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A geographically-based, ecosystem management strategy for the offshore regions of the Scotian Shelf / Bay of Fundy

Stratégie de gestion à référence spatiale des écosystèmes hauturiers du plateau néo-écossais et de la baie de Fundy

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ABSTRACT

An approach to an ecosystem-based management strategy for benthic ecosystems in the offshore Scotia/Fundy region is presented, which is based on multi-beam acoustics, bottom photography, and sediment mapping, groundtruthed by conventional benthic macrofaunal sampling to detect characteristic habitats and species richness. The overall management goal is to preserve benthic diversity throughout the region. The information will be used in the general model of Sala *et al.* (2002) to select a proportion of the total area of Scotia/Fundy to be allocated as marine reserves, where human activities will be limited. Geographic sub-divisions of offshore regions of the Scotian Shelf in Scotia/Fundy region, necessary for the process will be based on approximately forty *conservation planning areas* of unequal size, and *conservation planning units* (a total of 350 - 800 of unequal size). Choice of conservation planning units (both based on size and total number) will partly depend on an estimate of dispersal distances of larvae of benthic species. Because the proposed methods cannot be applied immediately, we offer some interim management guidelines designed to limit the effects of human activities, particularly benthic trawling, on benthic diversity in the offshore regions of Scotia/Fundy.

RÉSUMÉ

On présente une stratégie de gestion des écosystèmes benthiques hauturiers du plateau néo-écossais et de la baie de Fundy reposant sur des données de relevés acoustiques multifaisceaux, des photographies du fond et des cartes des sédiments, vérifiés sur place par un échantillonnage conventionnel de la macrofaune benthique, en vue d'identifier les parcelles d'habitat caractéristiques et la diversité des espèces. L'objectif de gestion global est de maintenir la diversité benthique dans toute la région. Les données recueillies seront intégrées au modèle général de Sala *et al.* (2002) pour établir un pourcentage de la superficie totale de la région qui sera désignée comme des réserves marines, où les activités anthropiques seront limitées. Les sous-divisions géographiques des eaux hauturières du plateau néo-écossais et de la baie de Fundy, nécessaires au processus, reposeront sur environ 40 *zones de planification aux fins de conservation* de superficie inégale et des *unités de planification aux fins de conservation* (350 - 800 unités de superficie inégale au total). Le choix des unités de planification aux fins de conservation (taille et nombre total) dépendra en partie d'une estimation des distances de dispersion des larves d'espèces benthiques. Étant donné que les méthodes proposées ne peuvent pas être appliquées immédiatement, on offre quelques lignes directrices préliminaires de gestion visant à limiter les effets des activités anthropiques, en particulier le chalutage dans le milieu benthique, sur la diversité de ce milieu dans les eaux hauturières du plateau néo-écossais et de la baie de Fundy.

INTRODUCTION

The Scotian Shelf and Bay of Fundy (Fig.1) include the continental shelf and coastal areas off Nova Scotia from northern Cape Breton Island and the Laurentian Channel to the Northeast Channel and including the southwest Nova Scotia shelf and macrotidal Bay of Fundy. The characteristics of the area are largely marine with estuarine influences in coastal areas and in the Bay of Fundy. Offshore, water characteristics are influenced by the outflow of the St. Lawrence River which results in a low salinity water mass which prevails over the eastern Scotian Shelf, while the principal freshwater input to the Bay of Fundy is from the Saint John River in New Brunswick, as well as other smaller sources in both New Brunswick and Nova Scotia which enter the Fundy basin. These areas encompass NAFO areas 4VWX and 5Y.

Management of the Scotian Shelf and Bay of Fundy falls under the Maritime Region of Fisheries and Oceans Canada. For management purposes we have divided Scotia/Fundy into near-shore (<50m contour) and offshore (> 50m contour) as shown in Fig.1. The marine ecosystem of the Scotia/Fundy region provides important services to Nova Scotians and New Brunswickers, a total of 944,765 and 756,652 individuals respectively (Statistics Canada, 2002) as well as to the people of the Gulf of Maine which Canada shares with the United States. The direct ecosystem services provided by the Scotian Shelf and Bay of Fundy to Maritimers are summarized as:

- A source of renewable biological and physical resources (e.g. commercial and recreational stocks of fish and invertebrates; potential for tidal or wind power extraction);
- A source of non-renewable raw materials (e.g. sand, aggregate, oil and gas);
- A reservoir for waste assimilation, inclusive of municipal and industrial wastes and dumping spoils from dredging;
- A means of transport for commercial and recreational purposes, with the consequent potential for pollution by oil spills and bilge water losses.
- Ecotourism, nature appreciation, human need to foster a notion of the free and unbounded ocean; importance of ‘charismatic species’ such as marine mammals.
- Identity of the population living near and working on the ocean.

Besides direct ecosystem services, there are many other, perhaps more important, indirect services contributed by the marine ecosystem, including climate control, and the ocean’s role in the hydrologic, carbon, and gaseous cycles. One characteristic of indirect ecosystem services is that they are difficult to value by current economic methods.

Managing human activities to balance the needs of various users and provide the above services based on ecosystem considerations is a challenge faced by DFO as a result of the implementation of *The Oceans Act*. The present RAP focuses on the benthos as an important component of the marine ecosystem of Scotia-Fundy. As a step in achieving the goal of ecosystem-based management of the benthos, the objective of this presentation is to provide answers to the following two questions related to the region’s benthic environment:

- What is the best way to measure the impacts of human activities on benthic habitats in the Scotian Shelf/Bay of Fundy?
- What guidelines and best practices can be used to manage human activities in the offshore regions of the Scotian Shelf/Bay of Fundy?

Human activities impacting the Scotian Shelf/Bay of Fundy

A wide range of human activities occur on the Scotian Shelf and in coastal areas (Table 1), summarized in several publications (Wilson and Addison 1984; Wells and Ralston 1991; Eaton *et al.* 1994; Stewart and White 2001). Most industrial activity is concentrated in coastal areas, although in both inshore and offshore, the relative intensity is highly localized, typically in major harbours around population centers. In the offshore, beyond the inshore zone defined by the 50 m contour, the major activities are: shipping, hydrocarbon exploration and development (including facilities and pipelines), commercial fishing, military activity, ocean disposal, and telecommunications (cables). Offshore aggregate extraction could occur on the Scotian Shelf in future; however the area affected is likely to be relatively small due to the logistics and the huge quantities available (for example, estimates for the North Sea indicated 0.03 % of the area was affected in 1986 and most was concentrated in coastal waters (de Groot 1996). Submarine cables also occupy a negligible percentage of the area of the offshore and their impact involves spatial conflicts with other human activities such as fishing and the hydrocarbon industry, and not habitat disturbance *per se* (Coffen-Smout and Herbert 2000). In 2000 there were six active cables as well as numerous inactive ones on the Scotian Shelf some with potential fishing exclusion zones of 1 km on each side. All the current activities with the exception of commercial fishing and offshore hydrocarbon development have relatively minor to negligible impact on benthic environments.

The offshore petroleum industry occupies a small footprint with its production facilities, pipelines, exploratory, development and production drilling almost exclusively in the offshore of the Scotian Shelf, although the potential to access nearshore reserves such as Sydney Bight and the western Gulf of St. Lawrence continues to be present. Exploration of reservoirs using seismic surveys covers a larger area, although it is likely that it will remain a relatively small proportion of the shelf as a whole. Seismic surveys are not usually repeated in a given area, or if so, only in small multiples of occasions separated by periods of one or more years. Since 1967, 194 wells have been drilled on the Scotian Shelf in support of exploration, development or production (Fig.2) (CNSOPB, Directory of Wells, 2003). Production facilities have been operated on Sable Island Bank at Cohasset Panuke for condensates by Encana Resources, and the Sable Offshore Energy Project (SOEP) currently has three platforms—Thebaud, Venture and North Triumph—producing natural gas. Three more (South Venture, Alma and Glenelg) are soon to be added in the second tier of the SOEP development. A further natural gas project, Encana's Deep Panuke Project, will probably be initiated in the near future southwest of Sable Island. The SOEP project includes a pipeline to shore, and the Deep Panuke development will also involve a pipeline, nearly parallel to the SOEP Pipeline. Several longshelf pipelines have been proposed (e.g. the El Paso Blue Atlantic pipeline). Drilling activity and construction and development activities associated with offshore production result in a range of impacts, from seabed disturbance, to drilling and operational and accidental releases of fluids and solids, and pipeline trenching, to routine discharges of produced water containing low concentrations of hydrocarbons and contaminants. On the Scotian Shelf as a whole, the area potentially influenced by oil and gas development and production is small, probably less than <0.5 % of the Scotian Shelf deeper than 50 m, although accidents such as blowouts and major spills would increase the areas affected.

An estimate of the area of hydrocarbon production facilities on the offshore Scotian Shelf is 0.2% and for wellsites is 0.4 % assuming an area of influence of 1 km around all facilities and operations and the offshore area of the Scotian Shelf seaward of the 50 m inshore contour is

162,420 km^2 (Fig.2). Estimate includes: Sable Offshore Energy Project (275 km^2, assuming a 1 km corridor for 265 km of pipelines, plus 1 km radius around each of three production facilities). Cohasset-Panuke facilities (no longer operating) and 500 m exclusion zone, 50 km^2. Exploratory, production and development wells (194) with an estimated 1 km radius around each, account for 610 km^2. Even assuming that the equivalent activity takes place in the future, the area is relatively small, though not insignificant.

The offshore hydrocarbon industry can have a wide range of effects on benthic communities, discussed in the review of Neff *et al.* (1989). The effects relate to releases such as drilling muds and fluids, and produced water during hydrocarbon production and development. Substrate changes may result also from fouling material sloughed off facility structures (Montagna et al. 2002). Multivariate analysis of community changes as well as benthic community diversity, using measures such as the Shannon-Wiener diversity index, have been used to monitor the impact of well sites and production platforms on benthic fauna (e.g. Olsgard and Gray 1995; Reiersen *et al.* 1989; Davies *et al.* 1989). Releases of mud and cuttings which settle on the seabed or move in flocculated form over the seabed, have the potential to smother benthic organisms in the immediate vicinity or impair feeding activity (Cranford and Gordon 1991; Gordon *et al.* 2000), and together with produced water releases, can lead to accumulation of contaminants in tissues, a particular concern with bottom dwelling resource species such as sea scallops. Pipeline servicing operations may require trenching and cause consequent damage to the seabed, while uncovered pipelines can develop fouling communities, and under certain conditions may heat or cool the seabed.

Commercial fishing activity impacts the largest area of the seabed of the Scotian Shelf at depths greater than 50 m. In the North Sea, fishing activity affected some 53% of the seabed (deGroot 1996). The main fisheries with the potential for impacting the seabed are trawl fisheries for groundfish; dragger fisheries for scallop on Western-Sable Island Bank (DFO 2001), and Browns and German Banks (DFO 1997); Arctic surf clam (Gilkinson *et al.* 2003; Roddick and Smith 1999; Roddick 1996), and shrimp fisheries prosecuted in several basins on the Eastern Scotian Shelf (DFO 2002; P. Koeller personal communication). Groundfish trawl fisheries in the offshore have been carried out widely on the Scotian Shelf although not on the bank tops and increasingly restricted to the shelf edge in recent years (Kulka and Pitcher 2001). Total areas impacted on the Scotian Shelf have not been measured, but on the Atlantic Shelf including the Scotian Shelf and Gulf of St. Lawrence, trawling grounds have occupied from 8 – 38% of the shelf area, with lower values occurring in recent years after declines of the groundfish stocks (Kulka and Pitcher 2001). Within fishing grounds, the most intensely fished areas amount to only a few per cent of the area of the Atlantic Shelf: <5 % for the total area (Kulka and Pitcher 2001). The area most consistently and intensely fished in the 1980-2001 period was on the Outer Scotian Shelf (Fig.3).

Hydraulic harvesting for Arctic surfclam on Banquereau Bank disturbs several hundred km^2 of the seabed annually; in 1995, 231 km^2 and potentially more were fished, comparable to the estimate of area potentially influenced by hydrocarbon production facilities and pipeline operations (Roddick 1996). As a percentage of the Scotian Shelf offshore region, surf clam harvesting in 1995 amounted to 0.14%, but it represented approximately 2 % of Banquereau. If the surf clam beds themselves are considered a rare habitat or resource on the Scotian Shelf, however, fishing activity is affecting most of it.

The northern shrimp fishery takes place using trawl gear in several small basins off Eastern Nova Scotia, and potentially could occupy a large area of the habitat, although analyses are not available to indicate the overall area of bottom covered annually or during the course of the fishery.

Trawling for groundfish typically with otter trawl gear can result in disturbance to the seabed although in some environments long-term impacts may not necessarily occur (Messieh *et al* 1991; Rowell *et al.* 1997; Kenchington *et al.* 2001; Schwinghamer *et al.* 1998; Gilkinson *et al.* 1998; Prena *et al.* 1999; Gordon *et al.* 2002; Morgan & Chuenpagadee, 2002). Damage results from the components of the gear, including the doors, the bridles/groundwarp and footgear of the net (Gavaris and Black, MS 2002). Continued fishing along the Scotian Shelf edge has resulted in significant damage to some communities of deep-water corals. Scallop dragging disturbs the upper few centimeters of the seabed (Murawski and Serchuk 1989), and leads to mortality of the target species. Scallop beds which had been dragged differed in associations of invertebrates and some natural associations ceased to occur in dragged areas (Langton and Robinson 1990). Hydraulic harvesting of surf clams on the Scotian Shelf results in changes in seabed topography due to dredge furrows and changes surface characteristics and the burrow density of non-target clam species did not recover (Gilkinson *et al.* 2003).

Methods to detect impacts of human uses on ecosystem services

In general, human uses of the marine ecosystem affect the direct services it provides in two ways:

- the contamination of seafood resources by human activity affects their utilization as food; and
- human industrial or recreational activity may impact the functional and structural components of the marine ecosystem and hence the direct services that it provides.

In this presentation we are concerned only with the latter of these, that is assessing impacts on the marine ecosystem.

A central problem in developing environmental monitoring tools is to distinguish between natural impoverishing events and resultant communities, and those that are caused by anthropogenic effects (Wildish & Kristmanson, 1997). Examples of natural impoverishment variables include salinity, organic enrichment, tidal velocity and wave activity. A good example is the effect of wave activity on benthic secondary production given in the review by Emerson (1989).

Five scientific goals of monitoring methods can be distinguished to detect the impacts of human uses on marine ecosystem services (Table 2). Four of these goals are associated with scientific hypotheses, and only one—practical monitoring—is designed specifically to give input to trigger management responses. In the Scotia/Fundy offshore, our focus will be assessment or monitoring of the spatial component or geographic goal (#3 in Table 2), with an emphasis on determining the area of impact.

Specific benthic monitoring methods are summarized in Table 3 and show that conventional sampling, including point-sampling with grab and corer (macrofaunal species and abundance analysis, sediment profile imaging, and sediment geochemistry, in Table 3), are well-established. The remaining methods are newer (aerial/satellite imagery, benthic video, and acoustic mapping) and best at sampling at the geographic spatial scale, although the meaning of their outputs are less well understood. For example, although potentially useful, multibeam acoustics has not yet been adequately ground-truthed by conventional methods, for example, to distinuish the full range of characteristic benthic habitats. The operational usefulness of many conventional benthic sampling methods is also determined by the type of substrate that is present (Fig.4), so that an otherwise superior method is replaced by an inferior one (e.g. grab sampling replaced by U/W photography on hard substrates). Since the work of Rowe *et al*. (1975) it has been realized that the pelagos and benthos are intimately linked and consequently in a comprehensive monitoring program it is necessary to consider both the benthos and the water column.

Management Approach

Review of Classifcation Schemes and Choice of Management Model

The Sala *et al.* (2002) general model for selecting marine reserves and determining their size is an example of a model which might be applied to dealing with the management of human activities and impacts on the Scotian Shelf ecosystem. The model divides an ecosystem into geographic units, in each of which constraints such as critical habitats, human activities such as fishing, etc., can be balanced and modeled using automated computer optimization techniques. The general model approach requires a large number of moderately-sized units. Hence this approach dictates the type of geographic classification which is appropriate. The idea of setting aside some areas having special ecological attributes (i.e. rare) is an accepted conservation principle in maintaining overall diversity; some areas and ecosystems cannot continue to be special or would be lost if they are exposed to human activities. So the idea of setting aside some areas is essential in an overall ecosystem-based management strategy. Possible alternative methods for choosing reserves are based on single species, by population viability analysis, or island biogeographic theory (Possingham *et al.* 2002). Such methods are neither ecosystem-based nor applicable in the benthic environment.

The first phase of this RAP process summarized a number of potential management divisions for the Scotian Shelf, including NAFO zones; oceanographic domains (northeastern, southeastern, central, and western Scotian Shelf, shelf edge and Gulf of Maine, Georges Bank and Bay of Fundy) etc. The ongoing efforts to develop classification schemes by V. Kostylev (and presented in this workshop) and the updated benthic and pelagic seascapes approach of the World Wildlife Fund, were reviewed for their potential to provide suitable conservation planning areas. The classification systems consulted are described briefly below:

Natural History of Nova Scotia—The offshore classification developed for the Natural History of Nova Scotia (Davis and Browne 1997; Davis *et al.*1994) provides a classification framework based on physiography of the shelf (King and Fader 1986). The classification divides the Scotian Shelf into inner, middle and outer shelf and subdivides it into several types of features, including banks, basins, and intervening areas including saddles and channels, and bank edges where submarine canyons such as The Gully occur, and the continental slope. It covers the entire Scotian Shelf but has a single classification for the inner shelf (shoreward of the 100 m contour) on the Atlantic coast of Nova Scotia; and single classification for the Bay of Fundy and Sydney Bight. Most of the banks on the Scotian Shelf and in the Gulf of Maine are included as entities in the classification scheme.

NRCan Classification—The model developed by Dr. V. Kostylev is an objective classification approach using both physical and biological parameters (e.g. primary productivity) of both the water column (e.g. mean tidal velocity, water temperature, variation in temperature, depth) and the seabed (e.g. sediment median grain size, sorting). Parameters are chosen to reflect their relative impact on communities in terms of a model developed by Southwood (1977), which classifies benthic communities into four states according to a combination of environmental factors, and to the physical substrate on which they occur. The "states" can be either adverse (e.g. wide temperature fluctuation both seasonally and in short term, high tendency for disturbance by waves and currents, poor or unreliable food supply) or benign (e.g. fairly stable temperatures, reliable food supply); while the substrate can be either stable in terms of movement or being fixed in space (e.g. exposed bedrock, coarse gravel, rock faces, which are all conducive to the occurrence of epifaunal communities, or stable in terms of cohesive sediments such as muds). Non-stable substrates, such as mobile sands form the second 'Unstable' category in the classification scheme. This approach has allowed the mapping of the four types of communities, which are borne out by ground-truthing (Fig.5).

We determined that these groupings were not useful as conservation planning areas (see discussion below for an explanation of conservation planning areas) for the Sala et al. (2002) general model. This is in part because they are multidimensional and it is difficult to relate them to tangible features, although they probably can be used in indicating potentially significant features. There are also too few of them to be conservation planning areas. They may be utilized to indicate environmental features, e.g. ocean climate, in conservation planning areas.

WWF Classification—The World Wildlife Fund has developed a classification of 'marine natural regions' and subregions called 'seascapes' for marine environments, and used it in a case study on the Scotian Shelf as part of its efforts to develop a system of marine protected areas (Day and Roff, 2000; Hussein and Roff, 2003). It is an extension of an approach to landscapes successfully used in terrestrial ecosystems. Like the NRCan model, it is an objective classification based on inputs of information known to be relevant to biological organisms, including sediment type, water temperature, and depth. Some features it includes are: temperature regimes (3 levels); benthic temperature (3); depth segregation (3 ranges for the Scotian Shelf); mixing and wave exposure; relief (three categories of slope); and sediments (five types). The combination of these features results in 'natural regions' defined based on climatic zone, and types respectively of the pelagic and benthic communities based on depth. Seascapes are basically stable, recurrent or predictable features in time and space, that occur within natural regions.

We could not, however, see how the regions and seascapes could provide the basis of conservation planning units for the shelf, because some of the major regions were spread out over large areas of the shelf (for example Region 8 extended from the Laurentian Channel to the Bay of Fundy), and the regions themselves were large (only 9 natural regions were defined). Further, the boundaries of the regions in general (as they are for the NRCan classification) are likely to be 'fuzzy' or have a high margin of error associated with their definition, and the newer (Hussein and Roff 2003) iteration has a comparatively low resolution (9 km squares). Some of the regions (e.g. the slope and some of the bank and basin units which were clearly associated with depth contours) may have been suitable, however. The WWF regions and 'seascapes', like the NRCan classification, could be used as attributes to describe the conservation planning areas.

To illustrate how the Sala *et al.* (2002) approach could be used, we chose conservation planning areas based on the survey strata used by DFO in summer groundfish research surveys. This proved to be the most practical in terms of demonstrating the management approach that we adopted, recognizing that other, more suitable, conservation planning divisions may be decided upon in future. The DFO strata (Fig.6) are based on geographic and physiographic considerations, principally dividing the Scotian Shelf into units based on geographic features such as banks, basins, and intervening areas, and subdividing if necessary for statistical and other reasons. The advantages are:

- that the system divided the majority of the shelf, including most of the Bay of Fundy (note that the inner shelf shallower than 100 m; the Inner Bay of Fundy bays including Minas Basin and Cobequid Bay; a zone around Sable Island; and the continental slope are not included);
- the number of conservation planning areas was approximately correct for the model;
- it is an existing zoning scheme, and consequently there is historic data (specifically groundfish catch and bycatch) and understanding of the areas;
- the units are smaller than some of the major features (e.g. Bay of Fundy, Sable Island Bank); and
- it includes 'natural' units such as banks and basins which also have an historic basis; the latter point also means that it relates closely to a widely-accepted classification scheme developed for the Scotian Shelf in the *Natural History of Nova Scotia.*

Conservation Planning Areas and Conservation Planning Units

In this presentation a *conservation planning unit* (CPU) is an arbitrary division of a larger *conservation planning area* (CPA). In Sala *et al.* (2003) the CPU were ~250 km^2, and to achieve this figure in Scotia/Fundy (Table 4), a large number of units would need to be created. Connectivity between various sizes of benthic patches, which are determined by benthic larval dispersibility characteristics (Sala *et al,* 2002), can determine the optimum patch size. In the absence of this information, an arbitrary, more practical choice based on ~350 conservation planning units throughout the Scotia/Fundy area, means that each would be ~553 km^2 in size (approximately 20 km by 25 km, assuming that all are of the same size). Each of the CPAs can be divided initially into a rectangular grid containing CPUs of approximately these dimensions (Figs 7a and b), but the CPA could also be subdivided by stratifying the conservation planning units based on depth. For the sample areas of Sable Island Bank shown in Fig.7b, each of the CPUs is assessed using available tools to determine the habitat types present, with the aid of multi-beam acoustics, and groundtuthed with benthic grab sampling to determine species richness. CPUs would be the basis for individual sampling and monitoring.

Managing the offshore Scotian Shelf/Bay of Fundy by maintaining benthic macrofaunal diversity: a proposal

We propose that benthic macrofaunal diversity be used as an indicator of ecosystem conditions, and that approaches towards regulating various human activities should focus on maintaining it. Faunal diversity, and, in particular, species richness, are integrated measures of community status. There is both a hierarchy of diversity, low to high, of benthic communities within natural communities, reflecting physical stress, type of substrate, food availability etc., as well as within particular habitats exposed to anthropogenic stress such as organic loading and various other forms of pollution. For example, communities in natural environments exposed to high physical stress such as surf zones and exposed rocky shorelines, which have high wave energy, rapid temperature fluctuations and dessication, support relatively few, well-adapted species compared to more stable communities. Human activity can introduce different types of stress which act to change diversity in particular communities. In a given environment, characteristically high diversity is associated with an unaltered ecosystem, and maintenance at the same level should ensure that ecosystem services are maintained (e.g. trophic support for groundfisheries production). The strategy proposed here is to use benthic macrofauna as a surrogate for an optimally functioning marine environment. Diversity is a tool or indicator to help identify important areas and assist in management, not an end in itself. Changes in diversity thus merely provide an indication of changes which may or may not be linked to changes in human impact. Within CPUs on the Scotian Shelf, diversity will be used in conjunction with hierarchical levels of biophysical classifications of the whole of the Scotia/Fundy conservation planning area (i.e. habitats or basic physical/biological units which may be repeated throughout the area of concern), and the more arbitrary consevation and planning areas and units, proposed in the management process. All would be mapped by multi-beam acoustic methods and groundtruthed by conventional benthic methods. Some attempts to do this within the region have been made. Thus, in part of the upper Bay of Fundy, in the “sand-with-bioherms” province (Wildish et al,1998), horse mussel reefs have been delimited. A more comprehensive study of all of Brown's Bank (Kostylev *et al.,* 2001) described seven habitats based on megafauna and sediment characteristics: shallow water sand, deep water sand, soft coral, and sea cucumber, scallop, *Terebratulina* (brachiopods), and deposit feeder communities. Various habitats which have been described in Scotia-Fundy are summarized in Table 6. It is proposed that classification of habitats must depend on all of the important species in the community, including infauna, and not just the megafauna. Our justification for this is that only a relatively small proportion of macrofaunal species are represented in the species list by megafauna (~ 15% according to Kostylev *et al.,* 2001), and that important ecosystem services may be overlooked if infauna are excluded.

Conventional benthic sampling could be used, and we suggest that the grab sampling for groundtruthing be standardized to an area sampled and sieve mesh size, and macrofaunal species and abundance be determined individually for each replicate grab. Replicate grab samples, taken from precisely positioned locations (Wildish *et al.* in press b), could be used to determine species richness/area curves, followed by predicting the equilibrium species number as in Wildish et al. (1989 and see Gray, 1997; 2002).

The general model of Sala *et al.* (2002), which we propose to use, allows the design of networks of marine reserves (= selected CPUs) in the Scotia/Fundy region as conservation areas where human activities will be limited. The use of mathematical methods for selecting marine reserves is discussed more fully in Possingham *et al.* (2002) and Leslie *et al* (in press). The approach will allow designation of the number of conservation planning units necessary to maintain benthic biodiversity in this area. Input information for the model is presented in Table 5. The choice as to where the reserves will be located is informed by the presence/absence of rare habitats, and if no rare habitats are present, the choice can be made on the basis of reducing conflicts with other activities and uses of the environment, such as commercial fishing.

Although the model could be used predictively in the Scotia-Fundy offshore, very little of the input information described in Table 5 is readily available from local sources (see Stewart *et al*. 1999, 2001). For instance there is no accepted list of the full range of habitats present in either the Bay of Fundy or the Scotian Shelf. A preliminary list of habitats, incorporating previously published work, is presented in Table 6. There is also no existing estimate of the relative rarity or commoness of habitats in Scotia/Fundy, or of species richness estimates based on replicate sampling within the habitat. The goals adopted for the percentage of a conservation planning area or unit to be protected, will depend on whether or not rare habitats are present. Sala *et al.* (2002) gave the 6 common habitats 20% protection and the 2 rare ones 100% protection, but this is an arbitrary choice by the manager.

These guidelines (Table 5) can be modified as further knowledge accumulates and our understanding of patch dynamics in the benthic environment increases. An important consideration is in determining the dispersal distances that benthic larvae will travel, since this is input data for the model and is used in optimizing the allocation of habitats, particularly for species which are of localized distribution. Since marine benthic larval dispersion is largely passive, the critical data required for determining their dispersibility are time spent in the plankton, and hydrodynamic conditions. Some species of macrofauna are non-dispersive and have no larval stage. Lecithotropic larvae (common in many bryozoans and ascidians) may spend only a few hours in the plankton; whereas some planktotrophic larvae spend up to 2 years there. Planktotrophic larvae are equipped to feed in the plankton, in both pre- and post-competent stages (e.g. sand dollars and some bivalves), before settling to a substrate (Wildish & Kristmanson,1997). Craft & Sacco (2003) have shown in *Spartina* marshes that colonization by macrofauna in a newly created marsh is more rapid by species which have a larval dispersive stage than by those which don’t have one. Estimates of dispersiblity will initially need to be focussed on rare habitats in an attempt to determine the larval connectivity required between isolated rare patches.

Discussion

The purpose here is to offer advice concerning the two questions highlighted in the Introduction.

What is the best way to measure human impacts?

The answer will depend on whether the impact occurs in the nearshore or offshore regions of Scotia/Fundy. Because of the multiplicity of competing human uses in the nearshore, all of the conventional point source (inclusive of benthic and seawater sampling) and geographic survey methods will need to be applied. This is because of the multiplicity of impacts to be expected from loss of habitat due to a range of activities in nearshore areas such as resource extraction, fishing, marine transport and ocean disposal as well as organic enrichment from municipal sewage and industrial and aquaculture sources causing eutrophication. Gray (1997), in a wide-ranging review, shows that losses of marine biodiversity are highest in coastal areas.

In the offshore, where a more limited range of human perturbations affect the ecosystem, and because of their nature (trawling impacts, resource extraction and pipe-laying and drilling and related activities in the hydrocarbon industry), it should be possible to manage effectively by geographic sampling methods only, as outlined in the previous section. Here the fundamental goal is the maintenance of benthic macrofaunal diversity within the conservation planning area of concern.

Although sidescan methods can help to visualize the trawling marks and area affected by trawling (e.g. Roddick and Smith,1999), acoustic methods have not yet been developed to measure trawling impacts on sediments and benthic communities. Nevertheless, it may be possible to estimate the geographic extent of trawling impacts from available sources of information gathered by DFO (Kulka & Pitcher, 2001; Gavaris & Black, 2002). There are concerns that the DFO data may be insufficient for some forms of trawling and incomplete for parts of the region. Obviously, it would be of considerable management value to have a contemporary map of trawling impacts to overlay on an existing benthic habitat map. Although managing activities may be possible on the basis of the general location of fishing activity, the degree of impact of trawling on benthic communities will depend on the number and timing of repeated trawlings in the same area. Its effects in soft sediments will be similar to wind stress effects on shallow sublittoral environments (Emerson *et al.* 1989)—causing a reduction in species diversity and limiting benthic secondary production.

What guidelines and best practices should there be for managing human activities in the Scotia/Fundy offshore?

Ultimately, a wide range of actions will be applied to managing human activities in the Scotian Shelf offshore. Measures should be science-based and achieved through extensive consultation with the sectors utilizing the resource. An example of guidelines which have been proposed by Morgan and Chuenpagdee (2003) for one sector are shown in Table 7, in this case aimed at limiting area of seabed trawled by the groundfishery. Other guidelines can be proposed to manage other sectors such as the offshore hydrocarbon industry. In terms of our proposal, the guidelines and practices should be developed to *maintain* benthic diversity, as an indicator of ecosystem health.
For the future we recommend taking steps towards determining marine benthic diversity and distribution of habitat on the Scotian Shelf and in the Bay of Fundy, and to gather input information needed to run general models, such as that proposed by Sala et al. (2002) for objectively designing a system of allocating and assigning levels of protection to conservation planning areas throughout Scotia/Fundy (see Table 5). The obvious approach, although it is impractical because of its sheer scale, is to map the entire Scotian Shelf using multibeam acoustics with groundtruthing through bottom photographs and benthic samples. A more practical approach would be to select sample areas from all major regions (e.g. all banks, basins, saddles, sediment types, etc.) of the shelf and carry out reconnaissance studies, to develop a regional understanding of processes and distribution of communities.This has been begun already, with multibeam/benthic habitat studies carried out on Browns Bank, Georges

Bank, and recently on the northeastern Scotian Shelf. The surficial sediment and benthic community types identified in such studies could then be sampled using conventional benthic samplers to determine benthic diversity. Regional studies could be extrapolated, although to a limited degree, to areas not surveyed, at least until further studies are completed.

The two primary goals of this research would be to provide a comprehensive habitat description of the whole area with estimates of species richness for each habitat. In addition, several locations sampled for benthic species richness could become long-term reference locations, which could also act as "benthic reference conditions" for these offshore habitats. Such locations need to be established, and re-located, with sufficient accuracy to ensure they sample a consistent substrate type (e.g. sand waves, lag gravel). Precise positioning (e.g. such as a Trackpoint system and multibeacon mounted near the grab sampler, see McKeown *et al* (in prep). can be a useful tool in relocating sites, but a camera system capable of allowing selection of individual bottom types would also be an asset. In addition, multiple grab samples could be made at a given site, suitably located, with retention of only the samples of the desired substrate.

A separate research project on larval dispersibility, which might concentrate initially on rare habitats with the aim of determining typical dispersion distances of the dominant or functionally important species, should also be carried out. Much early marine biological work was done on the topic of larval stages of benthic invertebrates because of its zoogeographic significance (e.g. Thorson 1936) and may be relevant to the Scotian Shelf, whose benthic fauna contains many elements in common with the northeastern North Atlantic. A collaborative project involving a larval biologist and a physical oceanographer would have the best chance of success. Lockwood *et al* (2002) have suggested that an isolated reserve needs to be two times greater in area than the mean larval dispersal distance; hence a knowledge of larval dispersal distances in Scotia/Fundy would inform the choice of conservation planning unit size.

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Table 1. Human activities which impact the marine ecosystem of the Scotia/Fundy region. The coastal zone extends to a depth of 50m.

Activity	**Effect**	**Coastal Zone**	**Offshore**
RESOURCE INDUSTRIES			
Aquaculture	Species introductions; ecosystem imbalance.	●	
	Organic loading, antibiotics, ecological effects.	●	
Agriculture	Siltation, pesticides/ herbicides, nutrients in runoff, toxic algal blooms.	●	
Commercial Fishing	Impacts of trawling; ghost nets; marine debris.	●	●
	Ecosystem imbalance.	●	●
Forestry	Siltation, pesticides, herbicides, nutrients.	●	
Hydrocarbon Exploration and Development	Seismic Surveys	●	●
	Oil and Gas Pipelines (Installation, fouling, thermal and noise pollution, habitat creation)	●	●
	Exploration Drilling	●	●
	Production Platforms, Facilities and Associated Infrastructure	●	●
	Accidental spills of chemicals and drilling fluids, wastewater, produced water.	●	●
Mineral Exploration and Development	Coal Mining (coastal infrastructure, coal dust, runoff and leachate)	●	
	Sand and gravel extraction (potential)	●	●
	Tailings and waste rock , acid mine drainage.	●	
OTHER ACTIVITIES & CONCERNS			
Communications	Submarine cables	●	●
Shipping and Transportation	Marine Vessel Traffic (e.g. tankers, fishing vessels, offshore support vessels), Noise, Marine Mammal Collisions	●	●
	Ballast and Bilge Water Release, Invasive Species	●	●
	Marine Debris	●	●
	Accidents, wrecks etc.	●	●
	Navigation (buoys, moorings)	●	
Dredging	Maintenance dredging of harbours and ports	●	
Ocean Disposal	Disposal of dredge spoil, fish waste, artificial reefs.	●	
Activity	Effect	Coastal Zone	Offshore

Table 1 (continued).

Activity	Effect	Coastal Zone	Offshore
Industrial Releases	Pulp and Paper discharges (organic loading, low level effluent contamination)	●	
	Offshore Oil and Gas (accidental spills of chemicals and drilling fluids, wastewater, produced water)		●
	Mining and Smelting	●	
	Thermal Power Generation (heated effluents)	●	
	Fish Processing (organic loading, oil and grease, BOD)	●	
	Marine Vessel Maintenance (e.g. paints, oil and grease, dust)	●	
Infrastructure Construction and Operation	Oil and Gas Pipelines (Installation, fouling, thermal and noise pollution, habitat creation)	●	●
	Hydrocarbon Production Platforms, Facilities and Associated Infrastructure		●
	Coastal Intakes and Outfalls	●	
	Wharves, Piers, Jetties, Marine Terminals, chemicals in paints and treatments.	●	
	Construction activities, infilling of coastal areas, suspended sediments.	●	
	Navigation (buoys, moorings)	●	
	Aquaculture (buoys, net pens, moorings)	●	
Electricity Generation	Thermal Power Generation (thermal effluents, coastal facilities, intakes and outfall, contaminants (e.g. PAHs and metals) in ash, leachates and dust)	●	
	Nuclear Power Generation (radionuclides in dust and effluents; cooling water)	●	
Oil Refining	Coastal facilities, intakes and outfalls; submarine pipelines, marine terminals.	●	
	Various chemical contaminants		
	Accidental releases.	●	
Non-Point Source Pollution	Siltation, hydrocarbons, metals, pesticides, industrial chemicals in runoff, dust and air.	●	
Urban Releases	Urban runoff (hydrocarbons, metals, pesticides, contemporary chemicals in runoff, dust and air).	●	
	Sewage (organic loading, pathogens, radionuclides, metals, organic contaminants).	●	
	Accidental hydrocarbon releases.	●	
Military	Debris, wrecks and ordinance, Vessel Maintenance; Training activities and testing; Submarine operations; Seabed infrastructure for acoustic networks.	●	●
Climate Change	Extreme weather, erosion, temperature regime changes in the marine environment,	●	●
	Coastal warming and toxic algal blooms.	●	

Table 2. Monitoring goals used in detecting human use impacts on marine ecosystem services (From Wildish et al, In prep. a).

Goals	Effect measured	Associated hypothesis
1. Site comparison	Difference between treatment/reference sites	H_0 reference = treatment site H_1 reference ≠ treatment site
2. Temporal	Before/after status	H_0 reference = treatment at t_0 H_1 reference ≠ treatment at t_1
3. Geographical	Limits of impact	H_0 reference condition throughout the study area H_1 reference and impacted area delimited within the study area
4. Source identification	Determines the effect source	H_0 reference = treatment source H_1 reference ≠ treatment source
5. Practical	Determines a relative impact	None, it triggers remediation or other management activity

Table 3. Benthic monitoring methods for detecting the impacts of human use on ecosystem services. Based on Wildish et al (2004). Goals as in Table 1. Speed of sampling is indicated and relative development of each method by asterisks. Plus or minus signs indicate the suitability of each method for each goal. One asterisk indicates technology is at an early development stage, and three asterisks, mature development and common use by the scientific community.

Method	Area per unit time Km^2h^{-1}	Goal 1	Goal 2	Goal 3	Goal 5
Macrofaunal species x abundance matrices	0.003	+ ***	+ ***	- **	- **
Sediment profile imaging (SPI)	0.001	+ ***	+ **	- **	+ **
Sediment geochemistry (Eh plus $S^=$)	0.003	+ ***	+ **	- **	+ **
Aerial/satellite photography (littoral)	10	+ *	+ *	+ *	-
Benthic video photography (sublittoral)	0.2	+ *	+ *	+ *	+ *
Acoustic mapping (sublittoral)	0.8 - 10	+ *	+ *	+ *	+ *

Table 4. Determination of the number of conservation planning units (CPU) per conservation planning area (CPA) based on a CPU area of 250 km^2 and assuming that CPA's are of the same size within each location

Location	Area Km^2	CPU	CPA	CPU/ CPA
Bay of Fundy	5504	22	6	4
Scotian Shelf	180300	721	34	21

Table 5. Input information required to run the general model for marine reserve designation according to Sala *et al* (2002).

Input #	Description
1	Habitat description Name, Area, Rare/Common, Species Richness estimates
2	Setting goals for the percentage area to be protected e.g. common habitats - 20%, rare habitats - 100%
3	Estimate of the benthic larval dispersibility
4	Designation of CPU's as reserves

Table 6. Preliminary list of possible offshore habitats in Scotia/Fundy and characterization of habitat rarity or commononeness. Based on (Kostylev *et al.* 2000 *;* Kostylev 2002; sediment types from surficial geology mapping, NRCan Atlantic).

Habitat	Sub-Classification	Sub-types	Common /Rare	#
Mud	Homogeneous (e.g. pelagic silts and clays, submarine canyons continental slope and abyssal areas)	1.Gorgonian coral protruding from mud with ridges and valleys, deep water, The Gully, *Lima* sp, stalked crinoids, solitary hydroids, brittlestars and amphipod colonie[2].	**C**	1
	Heterogeneous (gravel/sand/silt/ clay mixtures)	Predominantly clay (La Have Clay);	C	2
		Predominantly silt (Emerald Silt)	C	3
		Sandy silt, 130-410 m in The Gully, burrowing anemones, shrimp, krill, Ophiura brittlestar[2]. Silty sand to glacial till, tributary canyons, *Bathysyphon, Amphioplus* brittlestar, soft coral, anemones sponges and sea pens, The Gully, 200-600 m^2.		
	Exposed gravel/rock debris, bedrock on above.		C	4
Sand and Gravel	Heterogeneous Sand and Gravel (Sable Island Sand)	Predominantly Sand (Sable Island Sand) Predominates on Sable Island Bank.	C	5
		Predominantly Gravel. Predominates on middle shelf Banks.	C	6
	Homogeneous Sand	1. Thick Sand, Sand on Gravel, Shallow, Browns Bank[1] (Kostylev *et al.* 2000); 2.Thick Sand, Sand on Gravel, Deep, Browns Bank[1] (Kostylev *et al.* 2000), 3.Fine to Medium Sand (Sambro Sand). Occurs on flanks of banks. 4.Sand, 50-300 m, The Gully, sand dollar, *Ophiura sarsi* brittlestar, crabs, burrowing anemones[2].	C	7
	Exposed gravel/rock debris found on above.		C	8

Table 6 (continued).

Habitat	Sub-Classification	Sub-types	Common /Rare	#
	Heterogeneous Gravel	1.Gravel lag and gravel lag with thin sand (coral and sea cucumber habitat, Browns Bank) [1]; 2.Gravel lag and gravel lag with thin sand (sea scallop habitat, Browns Bank) [1]; 3.Silt on Gravel lag and gravel lag with thin sand (deposit feeder habitat, Browns Bank) [1]. 4. Gravelly bottom 250-650 m in The Gully, with *Ophiopholis* brittlestars, anemones, sponges and crinoids, slope water[2]. 6. Gravelly with sponges, tunicates, bryozoans, and hydroids, winnowed till (lag gravel), The Gully , 100-500m[2].		
Bedrock/ Boulders		Bouldery gravel lag with thin sand, brachiopod community, Browns Bank and The Gully (100-500 m)[1, 2].	C	9
Rock Walls		Deepwater brittlestar (*Ophiomusium),* and corals (The Gully)[2].	R	10
			C	11
Shell Beds				
Biological Habitats	Bioherms		C	12
	Mollusc Beds		C	13
	Coral Associations		R	14
			R	15

Table 7. An example of guidelines for management of trawling activity (from Morgan and Chuenpagdee 2003).

1. Change fishing practices from trawling to alternative methods which are less harmful to benthic habitats.
2. Concentrate trawling effort in specified trawling lanes.
3. Limit areas which can be trawled to <60% of the total area of a conservation planning area.
4. Only permit new areas to be trawled if it can be demonstrated that rare habitats are absent there.

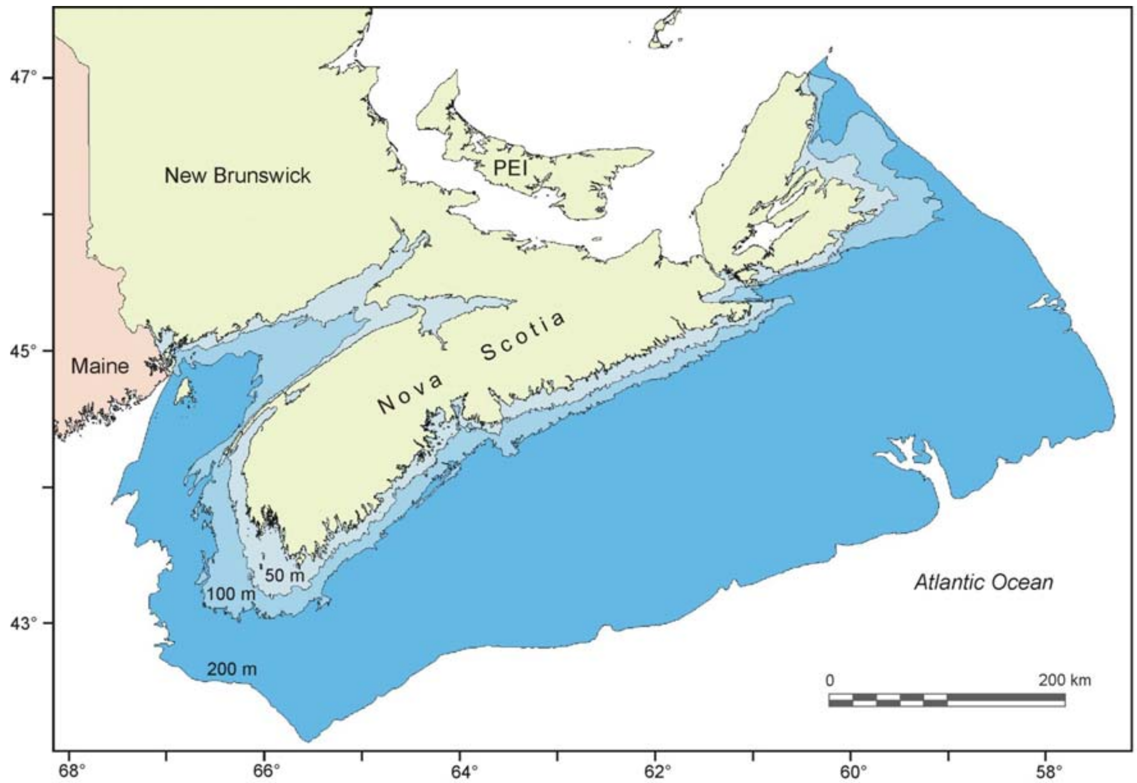

Figure 1. Map of the Scotian Shelf, showing the continental shelf, and 50 and 100 m contours.

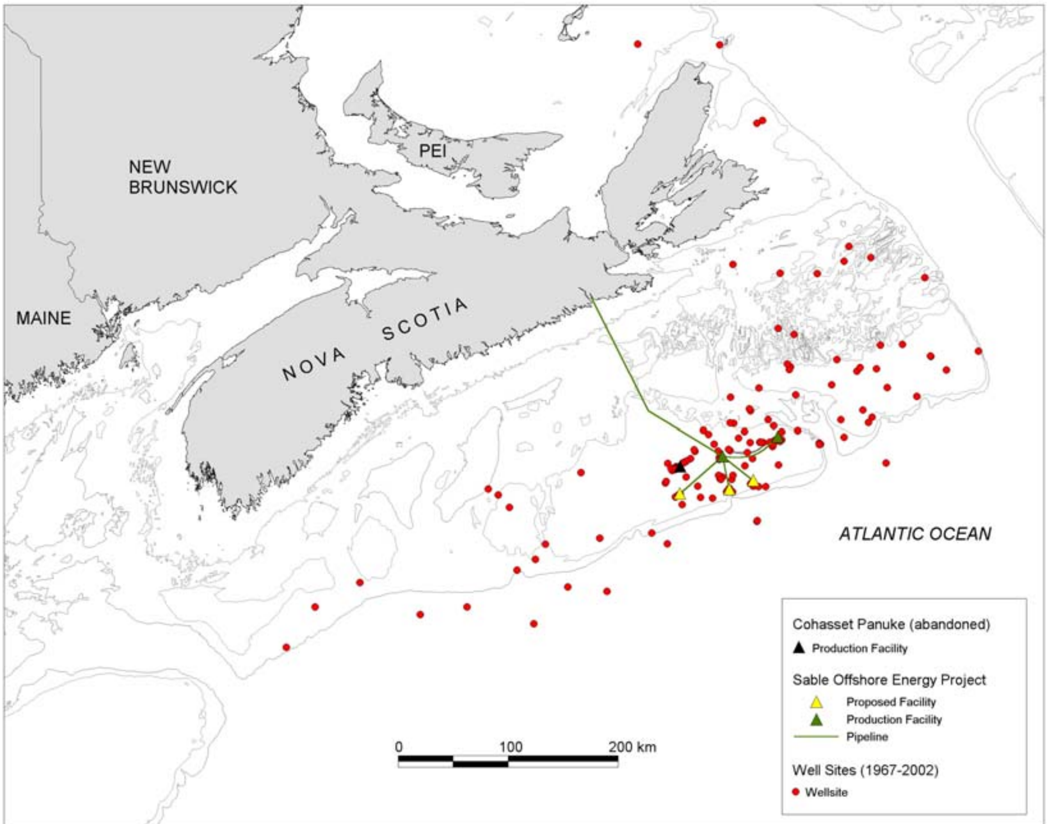

Figure 2. Locations of wellsites and hydrocarbon production infrastructure on the Scotian Shelf.

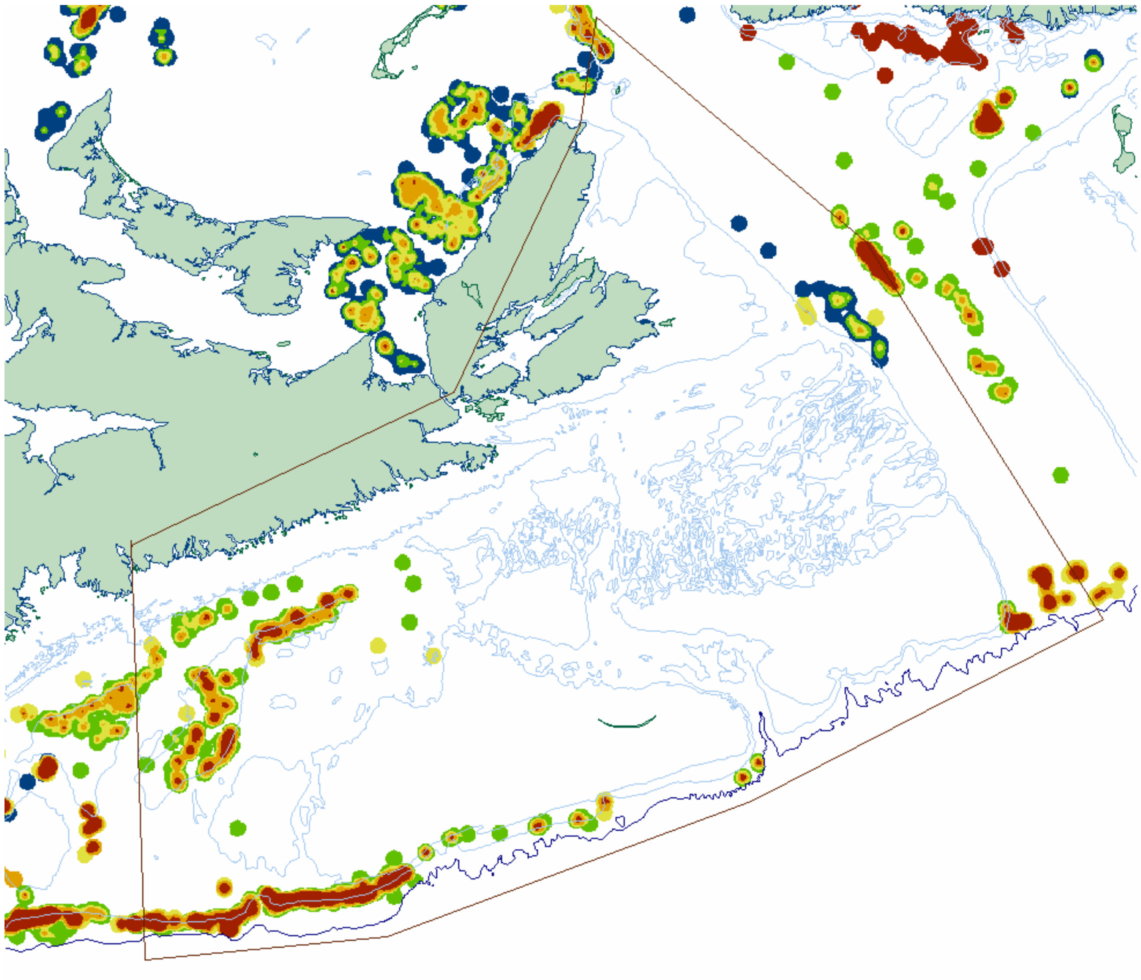

Figure 3. Location and intensity of seabed coverage by groundfish trawling in 2000. Trawler Classes 1-3, based on observer logbook data and extrapolated to represent entire fishery. Provided by D. Kulka, DFO, NWAFC. Red dots indicate 25 to more than 50% of the bottom in a given area was trawled in a given year.

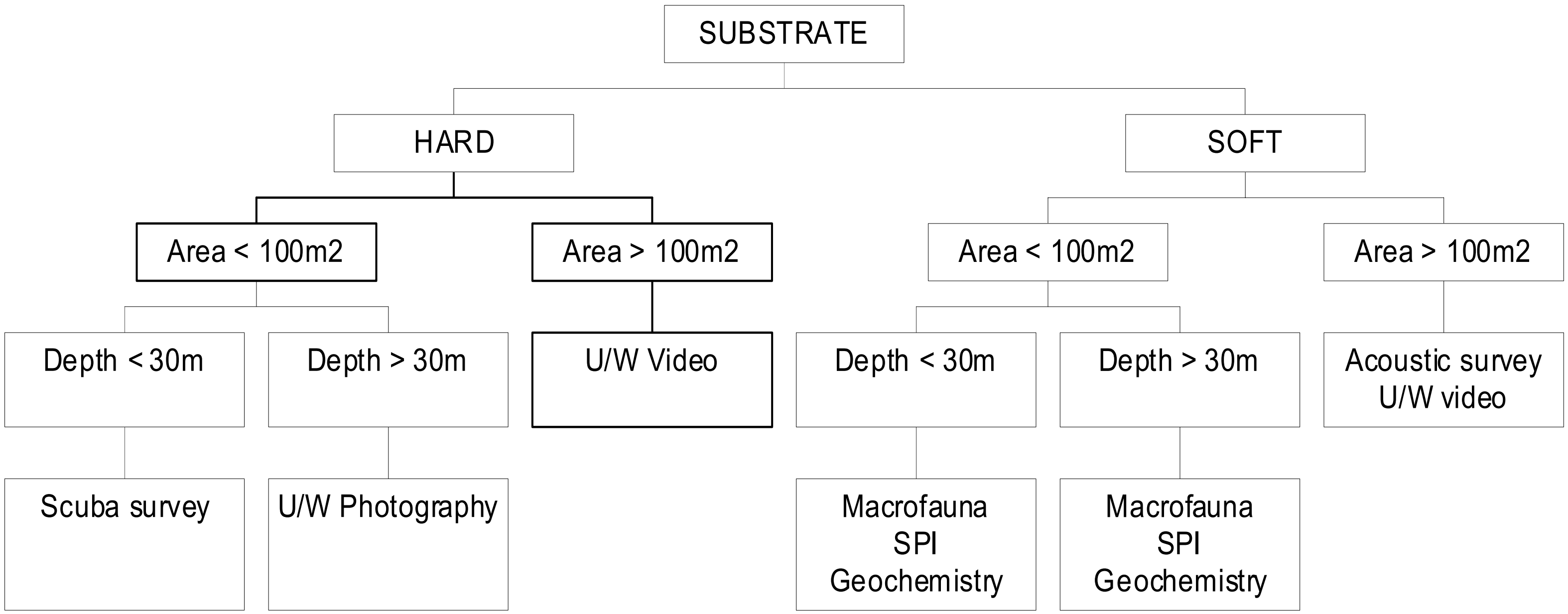

Figure 4. Decision tree for choosing the appropiate benthic monitoring method.

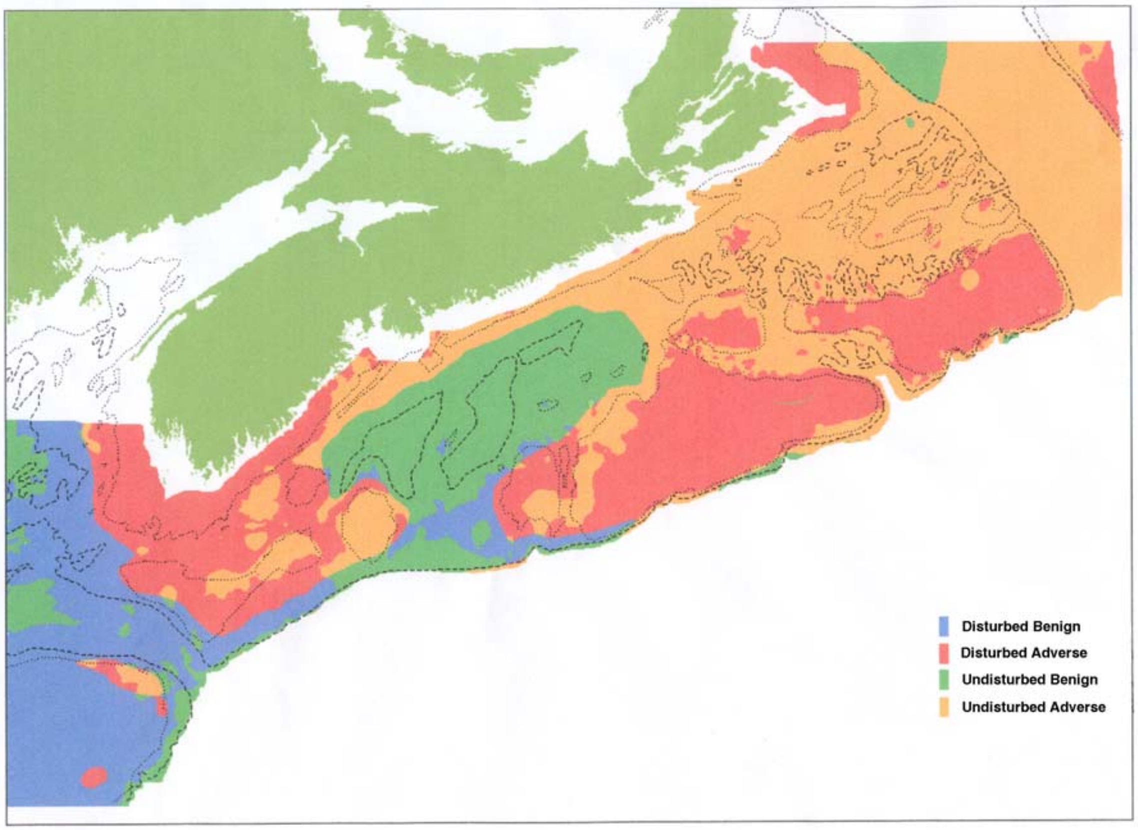

Figure 5. Preliminary map showing classification of benthic environments on the Scotian Shelf based on a model which groups environmental factors which are stressful or benign, and relative physical stability of the substrate (provided by Dr. V. Kostylev).

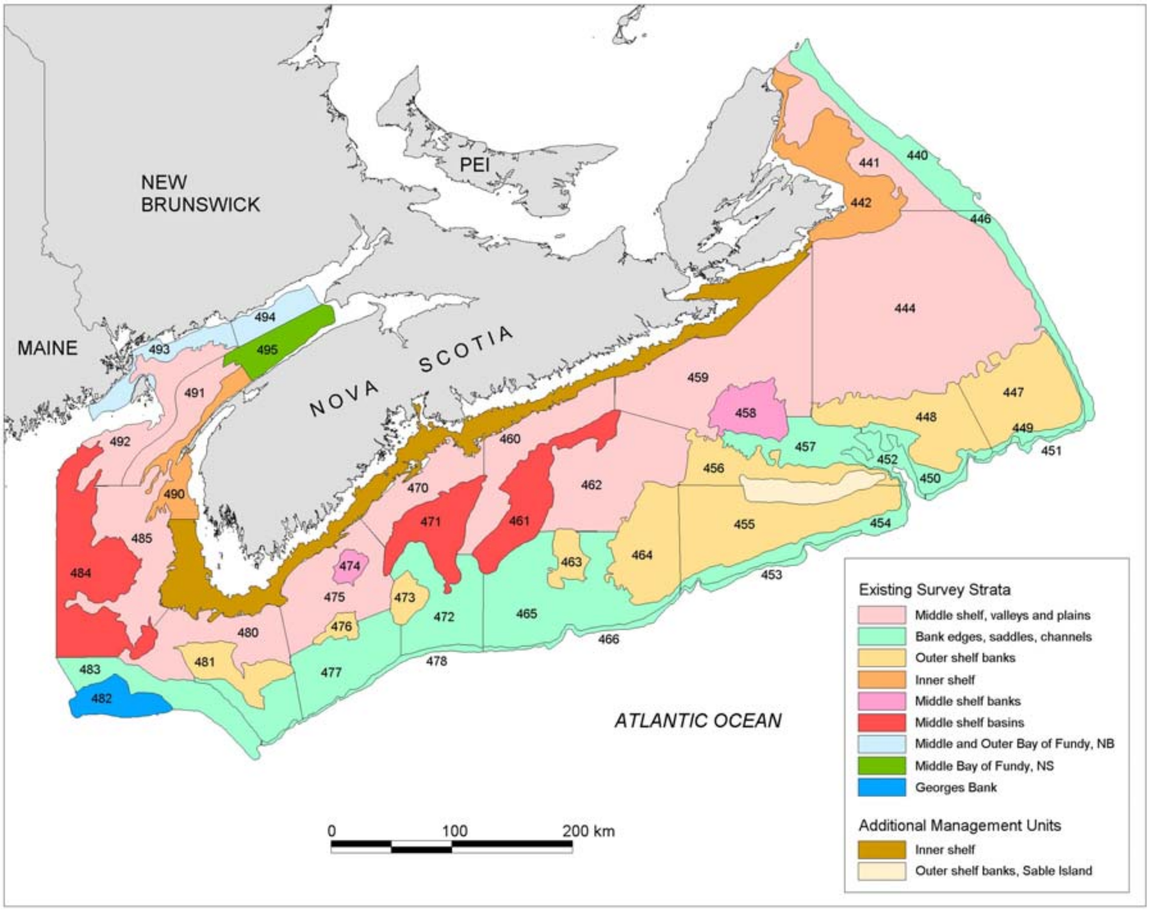

Figure 6. Possible conservation planning areas for the Scotian Shelf and Bay of Fundy, based on strata for DFO summer groundfish surveys. Areas are coloured to show correspondence to offshore regions from Fader and King (1986) and the *Natural History of Nova Scotia* (Davis and Browne 1997). Areas on the New Brunswick side of the Bay of Fundy were not included in Davis and Browne (1997).

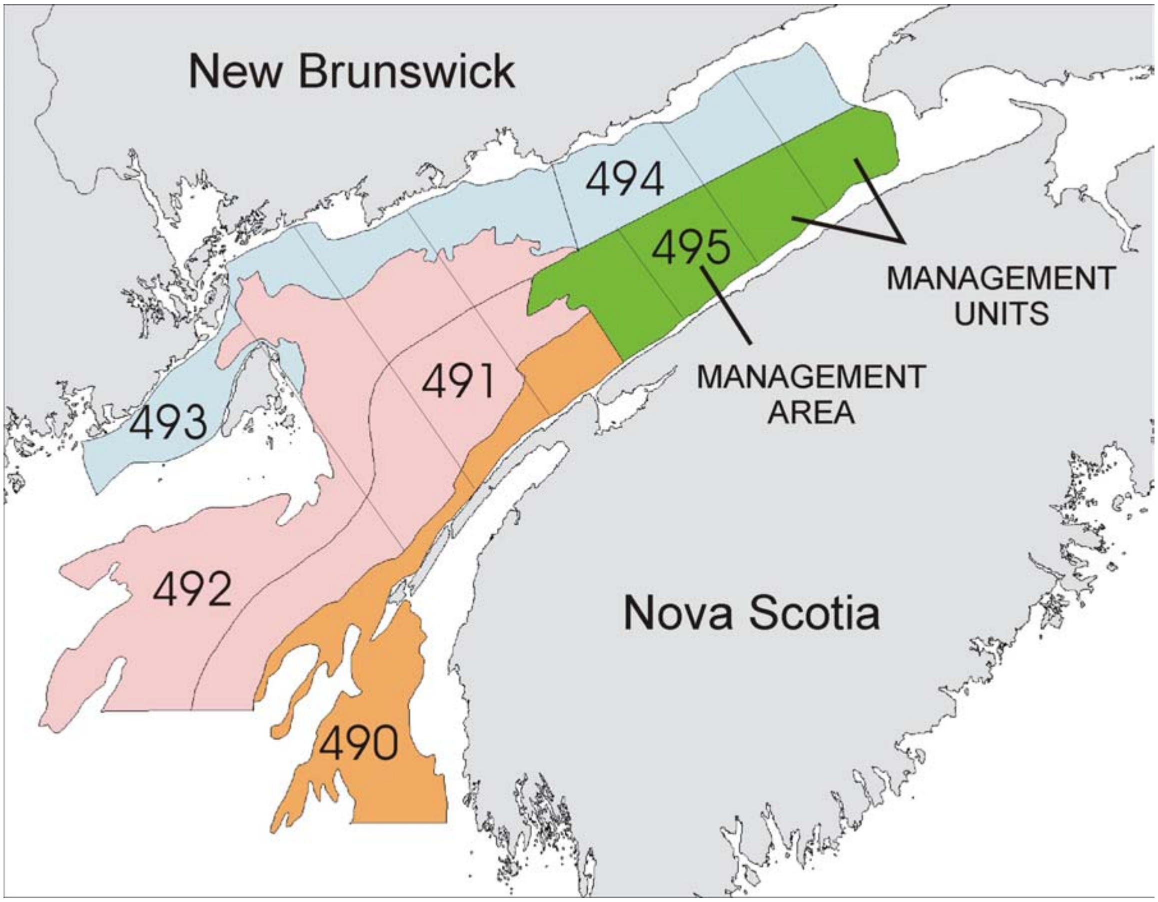

Figure 7a. Sample subdivision of the Bay of Fundy into CPA based on groundfish survey strata, and CPU of approximately 400-500 km^2.

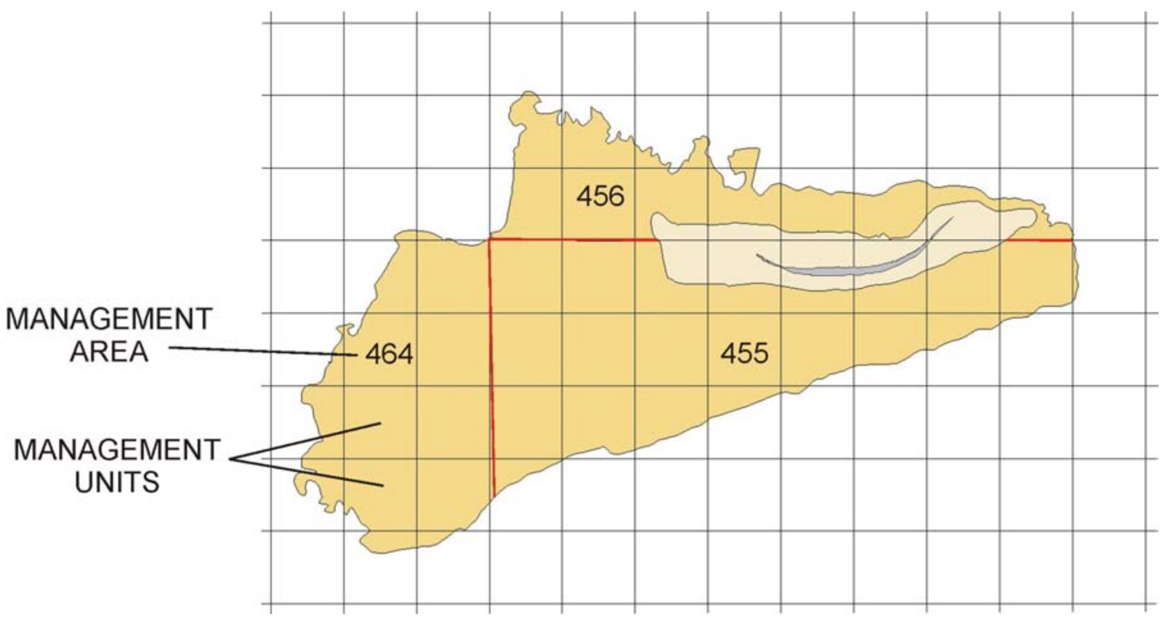

Figure 7b. Sample subdivision of Sable Island Bank/Western Bank into CPA (based on groundfish survey strata) and CPU of approximately 400-500 km2.