Habitat management template for Scotian shelf habitat mapping.

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Progress report for horizontal NRCan – DFO habitat mapping project.

About this document

This document is a progress report on interdepartmental (DFO – NRCan) horizontal initiative on benthic habitat mapping in the Scotia-Fundy area, prepared for presentation to scientists and stakeholders. The purpose of this document is to present and describe:

- steps taken to compile available oceanographic, biological and geological data;
- reasons for inclusion or exclusion of certain types of data from the habitat mapping framework;
- data layers used in habitat characterization;
- a proposed new mapping and classification framework;
- a draft habitat map for the Scotia-Fundy region

It was NOT intended in this document to give a complete description of benthic ecology, geology and oceanography of Scotian Shelf. The quality of compiled information and theoretical basis for the mapping framework will be reviewed and suggestions for their improvement presented at January 2004 benthic habitat RAP.

The results of this habitat mapping exercise are hoped to produce testable hypotheses and management insights.

Introduction

Department of Fisheries and Oceans in cooperation with Natural Resources Canada are making a significant progress in understanding ecology and structure of seafloor habitats of Eastern Canada. Cooperative habitat mapping effort is applied through interdepartmental agreements as well as through informal horizontal linkages between scientists from different disciplines. The aim of this undertaking is to provide products that can be used to plan installation of sea floor infrastructure and for the resolution of conflicts regarding sea floor use which will allow a balance between competing demands of renewable and non-renewable resources exploration with conservation. The data, expertise and mapping solutions will meet a broad range of needs of the Government, First Nations, oceans industry and resource users, environmental interest groups, coastal communities, and university researchers.

Objectives of the work

In this interdisciplinary framework on habitat mapping we are addressing the following key questions: Which areas of the seafloor are the most sensitive to human impacts and how to balance resource exploration and fisheries with available ecosystem services? These questions are answered through detailed mapping and characterization of seafloor environment based on current understanding of biological, geological and oceanographic patterns and processes on the Scotian Shelf.

Initial understanding and background

It was agreed (RAP Proceedings 2002) that the main purpose of benthic habitat mapping and classification scheme is ocean management. The classification was meant to guide the development of enforceable zoning scheme to control human activities on the shelf that have the potential to reduce or degrade marine biodiversity.

The following is a list of components of a classification scheme was recommended as a guide for habitat mapping at DFO Benthic Habitat Classification Regional Advisory Process (RAP Proceedings, 2002). All classification levels were suggested to be nested in higher levels and no attribute at one level was to exist at another level:

- Oceanographic domains, classified on the basis of:
    - Critical depths
    - Thermal regime
    - Current regime
    - Productivity regime
    - Disturbance regime

- Seabed domains within Oceanographic domains
    - Physiographic domains within which
        - Morphological domains, within which
            - Seabed texture
                - Topographic roughness
                - Surficial complexity
                - Bio-structural complexity
                - Particle roughness
                - Five types of substratum

Biological Communities

In this report I will describe the initially proposed data layers in detail, but also propose a new, conceptually different approach to classification and mapping of Scotian shelf.

1. Habitat management template

In the Proceedings of Geological Society of America Joel Hedgpeth (1957), the creator of the presently common classification system of marine environments, stated: "It should be understood that we are not referring to here to the realities or limits of these subdivisions or the problems of zonation on the shore, but to the manner in which the terms have been applied". This statement appeared in the report of the National Research Council committee on a treatise of marine ecology and palaeoecology which summarized several years of discussion and compilations based on questionnaires assessing acceptability of the proposed terminology to as many workers as possible.

Development of the common ecological dictionary empowered scientists across the world to communicate clearly, however new and increasingly complex classification schemes are being developed on a continuous basis (EUNIS, MARLIN, etc.). It may seem puzzling why it takes centuries to develop a common vocabulary or a marine classification scheme. After all we may easily agree on the less important definitions such as "tall" and "short" or "light" and "dark". The classification task is greatly simplified by introduction of measurable parameters, such as height in cm or brightness in lumen and clear definition of cut-off values. In marine environment littoral and sublittoral system are separated on the basis of low water stand (chart datum), but the division between littoral and sublittoral zones on shores exposed to waves is not located at the same water depth as on protected shores, based on the observations of distribution of benthic fauna. Similarly fuzzy is the perception and definition of terms like brackish and estuarine (Hedgpeth 1957), - researchers in North West Atlantic will have a different perception of the terms compared to the researches in the Baltic Sea. Again the ecological distinction is based on the observations of distribution of marine fauna.

It seems reasonable to assume that it is the living organisms which guide our classification of the environment, not just the easily quantifiable environmental factors. The example with salinity also suggests that the environments should be classified locally and the universal boundary definitions may not be meaningful everywhere. This does not negate the utility of common vocabulary, but questions usefulness of classification terms in broad-scale approaches (such as Scotian shelf mapping) because the researcher's goal is to understand the reasons for ecological gradients, and because of necessity to understand processes behind the observed patterns.

It was argued by Hatcher (2002) that classification for management is not necessarily the same as classification for scientific understanding because its goal is an enforceable zoning scheme. It can be argued however, that no reasonable zoning scheme can be developed unless boundaries and dissimilarities between zones, and ecological significance of the boundaries are understood.

Similarly to my previous (Kostylev 2002) concepts on habitat mapping I would like to emphasize that reasonable characterization of benthic habitats is not attainable without mapping. The logic of the proposed here approach is not to classify and then map, but to map continuous factors, discover discontinuities and ecological significance and then characterize or zone the sea floor. I also want to re-iterate three main concepts: 1) Classification and mapping have different purposes; 2) Mapping of classification system is not useful for management; and 3) Progress should go from mapping to classification, not vise versa.

Marine environment is highly variable spatially and temporally, the physical factors interact with each other in their effects on benthos, and therefore ecologically meaningful boundaries should be defined locally. Sound management practice should be based on clear understanding of distribution patterns of marine organisms or their assemblages. Why do we find deep-sea corals in some places and not the others? Why do we fish scallops on gravelly banks and not on the shelf slope? Why is the cod gone? Behind each pattern there is a process, that is happening either in ecological or in evolutionary time, the process which we need to understand in order to manage the species.

Species are prisoners of their evolutionary history, writes Southwood (1988), and phylogenetic drag or inertia ensures that all adaptation options are not simultaneously available to them. In other words there are no species that can be equally successful in every environment because their traits were selected by particular types of environments. Thus characteristics of habitats through selective forces such as biotic and abiotic factors affect fitness of individual organisms by modifying their growth rate, survival, fecundity etc. in ecological time, which leads to selection of optimum combination of traits/tactics and evolution of optimal life history strategy. Each adaptation however would have a cost: heavily armored animals can not run quickly, in animals with high fecundity juvenile survival is low, species with high adversity tolerance (e.g. lichens) have low competitive ability and species adapted to a unique habitat (e.g. through co-evolution, fig wasp) risk death with disappearance of specific habitat.

According to Southwood (1977, 1988) the main adaptation tactics are the following: a) Physiological adaptations to inclement physical conditions; b) Defence against predation; c) Food harvesting and somatic development; d) Reproduction; and e) Escape in space and time. These tactics manifest themselves in species migratory and trivial range, range of offspring dispersal, growth rates and body form, fecundity and age at sexual maturity etc. These traits are selected by two major forces, which are Southwoods (1977) durational habitat stability (frequency of disturbance) and adversity or severity of the environment. Disturbance-Adversity template defines and constrains life history characteristics of species, without imposing uniformity of the traits. Table 1 exemplified traits of species found in four classes of environment:

Table 1. Southwood's (1988) habitat template with an example of expected life history traits in each type of environment

	Benign	Adverse
Stable	Defense medium Migration Low Offspring medium and small Longevity medium Tolerance low	Defense high Migration low Offspring few and large Longevity great Tolerance high
Disturbed	Defense low Migration high Offspring many small Longevity small Tolerance low	Defense – high Migration high Offspring medium large Longevity medium Tolerance high

Disturbance axis reflects intensity of habitat destruction or alteration, or durational stability of habitat in general. Adversity is related to severity or unfavorableness of the habitat and factors that pose a cost for physiological functioning of organisms. In evolutionary perspective, an adverse environment will select species for their tolerance to extremes of physical factors. Disturbed environment will favor short-lived species, which can quickly colonize an area and reproduce. Ecosystems, like species may be arranged in pattern against habitat template (Southwood, 1997), where ecosystem character is a mix of population strategies and their interactions.

The first application of habitat template approach in benthic habitat mapping was tested on Georges Bank (Kostylev et al. in press), producing encouraging results. It was shown that distribution of benthic assemblages corresponds to the habitat template, with stations from same clusters showing strong fidelity to a single habitat type, defined as disturbed adverse, disturbed benign, undisturbed adverse and undisturbed benign.

Habitat template approach to mapping appears both theoretically valid and economical. With sound modeling of disturbance and adversity axes based on known physical variables it could alleviate difficulties inherent in simultaneous visual interpretation of a large number of environmental variables and arbitrarity of classification schemes. Note that both axes are continuous, and can be subdivided in as many levels of disturbance or adversity as needed for practical purposes. The benefits of habitat template to managers is twofold: knowing life history traits of an organism one could predict its distribution on the shelf; and knowing physical conditions in a given area one can predict likely inhabitants and biodiversity of the area.

The importance of considering life history traits in ocean management has been emphasized recently by Hiscock (1999) who suggests that the knowledge of life histories is important in considering likelihood of recovery of populations following a destructive event. He proposed that longevity, time to reach sexual maturity, frequency of reproduction, ability to re-colonise substrates and timing of critical life phases of benthic species should be considered before any disturbance is imposed on them. Populations of longer lived species for example are more sensitive because they will be replaced slower; if disturbance is more frequent than time to reach sexual maturity or frequency of reproduction then population recovery is not likely; risk to populations also increases if the species has restricted habitat requirements. An example of such species could be deep-sea corals, with traits similar to those described in stable adverse corner of habitat template (Table 1). Anthropogenic activities in the disturbed benign corner of the template are least likely to have drastic effects on the bottom fauna because the majority of species would have short life span, be mobile and produce abundant offspring.

Thus, mapping of the habitat template produces also the template for ocean management, based on ecological and evolutionary understanding of benthic patterns and processes.

2. Availability of data

This section describes unpacking of the available classification parameters in the order and extent **initially suggested** at Benthic Classification RAP (RAP Proceedings 2002). Not all of these layers are useful for habitat template approach.

Oceanographic domains

- Six domains were initially recognized at 2001 Habitat Mapping RAP (RAP Proceedings 2002):
  1. North-eastern Scotian Shelf,
  2. South-eastern Scotian Shelf,
  3. Central Scotian Shelf,
  4. Western Scotian Shelf,
  5. Scotian Shelf Edge,
  6. Gulf of Maine (including George's Bank and Bay of Fundy).

In order to describe oceanographic domains in terms of thermal, current and productivity regime and to establish disturbance rates and critical depths within each of them it is necessary to define their boundaries with the best degree of accuracy possible, which becomes especially important if the boundaries are used for mapping and decision making purposes. Because the oceanographic boundaries are assumed to carry a particular significance for benthic fauna, they may not be set arbitrarily. Oceanographic boundaries are dynamic entities whose change can influence distribution and structure of benthic populations and communities. Scotian shelf break fronts for example are known to vary by tens of kilometers in few days (Fournier, 1978). Due to this dynamic nature and absence of crisp boundaries between water masses, mapping them is more challenging then simply describing their general location and properties.

Commonly an oceanographic boundary is presented as a zone between contrasting water masses, where the degree of difference and the scale are vaguely defined.

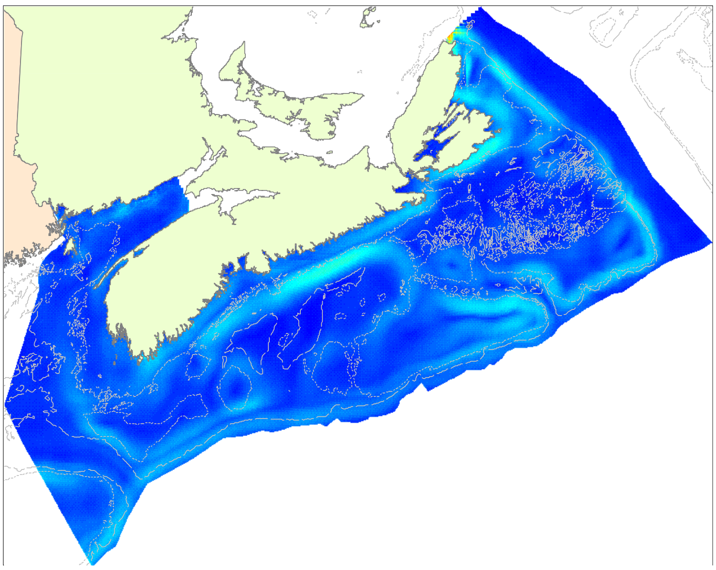


Fig 2.1. Oceanographic gradients based on average bottom temperature, salinity, chlorophyll concentration, current velocity, temporal variability in bottom temperature and vertical stratification parameter. Color brightness is proportional to steepness of gradients.

I approached boundary definition using a partitioning method (Fagan et al 2003), with 1500x1500 m kernel. A rate of change in each oceanographic variable was calculated and assigned to a center of a kernel, which produced a map of gradient strength for average seasonal temperature, salinity, RMS currents, water stratification and chlorophyll concentration. The gradient maps were given equal weight and averaged. The resulting map was used as a guide for defining frontal zones on the shelf. Note that the resulting boundaries between the water masses are fuzzy and have spatial uncertainty of ~20 km.

Most of the oceanographic gradients closely follow bathymetric boundaries (e.g. banks and slope), or strong circulation currents (e.g. alongshore current). Subdivision of the study area into six initially proposed domains is not clear, because of the high degree of variability introduced by interactions of water masses with bottom relief. The separation between North-East and South-East Scotian shelf is not present in gradient map (Fig. 2.1), although the boundary between the eastern and central shelf is clear. Subdivision of the remaining area into domains is in the eyes of the beholder and is scale-dependent (e.g. Fig. 2.2).

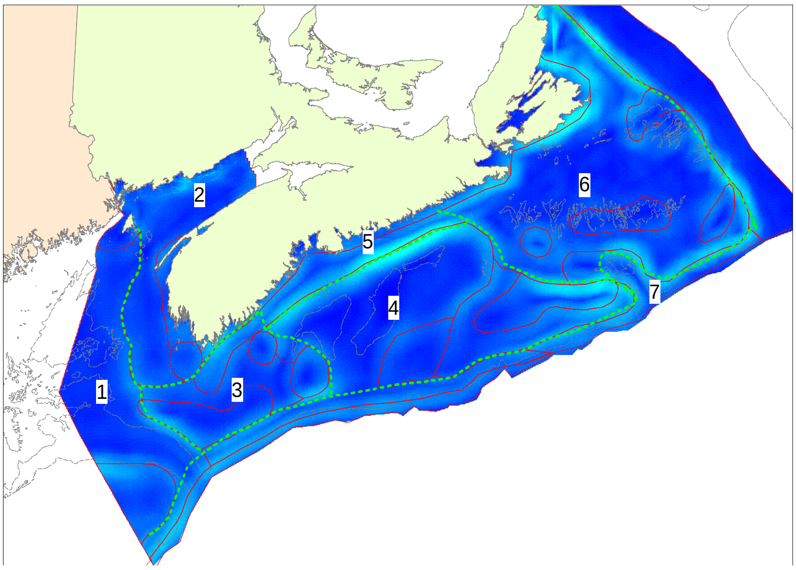


Fig. 2.2. One of the many ways to define oceanographic domains on the Scotian shelf. Steep oceanographic gradients outlined with red lines and possible oceanographic domains delimited with green dashed lines. 1) Georges bank and the Gulf of Maine; 2) German bank – Fundy; 3) Western shelf; 4) Central shelf; 5) Inner shelf; 6) Eastern shelf; 7) Shelf break and slope

Five classifying attributes were initially recommended (RAP Proceedings 2002) to map oceanographic domains: critical depths, thermal current and productivity regime, as well as disturbance rates.

Critical depths:

It is common to approach vertical classification of water masses by subdivision into a number of layers by fixed water depths, e.g. 0-50 m (euphotic), 50-200 m (aphotic), 200 – 2000 m (bathyal) (e.g. Day and Roff, 2000). Essential ecological processes such as light penetration, energy exchange and food supply change with water depth and consequently modify growth, reproduction, dispersal, recruitment and mortality of benthic organisms.

I tested the relationship between the oceanographic gradients occurring on the seabed and bathymetry by calculating a median and range values for gradient strengths on the shelf. Fig ??? shows that the strongest changes in water mass properties may occur at water depths of 180 to 140 meters, although the median values of gradient strength are similar across the whole bathymetric range, meaning that the change is in most places gradual. Neither 50 nor 200 m isobath appear important in separation of water masses in the study area.

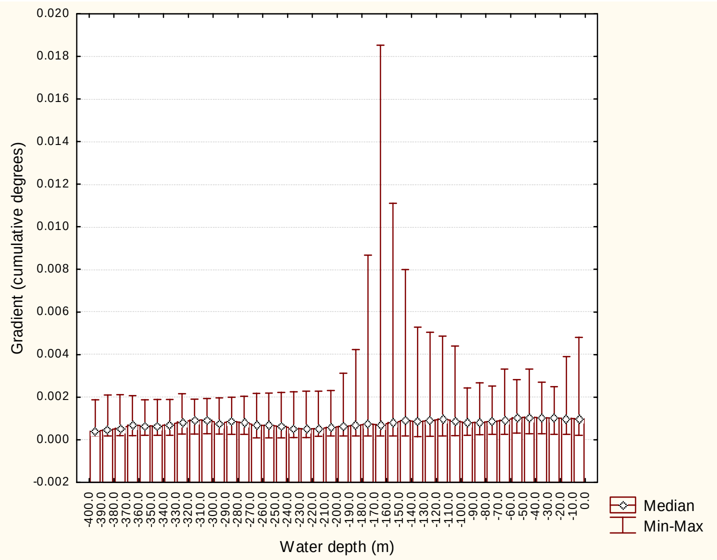


Fig. 2.3. Median and range of oceanographic gradient strengths plotted against water depth. The graph is suggestive of the most rapid change of water mass properties occurring at approximately 160 meters water depth and of majority of gradients on the shelf being smooth.

Particular attention at the first RAP meeting was paid to the following critical depths: Pleistocene still-stand depth, depth of photic layer and depth of mixed layer. Discussion of usefulness of these variables for habitat classification and mapping follows:

Pleistocene still-stand depth

Based on stratigraphic, textural and geomorphic evidence, a widespread, submarine, low sea-level stand occurred at a present depth of 110 -120 m across the Scotian Shelf prior to Holocene transgression (Fader 1989). It is likely that this water depth defined the upper margin for the existence of many enduring preglacial features and associated benthic fauna, and served as a “starting line” for the colonization of benthic habitats by the modern assemblages. Caution must be exercised in using the bathymetric contours for defining this boundary because the history of the bathymetry of the shelf has had changes in some areas through postglacial sedimentation and erosion, and also because the topography of the shelf has been altered due to lithospheric flexure caused by ice loading and subsequent rebound (Shaw et al 2002). In the Bay of Fundy, for example terraces indicating the lowest position of sea level shallow to a depth of 37 m (Fader et al., 1977) that have migrated from a low of 110 m in the adjacent Gulf of Maine. Additionally, in the Bay of Fundy, modern strong currents were initiated when the Bay reached its present shape and the outer Banks of the Gulf of Maine (Browns and Georges) became submerged after 8000 years ago. Therefore such a model of enduring features does not regionally apply to the Bay of Fundy where these modern conditions have overwhelmed the previous glacial and transgressive history.

It is not clear if the low stand boundary is well-represented in the distribution of benthic communities across the shelf because in some areas species colonization closely followed transgression through millennia, thus most likely leading to smooth gradients rather than sharp discontinuities in faunas. The bank sediments become sublittloral to themselves during transgression and the deeper parts become more and more relict with time. However the difference in sorting and particle shape of transgressed and untransgressed sediments can not be disregarded - glacial debris on bank tops has been reworked and redistributed by wave action with finer fractions removed and well-sorted lags of sand and well-rounded gravel left. The gravels below 120 m water depth are more angular, and there are thick accumulations of unmodified glacial debris (Fader et al., 1997). Although association of specific community types (e.g. deep-water corals) with glacial deposits and iceberg-scoured seafloor on Scotian Shelf was described (Fader and Strang 2001, Kostylev 2001), the relationship of the 120 m isobath with benthic habitat and associated communities remains not fully understood until more advanced palaeogeographic reconstructions that compare models of crustal response to glaciation and observed geological conditions (e.g. Shaw et al 2002) provide an exact position and characteristics of the low-stand boundary (G. Fader, personal communication). Currently assumed Pleistocene low water stand depth can be obtained from geological formation maps by tracing upper boundary of Sambro sand formation.

Mixed layer depth

Vertical mixing of water masses results from heating, freezing, and horizontal and vertical motion of waters with different temperature and salinity characteristics. Stratification of water masses influences productivity and community composition of planktonic organisms, which may have effects on fish and benthos. The thickness of the mixed layer varies seasonally and spatially. Strong tidal currents in the Gulf of Maine and the Bay of Fundy create well-mixed water masses, compared to the Scotian shelf. Frequent storms and lesser heating of surficial water layer lead to better mixing in Fall to Spring seasons. Additionally, exact vertical position of thermo- and halocline, when present, can only be identified from observations. High variability and uncertainty associated with this factor does not allow its use in hierarchical classification. For mapping purposes, however, summer density difference obtained from climatological observations and prognostic models was used (Fig. 2.4).

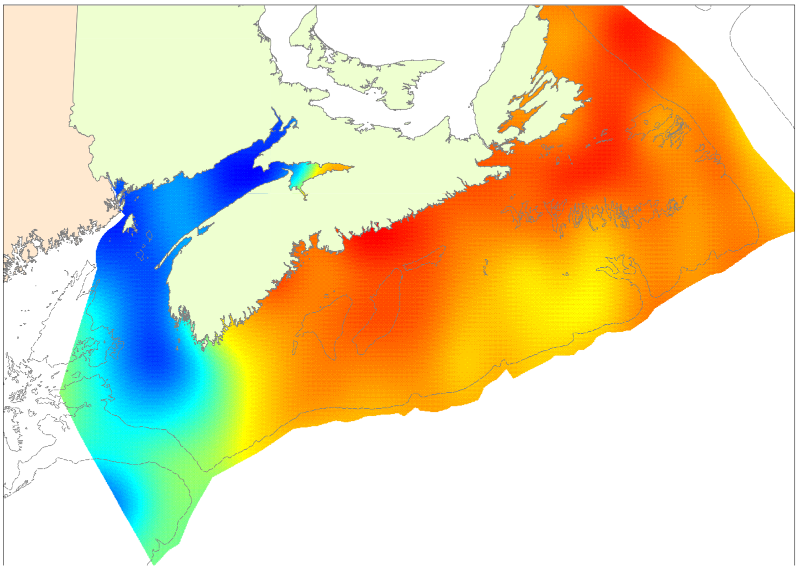
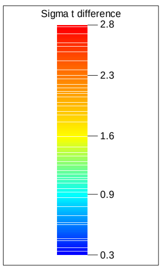


Fig 2.4. Sigma t difference (kg/m^3) between surface and 30 m water depth (July – September) from Scotian Shelf climatology (Data from Hannah and Soukhovtsev unpublished analysis based on the BIO data archives (Petrie et al. 1996).



Photic layer depth

The zone between the surface and the depth of total light absorption or depth to the compensation point is (where the rate of photosynthesis still exceeds the rate of respiration). The measurement of this depth is highly variable spatially (e.g. between Bay of Fundy and offshore waters), seasonally (depending on phytoplankton bloom) and with water depth (e.g. open ocean). Related to and can be deduced from productivity regime, vertical mixing, and currents. Direct measurements sufficient for spatial extrapolation are not available.

Thermal regime as epibenthic (bottom) seawater temperature Metrics / Variates: Min. and Max. annual temperature to a precision of 1^{o}C (from numerical models).

Temperature of seawater is casually related to growth of marine organisms and may affect marine fauna through its average and extreme values as well as the rate of change.
The common temperature range for physiological processes is 0 – 45 degrees C. With every 10 degrees increase in ambient temperature physiological processes intensify 2 to 3 times. Temperature serves a discriminant between community types at a scale of biogeographic areas.

Scotian Shelf – Fundy region is affected by different water masses which create longshore gradients in temperature, salinity and nutrients concentration. Temperatures and salinities generally increase from northeast to southwest (Fig. 2.5) because of the influence of the Gulf of St. Lawrence and from inshore to offshore because of the influences of the warmer, more saline offshore waters (Drinkwater et al 2002). Temperature and salinity on the shelf vary spatially due to complex bottom topography, transport from upstream sources, melting of sea-ice in spring, atmospheric fluxes and exchange with the adjacent offshore slope waters. Source waters for the Scotian Shelf as identified by Houghton et al. 1978 are the following: a) surface water flowing from the Gulf of St. Lawrence; b) surface water over the slope; c) water with minimum temperature and salinity characteristics of slope water and intermediate depths (100-150m); d) subsurface water (100-150m) in the Cabot Strait; e) deep slope water (200-300 m).

The presence of the cold water on the northeastern Scotian Shelf is believed to have led to an expansion of the distribution of cold-water species such capelin, turbot, shrimp and snow crab (Frank *et a*l., 1996; Tremblay, 1997; Drinkwater, 1999; Zwanenburg *et a*l., 2001)

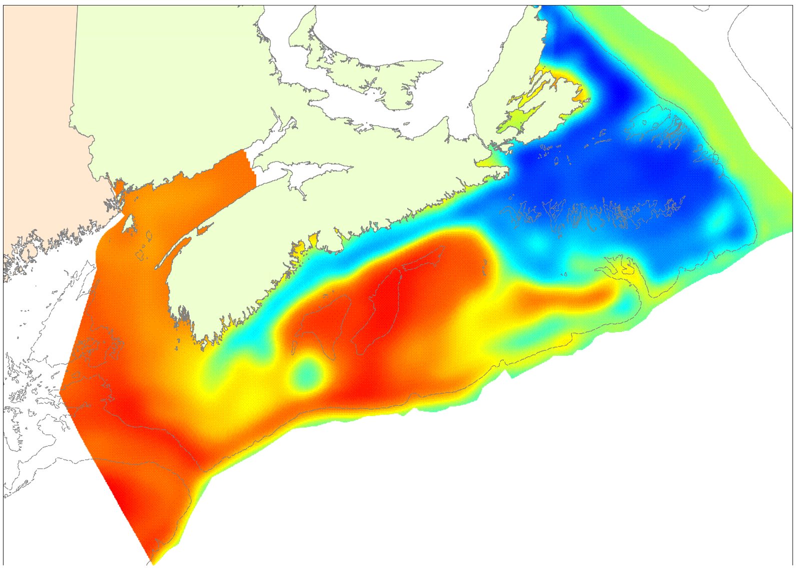
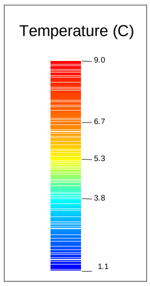


Fig 2.5. Average annual bottom temperature. From Breeze et al. (2002) based on results of Hannah et al. (2001) and Han et al. (1999).



Although at the surface, the seasonal range of temperatures is one of the highest in the Atlantic Ocean (16°C, (Weare, 1977), it rapidly declines with depth with little or no seasonal change at depths greater than approximately 100 to 150 m. Therefore it is likely that the effect of seasonal temperature range on benthic communities is strongly correlated with water depth. Long-term fluctuations of temperature may also influence distribution of enduring benthic communities.

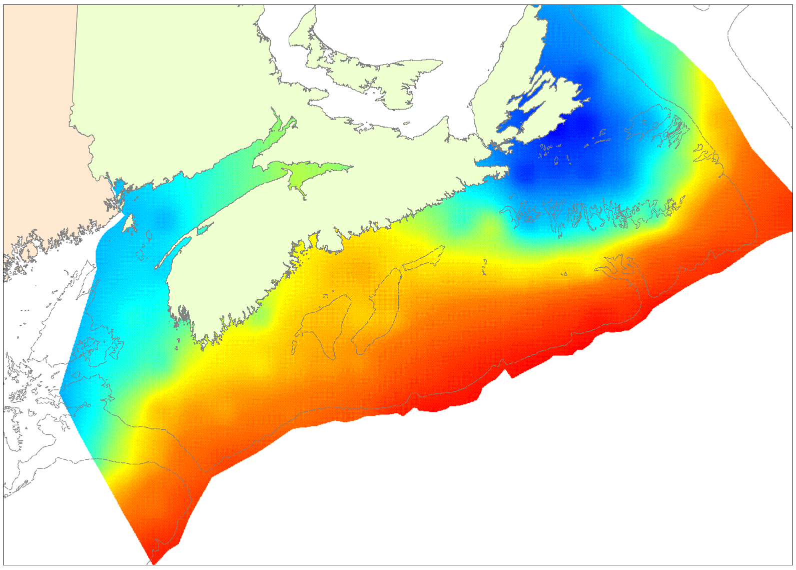
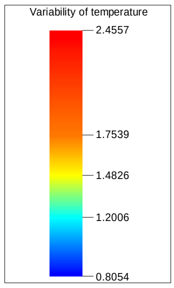


Fig. 2.6. Inter-annual variability in temperature (data from Hannah and Soukhovtsev unpublished analysis based on the BIO data archives (Petrie et al. 1996).



Inter-annual variability on the Scotian shelf (Fig. 2.6) is also among the highest in the Atlantic ocean (Drinkwater et al., 2002). This can lead to expansions and contractions of distribution ranges of stenothermic species (e.g. snow crab, shrimp). Areas of low inter-annual variability are more likely to have persistent benthic communities and are better suited for the incorporation of long-term biological observation in the analysis of relationships between biota and habitat. The map (Fig. 2.6) shows that bottom temperature on the inner Eastern scotian shelf (Canso, Scatarie and Misaine banks) is more stable than in the rest of the study area.

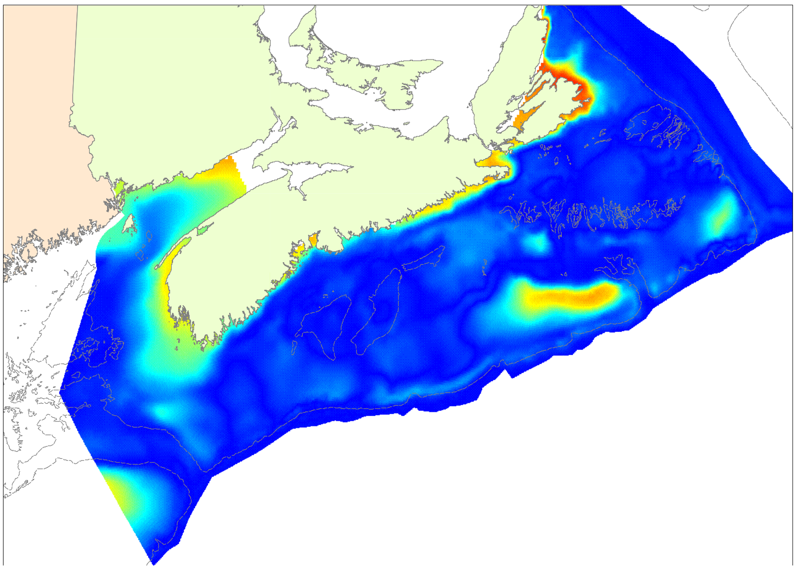
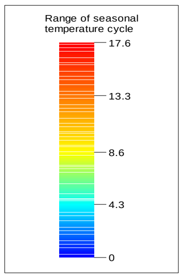


Fig 2.7. Range of seasonal temperature cycle. Calculated from seasonal temperatures shown in Breeze et al. (2002), based on results of Hannah et al. (2001) and Han et al. (1999).



Seasonal bottom temperature variability (Fig. 2.7) is strongly linked with water depth, due to increased summer heating and winter cooling of the mixed surficial waters. Extreme seasonal minimum and maximum temperatures affect survival of benthic species, thus limiting diversity of these areas.

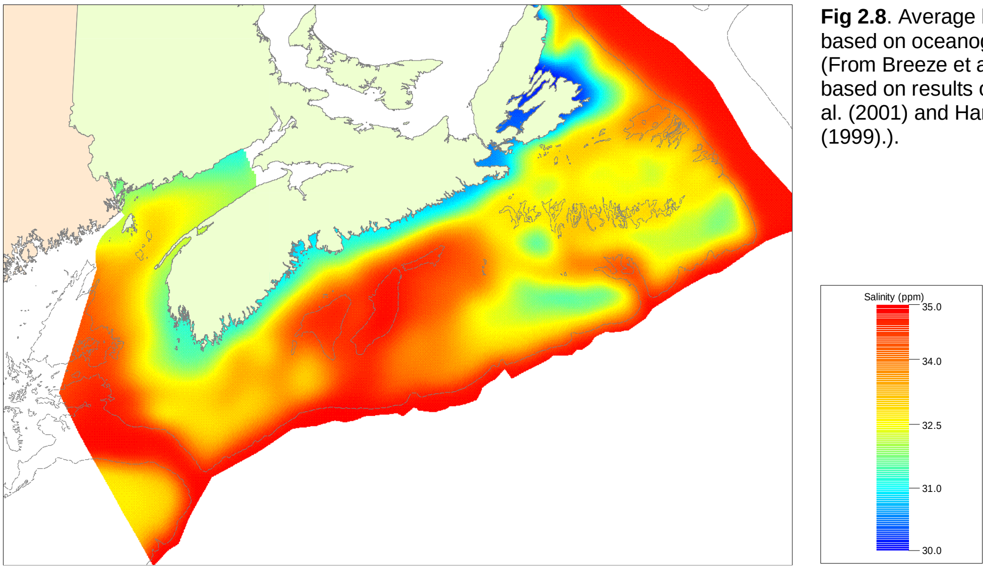


Fig 2.8. Average bottom salinity based on oceanographic models (From Breeze et al. (2002) based on results of Hannah et al. (2001) and Han et al. (1999).).

Water salinity was not included in the initially proposed classification (RAP Proceedings 2002), because of the narrow range of variability which would cause no effect on osmoregulation of benthic invertebrates. The figure 2.8 shows that Eastern shelf exhibits clear relationship with water depths. The general pattern of water salinity however corresponds to the distribution of competing water masses - saline water from Gulf stream, cold fresh water from the Gulf of St Lawrence and intermediate waters originating from the Labrador slope, with Sable and Banquereau banks dominated by surface waters flowing from the Gulf of St. Lawrence.

Current regime

Water motion has a significant effect on bottom communities and is causally related to the seabed disturbance, dispersal and food supply. Seasonal circulation and hydrography has been obtained from historical observations and a combination of diagnostic and prognostic models with forcing by tides, wind stress and baroclinic and barotropic pressure gradients by Hannah et al (2000).

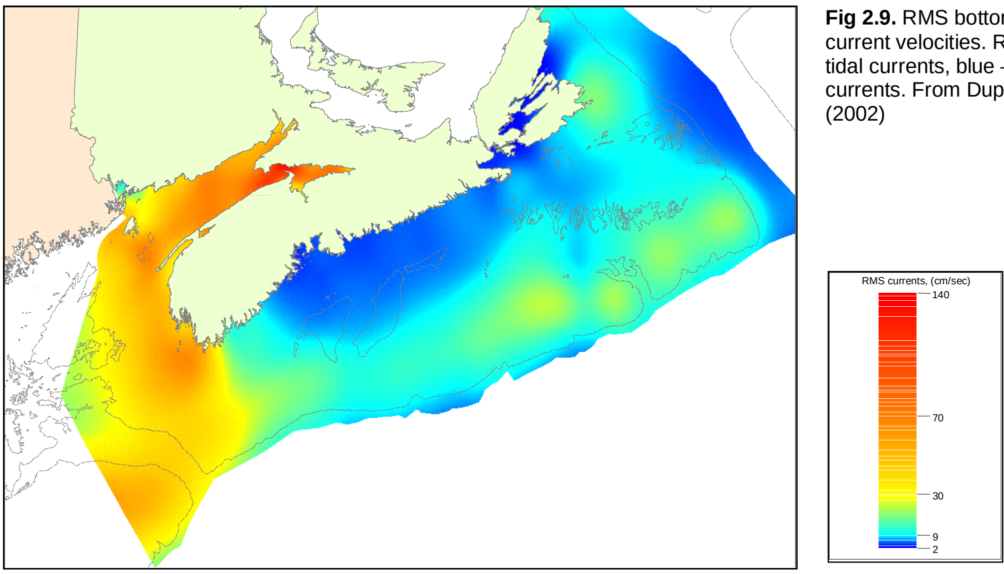


Fig 2.9. RMS bottom tidal current velocities. Red- strong tidal currents, blue – weak tidal currents. From Dupont et al. (2002)

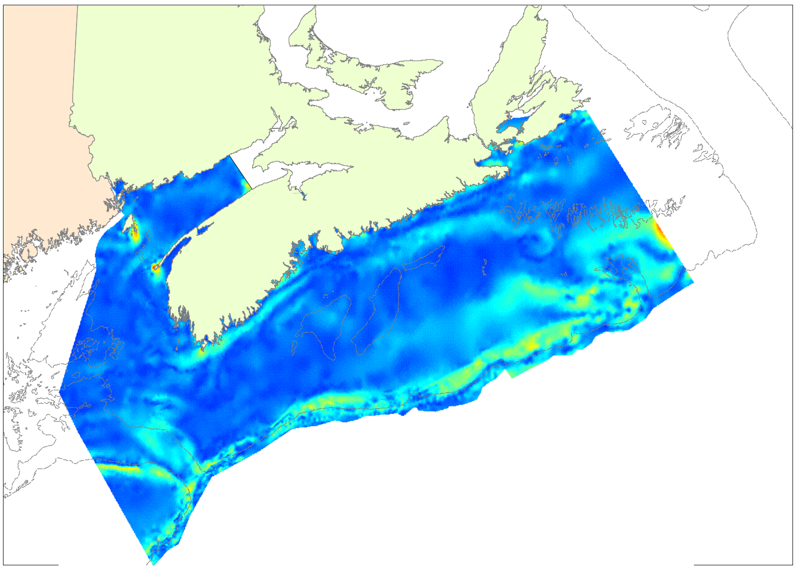
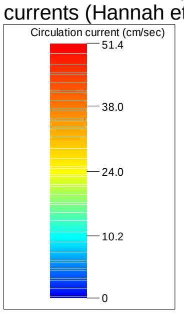


Fig 2.10. Nearbottom (spring) mean circulation current velocities. Circulation pattern is generally preserved through all seasons. Note that in the Western shelf and Gulf of Maine circulation currents represent 10% or less of tidal current strengths, while along the coast and shelf break they exceed tidal currents (Hannah et al. (2001)



Seabed habitats of the Gulf of Maine and outer banks of Scotian shelf are strongly affected by tidal currents (Fig. 2.9), while circulation current is stronger along the shelf break and Atlantic coastline of Nova Scotia (Fig. 2.10). Note similarity in the distribution of oceanographic fronts (Fig. 2.2) and circulation currents.

Productivity regime

Benthic biomass and productivity are commonly directly related to water column primary production (Hargrave and Peer 1973). Persistent plankton features may be causally related to food supply reaching benthic domain. It was initially suggested to use season and depth-integrated annual primary productivity of the water mass to a precision of 50 $gC.m^{-2}.y^{-1}$ from remote sensing and analytical models. However we have to be satisfied with Chlorophyll-a concentration estimated from SEAWIFS.

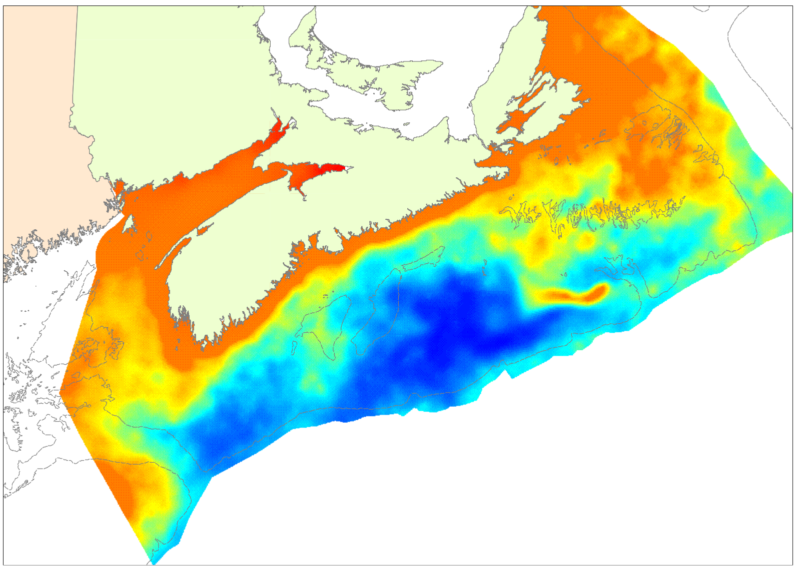
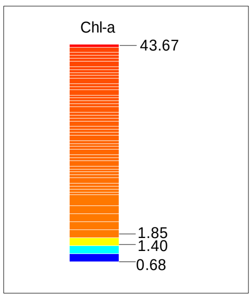


Fig. 2.11. Clrorophyll-a concentration during spring months, based on composite SEAWIFS data.



Spatial patterns in productivity are variable seasonally and from year to year. Composite map of spring chl-a distribution (provided by G. Harrison) was used as a proxy of primary production reaching seafloor, following the suggestion by Hargrave and Peer (1973) that benthic productivity has the strongest relationship with spring blooms.

The mapped pattern (Fig. 2.11), which is based on SEAWIFS data should be interpreted with caution because it represents only fluorescence of the surficial water masses and may be influenced by suspended inorganic particles. For example unusually high Chl-a values shown for the Bay of Fundy are likely artifacts caused by suspended mud (B. Hargrave, personal communication). Evaluation of the spatial pattern of the exact amount of primary production reaching seafloor requires detailed physical modeling which was not carried out on the Scotian shelf (G. Harrison, personal communication). Currently we can only assume that higher percentage of organic matter reaches seafloor in the retention areas, such as Georges, Browns, Sable Island and Banquereau banks. It is also likely that this occurs in frontal areas due to intensified vertical mixing.

Disturbance regime (as storm frequency)

Sediment disturbance of the seafloor occurs as a result of several processes, such as tidal and circulation currents, storm and internal waves. Wind generated wave hindcast for the 41 year period starting in 1958 was queried for the highest significant wave height which was subsequently used for calculation of shear stress (squared velocity) on the seabed. Figure 2.12 shows that storm waves have the strongest effect on the outer shelf, while basins and the Bay of Fundy seems relatively unaffected. Such pattern suggests that the bottom habitats of the banks can be highly disturbed by the major storms, with the effects protruding as deep as half of the wave length, which for the fully developed wind waves 14 m high equals approximately 100 m water depth.

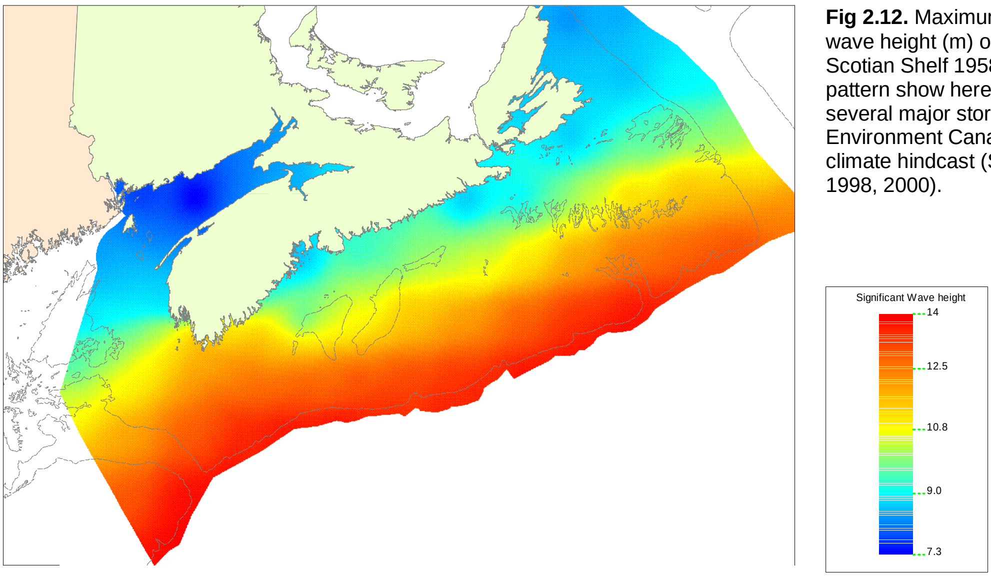


Fig 2.12. Maximum significant wave height (m) occurring on Scotian Shelf 1958 – 1999. The pattern show here is a result of several major storms. Based on Environment Canada wave climate hindcast (Swail et al 1998, 2000).

This map (Fig. 2.12) is a measure of maximum significant wave height, which may be assumed to correspond to maximum mechanical energy of the waves that can cause disturbance of seafloor through wave-generated currents. It currently over-estimates wave heights on bank tops (W. Perrie, personal communication) and has considerable spatial uncertainty because of the large separation between observations. Wave period associated with maximum wave heights are shown on Fig. 2.13.

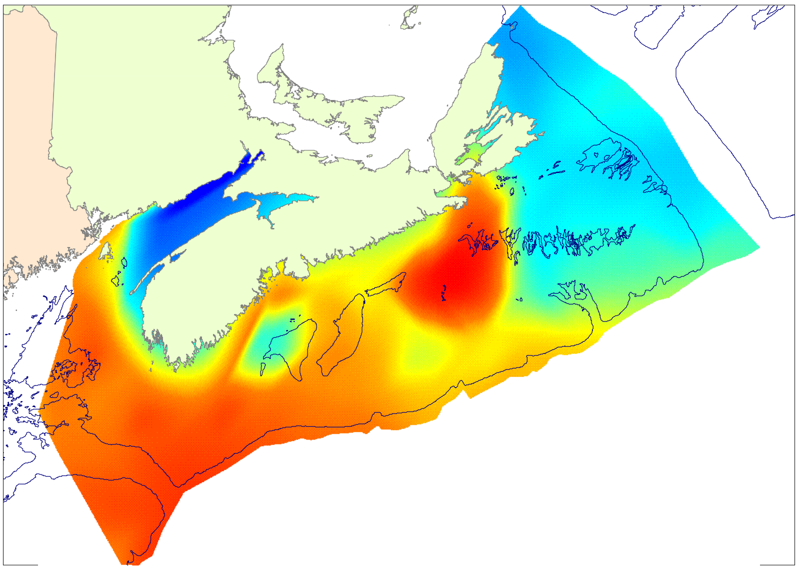
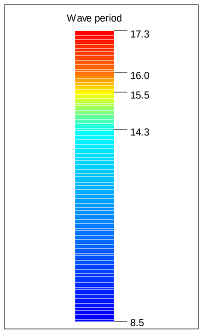


Fig. 2.13. Wave periods associated with significant wave heights hindcast (calculated from Swail et al 1998, 2000) (Fig. 2.12).



Annual probability of sand resuspension and transport or other measures of seafloor disturbance can be obtained from numerical models, linking tide and wave generated currents with seabed complexity and texture (e.g. wave model by W. Perrie, circulation models by C. Hannah and sediment transport models by M. Li). Such effort will require additional time and resources. Simplified approach to modeling seabed disturbance is described later in this document. It is remarkable that both tidal currents (Fig. 2.9) and probably wave-generated currents (based on the increased wave periods, Fig. 2.13) are stronger on the southern shelf, which corresponds to Amos and Judge (1991) observation that the abundance of hydrodynamically reworked sediment on Scotian shelf increases from north to south .

Seabed domains within Oceanographic domains

- Four **Physiographic domains** were recognized (RAP Proceedings, 2002):
  - Inner Scotian Shelf,
  - Middle Scotian Shelf
  - Outer Scotian Shelf
  - Scotian Slope

- Within which eight **Morphological domains** were recognized:
  - Banks
  - Bank Flanks
  - Basins
  - Saddles
  - Intermediate continuum (connecting those above, corresponding to “Valleys and Plains”)
  - Canyons
  - Upper Slope (Slope-Shelf transition)
  - Lower slope (Slope –Ocean basin transition)

Physiographic factors are thought of as an important factor in determining distribution of benthic communities. Several scales of physiographic variables should be distinguished, and often become the main accent (e.g. Greene et al., 2000) of habitat mapping:

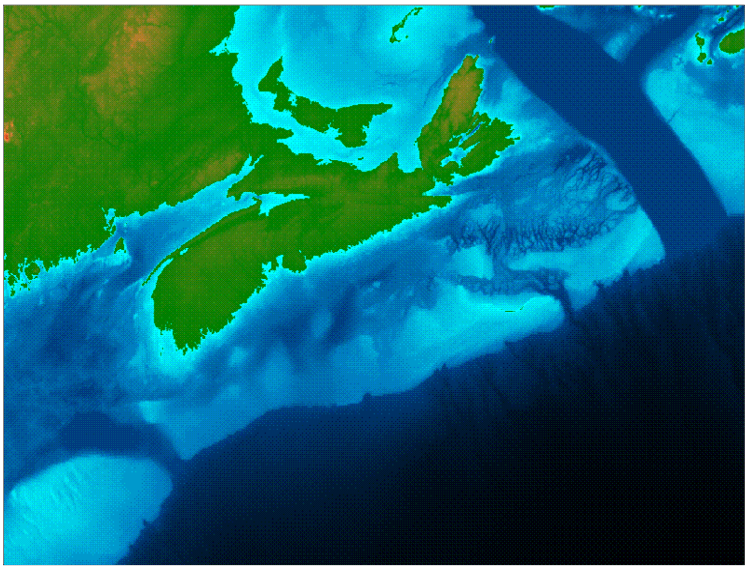


Fig2.14. Scotian shelf and the Gulf of Maine bathymetry. Data provided by J. Shaw, NRCan.

Large scale features such as subdivisions of shelf, e.g. outer, middle and inner shelf, shelf break and slope. Initial definitions of such areas are based on observations of varying oceanographic factors, or distance from the shore and do not represent real functional or ecologically meaningful units unless backed up by contrasting physical or ecological processes. Exact boundaries of large physiographic features are usually approximate. The inner shelf is an extension of coastal bedrock and has most complex seafloor bathymetry compared to other parts of the shelf. Seafloor here is mostly composed of bedrock outcrops with depressions in-filled with finer sediments and overlaid with glacial features, such as retreat moraines. The outer boundary of the shelf is usually defined by 200 m isobath, which is a common delimiter between pelagic and bathyal domains. In reality it can occur deeper (e.g. 400 m in the mouth of Northeast channel) or be poorly defined altogether (e.g. parts of Western shelf). Using bathymetric contours in such situation may lead to inaccuracies estimated in tens of kilometers. Shelf break is well-defined morphologically and can be traced more precisely using high-resolution bathymetry. Campbell and Piper mapped shelf-edge sediments in producing a deep-water habitat map. Shelf break was defined by a steepest slope, and the transition was commonly marked by difference in sediment types, with prevalence of coarser material (e.g. glacial till, sand and gravel) above the break. The boundary between the middle and outer shelves is less clear - although the difference in morphology of these two is perceivable, the exact shape of the two is in the eyes of the beholder, but can be roughly defined by bathymetric gradients (Fig. 2.15).

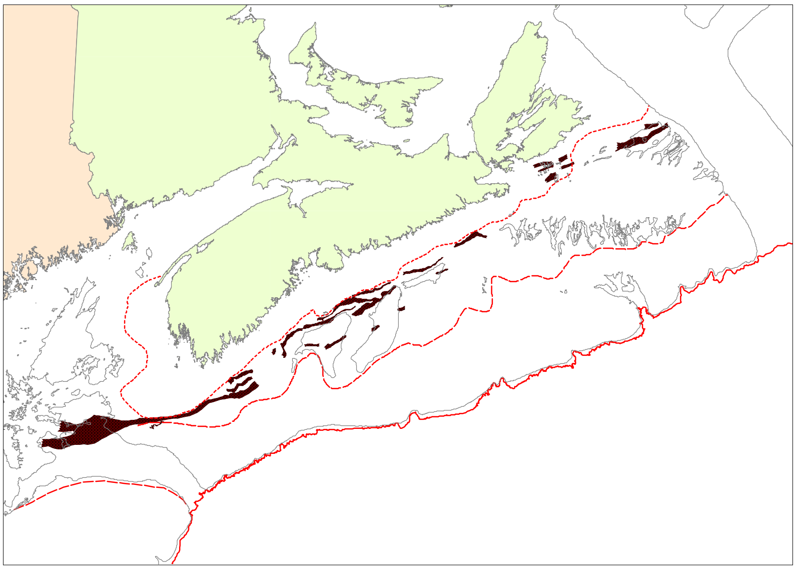


Fig. 2.15. Scotian shelf physiographic domains. A – inner shelf, defined by bedrock control; B – middle shelf, C – outer shelf. Shelf break is defined from multibeam bathymetry and sediment type interpretations. Dotted areas indicate locations of major glacial moraines.

Mezo-scale physiographic features, such as banks, basins, bank slopes, channels and gullies correspond better to our understanding of related processes. Bank slopes for example are often associated with oceanographic gradients, basins commonly have depositional environments, and canyons are assumed to serve as sediment transport pathways. These assumptions relate to likely, but not necessarily occurring processes. Additional problem is posed by the absence of distinct boundaries in many features. Bank boundaries for example are commonly drawn on the basis of an arbitrary isobath making the shape unrelated to the processes, which where the reason for defining the boundary in the first place.

I define physiographic features by tracing the sharpest bathymetric gradient. The example seabed slope map (Fig 2.16) shows all seabed gradients steeper than 0.5 degrees. The outlines of seabed features were constructed by tracing the steepest local slope. The map shows a number of bathymetric gradients dividing inner and outer parts of the shelf, outlining the shoreward slopes of the outer banks. Note that there is no clear definition of the separation between the outer banks. Because of the very smooth change in bathymetry the whole massif from Browns to Sable Island bank may be considered a single unit. Georges bank and Banquereau are the only outer banks that can be considered as separate units. Their boundaries are well defined by steep bathymetric gradients. The inner banks are defined better, such as Middle bank, Sambro bank, Misaine bank, etc. There is no clear separation between inner basins and western shelf slope, the pattern observed in oceanographic data as well. It is difficult to objectively distinguish banks from bank flanks and saddles and basins from intermediate areas as defined by Fader (personal communication).

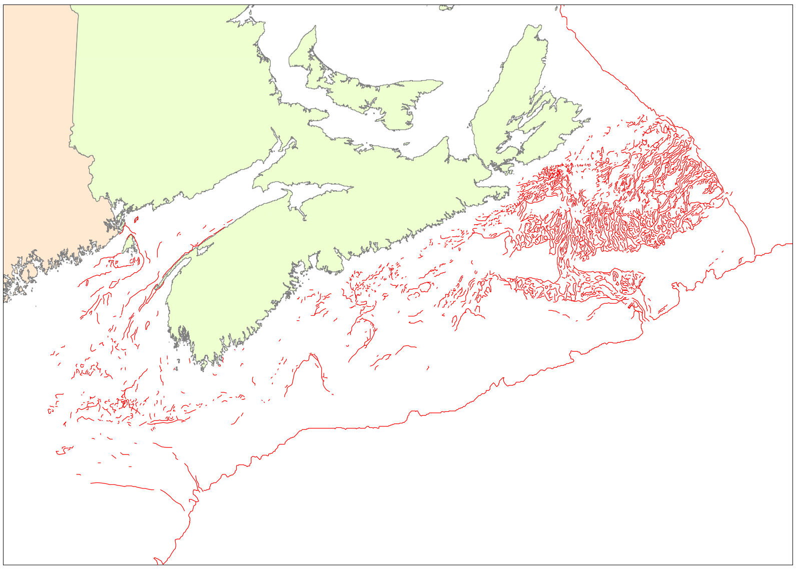


Fig 2.16. Tracing of seafloor slopes steeper than 0.5 degree, calculated from 3x3 neighborhoods using 500 m cell grid. Steep slopes in the near shore zone and on the shelf slope are not shown.

On a finer scale geological units and surficial sediment types may define community types of benthic fauna. These units may be nested within the higher hierarchy of features, and their distribution may be strongly related to the former, because of the similarity in morphogenetic processes.

Seabed texture

Within physiographic and morphological domains four scales of **Seabed texture** were recognized: topographic roughness, seabed complexity, particle roughness and biogenic structures. There is no clear and substantiated definition of spatial scales separating topographic roughness from seabed complexity and they are listed separately only for the compliance with initial characterization scheme.

Topographic roughness (broad scale)

Broad scale topographic complexity of seafloor may be related to dispersal, recruitment and diversity of benthic fauna. Bottom environments with highly variable bathymetry may influence vertical mixing, productivity patterns, and variability in habitat types, which in turn would lead to higher species diversity. Complex seabed topography may also interact with currents and affect sediment dynamics. The roughness index was measured by the 2nd derivative of water depth at a spatial scale of 1500 m, as a percent grade change of seabed slope. The general pattern shown on the resulting map is not very different from the slope map; however data errors in the bathymetry grid become more apparent (e.g. upper slope area, Fig 2.17). Because of the relatively low quality of the available bathymetric data the usefulness of second derivative of depth as a quantitative index of topographic roughness seems questionable.

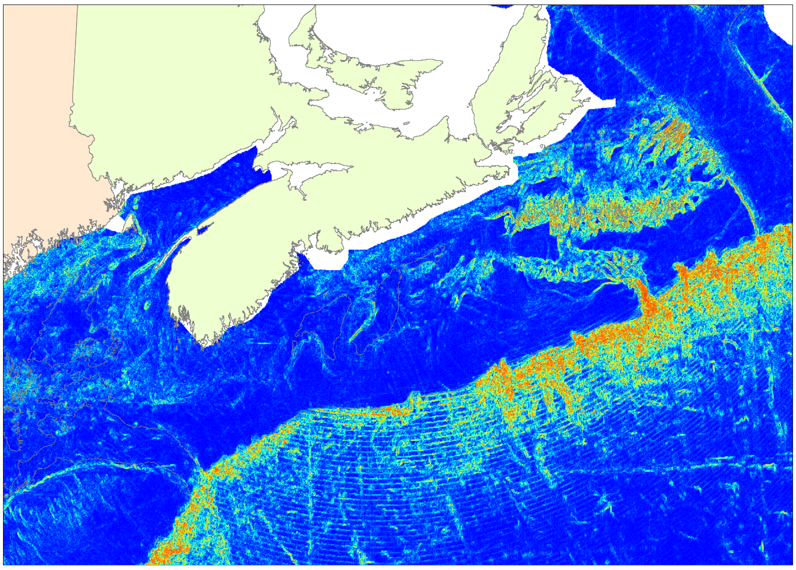


Fig 2.17. Second derivative of water depth. Calculations are based on 3x3 neighborhoods with 500 meters cells. Bathymetric data provided by G. Costello, CHS.

Seabed surface complexity (intermediate scale)

Topographically complex surfaces may contain more species due to increased habitat diversity or as a result of increased area per se, influencing community and population structure through effects on dispersal and survival of benthic invertebrates (e.g. Kostylev 1996). It was suggested initially (RAP Proceedings, 2002) that surficial complexity should be measured by the rugosity index or surface fractal dimension at a spatial scale of 100 – 1,000 m.

In order to adequately represent habitat structure the resolution of the data should correspond to the size of benthic organisms in question - centimeters rather than hundreds of meters. Presently there is not enough data to evaluate habitat complexity for the whole Scotia-Fundy area even at the initially suggested resolution. Multibeam mapping is seen as the only possible way to achieve accurate quantitative description of seabed complexity, and because continuous multibeam mapping of the shelf was not performed yet, habitat complexity can be mapped only locally where high-resolution data is available.

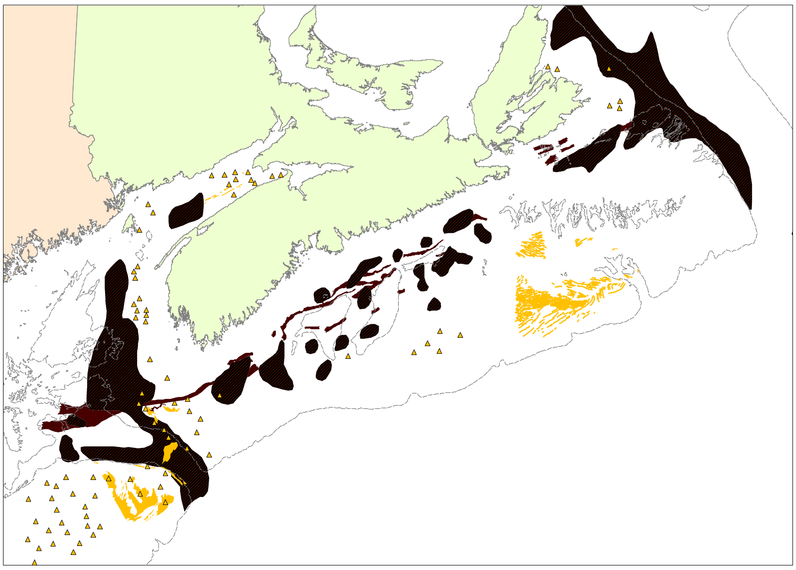


Fig 2.18. Distribution of major seabed features affecting surface complexity. Dotted polygons – moraines; dashed polygons – iceberg scoured seafloor; yellow polygons and lines – acoustically mapped bedforms; triangles – approximate location of other sand ridges and waves.

General patterns of surficial complexity can be inferred from geomorphological interpretations of seafloor (Fig. 2.18). Even though exact boundaries of large structures are defined with a positional uncertainty varying from meters to a few kilometers, they may be used for rough estimation of habitat type, complexity and dynamic properties of seabed.

Particle roughness (fine scale)

Continuous mapping of grain characteristics at a spatial scale of 10 – 1,000 cm is not available and can be performed only locally. Alternatively 10 – 1000 cm roughness can be qualitatively inferred from grain size and formation maps. High – resolution acoustic mapping of the whole study area and unrealistically high groundtruthing effort are required in order to map particle roughness with any confidence.

Bio-structural complexity

Attached seabed fauna, such as sponges, colonial polychaetes and corals can create secondary habitat structure on the seafloor, which is important for survival and recruitment of other marine organisms. This type of complexity is often related to the complexity of seafloor because coarse grained sediments and bedrock outcrops tend to provide suitable substrate for structure-forming fauna. Evaluation of the complexity of the secondary habitat may be carried out by systematic sampling and mapping of the occurrence of such features. Important biogenic habitat structures are known to exist on e.g. *Filograna* reefs on Georges bank (Collie et al., 2000), horse mussel beds in the Bay of Fundy (Wildish and Fader, 1998), abundant populations of Gorgonian corals North-East channel and Stone Fence *Lophelia* reefs (P. Mortensen, personal communication) (Fig. 2.19). However this class of habitat complexity is not considered in current mapping because of the following reasons: scarcity of data on distribution of structure-building benthic invertebrates and uncertainty in temporal persistence of these structures. The initial suggestion that bio-structural complexity should be measured as a ratio of mean element height to inter-element distance to a precision of 0.1 m at a spatial scale of 1-100 m requires stronger theoretical and practical backup.

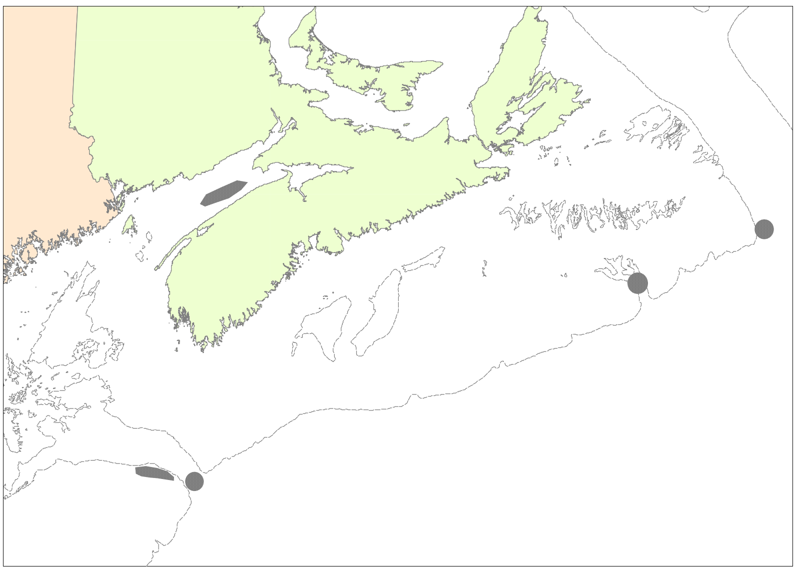


Fig. 2.19. Example locations of known biogenic structures which may have significance for bottom fauna.

Substratum types:

According to Fader (2002) the dominant controlling factors on sediment distribution and character were: 1) shelf wide glaciation which resulted in erosion and deposition of glacial materials, 2) lowering of sea levels to 110 m below present sea level, and 3) a final marine transgression of advancing beach processes to the present coastline. Banks, for example are created by glacial processes, but the current pattern of sand and gravel distribution is the result of post-glacial re-distribution of sediment by tides and waves. Glacial moraines may traverse different types of larger physiographic features, for example Fundian moraine which originates on the top of Browns bank and continues in the deeper waters of the Gulf of Maine. Thus, the initial proposal (RAP Proceedings 2002) to map substrate types as rock/gravel/sand and mud appears overly simplified.

Mapping of sedimentary units on Scotian Shelf was carried since 1962, based on acoustic and seismic surveys groundtrhuthed by sediment samples. As was shown by Fader (2002) the existing surficial sediment maps on the Scotian Shelf are very limited in their potential to be used for adequate management of seabed related activities because horizontal resolution of the maps, density of control and the precision and accuracy do not meet requirements of many user groups that require detailed seabed information. The use of multibeam bathymetry revolutionized seabed mapping providing high-resolution data on seabed shape and texture. This technology created great advantage for habitat mapping (Kostylev et al., 2001), allowing better understanding of organism-sediment relationships. However only minor fraction of Scotian shelf is mapped with multibeam and at present the best broad-scale sediment maps are the maps of sedimentary facies produced by L. King and G. Fader in 1970-ties (e.g. Fader et al., 1997) (Fig. 2.20). In addition to the limitations described earlier by Fader (2001) these maps may not be directly interpreted in terms of grain size or seabed texture.

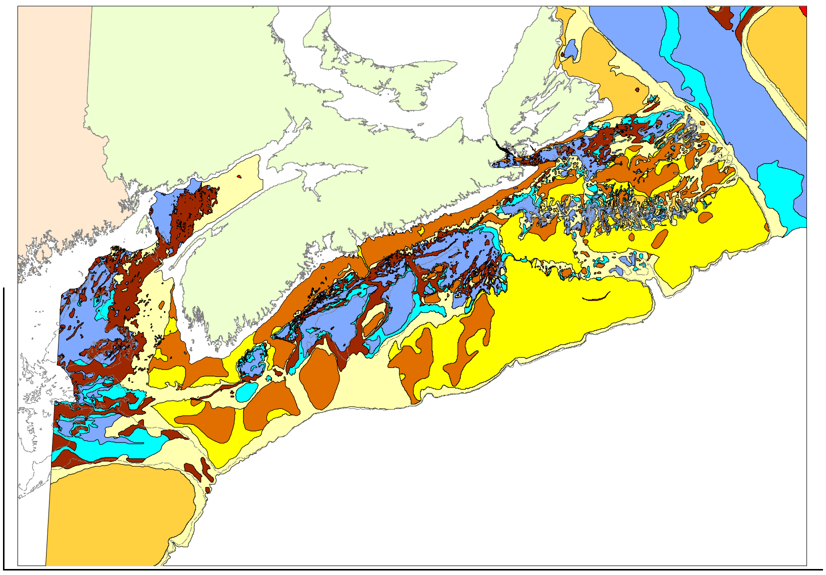


Fig 2.20. Surficial sedimentary facies on Scotian Shelf. NRCan official publication.

Grain size was mapped on the basis of 10000 sediment samples taken on Scotian shelf by NRCan and USGS. Mean grain sizes for the upper 10 cm of each sample were interpolated within similar sedimentary facies first, then the resulting interpolations were merged and spatially smoothed. This approach allowed to use acoustically verified boundaries between sedimentary formations while preserving patterns of grain size variability within them. The resulting grain size distribution map (Fig 2.21) is the first attempt to recreate a continuous sediment texture for the whole Scotia-Fundy area. Although initial quality control was carried on the sample database, further work is being carried by NRCan in order to verify validity of all samples. Additional texture descriptors suggested earlier (RAP Proceedings 2002) such as grain size skewness parameter, and cohesiveness are not available for all sampling locations and thus were not mapped. Cohesiveness may be assumed from the formation types (e.g. high for LaHave clay), but it is not possible to describe it quantitatively on a shelf scale.

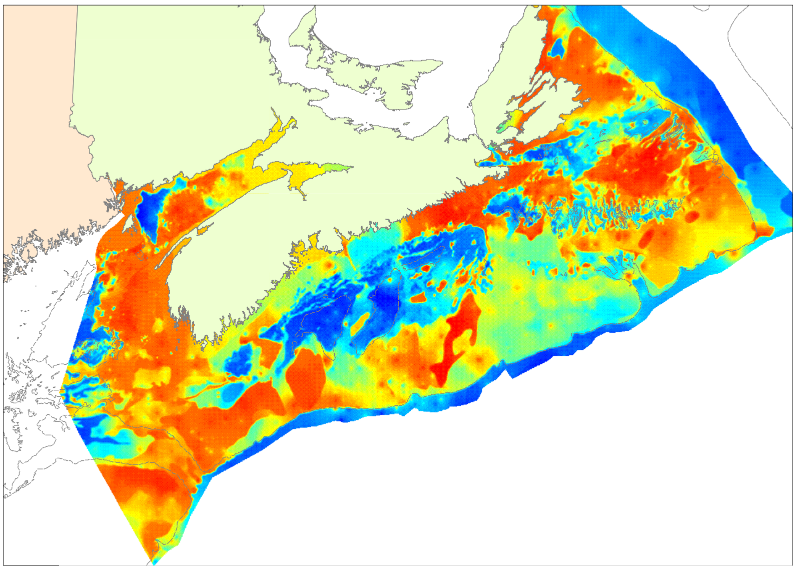


Fig 2.21. Grain size distribution for surficial sediments based on NRCan database of sediment samples and facies-constrained interpolation.

Red - coarse grained particles (e.g. gravel).

Blue – fine grained particles (e.g. mud).

Biological Communities

Benthic macro- and megafaunal assemblages as described from optical underwater observations and physical grab and dredge samples allow for synoptic description of animal-habitat associations on the seabed.

A number of datasets was analyzed for relationship with the above-mentioned habitat descriptors and with the proposed habitat template. Detailed results of the analyses will be presented at the RAP meeting. Only few results are shown in this document with the intent of provoking thought and discussion at the meeting. Description of the analysis and results for each of these datasets demands a separate extensive publication. The datasets were the following:

1) NRCan database of underwater photographs was transferred to digital media and supplemented by imagery from DFO expeditions.

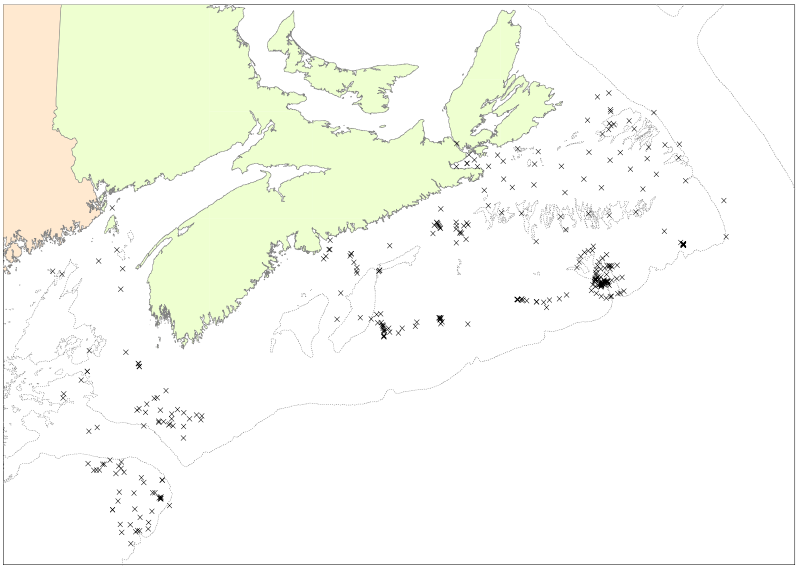


Fig. 2.22. Locations of photographic stations from NRCan and DFO archives used in the analysis of animal-habitat relationships.

The total of 350 unique sampling stations was summarized. Each photograph was analyzed for presence of benthic epifauna, and various features of seafloor structure (e.g. texture, habitat type, biogenic structures). For each station then habitat type, frequency of occurrence of taxa and average species richness was estimated. The data were used in multivariate analysis in order to define assemblages of species and their associations with habitat types. Life history traits and different descriptors of growth form - body shape, flexibility, mobility, hardness etc. are recorded for each taxon in the database for assisting interpretations of associations with habitat types. Even when detailed taxonomic identification of an organism was not possible, it could be distinguished as separate taxa by its shape, color and life habit, thus estimation of species richness is not taxonomically biased. Approximately 200 recurrent megabenthic taxa are described.

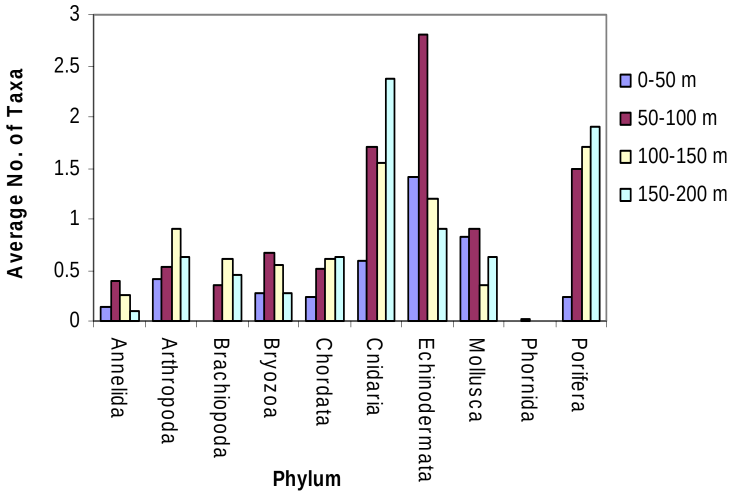


Fig. 2.23. Average number of taxa per observation at different water depths.

The restrictions of this dataset are that only megafauna (generally organisms larger that 1 cm) can be described, and taxonomic resolution for smaller organisms is low. The presence and composition of infauna can be deduced from burrows and surficial structures on the seafloor. However this is the only dataset which allows describing community composition, dominant megafaunal species and habitat type from direct observations and provides information on spatial context of benthic samples. There is also higher consistency in classification of observations and species descriptions in this dataset than in other datasets, because all of the taxonomic types are being recorded in a database of interpretations, such that any new observations can be compared to previously described taxa.

2) Database of benthic macrofaunal biomass based on grab and dredge samples (Stewart et al, 2001) was analysed for relationship with habitat type descriptors. The database was compiled from published and unpublished sources describing results of physical seabed sampling. Although the database provides area-normalized quantitative estimates of benthic biomass, different sampling tools and sorting techniques may bias the observations and affect subsequent interpretations of habitat – benthos relationship. The taxonomic information contained in the database is very limited (5 taxa) and not available for every station. Therefore only georeferenced data on benthic biomass from this database were used for the subsequent analysis (Fig. 2.24).

Distribution of biomasses obtained from the database is highly heterogeneous and sampling locations are distributed very patchily. In most cases benthic biomass on the shelf is within 100 g/m2 range, but in some cases can be estimated as high as 4000 g/m2 due to presence of large bivalve mollusks in the sample (e.g. *Modiolus modiolus* in the Bay of Fundy or *Spisula solidissima* on Banquereau bank). It is also likely that incorporation of data obtained with sampling tools of varying efficiency (e.g. Van Veen grab vs. hydraulic clam dredge) renders this data set unreliable as calibrated estimate of benthic biomass.

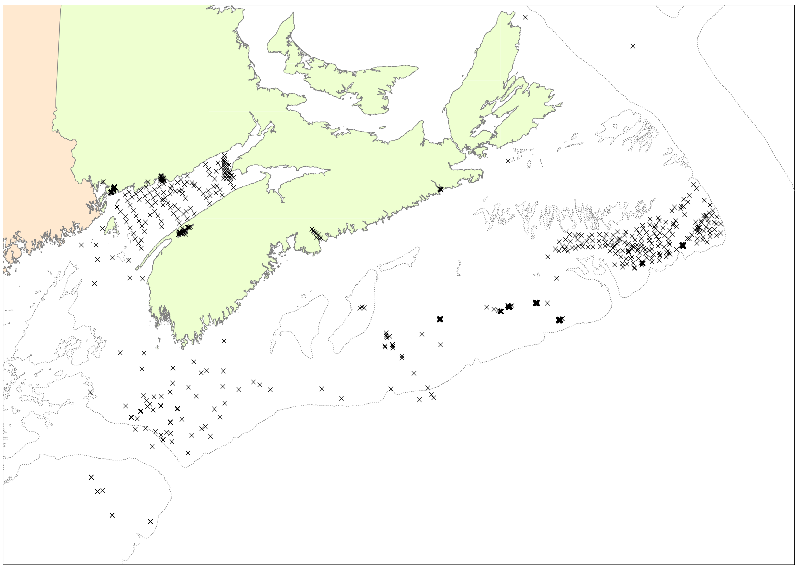


Fig. 2.24. Distribution of sampling locations for benthic biomass database (Stewart et al. 2001).

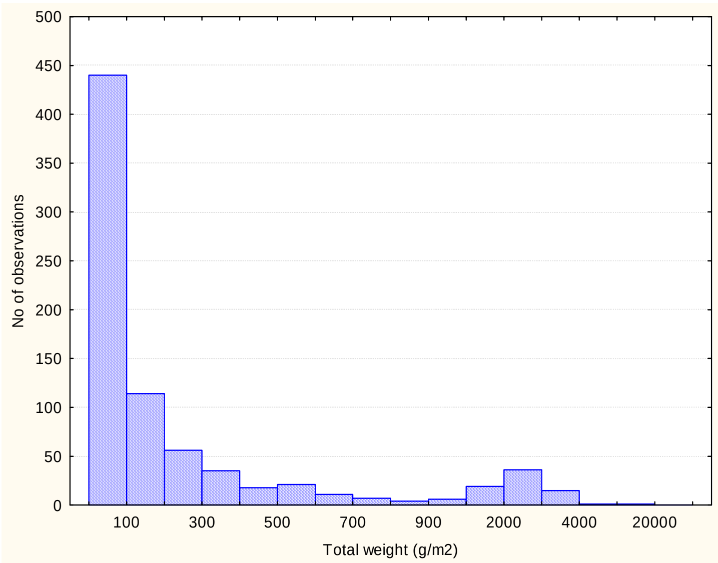


Fig. 2.25. Bimodal distribution of benthic biomass in the study area – different taxa or sampling tools?

DFO by-catch database: This information examines the Maritimes Science Virtual Data Center (VDC) scientific trawl survey database (Branton et al. 2003). Numerical abundance and biomass of by-catch species of benthic invertebrates was recalculated per square meter of areas trawled. The sampling covered a temporal period from July 1970 to July 2002. From a total of approximately 122,000 records constituting this data set 11798 records containing 78 invertebrate species, were extracted, which corresponded to 2297 spatially unique trawls. Distribution of abundance and biomass of separate species and total by-catch biomass per unique trawl were analysed in relation to environmental factors. The data were found unsuitable for community type analysis and biodiversity assessment because of the low number of different species in a trawl and low taxonomic resolution (e.g. umbrella descriptions of trawl contents like Asteroidea or Porifera). Observer variability may also have detrimental effect on taxonomic quality of the data.

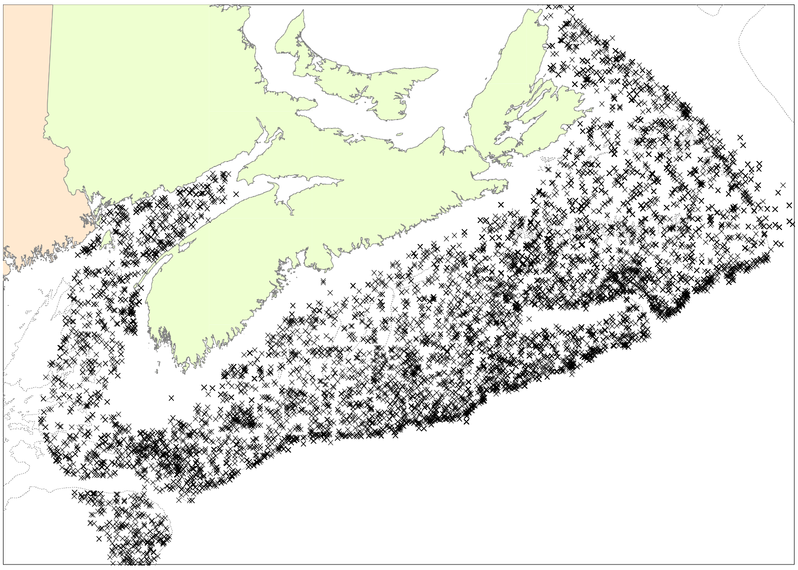


Fig. 2.26. DFO trawl survey database sampling locations (data provided by R. Brenton, Marine Fish Division).

Data on bycatch biomass were used in a number of univariate and multivariate analyses and compared to the results obtained from other data sets.

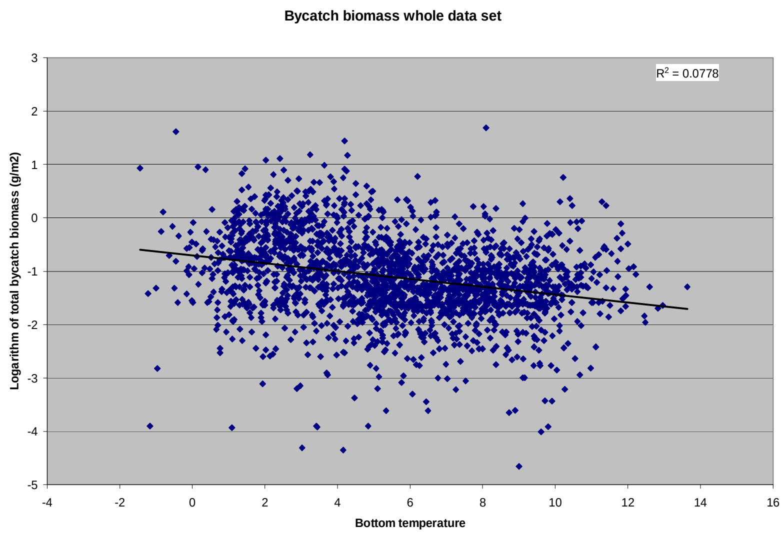


Fig. 2.27. Decrease of benthic bycatch biomass with average bottom temperature – effect of change in abundance or in body size? Low determination coefficient suggests that factors other than temperature may be more important in determining biomass distribution on Scotian shelf.

DFO groundfish survey data are also being analyzed in relation to benthic habitat structure (N. Schackell). Some of the results will be presented at the RAP meeting.

Maps of the distribution and abundance of benthic assemblages at shelf-scales, as well as maps of other organisms or characteristic assemblages at smaller scales will play key roles in testing and groundtruthing maps of benthic ecosystem types and the habitat template on the Scotian Shelf.

3. Modeling of habitat management template:

Disturbance:

Grime (1977) defined disturbance as mechanisms that limit the biomass by causing its destruction. Sousa (1984) defined it as a discrete punctuated killing, displacement or damaging of one or more individuals that directly creates an opportunity for new individuals to become established. Following Southwoods (1977) ideas on temporal stability I define disturbance in terms of temporal persistence of habitat structure. Disturbance may act through direct effects such as killing of benthic fauna or indirect effects - such as destruction of habitat through change in grain size, morphology of seafloor, sediment movement, etc. As described above, seabed currents and storms are major factors influencing stability of seabed structure. Benthic epifauna is more likely to suffer effects of disturbance than infauna. Posey et al. 1996 for example report that the strongest effect of a storm of a century off the northwest coast of Florida on shallow offshore benthic community was observed on surface-dwelling fauna (tube builders, juvenile bivalves, epifauna) with no significant effect on infauna. Examples of naturally disturbed environments on Scotian shelf are shallow bank tops with highly mobile sediments, where only mobile organisms are likely to persist (e.g. sand dollars, scallops, sea cucumbers).

Disturbance has strong effects on species' life history traits. With a reference to logistic equation of population growth, in a disturbed environments populations rarely reach carrying capacity (K), thus they are r-selected MacArthur and Wilson (1967) and likely to have fast population growth and high fluctuations in population size. Some testable traits for the disturbed vs undisturbed environment are the following:

	Stable	**Disturbed**
Mobility	Immobile-mobile	Mobile
Body form	Diverse	Streamlined – flattened
Body flexibility	Inflexible – flexible	Flexible
Attachment	None-firm	Firm
Potential for regeneration	Absent – present	Present

Modeling of seabed disturbance was based on the following factors: seabed grain size, tidal bottom currents, maximum significant wave heights and periods.

RMS from Hannah et al. circulation model was used as indicator of total energy of tidal currents affecting seafloor. The likelihood of sediment disturbance was calculated based on the empirical relationship between particle size and current strength needed to initiate sediment transport in cohesive sediments, from Hjulstrom diagram (Hjulstrom 1935). This model can serve as a general guide of a likelyhood of sediments being disturbed by tides. More detailed numeric modeling is required to acheicve accurate description of sediment transport. Erosional and depositional processes are not a linear function of current speed, but a result of complex interaction of the seafloor and moving water. The most mobile fraction of sediment is sand, which can be seen on the disturbance map. Re-suspension and transport of larger particles is limited by their mass and of the smaller particles - by viscosity, therefore cohesive fine sediments such as LaHave clay are less disturbed by currents. Seabed complexity and roughness may also affect erosinal and depositional processes non-liniarly. Detailed and continuous information on seabed structure is however lacking for the most of the shelf.

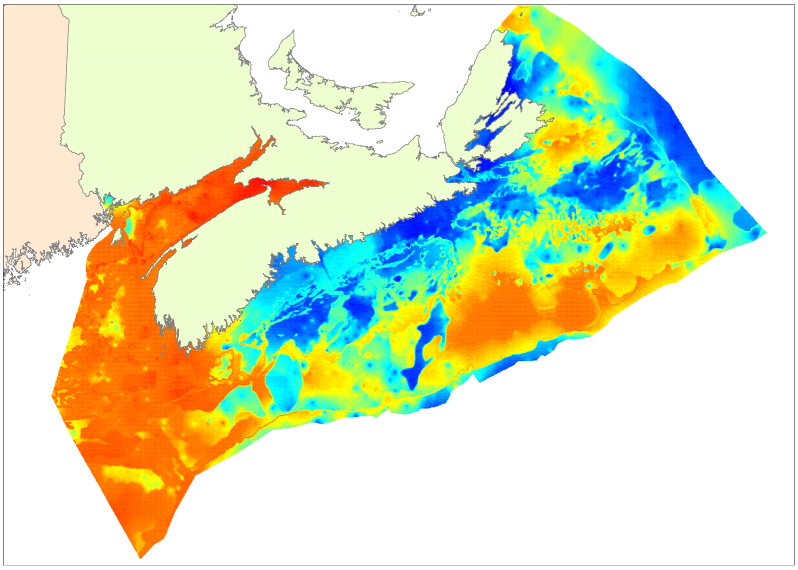


Fig. 3.1. Areas of seafloor where sediment transport is likely to be initiated by tidal currents, as a ratio of known RMS currents to critical current speed. Red areas are more likely to be disturbed that blue areas. Orange color indicates 1/1 ratio.

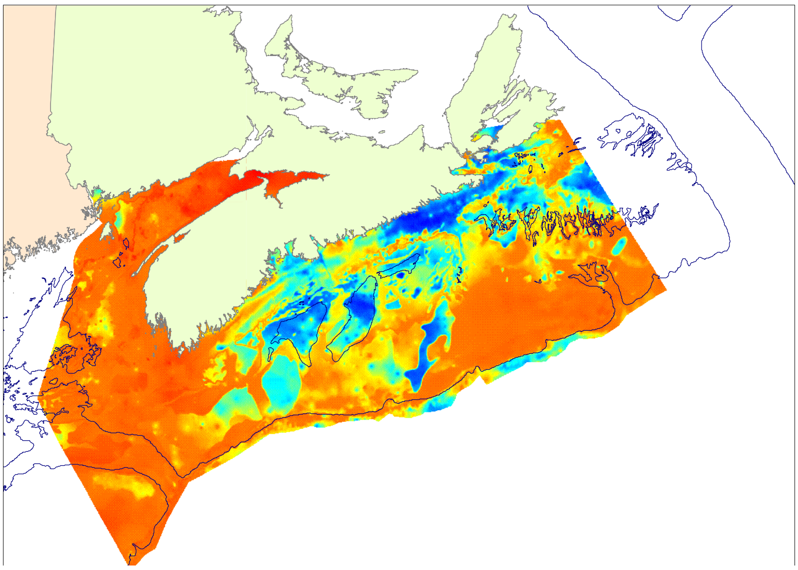


Fig. 3.2 Areas of seafloor where sediment transport is likely to be initiated by combination of tidal and circulation current, as a ratio of total current speed to critical. Orange color indicates 1/1 ratio.

When circulation modeling results for the whole shelf become available they will be incorporated in the sediment mobility analysis.

Storm waves can have a considerable effect of benthic environment. Their effect is strongly dampened by increasing water depth. Wave-generated currents can influence seafloor as deep as a half of their wave length. Wave-generated disturbance is different from the disturbance caused by tidal currents in it's spatial distribution and frequency. While tidal motion disturbs seafloor daily, large storms affect the shelf once in a few years. Relative strength of storm-generated current is shown on Fig. 3.3, based on the highest significant wave heights observed since 1951 (Swail et al 2000), and associated with them wave periods. It is assumed that the general pattern of wave-generated disturbance is similar. The calculation is based on the ratio of significant wave height to associated wave period with assumed constant wave number and water depth.

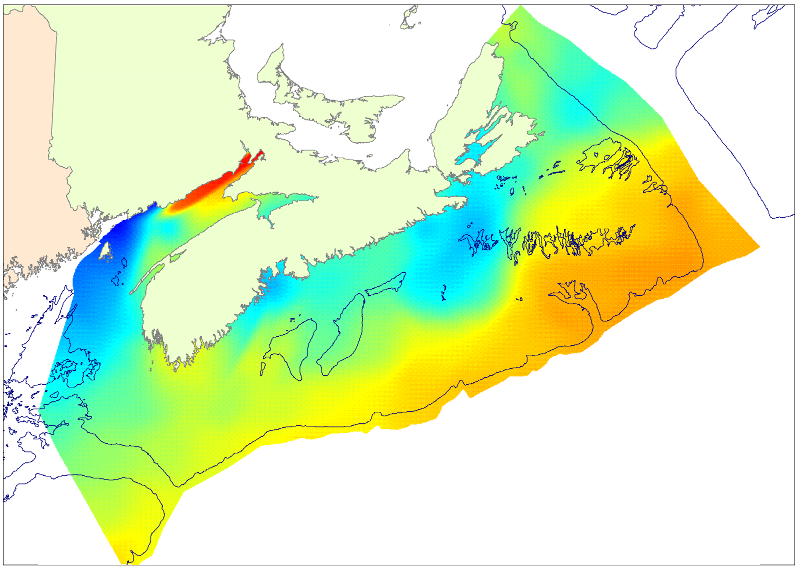


Fig. 3.3. Approximation of relative strengths of wave-generated currents. High values in the Bay of Fundy are an artifact of interpolation.

Disturbance modeling using SEDTRANS (Li and Amos 2001) is currently being carried out, in order to correctly describe wave- and current generated transport. Before physically realistic modeling of seabed disturbance by tide and storm generated currents is available, a number of generalized logical models can be applied and tested based on a likelihoods of disturbance caused by different forces. The following example map shows assumed seabed disturbance where tides to critical velocity ration, wave's ratio and reciprocal of bathymetry were normalized and averaged, giving equal weights to tides and bathymetry and half weight to wave patterns, because of their temporal variability. This simplistic model (Fig. 3.4) reflects assumptions that seabed is more likely to be disturbed if a) observed currents are stronger than critical velocities needed to initiate sediment transport, the wave energy is high, and it is shallow.

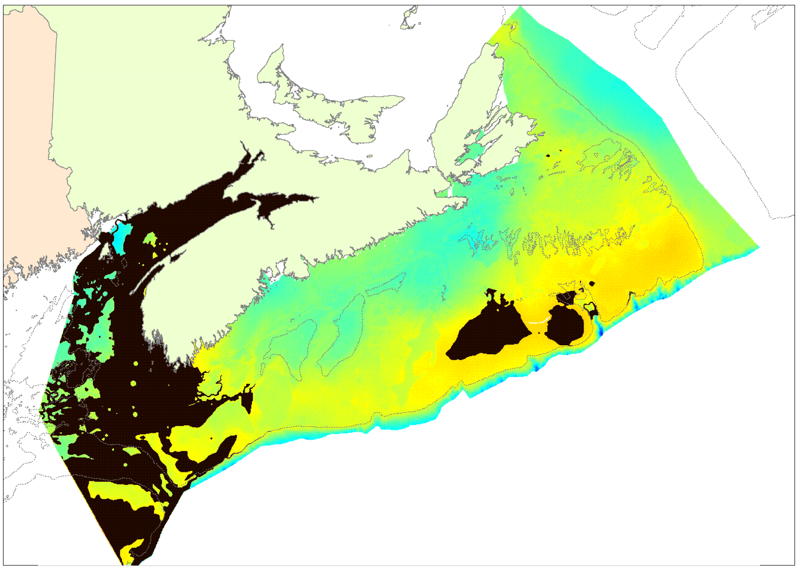


Fig. 3.4. Assumed generalized pattern of seabed disturbance by natural processes, giving equal weights to currents and water depth, and half weight to storms. Patterned areas show where sediment mobility may be initiated by tides only.

Adversity

Adverse conditions are such that pose a particular cost for the maintenance of normal protoplasmic homeostasis and the integrity, and normal functioning of membranes and enzymes (Southwood 1988). This habitat template axis was alternatively called by different authors “severity of the environment”, “habitat unfavorableness”, “growth rate”, “abiotic stress” or “resource level” (Townsend and Hildrew 1994). Overall the axis is negatively related to the amount of energy available for organism’s growth and positively related to energy spent on adaptation to severe environment, and is reciprocal of productivity (Southwood, 1988).

The assumptions behind adversity modeling were the following:

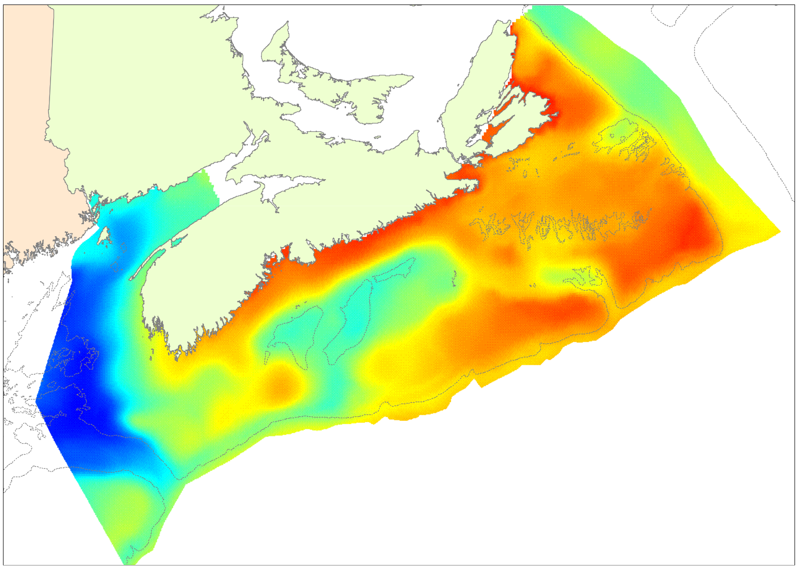
- High productivity (obtained from Chl-a concentration) in well mixed environment (from density stratification) create more favorable environment;
- Temperature relates to growth rate, with higher average temperatures being more favorable.
- Seasonal and interannual variability in bottom temperature are abiotic stressors, with higher variability leading to higher adversity
- Higher water salinity causes less osmotic stress in benthic fauna, with more saline waters being more favorable.

Two models are considered here: additive effects of favorable factors and limiting effects of adverse factors. The first model averages normalized (0-1) reciprocal values for favorable factors and normalized values for stress factors with an assumption that abiotic stress is the result of the sum of the considered processes. The limiting model is based on the theory that the factor which is in the least supply is limiting population growth and survival of the organisms. Because all input variables are scaled from 0 to 1 they serve as probabilities of the environment being favorable for benthos. Calculation of favorableness thus becomes a product, where the factor of least suitability will decrease the total favorableness stronger than in the first model.

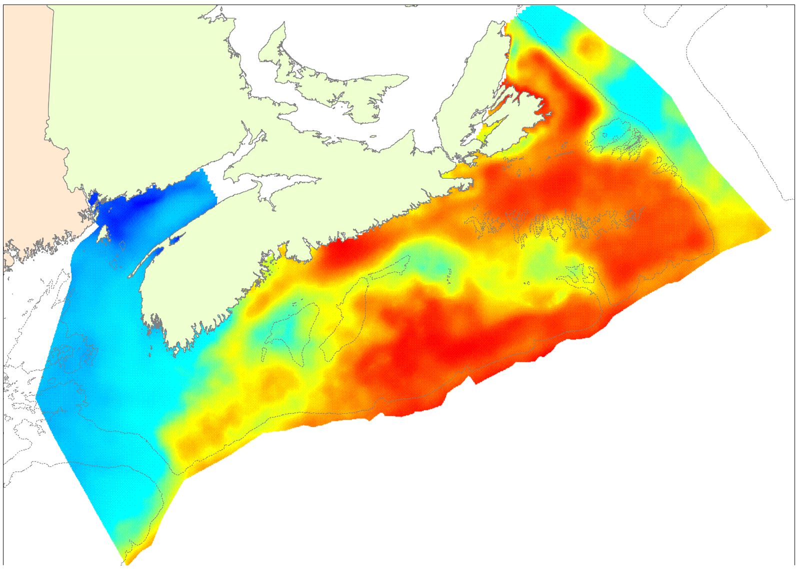
The resulting variable is dimensionless. Its spatial distribution (Fig. 3.5, 3.6) represents relative degree of adversity of environment, against which life history traits of benthic organisms and communities can be tested.

The adversity map based on limiting factors seems more valid theoretically. While the additive model (Fig. 3.5) shows mainly strong influence of salinity and temperature, the limiting model (Fig. 3.6) is also influenced by chlorophyll concentration and stratification. The quality of data included in both models is highly important for the validity of outputs. Relative importance of different variables has to be theoretically justified and discussed at the upcoming RAP meeting.

These models are oversimplifications of reality and are used to map the general understanding of the effects of environmental stressors and amount of primary production reaching sea floor. Quantitative oceanographic models are needed in order to better understand and map adversity axis of habitat template. Local benthic productivity studies (e.g. Hargrave et al., in press) will help to groundtruth this model.



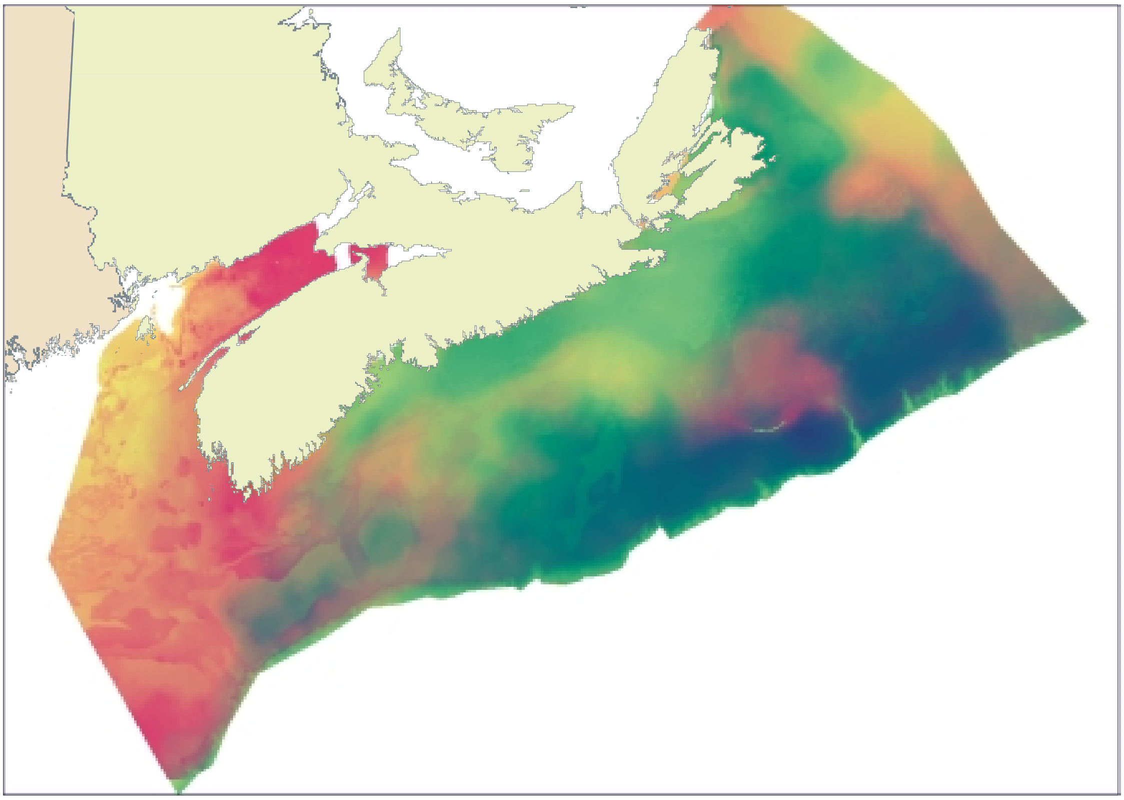
3.5. Additive model of habitat adversity. Red- high adversity, blue – low adversity.



3.6. Habitat adversity map based on assumption that any of the considered factors can be limiting, all factors are given equal weights. Red- high adversity, blue – low adversity.

Resulting habitat template:

Mapping of interaction of adversity and disturbance allows classification of the shelf in terms of habitat template. The following map shows continuous variability in both by mapping disturbance in increasing intensity of red color and adversity in increasing intensity of green color. Habitat template is painted with the same color palette for comparison. Subdivision of the shelf into four classes – stable benign, stable adverse, disturbed adverse and disturbed benign is possible, but not meaningful until clear reference values for disturbance and adversity are defined subdividing. Distribution of community types and life history traits of benthic invertebrates will be tested against this template.



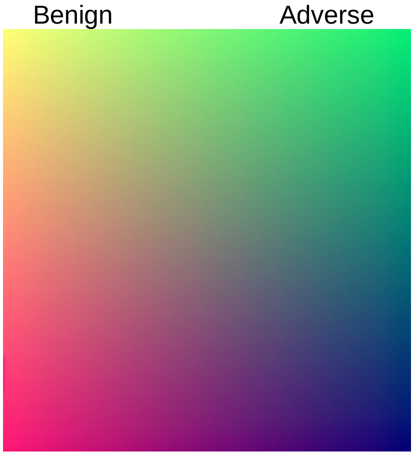


Fig. 3.7. Resulting habitat template applied to Scotian shelf.

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