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Proceedings of a Benthic Habitat Classification Workshop Meeting of the Maritimes Regional Advisory Process

Maintenance of the Diversity of Ecosystem Types

A Framework for the Conservation of Benthic Communities of the Scotian-Fundy Area of the Maritimes Region

25 and 26 June 2001
Bedford Institute of Oceanography
Dartmouth, N.S.

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Compte rendu d'une Atelier sur l'habitat benthique Réunion du Processus consultatif des provinces Maritimes

Maintien de la diversité des types d'écosystème

Cadre de conservation des communautés benthiques du secteur de Scotia-Fundy, Région des Maritimes

Les 25 et 26 juin 2001
L'Institut océanographique de Bedford
Dartmouth, (N.-É.).

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Foreword

The purpose of this proceedings is to archive the activities and discussions of the meeting, including research recommendations, uncertainties, and to provide a place to formally archive official minority opinions. As such, interpretations and opinions presented in this report may be factually incorrect or misleading, but are included to record as faithfully as possible what transpired at the meeting. No statements are to be taken as reflecting the consensus of the meeting unless they are clearly identified as such. Moreover, additional information and further review may result in a change of decision where tentative agreement had been reached

Avant-propos

Le présent compte rendu fait état des activités et des discussions qui ont eu lieu à la réunion, notamment en ce qui concerne les recommandations de recherche et les incertitudes; il sert aussi à consigner en bonne et due forme les opinions minoritaires officielles. Les interprétations et opinions qui y sont présentées peuvent être incorrectes sur le plan des faits ou trompeuses, mais elles sont intégrées au document pour que celui-ci reflète le plus fidèlement possible ce qui s’est dit à la réunion. Aucune déclaration ne doit être considérée comme une expression du consensus des participants, sauf s’il est clairement indiqué qu’elle l’est effectivement. En outre, des renseignements supplémentaires et un plus ample examen peuvent avoir pour effet de modifier une décision qui avait fait l'objet d'un accord préliminaire

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ABSTRACT

In June 2000, a joint Fisheries and Oceans Canada (DFO) Science-Oceans workshop was held on ecosystem considerations for the Eastern Scotian Shelf Integrated Management (ESSIM) Initiative. One of the key outcomes of the workshop was the decision that, based on present knowledge, the spatial distribution of benthic ecosystem types should be mapped within the ESSIM area. It was agreed that a series of Regional Advisory Process (RAP) meetings should be held to provide a framework and scientific basis for ecosystem objectives concerning the maintenance of benthic communities in the Scotia-Fundy area of the Maritimes Region. To complete the exercise, the following phases were identified:

- Phase I: Review existing approaches to classifying and characterizing benthic communities, present and assess a proposed classification scheme, and recommend a benthic classification scheme for use in the Scotia-Fundy area.
- Phase II: Apply the recommended classification scheme to the Scotian Shelf to test and validate the classification scheme, and produce a map of the benthic ecosystem.
- Phase III: Assess the sensitivity of the environments classified under the scheme to human activities prevalent on the Scotian Shelf, and set reference points within DFO's Ecosystem Objectives Framework.

These proceedings provide the results of the Phase I workshop held on June 25th and 26th, 2001. The workshop was attended by a range of experts including benthic scientists, ocean management specialists, industry representatives and academia. The objectives and workshop structure were as follows: (a) provide a review of existing approaches used in benthic classification in Canada and internationally; (b) based on

RÉSUMÉ

En juin 2000, les Directions des Sciences et des Océans du ministères des Pêches et des Océans (MPO) ont tenu ensemble un atelier au sujet des considérations relatives à l'écosystème dans le cadre du Programme de gestion intégrée de l'est du plateau néo-écossais (ESSIM). Un des principaux résultats de l'atelier a été la décision d'établir des cartes, en fonction des connaissances actuelles, de la distribution spatiale des types d'écosystèmes benthiques dans la zone visée par l'ESSIM. Il a été convenu de tenir une série de réunions dans le cadre du Processus consultatif régional (PCR) afin d'établir le cadre et la base scientifique des objectifs écosystémiques concernant le maintien des communautés benthiques dans le secteur de Scotia-Fundy de la Région des Maritimes. Pour mener à bien ce projet, on s'est entendu sur les phases suivantes :

- Phase I : Revoir les approches existantes en matière de classification et de caractérisation des communautés benthiques, présenter et évaluer une proposition de système de classification et recommander un régime de classification à adopter dans le secteur de Scotia-Fundy.
- Phase II : Appliquer le système de classification recommandé au plateau néo-écossais afin de le mettre à l'épreuve et de le valider, et produire une carte de l'écosystème benthique.
- Phase III : Évaluer la vulnérabilité des milieux classés selon le système aux activités anthropiques qui se déroulent sur le plateau néo-écossais et établir des points de référence au sein du cadre des objectifs écosystémiques du MPO.

Le présent compte rendu relate les résultats de l'atelier de phase I, tenu les 25 et 26 juin 2001. Des experts d'horizons divers ont assisté à cet atelier, dont des spécialistes des milieux benthiques, des spécialistes de la gestion des océans, des représentants de l'industrie et des universitaires. L'atelier visait les objectifs suivants : a) revoir les approches existantes en matière de classification benthique au Canada et à l'échelle

available information and present knowledge, present and review current classification maps of the benthic communities in the study area; and (c) recommend a classification scheme for use in the Scotia-Fundy area of the Maritimes Region.

Following the presentation of case studies and research results by several participants, a plenary discussion session was held to provide advice and direction for the development of a future benthic classification scheme for the Scotia-Fundy area. The conclusions of this workshop do not necessarily represent the official policy or the views of DFO. Efforts are currently underway, as part of Phase II, to validate and test the recommended scheme for the Scotia-Fundy area.

internationale; b) d'après l'information dont on dispose et les connaissances actuelles, présenter et examiner les cartes de classification courantes des communautés benthiques dans la zone à l'étude et c) recommander un système de classification à utilier dans le secteur de Scotia-Fundy de la Région des Maritimes.

Après la présentation d'études de cas et de résultats de recherches par plusieurs participants, on a tenu une séance plénière dans le but de formuler un avis et une orientation pour l'élaboration d'un futur système de classification benthique pour le secteur de Scotia-Fundy. Les conclusions de cet atelier ne représentent pas nécessairement la politique officielle ou le point de vue du MPO. Dans le cadre de la phase II, on s'efforce actuellement de valider et mettre à l'épreuve le système recommandé pour le secteur de Scotia-Fundy.

INTRODUCTION

The DFO Policy Committee tentatively defined seven objectives to guide ecosystem-based management. The first objective states that human activities should be managed so as to maintain the diversity of ecosystem types within acceptable bounds. A science workshop was held in June 2000 in support of the Eastern Scotian Shelf Integrated Management (ESSIM) initiative. It discussed indicators and reference points in relation to this objective but did not define specifics, leaving this to future detailed study. Concerning benthic environments, the workshop considered that, based on present knowledge, the spatial distribution of benthic ecosystem types could be mapped within the ESSIM area. Present ocean use activities could then be superimposed on this map to determine the proportion of each type that may be disturbed. This analysis would lead to the definition of areas in which there should be restricted or no activity. It was felt that the extent to which these measures would apply could vary by ecosystem type (e.g. deep corals may require a higher percentage of protection than sand – based communities).

A workshop to review the ecosystem objectives was held in Sidney, B.C., during 27 Feb – 2 March. This workshop reaffirmed that the maintenance of diversity should occur at the community, species and population level.

To further the objectives of ESSIM and related ocean management initiatives, the Maritimes Joint Branch Management Committee (JBMC meeting of 11 September 2000) agreed that a RAP meeting be held to provide the scientific basis for the maintenance of benthic communities in the Scotian-Fundy Area of the Maritime Region.

Issues and Objectives

This meeting will provide an opportunity to review benthic communities and habitat diversity in the Scotia-Fundy Region. It is recognized that some information from the pelagic zone and of fish distribution patterns will need to be considered. The definition of communities for the plankton and fish assemblages will be deferred to a separate review and then the two will be integrated into an ecosystem classification including all trophic levels and marine species.

There are three major phases to this exercise. The first will be to review existing approaches to classifying/characterizing benthic communities, present and assess a proposed classification scheme and recommend a benthic classification scheme for use in the Scotia Fundy area. The second phase will involve the application of the classification scheme to the Scotian Shelf in order to validate and test the scheme and to produce a map of the benthic ecosystem. The third phase involves the assessment of the sensitivity of these environments classified under the system to human activities prevalent on the shelf and the setting of reference points within DFO's Ecosystem Objectives Framework.

The approach taken here will be to address these components through a series of separate workshops. The first will address phase one and will provide the forum for developing the recommended benthic classification system. The second phase will be carried out through contract and in-house work and the third through a workshop that will be held at a later date to review the application of that system in the Scotia Fundy area and the application of that scheme to the identification of sensitive habitats.

The geographic focus of the review will be the Scotia-Fundy area of the Maritime Region (4VWX plus 5 up to the US/Canada border). Given the additional complexities of data availability within the intertidal zone, the review will address information beyond the coastal fringe (i.e., deeper than about 10 meters in depth). The following are the specific objectives of the meetings.

Phase 1:

Objective 1. Review the existing approaches used in Benthic Classification in Canada, the US and ICES.

Objective 2. Based on available information and present knowledge, present and review current classification maps of the benthic communities in the study area.

Objective 3. Provide a recommended classification scheme for use in the Scotia Fundy area of the Maritimes.

Phase 2:

Objective 4. Apply the classification and produce benthic ecosystem maps of the Scotian Shelf.

Objective 5. Validate the classification scheme and maps.

Phase 3:

Objective 6. Provide reference points that define the percentage area of each benthic community that needs to be protected by restrictions of uses that generate habitat impacts.

Objective 7. Document geographic patterns of human activity in the marine environment, and (to the degree possible) provide a measure of the impact of each activity on the benthic communities defined under objective one.

Objective 8. Recommend next steps required for the selection of areas that could be zoned for restricted use in order to achieve the putative conservation objective of "maintenance of benthic communities in the Scotia-Fundy area of the Canadian EEZ".

Products

Interim Products:

- Proceedings of the Phase 1 Workshop
- Benthic Classification Model
- Maps of the Benthic Ecosystems
- Habitat Status Report (HSR) (2 reports)

1) recommended Benthic Classification System; and
2) Sensitive Benthic Habitats
for presentation to various advisory boards and general public.

Research Documents summarizing the technical basis for the conclusions and recommendations in the HSR.

Proceedings document reporting the discussion of the RAP meeting.

Phase 2:

Application of the Classification Scheme

The classification system developed through workshop one will be applied to a pilot area on the Scotian Shelf. Shortcomings in the model will be identified and the classifications system modified. The classification will then be applied to the Scotian Shelf and benthic ecosystem maps produced.

Phase 3:

Assessment of Ecosystem Sensitivity

The third phase of the process will lead to an assessment of the sensitivity of the benthic ecosystems identified in Phase 2 to human activities found or anticipated on the shelf. This will be carried out through a workshop which will focus on presenting the uses and activities on the shelf, an assessment of how these activities will impact on the benthic ecosystems of the shelf and the development of reference points for the benthic ecosystems relative to the disturbances expected from these human activities.

WORKSHOP AGENDA

<u>Monday, 25 June 2001</u>

09:00 – 09:10 Introduction (J. Arbour)

09:10 – 09:30 Workshop Objectives and Agenda (J. Arbour)
The workshop background, objectives and agenda will be discussed. It will emphasized that we are looking for practical guidance and it is to be expected that as Science advances, we will need to change with it. What we will develop at the meeting will likely be applicable for 3 – 5 years and then be updated. Also, the outline of the HSR will be given and discussed.

09:30 – 10:00 Ocean Management Needs (R. Rutherford)
Use overview, issues, pressures and application of the information from this session. The use of the information produced by this RAP in the ocean management on the Scotian Shelf will be discussed.

10:00 – 10:30 Break

10:30 – 11:00 Framework for setting Ecosystem Objectives (R. O'Boyle)
A framework of objectives, indicators and reference points in relation to the maintenance of benthic communities will be presented. Particular attention will be given to the use of area as a tool to manage human impacts. This will provide the context for the rest of the meeting's discussion.

11:00 – 11:30 Data Availability (P. Stewart)
An overview of the availability of data to support the description of the benthic communities will be given.

11:30 – 12:00 A review of the Proposed ICES models for benthic classification (P. Boudreau)

12:00 – 13:00 Lunch

13:00 – 13:45 Geological Survey of Canada perspective (G. Fader and V. Kostylev)

13:45 – 14:15 A Definition of Benthic Diversity (E. Kenchington)
An overview of benthic community diversity will be given, along with what characteristics need to be measured. This will also aid in determination of classification needs.

14:15– 14:45 A review of the approach being taken by NOAA in the classification of marine habitats. Classification systems in use in the US (S. Brown)

14:45 – 15:00 Break

15:00 – 17:00 Discussion Groups

<u>Tuesday, 26 June 2001</u>

09:00 -- 09:30 Review of Day 1 discussion groups

09:30 -- 10:30 A proposed classification system (B. Hatcher)

10:30 – 11:00 Break

11:00 – 14:00 Working Groups (12:00-13:00 Lunch)
Participants in the working groups will assess the proposed classification scheme, identify gaps and weaknesses, recommend ways of strengthening the scheme and propose a recommended approach.

14:00 – 15:30 Reporting Back from Groups

15:30 – 15:45 Break

15:45 – 16:30 Plenary
Subsequent to the reports from the working group will be a facilitated discussion in plenary to identify the agreed upon components for the classification system and resolve gaps and differences.

16:30 Next Steps
(In the interim the recommended Classification Scheme will be applied to the Scotia Fundy Region and the associated maps produced.)

LITERATURE REVIEW

B. Hatcher
CFCL-CBCL Ltd.

This review was prepared as contract deliverable for Department of Fisheries and Oceans (Canada).

The challenge facing the regional assessment process (RAP) is to derive a scientifically defensible, legislatively robust and spatially-explicit benthic classification scheme for the massive Scotian shelf ecosystem. It must serve the needs of managers charged with the preservation of benthic biodiversity through the implementation of an ecosystem-based management policy for this ocean management area (OMA). The goal of this document is to recommend a framework for proceeding on the development of such a classification using the data, information, knowledge and wisdom presently available. Elaboration on and disagreements with the points raised here formed the basis of discussion at the RAP workshop, and may substantially alter the outcomes of the research as it progresses.

Objectives

- Present a discussion list of theoretical models and examples of ecological classification and zoning schemes that address the need for protecting benthic biodiversity.

- Assess the applicability of various benthic classification schemes to management planning for the maintenance of ecosystem types on the Scotian Shelf, and document the justification for the use of a range of ecological indicators and reference points. Identify gaps in scientific knowledge.

- Evaluate the benthic ecosystem types on the Scotian Shelf and justify proposed guidelines for conservation objectives for each type.

The Need to Maintain a Diversity of Marine Ecosystem Types on the Scotian Shelf

The reality and urgency of the need is taken as a given from the terms of reference for this research, and will not be reiterated or elaborated here. Simply put, the essential goal of ecosystem approaches to management of the Scotian Shelf ocean management area is to preserve its biodiversity, and thereby sustain the ecosystem goods and services provided to the people of Atlantic Canada, and to the rest of the world. The challenge is to provide robust decision-support for precautionary and adaptive management in the short-to-medium term. The precautionary principle requires that steps be taken to preserve the Scotian Shelf's biodiversity in the absence of complete knowledge of its magnitude or distribution, or of the anthropogenic effects on it. A benthic habitat classification scheme, albeit incomplete at the species level and at all spatio-temporal scales, is an essential part of the framework for action by the Department of Fisheries and Oceans.

Methods

A library and internet literature review was conducted using the following key words:
Marine continental shelf ecosystem(s), Marine continental slope ecosystem(s), Marine habitat classification, Marine habitat mapping, Seabed mapping, Marine benthic ecosystem structure, Marine benthic ecosystem dynamics, Benthic habitat classification, Benthic habitat mapping, Benthic zonation, Benthic community structure, Benthic community organization, Spatial distribution of benthos, Critical marine habitat, Marine biodiversity conservation.

A comprehensive table of all known marine ecosystem classification criteria was drawn up from the information presented in these references, and circulated to project staff on 22 January 2001.

Interviews were held with twenty-four (24) DFO scientists holding direct experience and data on Scotian Shelf ecosystems (including the Bay of Fundy). The information thus obtained was used to discover new concepts, research results and literature, fill in the classification table, and seek advice on priorities and progress in ecosystem classification of the Scotian Shelf. A discussion list of theoretical models and examples was circulated to project staff on 15 February 2001.

Based on these inputs, the characteristic metrics, domains, scales, grains and densities of data relevant to each criteria are being compiled for the Scotian Shelf (ongoing).

A draft research discussion document was circulated to project staff on 31 March 2001. A final discussion document, revised in light of feedback to the draft was circulated on the first day of the RAP meeting on 25 June 2001.

Definition of Terms

The following definitions are adopted for the purposes of this study. They represent common, current usage, but are not meant to be exclusive. Many analogous terms that are unique to specific classification schemes (e.g. Wilken, et al., 1996) or are not in common use are not explicitly defined here. It is crucial that the terms be clearly defined and consistently used in the context of this research. Elaborations or disagreements with these will form the basis of discussion, and may substantially alter the outcomes of the research.

<u>Scotian Shelf</u> extends from the SW edge of the Laurentian Channel to the NE edge of the great Northeast Channel and its extension to the US border in the Gulf of Maine; from the landward margin of the sublittoral zone (approximately 10m depth) to the shelfward edge of the abyssal zone (approximately 1200m depth). It thus includes the SE continental slope and the Bay of Fundy, and excludes the Georges Bank. It is a complex section of a NW Atlantic large marine ecosystem (LME) that includes all of the neritic and the continental shelf margin of the oceanic province. The area has been designated by the DFO as ocean management area (OMA).

<u>Environment</u> is the inorganic, non-living surroundings in which organisms, populations, assemblages and communities exist. The spatial scales of the environment are determined by its physical structure and the physical forcing. (Thus, we speak of the “tidally-dominated benthic environment” or the “deep slope environment”.)

<u>Habitat</u> is the characteristic environment in which a particular organism, population, assemblage and community lives. It includes the living and non-living organic components that modify the relevant environment. The spatial scales of habitats are defined by the interaction between the environment and the biota of concern, and may thus be characterized by the non-living or living attributes. (Thus, we speak of the “cobble-silt habitat” and also of “the kelp bed habitat” or “lobster habitat”.)

<u>Community</u> is a characteristic assemblage of organisms that has repeatable and predictable structure, function, habitat-association and environmental affinities. The spatial scales of communities are defined by the interaction between the physical-chemical boundaries of their habitats and the overlapping distributions of the community components. Operationally, we first describe an assemblage of organisms in a definable habitat and then, as we learn more about the ecological interactions and dynamics of the component populations, we may come to recognize a community of organisms with characteristic attributes. (Thus, we speak of the benthic community, and also of the kelp bed community.)

<u>Assemblage</u> is a group of organisms that occurs within an environment (no implication of repeatable structure or predictable function). The spatial scales of assemblages are defined by the extent of the sampling regime and the habitat they occupy. (Thus, we speak of the filter feeder assemblage and the deep coral assemblage.)

Population is an interacting group of organisms of the same species. Populations are further classified as local, meta and species populations according to the intensity of interaction amongst individuals and spatially separated groups within them ("stocks" may be defined at any of these levels depending on the relationship between the fishery and the species and its environment). The spatial scales of populations are defined by their distributions, generally increasing from local to meta to global species populations.

Benthos is the sum total of life forms in the benthic and epibenthic habitats: organisms, populations, assemblages and communities. As such, the benthos spans the entire range of spatial scales of the shelf.

Substratum is the non-living matrix in, on and immediately over which infaunal, benthic and epibenthic organisms, assemblages and communities exist (i.e. it is the solid component of the environment). Attributes of the marine benthic substrata include (at increasing spatial scales): sediment grain size, sediment porosity, sediment thickness, outcrop hardness-friability, rugosity, topographic relief, bathymetry and complexity (described using e.g. fractal dimension).

Ecosystem is an interacting assemblage of organisms and their environment in which the sum of the internal transfers of biogenic materials or energy exceeds the transboundary fluxes. The typology of ecosystems includes aspects of both the non-living and living components. Ecosystems are usually defined by the environment (e.g. the "shelf-edge canyon ecosystem"), often defined by the dominant forcing (e.g. the "upwelling ecosystem"), and sometimes defined by the characteristic community within them (e.g. the "coral reef"). Ecosystems may exist across the full range of spatial scales, from an interstitial space, to a large marine ecosystem such as the Gulf of Maine, to the ecosphere. The definition is first operational, and the spatial domain follows. (A trite, but not unrealistic alternative definition is that an ecosystem is what a competent ecologist says it is!)

Ecological Unit is the lowest level in a hierarchical classification of ecosystems. Units are contiguous and not repeatable (i.e. each is unique), but there may be more than one of the type or next higher level of classification. Thus, we may speak of "fields of sand waves" that occur in places where near-bed tidal flows over unconsolidated sediments are very strong, but the field of sand waves at the SW entrance to Halifax's outer harbour is a unique ecological unit - there is only one.

Biodiversity is the variety of life forms inhabiting a defined area. As the spatial scale increases, it includes progressively more levels of the hierarchies of biological and ecological organization (i.e. ecosystems): genes, genotypes, phenotypes, organisms, populations, assemblages, communities, habitats, biotopes, etc. Emergent properties at the levels of organization above the species population mean that the whole is greater than the sum of the parts, and must be preserved as such if the ecosystem functions inherent to a biodiverse structure are to be maintained.

Classification is the process by which mapable units of biological organization are identified. A classification scheme provides the framework of criteria upon which biological units are assigned to a spatially-distinct group. (Note well the distinction from the taxonomic classification of benthos, which is space-independent.)

The Requirement for a Marine Habitat Classification Scheme

The spatial extent and the diversity of known marine habitats of the Scotian Shelf precludes complete knowledge of the distribution and abundance of all the life forms that contribute to marine biodiversity: generalizations about the distribution of these life forms must be made at higher taxonomic levels than the individual or species. That life forms are hierarchically distributed across multiple level of organization in predictable patterns is a "given" of ecology. The rules of assembly for these units in any given environment are poorly understood however, and operate at multiple scales of space and time: generalizations can only be made for the units that persist at larger, longer scales (i.e. habitats). The variety of (often overlapping) human uses of the Scotian Shelf OMA demands spatially explicit management (i.e. zoning) that must be informed by the distribution of habitats. It follows that a marine habitat classification is an absolute pre-requisite for any management strategy designed to maintain a diversity of ecosystem types at the scales of the Scotian Shelf. The focus is first on a classification of benthic habitats because the spatial stability of seabed compared to the water masses makes it easier to map and zone. The major contribution of benthos to marine biodiversity, and the demonstrated impacts of many human activities on benthic communities also argue that priority be given to the classification of benthic habitats.

Ecological Classification and Zoning Schemes that Address the Need for Protecting Benthic Biodiversity on the Scotian Shelf

The requirement for a geo-referenced classification scheme for marine and coastal ecosystems to support management policy and implementation based on the zoning of human activities is near-universally accepted in the DFO, in Canada and in most other maritime nations. In the context of DFO's mandate for the Scotian Shelf, the scheme must identify indicators of benthic biodiversity and reference points against which management performance can be assessed. This requirement for defensible regulatory support, as well as the operational limits on monitoring, control and surveillance of ocean space at the scale of the Scotian shelf influence the goals and scales of the habitat classification scheme that might be employed.

There is as yet no consensus on the structure of that classification. This is in part because there is recognition that different classifications are required for different applications (e.g. the preservation of rare and endangered species at risk vs. the maintenance of the diversity of ecosystem types), and in part because the theoretical underpinnings of such classifications are poorly developed.

Several organizations and agencies throughout the world are researching and using classification schemes for marine benthic ecosystems. Many scientists and managers within the DFO and several other relevant agencies in eastern Canada are actively engaged in developing classifications and maps of the marine ecosystems of the Scotian Shelf (including the Bay of Fundy).

Even recognizing the importance of the benthos to marine biodiversity, there are strong arguments for including water column attributes and processes in a list of criteria for benthic classification. These include the importance to benthic community structure and function of sedimented organics derived from water column production, and the magnitudes of benthic-pelagic coupling in energy, nutrient and reproductive fluxes.

There are strong arguments for including littoral and coastal attributes in a list of criteria for benthic classification of certain parts of the Scotian Shelf (i.e. the Bay of Fundy). These include the importance to benthic community structure and function of terrestrial inputs of organics and nutrients, and intertidal resuspension and transport of materials and organisms.

The size of the Scotian Shelf domain means that it will never be fully sampled. Therefore, any benthic classification scheme that supports zoning for biodiversity preservation must involve scaling up from sample areas to the shelf scale. The selection of a suitable framework for classification is largely predicated on its ability to up-scale to that of the ocean management area with sufficient spatial accuracy for the management actions intended (e.g. multiple use zoning, MPAs, etc.).

Temporal variation in the abundance and spatial distribution of benthic organisms is manifold at many scales. Any map of benthic communities will be a snapshot. The classification framework must optimize the match of temporal-spatial scales such that the zonation depicted has ecological and practical meaning over typical management decision periods.

There are compelling arguments for using a hierarchical classification system for the Scotian shelf's ecosystems. The processes which structure benthic communities, the data which are available to describe pattern, and the purposes to which the mapped outputs will be applied all extend across a range of organizational levels and scales of space and time.

Types of Benthic Classification Schemes:

Spatial classifications of marine benthos are based on process (ecological function) and pattern (ecological structure). The approaches are not mutually exclusive, as structure and function are intimately linked at all levels of biological organization. Most schemes incorporate both aspects, but process-based classifications focus either at the very large (macro) scales of biogeography where geological, oceanographic and evolutionary processes dominate, or at the very small (micro) scales of settlement and competition where biological processes are important. For mapping purposes, process-based classifications require an underlying, theoretical basis (model) that relates the process to the distribution of biotic units. Pattern-based classifications span the full range of spatial scales, but are dependent upon (and limited by) empirical descriptions of the distribution of biotic units. Process-based classifications may be developed in the absence of empirical data (although such are essential for calibration and verification), and thus are more likely to result from deductive approaches. Pattern based classifications may be developed *a posteriori*, in the absence of a theoretical model, and are thus often derived by induction.

The development and application of landscape (i.e. terrestrial) classifications and habitat maps have a longer history than those of seascapes. The empirical tools are particularly well developed, perhaps because of the relative ease of sampling the land, and the analytical tools are directly applicable to the marine realm. Landscape ecology has fewer lessons for process-based marine classification because of the fundamental differences between the ocean and land environments and between the adaptations of marine and terrestrial organisms.

For practical reasons, hierarchical classifications usually use the distribution of major physical structures and processes to map benthos at the higher levels of organization and larger spatial scales (i.e. communities and above at shelf scales), and the distribution of biota to map benthos at the community level and below. This reflects both the scale of process that determine pattern in the benthos, and the density of empirical data available. New technologies of remote sensing and underwater visualization are releasing these constraints.

A major challenge is to identify an adequate (and ultimately an optimal) scheme of classification for protecting marine benthic biodiversity. The fact that biodiversity is hierarchical argues a hierarchical approach to classification and mapping. The current level of human use of and impact on marine environments and biota, the precautionary principle, and the perceived urgency in statute and soft law as well as some public opinion recognize the necessity of a defensible benthic classification scheme to support adaptive management decisions in the near future. Expediency requires that the distinction be made between scientific models designed to improve understanding of how nature works, and those designed to support the management of human behaviour. There is also a necessity to match the scales of habitat mapping to the scales of human activities.

There are at least 40 classification systems that have been developed to some degree for marine ecosystems (but less than 20 have been applied). It is appropriate to synthesize the strengths and weaknesses of these in the context of the goal for the Scotian Shelf. The following survey of theoretical models and examples of benthic classification and zoning schemes is not meant to be exhaustive, as the exercise has been undertaken recently by several authors (e.g. Frith, et al., 1993; Robinson and Levings, 1995; Watson, 1997; Buchanan and Christian, 1999; NCER, 2000). The results represent priorities for further research, based on the information and wisdom gathered to date.

Biogeographic zonation schemes use empirical knowledge of the geographic extent and spatial distribution of benthos units that are stable at ecological to evolutionary time scales. The typical biological metric is the presence-absence or density of benthic organisms. The distributions are derived from published records of species occurrence and from interpolations among benthic grab, photo or video samples. *A posteriori*, multivariate classification or ordination techniques are often used to identify populations of indicator species, characteristic assemblages of associated organisms or distinct benthic communities. The analysis of biota belonging to many taxa sampled over many years and spatial scales leads to the identification of biogeographic provinces at continental shelf scales, while more localized and denser sampling is used to produce maps of ecological units at habitat scales.

The ecological processes that control the associations between biota and geographic variables such as latitude and depth are inferred, and need not be explicit or understood for the application of the scheme. None-the-less, spatial correlations with environmental variables such as temperature and circulation cells are often assumed to be causal relationships.

Examples of Biogeographic zonation schemes include:
- CSIRO's (1996) Interim Marine Bioregionalisation for Australia
- Sullivan Sealy and Bustamente's (1999) EcoRegions
- NOAA's Benthic Habitat Classification Scheme (Coyne, et al., 2001)
- Roberts and Hawkin's SeaMap http://www.ncl.ac.uk/seamap (accessed 27 May 2001)
- Mahon, et al.'s (1998) east coast NA demersal fish assemblages
- Gomes, et al.'s (1992) Grand Banks demersal fish assemblages

<u>Oceanographic control schemes</u> apply theoretical or empirical relationships between benthos and hydrodynamic-hydrologic attributes of water masses to known distributions of physical oceanographic features. Typical hydrodynamic metrics are exchange turnover rate, residence time, stratification, mixing, current velocity and bottom shear velocity. Typical hydrologic metrics are temperature, salinity, and their temporal variance. Their spatial distribution may be determined from interpolations among hydrographic stations (e.g. T-S fields), mapped with remote sensing tools (e.g. Synthetic Aperature Radar), or predicted from numerical models (e.g. CANDIE). Biota are related to these attributes in terms of presence-absence and sometimes abundance or biomass. The typical biological unit is the species, assemblage or community. The associations may be determined a priori from the literature (e.g. research on the effect of near-bed current on feeding and dispersion of macro-invertebrates), or *a posteriori* from classification analysis of biota sampled under different hydrological regimes). The ecological processes that determine the associations between biota and water masses are usually explicit and well understood.

Examples of Hydrodynamic-Hydrological control schemes:
- Marine Environmental Quality Advisory Group's (MEQAG, 1994)
- Longhurst's (2001) Marine production zones
- Loder, et al.'s (2001) Scotia-Maine hydrographic and circulation regimes
- LOICZ's Typology of coastal and marine environments http://water.kgs.ukans.edu:888/public/Typpages/index/html (accessed 17 June 2001)
- Wolanski's (2000) Great Barrier Reef oceanographic zones

<u>Geomorphological correlation schemes</u> apply empirically known associations between benthos and substratum type to known or extrapolated distributions of substratum. Typical substratum metrics are seabed relief, rugosity, sediment thickness and grain size. Their spatial distribution is either interpolated from point photo or grab samples (geological maps), or mapped with remote sensing tools (e.g. side-scan sonar). Biota are related to these attributes in terms of presence-absence and sometimes abundance or biomass. The typical biological unit is the species or the assemblage. The associations may be determined a priori from the literature (e.g. research on the abilities of infauna to survive in different types of sediment), or *a posteriori* from classification analysis of biota sampled on different substrata. The ecological processes that control the associations between biota and substratum are inferred, and need not be explicit, or even understood for the application of the scheme.

Examples of Geomorphological correlation schemes:
- Andrefouet, et al.'s (2001) Typology of atolls
- Davis et al.'s (1994) Biophysical classification of offshore regions of N.S.
- Day and Roff's (2000) Framework classification of Canada's oceans
- GBRMPA's Great Barrier Reef marine ecoregions. http://www.gbrmpa.gov.au/corp_site/key_issues/conservation/rep_areas/documents/bioregions_2001_06.pdf (accessed 13 March 2001)
- Kostylev, et al.'s (2001) Benthic habitat mapping on the Scotian Shelf
- Mumby and Harborne's (1999) Caribbean marine habitat classification scheme

Ecological control schemes use established models of biological processes, interactions and fluxes of biomaterials to predict the distributions of organisms, populations and communities.

Typical metrics include genetic distance, recruitment rate, primary production, ecotrophic efficiency, organic sedimentation rate, etc. These ecological inputs to the models may be measured directly, derived from linked bio-physical and biogeochemical models, or assumed from literature values.

Model outputs indicate the presence and density of benthos as a function of the ecological control process and input parameter values. Determining the spatial distribution of ecological units requires that the models be spatially explicit, or that the distribution of the input parameters be known (e.g. the spatial pattern of primary production).

Limitations of models and data mean that these classification schemes are usually locale-specific and small in scale.

Examples of Ecological control schemes:
- Bruno and Bertness's (2001) benthic habitat facilitation model
- Massell and Done's (1993) hydrodynamic classification of wave effects on coral benthos
- Minn's (1997) fish habitat identifications
- Sousa's (2001) disturbance models

Hybrid geo-physical or bio-physical schemes use a combination of the physical and biological schemes outlined above.

Typically, the spatial distribution of physical environments is further partitioned by known affinities or occurrences of characteristic biota.

Examples of hybrid classification schemes:
- Harper, et al.'s (1983) Marine regions of Canada
- Hiscock's (1995) and Connor, et al.'s (1997) Classification of benthic marine biotopes in the U.K.
- Australian Environmental Conservation Council's (EEC, 2000) Marine habitat classes
- Frith, et al.'s (1993) Habitat classification systems for coastal B.C.
- Hooper's (1997) Coastal marine habitat classification system for Nfld.
- Deither's (1990) Marine and estuarine classification system for Washington Greene, et al.'s (1998) Classification of deep seafloor habitats
- Brown's (1993) Classification system of marine and estuarine habitats

Hierarchical Hybrid schemes use a combination of physical and biological schemes arranged in organizational and spatial hierarchies such that the scheme used for any given level provides the most powerful prediction of the distribution of biota.

Examples of Hierarchical Hybrid schemes considered:
- Cowardin, et al.'s (1970) Classification of wetlands and deepwater habitats of the United States
- Environment Canada's Marine Ecological Classification System (MEQAG, 1994)

- Zacharias, et al.'s (1998) British Columbia marine ecosystem classification
- DFO Coastal and Estuarine classification for fish habitat (Williams, 1989)
- European EUNIS marine habitat classification (Davies and Moss, 1999) http://mrw.wallonie.be/dgrne/sibw/EUNIS/eunis.fulllistA.html (accessed 8 June 2001)
- Hatcher, et al.'s (1990) Marine habitat classification of the Abrolhos

From this categorized list it may be seen that benthic classification schemes developed to date use a wide range of criteria, may be categorical or hierarchical, and non-dimensional or explicitly spatial. It is apparent that different schemes are developed to meet different needs, and not all schemes need, or result in actual maps of the spatial distribution of classes. Spatial classifications of marine benthos are based primarily on pattern (ecological structure), while non-dimensional classifications depend more on process (ecological function). The approaches are not mutually exclusive, as structure and function are intimately linked at all levels of biological organization. Most schemes incorporate both aspects, but process-based classifications focus either at the very large (macro) scales of biogeography where geological, oceanographic and evolutionary processes dominate, or at the very small (micro) scales of settlement and competition where biological processes are important.

For mapping purposes, process-based classifications require an underlying, theoretical basis (model) that relates the process to the distribution of biotic units. Pattern-based classifications span the full range of spatial scales, but are dependent upon (and limited by) empirical descriptions of the distribution of biotic units. Process-based classifications may be developed in the absence of empirical data (although such are essential for calibration and verification). Pattern based classifications may be developed *a posteriori*, and may proceed in the absence of a theoretical model.

The development and application of landscape (i.e. terrestrial) classifications and habitat maps have a longer history than those of seascapes. The empirical tools (e.g. vegetation mapping) are particularly well developed, in part because of the relative ease of sampling the terrestrial environment, and the analytical tools (e.g. GIS) are directly applicable to the marine realm. Landscape ecology has fewer lessons for process-based marine classification because of the fundamental differences between the ocean and land environments and between the adaptations of marine and terrestrial organisms.

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A major challenge is to identify an adequate (and ultimately an optimal) scheme of classification for protecting marine benthic biodiversity. The fact that biodiversity is hierarchical argues a hierarchical approach to classification and mapping. The current level of human use of and impact on marine environments and biota, the precautionary principle, and the perceived urgency in statute and soft law as well as some public opinion highlight the necessity for a defensible, spatially explicit benthic classification scheme to support ocean planning and zoning decisions in the near future. Expediency requires that the distinction be made between scientific classification models designed to improve understanding of how nature works, and those designed to support the management of human behaviour. There is also a necessity to match the scales of habitat mapping to the scales of human activities in the ocean, and to the scale at which management can be effective (i.e. the area of the minimum manageable unit that can be monitored and controlled, typically $10km^2$ near shore and $100km^2$ offshore).

Generalized Applications of Habitat Classification to the Scotian Shelf

All classification schemes of marine benthic communities developed for management decision support (see recent reviews by Watson,1997; Buchanan and Christian, 1999; NCER, 2000; as well as overview in previous section) are intended to result in quantitatively mapable units (i.e. they are spatially explicit models that seek to define how much of what will be found where). The mapable unit selected in these schemes is more often than not the habitat . This choice also has some support in the theoretical literature. Southwood (1977) calls habitats "the templates for ecology", upon which rest all ecosystem components. Gray (1997) defines marine habitats as units with distinct physical and biotic features, and goes on to note that their fragmentation is the greatest threat to biodiversity (a conclusion also supported by the GESAMP, 2001). I believe that this analysis of threat is one-dimensional, and suggest, conversely, that the homogenization of benthic marine habitats is the greatest threat to marine biodiversity. Bottom dragging and trawling are but one of several human activities that smear and break down habitat boundaries and structures in the ocean environment, with increasingly well-known negative effects on biodiversity (Auster, 1998).

Whatever the classification criteria selection or the unit selected for mapping, there appear to be two basic approaches to achieving the goal of defining how much of what is where: the deductive and the inductive.

The *deductive* approach classifies benthic communities *a priori* from analysis (often mapping) of the physical environment. The method uses established or assumed ecological classification models to infer the types and spatial pattern of benthos from first principles, and from knowledge of the nature, magnitude and distribution of forcing or structuring attributes of the physical-chemical environment. Because of its dependence upon physical attributes, this might be called the "physical" mapping approach to marine benthic classification.

The *inductive* approach classifies benthic communities *a posteriori* from analysis of the associations among biota. The method uses pattern searching and defining tools (usually statistical) to infer the spatial pattern and classification and of benthos from direct or remote sampling of benthic biota. Because of its dependence upon biological attributes, this might be called the "biological" mapping approach to marine benthic classification.

The deductive (i.e. physical) approach is by far the most common for areas of the size of the Scotian Shelf because of the impossibility of sampling the entire domain at a spatial density adequate to resolve the distribution and abundance of benthic organisms in the finer grain habitats. It also avoids the major problem of temporally variable distributions of organisms, which requires periodic, long term monitoring to resolve. The models are typically (but not always) hierarchical, derived from terrestrial (landscape) ecology, and based on known or assumed relationships between physical-chemical attributes of the environment and characteristic assemblages of macroflora and macrofauna (Table 1). The mapping aspects are almost always handled using remote sensing technologies, and increasingly using geographical information systems (e.g. Fader, et al., 2000; CEIMATE, 2000), and it is the ability of these tools to produce synoptic maps of vast areas that is the great strength of this approach to benthic habitat classification.

Limitations of the physical-chemical data sets, the accuracy of their measurement and the technologies for mapping them constrain the power of this approach, but the real challenge (and certainly the art) lies in the selection of physical classification parameters to be measured and mapped. The classification of biological communities by this method is only as good as the robustness and fidelity of the assumed relationships between the physical environment and the biota. When insightful choices of parameters are made: these relationships can be statistically robust (e.g. Kostylev, et al., 2001), and may be perfectly adequate for classifying benthic communities at the spatial scale of minimum manageable unit (MMU). The risk lies in committing to expensive programmes of measurement and mapping of physical parameters that do not predict the distribution and abundance of benthic communities. This risk is inversely scale-dependent, being lowest at shelf scales (i.e. 100 to 1000 km) where physical controls dominate the coarse grained distribution and abundance of biota, and greatest at sub-habitat scales (i.e. 0.01 to 10 km) where biological controls may dominate (Levin, 1992). The MMU for the Scotian Shelf (approx. 10km x 10km) clearly falls in between these two spatial domains, and hence the risk is real, but probably manageable.

Davis and Browne (1994) and Davis, et al., (1994) provide an example of the deductive approach by building on the hierarchical, "ecozone" classification of Canada's marine regions developed for National Parks by Harper, et al., (1983; 1993) and Hiroven, et al., (1995). These are essentially geographical classifications, stated by the authors to be based on geology and physiography, rather than oceanography. A wide range of classification parameters (including those oceanographic) are apparently used, however, albeit not in a quantitative fashion. Four (4) "districts" corresponding to across shelf location (i.e. inner, middle, outer and slope) are recognized, and eleven (11) classes of "units' that include nearshore water bodies such as bays and lakes, and offshore features such as bank tops, saddles, basins, plains, valleys, channels and canyons. Each unit is further sub-divided at the next level of the hierarchy into pelagic and benthic "habitats", yielding a total of 58 unique habitats (the later ranging in size from approx. 4,800 to 48,000 km^2). The classification does not distinguish between the boundaries of benthic and pelagic habitats (a patently unrealistic assumption for areas that are not hydrodynamically constrained by topography). While characterizations of typical sediment, hydrological and biotic attributes of each unit are made, no attempt is made to identify benthic communities from this mapping exercise.

Day and Roff (2000) provide another example of the deductive approach to classifying all Canadian marine space, with a tentative application to the Scotian Shelf. Seven (7) physical parameters belonging to four (4) hierarchical levels are used to delineate nine (9) "natural regions" and 62 unique "seascape" units (the later ranging in size from approximately 30 to 370,000 km^2). No attempt is made to identify benthic communities from this mapping exercise, however.

The inductive (i.e. biological) approach is more common for smaller, and usually shallower areas where dense sampling and direct observation of the benthos are feasible. The approach draws on a large body of ecological and biogeographical knowledge and practice in the sampling and organisms to describe community structure and function, ranging in scale from tide pools to ocean basins (e.g. Hedgepeth, 1957; Levinton, 1982; Polis, et al., 2001). Information may be obtained by actually collecting organisms (using SCUBA or with trawls and grabs), or by inspection and enumeration by SCUBA divers or by viewing U/W photos or video images. The derivation of spatial pattern from such data draws on an equally strong body of knowledge and tools for analysing multivariate data (e.g. Pielou, 1972; Andrew and Mapstone, 1987; Warwick and Clarke, 1998). The great strength of this approach is that it actually measures the diversity, abundance and distribution of organisms within the sample area: the dependence on environmental surrogates (i.e. correlates) is removed. The limitations of the approach are essentially those of sampling offshore marine ecosystems: logistic challenges of work at sea and vast, unseen areas to sample, equivocal criteria for sample stratification, and highly variable rates of temporal change in ecological processes affecting community structure. To this problem is added the inherent unpredictability of community structure at the level of the local species population.

Most of the well-developed examples of the inductive approach come from Europe, where a series of marine habitat characterization and mapping initiatives (e.g. Earll, 1992; Hiscock and Conner, 1995; Conner, et al., 1995; Nijkamp and Peet, 1994) are coalescing towards a uniform classification scheme based on characteristic assemblages of marine organisms (e.g. BioMar, MarLIN, EUNIS). Similar initiatives are underway in Australia (Lyne and Last, 2001). These activities have focused primarily on shallow water environments, and draw on a series of extensive, long-term investments in marine sampling. In these schemes, the geological and oceanographic parameters are associated with benthic communities *a posteriori*, and not, to date, in a quantitative fashion.

Stewart, et al., (2001) have recently compiled data from 122 benthic grab sample stations on the Scotian Shelf, and a further 310 in the bay of Fundy. Hargrave subsequently related these qualitatively to the geo-physical habitat classification of Davis and Brown (1994), recognizing the inner shelf, banks, basins and slope as the primary zones, and substrate type in terms of sediment grain size (4 ranges) and proportion of hard substratum (3 ranges) as the next lower level of classification.

Hargrave (unpub.) concludes that sedimentary facies determine the benthic community type (as defined by the major taxa of macrofauna), while diversity (in terms of species composition) is determined by habitat complexity, predation and other biological factors. He further suggests that benthic, macrofaunal biomass is determined by the food supply, along a gradient of diminishing supply across-shelf. Hargrave's conclusions are in broad agreement with the literature on factors controlling benthic community structure in deep sedimentary environments, but the lack of explicit recognition of historical factors relating to disturbance and succession ignores a large body of understanding derived from experimental work in shallow, hard bottom communities. They may explain why relationships between metabolism or turnover and position along the cross-shelf (i.e. food supply) gradient are not apparent. The major limitation on this work, however, is the small area sampled (<1m^2 per station) and low density of sample stations (ranging from approx. 90 per 12,350km^2 in the Bay of Fundy, to <50 on the Western shelf, to <1 on the remainder of the Scotian Shelf. For the purposes of defining indicators and setting reference points for benthic biodiversity preservation, the problem of inadequate sampling rules out a strictly inductive approach.

Kostylev, et al., (2001) have combined the two approaches for the Browns bank area of the Scotian shelf, and more recently, in the area of the Gully on the Eastern Shelf. Multibeam remote sensing, augmented by side-scan sonar and seismic profiles was ground-truthed with grab samples and still photography to sample the megabenthos at 24 and 115 stations respectively. Seven (7) benthic habitats are recognized *a posteriori* on the basis of cluster analyses. The identified 'habitats' are actually a mixture of bio-physical attributes that may be considered as benthic community types. Two habitats are simply charaterized by depth (shallow vs. deep), one by broad trophic category (deposit feeders), and three by dominant genera or species). The distribution of the communities is related to four (4) sediment types, four (4) depth zones, three (3) relative estimates of near-bed current speed, and two (2) measures of temperature: annual mean and seasonal variance. Three (3) relative levels of a derived factor: substrate structural complexity (related to grain size), are added to the classification but not rigorously assessed. Parametric statistical tests showed highly significant differences between these habitat types due to the sediment type factor, while the co-variate depth did not exert a significant effect. Muti-variate tests distinguished two factors that explained about 30% of the observed variance in the distribution of megafauna taxa, and about 42% of the observed variability in abundance. Sediment type was by far the most important correlate in these analyses, while depth-related factors of the hydrodynamic and thermal regime were significantly correlated, but explained the smaller proportions of the partitioned variance. These power of these relationships is similar to that obtained in other studies of this sort at these scales (e.g. Warwick and Uncles, 1980; Warwick, 1988; Clarke and Ainsworth, 1993). At only 30 to 40% of the variance explained, they tend to be at the lower end of the range of 30 to 90% of variance in macrofaunal distribution and abundance that can be assigned to physical variables in intertidal and pelagic environments (Mann and Lazier, 1996; Lengendre and Legendre, 1998; Denny and Wethey, 2001).

An important question is whether the spatial accuracy and repeatability of these classes of benthic community type can be substantially improved. If so, whether most cost-effectively by increasing the number or range of physical-chemical parameters in the analysis; increasing the accuracy of measurement or estimation of the variates already used, or by increasing the density and detail of the benthos sampling. At the scales of the MMUs of the Scotian shelf (typically 100km^2), and given the physical-chemical data sets already available for the area, the first options is certainly a priority.

A clear gap in virtually all the analyses undertaken to date is the lack of explicit inclusion of measures of community function in the classification schemes. The two ecological processes best known to influence benthic community structure are the frequency and intensity of physical disturbance, and the rate and form of delivery of consumable organic material. Both of these factors can be directly and quantitatively linked to species diversity (e.g. Connell, 1978; Tyler, 1986). Both factors are, in turn, determined by the oceanographic, hydrodynamic, and, in some cases, fishing regimes, as well as by patterns of primary productivity, and the delivery of land-based sources of nutrients and organic material. Some excellent, synoptic data sets exist for all of these aspects of the Scotian shelf environment (e.g. Elsner, 1999; O'Boyle, et al., 2000; and references therein).

It is important to reiterate that neither the deductive (primarily physical) nor inductive (primarily biological) approaches require a theoretical understanding of the mechanistic controls over the distribution and abundance of benthos. Correlation and ordination do NOT demonstrate causality, even at the level of the sediment-grain-size vs. infauna relationship (Snelgrove and Butman, 1994), yet the empirical results of sound analyses can be used to accurately identify communities of organisms that are coherent in space and persistent in time.

In short, the deductive approach suffers from a lack of testing of the relationships between physical forcing and community structure, while the inductive approach suffers from lack of data. It is for this reason that both approaches are generally combined in comprehensive benthic classification schemes (Watson, 1997; Buchanan and Christian, 1999).

Recommendations for Developing a Classification of Benthic Ecosystem Types for the Scotian Shelf

A set of fundamental conclusions and underlying assumptions are derived from the research described above, and presented as observations and recommendations to inform the methodology and outputs of the workshop exercise of selecting a classification scheme for the benthic ecosystems of the Scotian Shelf. These are stated clearly and explicitly for debate. Elaborations and revisions resulting from the workshop will form the basis of further discussion, and may substantially alter the outcomes of the research.

1. The main purpose of the classification scheme is management of our oceans.

It is not necessarily the same as classification for scientific understanding. The application goal of an ecosystem classification scheme is to guide the development an enforceable zoning scheme to control human activities on the shelf that have the potential to reduce or degrade marine biodiversity.

Better understanding of how the Scotian Shelf ecosystem functions may be an important by-product of the classification exercise in the context of experimentation within adaptive management regimes (sensu Holling, 1978). Hence, the classification scheme to be developed here is a model for management and control, rather than for understanding and prediction (Bradbury, et al., 1983). The focus on precautionary and adaptive management has important implications for research priorities and budgets.

It is accepted that habitat classification schemes must be designed to meet a specific requirement or answer a well-defined question (Ray, 1976; Watson, 1997), for example definition of biodiversity hotspots. There can be no universal classification scheme for the Scotian Shelf that meets all possible requirements.

2. SCALES of benthic classification should be initially set by compliance and enforcement capacity.

The operational limitations inherent in the implementation of zoning-based management on the Scotian Shelf define the minimum spatial and temporal scales of resolution required for ecosystem classification.

Zoning-based management in the present context depends on the resource users' and the managers' ability to detect and respect spatially defined zones of activity in the open ocean. Given present technological and operational limitations, this resolves to a minimum manageable unit (MMU) of an area of approximately $100km^2$, with no more than 6 way points connected by straight lines (J. Calvesbert, pers. comm.). It follows that the mapping of ecological units at finer resolution can be justified only if essential for the classification of benthic ecosystems at the spatial scales at which zoning can be implemented (e.g. Hatcher, et al., 1990). This practical reality has important implications for the design and investment in sampling programmes aimed at mapping benthic biodiversity on the Scotian Shelf. The most common spatial scale of the minimum mapable unit used in benthic classification schemes developed for zoning is on the order of 1 to 10 km^2.

3. Classify ecosystems hierarchically and zone adaptively from the upper levels of the hierarchy.

The organization of nature is hierarchical, as is the organization of the societal structures that lead to sound oceans governance. Both the spatial and temporal scales of seascapes, habitats, oceanographic and ecological processes form nested clusters rather than smooth continua (Dethier, 1990; Frith, et al., 1994). There simply does not exist a body of empirical knowledge or a set of theoretical models that can unequivocally identify the best classification scheme for describing and maintaining the diversity of benthic community types on the Scotian Shelf. The goal of optimally matching the tasks of zoning and monitoring to the levels and scales of natural phenomena will only be achieved through a series of management experiments, the results of which inform the subsequent trials. It is logical therefore to start this process at the higher levels of the hierarchies (e.g. physiographic zones) where current knowledge is best, where cost-effectiveness is greatest, and where the risk of having to change the framework of classification is lowest. Hierarchical classification schemes are well-suited to the addition of lower levels as knowledge increases, but are less amenable to the addition or removal of classes within levels than are flat classification systems (e.g. MarLIN; Hiscock, 1995), because of upwards-downwards linkages and their implications for nesting.

4. Use the biological COMMUNITY as the minimum ecological unit (MEU) and the benthic HABITAT associated with the community as the minimum mapable unit (MMU) for the purposes of management.

The biological community is the most appropriate lowest level of classification for characterizing benthic biodiversity on the Scotian Shelf for three reasons: i) the high fidelity of species to benthic communities; ii) the close correspondence of benthic communities to habitats characterizable by attributes of the physical-chemical environment; and iii) the match between characteristic scales of benthic habitats and management zones (i.e. MMUs).

Ecosystems may be conceptualized as comprising dual hierarchies of organization and function that do not map linearly onto spatial or temporal scales (O'Neill, 1989). Biodiversity is inherent at all levels in these hierarchies, not only at the level of the species population (Wilson, 1988). The science of marine ecology focuses primarily at the level of the community, and that is where our most robust paradigms, models and data sets apply (Bertness, et al., 2001). Biological communities map directly onto, and often define habitats, which are seen as the template of ecology (Southwood, 1977; Gray, 1997). Given the spatial scale of management and current knowledge of species' distributions on the Scotian Shelf, it is impractical to attempt mapping biodiversity at the level of the species population. Even were that possible, the emergent properties that define enduring or recurrent features of community structure and function are unlikely to emerge from such an empirical classification (Watson, 1997; Buchanan and Christian, 1999; Day and Roff, 2000; CEIMATE, 2000).

The main ecosystem services provided by the Scotian Shelf are the result of intact and functional communities of organisms, rather than of their discrete populations. It follows that the first attempt to define indicators and set reference points for biodiversity preservation on the Scotian Shelf should take a nested approach, starting with the integrated entity of the benthic community. The community focus has implications for the targets and methods of benthic sampling to be undertaken on the Scotian Shelf.

5. Incorporate the role of history explicitly into the classification of benthic communities.

The temporal dynamics of marine benthic communities dictate that the spatial patterns of distribution and abundance of organisms are not fixed, and future patterns cannot be predicted solely on the basis of present patterns. The pattern of benthic communities currently observed on the Scotian Shelf is not only a reflection of current environmental conditions, but also a temporal integration of processes operating at multiple scales. At the scale of the shelf, biogeographical processes related to ocean-climate systems, geological and evolutionary processes have produced cross- and along-shelf patterns of benthic communities. At the scale of benthic habitats, the cumulative flux of organic matter and the physical disturbance regime are the primary determinants of the historical components of community pattern. As anthropogenic disturbance is both extensive and patchily intense on the Scotian Shelf, a classification that ignores history may fail to identify benthic community types that were common or distinctive in the absence of human impacts. Answers to the question whether we wish to maintain formerly common but currently benthic community types will have significant implications for the zoning management regime to be implemented.

6. Equate habitat complexity to biodiversity in developing indicators and reference points.

Surrogate or proxy measures of species richness and community structure must be used to map and monitor biodiversity at shelf scales because of the high costs of direct sampling and long term monitoring. This is the accepted approach adopted by virtually every one who has considered the problem (Cowardin, et al., 1979; Brown, 1993; Hiroven, et al., 1995; Zacharias and Howes, 1998; Day and Roff, 2000; and see reviews by Frith, et al., 1993; Watson, 1997; Buchanan and Christian, 1999; CEIMATE, 2000). The physical environmental indicators should be synoptic and cost-effective for identifying the location, size and shape of areas that will be zoned to preserve the diversity of benthic community types. Remote sensing technologies are the only way to accomplish this, and have been the method of choice for terrestrial habitat mapping since the 1940s (CEIMATE, 2000). In the first order, indicators of habitat complexity may be used to predict areas of high biodiversity and to maximize the range of benthic community types included within a management zones. Verification and refinement by direct sampling of biota should be driven by hypotheses about the mechanistic nature of relationships between physical controls and biological processes generated from current theory and from prospective surveys and analyses.

Empirical correlations have been established in many ecosystems between physical-chemical attributes of marine habitats and the structure and function of communities of organisms that inhabit them (e.g. Warwick, 1988; McGhee, 1994; Hiscock, 1995; Mahon, et al., 1998; Kostylev, et al., 2001). Such relationships are rarely robust at the level of the individual species' distribution, primarily because of temporal variability in disturbance regimes, recruitment and movement (Dayton, 1971; Underwood and Fairweather, 1989; Sousa, 2001). At the scale of zoning-based management (i.e. 10s of kilometres), habitat complexity includes the variety of habitats within an area as well as the patchiness of those habitats (i.e. the mosaic grain, sensu Levin, 1992), and the distances between them (i.e. connectedness). Within habitat patches, the rugosity (i.e. fine-scale topographic complexity, including sediment grain size) is the most powerful indicator of community structure. While biota create habitat in many marine environments (e.g. Woodin, 1978; Thistle and Eckman, 1990), such "foundation species" are generally confined to shallow, nearshore, euphotic areas (Bruno and Bertness, 2001). In some habitats on the Scotian Shelf, certain bivalves and corals may serve as foundation species. Among habitat patches (i.e. at the larger scales of the Scotian Shelf), physical-chemical environmental variates related to the geological (e.g. bedforms) and oceanographic (e.g. thermal and hydrodynamic) regimes exert the most predictable control on the diversity of benthic community types.

It is one thing to identify relationships between physical attributes of an environment and the biotic components (e.g. the increase in filter feeders with near-bed flow velocity, Snelgrove and Butman, 1994). It is quite another to use the relationships to predict the space-time co-ordinates of maximum abundance and diversity of organisms from those relationships. The interplay between ecosystem structure (in terms of biodiversity) and function is far from obvious or linear in terms of the relative effects of physical and biological controls (Mooney, et al., 1996). This ambiguity begs the question of whether causal or mechanistic relationships between physical forcing and biological process are necessary and sufficient for predicting benthic community structure.

Conclusions

1. The DFO should take a hierarchical, risk-averse approach to the classification process. (i.e. the methodology must mirror the structure and organization of nature). Start at high levels of ecological organization using broad scale mapping of variates selected on robust theory and empirical relationships, then working down to lower levels and smaller domains as required.

2. It is not presently possible, and will likely never be possible to delineate the exact boundaries of marine communities on the Scotian shelf. It is possible, however, for the purpose of classification, to delineate the boundaries of areas approximating or exceeding minimum management units (approx. 100km^2) that have a very high probability of containing representative or unique assemblages of benthic organisms.

3. A minimum set of physical-chemical parameters can be specified a priori that already exist in the literature or available data banks, that will provide defensible biodiversity criteria for demarcating MMUs, and practical guidelines for monitoring. The parameters that encompass the known requirements of intact benthic communities and are known to influence biodiversity are: topographic and substratum complexity, intermediate disturbance regimes, predictable delivery of nutrients, organic material and reproductive propagules. A set of 6 to 10 measurement variates are adequate for a first set on indicators and reference points for maintaining the diversity of ecosystem types on the Scotian shelf.

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SUMMARY OF WORKSHOP PRESENTATIONS

AN OCEANS MANAGEMENT PERSPECTIVE ON A BENTHIC CLASSIFICATION FRAMEWORK

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The purpose of this presentation is to highlight the need and role for an ecological, including benthic, characterization framework for oceans management and planning in the Scotia-Fundy area. As one of the key “end users” of current frameworks, any future product from this exercise, we have provided a brief overview of past approaches used for characterization in the offshore portion of the Scotia-Fundy region; examined the application and key elements of a future benthic framework; and provided recommendations on next steps.

The Oceans Act: Basis for Ecosystem Approach to Ocean Management and Planning

The *Oceans Act* provides a legislative foundation for integrated oceans and coastal management in Canada’s estuarine, coastal and marine ecosystems. For the purposes of this workshop, it is useful to note that the Act mandates DFO, in collaboration with other organizations and groups, to adopt and operationalize the sustainable development, ecosystem and precautionary approaches for the management and conservation of our marine environments. This means balancing multiple oceans use and economic development with the conservation and protection of biodiversity and marine health at all ecosystem levels. The Act also recognizes that effective management requires a foundation of scientific understanding of ecosystems and all their components. Therefore, the development of both a broad ecosystem and a benthic characterization and conservation framework is essential for the implementation of the *Oceans Act*.

Fisheries and Oceans Canada is implementing the vision of the *Oceans Act* through several programs for the management and protection of coastal and offshore environments in the Maritimes. Individual initiatives conducted over the past few years are being implemented on wide range of spatial scales. At the broadest scale, the region has been divided into two Large Ocean Management Areas (LOMAs), with the Eastern Scotian Shelf Integrated Management (ESSIM) initiative representing the primary effort to date. Within the LOMAs are a number of Coastal Management Areas (CMAs). Projects include planning efforts in the Minas Basin in the Bay of Fundy and the Bras d'Or Lakes. Two marine protected area (MPA) initiatives include the Sable Gully and the Musquash Estuary. These are the first of a broader system of MPAs planned for the region.

Frameworks to Assist Planning

As part of many of these initiatives we are compiling “ecosystem overviews” to assist in the planning activities, including descriptions of benthic communities. To complement these information gathering exercises ecosystem objectives are being developed at both the general/national scale and at the smaller scale through vision setting discussions with the local communities. Species habitat profiles for indicator or key species will be used with measurable health indicators (e.g. salinity, temperature ranges, and acceptable contaminant levels) to help define the ecosystem vision. This ecosystem framework is part of the management plan’s performance measurement, which tells us if we are moving toward the defined social/economic/environmental management vision. An agreed to benthic characterization framework will assist in the identification of appropriate benthic indicators and management targets for the maintenance of the health, productivity and diversity of the ecosystem types.

From an ocean management and planning perspective, a benthic framework will provide a fundamental ecological input to plans and decisions on how our ocean areas will be managed and used. Future ocean use zoning and MPA planning provide good examples of future applications for a benthic characterization framework, e.g. capturing particularly special and important benthic communities. Given the complexity of oceans management and decision-making, the benthic component is just one of many layers to consider when exploring zoning concepts and options for an area such as the Scotian Shelf. It is just one, albeit an essential, piece of the puzzle. A useful example to consider from elsewhere is the work recently completed at Great Barrier Reef to assist with both long-term and day-to-day planning needs. It is not benthic-specific and it provides a synthesis of many data layers. The Barrier Reef approach illustrates the applications of ecosystem classification frameworks to oceans management and planning, essentially providing a basis for decision-making and ocean use zoning.

One of the key uses of the framework will be to provide direction for the identification of ecologically sensitive areas, and for the assessment of impacts/effects of individual and multiple activities. As well, a benthic framework will be an important tool for the environmental assessment process, although it must be emphasized that a regional framework will not remove the need for site-specific assessments. It is hoped that the framework will also contribute to the scientific community, providing a basis for ecosystem understanding, scientific inquiry and research planning.

What is Currently Available to Oceans Planners?

To support initiatives and broad objectives noted above what is currently available “off the shelf” to ocean planners and the various sectors and communities involved? Over the years several approaches by government and non-government researchers to describing benthic communities in the offshore. The various efforts include taking biological, biophysical, and physical approaches. The presentation illustrated samples of the various data collections, mapping approaches and planning “tools” currently available to oceans planners to incorporate benthic considerations in oceans management.

A common biological approach is to use resource survey information for particular species, such as scallops. Although this helps in the identification of key or important benthic organisms in some areas, non-commercial species are rarely captured in the analysis and the spatial coverage corresponds to primary fishing grounds, e.g. bank environments. However, the fact that we have a good knowledge of commercial species will help us to both develop and test the benthic classification scheme in the Scotia-Fundy area. For many stakeholders the planning objectives set around commercial species will be highest importance. Unfortunately the level of sampling across the shelf has been limited, and therefore restricts our ability to solely rely upon biological data to develop the scheme.

Ecological “classification” has a long history in Canada - particularly at a national scale. For example, Parks Canada has developed the concept of marine regions, which was developed for National Marine Conservation Area planning. This scale is not very useful for planning initiatives such as ESSIM. On a Scotian Shelf scale the Nova Scotia Museum has taken a Natural history approach and derived a scheme showing basic biophysical zonation of the marine environment. Characteristic benthic organisms are provided for each zone. Although the spatial coverage of the scheme is adequate for ocean planning, the level of detail on the specific ecological or benthic organisms is lacking. Similarly, in support of environmental assessments for the oil and gas industry a number of mapping efforts have been used to classify the benthos. Often this approach characterizes “dominant organisms” on the Scotian Shelf with the intent of viewing the impacts and setting of specific projects.

In 1998, the WWF (Day and Roff) began work on developing a hierarchical model for marine classification using the Scotian Shelf as a case study area. This approach combines various physical data layers to characterize the benthic habitat or ecotypes, as well as pelagic components. It was felt that we had a better understanding of the physical variables that combine to make up the different ecotypes than we did of the biological or distribution of species assemblages. The theory is very appealing and should be seriously considered in any characterization scheme that is developed but it did not provide a map, which explains what we know of the biological distribution of assemblages. There are several reasons for this; DFO did not have the right data to feed the model for example the surfical geology did not include the immediate subsurface or the bed forms, which are both controlling factors; some variables which were applied on a large scale, for example temperature, had a controlling or limiting effect on communities at a smaller scale and range, so was under weighted in the characterization; tidal mixing along thermoclines on the Shelf edge produced well fed benthic communities that the stratification layer, used as a surrogate for mixing, implied did not exist; depth was not a controlling factor as was assumed; and bottom currents which have a major affect on the benthos were not available and so not included.

Although this map has several features marine biologists might recognize, it has raised many questions and does not reflect what we perceive to be the characterization based on our understanding of the biology.

From the oceans planning perspective and to meet the objectives described earlier, there is no one “off the shelf” product that meets our needs, either from a spatial extent or a biological description perspective. This underscores the requirement for a synthesis of existing information into one agreed framework for classifying, understanding and conserving/managing benthic communities.

Conclusion

In conclusion, it is useful to put out some suggested “goals” or “criteria” for building the benthic framework:

- Beyond the requirement for solid, peer-reviewed science, broad agreement among the science, management/regulatory, and marine user communities is essential for acceptance of future decisions based on the framework.
- The framework will need to be geo-referenced so that it can be incorporated into various mapping initiatives, a fundamental tool for ocean planning and decision-making.
- When building the framework, we have to consider the scales of use and application. A hierarchical approach will allow for application through a range of spatial scales.
- Consider both infauna and epibenthic organisms in the scheme
- Bearing in mind that we will never be satisfied with the amount and quality of our information and understanding, we have to adopt a pragmatic approach based on what we do know and what data we have, this will mean the use of predictive/deductive approaches based on expert opinion and theory derived from the areas were we have enough data to take a data driven approach. By building durability and flexibility into the framework, we can add, change and improve it over time.

In recent years there has been growing agreement on the layers and variables (e.g. substrate, water column characteristics, temperature, currents, temporal circulation, depth, structural complexity, level of natural disturbance, etc.). The challenge now lies with the details in selecting and combining these layers.

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OBJECTIVES, INDICATORS, AND REFERENCE POINTS FOR CONSERVING HABITAT

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The purpose of the talk was to provide an objectives, indicators and reference point framework to guide the conservation of habitat. As many of the concepts were new to the audience, the talk would hopefully stimulate development of new ideas and approaches. First, some background on concepts was presented. The findings of the 2000 ESSIM Workshop were presented, specifically the main elements of a precautionary approach (objectives, indicators and reference points, account for uncertainty, decision rules and performance measurement) and the key objectives of ecosystem-based management (EBM). The latter include the conservation of biodiversity, productivity and water quality. It was highlighted that the DFO National Policy Committee had considered the ESSIM objectives and struck a national working group to develop them further at a national workshop (Sidney, BC in February 2001). The latter redefined the ESSIM Workshop objectives by replacing water quality with habitat and by further developing the hierarchical structure under each, which was presented. The process ('unpacking') whereby operational objectives are developed from these conceptual objectives was outlined, along with the terminology used. Examples of unpacking for diversity and habitat were discussed for illustration. It was noted that, similar to harvest fisheries, 'control rules' are needed for conservation of habitat. This led to a discussion on how multi-indicator arrays for habitat can be assessed using a Traffic Light Approach, which has been used for harvest fisheries. Some of the strengths and weaknesses of the approach were outlined. The talk concluded with a call for an 'unpacking' workshop on a specific habitat issue to test the concepts and approach.

AVAILABILITY OF INFORMATION ON BENTHIC MACROINVERTEBRATE COMMUNITIES FOR CLASSIFYING MARINE ENVIRONMENTS ON THE SCOTIAN SHELF

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The macrobenthic communities (organisms retained on an 0.5 mm sieve) of the Scotian Shelf, the continental shelf off Nova Scotia from Northeast Channel on the Southwest to the Laurentian Channel on the Northeast, are comparatively little studied. No comprehensive studies to sample communities and determine their distribution on the shelf as a whole have been carried out; however a range of independent studies both carried out over time and ongoing, though still small in number, are gradually improving the understanding of this part of the eastern Canadian continental shelf. The level of knowledge of macrobenthic communities on the Scotian Shelf is less extensive, however, than for shelf environments in other areas such as the northeastern continental shelf of the US (e.g. Wigley and McIntyre, 1964; Wigley, 1962; Emery, et al., 1965; Theroux and Wigley, 1998; Maciolek-Blake, et al., 1985) and on the European continental shelf (e.g. Buchanan, 1963; Duineveld, et al., 1991).

Current knowledge of benthic communities comes from a range of sources. A comprehensive review of anecdotal surveys and reports of spot sampling pre-1983 is summarized in Mobil (1983) (Figure 1) and more recently in SOEP (1996) and Wildish (1998). Studies have included bottom sampling in support of Russian fisheries investigations which sampled a handful of stations on the eastern Scotian Shelf (Nesis, 1963; 1965) (Figure 2); bottom photographic surveys of geological surface features and distribution on Sable Island Bank and the Northwestern Gully (Stanley and James,1971); US geological and fisheries surveys extending into Canadian waters (Southwest Scotian Shelf on Browns Bank and vicinity, Emery, et al., 1965; Wigley and McIntyre, 1964; Theroux and Wigley, 1998) research studies on benthic processes in specific locations (Browns Bank, Wildish, et al., 1989; 1993; Mills and Fournier, 1979), transect between Emerald Basin and the Scotian Shelf (Grant, et al., 1987; 1991) Emerald Bank, Basin and Continental Slope; and Volckaert (1987) St. Margaret's Bay and Emerald Basin. Recent localized data collection studies by Fisheries and Oceans Canada in support of strategic objectives (e.g. impacts of trawling, Prena, et al., 1996) and impacts of drilling wastes, as well as other data collected by DFO (biomass data summarized in Stewart, et al., 2001); and studies to provide background for marine protected area development in The Gully—Hargrave and Hawkins (2001 MS); Kostylev (2001 MS) (Figure 3). Recently, biological/geological studies to develop remote mapping technology for biological community types (Browns Bank, Kostylev, et al., 2001) and to determine distribution of community types in support of offshore hydrocarbon development on the Scotian Slope southwest of Sable Island and off Logan Submarine Canyon (Geological Survey of Canada, 2000a and b) have been carried out (Figure 3). Sampling of benthic communities is also commonly carried out as part of environmental monitoring activities at offshore wellsites; several studies carried out in the 1990s and largely unpublished (summarized in Stewart, et al., 2001), and similar ongoing and new studies will be a source of information, though localized, in future while proposed efforts such as the SEAMAP project may yield information on benthic communities through biological samples obtained for ground-truthing the acoustic and bottom photographic data. In addition, independent and anecdotal studies of distribution of coldwater corals (Breeze, 1997; Breeze and Davis, 1998) have been carried out; and resource surveys for commercial clam species on major banks (Rowell and Chaisson, 1983; Chaisson and Rowell, 1985; Roddick and Lemon, 1992; Roddick and Kenchington, 1990; Roddick, 1996) have also provided data on components of the benthos (Figure 4). Some of these studies (e.g. Roddick and Kenchington, 1990), also included lists of invertebrate by-catch of clam surveys. Resource surveys for commercial shrimp (e.g. Koeller, 1996a and b) are also relevant to characterize benthic communities in certain areas. Biomass data from the Scotian Shelf from all studies to 1998 are summarized in Stewart, et al., (2001) and are currently available on the DFO, Marine Fish Division Virtual Data Centre, through the DFO Intranet (Figure 5). Part of this project will use biomass data and its relationship with sediments, depth and other factors to estimate patterns of biomass distribution on the Scotian Shelf as a whole. Examination of biomass data for areas where both commercial clam surveys and DFO grab sampling in support of trawling impacts studies has taken place, gives an indication of the size spectra of biomass, and also the contribution of different groups. DFO commercial clam surveys (e.g. Rowell and Chaisson, 1983; Roddick, 1996) sample the size fraction above 5 cm over large areas of Banquereau and some of the other banks, and have given good estimates of biomass in that size fraction over large areas of Banquereau and Sable Island Bank. Grabs taken in the same area as some of the trawl sites show a lower biomass, and also different species composition, in the smaller size fraction (Figure 6). In grabs, the high biomass is dominated by the Northern Propeller Clam (*Cyrtodaria siliqua*) compared with the Stimpson's surf clam (*Mactromeris polynyma*) in the commercial clam surveys. In some areas, large clam species are responsible for the majority of the biomass (Figure 7). This type of information coupled with knowledge of bottom type can be used to provide estimates of biomass over wide areas of the shelf.

Several maps of distribution of benthic communities on the Scotian Shelf, based on existing data, have been assembled, in all cases based on limited data, and probably do not represent actual communities and dominance relationships very well. More recent studies, such as the sampling done for assessing the impacts of trawling, although still limited, suggest that there is significant regional variation in communities, which is not reflected in the early representations. Nesis (1965) provided the first distribution map, which covered only the eastern Scotian Shelf in addition to the Grand Banks and Labrador continental shelf (Figure 8).

Steele, et al., (1979) summarized benthic communities on the Scotian Shelf from limited existing information (Figure 9), and incorporated the map from Nesis (1965), in an exercise to provide supporting information in Parks Canada's efforts to identify representative terrestrial and marine areas for the national parks system. A subsequent map of benthic communities was prepared from this and other data as part of the environmental impact statement for the Venture gas project in the mid-1980s (Mobil, 1983) (Figure 10), and was updated for the Sable Offshore Energy Project environmental impact statement (SOEP, 1996) (not shown). The latter was largely based on the pre-1983 data presented in Mobil (1983) with the addition of information on distribution of large clam species (Mactromeris, Arctica, and Cyrtodaria) obtained from commercial clam surveys on the Scotian Shelf (Rowell and Chaisson, 1983; Chaisson and Rowell, 1985; etc.) (see above) as well as known areas of scallop distribution from commercial scallop surveys carried out by DFO.

The paucity of information on macrobenthic communities makes it difficult to use them in classifying benthic environments for the Scotian Shelf as a whole, though enough information may be available to begin to characterize specific areas. Surficial geology can provide a structure or framework on which the biological communities can be associated, although the conditions conducive to their development depend on a range of physical and biological conditions, many of which are equally important in determining communities which occur there (Figure 11). Recently, surficial geology maps for the Scotian Shelf have been digitized (MapInfo) by DFO, Oceans and Coastal Management Division, and will provide an additional tool in studying benthic communities in the area (Figure 12).

An approach developed by the Geological Survey of Canada, Atlantic Geoscience Centre, utilizing physical characteristics of the bottom determined by multibeam sonar, sidescan, and acoustic reflectance studies, coupled with bottom photographs, calibration by grab samples, and multivariate analysis (e.g. Kostylev, et al., 2001) is a useful way to characterize large scale distribution and variations in seabed communities. Within those large scale features it may be possible to use the geological understanding and knowledge of distribution of bedforms (surface features of a scale of a few centimetres to kilometres), such as sand ripples, sand waves, megaripples, and sand ridges (see Amos and King, 1984) to predict the occurrence of benthic communities. An understanding of the dynamics of many of these surface bedforms has been developed for parts of the Scotian Shelf. Sediment type is one of several factors in the biology of benthic communities, and influences biology at several scales (Figure 13). Small scale features having dimensions ranging from centimetres to tens of centimetres include sand ripples caused by waves and currents (Amos, et al., 1988), shell and detritus, all of which are mobile and temporally unstable, and are probably least significant in determining biological community type. Medium scale features, ranging from tens of centimetres to kilometres, include bedforms such as sand waves, sand ribbons, sand ridges, and megaripples (Amos and King, 1984) on which it may be possible to determine small scale distribution of biological communities (Figure 14). Still larger are the extensive features which can be identified by the approach using multibeam, sidescan, and multivariate approaches as noted above for Browns Bank, which are subunits of the zones of similar sediment types and origins presented on the surficial geology maps for the area (e.g. King, 1970) which represent the highest level. The bottom types identified by the multibeam sonar and multivariate methods are likely to be the most useful in overall classification of the shelf for management purposes, while the small features within these types are the 'texture' or 'environmental grain', to which small scale distributions of biological communities can be correlated, and extrapolated to the larger context, providing important input on the quality and importance of these bottom types.

Several examples of repeating geological features which have distinctive biological attributes are available. Bioherms (biological communities associated with particular seabed geology features) have been studied in the Bay of Fundy; beds of horse mussel of (*Modiolus modiolus*) are associated with repeating ridges (Wildish, et al., 1998) (Figure 15). Benthic productivity of these sites has been estimated and can provide an overall ranking of the importance of these features to other environments. Similarly, in the English Channel, bottom communities have been linked to tidally generated seabed sand ribbons and furrows (Holme and Wilson, 1985) (Figure 16). In a similar way, biological communities can be shown to vary with location in relation to position on sand ridges and trough systems off Sable Island. Sand ridges have a grain size variation with medium sand on the tops, fine sand on the down-current slope and coarse sand on the up-current side and trough (Amos and Nadeau, 1988) (Figure 17). Sand ridges are a conspicuous feature of the seabed south and southeast of Sable Island (Figure 18). Sampling on sand ridges for environmental monitoring of offshore hydrocarbon development has demonstrated different communities in the ridges than in the troughs, corresponding to different grades of sediment (Envirosphere Consultants Ltd., 1998) (Figure 19). A similar approach on the Grand Banks at Hibernia shows that there are distinct communities on different grades of sand (Hutcheson, et al., 1981). These studies indicate that there is potential for using small scale distribution of communities in relation to geological features to extrapolate distributions to larger areas, using knowledge of the distribution and relative abundance of bedforms over large areas. In summary, an approach to delineating biological communities based on surficial sediments (as one of several environmental variables) could be to use the large scale mapping capability and existing understanding of surficial geology to identify the broadly similar (physically) units; identify the individual surface feature units or 'repeating elements' that make up the 'texture' of the units; and conduct small scale biological studies of representative repeating units, which can then be used to extrapolate to larger areas.

Currently there is not enough information on distribution of seabed biological communities to serve as a basis for classifying seabed environments on the Scotian Shelf. However, we present here a number of comments about approaches to the classification of continental shelf environments. In the interest of efficiency, we feel it is important to use existing efforts at classifying shelf environments as much as possible. The process of classifying benthic environments is not new and intensive efforts have been made worldwide to develop meaningful classification systems (e.g. Ray, et al., 1982; Hayden, et al., 1984; Bailey, 1998), including various efforts to classify marine regions of Canada (e.g. Wiken, et al., 1996; Harper, et al., 1993; Levings, et al., 1996) (Figures 20 and 21). In particular, Parks Canada has commissioned numerous studies to delineate marine regions as part of its efforts to develop its national system of parks.

One of us was involved in the development of the classification of the offshore regions of the Scotian Shelf for the Natural History of Nova Scotia (Davis and Browne, 1997; Davis, et al., 1994) (Figure 22). This exercise involved consideration of physiographic, geological, oceanographic, and biological features and a review of world classification systems. The approach used in the Natural History of Nova Scotia was modelled, with some modifications, after approaches which had successfully been used on terrestrial environments to describe ecologically significant units, but included consideration of the three-dimensional nature and other characteristics of the ocean, such as ocean currents and upwellings. In particular, the physiographic divisions of the Scotian Shelf described in King and Fader (1986) were used in subdividing the shelf into useful units. In addition, some consideration of existing marine classifications for the Scotian Shelf would ensure that the system fits both the context of previous knowledge and as well provides a framework into which management systems for adjacent regions (e.g. Newfoundland) could fit. Some classification efforts such as the classification of Large Marine Ecosystems (LMEs) (Sherman, et al., 1990) (Figure 23) may not be suitable, however, having been set up with only limited consideration of global classification then available, and are not as appropriate as those such as Wiken, et al., (1996) which present extensions of an accepted global system. Efforts on marine classification on the west coast of Canada (Levings, et al., 1996) have already productively used the marine classification presented in Wiken, et al (1996), and we would recommend that at the very least, the Scotian Shelf should as well, falling in the 'Atlantic Marine Ecozone', which is the appropriate zone from that system.

Systems which use a biophysical approach are to be preferred since biological systems on the seabed and in the water column depend ultimately on both physical and biological factors. For example, although surficial geology distribution can influence benthic communities, types of communities are also related to water temperature; benthic biomass and productivity are commonly directly related to water column primary production (Hargrave and Peer, 1973; Figure 24); and benthic biomass is inversely related to depth, reflecting the utilization of carbon fixed in the water column and decreasing amounts reaching the bottom with increasing depth (Figure 25). Except in shallow nearshore waters where seaweed production is equally important, the seabed communities on the continental shelf are dependent on production in the water column.

Benthic processes are closely connected with water column ones, particularly at shallow depths where the benthos interacts with water column processes through benthic pelagic coupling, releasing nutrients back into the water column. In places where the mixed layer meets the seabed, water column production can be channelled directly to the seabed through settling of phytoplankton and detrital particles. It could be hypothesized that the zone above the typical mixed layer depth might support distinctive biological communities. Objective biophysical classifications such as that developed by the World Wildlife Fund (WWF) (Day and Roff, 2000), although at an early stage of development, can identify bottom communities which may be significant, such as a cold-water dominated zone off Cape Breton Island and the shallow zone around Sable Island which corresponds to the zone above the approximate depth of the mixed layer (Figures 26 and 27). Approaches of this type with refinement and input of latest data on biophysical parameters of temperature, circulation, and depth, as well as biological parameters such as productivity, may be able to provide refined classifications based on the WWF 'landscape' model.

In summary, a classification approach that would be suitable would: 1) be consistent with existing global systems and approaches, at least at the largest scale; 2) include the three dimensional nature of the marine environment; 3) deal with the pelagic and benthic communities of given areas as parts of the same ecosystem; and 4) be flexible enough to deal with the absence of knowledge about some ecosystem components.

Current interest in management of Canada's continental shelves, and concerns over conservation of a range of species—from whales to coldwater corals; recognition of impacts of long-standing industries such as the offshore trawling fishery; and increasing interest in development of offshore hydrocarbon resources on the Scotian Shelf; as well as development of new geological techniques, have begun to extend our knowledge of and interest in offshore benthic communities. This knowledge will be useful in understanding and classifying the Scotian Shelf for ocean management purposes in the future.

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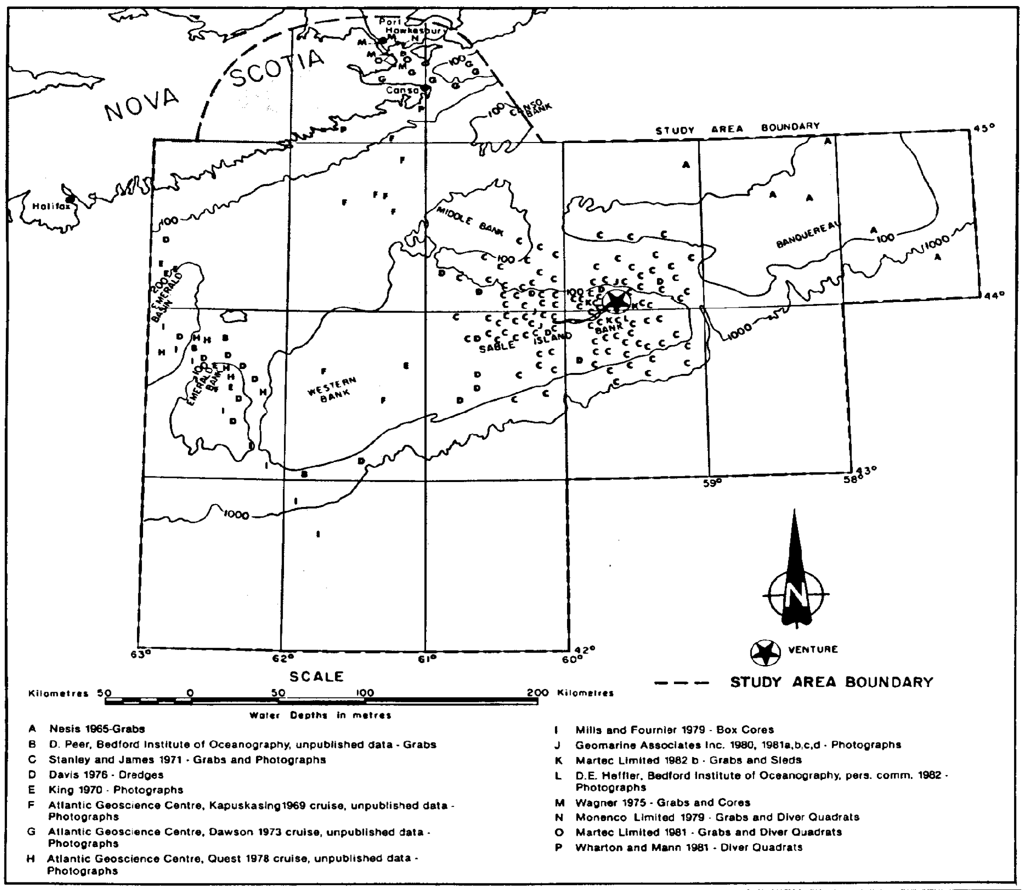

Source: McLellan 1957; Sutcliffe et al. 1976; Smith 1978; Houghton et al. 1978

Figure 1. Summary of sources of information on benthic communities of the Scotian Shelf carried out pre-1983 (Mobil, 1983).

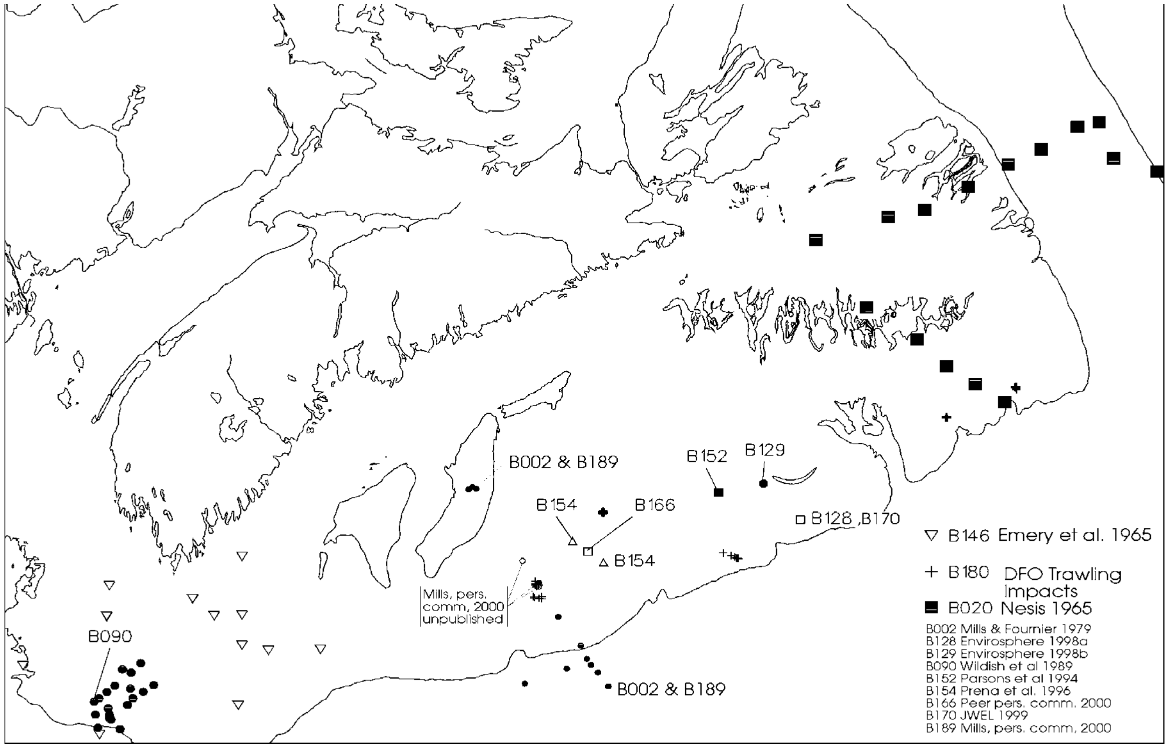

Figure 2. Studies of Benthic Invertebrate Biomass on the Scotian Shelf, 1965-1998 (from Stewart, et al., 2001).

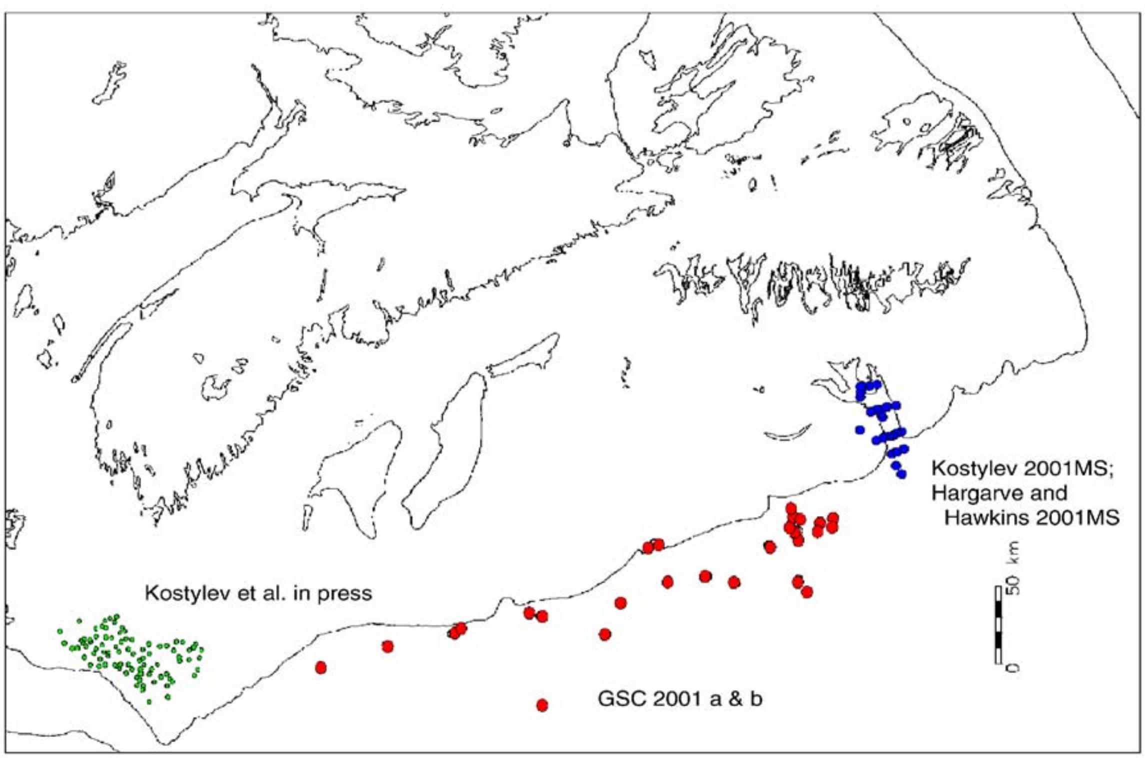

Figure 3. Recent studies of benthic communities using combined acoustic and geological methods, bottom photographs and spot grab sampling to classify extensive areas of the seabed.

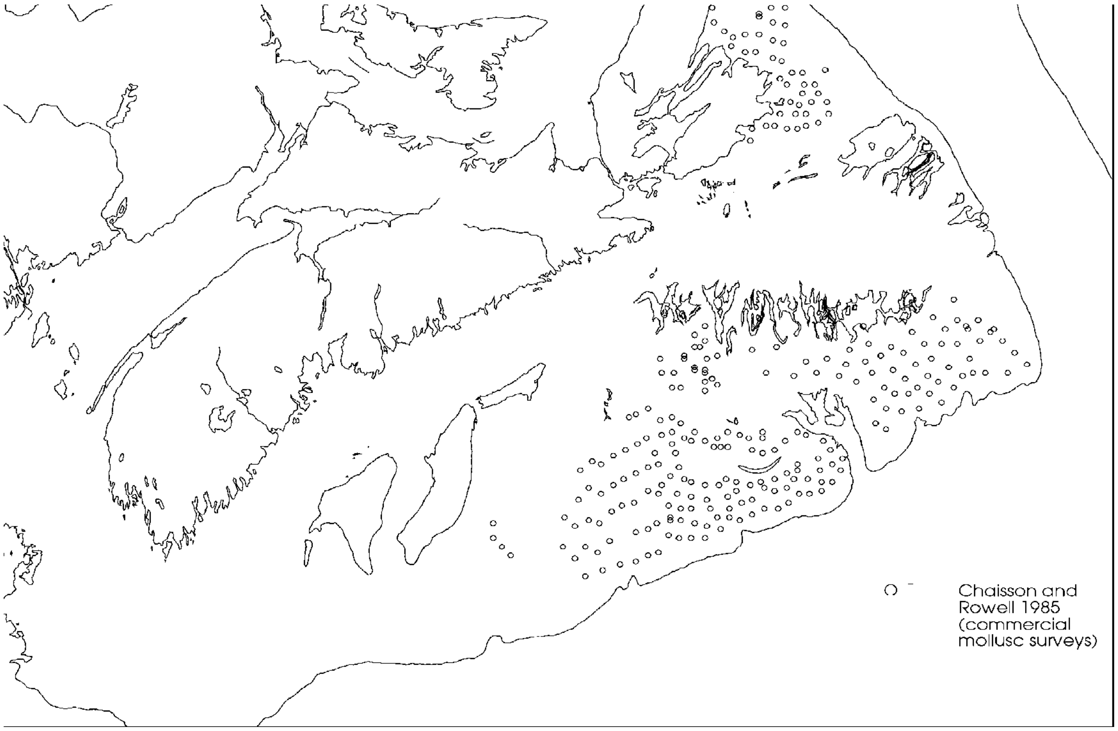

Figure 4. Locations of sampling for commercial molluscs, *Mactromeris* and *Arctica* on the Scotian Shelf (Chaisson and Rowell, 1985).

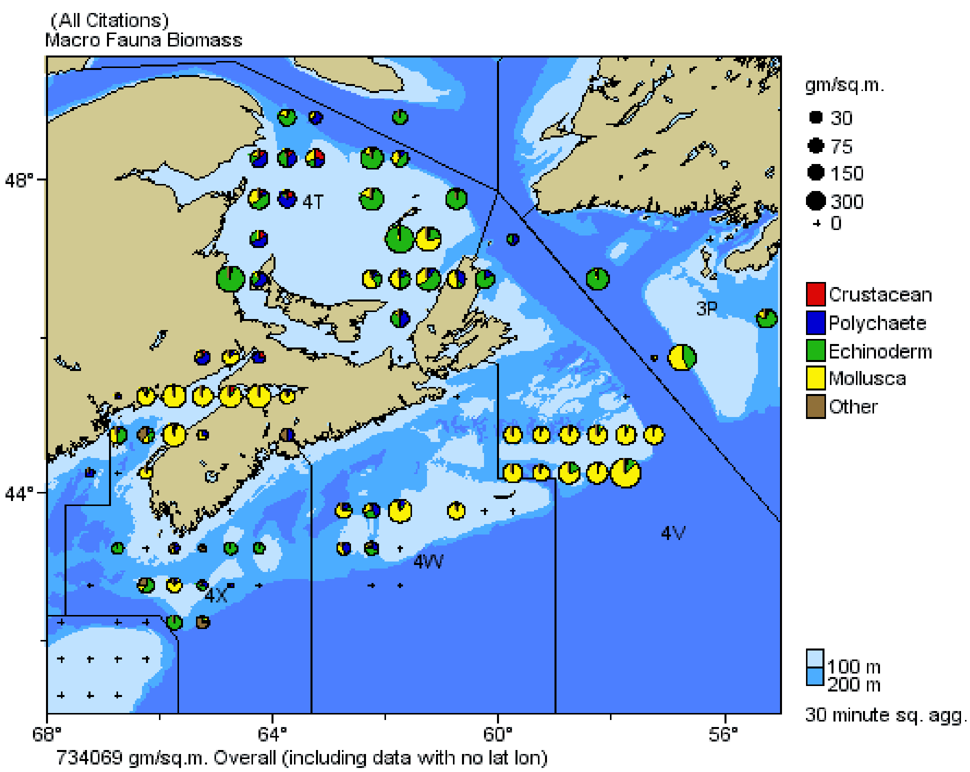

Figure 5. Mapping capability for macrobenthic biomass data in the DFO, Marine Fish Division Virtual Data Centre.

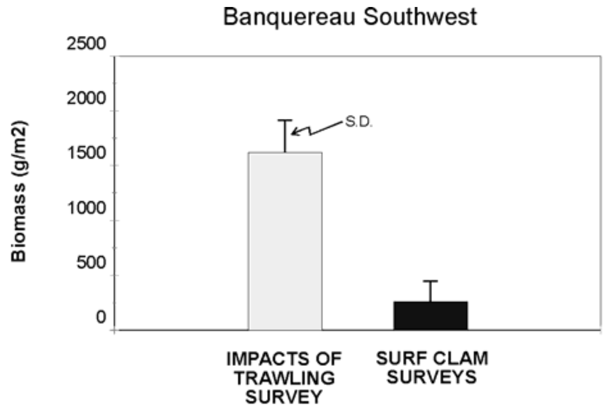

Figure 6. Biomass of the benthic community at a location on Banquereau Bank is greater than for the size fraction containing the commercial species (Stimpson's Surf Clam, *Mactromeris polynyma*). (Data source: Fisheries and Oceans Canada, Kevin MacIsaac).

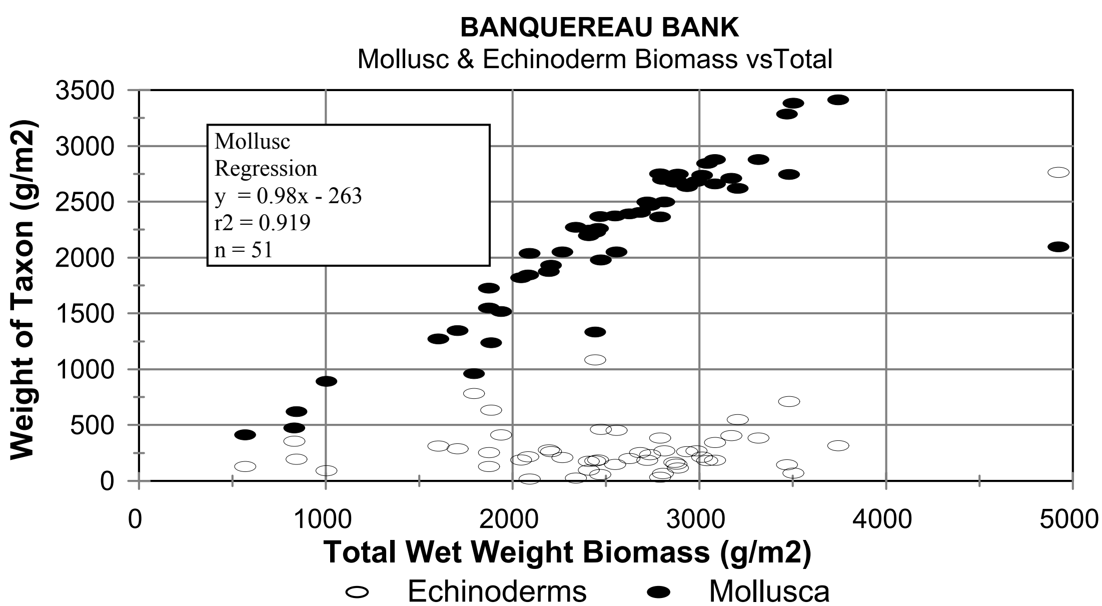

Figure 7. Relationship between benthic biomass and biomass of molluscs and echinodrems, Banquereau Bank (Data source: Fisheries and Oceans Canada, Kevin MacIsaac).

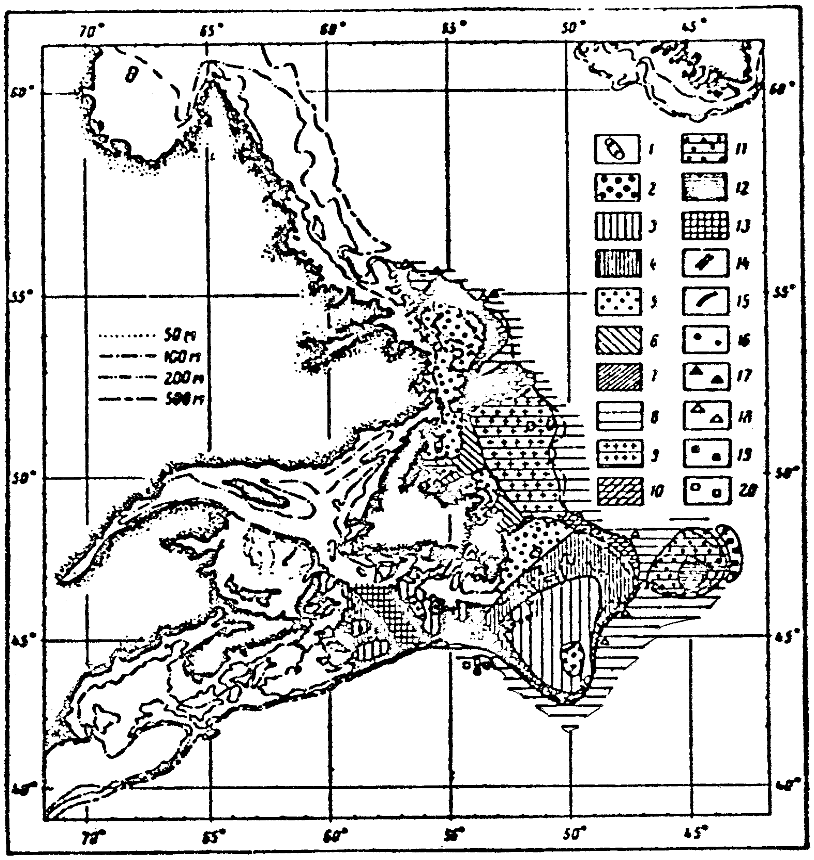

Figure 8. Biocoenoses of the Canadian eastern continental shelf and slope (Nesis, 1965).

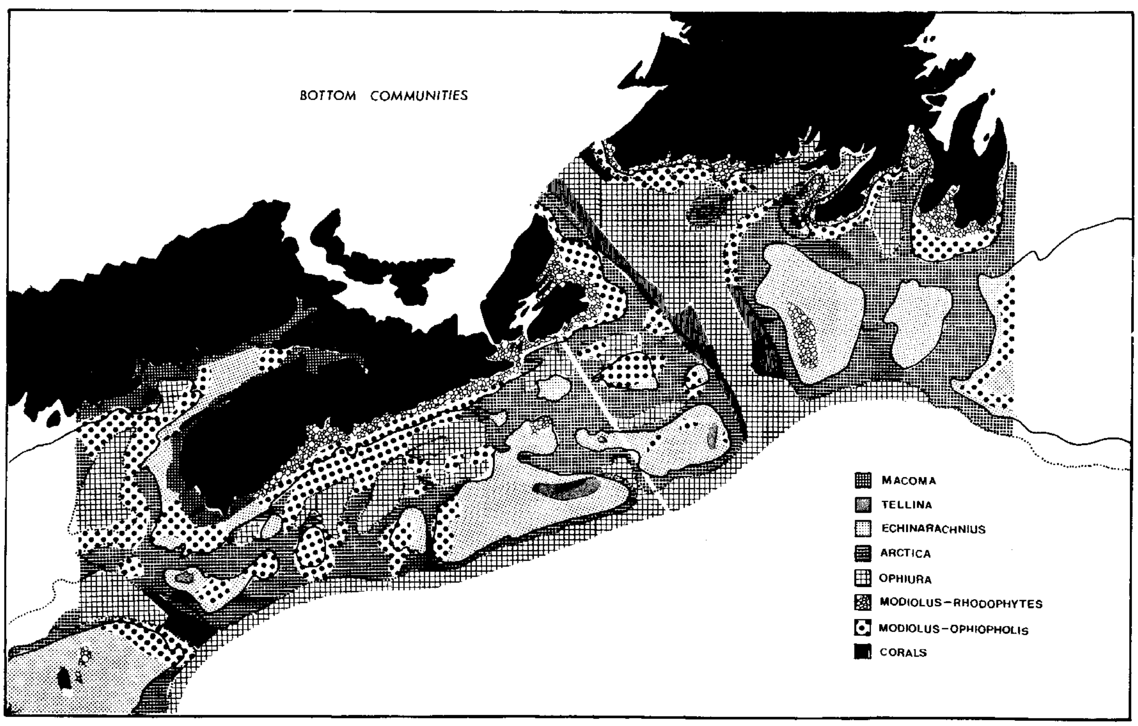

Figure 9. Bottom communities on the Canadian eastern continental shelf and slope (Steele, et al., 1979).

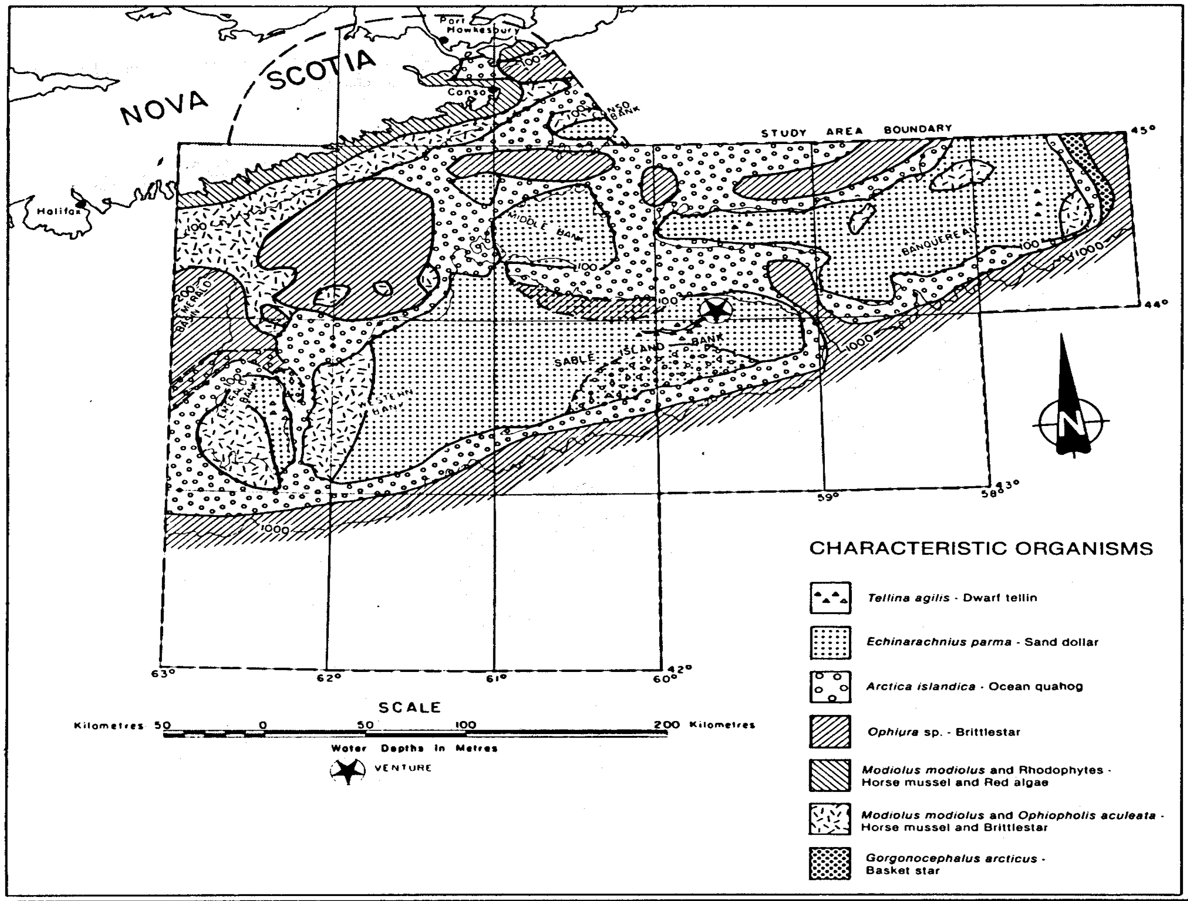

Figure 10. Characteristic benthic communities from the central Scotian Shelf (Mobil, 1983).

Determinants of Benthic Biological Communites

- geography/water masses/temperature
- food supply
- bottom substrate and stability
- interactions with other species (e.g. predation)

Figure 11. Determinants of benthic biological communities.

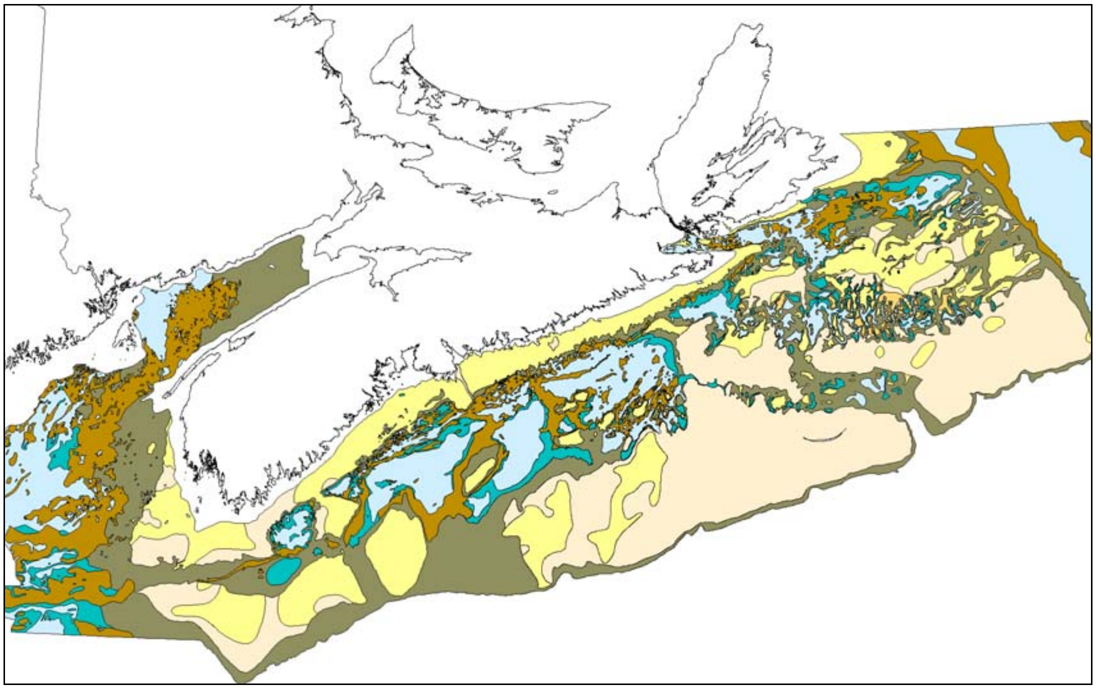

Figure 12. Distribution of surficial sediments, Scotian Shelf.

Scales of Seabed SedimentVariability

- centimetres to tens of centimetres
  (sand ripples, rocks, stones shells, territory of commensal species)
- metres to tens and hundreds of metres
  (sand waves, megaripples, sand ridges; shell beds)
- hundreds of metres to kilometres
  (sand ridges, gravel waves)
- kilometres to tens and hundreds of kilometres
  (geological scale sediment facies)

Figure 13. Scales of seabed sediment variability.

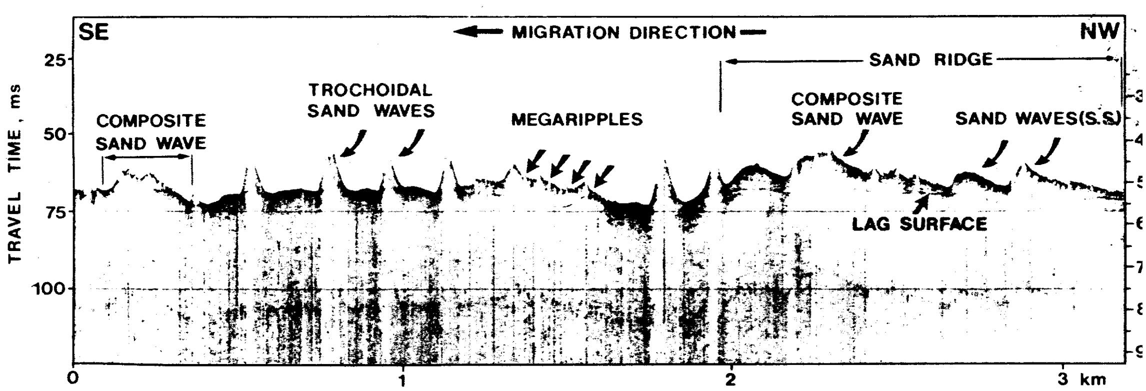

Figure 14. Surficial sediment bedforms on the eastern Canadian continental shelf (Amos and King, 1984).

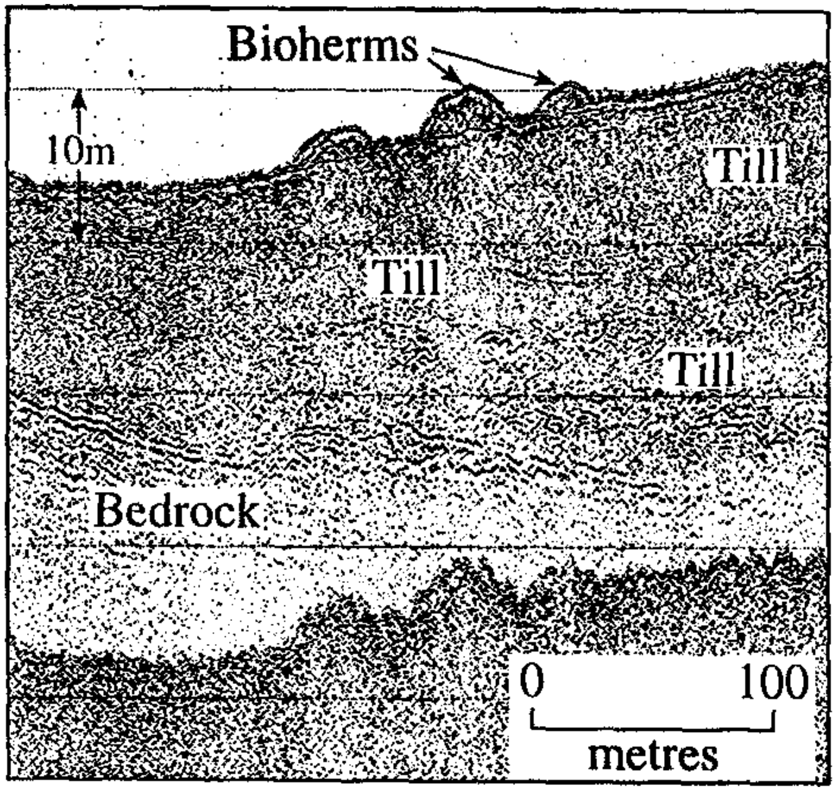

Figure 15. Bioherms (seabed features with associated biological communities) in the Bay of Fundy (Wildish, et al., 1998).

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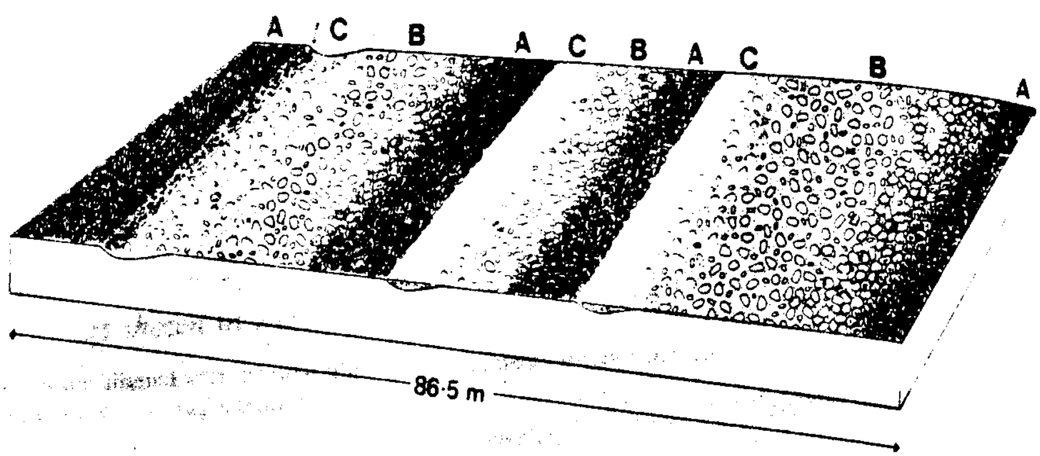

Figure 16. Biological communities are associated with seabed geological features in the English Channel (Holme and Wilson, 1985).

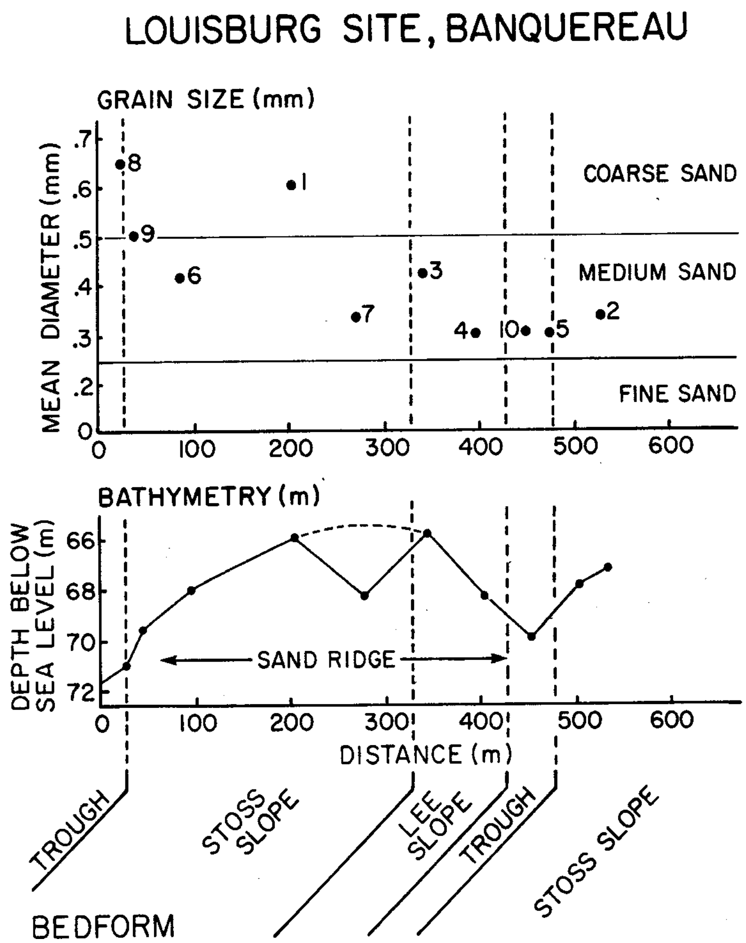

Figure 17. Sediment grain size variation across a sand ridge, Banquereau Bank (Amos and Nadeau, 1988).

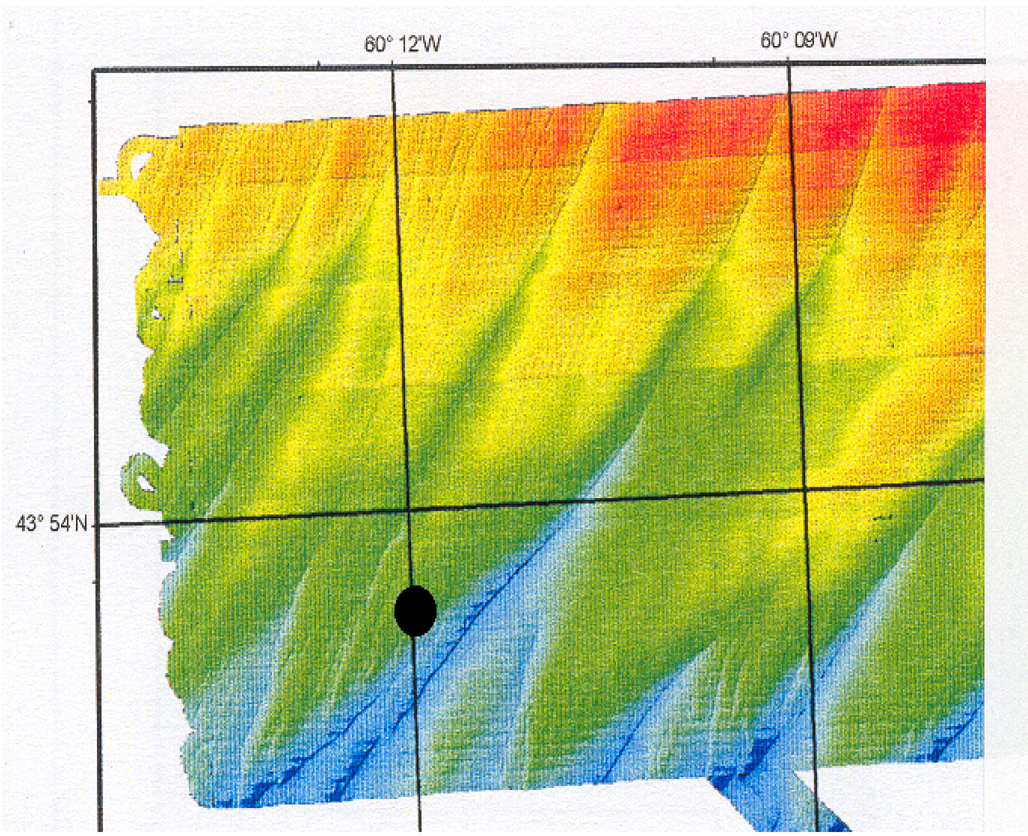

Figure 18. Sand ridge formations south of Sable Island in the vicinity of the Thebaud well site (Li, et al., 1999 MS). Dot indicates location of wellsite.

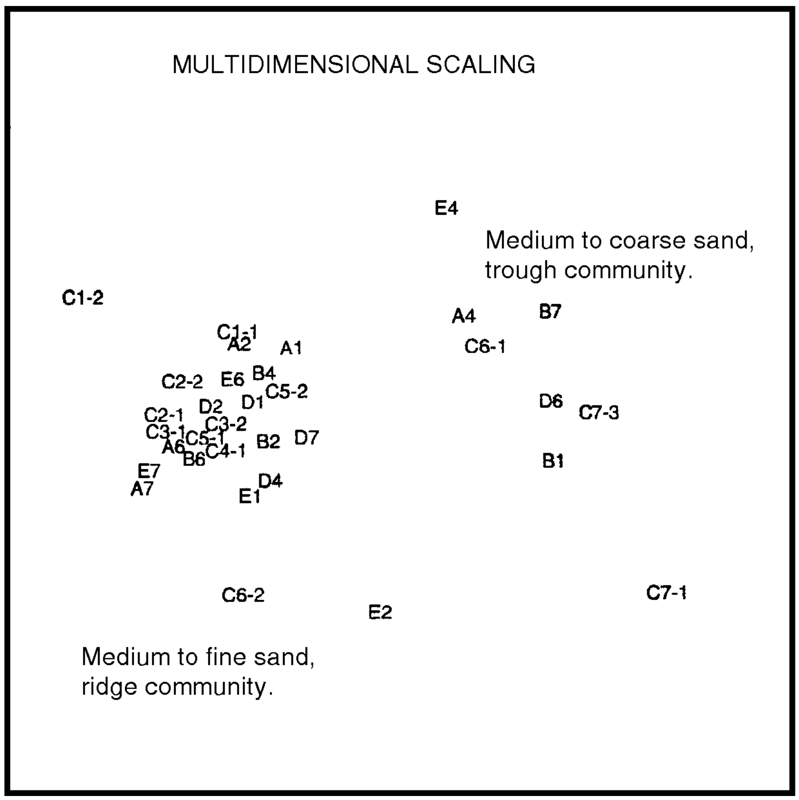

Figure 19. Multidimensional scaling plot of stations on sand ridge system based on benthic community composition. (Envirosphere Consultants Limited, 1998).

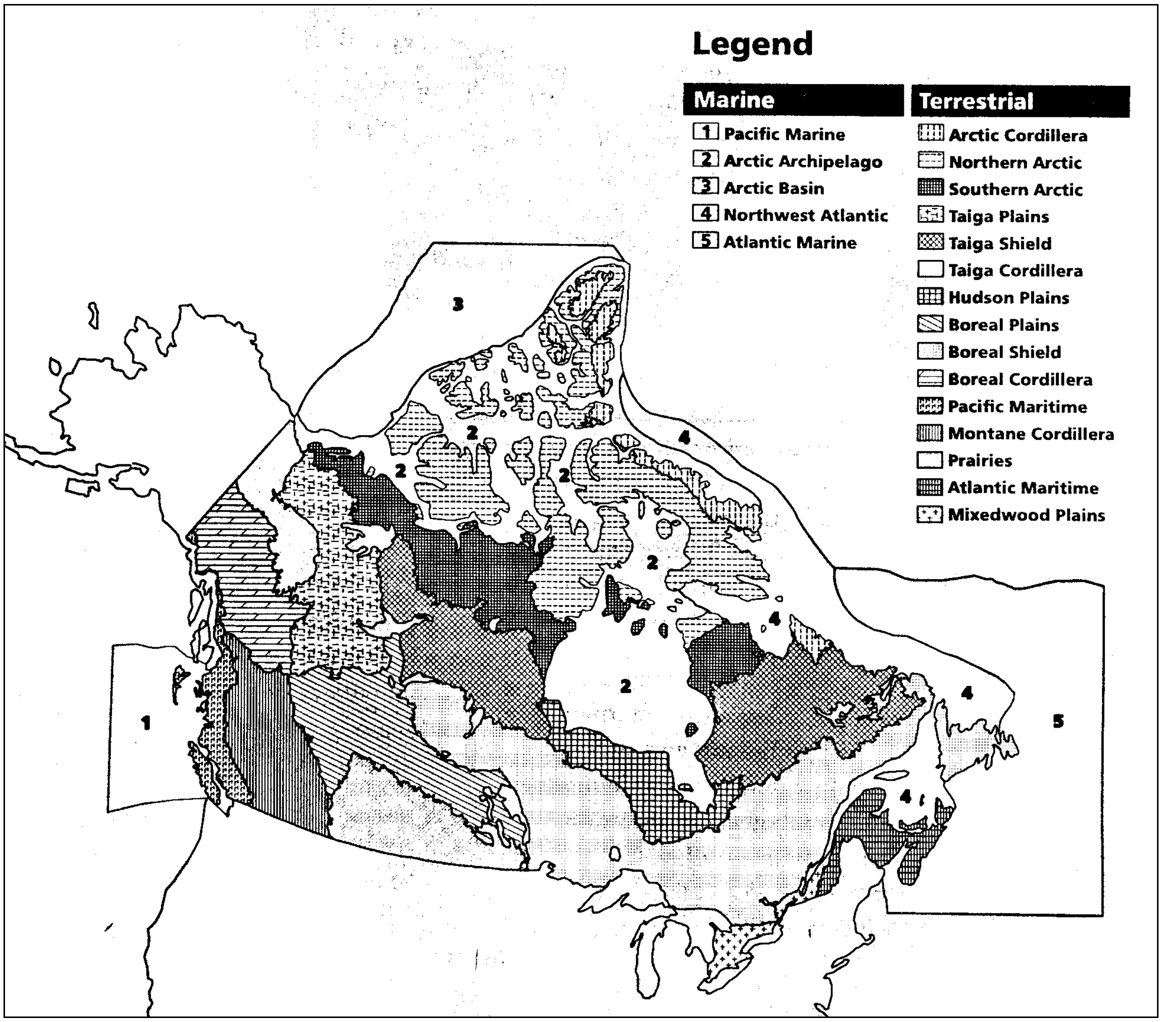

Figure 20. Ecoregions of Canada (from Wiken, et al., 1996).

Hierarchy of Ecosystems

- eco-*zones*
- eco-*regions*
- eco-*districts*
- eco-*sections*
- eco-*sites*
- eco-*elements*

Figure 21. Ecosystem regions for the classification of terrestrial and marine regions of Canada (Wiken, et al., 1996).

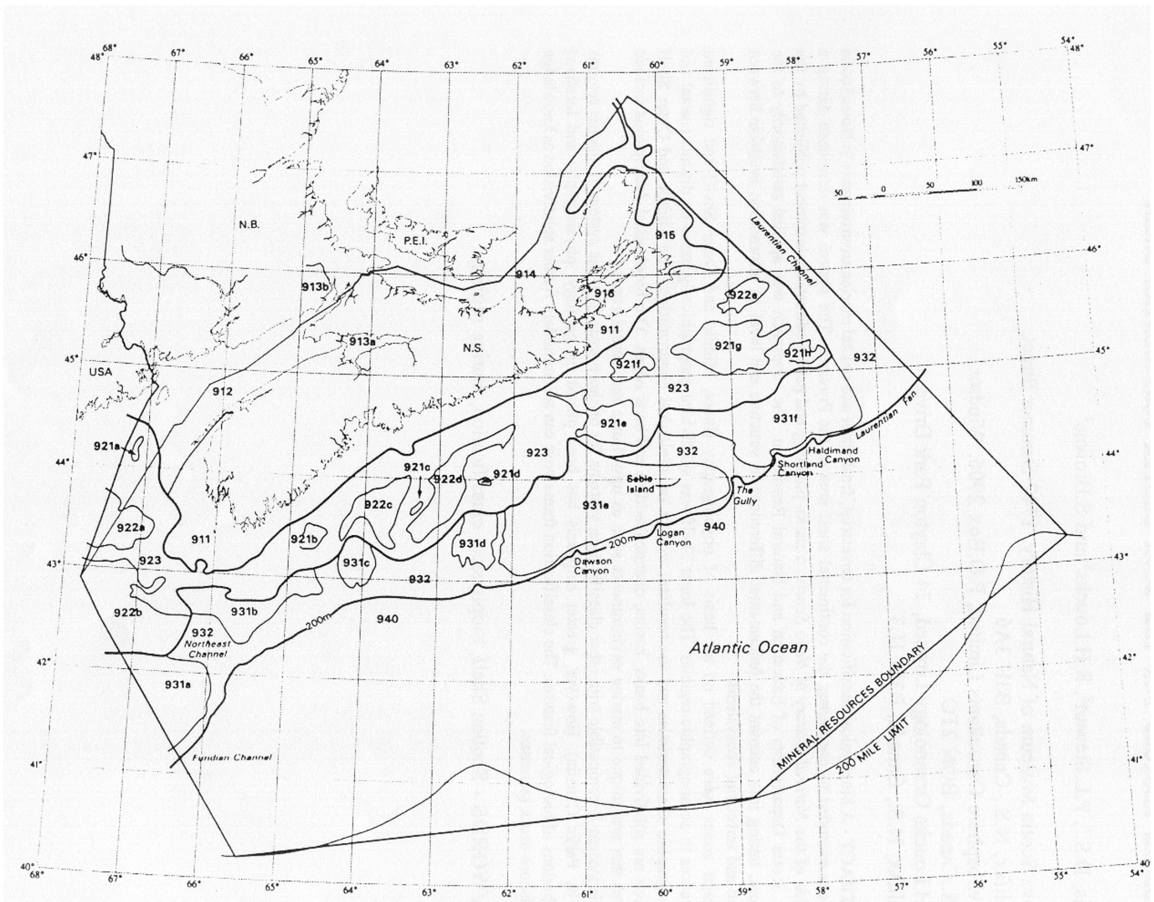

Figure 22. Classification of offshore regions from the Natural History of Nova Scotia (Davis and Browne, 1997).

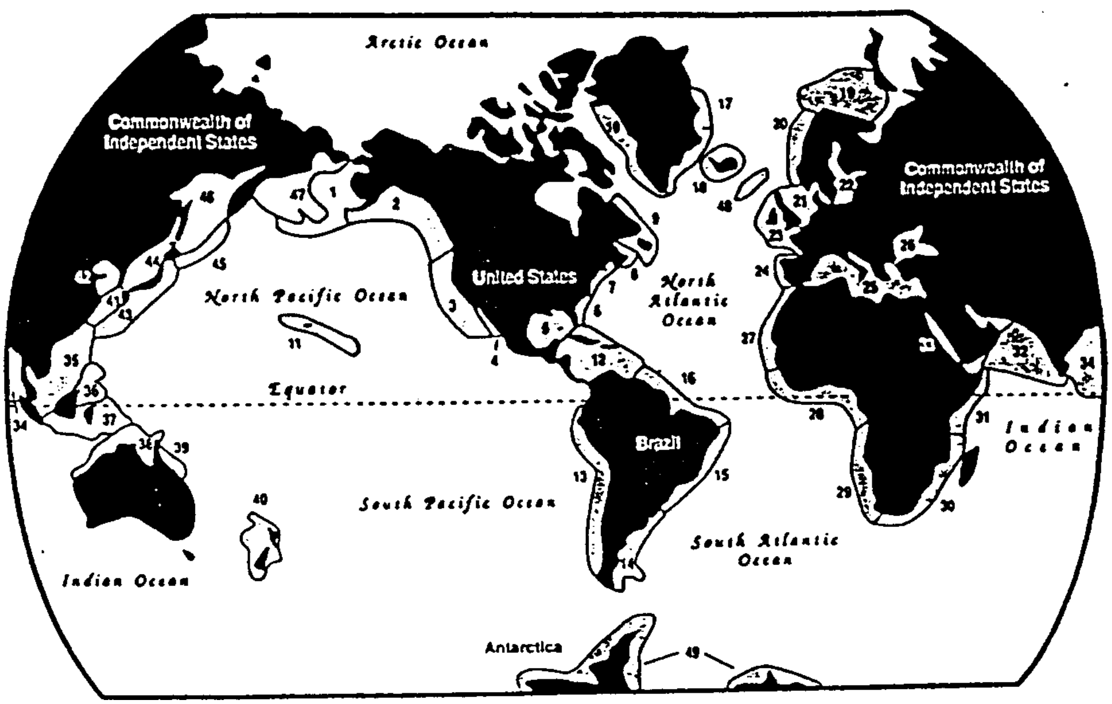

Figure 23. Large marine ecosystems (Sherman, et al., 1990).

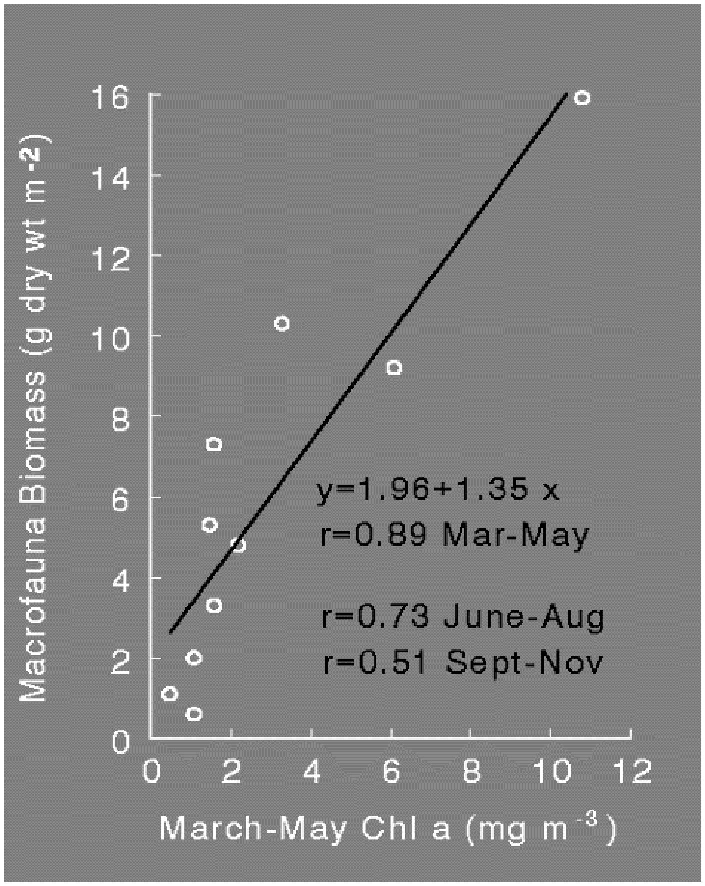

Figure 24. Relationship of benthic community biomass to primary productivity in the water column (from Hargrave and Peer, 1973).

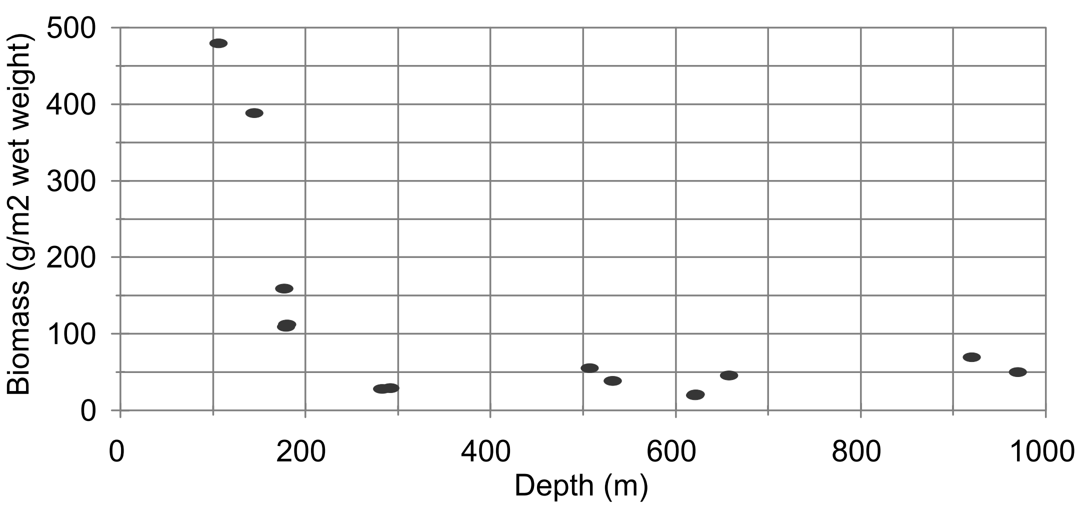

Figure 25. Typical variation of benthic community biomass with depth between continental shelf and slope environments (from Stewart, 1983; for the continental shelf of the Davis Strait and Ungava Bay).

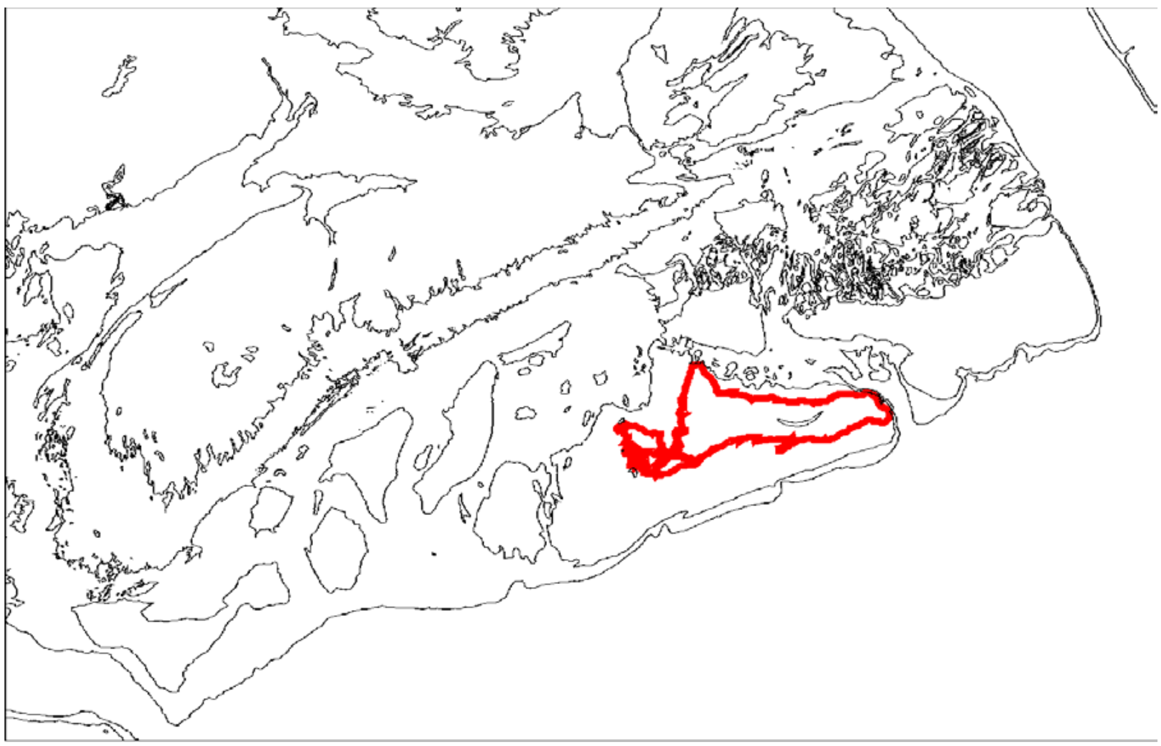

Figure 26. Location of the 50m contour on Sable Island Bank, as an indication of the contact of the surface mixed layer with the seabed.

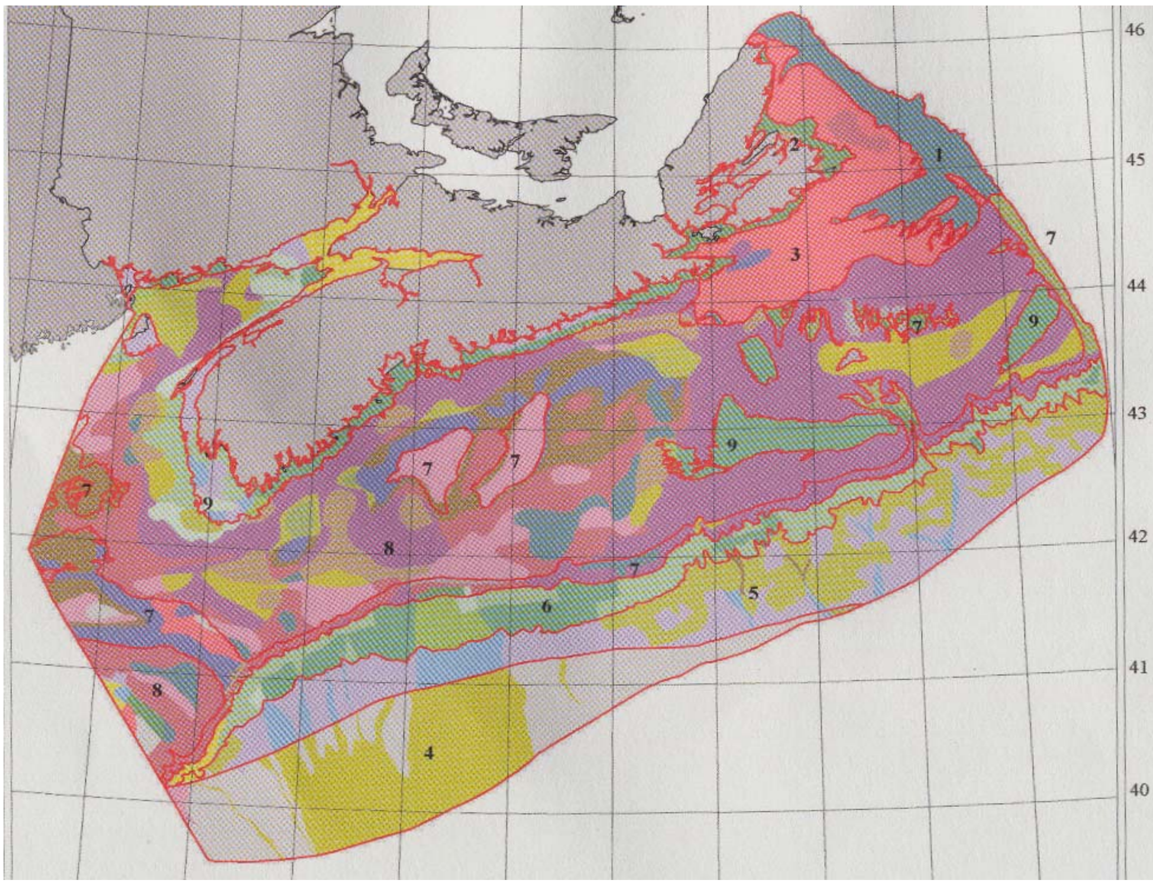

Figure 27. Classification of environments on the Scotian Shelf based on a 'landscape' approach (Day and Roff, 2000) is an objective approach which identifies regions which may be biologically significant.

EUNIS CLASSIFICATION: AN EXCELLENT EXAMPLE OF A WELL-DEVELOPED GENERAL CLASSIFICATION SYSTEM FOR MULTIPLE USES

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http://www.bio.gc.ca/

The European Union Nature Information System (EUNIS) has been under development for a number of years with the goal of establishing a useful habitat classification system for all terrestrial and aquatic lands.

The goals of the effort are to:

- provide a “common language”;
- enable mapping of units at a regional level;
- be comprehensive and applicable at different levels of complexity;
- allow aggregation, evaluation and monitoring of habitat units; and
- provide a common framework for new information and links to other classifications.

It is based on a number of previous classification efforts and builds on them by using a number of workshops and consultations with researchers with experience in the various aquatic habitats. The International Council for the Exploration of the Seas (ICES) has played a role in this process and has accepted the EUNIS classification down to level 3 as a working framework for implementing and testing its usefulness.

The principles of the EUNIS classification are:

- Classification is hierarchical;
- Units at a given hierarchical level to be of similar importance;
- Clear criteria for each division;
- Logical sequence of units;
- Use clearly defined non-technical language;
- Ecologically distinct habitat types supporting different plant and animal communities should be separated;
- Habitats from different locations differing on the basis of geographical range only should not be separated; and,
- Habitat units and habitat complexes are separated.

These have been worked out through the numerous attempts to apply the classification and are not always found in other systems.

EUNIS uses a well-documented decision key to separate dissimilar habitats. The high levels are determined primarily by water depth and surficial geology/sediment type. The following figure shows the decision system down to level 2 in the classification (Figure 1).

Although ICES has only accepted down to Level 3, the system readily supports the development and definition of the additional levels of detail. In the United Kingdom, EUNIS levels 4, 5 and 6 have been identified for many habitats. At this higher resolution, biological parameters, such as functional groups, species groups and specific indicator species is used.

Each classification and decision point is well defined and supported by documentation. The extensive web page provides all of the background documentation, including an extensive list of classifications:

http://mrw.wallonie.be/dgrne/sibw/EUNIS/eunis.fulllistA.html.

As an ICES country, Canada has committed to considering the application of the EUNIS system, down to level 3, for use in classifying aquatic habitats. Application of this classification in the Northwest Atlantic will require much additional work to map the necessary underlying bathymetry, sediments and distribution of biological communities. Recognising the limited resources available to classify and map benthic habitats, the EUNIS system may be worth considering as a proven workable framework, even if it may not be totally transferable.

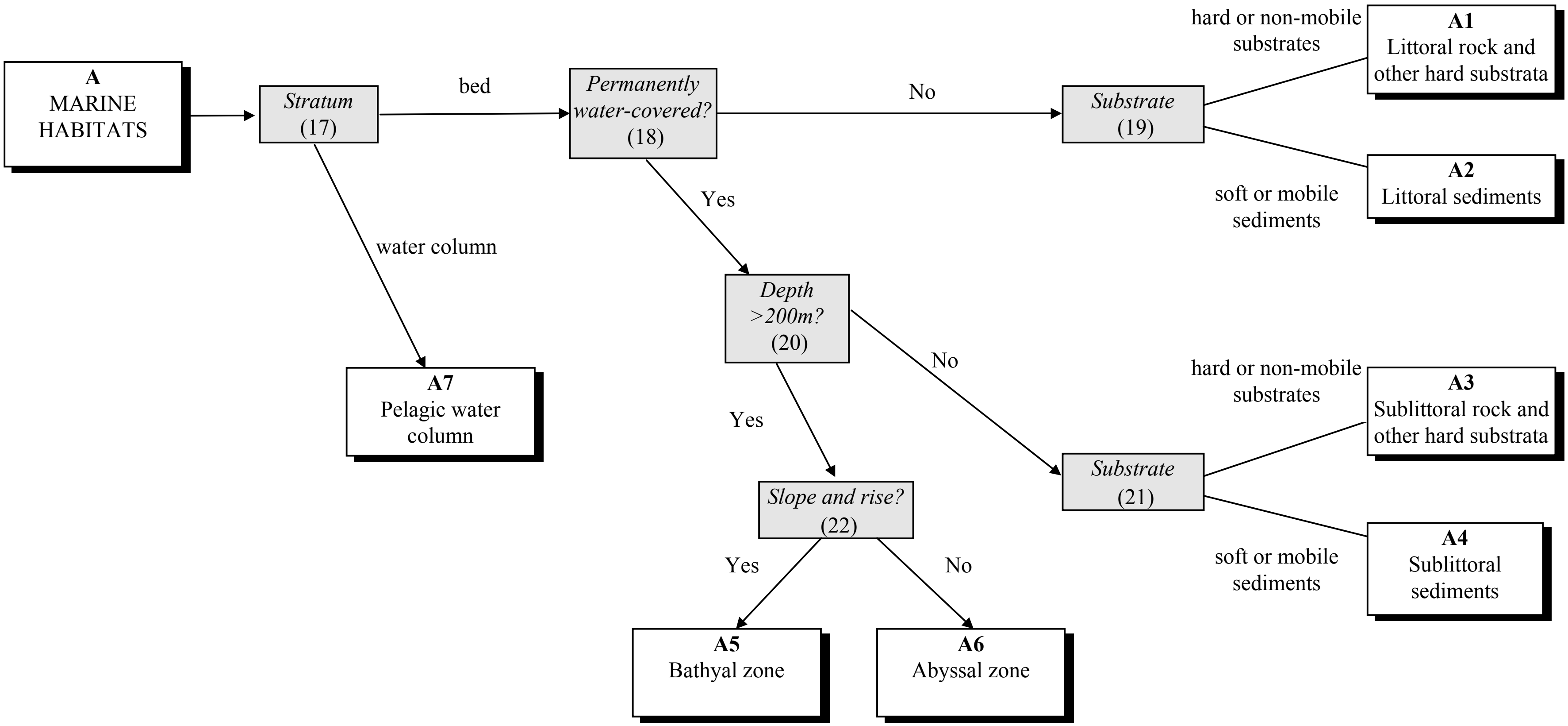

Figure 1. Decision tree down to level 2 in EUNIS habitat classification system.

THE SURFICIAL SEDIMENTS OF THE SCOTIAN SHELF: A REVIEW OF PUBLISHED MAPS, LIMITATIONS, FUTURE USES AND RECENT ADVANCES IS SEABED MAPPING

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The surficial sediments on the Scotian Shelf were studied and mapped by the Geological Survey of Canada in a first round of seabed mapping that occurred from 1967 to 1984. The program was regional in scope and began with the production of the first map in an area extending from Halifax to Sable Island (King, 1970) where the methodology was developed. Subsequent studies and maps in the series by Fader, et al., (1977), Drapeau and King (1972), MacLean and King (1971), MacLean, et al., (1977), Fader, et al., (1988), and Fader, et al., (1982), produced an understanding of the surficial geology of the Scotian Shelf and adjacent areas. Kranck (1971) followed with a similar approach for areas of the Northumberland Strait, and Loring and Nota (1973) mapped the surficial geology of the Gulf of St. Lawrence with an emphasis on sample analysis. From these studies, a formal stratigraphy for the Scotian Shelf was defined and refined (King and Fader, 1986). Summary surficial sediment compilations were produced for the Scotian Shelf Basis Atlas Series (Fader, 1991). All of the surficial geological maps are accompanied by detailed reports on methodology with details on sediment distribution, character and stratigraphy.

The maps produced from this systematic mapping program were based on interpretation of echograms of the seabed, which are similar to high-resolution seismic reflection profiles, combined with analysis of many thousands of grab samples and bottom photographs. Interpretation of echograms considered acoustic penetration, seabed hardness, internal unit reflection character, seabed micro and macro roughness, and sediment stratigraphy. Five surficial sediment units, termed formations, were identified and mapped (Scotian Shelf Drift, Emerald Silt, Sambro Sand, Sable Island Sand and Gravel and LaHave Clay), and a chronology of the geological history was proposed. 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 110m below present sea level, and 3) a final marine transgression of advancing beach processes to the present coastline. These are the key concepts that lie behind the interpretation of the sediments and the production of the maps, which display a mix of fact and interpretation. The maps and associated reports have provided a conceptual framework for knowledge of the distribution and character of sediments on the Scotian Shelf. Over 60% of the sediments on the Scotian Shelf can be described as being predominantly relict, that is, exhibiting characteristics of past and non-active environments, with little modern modification. Most recent maps in the series benefited from advancing technology such as the application of high-resolution seismic reflection profilers and sidescan sonar systems (Fader, et al., 1982).

Recently there has been a renewed interest in the surficial maps of the Scotian Shelf in response to Canadian requirements for improved management of the seabed derived from legislation in the Oceans Act that includes diverse activities such as habitat characterization, conflict resolution, resource extraction and conservation, and the selection of Marine Protected Areas. The question that arises in light of these requirements is to the validity and utility of the existing maps for such applications.

For proper use of the seabed to be effected and conflicts to be avoided or mitigated, detailed knowledge of living and non-living seabed resources, as well as seabed characteristics and processes, is essential. Users of the seabed generally require three categories of knowledge.

These are:

1. the distribution of materials and their associated properties;
2. the morphology of the seabed (commonly defined as bathymetry); and
3. an understanding of seabed dynamics (erosion, deposition, sediment transport, stability).

To evaluate the existing maps from this perspective it is necessary to assess how they address each of the three requirements. The most important contribution of the maps is their portrayal of sediment type, classification and distribution in a conceptual model framework. This was the prime intention of the initial mapping program. The formational basis of sediment classification enables complex sediment variations to be combined in a logical, simplified and workable geological framework that can accommodate sampling problems and errors, minor local variations, post-depositional winnowing and a lack of continuous seabed information. Simple textural maps based on sample control alone would not be able to characterize the seabed in a coherent geological sense and would be of little practical value. For example, the classification of glacial till (Scotian Shelf Drift) allows a wide variety of mud, sand and gravel mixtures to be summarized within a coherent depositional unit directly deposited by glacial ice as a moraine.

On the other hand, the morphology of the seabed is poorly represented on the surficial maps. The bathymetry was extracted from published hydrographic charts produced at similar scales and projections and intended for safe navigational purposes and not intended (or able) to portray the detailed morphology of the seabed. In many areas the survey control is spaced at distances of hundreds of meters to several kilometres, thus small-scale morphological variations over features such as sand waves, iceberg furrows, pockmarks, and bedrock are not resolved.

Regarding a dynamic assessment of the seabed, the maps also poorly represent conditions of sediment transport and deposition. In a broad sense, depositional areas can be defined where, for example, LaHave Clay deposits occur, but details of dynamics are not portrayed nor are they interpretable. Sidescan sonar data, which clearly portrays dynamic sediment features, was largely unavailable for the production of the earlier maps. However, later maps on the eastern and western areas of the Scotian Shelf depict fields of bedforms (sand waves) from interpretation of limited sidescan sonar coverage.

This assessment clearly shows that the earlier maps, although rich in ground-truthed sediment data, are lacking in morphological detail and dynamic content. The recent application of new multibeam bathymetric mapping techniques to several previously mapped areas has given very high-resolution (decimetre) insight into morphological character and dynamic processes active on the continental shelf. Such dynamic processes, interpretable from multibeam data, include seabed current and wave scouring, non-depositional moat development, bedform formation, sediment transport pathways, sedimentary furrow formation, etc. Through digital processing techniques, multibeam bathymetric data can also be displayed to enhance subtle morphological attributes giving considerable insight into previously unknown relationships between currents, waves and resulting seabed processes of erosion and deposition.

The conclusion to be drawn from this assessment is that the existing surficial maps on the Scotian Shelf are very limited in their potential to be used for adequate management of seabed related activities such as outlined above. The 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. They do, however, provide an essential framework of understanding and can serve as the basis for definition of future detailed study areas and geological interpretation.

In order to address modern issues on the continental shelf involving the seabed, multibeam bathymetric mapping and its associated thematic products of morphology, backscatter (proxy for sediment type), slope, interpreted geology and habitat maps are required. Such an approach is captured in the Canadian SeaMap proposal to map the offshore areas of Canada with a long term, systematic program.

If the existing surficial geological maps are to be used in the future until supplanted by new high-resolution multibeam derived products, then there are limitations on their use that must be understood by geologists, biologists, managers and policy formulators. For example, it is not advisable to try and extract site specific textural information from the maps unless the location represents a sample site. The maps were based on textural data from many samples and the actual data base for the site sediment information can be accessed in a GSC Open File Report # 1430 (Sonnichsen, et al., 1987). The coarser the sediment, the less reliable the textural information. This is partially a function of the equipment used to collect samples of the seabed and a general inability to properly sample coarse gravely sediment. Gravel clasts often prevent the jaws of sampling equipment from completely closing which results in a loss of finer-grained material and a skewness toward coarseness. Thin gravel lag surfaces overlying different sediment types result in unique sampling problems whereby the sediments often get mixed during the sampling process. Therefore, the sediment analysis from coarse sediment (till and gravels) is largely sampler dependent and historically less accurate. Modern seabed sampling with large seabed invasive samplers, such as the IKU bucket grab, is designed to take large volume grabs to penetrate the sediments and preserve structure down to 0.75m depth.

Fine-grained sediment boundaries, for example, between LaHave Clay and till on the early maps, are generally very accurate, whereas the coarser grained sediment boundaries (between Sable Island Sand and Gravel) are less accurate. This is because the fine-grained clays and silts are easily differentiated acoustically from coarse sediments and their boundaries can be mapped in great detail. Coarse-grained sediments are not easily differentiated with echograms and mappers had to rely on the collection of many samples or other parameters such as roughness and bedforms to differentiate sands and gravels, particularly on the offshore banks.

The early surficial maps also have shortcomings in the nearshore on the inner Scotian Shelf. Here the seabed was mapped as dominantly gravel with minor sand located in isolated patches and channels. Modern multibeam bathymetry and sidescan sonar systems show large expanses of exposed bedrock, often in ridges in these areas. However, attempts at sampling these surfaces retrieved gravel, which had accumulated at the base of steep bedrock slopes where samplers tended to fall. On echograms, gravel and bedrock have similar acoustic characteristics.

In conclusion, caution should be exercised in using the existing surficial maps for management of the seabed of the Scotian Shelf. The Geological Survey of Canada, in a 1996 report on the status of marine geoscience in Canada, suggested that present knowledge of the vast offshore area is roughly equivalent to what was known about onshore Canada in the late 1800s. Modern mapping technologies must be applied to the offshore to adequately address an emerging suite of management issues.

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CHALLENGES IN HABITAT CLASSIFICATION AND MAPPING

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Characterization and classification of the benthic environment is required for educated management of natural resources in Canadian territorial waters. This activity demands development of an informed view on the distribution of marine ecosystems, their function, and biological diversity. It also necessitates geographically accurate representation of acquired knowledge on maps, which would allow planning of management activities and even navigation. Thus, ultimately, a manager would require a map representing areas, which are ecologically different and carry meaningful information required for decision making.

Classification vs. Mapping

Two steps in this process are obviously related and interdependent – classification and mapping. While the first does not necessarily require visual representation, the map is a visual aid by definition, and while imprecisions in classification systems are hidden behind the terms, the maps are assumed to correctly represent nature and the user will immediately discover discrepancies in practice if the map is wrong. Therefore it is important to see the fundamental differences in habitat classification and habitat mapping – their assumptions, use and implications of possible imprecision and inaccuracy.

Any verbal classification is to some degree an exercise in coining terms. Ecological classifications are aimed at pointing out differences between different systems (e.g. shallow vs. deep-water environment), but the borderline between the two is not well defined quantitatively. Because of that an arbitrary classification system displayed on a map would not aid the management system, but to the contrary – obscure the patterns being sought.

An example of mapping a classification system is presented as Theme Regions for the Scotian Shelf (Davis, et al., 1994). While greatly aiding understanding of the nature of shelf environment on a large scale, the system is based on a number of set isolines, which serve as guides for defining the regions, e.g. fishing banks. The portrayal of sea-floor morphology by bathymetric contours involves a prejudicial simplification of the shapes (Froidefond and Berthois, 1983) and the confusion is obvious when a person used to metric system tries to find familiar shapes on a bathymetric map drawn in imperial units. This is not the only problem. If the shelf is subdivided along the contours of e.g. 100 and 200-meter isobaths then it is valid to ask if these particular isobats have any ecological significance?

The most notorious bathymetric contour in marine biology is 200 meters. It is commonly used in reference to “deep-sea” environment, lying deeper than the depth of continental shelves, which is assumed to correspond to 200 meters. Francis P. Shepard (1959) in his description of geology of continental shelves writes the following:

> *“In virtually annexing the shelf, we defined it as the shallow-water area extending to a depth of 100 fathoms (182.88m). This, however, is purely arbitrary [text omitted] and it is only rarely that they [shelves] terminate at or even close to 100 fathoms”.*

Joel Hedgpeth (1957) whose bathymetric classification system is referred to in many marine biology textbooks also mentions the lack of precision in defining different depth zones in the sea:

> *"It should be understood that we are not referring 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".*

The titular nature of classification nomenclature is even more evident from Hedgpeth's discussion of the use of term "bathyal" that has been applied to the environment of continental slope down to about 1000-2000 meters.

> *"We suspect some difference between the environment of the intermediate bottoms and the great abyssal depths, but do not know where transition is".*

There is no controversy that shelf and slope physical environments are considerably different and it is valid to assume that they differ ecologically as well. Current high-resolution bathymetric mapping permits accurate determination of the shelf break and thus, instead of mapping an arbitrary isobath one can draw confident contours of the shelf.

Apparently visualization of an arbitrary classification system immediately uncovers its limitations, and just a minor change in classification system (e.g. replacing 200m depth with seemingly non-quantitative term 'shelf break'), may lead to ecologically justifiable and scientifically meaningful maps that can be used for management purposes. The map is an ultimate test for a classification system and an ultimate product required by managers at the same time.

Top-down vs. Bottom-up Approaches

When used for the purpose of mapping, a-priori classification of environment may be thought of as 'top-down' approach. Assumptions based on the knowledge acquired elsewhere are propagated along the route from general theory to small-scale spatial definition. The mapping then is based on the assumption of some relationship between physical factors and biological components and thus is strongly based on the combination of maps of physical variables.

'Bottom-up' approach leads from observation to generalizations, and is based on grouping of observations on the basis of their similarity. Observations are usually well defined spatially and the errors in defining boundaries of groups of similar observations depend on the intensity and grain of sampling. The main assumption of this approach is that our sampling correctly represents the reality, which is not necessarily true. Of course we need a sufficient number of samples to cover the study area.

Habitat maps were created for separate commercial species and have had distinct value for commercial fishery and management. An ecosystem approach requires knowledge of distribution of spatially defined areas populated by distinct biological communities. Therefore we look at groups of species and agglomerate similar areas occupied by similar benthic communities. Community ecology, however, has endured two opposite views on community - a 'superorganism' theory (Clements, 1916) which emphasizes binding between species through their co-evolutionary history, and the view that communities are simply assemblages of species which are distributed along environmental gradients and co-occur because of similar preferences to their environment (Gleason, 1926). In either case groups of organisms are related to physical factors and can be used to define sets of physical variables that are important to them.

The current, generally accepted view is closer to the latter, therefore it seems reasonable that it is possible to start from the factors and proceed 'down' to communities. Recall, however, that it is the ecological niche which is commonly defined as the limits, for all important environmental features, within which individuals of a species can survive, grow and reproduce (Begon, et al., 1996). Thus the 'top-down' approach would map niches for different associations of species, and not the distinct habitats. This approach disregards the fact that the presence of communities depends not only on a suitability of physical factors, but on the history of ecological succession, colonization and disturbance.

Therefore, the apparent simplicity of a top-down approach is masking two problems – the first one is the contradiction between the inherent belief of Gleassonian approach in the absence of communities, with defining community boundaries, and the second – mapping of ecological niches instead of habitats. While niches are theoretical generalizations, habitats are real by definition.

The basic definition of habitat is the following: it is simply the place where a plant or an animal lives (Begon, et al., 1996). Unfortunately the term "habitat" may be successfully removed from text or replaced by a term "location" in the greater part of scientific literature. Any classification of habitats is arbitrary unless it deals with living organisms or their assemblages, and there would be no need for benthic habitat mapping if the Ocean was devoid of life. Habitat of an organism is a tangible and spatially defined area where the organism lives, that also implies a set of associated environmental descriptors (e.g. substrate, temperature, salinity, etc.). The characterization of habitat requires definition of spatial boundaries and ranges of physical factors based on distribution of a particular organism or group of organisms that share environmental preferences and occupy the same locality. Therefore for the purpose of classification and mapping our working definition of a habitat should be "a spatially defined area where the physical, chemical and biological environment is distinctly different from the surrounding". This definition allows avoiding differences in theoretical connotation of ecological communities, and permits the use of statistical ordination techniques for differentiating distinct benthic environments through the analysis of distribution of benthic assemblages.

Bottom-up Approach

Mapping habitats from species-up assumes that distribution of animal assemblages adequately represents environmental factors, which are responsible for shaping modern day communities. It is assumed that animal communities are indicative of the state of environment during a certain period of time and this way data, especially on distribution of sessile species, explicitly incorporates history of physical environment and existing environmental impacts. Success in interpretation and interpolation of empirical observations on a map depends, among other things, on spatial heterogeneity of studied system and on the grain of sampling. Computer-generated isolines are aesthetically appealing and may produce generalized patterns of studied variables e.g. biodiversity. However, the representation may become dubious when more information about the distribution of sampling effort is available and may become completely misleading when knowledge of the general environmental settings is available. For example one can not interpolate biomass of sand dollars across a canyon. In the Sable Island Gully (Kostylev, 2001) sampling of different geomorphologies showed the distinct differences in species richness between coarse grained glacially modified terrain and other types of substrates (e.g. bedforms, bank top sands, inner canyon environment). This suggests that mechanistic interpolation and extrapolation of sampling data is meaningless, unless the factors responsible for variability in observations are revealed and accounted for.

Because mapping is often based on insufficient data, and involves interpolations and extrapolations often rooted in many assumptions, habitat mapping should be considered geographically referenced modelling, which should be scientifically defendable, and founded on strong ecological theory and meticulous observations.

Some Sources of Mapping Error

It is generally agreed that the diversity in habitat types is important for sustaining high biological diversity. It is necessary therefore to have an accurate description of spatial distribution of different habitats. In defining Marine Protected Areas, for example, it is suggested to assign a region, that contains the highest diversity of habitat types, adequately represents each of the present habitats and has connections to surrounding seascapes as MPA (Day and Roff, 2000). It is evident that definition of such area requires explicit knowledge of distribution of habitat types and accurate representation of their boundaries. Boundaries on geographical maps however, are usually of two types – arbitrary and approximate.

Top-down habitat mapping approaches (e.g. Day and Roff, 2000) involve discrimination of habitat types based on overlaying isolines of different factors and treating their intersections as biologically meaningful regions. For example overlaying depth, temperature, slope, water stratification and sediment type isolines produces a multitude of polygons assumed to be distinct environments. The rationale behind this is the following: if values of isolines correspond to biologically meaningful boundary values of relevant physical factors, then each polygon will represent a distinct environment, which may have distinctive fauna.

There are several problems with such an approach. First – as discussed earlier some isolines are arbitrary; secondly, the errors in spatial allocation of isolines make intersections meaningless. As a result, a count of number of polygons within certain area will have a vague if any relation to the diversity of habitats or fauna. There is a multitude of sources of errors, which lead to imprecision in mapping of individual factors. These are due to natural variability, scarcity of observations, inherent variance in modelling outputs, just to mention a few and just pertaining to variables describing water masses.

Suggestions for Habitat Mapping

Based on our knowledge of benthic communities and their association with the physical environment we can map benthic habitats, being aware of our limitations. It is necessary to recognise that there is a high degree of error in top-down mapping of habitats, and there are very scarce observations on benthic fauna that are available for a consistent analysis and useful for habitat mapping. Therefore the only practical approach for broad scale habitat mapping on Scotian shelf at this moment would be finding a middle way between top-down and botttom-up approaches through cross validation. It is necessary to develop statistically and logically valid approaches for dealing with empirical observations and incorporating them into larger picture, i.e. shelf-wide habitat map.

It is often better to see than to assume. Scientific methodology is plagued with assumptions, which are easily overlooked during design, analysis and interpretation of scientific data. Habitat maps in particular are hypotheses that have to be tested. It is necessary therefore to increase sampling effort on Scotian shelf, through series of dedicated habitat mapping cruises, which involve both DFO and NRCan scientists.

Geological maps offer the highest precision compared to other factors, convey information about bathymetry and texture, and habitat complexity, and undoubtedly should be used as a matrix for habitat mapping.

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HABITAT CLASSIFICATION:
A U.S. (NOAA FISHERIES) PERSPECTIVE

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The USA's National Oceanic and Atmospheric Administration (NOAA) has numerous mandates involving marine habitat (Table 1). The relevant habitats range from the headwaters of salmon spawning streams through the entire U.S. Exclusive Economic Zone, and from the arctic to the tropics. These mandates are fairly recent in origin, so that, in contrast to a more established field, such as fisheries management and stock assessment, NOAA's basic terminology, concepts, and data streams are still being defined.

The Sustainable Fisheries Act established new Essential Fish Habitat (EFH) requirements in 1996. Fishery management plans are now required to include amendments to identify, conserve, protect, and restore EFH. This requirement has greatly increased the involvement of NOAA Fisheries in habitat science and management. At present, many, but not all, of the approximately 40 fishery management plans have approved EFH amendments, but, even for the approved amendments, there are many acknowledged shortcomings in the level of available information.

Some Marine Habitat Classification Systems

Establishment of a widely accepted system of habitat classification is a key aspect of managing and studying habitat. Many systems have been proposed for the marine environment, both in the USA and in other regions. However, there is no comprehensive or widely accepted classification system.

Habitat classification systems share several characteristics:

- they have a specific purpose or application;
- they are applied to some spatial domain and scale;
- they are applied to a particular group of organisms; and
- they are usually hierarchical.

Some major marine habitat classification systems developed in the U.S. include those of Cowardin, et al., (1979); NOAA Fisheries and the Ecological Society of America (Allee, et al., 2000); Greene, et al. (1999); and NOAA Fisheries' *Our Living Oceans Habitat* (Brown, 2000) project. In addition, habitat suitability modelling (Brown, et al., 2000) provides an approach for habitat mapping based on environmental characteristics and the habitat requirements of a species or group of species.

The purpose of the Cowardin, et al., (1979) system, developed by the U.S. Department of the Interior, is to classify wetland and deepwater habitats for fish and wildlife. It is hierarchical, with five systems at the top level: marine, estuarine, riverine, lacustrine, and palustrine (Figure 1). Each system contains 0-4 subsystems; each subsystem contains 1-8 classes, based on substrate, flooding regime, or vegetative form. Each class contains 2-7 subclasses, based on dominant substrate, or plant or animals forms. For example: Marine/subtidal/rock bottom/bedrock. Modifiers (e.g., based on chemistry or anthropogenic impacts) can be applied to classes and subclasses.

The purpose of the Greene, et al., (1999) system is to characterize deepwater habitats of vertebrates and invertebrates for establishment of marine reserves and for identifying EFH. It is an elaboration of a component of the Cowardin, et al., (1979) system, but is applied only to deep seafloor habitats. Four scales of habitat are recognized: megahabitat (>1 km), mesohabitat (10 m^{-1} km), macrohabitat (1-10 m), and microhabitat (cm). The hierarchy consists of system (marine benthic only), subsystem (mega- and mesohabitats based on physiography and depth), class (meso- and macrohabitats based on seafloor morphology), and subclass (macro- and microhabitats based on substratum textures or slope). Modifiers are included, based on bottom morphology, deposition, and texture; and/or on physical, chemical, biological, or anthropogenic processes.

The purpose of the system under development by NOAA Fisheries and the Ecological Society of America (Allee, et al., 2000) is to provide a framework for a national habitat classification for inventorying and tracking habitat changes. Although EFH is not referenced in Allee, et al., (2000), establishing a national system for classifying habitat would have obvious relevance for any national or regional program to protect and conserve EFH. The proposed system emphasizes functional links between ecosystem structure and biological communities. It establishes a 13-level hierarchy (Table 2). This system has never been fully defined or tested, but it may form the basis for a more completely defined system currently being developed by a contractor.

NOAA Fisheries' *Our Living Oceans* program publishes national syntheses on key aspects of fishery management. The information is technical, but the reports are targeted at a lay audience of senior resource managers, politicians and their staffs, and the general public. The purpose is to communicate with these constituencies about the status of the resources for which NOAA Fisheries bears responsibility, and to provide them with an assessment of management and scientific needs. Several editions of the *Our Living Oceans* report on living marine resource stocks were published in the 1990s. The most recent (NOAA Fisheries, 1999) describes the status of 25 species units, which cover over 600 fish, marine mammal, and sea turtle stocks. The report also summarizes the degree of utilization for the relevant fisheries. One edition of an *Our Living Oceans* report on economics has been published (NOAA Fisheries, 1996). A new *Our Living Oceans* report on habitat is currently in development (Brown, 2000). The long-term vision is to publish these three reports on a rotating annual basis.

The *Our Living Oceans* report on habitat is still being designed. Unlike the reports on stocks and economics, there is no well-established conceptual framework or program of research and monitoring generating data for such a report. Nonetheless, the concepts for developing and analyzing the data for the *Our Living Oceans Habitat* report have been defined (Brown, 2000). The report will be based on two fundamental components of information:

1. Species use of habitat – a checklist of the major habitat types used for each species by life stage;
2. Usable habitat – quantity and quality of available habitat;
3. Compared to the historical maximum; and
4. Trends over the most recent ten years.

The data to be gathered will be qualitative in nature based on the knowledge of experts in each region. There will be no spatial data or maps in the initial version of the national database, although case studies of small regions will be included to illustrate the use of spatial data in the *Our Living Oceans* context. The long-term vision is to evolve into a framework based on spatial data, but the *Our Living Oceans* team recognized that there is not a sufficient amount of spatial data available to develop a national report on marine habitat at this time.

One of the initial requirements for developing the *Our Living Oceans Habitat* report is to develop a habitat classification system. The current draft of this system is a six-level hierarchy. The top level consists of five broad categories: Fresh Water, Estuary, Nearshore, Offshore, and Offshore Islands and Banks. Each habitat type within the hierarchy has its own unique numerical code (Table 3), which indicates where it fits within the hierarchy. This system is still being refined and reviewed by the *Our Living Oceans* team, including development of definitions for each habitat type.

The habitat classification system for *Our Living Oceans* is intended for broad-scale tracking of the quantity and quality of habitat for the species for which NOAA Fisheries bears management responsibility. It is not highly detailed (e.g., there is only one habitat type for estuarine intertidal seagrass beds, with no finer-scale information on species composition, density, etc.). Therefore, it has certain limitations. Because its intended use is to summarize habitat quantity for large regions (e.g., Gulf of Maine), it has not been designed to handle mixed habitat types or small-scale patchiness.

Habitat Suitability Modelling

Habitat suitability modelling is a different approach to habitat classification and mapping. It has a fairly long history, primarily in terrestrial and freshwater systems, which will not be reviewed here (e.g., U.S. Fish and Wildlife Service, 1980). Brown, et al., (2000) developed habitat suitability index models for mapping habitat distributions for eight fish and invertebrate species in the Gulf of Maine. These models classify habitat according to the habitat affinities of a species and life stage. The mapping process, which requires use of a geographic information system, is illustrated in Figure 2. Each environmental variable in a model is plotted in a separate raster (i.e., gridded) map. Each map is then reclassified to a model-specific suitability scale, which ranges from 1.0 for the most suitable range of the environmental variable, to 0.0 for ranges of the variable in which the particular species or life stage does not occur. Then model calculations are then made on a grid cell by grid cell basis. In Brown, et al., (2000), the models were the geometric means of the suitability values of the variables in the model. More sophisticated models could be used where data availability is sufficient to support their development.

The output of the above process is a map of habitat distribution. Figure 3 is an example for winter flounder adults in Casco Bay during the summer. These maps should be interpreted at a level appropriate for the information used in their development. In this case, spatial resolution is limited to 100 x 100 m grid cells. Temporal resolution is limited to season, because the temperature and salinity maps used to calculate model outputs depict seasonal means. Prior to plotting the results, the model outputs were “binned” into categories of high, medium, and low suitability, and unsuitable. Comparisons for these categories were made among seasons, species and life stages. The models were not intended to be interpreted at small scales, such as by individual grid cells or at specific locations, such as a rock outcrop.

Conclusions

Habitat classification systems are designed for a particular purpose, and may depend on the scale and the organisms of interest. Developing a hierarchical system allows the flexibility to move up or down in specificity and scale. Links among species, ecosystem function, and habitats should be clearly recognized. Many systems have been proposed and used for particular applications. Developing a system specifically for maintaining a diversity of benthic habitat types on the Scotian Shelf will require development of a classification system appropriate to the task. It may be possible to adapt an existing system, which would have the advantage of consistency with other standards.

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Table 1. Major mandates that establish NOAA's responsibilities for marine habitat.

Magnuson-Stevens Fishery Conservation and Management Act (also termed the Sustainable Fisheries Act) – establishes the regulatory framework for federally managed fisheries, including Essential Fish Habitat requirements.

Endangered Species Act – requires identification and conservation of Critical Habitat for species at high risk of extinction. NOAA is responsible for fish, invertebrates, marine mammals, sea turtles, and one species of sea grass.

National Marine Sanctuaries Act – establishes marine sanctuaries in U.S. waters. Management plans include conserving and protecting habitat.

Executive Order #13089 - establishes federal policy on coral reef protection, including mapping and conservation. NOAA and the U.S. Department of the Interior are the federal agencies leading the Coral Reef Task Force.

Executive Order #13158 - establishes federal policy on marine protected areas (MPAs) as a means for managing and conserving living marine resources and their habitats. NOAA leads the MPA Initiative, in cooperation with the U.S. Department of the Interior and many other partners.

Table 2. Thirteen-level NOAA Fisheries/Ecological Society of America habitat classification hierarchy (Allee, et al., 2000).

1. Life Zone - climate
2. Water/Land
3. Marine/Estuarine/Freshwater
4. Continental/Oceanic
5. Bottom/Water Column
6. Depth - shelf/slope/abyssal
7. Regional Wave/Wind Energy
8. Hydrogeomorphic/Earthform Features
9. Hydrodynamic Features
10. Photic/Aphotic
11. Geomorphic Types/Topography
12. Substratum/Eco-Type
13. Local Modifiers and Eco-Units

Table 3. Example for *Our Living Oceans* habitat classification system, showing a segment for bottom habitats of the nearshore intertidal zone. The numbers are the numerical code for each habitat type.

3 Nearshore
- (31 Supratidal Zone…)
- 32 Intertidal Zone
  - 321 Bottom
    - 3213 Vegetated bottom
      - 32131 Rooted vascular
        - 321311 Seagrass beds
      - 32132 Algal beds
        - 321321 Macroalgae (e.g., *Fucus*)
        - 321322 Microalgae (e.g., calcareous green algae)
      - 32133 Marine moss
      - 32134 Emergent wetland

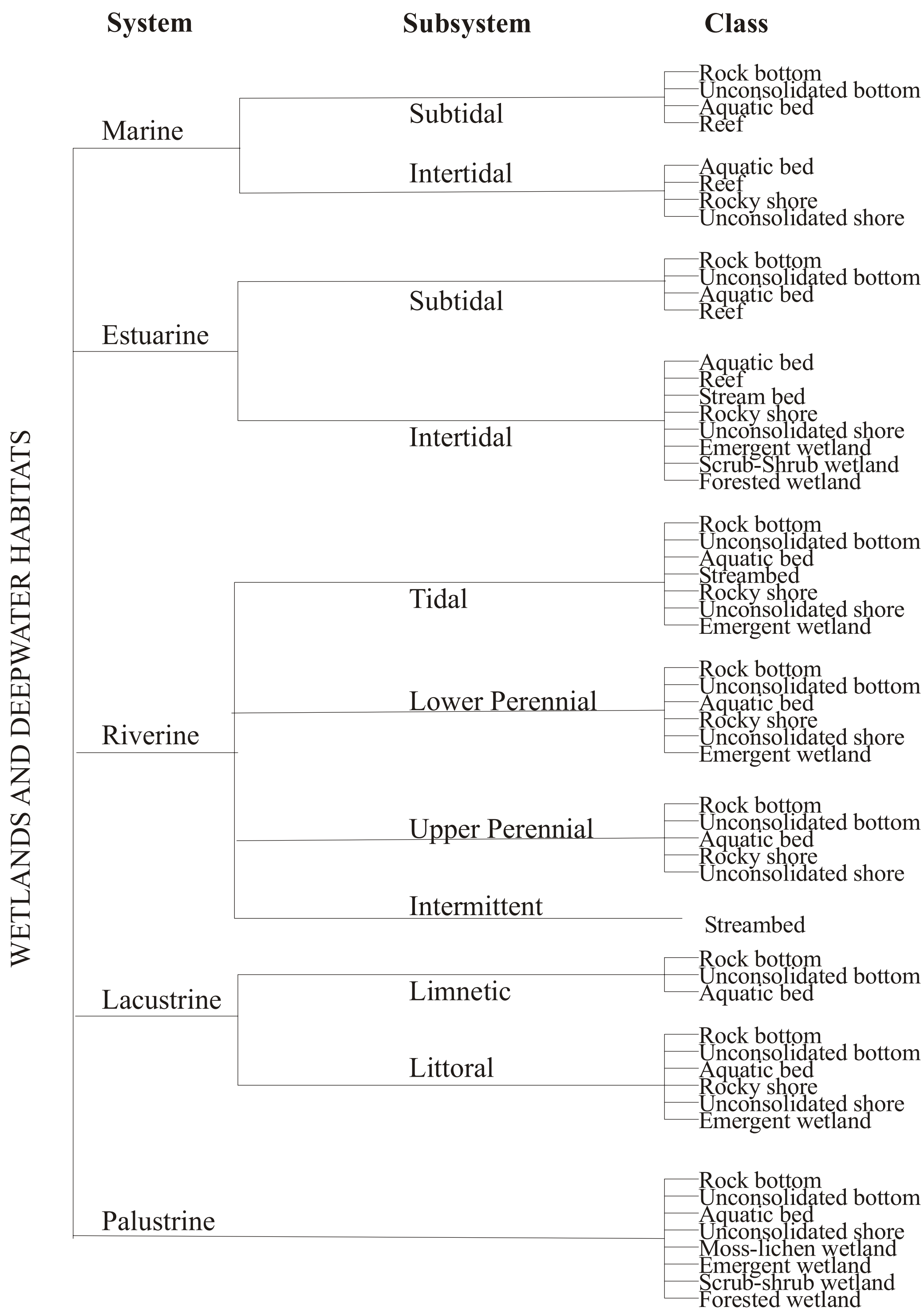

Figure 1. Cowardin, et al., (1979) classification hierarchy.

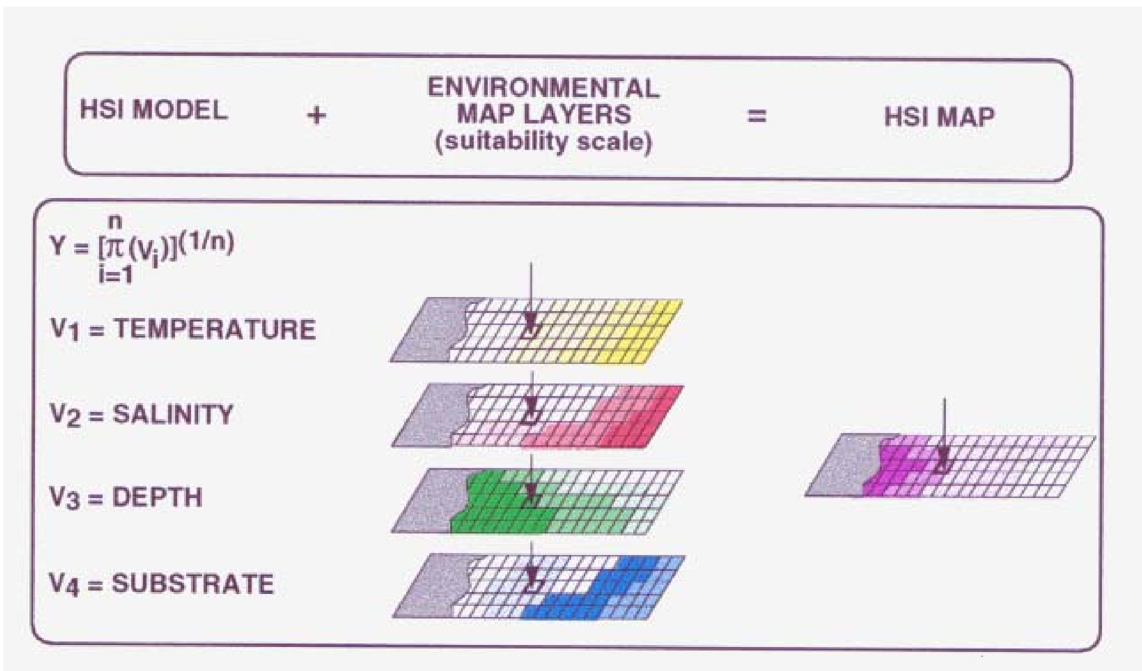

Figure 2. The process for classifying and mapping habitat using the habitat suitability index models of Brown, et al., (2000).

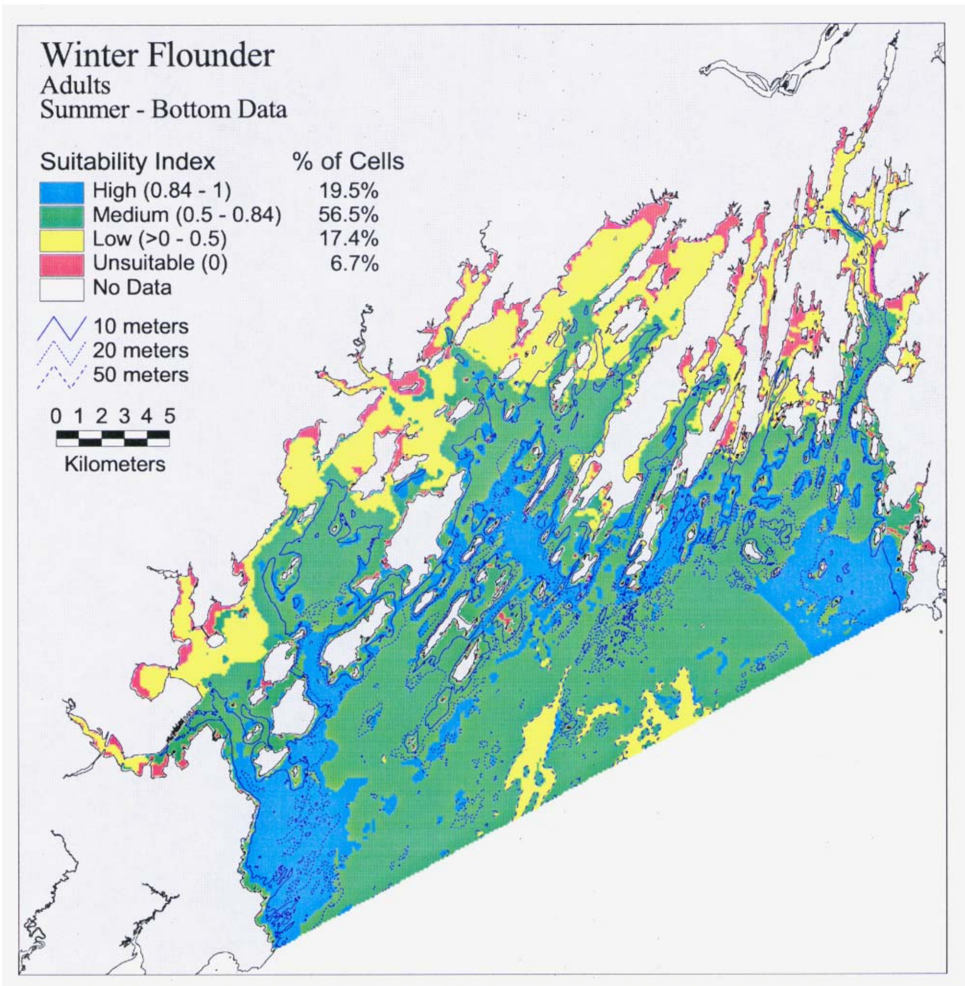

Figure 3. Habitat suitability index map for winter flounder adults in Casco Bay, Maine, during the summer (Brown, et al., 2000).

WORKSHOP OUTPUTS

OUTPUTS OF WORKSHOP

Following the presentation of case studies and research results from several participants of the workshop, a plenary discussion was held. The results presented below are mainly the comments of workshop participants. They provide advice and direction to DFO as they proceed to develop the classification. The views outlined here do not necessarily represent official policy or management position of DFO.

Day 1: Discussion Among Participants on the Goals of the Workshop

Workshop participants agreed that the primary goal is to define a marine habitat classification framework that spans a range of organizational levels and spatial scales and that is suitable for development of integrated management plans for large ocean management units, and for planning to preserve marine biodiversity.

The workshop outputs are not intended for the management of exploited fish stocks or fisheries. Although the outputs of the workshop are primarily of a scientific nature, the outcomes will be of great interest to Scotian Shelf resource user groups (i.e. stakeholders) because of their direct implications for management by regulation and zoning. It was found necessary to ensure that stakeholders are included as fully as they wish to be in the development of the classification framework, and that the scientific basis for the resulting scheme is presented to stakeholders in a manner that is clear, defensible, and consistent with best practice elsewhere.

Consensus from the Participants on the Ocean Domain to be Considered

It was generally agreed that the large marine ecosystem of the Scotian Shelf to be classified extends from:

1. the middle of Laurentian Channel to the North, corresponding to regional boundary line, to the border with the U.S. on the Georges Bank and in the Gulf of Maine to the South (explicitly including the Bay of Fundy); and
2. the 50m depth contour closest to the coasts of Nova Scotia and New Brunswick (inshore) to the base of the continental slope (1200m depth contour offshore).

These boundaries, although arbitrary in detail, reflect real and significant ecological separations or transition zones, except in the case of the U.S. border (which is entirely political and cuts areas of demonstrable ecological integrity).

The classification framework to be developed should allow downstream compatibility with future schemes to be developed for coastal areas and the U.S. areas of the Gulf of Maine and Georges Bank (particular emphasis should be placed on joint development with U.S. counterparts in the later case). Compatibility with mapping schemes in overlapping, conjoint and adjacent ecosystems was thus seen as essential. Compatibility of the Scotian Shelf classification scheme with other classifications developed at larger scales and for non-adjacent ecosystems was found not essential, but desirable.

The Pelagic and Benthic communities of the Scotian Shelf are intimately and inseparably linked by physical and ecological processes, and that a scientifically defensible benthic classification scheme can not be developed in isolation from parameters of the overlying water column. The workload and available resources however may not allow simultaneous benthic and pelagic classification activities.

Thus, at present time, it is possible to classify the benthic ecosystems of the Scotian Shelf in the context of pelagic ecosystem attributes, and to follow with the pelagic classification exercise in timely fashion, being prepared to revise the benthic classification in light of that future classification.

Following the overview of workshop goals and lessons learned from other classification schemes, a series of nine (9) framework recommendations prepared and previously circulated by the consultant were presented in plenary and discussed until consensus was reached on the second day of the workshop.

Framework Recommendation #1

Development of a management oriented model for benthic classification that will:

1. Support development of an enforceable zoning scheme.
2. Will guide human activities with the potential to reduce or degrade marine biodiversity.
3. Support implementation of integrated oceans management.
4. Improve understanding of marine ecosystems.
5. Not place unrealistic requirements for data, time and funding.

It is necessary to apply a scientific approach to the process of habitat classification and mapping, recognizing the need to educate managers and resource users about the scientific basis and procedures used for classification. The managers should set forth clear and realistic goals for scientific research on the topic of ecosystem classification. Both managers and scientists have to be pro-active in this endeavour.

It is necessary to devise and assign metrics of accuracy and precision (i.e. uncertainty) to the indicators of benthic ecosystem type and their spatial boundaries. This was judged to be essential if the classification scheme is to produce maps of benthic ecosystems that are useful for management decision support.

The development of a benthic classification scheme for the Scotian Shelf is not a “one-shot” activity. It must be an adaptive, continuously evolving process of hypothesis generation, experimentation, testing and revision. This workshop is seen as a starting point, not an end point in the process.

Framework Recommendation #2

Set classification scales by capacity for compliance and enforcement such that:

1. The domain is defined by Ocean Management Area (OMA).
2. Grain defined by the Minimum Manageable Unit (MMU).
3. The Minimum Manageable Unit should exceed size of Minimum Mapable Unit.
4. The Minimum Manageable Unit does not necessarily have to correspond to Minimum Ecological Unit (MEU).

It is recognized that the actual size of the minimum management unit for the Scotian Shelf is yet to be determined, and it may not be the same size for all management strategies.

Framework Recommendation #3

Classify HIERARCHICALLY and zone ADAPTIVELY from the upper levels recognizing:

1. That hierarchies of biological organization and ecosystem function map less cleanly onto spatial-temporal scales than do physical-chemical processes.
2. Hierarchies of physical-chemical process to classify and map benthic habitat.
3. Hierarchies of ecosystem structure and function sparingly within narrow ranges where boundaries between levels are clear.

Spatial resolution in classification scheme is defined by the availability of data, whereas the sizes of management units depend on the nature of managed activity.

There is an hierarchy of management units, some of which are rather small (e.g. point source impacts such as drilling rigs, known locations of rare and valuable, sessile organisms). Buffer zones around such small areas, depending on the kind of activity would bring the size of the management unit up to the tens or km^2. Moving down the hierarchies of spatial scale for both benthic mapping and ocean management increases the uncertainty and costs exponentially, and it is recommended that such decisions would be made on a “need-to-know” basis.

A spatial hierarchy of management units matches a spatial hierarchy of mapable units, both having different levels of uncertainty, depending on the technologies used. Remote sensing technologies can map oceanographic features down to $10km^2$ with a precision of 1 km^2, and seabed units down to $100m^2$ with a precision of $1m^2$. The main challenge here is downscaling from the synoptic view to the MEU.

Benthic sampling technologies can map macrofaunal communities down to $10m^2$, but with a low precision on the order of $10,000m^2$ because of the errors of interpolation among samples. The main challenge here is up-scaling from the sample unit to the habitat and shelf scales.

Framework Recommendation #4

Use the benthic assemblages as the Minimum Ecological Unit (MEU):

1. Communities or species assemblages should be considered as indicators of environmental conditions.
2. Benthic habitat associated with assemblages of species should be considered as the minimum mapable unit (MMU).
3. Close correspondence of benthic communities to physically-defined habitats should be supported by empirical data.

Benthic habitat explicitly includes structuring biotic components (e.g. corals), as well as physical structure and biophysical attributes of the overlying water column. Biological community responds to ambient physical factors and simultaneously modifies them. Additionally the members of biological community have unique and often strong influence of each other.

Causal and statistical relationships established between the distribution and abundance of benthic organisms (such as individuals, populations or species) and the structure of the benthic habitat are highly variable, and often of low predictive power. However, the relationships between structural and particularly functional attributes of enduring benthic communities and the physical attributes of their characteristic habitats are more robust, and thus potentially more useful for the purposes of this exercise. The use of spatially repeated functional groupings of organisms was recommended for identifying mapable benthic habitats.

Framework Recommendation #5

Incorporate Oceanographic and Trophodynamic processes explicitly where:

1. Water column structure and processes or pelagic communities can not be considered separately from benthic communities, as they exert dominant controls, such as;
   - regulate environment,
   - create disturbance regime,
   - deliver food and recruits, and
   - cycle energy and materials.

2. Including nearshore areas especially in the Bay of Fundy, but not as strongly off Southern and Eastern Nova Scotia because of oceanographic separation of coastal and shelf water masses.

Pelagic and Benthic communities of the Scotian Shelf are intimately an inseparably linked by physical and ecological processes, and that a scientifically defensible benthic classification scheme can not be developed in isolation from parameters of the overlying water column.

Framework Recommendation #6

Incorporate the role of HISTORY in classification of benthic habitats:

1. Distribution and abundance of organisms not fixed in space-time and may vary at scales smaller-faster than MMUs.
2. Variation in oceanographic conditions (e.g. organic supply to benthos) is cumulative and the effects are often lagged.
3. Disturbance frequency and intensity exert strong controls on benthic communities, it may have physical or biotic origin.
4. Need to distinguish and quantify natural (e.g. sediment mobility, species interactions) and anthropogenic disturbance rates.

Mapping natural and anthropogenic disturbance is essential to the implementation of management strategies, and therefore such information must be explicitly identified and incorporated with the benthic classification scheme.

Framework Recommendation #7

Operationalize classification by MAPPING enduring habitat units:

1. Habitat units should be defined by;
    - marine environment,
    - substratum,
    - food supply, and
    - disturbance regime.
2. Define benthic community types based on theoretical and empirical relationships with these habitat attributes.
3. Scale-up from verified and calibrated areas to entire shelf using synoptic maps through Iteration, improvement and cross-validation.
4. Sampled biota and measured physical variates may be classified *a posteriori*.
5. Multivariate tools should be used for classification because they are powerful classifiers even in the absence of mechanistic understanding.
6. Pattern description is suitable for habitat mapping.

The characteristic scale of minimum mapped units (i.e. the grain) of the benthic habitat classification must be larger than the characteristic size of habitat patches that are subject to high frequency (i.e. faster than decadal period) variation in their location or boundaries.

Development, implementation and adaptive revision of zoning-based management strategies derived from the benthic habitat maps could range from years to a decade and therefore should be attempted as soon as possible.

Framework Recommendation #8

Map benthic habitats first on the basis of SHELF-SCALE SYNOPSES of:

1. Oceanography: water masses, circulations, regimes (4)
2. Physiography: topographic hierarchy (2 levels, 8 classes)
3. Substratum (2 levels, 7 classes)
4. Commercial fish and by-catch
5. Invertebrates
6. Rare, long-lived and structuring species

7. Finer-grained, continuos variables should be added if available (e.g. U*)
8. Second on the basis of sampled distributions of biota

Detailed description of initial benthic habitat mapping framework for the Scotian Shelf is presented at the end of this document.

Framework Recommendation #9

Relate HABITAT COMPLEXITY to biodiversity:

1. Biodiversity is well-related to complexity of environment;
   - Architectural complexity of substrates increases alpha diversity, and
   - Variability of habitat types within an area increases beta diversity.
2. Use habitat attributes and landscape structure as proxys, surrogates or indicators for diversity of benthic organisms.
3. Establish reference biodiversity areas (such as potential MPAs).

Management goal of preserving benthic biodiversity on the Scotian Shelf is not restricted to simply identifying and protecting those areas identified as having the maximum biodiversity. It entails protecting distinct habitats that may support both high and low diversities of structure and life forms.

Day2: Proposed Benthic Habitat Classification and Mapping Framework

In the final activity of the workshop, the group discussed in plenary a proposed, minimum initial set of shelf habitat zones, features, variables and metrics that would be compiled and mapped to produce a draft framework. This will then be circulated to the scientific community and stakeholder groups for criticism and revision as part of the second phase of the project.

The following is a description of a proposed fully hierarchical classification scheme where all levels are nested in higher levels and no attribute at one level exists at another level.

Level 1: Oceanographic Domains

- Six (6) domains were recognized:
  - North-eastern Scotian Shelf,
  - South-eastern Scotian Shelf,
  - Central Scotian Shelf,
  - Western Scotian Shelf,
  - Scotian Shelf Edge, and
  - Gulf of Maine (including Georges Bank and Bay of Fundy).

- Five (5) classifying attributes were recommended to map these domains:

1. **Critical depths** (related to the essential ecological processes of food supply, growth, disturbance, reproduction/dispersal/recruitment, and mortality).
   - Metrics / Variates (scaled): Pleistocene still-stand depth/z; mixed layer depth/z; photic layer depth/z to a precision of 1m (derived from digital bathymetry).
2. **Thermal regime** as epibenthic (bottom) seawater temperature (causally related to the survival and growth of benthic biota).
   - Metrics / Variates: Min. and Max. annual temperature to a precision of 1^{o}C (from numerical models).
3. **Current regime** as epibenthic (near-bed) water current velocity gradient (causally related to the disturbance, dispersal and food supply).
   - Metrics / Variates: typical value of U* to a precision of 0.01 ms^{-2} (from numerical models).
4. **Productivity regime** as persistent plankton features (causally related to food supply).

   - Metrics / Variates: 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; may have to be satisfied with Chlorophyll-a concentration).
5. **Disturbance regime** as storm intensity and frequency (related to food supply, dispersal and mortality).
   - Metrics / Variates: Annual probability of sand resuspension and transport for 24h or longer to a precision of 5 $d.y^{-1}$ (from numerical models).

<u>Levels 2-3: Seabed Domains Within Oceanographic Domains</u>

- Four (4) **Physiographic domains** were recognized:
  - Inner Scotian Shelf,
  - Middle Scotian Shelf
  - Outer Scotian Shelf
  - Scotian Slope

- Within which eight (8) **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)

- Within which four (4) scales of **Seabed texture** were recognized:

1. **Topographic roughness** as measured by the second derivative of depth at a spatial scale of 1-100 km (related to dispersal, recruitment and diversity).
   - Metrics / Variates: z* to a precision of 1 m^{-2}.
2. **Surficial complexity** as measured by the rugosity index or surface fractal dimention at a spatial scale of 100 – 1,000 m (related to survival, recruitment and diversity).
   - Metrics / Variates: ratio of actual to vertically projected length, or F, to a precision of 0.1, fractal dimention to a precision of 0.01.
3. **Bio-structural complexity** as measured by the aspect ratio of biogenic structural elements at a spatial scale of 1-100 m (related to (growth, survival and recruitment).
   - Metrics / Variates: ratio of mean element height to inter-element distance to a precision of 0.1.
4. **Particle roughness** as measured by the grain characteristics at a spatial scale of 10 – 1,000 cm (related to feeding, growth, survival, recruitment and diversity).
5. **Five types of substratum** are recognized;
      1. Rock (outcrop or bedrock, which is sub-divided into hard and soft rock),
      2. Gravel,
      3. Sand,
      4. Sand/Mud, and
      5. Mud.
   - Metrics/Variates:
      1. Mean grain size to a precision of 0.001 mm or Phi to a precision of 0.1 (related to rugosity and pore size).
      2. Skewness to a precision of 0.01 (related to sediment erosion and resuspension).
      3. Cohesiveness to a precision of 0.1 dynes (related to biocementation).

Level 4: 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.

Metrics/Variates:
1. Within-habitat species diversity,
2. Frequency of occurrence, biomass, abundance of individual species,
3. Degree of association between species and physical habitat,
4. Dominant megafaunal species, and
5. List of associated species for each habitat type.

Maps of the distribution and abundance of benthic assemblages at shelf-scales, as well as maps of other organisms or characteristic assemblages of organisms at smaller scales (e.g. within morphological domains or areas of uniform seabed texture), will play key roles in the development of the framework classification of benthic ecosystem types on the Scotian Shelf. Some of these data sets exist already, while others will be identified as priority topics for future research and experimentation. Several groups of foundation organisms were recognized as well-enough known by their fundamental niches, ecological roles and distribution and abundance on the Scotian shelf may be mapped at this stage. These may be surf clams, scallops and sand dollars, demersal fish, gorgonian and scleractinian corals.

The uses of these distribution maps of biological components of the Scotian Shelf ecosystem are:

1. To demonstrate and quantify empirical relationships between physical attributes of the habitats and their biological diversity using rigorous parametric and multivariate statistical tools.
2. To test and verify predictions of the distribution and abundance of organisms based on extrapolations from the benthic habitat maps.
3. To revise and improve the accuracy and detail of the proposed classification system to the point where the proxies, indicators and reference points provide the best possible support for management decisions regarding the preservation of biodiversity on the Scotian Shelf.

The proposed approaches stated here will be taken in consideration by DFO in developing benthic habitat classification.

BENTHIC WORKSHOP ATTENDEES

DFO Maritimes

Paul Boudreau - MESD/Habitat Ecologist
Don Gordon - MESD/Research Assistant
Ellen Kenchington - Science/Research Scientist
Bob O'Boyle - Science/RAP Coordinator
Bob Rutherford - OCMD/Section Head
Derek Fenton - OCMD/Policy Advisor
Joe Arbour - OCMD/Division Manager
Paul Macnab - OCMD/Oceans Act Coordinations
Glen Herbert - OCMD/Oceans Act Coordinations
Scott Coffen-Smout - OCMD/Oceans Act Coordinations
Heather Breeze - OCMD
Jennifer Hackett - OCMD/Oceans Management Coordinator
Denise McCullough - OCMD/Community Initiatives Officer
Barry Jones - OCMD/Section Head
Glen Harrison - Science /Research Scientist
Maxine Westhead - OCMD/Oceans Biologist/Bay of Fundy
Jason Naug - OCMD/Oceans Policy Officer

Non-DFO/Federal Government

Brian Todd - Natural Resources Canada/GSC Atlantic
Vladimir Kostylev - GSC/DFO
Dick Pickrill - Natural Resources Canada/GSC Atlantic
Gordon Fader - Natural Resources Canada/GSC Atlantic
Kyle Penney - Department of National Defence/Formation Environment

Non-DFO/Government

Derek Davis - MIDI Marine Invertebrates Diversity Initiative/Chair
Bruce Hatcher - Canadian Fishery Consultants Ltd.
Brian Giroux - SF Mobile Gear Fishermen's Association
Lea-Ann Henry - Dalhousie University/Department of Biology
Martin Willison - Dalhousie University
Pat Stewart - Envirosphere Consultants Ltd.
Brad Barr - NOAA-National Oceanic and Atmospheric Administration
Steve Brown - NOAA-National Oceanic and Atmospheric Administration
Marty King - Dalhousie University/Student
Jayne Roma - MIDI/Coordinator
Bruce Chapman - Fisheries Resource Conservation Council
Mark Butler - Ecology Action Centre
Nancy Witherspoon - Canadian Aquatic Environmental Consultants Inc.
Susan Gass - Ecology Action Centre
Kim Doane - Nova Scotia Petroleum Directorate
Andre d'Entremont - Kerr-McGee Inc.