systems.

AZMP provides a useful foundation for operational oceanography. AZMP's regular collection of oceanographic data and the opportunity to incorporate other observations such as Argo float profiles, satellite altimetry, sea surface temperature, and the emerging mammal-based measurements described here are essential to ocean forecast systems in Atlantic Canada.

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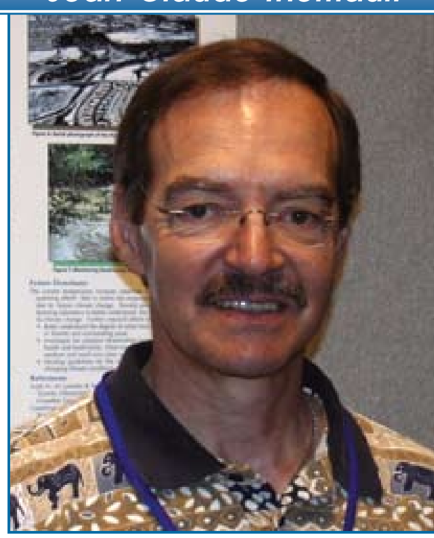
Jean-Claude was part of many first steps in the development of oceanographic research in Canada. His oceanographic career began as a summer student for Dr. Guy Lacroix at Laval University (1968-69), at the time when GIROQ, the Groupe interuniversitaire de recherche en océanographie du Québec was created. After completing his M.Sc. (Laval) and Ph.D. (Dalhousie), he became part of a four-member team (along with Jean Boulva, Jean Piuze, and Paul Montreuil) who started the federal marine science research program in Québec in 1976-1977. He then went on to develop the most important francophone group working in oceanographic research in Canada, for the Department of Fisheries and Oceans.

Among his many responsibilities, Jean-Claude took on the leadership of the Working Group on Ocean Monitoring with the task of identifying the requirements for the implementation of a zonal monitoring program for the northwest Atlantic. Through his dedication, his stimulation of the working group participants, and his tenacity, Jean-Claude was able to coordinate the development of a plan that was strong enough to warrant significant investment of new and existing resources to form the Atlantic Zone Monitoring Program, which is considered a model, nationally and internationally. To see the vision through, he guided the program through its formative years, serving as Chair from 1998-2002 and as chief editor for the first six issues of this bulletin. His trademark phrase that signalled imminent, decisive action was "I kind of agree with you, but...."

**Jean-Claude Therriault**



On his retirement from the Department of Fisheries and Oceans Canada, we the members of the Atlantic Zone Monitoring Program would like to express our appreciation and gratitude for all his efforts, above and beyond what others would have done. It has been our privilege to have worked with him and to regard him as a friend.

Jean-Claude a pris part à plusieurs initiatives pour le développement de la recherche océanographique au Canada. Il a débuté sa carrière d'océanographe comme étudiant d'été sous le professeur Guy Lacroix de l'université Laval (1968-69), à l'époque où le GIROQ, le Groupe interuniversitaire de recherche en océanographie du Québec, fut créé. Après avoir terminé des études de maîtrise (M.Sc., Laval) et de doctorat (Ph.D., Dalhousie), en 1976-1977 il rejoignait l'équipe de quatre personnes (soit Jean Boulva, Jean Piuze et Paul Montreuil) à Québec pour démarrer le programme fédérale de recherche en science marine. Par la suite, il a développé le plus important groupe de chercheurs francophones en océanographie au Canada pour le ministère des Pêches et des Océans.

Parmi ses nombreuses responsabilités, Jean-Claude a été le leader du groupe de travail sur le monitorage qui avait pour tâche de définir les besoins essentiels pour implanter un programme de monitorage zonal pour le nord-ouest Atlantique. Par sa persévérance, sa ténacité, et sa capacité à motiver le groupe de travail, Jean-Claude a réussi à coordonner la préparation d'une proposition forte qui a mérité un investissement important de ressources nouvelles et déjà existantes pour la création du Programme de monitorage de la zone Atlantique, lequel est considéré comme un modèle du genre au niveau national et international. Pour assurer la réalisation de son plan, il a dirigé le programme pour ses premières années, en agissant comme président de 1998 à 2002, et il a été l'éditeur en chef des six premiers numéros de ce bulletin. Au cours de ces années, sa phrase caractéristique pour signifier le besoin d'action étant: « je suis d'accord avec toi mais… ».

Au moment de sa retraite du ministère des Pêches et des Océans du Canada, nous, les membres du Programme de monitorage de la zone Atlantique, désirons exprimer notre appréciation et notre gratitude pour tous ses efforts, lesquels ont surpassé ce que d'autres auraient fait. Nous avons été privilégiés d'avoir pu travailler avec celui que nous considérons comme un ami.