



## State of the Eastern Scotian Shelf Ecosystem

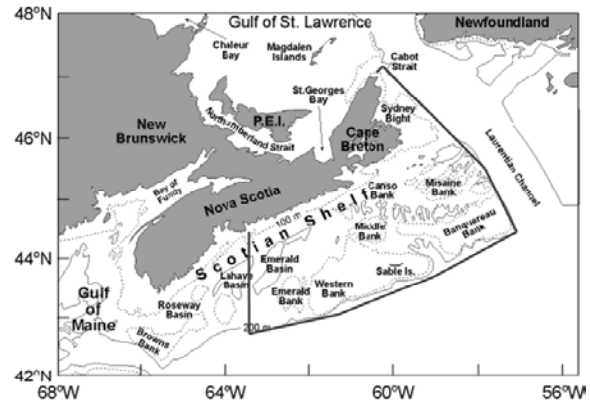
### Background

The Eastern Scotian Shelf, comprising NAFO Div. 4VW, is a large geographic area (~108,000 km<sup>2</sup>) supporting a wide range of ocean uses such as fisheries, oil and gas exploration and development, and shipping. It is currently the focus for the development of an integrated management plan intended to harmonize the conduct of the various ocean use activities within it (referred to as Eastern Scotian Shelf Integrated Management or ESSIM). The area is unique for having a year-round closure for directed fishing of groundfish since 1987, associated with Emerald and Western Banks. In addition, The Gully has been declared a pilot marine protected area.

The Eastern Scotian Shelf consists of a series of outer shallow banks and inner basins separated by gullies and channels. The mean surface circulation is dominated by southwestward flow, much of which originates from the Gulf of St. Lawrence with anticyclonic circulation tending to occur over the banks and cyclonic circulation around the basins. The northeastern region of the Shelf is the southern-most limit of winter sea ice in the Atlantic Ocean.

This document provides an assessment of the current state of the Eastern Scotian Shelf ecosystem. The analysis focuses on time trends in all available data series associated with three categories of variables: biotic, abiotic, and human. Biotic variables generally include information on the abundance, distribution and composition of finfish and invertebrates, phyto- and zooplankton, and marine mammals. Abiotic variables include oceanic and atmospheric data that provide insights into ocean climate conditions. Human variables range from fishery landings, fishery revenue, activities associated with oil and gas development to contaminants. The current evaluation uses over 60 data series, most of which extend back to at least 1970. A comprehensive picture of the baseline or unperturbed state of the system is unknown.

This report is a product of a working group that compiled and analyzed various data relevant to the evaluation of the Eastern Scotian Shelf ecosystem. It also benefited from input from several DFO staff, industry participants and external reviewers as part of DFO's Regional Advisory Process (RAP).



### Summary

Many features of the Eastern Scotian Shelf ecosystem have changed dramatically during the past thirty years:

- A major cooling event of the bottom waters occurred in the mid-1980s that persisted for a decade and recent intensive stratification in the surface layer has been apparent; both phenomena are associated with flow from upstream areas.
- The index of zooplankton abundance was low in the decade of the 1990s when phytoplankton levels were high and the opposite pattern was evident in 1960s/early 1970s.
- Major structural changes have occurred in the fish community: groundfish have declined while small pelagic species and commercially exploited invertebrate species have increased.
- Changes in the physical environment were associated with the expansion of range of some species and the occurrence of species new to the area.
- Reductions in average body size of groundfish have occurred and there are currently very few large fish – a situation likely to have never been witnessed in the past.
- Condition and growth of several groundfish species has remained low during the past decade contrary to expectations for improvement.

- The abundance of grey seals has risen steadily during the past four decades and the population may have doubled since the last survey in 1997 to near 225,000 in 2002.
- It is not yet possible to predict how long the current situation will persist and whether or not the system will return to its previous groundfish-dominated state.

With respect to the major human activities on the Eastern Scotian Shelf, the following observations were made:

- The fishery is increasingly targeting species at lower levels in the food web because there now exists a lack of availability of groundfish at the higher trophic levels.
- Oil and gas exploration and development has been highly episodic though it is presently increasing.
- There are too few reported data on contaminant concentrations in water, sediment or biota from the area to establish either distributional patterns or trends in space or time.
- When all sources (i.e. all human uses) are taken into account, the potential cumulative effects give grounds for concern.

In an evaluation of such broad scope, data shortcomings become readily apparent:

- Knowledge about the diversity of species becomes increasingly sparse at lower trophic levels; there is a particular need for monitoring of benthic invertebrate species and contaminants.

## ***Introduction***

The need for this report stems from a number of recent developments. The Eastern Scotian Shelf is an area where there are a number of marine ecosystem issues and an integrated management planning process known as the ESSIM is currently being developed. Associated with this plan are conservation objectives related to biological diversity and productivity whose performance may, in the near future,

be judged on the basis of a report similar in structure to the one presented here. There is a need to incorporate broader conservation objectives within fisheries management plans. The ever-growing body of data resulting from various monitoring programs requires continuous consolidation and synthesis. The present analysis builds on an initial synthesis by Zwanenburg et al. (2002).

Ultimately, such a report as this can be seen as a means to gauge the success of ecosystem-based management schemes while providing an assessment of the state of the ecosystem. It is the latter aspect that is the focus here. The report highlights major changes and trends in various ecosystem attributes. The evaluation does not include the nearshore waters (with the exception of fisheries landings and revenue) and as such only provides an “offshore perspective”.

## ***Fishery Landings, Revenue and Exploitation, Oil and Gas Development, Contaminants***

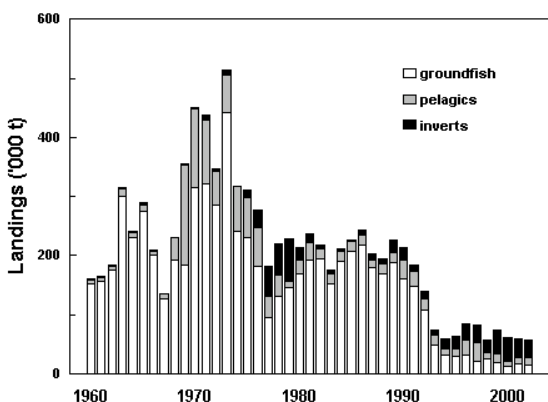
The evaluation begins with a consideration of the human variables. Three categories of human uses are reviewed including fisheries, hydrocarbon development and contaminants. Frequently, these are the major perturbations acting on continental shelf ecosystems and the Eastern Scotian Shelf is no exception. For instance, over-exploitation was one of the factors contributing to the collapse of cod and haddock in the early 1990s, which were subsequently placed under a fishing moratorium. Such human activities have the potential to influence the structure of biological communities through direct impacts on the target species as well as those that have an associated ecological dependence.

Other activities having potential ecosystem impacts in the study area were commercial shipping, naval operations, government research, ocean disposal, submarine cables

and pipelines. Their omission in the current report is due to either a relatively brief data series or none at all. Some of these ocean uses and their impacts are discussed in Coffen-Smout et al. (2001).

Fishery Landings, Revenue, Exploitation

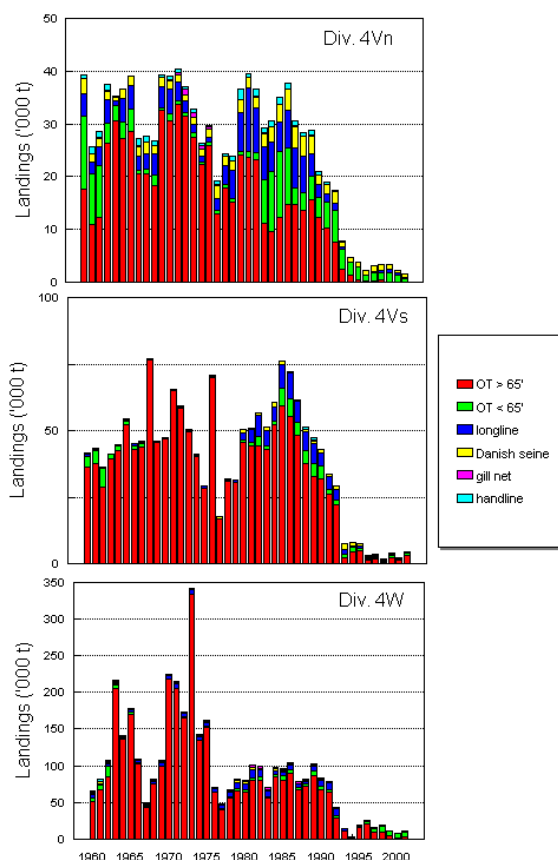
Landings data from the eastern Scotian Shelf show peaks during the late 1960s/early 1970s when foreign fleets were active in the area. Total landings were relatively stable in the 1980s but were below the previous maximum. In the early 1990s, total landings reached historical low levels due to the collapse of cod and haddock stocks. Exploitation rates of cod were particularly high prior to the collapse. Throughout most of the series, groundfish dominated the landings. However, invertebrate landings have been steadily increasing since the mid-1980s and overtook groundfish as the main contributor in 1996. Pelagic landings were highest in the late 1960s/early 1970s and presently are low.



Recent research conducted by Zwanenburg (2003) provides historical landing estimates for the Scotian Shelf dating back to the early 1770s. At this time, groundfish and pelagic landings were on the order of 10,000 t annually. During the early 1800s, groundfish landings were close to 50,000 t and remained at that level until the early 1900s when annual landings ranged between 100,000 to 200,000 t. Thus, historical

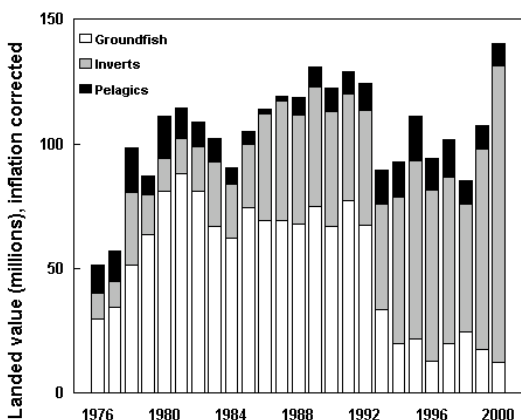
exploitation levels were relatively low compared to those in recent times.

Groundfish landings by management area and gear type revealed that Div. 4W yielded the highest average landings per decade by 2-5 fold relative to Div. 4Vs and 4Vn and that otter trawl catches predominated in all areas. Fixed gear catches were generally less than 10% of the total landings in each area, with the exception of Div. 4Vn where it amounted to 20%. Detailed spatial information associated with commercial landings data is generally not available prior to the 1990s.



The overall landed value generated by the fishery increased most dramatically from 1977 to 1978, coincident with extended jurisdiction to 200 miles. Throughout the 1980s and early 1990s, landed value was generally greater than \$100 million and in 1993 fell to less than \$100 million with the cessation of the directed fishery for cod and haddock. The year 2000 was the highest

value in the series (slightly above \$140 million). All landed values were corrected for inflation and expressed as dollars in 2002.

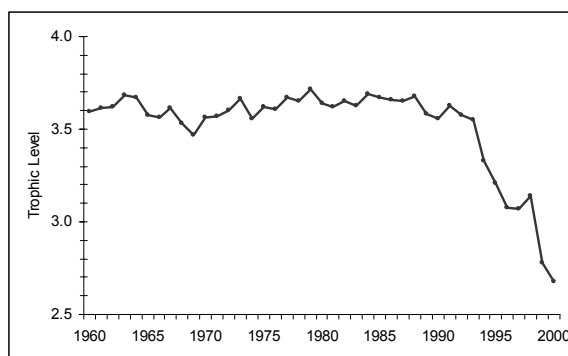


In 1980, 1990 and 2000, the percentage contribution of groundfish to the total landed value was 73, 55 and 9% respectively. In contrast, the value for invertebrate fisheries rose from 12 to 38 to 85%. The value of the pelagic fisheries did not show any trend and ranged from 8-15%. The major contributor to the rise in revenue associated with the invertebrate fisheries was lobster, snow crab and northern shrimp, with the latter two species associated with a greatly expanded fishery in recent times. Maximum landings of both snow crab and shrimp peaked in 2000 at 10,000 and 5,400 t respectively. On the Eastern Scotian Shelf, invertebrates, not finfish, are now by far the most valuable commercial fisheries. These invertebrate species maintained and eventually increased fisheries revenues in the area despite the downturn in the traditional groundfish fishery.

Several fisheries were newly created since the collapse of the groundfish fisheries in the early 1990s. The target species include Arctic surf clam, with maximum landings of 24,950 t recorded in 1999, winter skate with a peak in landings of 2,200 t in 1994, and various crab species (toad, rock and red) supporting fisheries less than 300 t. Most of these species represent potential prey of groundfish. Some of them represent range extensions from upstream areas, such as snow crab that are at the southern limit of

the species distribution, and hence their occurrence on the Eastern Scotian Shelf may only be temporary.

The temporal change in the average composition of the landings has been witnessed in several other fishery systems and has been termed “fishing down the food web”. It occurs when the average trophic level of the catch declines over time and the total catch decreases (Pauly et al., 1998). On the Eastern Scotian Shelf, the average trophic level (position in the food chain) of the catch of all species was relatively stable until the late 1980s. Since then, the trophic level of the catch has declined from an average of 3.6 to a low of 2.7 in 2000. This is of concern since the total catch from the Eastern Scotian Shelf has also declined. A lack of availability of groundfish has been created at the higher trophic levels of the ecosystem, and now the fishery is increasingly targeting species at lower levels in the food web.

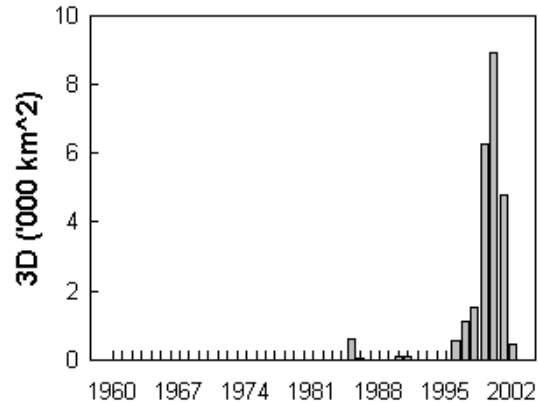
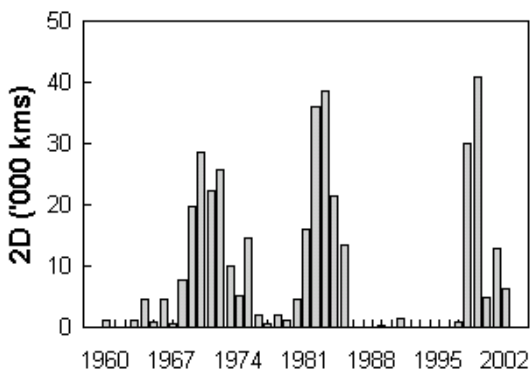


Two large geographic areas on the Eastern Scotian Shelf have been given special consideration in the recent past. In 1987, Emerald and Western Banks, totaling 13,700 km<sup>2</sup>, were closed year-round to mobile gear fisheries in order to protect juvenile haddock and allow the stock to rebuild. The closure was expanded in 1993 to include fixed gear fisheries directing for groundfish; this management measure remains in effect to the present. The resident haddock stock has been increasing slowly although the response cannot be entirely attributed to the closure. However, spillover of haddock and other species from

the closed area to adjacent areas has been documented (Fisher and Frank 2002). The Gully (area = 2360 km<sup>2</sup>) is a large, unique submarine canyon lying between Sable Island and Banquereau Banks. It supports a variety of habitat types and is an important area for an endangered population of the Northern bottlenose whale. It has been designated as a pilot project in DFO's Marine Protected Areas program.

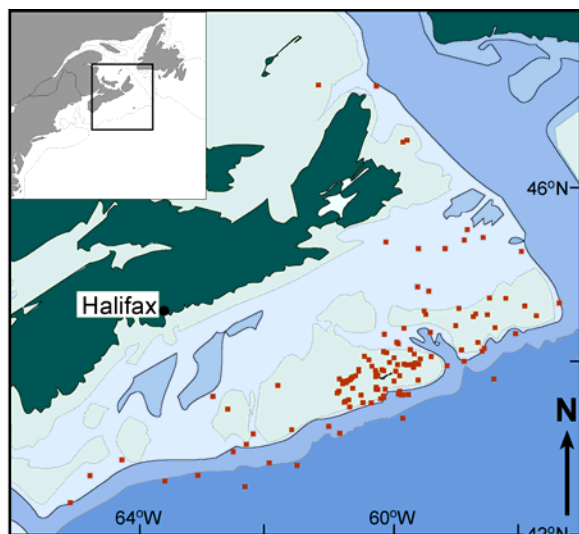
Oil and Gas Exploration and Development

The pattern of usage of the Scotian Shelf by the petroleum industry can be characterized as one of periodic high interest and expenditure followed by diminished activity. Exploration is based on seismic surveys, used to detect petroleum deposits beneath the ocean floor that involve the use of air-guns discharging sounds over 250 decibels. Peaks in area surveyed occurred in the early 1970s, early 1980s and late 1990s. About 385,000 km of tracks have been made using 2D technology and nearly 25,000 km<sup>2</sup> with 3D. The two methods differ on the basis of the distance between seismic lines; with 3D having much more closely spaced lines that yield highly resolved spatial structure without the need for interpolation. Survey costs totaled about \$168 million between 1967 and 1997.

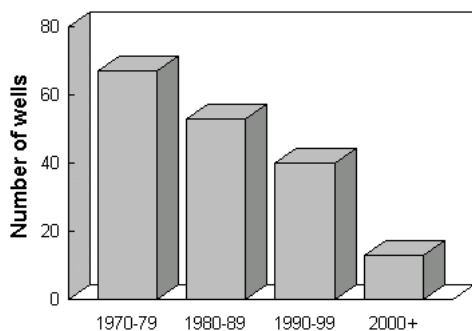


Seismic activity has the potential to cause effects on fish, invertebrates, marine mammals, and sea turtles. Scientific understanding of the immediate and cumulative effects of spatially and temporally overlapping seismic programs on the Scotian Shelf is lacking. Seismic activities on the Eastern Scotian Shelf currently overlap with known distribution areas of threatened and endangered species. However, research on the effects of seismic surveys on bottlenose whales is currently underway. Concerns have also been raised about the influence of such activities on research vessel surveys. A protocol is being developed to keep seismic surveys 30–40 km away from them.

Each of the peaks in seismic survey activity was followed by an increase in drilling. One hundred and eighty-eight wells have been drilled on the Scotian Shelf with expenditures close to \$5 billion. Most of the wells are categorized as exploratory wells with a few development wells (discussed later). Drilling has been concentrated around Sable Island.



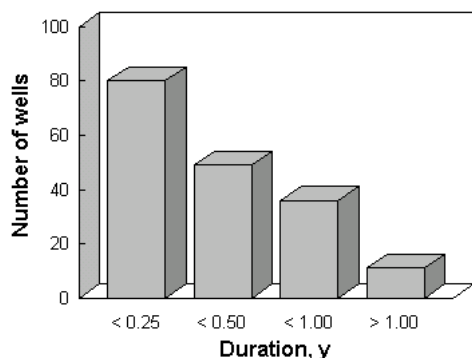
years. Environmental effects monitoring programs have been designed and conducted by industry for both projects. There are a variety of wastes from oil and gas operations that are detrimental to marine life and waste release guidelines have been developed and applied to eliminate and/or minimize negative effects. Known impacts of drilling wastes appear to be relatively minor and limited to areas within a few kilometers of the rig. However, the issue of produced water is expected to be of concern in the future. The observed very high sensitivity of sea scallops to drilling wastes also remains a concern (Cranford et al. 2001).



Most of the wells drilled exist for a relatively short time, i.e. less than three months. The industry is currently in a period of active exploration with emphasis on moving into deeper slope waters.

Contaminants

There are very few reported data on contaminant concentrations in water, sediment or biota from the Eastern Scotian Shelf area that can be used to establish either the distributional patterns of contaminants or trends in space or time. Data collected in the last decade are restricted to surveys of metals in water and sediments, metals and hydrocarbons in sediments and biota from the offshore oil and gas assessments and monitoring, and chlorinated organics in seals from Sable Island.

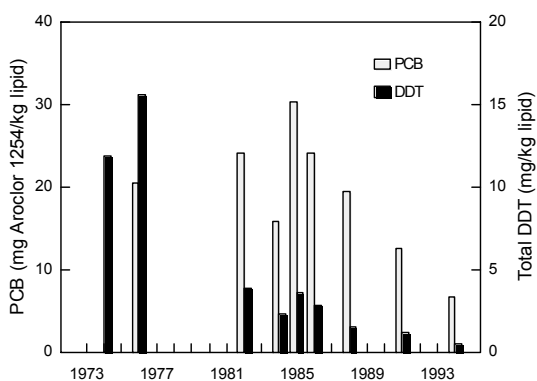


The metal data can be used to estimate spatial distributions for the Eastern Scotian Shelf area. Sediment samples collected in basins from the eastern and central shelf show that concentrations of arsenic (As), cadmium (Cd), copper (Cu), lead (Pb) and mercury (Hg) are higher to the east. Dissolved metal concentrations, based on three cruises between 1985 and 1997, show a similar northeast to southwest gradient for copper. Copper is perhaps of greatest ecological concern because it is a well-known algicide and toxic to some plankton species at concentrations only slightly greater than the natural concentrations. The dissolved copper concentrations are negatively correlated with salinity indicating the importance of freshwater inputs as a source of copper. For the rest of the

There have been two offshore development projects: CoPan (now abandoned) and SOEP, with three sites already developed and at least two more underway. The project lifetime is expected to be at least 20

metals, other sources, atmospheric inputs for Pb, offshore waters for Cd, etc., also contribute to the observed distributions. For all metals, the distributions reflect inputs from both natural and anthropogenic sources. No temporal trends in dissolved metal concentrations are evident from these three datasets.

The only evidence of trends in contaminant concentrations with time for the Eastern Scotian Shelf is the Addison and Stobo (2001) study of chlorinated organic contaminants in grey seals from Sable Island. This study, covering the period from 1976 to 1995, shows decreasing concentrations of DDT and DDE in adult seal blubber throughout the time series, and increasing concentrations from 1974 to 1985 and decreasing concentrations thereafter for PCBs. Industrial use of all of these chemicals was curtailed during this time period and these trends reflect the success of regulations. Less dramatic decreases were observed for the pesticides oxychlorane, alpha-hexachlorocyclohexane and trans-nonachlor. Hexachlorocyclohexane, on the other hand, did not show a significant decrease. Other data sets for contaminants in biota are very limited in scope and cannot be used to establish spatial or temporal trends.



### Cumulative Effects

When all sources and activities (i.e., noise, contaminants, and physical alteration) are taken into account, the collective effects give grounds for concern. If activities and

sources are considered collectively in time and space, their additive and/or synergistic effects may cause serious impacts. An area that needs attention and research is the cumulative effects of human activity on the eastern Scotian Shelf environment. Current research and monitoring has focused on the impact of individual activities. For example, in addition to seismic, there are multiple acoustic disturbances on the Scotian Shelf from commercial shipping, naval operations, drilling rigs, and the fishing industry.

### **Physical Oceanography**

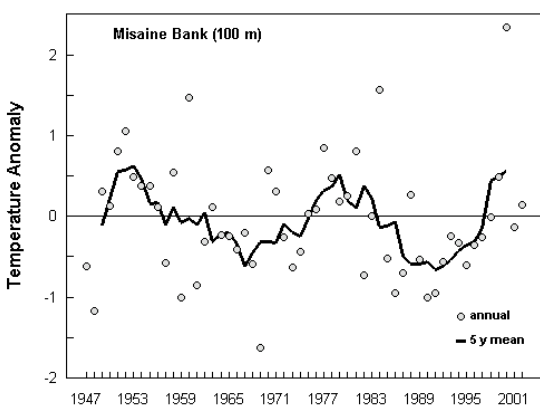
Environmental variation has long been known to influence the distribution and abundance of marine organisms. Temperature is well recognized in terms of its effect on growth and maturation of most fish and invertebrate species. The timing of the onset of the spring phytoplankton bloom and its duration, known to be influenced by physical and chemical properties, can influence survival during the early life stages of a variety of species. Variability in circulation patterns can alter drift patterns and migration routes. Collectively, the environment provides a variable setting within which species evolve and adapt. However, many environmental events are unpredictable, such as sudden intrusions of water masses, extreme storms, or persistent changes in temperature or salinity regimes.

Temperature and salinity of the Scotian Shelf waters vary spatially due to complex bottom topography, advection from upstream sources such as the Gulf of St. Lawrence and the Grand Banks of Newfoundland, melting of sea-ice in spring, local ocean-atmosphere fluxes and exchange with the adjacent offshore slope waters. The seasonal temperature range at the surface in the Eastern Scotian Shelf is upwards of 16° C, one of the highest anywhere in the Atlantic Ocean. This range decreases almost exponentially with depth, with near negligible changes at depths greater than approximately 150 m.

In the winter, the water column in the southwestern region of the Eastern Scotian Shelf consists of two layers. The upper layer, which extends to 100 m and deeper, is mixed by the winter winds and contains cold, low salinity water. The bottom layer is relatively warm and salty, originating from the offshore “slope waters” and enters through the deep trough between Emerald and LaHave banks. In summer, the remnant winter-cooled waters are sandwiched between the solar-heated warm upper layer (30-40 m deep) and the warmer bottom waters. The former, known as the cold intermediate layer (CIL), occupies depths from approximately 40-150 m. Spatial variation in this vertical structure occurs over the shelf, however. The warm offshore waters cannot penetrate far onto the northeastern Scotian Shelf due to topographic restrictions, therefore the CIL (temperatures < 5°C) generally extends to the bottom throughout the year in this area.

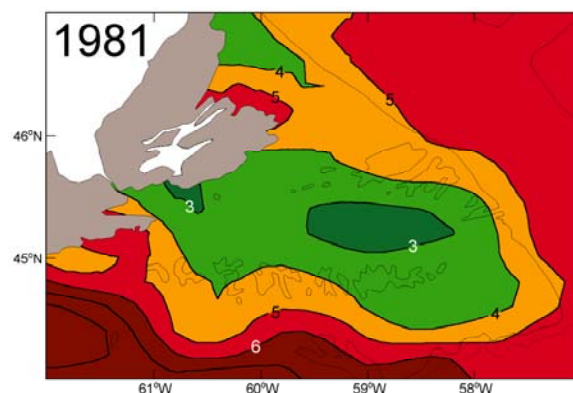
### Recent Variability

During the past two decades, the temperature and salinity conditions of the waters on the ESS have undergone important changes. Of particular note is the presence of cold subsurface waters (below 50 m) in the northeastern region. Temperatures declined through the 1980s and dropped significantly to below normal (relative to the 1971-2000 mean of 1.73° C) in 1985.

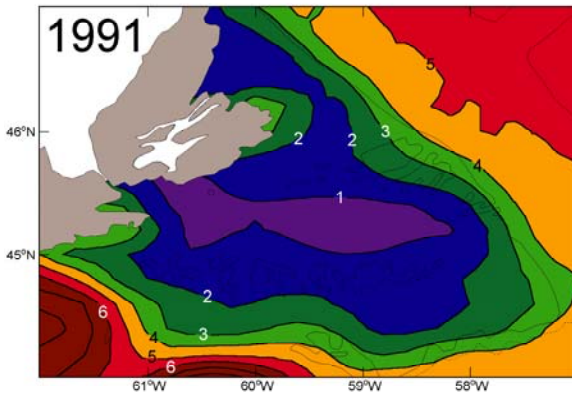
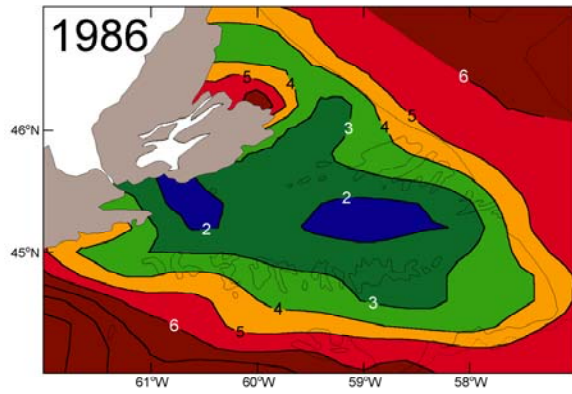


They continued to decline, reaching a minimum in the early 1990s. They then rose slowly, eventually rising above normal

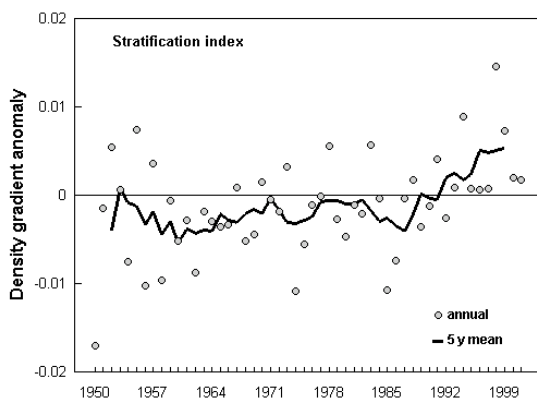
by the late 1990s. The almost 15-year duration of colder-than-usual temperatures is a significant feature in the over 50-year temperature record from the region. Also, the early 1990s were generally the coldest years on record. The principal cause of these cold conditions appears to be along-shelf advection (flow) from both the Gulf of St. Lawrence and off southern Newfoundland, plus the possibility of local *in situ* atmospherically-induced cooling. Similar cold conditions were observed in the nearshore regions along the entire extension of the Eastern Scotian Shelf but not in the southwestern region of the area such as in Emerald Basin. There, the influence of the offshore Slope waters penetrating onto the shelf through the Scotia Gulf, kept subsurface temperatures relatively warm throughout the 1980s and 1990s. An exception was in 1997-98 when cold Slope Water originating from the Labrador Current arrived along the shelf break and pushed the normal warmer slope waters offshore. These cold slope waters subsequently flooded the lower layers of the central and southwestern regions of the Scotian Shelf. While this event produced the coldest near-bottom conditions in these Shelf regions since the 1960s it was of short duration, lasting about one year.



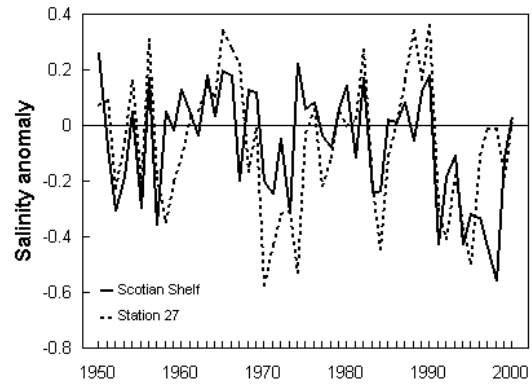




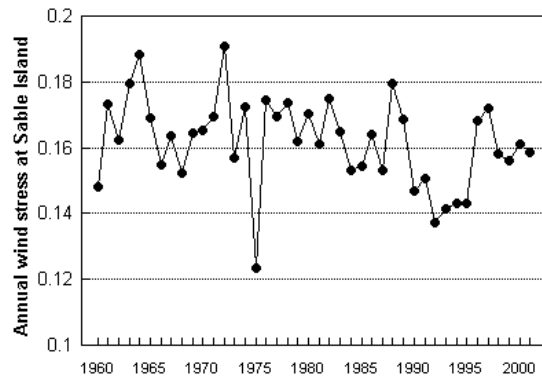
In addition to the subsurface changes, there have been important changes in the near surface waters. Foremost among these has been the increase in vertical density stratification. It increased to its highest level in the past 50 years over the top 50 m in the ESS during most of the 1990s.



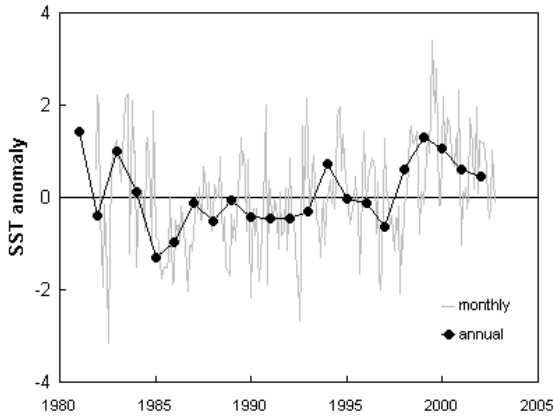
This was principally a result of record low salinities in the near-surface waters that were advected onto the Shelf from off the Grand Banks.



Reduced storminess, as measured by the variability (standard deviation) in the wind stress at Sable Island may also have contributed to the increasing stratification during at least the first half of the 1990s through reduced vertical mixing.



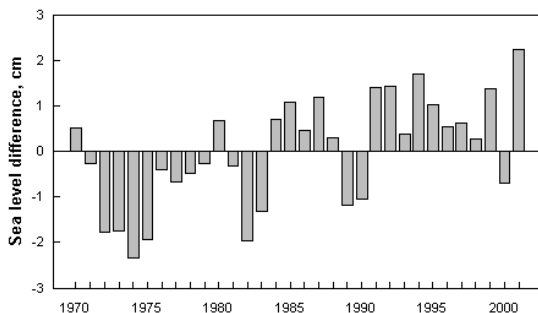
Freshwater discharge into the Gulf of St. Lawrence eventually reaches the Scotian Shelf. This discharge during the 1990s decreased relative to earlier years; thus it is not expected to have played a role in the lower salinities and increased stratification on the Scotian Shelf. Surface layer temperatures during the period of strong stratification were variable, although satellite data suggest that there were several years of high temperatures in the late 1990s, with the maximum during 1999.



This corresponded to the year of record setting air temperatures over the Scotian Shelf.

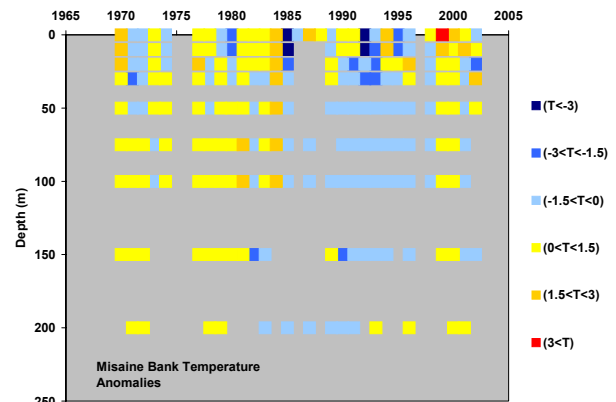
Sea Level Gradients

The Nova Scotian Current flows from the Gulf of St. Lawrence through Sydney Bight and down the coast past Halifax, driven in part by an alongshore pressure gradient. The sea level difference between North Sydney and Halifax provides a measure of the relative (not absolute) sea level difference along the Nova Scotian coast. If the relative difference is large, a stronger Current and potentially more Gulf of St. Lawrence water on the shelf is expected; on the other hand, if the difference is small, then the influence of the Gulf water could be reduced. In the figure below, two graphs are presented. The time series of annual sea level difference anomaly between North Sydney and Halifax.



A positive anomaly means that North Sydney sea level is higher than normal relative to Halifax and a negative anomaly that it is lower. The periods of negative sea level

difference anomaly (hypothesized as corresponding to reduced St. Lawrence outflow) are generally associated with periods of warmer conditions. The periods of positive sea level anomaly (hypothesized as corresponding to enhanced St. Lawrence outflow) are generally associated with periods of colder conditions. The temperature anomalies for July over Misaine Bank, at 0, 10, 20, 30, 50, 75, 100, 150, 200 m, are colored to reflect their magnitude and sign. Note in particular the transition from warm conditions in the 1970s and early 1980s to cooler conditions in the mid-1980s to mid 1990s when the eastern Scotian Shelf was strongly influenced by advection from upstream.



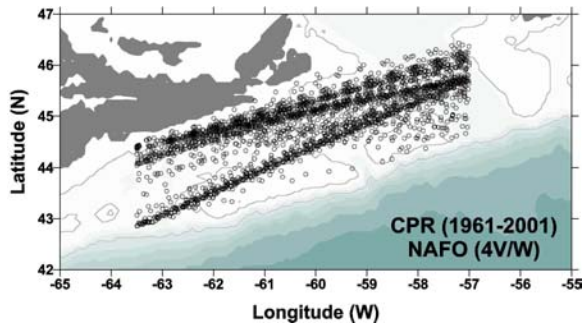
**Phyto-, Zoo-plankton, Benthos, Fish, Marine Mammals**

A wide variety of organisms are important components of the biology of the Eastern Scotian Shelf. Only those groups having details about their abundance and whether or not it has changed with time are reported here. For several groups of organisms, including cetaceans, seabirds, sea turtles, and most invertebrates, consistent time series data are not available.

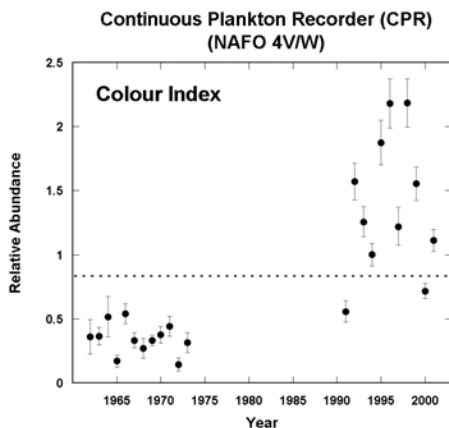
Phyto-, zoo-plankton

Estimates of the abundance of phytoplankton on the ESS come from the Continuous Plankton Recorder (CPR), the longest plankton time-series in the Northwest Atlantic. Historical CPR data are

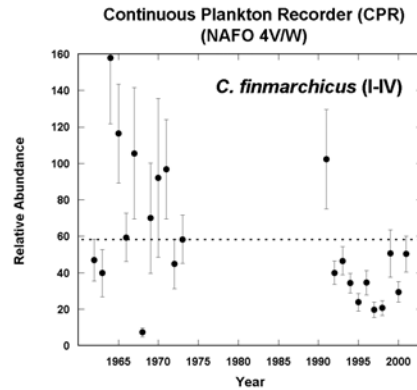
analysed to detect differences in the indices of phytoplankton (colour and relative numerical abundance) and zooplankton relative abundance at approximately monthly intervals. The sampling methods from the first surveys in the NW Atlantic to the present are the same, allowing comparisons between years. Surveys begun in 1961 were discontinued in 1976 but reinstated in 1991 and continue to the present. Data collected in 1961 and 1974-76 were incomplete and therefore excluded from the analysis.



Phytoplankton abundance can be characterized by considerable interannual variability, however, the CPR colour index and diatom and dinoflagellate counts per tow show that levels in the most recent decade (1991-2001) are significantly higher and more variable than seen in the 1960s and early 1970s. Decadal changes appear to be more pronounced in diatoms than dinoflagellates. There is also evidence that the spring blooms have been larger, started earlier and lasted longer in the decade of the 1990s compared to the 1960s and 1970s.



In contrast to decadal changes in phytoplankton abundance, abundances of one of the most important Northwest Atlantic zooplankton species, *Calanus finmarchicus*, decreased in the most recent decade compared with the 1960s/1970s and the differences were statistically significant.



Interannual variability in the 1990s was less pronounced than during the early CPR surveys. Other common temperate species (e.g. *Paracalanus*, *Pseudocalanus*) showed little change over the data record, while cold-water species originating from the Gulf of St. Lawrence and the Labrador Current (e.g. *Calanus hyperboreus*) were more prevalent in the 1990s, compared with the 1960s/1970s. The CPR total numbers of krill (euphausiids) were low in the 1990s compared to the 1960s/early 1970s, similar to observations made for *Calanus* (DFO, 2000).

Index	1962-1973	1991-2001
Colour	0.35 (0.12)	1.39 (0.54)
Diatoms	44,448 (29,916)	125,361 (57,989)
Dinoflagellates	22,611 (11,482)	32,229 (9,282)
<i>C. finmarchicus</i> (I-IV)	74.6 (40.8)	41.1 (23.2)
<i>C. finmarchicus</i> (V-VI)	17.8 (11.6)	8.3 (3.4)
<i>C. hyperboreus</i>	0.018 (0.029)	0.192 (0.312)
Para/Pseudo-calanus	129.1 (62.6)	145.5 (58.0)

Values represent mean and standard deviation (in parentheses); units are counts per tow excluding colour which is measured as "greenness"

Because of the large data gap between the mid-1970s and 1990s, it is not possible to

ascertain whether the decadal changes in plankton observed on the ESS were gradual or rapid. The biodiversity of phyto- and zooplankton has not been adequately studied and requires attention. For instance, the collection programs for zooplankton have thus far assessed only common species and their various developmental stages.

### Benthos

In relative terms, the benthic community on the Eastern Scotian Shelf is poorly understood. However estimates do exist for some species groups in a few areas. At a study site on Banquereau Bank, 270 benthic macro- and mega-faunal species have been recorded; 341 have been recorded at a site on Western Bank. Meiobenthic species (e.g. nematodes) were not assessed at these sites.

A comprehensive account of the benthic community, in terms of species diversity and distribution of major taxa on the Eastern Scotian Shelf, can be found in Breeze et al. (2002). The distribution of benthic invertebrates on the Eastern Scotian Shelf is strongly associated with sediment type and water temperature. Sand dollars (*Echinarachnius parma*) are typical invertebrates of banks with fine sandy, sediments. Ocean quahaugs (*Arctica islandica*) and Arctic (Stimpson's) surf clams (*Mactromeris polynyma*) are typical species of coarser sandy bottoms and are frequently found with northern propeller clams (*Cyrtodaria siliqua*) and sea cucumbers (*Cucumaria frondosa*). Sea scallops (*Placopecten magellanicus*) and their associated species are common on sandy-gravel bottoms of the banks.

Typical invertebrates of the cool waters and fine sediments of the depressions near Misaine Bank include snow crabs (*Chionoecetes opilio*), brittle stars (*Ophiura* spp.), and northern shrimp (*Pandalus borealis*). Common species of the fine sediments of Emerald Basin are somewhat different than those found in the cool waters

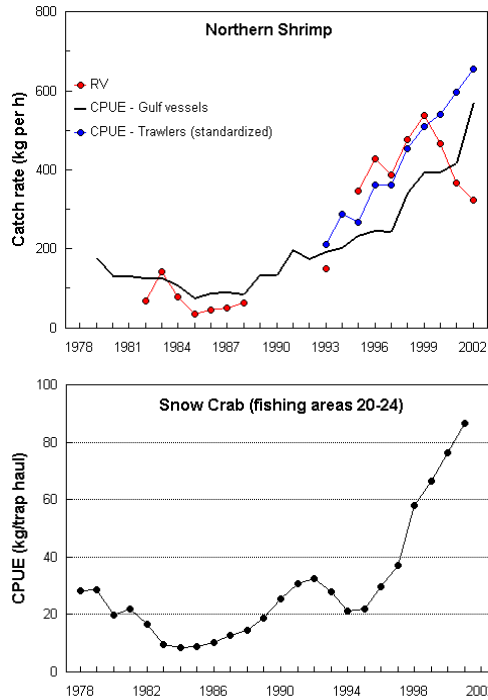
further northeast. Jonah crab (*Cancer borealis*) is common throughout the basin and in deeper waters of the central Scotian Shelf but is uncommon further east. Snow crabs are uncommon on the central and western Scotian Shelf. Polychaetes from the families Serpulidae and Onuphidae are found in areas with fine sediments, with cold water species in the area near Misaine Bank and the slope of the Laurentian Channel and warmer water species in Emerald Basin and the slope south of Western and Emerald Banks.

From the few studies of the benthic environment of the slope, sea pens (Pennatulacea), solitary cup corals (*Flabellum* spp.), and brittle stars (Ophiuroids) are relatively common on fine sediments. Ice-rafted boulders found on the upper slope (above 800 meters) and various other areas of the Eastern Scotian Shelf host many species of attached invertebrates, including sponges, bryozoans, anemones, and soft corals.

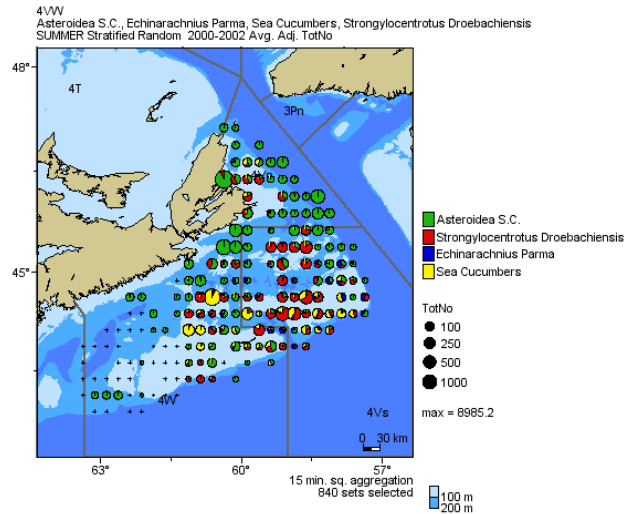
Environmental conditions in parts of the Eastern Scotian Shelf and Slope support unique or patchily distributed benthic communities. Concentrations of large gorgonian corals are found in submarine canyons and deep channels.

Routine, annual surveys of the benthic invertebrate community are not available, with the exception of directed surveys for commercially exploited species such as shrimp and snow crab. These species both show dramatic increases in abundance since the early 1990s, which have sustained a greatly expanded fishery. It should be noted that there is uncertainty in using CPUE as an index of abundance for snow crab. In particular, there has been a progressive switching to more efficient traps in recent years (DFO, 2003a). These recent increases may be overstated and indeed the shorter research survey time series shows a recent decline in abundance. Also, as stated earlier, snow crab is at the southern end of their species distribution

and thus their occurrence may only be temporary.



Future evaluations on non-commercial species may be possible given that in 1999, the July research vessel (RV) survey of the Scotian Shelf has started to systematically identify components of the benthic community, both non-commercial and commercial. For example, the distribution of sea cucumbers, sea urchins, sand dollars, and sea stars are shown, illustrating the future potential of this growing database for discerning patterns of distribution. It should be noted that otter trawls are inefficient at capturing epi-benthic organisms and completely miss organisms buried in the sediments, i.e. the so-called infauna. Collection of comprehensive time series data might be best achieved by revisiting various DFO study sites where baseline data exists, such as those associated with clam dredging on Banquereau, trawling impacts on Western Bank and a current fish habitat project on Emerald, Western and Sable Island banks.

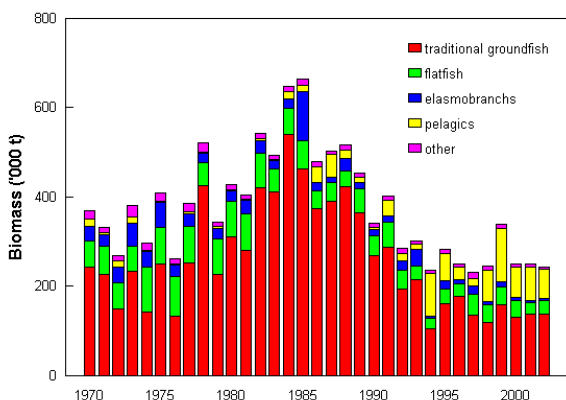


Fish

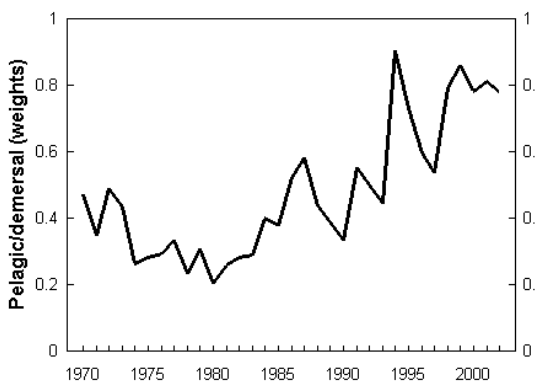
The primary source of information used to examine fish community structure was based on the July RV survey that has been conducted since 1970. It is the primary, fishery independent index used in the assessment of commercially exploited stocks on the Scotian Shelf. It provides quantitative estimates of a vast array of demersal (groundfish) and pelagic species. Additionally, length and weight measurements have been made on most species throughout the survey series. Slightly more than 130 species have been captured since the inception of the survey.

Trawlable biomass estimates for five groups of species were determined including traditional groundfish (includes cod, haddock, white hake, red hake, silver hake, cusk, pollock, offshore hake, redfish), flatfish (halibut, turbot, plaice, witch, winter flounder, Gulf Stream flounder, windowpane, fourspot), elasmobranchs (thorny skate, smooth skate, little skate, winter skate, spiny dogfish, black dogfish), small pelagics (herring, mackerel, capelin, sandlance, argentine, shad, alewife) and others (everything else). Overall, total trawlable biomass dropped from a peak exceeding 600,000 t during the mid-1980s to slightly above 200,000 t during the last several years. Traditional groundfish experienced the greatest decline followed

by flatfish and elasmobranchs. In contrast to groundfish, small pelagics greatly increased. A similar pattern was evident when expressed as abundance, however the change in pelagics was extraordinary amounting to a 400-500 fold increase since the early 1980s. Given that the survey gear used to capture pelagic species, such as herring, mackerel, sand lance and capelin, is not very efficient, the estimates of pelagic abundance are indeed very conservative (i.e. an underestimate).

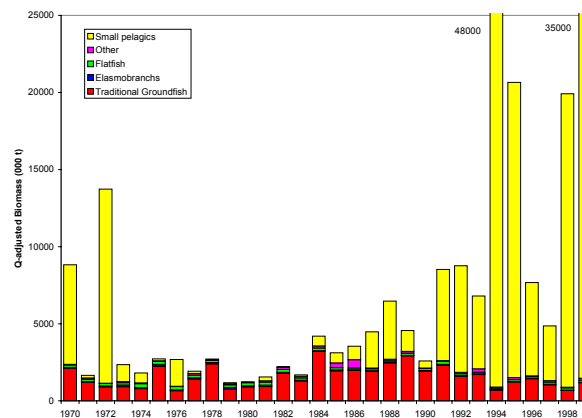


A simple expression of the ratio of pelagic to demersal biomass provides a compelling demonstration of the shift in community structure.



When survey estimates of trawlable biomass are adjusted for catchability (i.e. application of a scaling factor representing the degree to which the survey gear under-samples a given species), the result is an estimate of absolute population biomass. While such estimates are somewhat uncertain and require many assumptions

based on the behavior of individual species (Harley et al., 2001), such conversions provide another view of the magnitude of changes in fish biomass. Adjusting for the relative catchability of all species to the groundfish trawl survey indicates an increase in total biomass and a system that is currently strongly dominated by small pelagic biomass (K. Zwanenburg, DFO, personal communication). The catchability-adjusted data provide a more realistic view (increasing) of the recent trend in total fish biomass compared to the un-adjusted series. High variability in the total biomass estimates are due to the variable contribution made by pelagic species associated with the inefficient method of sampling this group.



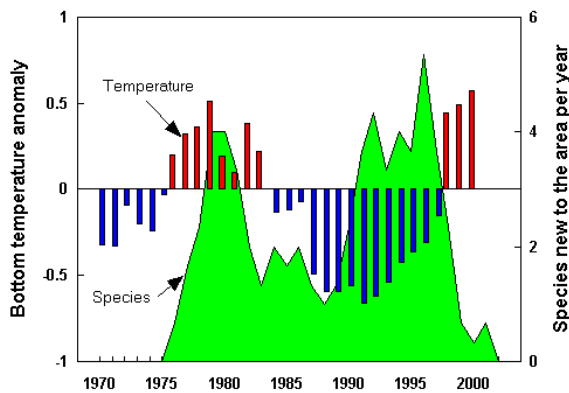
Species composition differed strongly between years of the survey with three general groupings evident: 1970-1980, 1981-1992, and 1993-2002. A dynamic community composition is evident with a continual progression away from the earlier states.

Top Ten	1970-1980	1981-1992	1993-2002
1	Redfish	Redfish	Sand lance
2	American plaice	Silver hake	Capelin
3	Yellowtail flounder	Haddock	Silver hake
4	Cod	Cod	Haddock
5	Sand lance	American plaice	Herring
6	Silver hake	Yellowtail flounder	Redfish
7	Haddock	Herring	American plaice
8	Thorny skate	White hake	Yellowtail flounder
9	Witch flounder	Capelin	Cod
10	Longhorn sculpin	Thorny skate	Witch flounder

The composition of the top ten species, based on abundance, changed dramatically in the most recent period with pelagic species such as sand lance, capelin and herring now being dominant. Only silver hake and haddock have remained near the top since the early 1980s, while cod, redfish, white hake, and thorny skate have decreased. In addition, 10-50-fold increases in the abundance of daubed shanny, turbot, snake blenny and sea poacher were evident in the most recent period relative to 1981-1992. It is notable that the increasing species are all small-bodied, with the exception of turbot. In addition, temperature conditions appear to influence the occurrence of new species in the area, particularly when conditions remain persistently above or below normal.

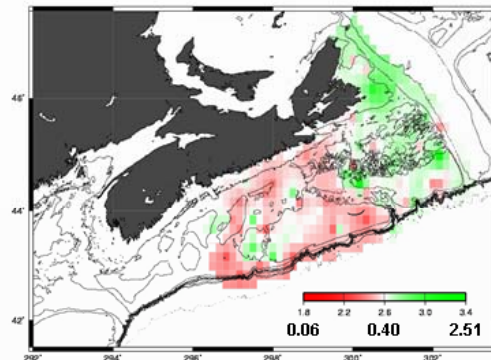
Several species of sub-Arctic origin were first recorded during the anomalous cooling period that began in the mid-1980s, including shorthorn sculpin, sea tadpole, Newfoundland eelpout, two horn sculpin, little grubby and checker eelpout. Overall, thirty species new to the area have been captured since 1991, with the vast majority less than 35 cm. Conversely, during the warm water conditions that began in the late 1970s several warm temperate/sub-tropical species were captured including beardfish, barracudina, batfish, greeneye, common wolfeel, deepwater flounder and snipe eel.

length and weight averaged across all groundfish species would be evident. The pattern of reduced weight (units = kg) was most evident during the 1990s with the largest reduction in the 4Vn and 4Vs areas. Changes in length mirror these patterns. Declining average weight, as depicted above, not only reflects increased abundance of small bodied species but also contracted size distribution of large-bodied species.

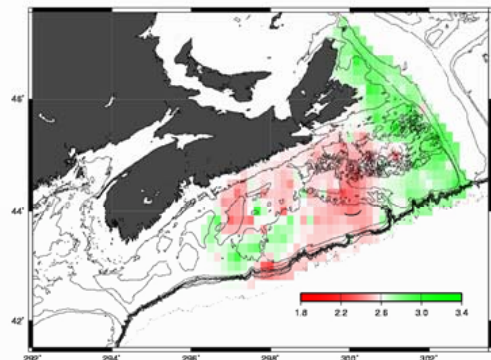


The foregoing description of temporal changes in species composition and abundance suggests that decreases in

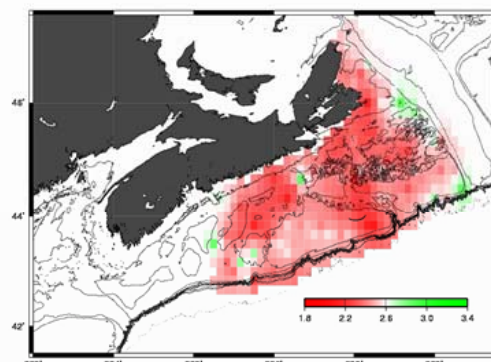
Mean fish weight (1970's)



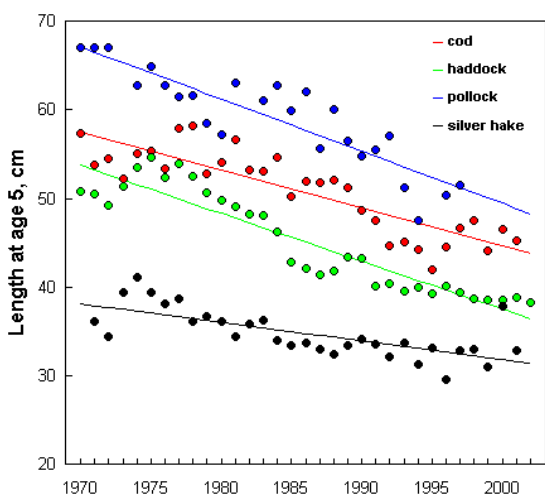
Mean fish weight (1980's)



Mean fish weight (1990's)



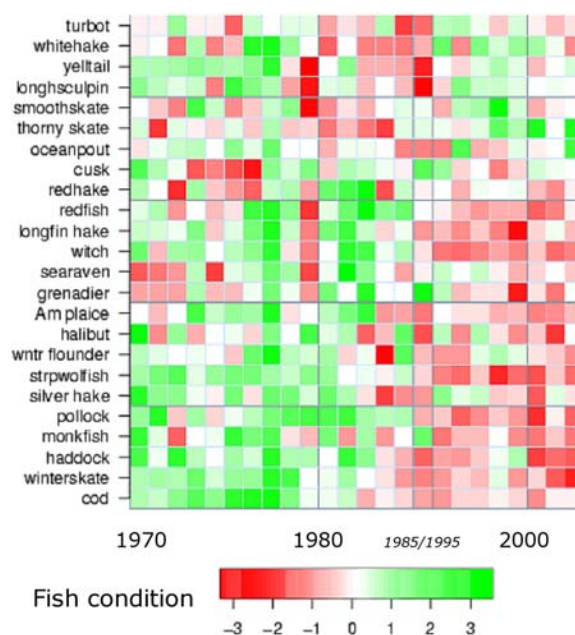
Although only few of the several traditional groundfish species have been routinely aged, the available information reveals striking and unexpected reductions in growth. For example, adult cod, haddock and pollock (age 5) are now much smaller, on average, compared to individuals from the 1970s and 1980s. Reductions in size at age have also occurred in silver hake. The trend of reduced size has occurred, despite current low population levels, suggesting that a fundamental, population dynamic process (compensatory growth) is not working among these species.



There are numerous potential implications of these changes in average body size associated with the formerly large-bodied species such as shorter generation times, increased natural mortality, and increased population variability. Direct estimation of natural mortality for cod and haddock was made possible by closure of the directed fishery and revealed levels 2-5X higher than commonly assumed (DFO 2003b, Mohn and Simon 2002). Such changes do not necessarily translate to an unhealthy ecosystem but simply one that is functioning in a different manner than in the past.

We can, however, evaluate health of one component of the ecosystem directly and that is the physiological condition of the various species, the condition factor, a simple indicator of energy storage. Data are available from both commercial and non-

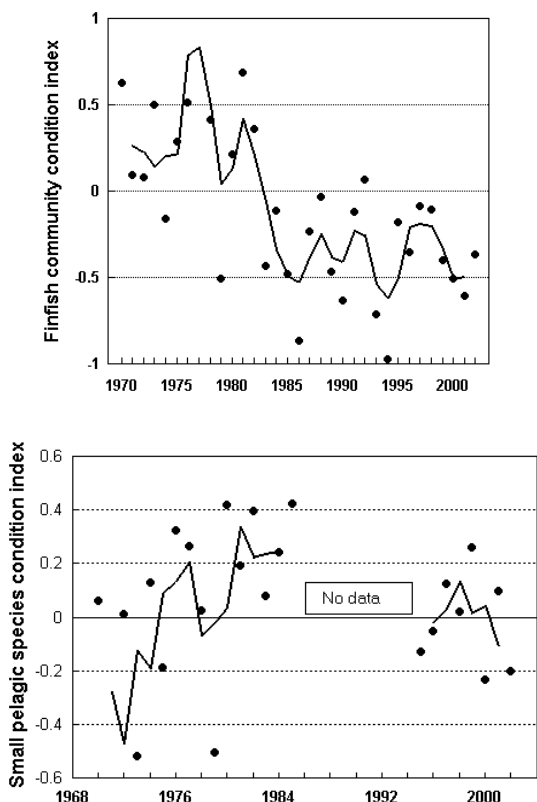
commercial species, and it is not influenced directly by fishing pressure (such as size selective fishing). A multi-species condition index was developed by expressing variation in the predicted weight at a given size for each species as an anomaly in standard deviation units. The standard deviation was color coded from green to red, representing strongly positive to strongly negative anomalies respectively. Twenty-four common species were used in the analysis with predicted weight estimated for sizes corresponding to adults. The analysis revealed that a wide variety of species changed condition in a similar manner from year-to-year, sixteen of which were in relatively good condition up to 1982 followed by a prolonged period of below average condition to present.



A temporal series of fish community condition was developed by taking the average across species each year. The first half of the series reflects the high above-average condition of the community followed by a rapid drop to below-average condition since 1983 that continues to persist. For pelagic species, the data are relatively spotty but do show that condition peaked in the mid-1980s at the time when groundfish condition was dropping. Recent



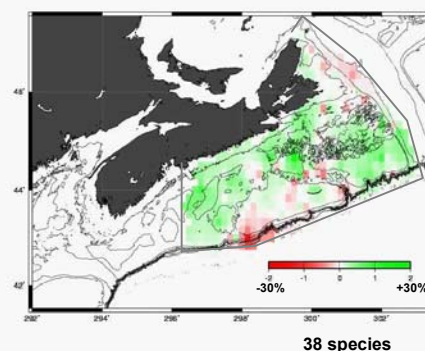
condition is close to normal, again in contrast to its demersal counterpart.



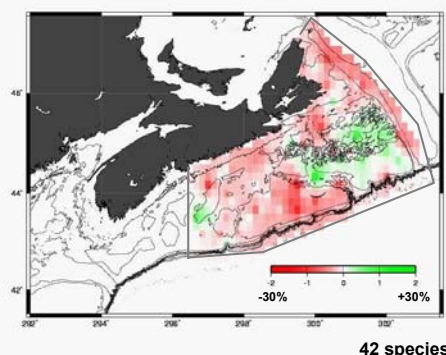
Using a complimentary method for evaluating condition that incorporated all groundfish species having length and weight data ( $n=43$  species), fine scale spatial patterns of condition were determined.

Extensive areas on the Eastern Scotian Shelf were inhabited by fish species in relatively good condition up to 1982, thereafter a reversal of the situation occurred. Interestingly, the Misaine Bank region, an area of complex topography, has remained an area in which the fish are in relatively good condition. The Eastern Scotian Shelf ecosystem has not had a prolific groundfish population for nearly two decades.

Fish community condition (1970-1982)



Fish community condition (1983-2002)

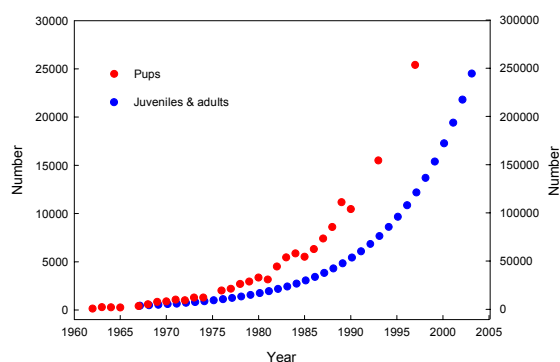


### Marine Mammals

Twenty-three species of marine mammals inhabit the Eastern Scotian Shelf either seasonally or throughout the year. Although five seal species occur in the area, only harbour and grey seals are common to abundant and have been studied annually for some time. The remaining 18 species are represented by a variety of toothed whales (i.e., odontocetes), including the bottlenose whale and sperm whale, and baleen whales. With the exception of the northern bottlenose whale, there is little information on temporal changes in abundance of cetaceans within the Eastern Scotian Shelf. Nevertheless, a number of the small odontocete species are thought to be common to abundant seasonally. Vessel-based surveys of bottlenose whales have been conducted since 1988 in the Gully. Sighting rates (i.e., sightings/hour searching) between 1988 and 1999 have varied among years, but without evidence of trend, and there was no significant difference in population estimates for 1990,

1996 and 1997 (Gowan et al. 2000). The most recent analysis, based on resightings of naturally marked individuals, indicates a population size of 130 whales (Gowan et al. 2000).

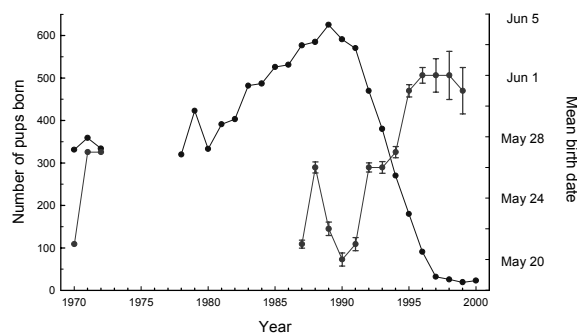
Grey seal pup production has been increasing at an annual rate of 13% per year for the past four decades (Bowen et al. 2003a). Concerns have been expressed repeatedly about the impact of the expanding grey seal population on the recovery of cod. Sand lance and other non-commercial species are the most common prey in the diet with cod contributing a small fraction of the fish consumed. Because the cod population is so low, it is assumed that any additional source of mortality may be detrimental to the remaining stock.



Estimates of grey seal consumption are calculated from a population model, which incorporates metabolic requirements of individual seals (Mohn and Bowen 1996). Current population size and diet of grey seals are not available. But if the rate of growth has continued at past levels, then the population could have doubled since the last survey in 1997 to near 225,000 in 2002. Based on this extrapolation and recent evidence from fatty acids that cod may account for only about 1% of the diet in recent years, the estimated consumption of cod by grey seals is in the order of 3,000 t, compared to a total cod population biomass of 8,800 t (DFO, 2003b). Recent satellite tracking of adult grey seals indicates that a fraction of the Sable Island population forages in areas beyond the boundaries of the Eastern Scotian Shelf ecosystem.

Therefore, the consumption of cod by grey seals in this ecosystem may be less than that currently estimated. The impact of grey seal predation on the dynamics of cod is an active area of research and there are continued concerns on the role of seal predation on cod recovery.

Harbour seals are widely distributed on the Eastern Scotian Shelf at both coastal and an offshore site, Sable Island. Pup production has been monitored on Sable Island since 1973 and the number of pups born steadily increased through the late 1980s. However, during the 1990s, pup production fell rapidly and dramatically as a result of increased shark predation and presumed competition for food with the expanding grey seal population (Lucas and Stobo 2000, Bowen et al. 2003a). Coincident with a decline in number was an increase in the mean birthing date of females (red symbols), suggesting nutritional stress prior to the breeding season. By 2002, less than a dozen pups were born on Sable Island and in all likelihood Sable Island will become a non-breeding site in the future. Conversely, harbour seal populations in the Gulf of Maine and on the western part of the Scotian Shelf appear to be increasing.



## Synthesis

An overall picture of the changes that have taken place on the Eastern Scotian Shelf since 1970 was addressed by adopting an approach similar to the traffic light framework used in stock assessments and recently utilized by Link et al. (2002) for an

ecosystem evaluation in a fisheries management context of Georges Bank. Sixty-four metrics were used in the evaluation with 50 representing primary indices and 14 indicative of second order indices, i.e. higher level processes such as community composition, ratios of variables, growth, etc (see Appendix Table 1). The indices were made directly comparable to one another by expression as anomalies (deviation from long-term mean) in standard deviation units. Colors were used to display the magnitude of the anomalies ranging from strongly negative (red) to strongly positive (green). The color scheme was not chosen to convey judgment on the direction of change (i.e. good or bad).

The metrics shown in Appendix Table 1 have been ordered to show how they change in a coordinated manner over the study period. Thus, the location of the variables along the sequence in the table reflects the relative similarity in the manner in which the metrics vary over time. For example, seal abundance, pelagic fish abundance and the pelagic:demersal ratios (metrics located at the top of the table) change in a coherent manner relative to those further down the list. What is visually striking is the change in state of almost all the metrics over the study period, with the transition occurring between the years 1985 to 1990. There is also evidence of reciprocal changes in the sign of the standardized anomalies from those indicators of groundfish abundance to pelagic abundance to zooplankton to phytoplankton – that is the components of a simplified food chain. When the indicators of groundfish abundance were high during the 1970s/mid-1980s, pelagic abundance was low, zooplankton abundance was high and chlorophyll was low. Throughout the 1990s, a reversal of this pattern was evident when the indicators of groundfish abundance were low. These patterns remain, as yet, unexplained however a few key hypotheses deserve consideration: 1) “Top-down” or predator control of food webs is one possible explanation for the reciprocal changes in abundance among adjacent

trophic levels. 2) Physical changes associated with increased stratification could favor the proliferation of a pelagic-based food web and limit the flux of nutrients to the benthos. 3) Cooling and increased advection were associated with colonization by sub-Arctic species, increases in abundance of snow crab and shrimp, and declining groundfish productivity. Coupled with high exploitation pressure on groundfish, dominant species such as cod and haddock may have been made more susceptible to these physical changes. It should be noted that the hypotheses are not mutually exclusive and elements of each one may be contributing to the observed patterns.

The sequence of metrics in Appendix Table 1 is derived from a multivariate ordination of the anomalies (in this case, Principal Components Analysis; see Appendix Figure 1), a technique that objectively describes and summarizes these suites of changes in the metrics. The primary suite of changes (PCA axis 1) are related to the changeover from a predominantly demersal system in the 1970s to a more pelagic system in the current decade. The relative position of the years provides an indication of their relative similarity in the metrics used to characterize the Eastern Scotian Shelf. The relative location of the metrics indicates the degree to which these variables influence the associated years. Thus, for example, the years 1970 to 1980 are all located towards the left in Appendix Figure 1 and are associated with large length-at-age of cod and haddock, high relative fishing mortality, large mean size of demersal fish, high landings of groundfish and high levels of PCB concentrations in seal blubber. Conversely, the late 1990s are associated with high landings of invertebrates, stronger stratification anomalies, elevated pelagic:demersal ratios, elevated seal abundance, and elevated CPR colour levels. The second most dominant suite of changes (PCA axis 2) contrasted the temperature variations on the eastern Scotian Shelf, highlighting the distinctive character of the period between 1985 to

1993, when ice coverage was higher and lower bottom temperatures prevailed in Misaine Bank.

## Outlook

Several components of the Eastern Scotian Shelf ecosystem have changed as a consequence of human actions and environmental variability. The magnitude of change has been rapid and from a species perspective some groups are proliferating while others are not. Several invertebrate species are now supporting either new or expanded fisheries. Small pelagic fishes are flourishing. The persistent reduced condition of a variety of groundfish species, the low size-at-age and high natural mortality of a subset of species of commercial importance is perplexing to say the least. Given low groundfish abundance and generally high prey abundance, conditions for growth should be good. Temperature conditions have also moderated since the late 1990s. In particular, cod has failed to recover due both to poor growth and lack of recruitment. At Sable Island, grey seals have been steadily increasing during the past four decades whereas harbour seals are declining. Changes in the physical environment have also been apparent and it is too early to tell whether such regional changes reflect only natural variation or are part of the anticipated larger scale climate changes associated with the "Greenhouse" effect. Ever growing demands for fossil fuels will also result in continued exploration and development with their attendant impacts, which at present appear to be either localized or unknown. Prediction of how long the current situation will persist and whether or not the system will return to its previous groundfish-dominated state is not yet possible as there is limited understanding of the dynamics of marine ecosystems.

In an evaluation of such broad scope in a relatively well studied area, some data shortcomings are apparent and it is important these be noted to capture the uncertainty in the conclusions and for

consideration of whether or not such gaps should be filled. For all but the higher trophic levels, there is a current lack of knowledge about the diversity of species, either past or present, inhabiting the offshore waters. There is a need for monitoring benthic invertebrate species. There is also very little information on contaminant concentrations in water, sediment or biota that would be used to establish either distributional patterns or trends in space or time. Collectively, these shortcomings are not just symptomatic of the study area but typify many offshore marine ecosystems throughout the world.

## For more Information

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## References

- Addison, R.F., and W.T. Stobo. 2000. Trends in organochlorine residue concentrations and burdens in grey seals (*Halichoerus grypus*) from Sable Is., NS, Canada, between 1974 and 1994. *Environ. Poll.* 112: 505-513.
- Bowen, W.D., J.I. McMillan, and R. Mohn. 2003a. Sustained exponential population growth of the grey seal on Sable Island. *ICES J. Marine Sci: In press.*
- Bowen, W.D., .S.L. Ellis, S.J. Iverson, and D.J. Boness. 2003b. Maternal and newborn life-history traits during periods of contrasting population trends: implications for explaining the decline of harbour seals, *Phoca vitulina*, on Sable Island. *Journal of*

- Zoology, London: *In press*.
- Breeze, H., D.G. Fenton, R.J. Rutherford, and M.A. Silva. 2002. The Scotian Shelf: an ecological overview for ocean planning. Can. Tech. Rep. Fish. Aquat. Sci. 2393.
- Coffen-Smout, S., R.G. Halliday, G. Herbert, T. Potter, and N. Witherspoon. 2001. Ocean activities and ecosystem issues on the Eastern Scotian Shelf: an assessment of current capabilities to address ecosystem objectives. CSAS Res. Doc. 2001/095.
- Cranford, P.J., K. Lee, J.W. Loder, T.G. Milligan, D.K. Muschenheim, and J. Payne. 2001. Scientific considerations and research results relevant to the review of the 1998 offshore waste treatment guidelines. Can. Tech. Rept. Fish. Aquat. Sci. 2364.
- DFO, 2000. State of phytoplankton, zooplankton and krill on the Scotian Shelf in 1998. DFO Science Stock Status Report G3-02 (2000).
- DFO, 2003a. Eastern Nova Scotia Snow Crab. DFO Science Stock Status Report 2003/029.
- DFO, 2003b. Eastern Scotian Shelf Cod. DFO. Science Stock Status Report. 2003/020.
- Fisher, J.A.D., and K.T. Frank 2002. Changes in finfish community structure associated with an offshore fishery closed area on the Scotian Shelf. Mar. Ecol. Prog. Ser. 240: 249-265.
- Gowans, S., H. Whitehead, J.K. Arch, and S.K. Hooker. 2000. Population size and residency patterns of northern bottlenose whales (*Hyperoodon ammpullatus*) using the Gully, Nova Scotia. J. Cetacean Res. Manage. 2: 201-210.
- Harley, S.J., R. Myers, N. Barrowman, K. Bowen, and R. Amiro. 2001. Estimation of research trawl survey catchability for biomass reconstruction of the eastern Scotian Shelf. CSAS Res. Doc. 2001/084.
- Link, J.S., J.K.T. Brodziak, S.F. Edwards, W.J. Overholtz, D. Mountain, J.W. Jossi, T.D. Smith, and M.J. Fogarty. 2002. Marine ecosystem assessment in a fisheries management context. Can. J. Fish. Aquat. Sci. 59: 1429-1440.
- Lucas, Z., and W.T. Stobo. 2000. Shark-inflicted mortality on a population of harbour seals (*Phoca vitulina*) at Sable Island, Nova Scotia. Journal of Zoology, London 252: 405-414.
- Mohn, R., and W.D. Bowen. 1996. Grey seal predation on the eastern Scotian Shelf: modelling the impact on Atlantic cod. Can. J. Fish. Aquat. Sci. 53: 2722-2738.
- Mohn, R.K., and J.E. Simon. 2002. Biological information relevant to the management of 4TVW haddock. CSAS Res. Doc. 2002/102.
- Pauly, D., V. Chrisensen, J. Dalsgaard, R. Froese, and F.C. Torres, Jr. 1998. Fishing down marine food webs. Science 279: 860-863.
- Thompson, D.H., J.W. Lawson, and A. Muecke. 2001. Proceedings of a workshop to develop methodologies for conducting research on the effects of seismic exploration on the Canadian east coast fishery, Halifax, Nova Scotia, 7-8 Sept. 2000. Environmental Studies Research Funds Rep. No. 139. Calgary.
- Zwanenburg, K., D. Bowen, A. Bundy, K. Drinkwater, K.T. Frank, R.N. O'Boyle, D. Sameoto, and M. Sinclair. 2002. Decadal changes in the Scotian Shelf large marine ecosystem, pp. 105-150. *In:*

K. Sherman and H.R. Skjoldal. (eds.).  
Large marine ecosystems of the North  
Atlantic: Changing states and  
sustainability. Elsevier.

Zwanenburg, K.C.T., 2003. The Scotian  
Shelf. In: Large Marine Ecosystems of  
the World - Trends in Exploitation,  
Protection, and Research. G. Hempel  
and K. Sherman [Eds.]. pp 75-91.  
Elsevier, New York: *In press*.

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Appendix Table 1. The color table on the next page shows the 64 metrics grouped according to the similarity of their changes from year-to-year. The variables from top to bottom are grey seal abundance, pelagic fish abundance (numbers), pelagic:demersal fish ratio (based on numbers), landed value of invertebrate fisheries, biomass of pelagics, diatom abundance, grey seal pups, landed value of pelagics, colour (greenness index), dinoflagellates, fish diversity (richness), 3D seismic (km<sup>2</sup>), position of Gulf Stream, stratification anomaly, ratio of diatoms:dinoflagellates, sea level anomaly, volume of CIL source water, invertebrate landings, area of bottom < 3° C, Sable Island winds (Tau component), SST anomaly (satellite), chlorophyll, temperature of the mixed layer, NAO, bottom temperature at Emerald Basin, Para and Pseudo-calanus abundance, shelf-slope front position, storm index, bottom temperature at Misaine, groundfish landings, length-at-age (haddock), bottom area trawled (vessels > 150t GRT), length-at-age (cod), average weight of an individual from RV survey, fish community similarity index (Bray-Curtis), PCB in seal blubber, relative F of groundfish, length-at-age (pollock), *Calanus finmarchicus*, groundfish RV biomass, pelagic landings, length-at-age (silver hake), community condition (based on predicted weight at length), mixed layer depth (Z), community condition index (based on residuals from population length-weight relationship), proportion of area with fish in good condition, RIVSUM, sigma-t in mixed layer, oxygen (below 150 m), wind stress (total), wind stress (x-direction), wind stress amplitude, SST at Halifax, landed value of groundfish, salinity in mixed layer, ice coverage, wind stress (tau), number of wells drilled, nitrate (below 150 m), groundfish abundance (numbers), Shannon diversity index for fish, seismic 2D (km).





Appendix Figure 1. Principal component analysis showing the first two principal components with loading from the various metrics in the model. Note that only a subset of the total number of metrics used in the analysis are shown.

