10.0 Ecosystem Classification

10.1 A System Planning Approach to Marine Classification and Boundary Considerations

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10.1.1 Defining Marine Representivity and a Hierarchical Classification System

As our understanding of the relationships between biological characteristics and physical factors within ecosystems has evolved, so has our ability to use ecological principles to determine which are the more appropriate areas or spaces for protection. In terrestrial ecosystems, the term 'enduring features' has a specific meaning that incorporates those 'enduring' elements of the landscape; in terms of human life spans, these do not change, and they are known to control and influence the diversity of biological systems. For the purposes of identifying terrestrial protected spaces, 'enduring features' are closely associated with terrestrial abiotic (or physical) features (Kavanagh and Iacobelli, 1995). This includes such stable features as landforms, physiography and soils that have been demonstrated to play a significant role in the distribution and diversity of flora and fauna at small to medium scales. Furthermore, these features can be readily mapped in a two dimensional format, and there are considerable data at various scales throughout Canada to accomplish such mapping.

Marine systems are basically different from terrestrial ones, but they also consist of interacting physical and biological components. However marine systems exhibit more complex spatial-temporal relationships than terrestrial systems; this has made the development of comparable ecological classification techniques for marine systems more difficult. Furthermore, the concept of stable, enduring features as a basis of delineating marine natural regions is made more difficult, because two very different communities - the pelagic and the benthic - exist in three and two dimensions respectively, with dynamic and variable interactions between them. Unlike terrestrial enduring features, the equivalent ecological attributes of marine ecosystems may change spatially and temporally in predictable or unpredictable ways, particularly in pelagic seascapes. In marine environments two broad sets of attributes can be recognized:

1. more-or-less enduring physiographic features such as geographical position, geological history, bathymetry, slope, sediment particle size, substrate heterogeneity (the closest analog of terrestrial enduring features);

2. generally less enduring, but recurrent oceanographic features or processes such as salinity, water masses, temperature, dimensional segregation, stratification, light penetration, and exposure that may not be at all permanent, but which may re-occur daily, monthly, seasonally or yearly in predictable fashion in the same geographical area.

Using the terrestrial representation paradigm (Hill, 1961) as a starting point, a marine classification framework has been developed by Geomatics International (1996) and modified by Day and Roff (1998). Their approach to marine classification utilizes the enduring and recurrent oceanographic and physiographic features of the marine environment. The framework is a natural hierarchical classification of marine environments which leads to the delineation of marine representative units (MRUs). When applied, this framework is believed to capture and represent the ecological diversity of marine communities in Canadian waters. The framework has been developed through the collaborative efforts of World Wildlife Fund Canada, consultants and various academic and agency personnel.

The framework that has been applied is basically a "community level" analysis of marine systems and differs from classification previously developed (e.g. Harper et al. 1993) in a couple of ways:

- it uses physical attributes alone and essentially predicts the expected biocoenosis (community type) on the basis of documented habitat characters (i.e. reconstructing the biotopes). A major advantage of this approach is that MRUs can be identified from already mapped geophysical features, or by remote sensing of appropriate surrogate variable. Most importantly, boundaries between community types can be functionally defined, even where detailed biological data is lacking;

- it recognizes and classifies the two major marine communities (the pelagic realm and the benthic realm) which have entirely different communities and are driven by different processes.

There are six levels in the hierarchical classification (Table 10.1.1).

Level One: separates all aquatic environment into one of the following:

- Lotic (streams and rivers)
- Lentic (lakes)
- Estuaries
- Marine

Level Two: separates the lentic (lakes), estuaries and marine environments on a geographical/temperature basis:

- Lentic
    - Arctic
    - Sub-Arctic
    - Temperate
    - (no sub-tropical in Canada)

- Estuaries — Arctic (seasonal ice)
Sub-Arctic (Atlantic)
Temperate (Atlantic)
Temperate (Pacific)
(No tropical in Canada)

- Marine — Arctic (permanent ices)
Arctic (Atlantic)
Sub-Arctic (Atlantic)
Temperate (Atlantic)
Sub-tropical (Atlantic)
Temperate (Pacific)

Level Three: is a dimensional segregation that separates all relevant communities in Levels One and Two in Pelagic and Benthic realms.

Level Four (Benthic): is a vertical division that distinguishes between depth classes on the substrate.

Light condition is particularly relevant to benthic communities and is used to delineate the sub-littoral euphotic zone (<50 m). Between 50-200 m is the dysphotic zone where light is still present, but is too low in intensity to support plant growth; below this again, the great majority of the oceans' depths lie within the aphotic zone, where no light penetrates. Rather more arbitrarily, the benthos is also divided into the bathyal zones (200m to 2000m) and abyssal/hadal zones (>2000 m).

Level Four (Pelagic): is a vertical division which distinguishes between depth classes within the water column.

Within the water column, depth, pressure, light penetration and turbidity are all inter-correlated. Moving from the shoreline onto the Continental Shelf and then offshore beyond the Continental Slope, water column depth increases, light penetrates further (because of grater water clarity and lower turbidity), and pressure increases with depth. Water column depth itself therefore acts as a suitable discriminant of community type, also accounting for the correlated factors of light penetration and pressure.

Level Five (Pelagic): distinguishes whether water is stratified, non-stratified (well-mixed), or frontal (also referred to as "transititional").

The vertical stratification of a water column separates its communities both spatially and temporally. Stratified and non-stratified waters will differ both in their annual productivity regimes and in their annual community structures. Thus, many banks and coastal regions of high tidal amplitude will remain unstratified and may retain *or accumulate populations of important pelagic* species *(e.g. larval fish, lobsters, etc.)*

Level Five (Benthic): segregation is based on substrate type

The substrate within specific deposition and erosional regimes tends to be relatively constant and is a major factor influencing the biota associated with the bottom. There is a relation between sediments and water motion and the latter may be significant both as an erosional force as well as one which brings food and nutrients to the zone. There are obvious difference between rocky, sandy and muddy shores though in deep waters the distinctions are reduced and only muds and sands are distinguished. Fine sands, silts and clays are found in the deeper regions.

Level Six (Benthic): distinguishes between degree of exposure for the intertidal and immediate sub-tidal areas; or the degree of slope in water >50 m.

Stable marine slopes for sediment accumulation are much lower angles than terrestrial slopes for similar grain sizes. Mass movements of materials have been known to occur at angles as low as 1^o.

Marine biological ecosystems include extremely disparate communities within the same 'area' as defined using two-dimensional mapping. It is therefore difficult to identity boundaries in marine systems because they are so dynamic (e.g., Tremblay and Roff, 1983), particularly when using traditional mapping techniques. Nevertheless, it is still appropriate to examine marine ecological characteristics and to define representative and distinctive communities in terms of their relationships to enduring physical factors or recurrent processes. While such a classification will not account for large scale or unpredictable disturbances, like hurricanes, communities generally re-establish themselves in due course and due composition based on the enduring physiographic and recurrent oceanographic factors.

This proposed hierarchical classification framework is theoretical. However, it is currently being tested on a region of the Atlantic coast known as the Scotian Shelf as part of a collaboration between World Wildlife Fund Canada, consultants, and various academic and government agency personnel. The results of applying this framework to the Scotian Shelf will be the selection and delineation of marine natural regions and MRUs within the study area. As a feature of the Scotian Shelf, the Gully will be part of this evaluation.

10.1.2 Boundaries Refined by Ecological Principles

Once enduring features are mapped, the boundaries of a proposed *representative or distinctive protected area* need to be evaluated using ecological criteria that will support the long-term viability of the protected area. Such long-term protection of biodiversity requires that important ecological processes are maintained. As a result, protected areas systems planning should reflect the scales at which these ecological processes occur. Protected areas must be judged to be in the right place, of the right size, and the right configuration to help protect biodiversity over the long-term.

According to Noss (1995), "simply representing the enduring features of the vegetation of a natural region in a reserve network will not guarantee that all species native to the region will survive there or be able to migrate elsewhere when conditions change. Nor does representation by itself assure the maintenance of natural processes necessary to keep ecosystems and their component populations health". Subsequently, a complementary goal to adequate representation is to maintain ecological integrity. The Canadian Council on Ecological Areas (CCEA) defines ecological integrity as "the capability of an ecological area of supporting and maintaining processes and assemblages of organisms (communities) that have a composition and function organization comparable to that of similar landscape units of the region." (Gauthier, 1992).

WWF is currently refining the methodology that will use the hierarchical classification framework to identify marine natural regions and marine representative units (MRUs) and assess marine protected area proposals from an ecological perspective. In a report prepared for WWF, Shackell *et al*. (1996) examined ecological principles that could be used as criteria in defining boundaries for marine protected areas (MPAs). These principles are discussed in the context of *core* and *buffer* zones which would allow for several levels of protection (Salm and Clark, 1984; Noss, 1995). The purpose of a core zone would be to protect fully the representative biodiversity and physical features and to allow for natural rates of variability. The core zone would include the representative area itself. The buffer zone is designed to surround the core zone to safeguard it against harmful human activities and to monitor activities which may affect the core zone. The following list of ecological principles is drawn from their report.

10.1.3 List of Ecological Principles for Boundary Considerations

10.1.3.1 Habitat Heterogeneity and Resilience

Because organisms are associated with a given set of physical factors, physical gradients (temperature, salinity, depth, current strength, sediment type) reflect habitat heterogeneity within a seascape. A scientific hypothesis is that biological diversity and community structure contribute to resilience. The principle is that a system comprised of diverse components is more resilient to unfavorable environmental conditions than a simpler system.

The concept of increased resilience with increased diversity can be applied to natural systems from the genetic to the global scale; whether the concept applies depends on the scale and the system. When applied to the scale of an ecologically representative area, the resilience of the entire area increases with an increase in the number of habitats within an area. One method for protecting natural areas is to including a diverse array of habitats within an ecologically representative area. In this way, the shape and size of a protected area would be designed to maximize habitat heterogeneity among seascapes.

Implications For Boundaries

Habitat heterogeneity in a protected area is maximized by including environmental gradients within the core (Rowley, 1994 and Noss, 1995). Depth is related to salinity, temperature, light levels, current strength and sediment type. Interactions among physical factors results in an array of habitat types, which are further modified by biological processes. In offshore regions, the maximization of habitat heterogeneity can be generally accomplished by representing the entire depth gradient, and corresponding surface waters, within the core area. In the event that other biophysical factors are sufficiently known to alter habitat heterogeneity, that knowledge should be used to design core and buffer boundaries.

10.1.3.2 Water movement

In offshore regions, wind-driven, density-driven and tidal currents are a major determinant of the abundance and distribution of flora and fauna on a regional scale. Autotrophic production in surface waters is the basis of offshore food chains (see Fader, 1991 for a description of chemosynthetically-based biological communities on the seabed). Photosynthetic production is influenced primarily by light, which attenuates in deeper waters. Within a region receiving relatively constant surface light, the availability of nutrients becomes important; nutrients are distributed by horizontal and vertical mixing (see Sections 6.1 - 6.3).

Turbulence affects primary productivity by concentrating or dispersing nutrients and/or the plankton itself. For example, turbulence can cause phytoplankton cells to sink to depths at which there is insufficient light to support photosynthesis, or turbulence can distribute nutrients to the euphotic zone. Generic forms of turbulence include: upwelling (upward flow of nutrient-rich water), Langmuir cells (wind-generated turbulence that results in circulating vertical cells), internal waves (subsurface waves generated by the density difference between two water masses), fronts (boundaries between two distinct water masses), and gyres (rotating circulation as a result of a balance between the force of the earth's rotation and the force of a pressure gradient, *i.e.* geostrophic balance).

The distribution and rate of phytoplankton growth determine secondary production. In turn, the distribution of planktonic secondary producers is determined by water movement. For example, copepods are advected onto the Western Bank of Sable Island Bank from the northeast, and are associated with high concentrations of cod (*Gadus morhua*) larvae. Presumably, the copepods and larvae are entrained in a gyre over Western Bank (McLaren and Avendano, 1995).

The organic matter which falls to the ocean floor (dead flora and fauna, fecal pellets, exudate, etc.) is used by benthic animals as food. Benthic communities are influenced by the rate and type of organic matter flux as determined by water movement, depth, temperature, and bacterial consumption en route. The extent of benthic/pelagic coupling varies among systems (see Section 6.4.1).

Benthic communities are also influenced by sedimentary characteristics (*e.g.* deposit feeders predominate in mud, filter feeders predominate in sand). Sediment type and size are a result of geological processes, and are continually modified by water currents. The general rule is that sediment size is larger in high energy (strong currents) environments and smaller in low energy (weak currents) environments. Wind-driven currents decrease with depth and so have less influence in deeper water, although all currents are commonly modified by topography (Pinet, 1992). On a smaller scale, biological interactions, such as predation and bioturbation (Posey, 1990) and behavior (Langston *et al*. in press) can regulate the composition of benthic communities.

Implications for Boundaries

Water movement and depth influence the extent of benthic-pelagic coupling, and levels of productivity. Physical mechanisms of turbulence and consequent productivity and distribution vary on spatio-temporal scales. Both the benthic and pelagic ecosystems should be included in the core area.

10.1.3.3 Spatial/Temporal Environmental Variability

Temperature, salinity, and therefore density vary on spatio-temporal scales (see Section 6.1). Such variability can result in spatial shifts in the distribution of marine species.

Implications for Boundaries

The core and buffer zones of the Gully should be sufficiently large to accommodate variation in physical factors.

10.1.3.4 Life History Strategy of Marine Species

Many of the abundant marine species are highly fecund but larval survival is low and highly variable. This life history pattern is common because the marine environment is variable. Organisms optimize the chances of survival by spawning a large number of eggs over time and space to counteract environmental variability. That is, if organisms are highly fecund, there is a higher probability that at least some of those eggs will experience a favorable environment and survive to reproduce.

Implications for Boundaries. See 10.1.3.5 below.

10.1.3.5 Migratory Behaviour and Larval Dispersal

Many of the larger species migrate long distances either seasonally or during different life history stages. Both large and small species can have pelagic larvae which disperse widely (see Section 7.1).

Implications for Boundaries

Protection of widely-ranging populations may be achieved through establishing a network of ecologically representative areas within a region, and through the use of high conservation standards outside of protected areas.

10.1.3.6 Variable Food Webs

Marine species distributed throughout the water column are linked through the food web. Primary producers (phytoplankton and chemoautotrophs) are food principally for zooplankton and bottom-dwelling invertebrates, which in turn are food for others (crustaceans, fish, seabirds, mammals).
It is important in considering the boundaries to recognize that the strength of various linkages among groups in the food web is not fully understood. For example, researchers have only recently discovered that bacteria can play a far greater role in production and nutrient regeneration than had been previously thought (Fuhrman, 1992). Our incomplete knowledge of marine systems re-enforces the need to define physical measures that will act as a surrogate for the biological measures we do not completely understand.

Implications for Boundaries

If some areas are relatively free from human activities we can partially compensate for our lack of knowledge of ecological processes, such as energy transfer in food webs. A sufficiently large protected area should be designed to ensure that food webs are maintained.

10.1.3.7 State of Knowledge and Uncertainty

Marine ecosystems are large-scale. The method of protecting *ecosystem integrity* is difficult to apply on a practical basis because of natural variability, the large scale of various ecological processes, and our general lack of understanding of marine systems. In temperate marine regions, it is improbable that we could delineate boundaries that would enclose a "self-sustaining" ecosystem.

Implications for Boundaries

In the absence of empirical evidence, the use of oceanographic principles and theory, combined with a precautionary approach, is appropriate for designing boundaries.

10.1.4 Conclusion

The gaps in our knowledge about marine species, habitats, and processes and the growing conservation imperative for the marine environment "... dictates a need to balance fine-scale, detailed information gathering exercises with coarse-scale planning that can operate in shorter time frames while still delivering protection to a significant proportion of Canada's native biodiversity" (Kavanagh and Iacobelli, 1995). A system planning approach, similar to the terrestrial approach, can assist in striking this balance by: 1) providing a framework that will help identify the most appropriate scale within which planning can operate; and 2) once the appropriate scale is identified, help to identify the ecological criteria that can be used to define the *landscape* or *seascape* units that will serve to delineate boundaries.

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Table 10.1.1. Framework for a hierarchical classification of all aquatic environments. (Day and Roff, 1998).

LEVEL ONE Environment Type/Salinity	**LEVEL TWO** Geographic/ Temperature	**LEVEL THREE** Dimensional Segregation		**LEVEL FOUR** Vertical Division	**LEVEL FIVE** Benthic - Substrate Type Pelagic - Stratification Mixing	**LEVEL SIX** Exposure or Slope
Lotic [Stream + Rivers]	(Not considered in this Framework)					
Lentic [Lakes]	ARCTIC	(Not considered in this Framework)				
	SUB-ARCTIC	SMALL LAKES	(Not considered in this Framework)			
		LARGE LAKES	(Not considered in this Framework)			
	TEMPERATE	SMALL LAKES	(Not considered in this Framework)			
		LARGE LAKES	PELAGIC			
			BENTHIC			
Estuarine	ARCTIC [Seasonal Ice]		PELAGIC			
			BENTHIC			
	SUB-ARCTIC [Atlantic]		PELAGIC			
			BENTHIC			
	TEMPERATE [Atlantic]		PELAGIC			
			BENTHIC			
	TEMPERATE [Pacific]		PELAGIC			
			BENTHIC			
Marine	**ARCTIC** **[Permanent ice]**		PELAGIC	EPIPELAGIC (0-200 m)	Not Applicable	
				MESOPELAGIC (200- 1000 m)	Not Applicable	
				BATHYPELAGIC (1000-2000 m)	Not Applicable	
				ABYSSAL/HADAL (> 2000 m)	Not Applicable	
			BENTHIC	SUB-LITTORAL DYS/APHOTIC (50-200 m)	Gravel/Sand	Low Slope
						High Slope (Shelf Edge/Sea Mounts/Gullys/ Canyons)

				Mud/Silt	
			BATHYAL (200-2000m)	Gravel/Sand	Low Slope
					High Slope (Shelf Edge/Sea Mounts / Gullys/ Canyons
				Mud/Silt	
			ABYSSAL/HADAL (>2000m)	Gravel/Mud	Low Slope
					High Slope (Sea Ridges/Canyons)
				Mud/Silt	
	ARCTIC **[Seasonal Ice]**	PELAGIC	EPIPELAGIC (0-200m)	Stratified (salinity effect)	
				Non-stratified	
			MESOPELAGIC (200- 1000m)	(Winter Polynyas)	
			BATHYPELAGIC (1000-2000 m)		
			ABYSSAL/HADAL (> 2000 m)		
		BENTHIC	LITTORAL (=Intertidal)	Rock/Boulders	Exposed/Very Exposed
					Moderately Exposed
					Sheltered/Very Sheltered
				Pebbles/Gravel/Coarse Sand	
				Fine Sand	
				Mud/Silt	
			SUB-LITTORAL EUPHOTIC (0-50M)	Rock/ Boulders	Exposed/Very Exposed
					Moderately Exposed
					Sheltered/Very Sheltered
				Pebbles/Gravel/ Coarse Sand	
				Fine Sand	
				Mud/Silt	
			SUB-LITTORAL DYS/APHOTIC (50-200M)	Gravel/Sand	Low Slope
					High Slope (Shelf Edge/Sea Mounts/Gullys/ Canyons
				Mud/Silt	
			BATHYAL (200-2000 m)	Gravel/Sand	Low Slope
					High Slope (Shelf Edge/Sea Mounts/Gullys/ Canyons
				Mud/Silt	

			ABYSSAL/HADAL (>2000m)	Not Applicable	
	SUB-ARCTIC **[Atlantic]**	PELAGIC	EPIPELAGIC (0-200m)	Stratified (T & S effects)	
				Frontal	
			MESOPELAGIC (200-1000m)	Non-stratified (T& S effects)	
			BATHYPELAGIC (1000-2000 m)		
			ABYSSAL/HADAL (>2000 m)		
		BENTHIC	LITTORAL (=Intertidal)	Rock/Boulders	Exposed/Very Exposed
					Moderately Exposed
					Sheltered/Very Sheltered
				Pebbles/Gravel/Coarse Sand	
				Fine Mud	
				Mud/Silt	
			SUB-LITTORAL EUPHOTIC (0-50M)	Rock/Boulders	Exposed/Very Exposed
					Moderately Exposed
					Sheltered/Very Sheltered
				Pebbles/Gravel/Coarse Sand	
				Fine Sand	
				Mud/Silt	
			SUB-LITTORAL DYS/APHOTIC (50-200M)	Gravel/Sand	Low Slope
					High Slope (Shelf Edge/SeaMounts/Gullys/ Canyons)
				Mud/Silt	
			BATHYAL (200-2000 m)	Gravel/Sand	Low Slope
					High Slope (Shelf Edge/Sea Mounts/Gullys/Canyons)
				Mud/Silt	
			ABYSSAL/HADAL (>2000 m)	Not applicable	
	TEMPERATE **[Atlantic]**	PELAGIC	EPIPELAGIC (0-200 m)	Stratified ("S" > 1.5)	
				Frontal ("S" = 1-2)	
			MESOPELAGIC (200-1000 m)	Non-stratified ("S" < 1.5)	

			BATHYPELAGIC (1000-2000 m)		
			ABYSSAL/HADAL (>2000 m)		
		BENTHIC	LITTORAL (= Intertidal)	Rock/Boulders	Exposed/Very Exposed
					Moderately Exposed
					Sheltered/Moderately Sheltered
				Pebbles/Gravel/ Coarse Sand	
				Fine Sand	
				Mud/Silt	
			SUB-LITTORAL EUPHOTIC (0-50 m)	Rock/Boulders	Exposed/Very Exposed
					Moderately Exposed
					Sheltered/Moderately Sheltered
				Pebbles/Gravel/ Coarse Sand	
				Fine Sand	
				Mud/Silt	
			SUB-LITTORAL DYS/APHOTIC (50-200 m)	Gravel/Sand	Low Slope
					High Slope (Shelf Edge/Sea Mounts/Gullys/Canyons
				Mud/Silt	
			BATHYAL (200-2000 m)	Gravel/Sand	Low Slope
					High Slope (Shelf Edge/Sea Mounts/Gullys/Canyons
				Mud/Silt	
			ABYSSAL/HADAL (>2000m)	Not Applicable	
	SUB-TROPICAL **[Atlantic]**	PELAGIC	EPIPELAGIC (0-200 m)	Not Applicable - Always stratified	
			MESOPELAGIC (200-1000 m)	Not Applicable	
			BATHYPELAGIC (1000-2000 m)	Not Applicable	
			ABYSSAL/HADAL (>2000 m)	Not Applicable	
		BENTHIC	BATHYAL (200-2000 m)	Gravel/Sand	Low Slope
					High Slope (Shelf Edge/ Sea Mounts/Gullys /Canyons
				Mud/Silt	

			ABYSSAL/HADAL (>2000m)	Not Applicable	
	TEMPERATE **[Transitional]** **[Pacific]**	PELAGIC	EPIPELAGIC (0-200 m)	Stratified ("S" > 1.5)	
				Frontal ("S" = 1-2)	
				Non-stratified ("S" < 1.5)	
			MESOPELAGIC (200-1000 m)		
			BATHYAL (200-2000 m)		
			ABYSSAL/HADAL (>2000m)		
		BENTHIC	LITTORAL (= Intertidal)	Rock/Boulders	Exposed/Very Exposed
					Moderately Exposed
					Sheltered/ Very Sheltered
				Pebbles/Gravel/Coarse Sand	
				Fine Sand	
				Mud/Silt	
			SUB-LITTORAL EUPHOTIC (0-50 m)	Rock/Boulders	Exposed/Very Exposed
					Moderately Exposed
					Sheltered/ Very Sheltered
				Pebbles/Gravel/Coarse Sand	
				Fine Sand	
				Mud/Silt	
			SUB-LITTORAL DYS/APHOTIC (50-200 m)	Gravel/Sand	Low Slope
					High Slope (Shelf Edge/Sea Mounts/Gullys/Canyons
				Mud/Silt	
			BATHYAL (200-2000 m)	Gravel/Sand	Low Slope
					High Slope (Shelf Edge/Sea Mounts/Gullys/Canyons
				Mud/Silt	
			ABYSSAL/HADAL (>2000m)	Not Applicable	

10.2 Submarine Landscapes

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10.2.1 Introduction

The identification of landscape elements using biophysical parameters is a useful tool for studying landscape processes within a defined geographic area. Landscape elements of the Nova Scotia land area, including the coast, have been described in the *Natural History of Nova Scotia* (Simmons *et al*. 1984). The second edition of this publication provides descriptions of landscape elements that occur in the sea (Table 10.2.1). These elements have been identified using a method similar to that used to identify terrestrial landscapes but also including the physical characteristics of the sea bottom and overlying water (Davis and Browne, 1997 and Davis *et al*. 1994). The submarine landscapes identified by this method are similar to those being proposed as part of a national marine classification system (Geomatics International Inc., 1997; see also Section 10.1).

Table. 10.2.1. Natural History of Nova Scotia - Hierarchic System

Ecological Landsurvey Equivalent	Ecoregion	Ecodistrict	Ecosection	-	Ecosite (Landform)	Ecoelement	-
Natural History	Region	District	Unit	Sub-Unit (Geographic)	Habitat	Vegetation Association	Plant and Animal Species Inventory
					Based Upon Physical Description	Based Upon Biological Description	

The marine Region 900 is the area around Nova Scotia covered by seawater and extends from the shoreline to the Provincial and National boundaries and to the limits of the declared fisheries and mineral resource management areas. The Region is divided into four Districts of which two (930 and 940) have relevance to a greater management area for the Gully as proposed by Shackell *et al* . (1996). District 930 (Outer Shelf) is divided into two Units; 931 (Outer Shelf Banks) and 932 (Saddles, Shelf Edge, Submarine Canyons and Channels). Unit 931 has two Sub-Units; 931e (Sable Island Bank) and 931f (Banquereau) as separate geographic elements of the same landscape Unit. District 940 is the area of the Scotian Slope which begins at 200 m depth and extends onto the Continental Rise at depths of between 4000 and 5000 m. The locations of these landscapes are shown in Fig. 10.2.1.

The following descriptions have been slightly edited for the purposes of this document but are otherwise taken directly from Volume 2, *Theme Regions,* of the second edition of the *Natural History of Nova Scotia* (1997). Sections of the original descriptions dealing with Cultural Environment and the lists of Associated Topics and Associated Habitats used to cross reference with Volume 1 have been omitted here. Descriptions of other areas of Units 931 and 932, that are not part of the proposed greater management area for the Gully, have been retained to provide a broader context for the features described. The area of the Gully has representative elements of four of the 30 submarine landscapes described in the *Natural History of Nova Scotia*. The four landscapes are elements of more widely occurring landscapes. Unique features of the Gully may be detected at higher levels of resolution such as an analysis of habitats and species associations. However, a detailed classification of habitats and species associations similar to that used for terrestrial landscapes needs to be developed for submarine landscapes.

The text descriptions of Region 900 and the map (Fig. 10.2.1) which follow are reproduced with the permission of the Nova Scotia Museum.

10.2.2 District 930 - Outer Shelf

Geology and Landscape Development. The Outer Shelf is a broad zone (50-75 km wide) consisting of banks and intervening areas (saddles, channels and one major submarine valley, the Gully) extending from Banquereau on the east to Georges Bank on the west. The main banks (Banquereau, Sable, Western, Emerald, LaHave, Browns, and Georges in Unit 931) are relatively large, shallow (30-80 m), and more or less flat topped, representing features in the ancient bedrock which were overlain with glacial till and then leveled by the advancing sea following the latest glaciation (see also Section 3.0). Sable Island protrudes to a height of 26 m above the surface of Sable Island Bank and is the furthest offshore island. Relief of the banks relative to the other features of the Outer Shelf is comparable to areas of the mainland today: elevations of the outer banks are generally less than that of the Cobequid Mountains in the Wentworth area of Cumberland County and much less than the Cape Breton Highlands. On the other hand, the Gully, a submarine canyon between Sable Island Bank and Banquereau, is about half as deep as the Grand Canyon in the United States.

Sediments. The bank tops contain sand and gravel deposits, and, in the case of Sable Island, have been reworked and moved around to form extensive sand fields. Below a depth of about 110 m the bottom sediment consists of sand with silt and clay mixtures. The Outer Shelf contains no basins and the only clay deposits are found in the Laurentian Channel, which borders the eastern end of the District.

Oceanography. The front off the Scotian Shelf lies on average about 100 km seaward of the shelf break. This shelf break front is caused primarily by the confluence of relatively cool and fresh shelf water with warmer, saltier slope waters. Strong tidal flows, particularly over Browns and Georges Banks, also generate fronts whose positions are strongly related to the topography of the banks. In general, the shallower areas of these banks have large tidal currents that can keep the waters well mixed throughout the year. As the depth increases, tidal currents, and consequently mixing, decrease leading to stratified conditions and a temperature and salinity front. The tidal mixing can also be augmented by winds. In addition, this mixing and other tidal processes can lead to the formation of gyres around these banks. The resulting circulation can contribute to the retention of fish eggs and larvae.

Plants. The plant life is dominated by phytoplankton, but encrusting algae may occur in shallow water on suitable hard substrate in some of the bank areas. The outer edge of the continental shelf has enhanced plant productivity due to the interaction of shelf and slope water masses which bring nutrients to the surface.

Animals. The offshore banks are inhabited by many species of fish (see also Section 7.1). Some species prefer the finer bottoms around the margins. Groundfish live on or near the bottom and feed on invertebrates and other fish. Several species of large burrowing molluscs occur in the sandy substrate of offshore banks.

Lobster commonly move from the Inner Shelf to the Outer Shelf banks and continental slope, and can occur along the Outer Shelf and upper slope from Browns Bank to south-east of Sable Island.

10.2.2.1 Unit 931 - Outer Shelf Banks

Geology and Landscape Development. The Outer Shelf Banks include 931a East Georges Bank, 931b Browns/Baccaro Banks, 931c LaHave Bank, 931d Emerald Bank, 931e Sable Island Bank and 931f Banquereau. They were initially bedrock features known as cuestas, typically formed in coastal plain environments by erosion during early geological periods, before they were submerged. Their appearance has been transformed by deposition of glacial till, which has been reworked by the sea to form the present-day surfaces. The banks have moderate relief, generally between 100 and 150 m.

The sandy components of the sand and gravels that are found on the tops of the banks can be shaped by wave and current activity into a variety of seabed features, including sand ridges, sand waves, ripples and megaripples. Significant sand wave fields are seen on the western and eastern bars of Sable Island and magaripples, sand ridges and ribbons occur on west Sable Island Bank (sub-Unit 931e) and Middle Bank (sub-Unit 921e). On Browns Bank (sub-Unit 931b) there are sand waves that have megaripples on their sides. Sand waves and megaripples also occur in parts of Georges Bank (sub-Unit 931a) and there are large tidal ridges on the bank tops. Sand ridges are the largest of the features and migrate over long periods of time. Various ridges on Sable Island Bank mark the "footprint" of Sable Island as it moves to the east.

Patches of gravel, shell beds and even boulders occur. Many of the surface features change with each storm or tidal event, and many of the small scale features are erased during intervening periods. The northern edges of Sable Island Bank and Banquereau (sub-Unit 931f) have numerous steep-sided hanging valleys formed by glacial meltwater that ran over their edges. These hanging valleys extend onto the bank under the cover of surface sediments and are called tunnel valleys. Sediments moving off the edge of the shelf in these areas contribute material to the Gully, a major submarine canyon and a probable remnant of an early drainage system. Similar movements of sediments on the outer edges of the Outer Shelf Banks, particularly during low sea level stand, have led to the formation of distinct submarine canyons.

Sediments. The surfaces of the Outer Shelf Banks shallower than about 110 m consist chiefly of sands and gravels in various combinations in a layer generally less than 15 m in thickness. In some areas (such as the top of sub-Unit 931d Emerald Bank), gravel predominates, while Sable Island Bank is predominantly covered in sand. Where gravel is found, it can form a protective pavement of rounded stones embedded in the bottom. The sand tends to be hard, smooth and flat with a variety of surface bedforms as previously mentioned. Both types of bottom are classified as Sable Island Sand and Gravel. The margins of Outer Shelf Banks below 110 m have sediments that are principally sand, and that contain small amounts of clay, silt and (frequently) gravel. The surface may be flat and smooth to undulating and hummocky. Called Sambro Sand, these deposits cover the saddles adjacent to the Outer Shelf Banks in many cases.

Oceanography. The currents over the outer shelf banks are mainly caused by the interaction of the southwestward mean flow originating from the Gulf of St. Lawrence and the Newfoundland shelf-slope area with local topographic features, by tidal currents, and by wind-forced flows. The mean flow-topography interaction contributes to the gyre-like circulation in the Gully region and over Western Bank. Tidally generated currents are major features of the circulation around Browns and Georges Banks. From time to time, wind-forced flows dominate the circulation over all of the banks, particularly during winter storms. Tides and wind driven currents also contribute to vertical mixing over the banks. Tidal currents are strong enough to maintain well-mixed areas over Georges and Browns Banks year round.

Plants. The biomass and seasonal pattern of phytoplankton and productivity of the waters over the shelf edges is similar to those of the adjacent banks and saddles, with the exception of the outer edges. Here phytoplankton productivity is greater as a result of the interaction of shelf and slope water that occurs in the area.

Animals. More phytoplankton production reaches the seabed on the banks than in adjoining areas. Consequently benthic animal populations, including groundfish which feed near the bottom, are more significant on the offshore banks than in adjoining areas.

Cod stocks from Banquereau and Sable Island Bank migrate during the summer to the outer coast of Nova Scotia and northern Cape Breton Island. Some of the fish also go to the Gulf of St. Lawrence. Southern Scotian Shelf cod overwinter in deeper water around LaHave and Browns Banks. Some move from deeper water to the shallower areas of the banks in summer. On Georges Bank, Atlantic Cod occur principally on the eastern part.

Notable concentrations of Atlantic Halibut occur along the edges of Georges Bank, Sable Island Bank and Banquereau. Witch Flounder have localized areas of high abundance in the deep holes of Banquereau. Sand and gravel bottom typical of the banks is suitable for haddock spawning. They aggregate around the offshore banks at the beginning of the year and move onto the banks to spawn as the water temperature rises. Pollock (Boston Bluefish) spawn on the northeast part of Georges Bank and Browns Bank. They also spawn at several other locations on the Scotian Shelf and at Jeffries Ledge in the Gulf of Maine, and migrate as juveniles to inshore areas. Eggs and larvae of cod, haddock, pollock and Silver Hake are abundant on Western and Sable Island Banks. Those of cod and pollock are there during midwinter and early spring , and those of Silver Hake during midsummer.

Sea Scallop occur on Georges and Browns Banks particularly where the bottom consists of firm gravel, shells and rock. Two other large bivalve mollusc species, Ocean Quahog (*Arctica islandica*) and Stimpson's Surf Clam (*Mactromeris polynyma*), are found typically on most of the offshore banks but they are only locally abundant. The Ocean Quahog is the main species on Georges Bank and concentrations have also been found on Western and Sable Island Banks. Stimpson's Surf Clam is found mainly on Banquereau.

Sandy areas which make up much of Sable Island Bank provide habitat for benthic organisms such as the sand dollar, *Echinarachnius parma,* and the amphipods *Uniciola irrorata* and *Leptocheirus pinguis*. Sand dollars are extremely abundant in some locations. Parts of the banks having coarse substrate (gravel) are expected to have populations of Horse Mussel (*Modiolus modiolus*), brittlestars (*Ophiopholis aculeata*), Sea Scallops, lobster and Toad Crab (*Hyas coarctatus*).

10.2.2.2 Unit 932 - Saddles, Shelf Edge, Submarine Canyons and Channels

<u>Geology and Landscape Development.</u> The banks of the Outer Shelf are bordered by intervening deep-water areas which include saddles and channels, submarine canyons and the continental slope. Saddles generally have gentle relief and are shallower than about 200 m, while channels are deep, broad lowland features occurring at a similar depth to the basins of the Middle Shelf. Saddles are found between Sable Island/Western Bank and Emerald Bank, and between Emerald Bank and LaHave Bank. Northeast Channel separates Browns and Georges Banks and Laurentian Channel separates Banquereau and the eastern Scotian Shelf from the banks off the coast of Newfoundland.

Submarine canyons occur along the outer edges of the Outer Shelf and extend down the continental slope. These are narrow, deep and steep-sided features and include the Gully, and Verrill, Dawson, Bonnecamps, Logan, Shortland, and Haldimand Canyons. The Gully is a submarine canyon that approaches Colorado's Grand Canyon in depth, extending from 100 m to more than a kilometer between Sable Island Bank and Banquereau Bank (the Cape Breton Highlands by comparison are roughly 500m high). The Gully probably originated as a drainage channel and later developed into a canyon. The river and submarine canyon at the mouth of the Hudson River on the United States East Coast is an analogous feature.

Northeast Channel joins the Outer Shelf between Browns and Georges Banks with the basins of the Gulf of Maine at depths between 200 and 300 m. Megaripples occur on the northern and eastern flanks of Northeast Channel at depths of 100-150 m, and sand waves on the bottom of Northeastern Channel at depths of 230-260 m are evidently caused by tidal currents. These are some of the deepest recorded sand waves on the continental shelf, caused by the strong tidal currents in the Bay of Fundy-Gulf of Maine.

Laurentian Channel is the most impressive of these features, arising as a former river valley deepened by glacial ice and having a sill (a shallower portion near the outer edge). The Channel extends 700 km from the junction of the Saguenay and the St. Lawrence Rivers in Quebec to the edge of the continental shelf between Nova Scotia and Newfoundland, and was cut 300 m below the rest of the shelf by the advancing ice. Down the slope from the Channel the Laurentian Fan occurs, a delta-like feature containing sediments from the ancestral St. Lawrence River and from recent sediment flow activity.

At the edge of the shelf, the bottom plunges downward to the continental slope. The shelf edge is marked by the occurrence of submarine canyons and glacial features which demonstrate the furthest extent of the ice sheets.

Sediments. Saddles between Outer Shelf Banks (Unit 931), parts of Northeast Channel and the Gully generally have a cover of sand containing clay, silt and frequently gravel (Sambro Sand, see above). The outer and inner ends of Northeast Channel, in addition, have a cover of glacial till, consisting of mixtures of significant amounts of silt and clay in addition to sand, gravel and boulders. The glacial till is classed as Scotian Shelf Drift.

In the Laurentian Channel the bottom consists of glacial sediments, mainly clay, with silt exposed in some places. Flows of sediment down the slope from the Channel can leave coarse deposits.

Oceanography. Saddles occur at depths less than 200m, and form an entrance to the basins of the Middle Shelf (District 920) for subsurface water masses, typically the warmer, deeper Slope Water from the shelf edge. Georges Bank with depths greater than 200m is profoundly influenced by tides and serves as a pathway for water exchanges between the Gulf of Maine and the slope region. The deep Laurentian Channel permits incursions of deep water of Atlantic origin into the Gulf of St. Lawrence.

Plants. Productivity of the waters, biomass of phytoplankton and seasonal patterns in saddles and canyons are similar to that of the adjacent shelves. The outer margin of the continental shelf, however, has greater plant productivity due to the interaction of shelf and slope water masses in a "frontal zone" whose position changes from year to year. The elevated productivity is used by, and is believed to enhance, populations of fish and other organisms in the area.

The edge of the Outer Shelf is exposed periodically to water masses derived from the Gulf Stream which flows to the south. Occasionally masses of the seaweed *Sargassum* can be found floating in the area.

Animals. Witch Flounder are associated with deep holes and channels between the coastal banks, along the deep edges of the banks where water temperatures are suitable, and in gullies where bottom is usually clay, muddy sand or mud. This species has localized areas of high abundance along the edge of the Laurentian Channel, between Sable Island and Banquereau and in deep holes of Banquereau. Notable concentrations of Atlantic Halibut occur along the edges of Georges, Sable Island and Banquereau Banks. Various flatfish species occur in areas fringing the banks. Owing to the warmer water there, the outer margin of the shelf is a principal area of concentration of Silver Hake which move onto the Scotian Shelf as temperatures warm in summer. The main known overwintering area for Atlantic Mackerel is the continental shelf south and south-west of Georges Bank.

Short-finned Squid are usually most common along the outer edge of the Scotian Shelf in June, usually between Emerald and LaHave Banks and in some years along the entire edge of the Shelf. They spread over the shelf later in the summer and still later migrate south-west down the North American east coast. The young are brought back into the area by the Gulf Stream. Juveniles live in the Gulf Stream frontal zone and Slope Water off the edge of the continental shelf until they reach about 10 cm in length.

Deep-sea Red Crab (*Geryon quinquedens*) are abundant along the shelf edge from the Fundian Channel to Sable Island at depths of 180-550 m. Significant quantities of lobster occur at the shelf edge from Browns Bank to Sable Island Bank.

One of the two best-known areas of concentration of the Northern Bottlenose Whale is in the Gully (see also Section 9.0).

Seabird concentrations are greater in the shelf edge region owing to the elevated productivity there (see also Section 8.0). Wintering Dovekies are most common over the edges of the Scotian Shelf. On Georges Bank, Wilson's Storm Petrels are most common over the shelf-break.

10.2.3 District 940 - Scotian Slope

The Scotian Slope District is a very large area extending from the outer limit of District 930 (at approximately 200 m deep) to the political and resource management boundaries at depths of 4,000 to 5,000 m. This is a fully oceanic environment.

Geology and Landscape Development. The District includes the continental slope and rise, but as the boundary between them is not distinct no attempt has been made to separate them as Units. The slope is indented by canyons and channels, including the Gully and the Laurentian Channel, both of which originate in District 930.

The area is underlain by thick post-Atlantic Rift sediments which have been accumulating continuously in the Scotian Basin since the Mesozoic. The Jurassic and Cretaceous rocks are mildly folded and faulted along the continental margin. Both the Shelbourne sub-Basin in the southwest and Sable sub-Basin in the northeast have extensive salt deposits. Late Tertiary and Quaternary deposits are horizontally bedded and some outcrop in canyons and scarp features on the continental slope. The area is subject to high seismic activity with main stress in a southwest/northeast direction with the earthquakes up to magnitude 6. The Newfoundland earthquake of 1929 registered 7.2 on the Richter Scale.

<u>Sediments.</u> Recent sediments accumulating on the continental shelf are slumped along the shelf break and travel down the slope, often in the canyons, as turbidity currents. Thick accumulations of these slumped sediments are found on the slope between 200 m and 2,000 m depth. This talus material includes sand (Sable Island Sand and Gravel), marine silty clay (LaHave Clay), glaciomarine silty clay (Emerald Clay) and Diamicton/Till. The surfaces of these deposits are marked with pockmarks, palaeoiceberg scour marks and sand ridges (Laurentian Fan). From the base of the slope towards the deep water there is a gradation of surficial sediments; discontinuous, stratified mud series, muds alternating with silt and sand and finally a sand sheet of Later Pleistocene or Holocene age. These deposits are cut by erosion channels of the same age. The deep water sediments are covered with a thin layer of pelagic or hemipelagic sediment which include fine mineral particles and the shells and spicules of marine organisms, *e.g.* Radiolaria.

<u>Oceanography.</u> This District is generally oceanic in character though on average a surface wedge of shelf water approximately 50 m deep extends 100 km seaward of the shelf break. Two main types of slope water underlie the shelf water. Labrador Slope Water is relatively cool and fresh, and Warm Slope Water, derived from a mixture of shelf waters and offshore waters associated with the Gulf Stream, is warmer and more saline. A number of processes contribute to the mixing of shelf and slope waters; however, one of the most effective mechanisms is caused by the entrainment of shelf water by Gulf Stream rings and meanders. Wind-induced upwelling and the generation of internal tides and waves at the shelf break contribute to the vertical mixing and transport of nutrients in the region.

<u>Plants.</u> Phytoplankton in the surface water is responsible for the primary productivity that occurs in the District. However, this is only significant in the area of the shelf break as the level of nutrients available diminished rapidly towards the deep water. Some floating patches of *Sargassum* weed occur which are of relatively little ecological significance although they support a distinct community of animals and may, rarely, reach the Nova Scotia coast.

<u>Animals.</u> The deep water and oceanic conditions of District 940 support communities of species of animals not normally encountered in continental shelf waters. The two Habitats of the Offshore, Open Water Ocean and Benthic Ocean, will be treated separately.

Open water ocean species of pelagic animals depend upon the primary productivity of the surface waters. Phytoplankton is grazed by herbivorous zooplankton; copepods, cladocerans, euphausiids and a wide range of larval forms. There are many carnivorous species including crustaceans, medusae and the larvae and juveniles of fish. The nekton or free-swimming animals range in scale from jellyfish to whales, but the predominant forms are crustaceans, cephalopods and fish. In the deep water these animals are grouped into vertically zoned communities; epipelagic (top), mesopelagic (middle) and bathypelagic (bottom).

The epipelagic community includes surface swimming molluscs (*Janthina* and *Argonauta*), coelenterates (*Valella* and *Physalia*) and fish (Swordfish and Flyingfish). A number of species of invertebrates and fish are associated with *Sargassum* weed and Goosebarnacles (*Lepas*) are associated with floating objects. The mesopelagic community is characterised by a diurnal vertical migration; rising to the surface at night and descending to the depths at day. This migration of several hundred metres allows the deep water species to take advantage of surface productivity. The mesopelagic community is composed of crustaceans (shrimps and amphipods), cephalopods (squid and pelagic octopus) and fish, particularly the distinctive Lanternfish, Viperfish and Hatchetfish). These species are all predatory carnivores, often darkly coloured and may have reflective plates and photophores (light-producing organs). Lanternfish are found at a depth of 700 to 1200 m during the day but rise to within 100 m of the surface to feed at night. The bathypelagic community lives in close association with the bottom and includes economically important types such as grenadier that occur down to 2,500 m depth. Many of the species that occur in the bathypelagic zone, such as the Giant Squid which appears on a thirty-year cycle, are poorly known.

The benthic ocean habitat includes those communities that live in or on the ocean bottom. In District 940 this is an environment without light. The generally soft sediments support an infauna of worms; Pogonophora and Polychaeta, coelenterates; seapens, gorgonian (*Radicipes*) and solitary corals (*Flabellum*), a wide variety of scaphopod, pelecypod and gastropod molluscs and echinoderms. The crinoid (sea lily), *Rhizocrinus lofotensis*, has been found on the slope at a depth of 1700 m. Epifauna includes any animal that roams around the sea bottom or attaches itself to a solid object. Old ice-rafted boulders are colonised by sponges, coelenterates, bryozoa and brachiopods while crustaceans, seaspiders and brittlestarfish are vagrants. Rock bottoms provide habitat for a distinct community of gorgonian corals, including *Paragorgia*, *Primnoa* and *Keratoisis.* A variety of bottom feeding fish occurs including the Atlantic Batfish, Monkfish, anglerfish and Chimaera. Blue Hake, *Antimora rostrata*, occur between 1300 and 2500 m depth.

10.2.4 References

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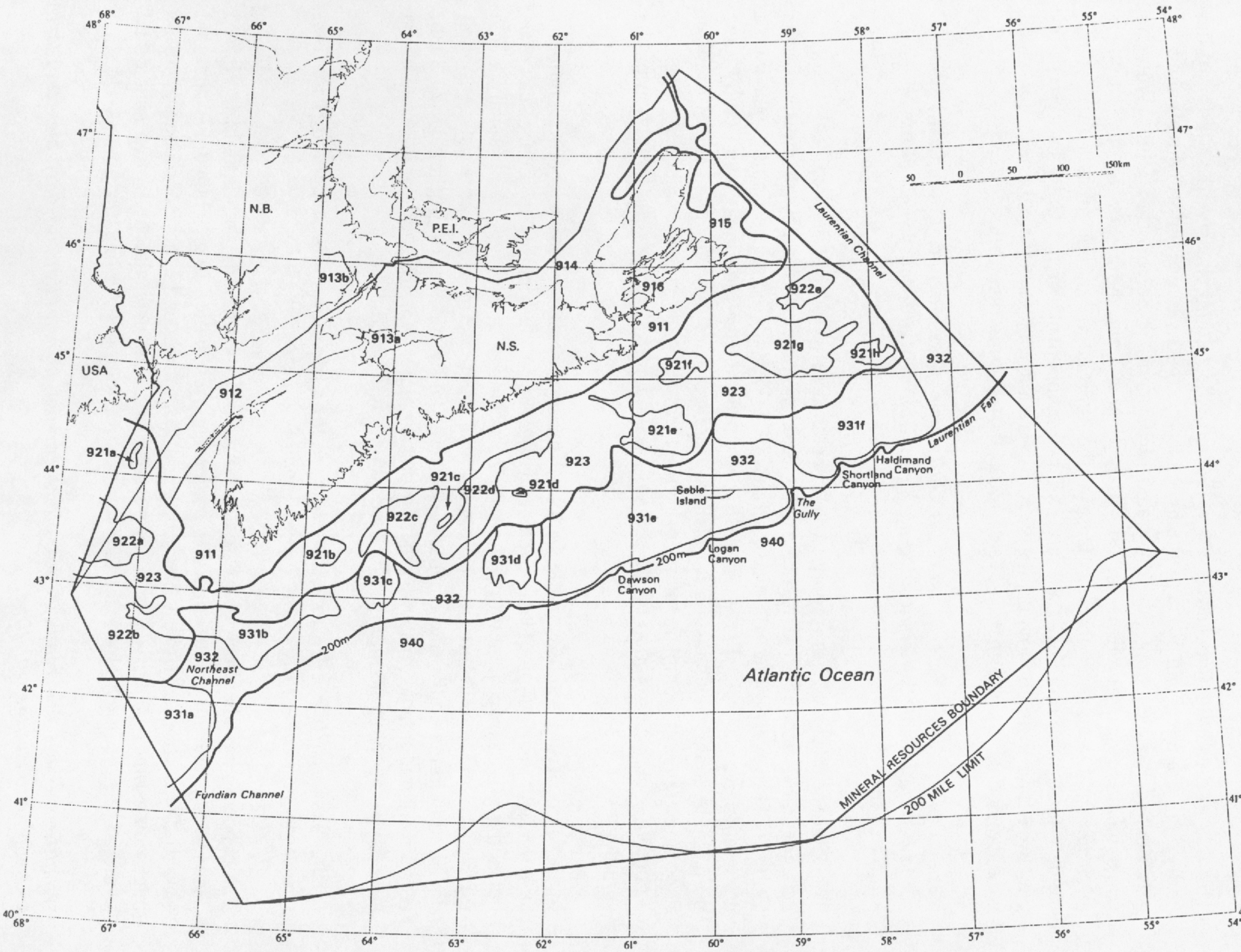

Fig. 10.2.1. Submarine landscapes of the Scotian Shelf. (from *The Natural History of Nova Scotia* 1997. Vol 2). The four landscapes in the Gully area are sub-units 931e and 931f (Outer Shelf Banks), Unit 932 (Saddles, Shelf Edge, Submarine Canyons and Channels) and District 940 (Scotian Slope).

11.0 Knowledge Gaps, Recommendations and Future Research Requirements

The goal of the Gully Science Review was to provide a comprehensive description of the Gully's environment and its ecosystems. Ideally, the available information would be sufficient for developing an integrated ecosystem view of the Gully with an understanding of it components, how they interact, and how they respond to their environmental regulating forces. Despite the substantial amount of data the Science Review team has compiled, there are still key components of the Gully ecosystem for which we have virtually no quantitative information and other key components for which we have incomplete information (Table 11.0.1). As a consequence:

a complete ecosystem description of the Gully is not possible now, although the same could be said for our understanding of the environment and ecosystems of the Scotian Shelf in general.

The Science Review has produced a general description of the regional geology, oceanography, fisheries and higher trophic level fauna (seabirds and mammals) of the Gully. However, none of these components could be identified as having a comprehensive dataset. For example, most current meter moorings in the Gully have been single deployments lasting for a short time; arrays of instruments have not been set in conjunction with complementary hydrographic, biological and chemical sampling. As a consequence, a description of the general circulation in the area rests largely on model simulations.

In the case of the benthos of the Gully, virtually nothing is known about community structure and distribution. Data have been collected on the occurrence of deep sea corals but nothing is known quantitatively about their ecology or biology. Additionally, some information on the occurrence of commercial benthic invertebrates exists but their distribution in the Gully, movements between the Gully and the rest of the Scotian Shelf, recruitment and interactions with other species are unknown. This lack of information on a fundamental component of the Gully ecosystem requires that:

further research is needed to establish a baseline of information on the distribution, structure and functioning of the benthic communities of the Gully.

The concern has also been expressed that much of the existing data are old (collected decades ago) and may not reflect the contemporary situation (e.g. ichthyoplankton, and seabird distributions). Have there been significant changes in these components in the intervening time? Other datasets are reasonably up to date although often sparse and scattered (e.g. geology, physical and chemical oceanography, finfish, mammals). Thus:

scientific surveys are required to collect current information on variables that are susceptible to change with time.

Another recurring concern is that the spatial and temporal resolution of the available data are inadequate to address unambiguously questions relating to: (1) the uniqueness of the Gully as compared to the rest of the Scotian Shelf and slope, (2) the processes occurring within the Gully that influence productivity of the region and (3) the issue of defining operational "boundaries" for the Gully. Notably, descriptions of the physical, chemical and biological oceanography from limited small-scale studies showed that oceanographic conditions conducive to enhanced nutrient supply and productivity might exist in the Gully but were not discernible from conventional coarse-scale sampling. A similar argument was made in evaluating the distribution of pelagic seabirds in the vicinity of the Gully. Clearly, data with a spatial resolution considerably less than the 10s of km that define the bathymetric "boundaries" of the Gully (e.g. the 200m contour) and temporal resolution shorter than seasonal or monthly means would be required to address the dynamics that characterize the Gully on the small scale. At present, the only data with adequate spatial resolution are the multibeam bathymetry for geological and hydrographical studies, acoustics and towed instrumentation (including video) for oceanography and fish, and airborne surveillance for seabirds and mammals. These data are limited to small areas of the Gully or are simply unavailable, however. It is evident, therefore, that:

the more widespread use of technology that permits rapid, high spatial resolution sampling will be required to adequately address questions relating to the characteristics of the Gully with regard to its ecologically dynamic features and will be required to delineate Gully boundaries based on biological as well as physical properties.

Filling information gaps will be a necessary but not sufficient condition to develop an integrated ecosystem description of the Gully. Fundamental questions remain about the functional linkages between ocean physics-chemistry and productivity of the plankton, the benthos (i.e. benthic-pelagic coupling) and the aggregation of seabirds and marine mammals in the region. No single research organization, including DFO, has the capabilities to carry out a complete system study. It is essential, therefore, that:

the various government and NGO researchers and stakeholders should commit resources for more focused, coordinated and comprehensive research in the Gully region in order to develop a better understanding of the processes that account for its abundant and diverse biota. Scientific information collection will also benefit from and should be supplemented by the working knowledge of resource users, i.e. traditional ecological knowledge.

The Science Review team acknowledged that information gaps will exist even if all recommendations are implemented. Therefore:

in cases where crucial scientific information is lacking, the "precautionary principle" as stated in the Oceans Act must be applied.

The Gully Science Review team was given the task of assembling information on a geographically small area of the Scotian Shelf but without being given strict guidelines on the nature and scope of the review. This can be described as a "bottom-up" approach for developing an understanding of a region's environment and ecology. That is to say, the primary focus is on the description of a specific region with its relationship to surrounding regions being secondary. The Gully Science Review has taken almost a year to complete and has involved the commitment of considerable time from numerous experts from within and outside the government. Two reports at the end of the Science Review propose that a "top-down" approach based on a systems classification scheme may be a more logical and efficient starting point. Here, the specific region of interest is placed in the context of the surrounding regions right at the onset. The science of system planning is, in fact, a mature one, developed decades ago and successfully applied as a tool for classifying terrestrial ecosystems. It is currently being adapted to marine ecosystems. It is the consensus of the Gully Science Review team in judging the merits of "bottom-up" versus "top-down" approaches that consideration of the time and resources that went into the Gully Science Review, the prospect for others in the future, and considering that much of the ground work has already been laid in systems classification of the Scotian Shelf:

a systems approach to ecosystem classification should be implemented by DFO as a framework for meeting future departmental requirements for science information for our regional waters.

Systems classification is not considered a substitute for the site-based, focused research required to address region-specific questions but will provide the background information necessary for more efficient use of research personnel and resources and for placing the scientific understanding gained in the broader system context.

Table 11.0.1. Current status of information on the environent and ecosystem of the Gully.

Component	Information				Data*	Gaps
	Good	Useful	Poor	Analog		
Geology		X		X	x	Limited to shallow zone (<600 m); Little multibeam data.
Hydrography		X		X		Coverage <1% of the bottom area.
Ambient Noise			X		x	Not addressed in Gully Science Review.
Oceanography						
Physical		X		X		Limited to shallow zone; Sparce data for circ. model calibration.
Chemical		X				No contaminants data; Poor small-scale spatial/temporal coverage.
Biological		X				Lack of contemporary data; Poor small-scale spatial/temporal coverage.
Benthos			X	X	?	No quantitative data.
Fish						
Finfish	X			X	x	Poor small-scale spatial/temporal coverage.
Invertebrates			X	X	x	Lack of data on distribution, movements, recruitment.
Seabirds			X			Poor small-scale spatial/temporal coverage.
Mammals	X			X		Lack of data on at-sea distribution of pinnipeds; Lack of data on cetacean distribution outside summer.

*Additional data available but not analyzed

12.0 The Gully Ecosystem - An Integrated View

Despite gaps in our knowledge of a number of important environmental and ecological elements of the Gully (Section 11.0), enough is presently known from this and analogous regions to describe the key processes and interactions which define submarine canyon ecosystems in general and the Gully in particular (Fig. 12.0.1).

The Science Review revealed that the Gully is the largest of the submarine canyons which cut into the eastern continental margin of North America. It is equally distinctive for its penetration well onto the continental shelf and for its depth (>2000 m) and extremely steep walls. Collectively, these physiographic features have important implications for local circulation, onshelf nutrient fluxes, sediment dynamics, and the distribution and structure of biological communities.

On the basis of scientific observations in the Gully, modelling results and more extensive studies in analogous regions, it is clear that circulation in submarine canyons is strongly influenced by the local topography and mean flows along the adjacent continental shelf and slope. Evidence suggests that the Gully may act at times as a significant conduit for material transport onto and off of the shelf and may be an area of significant material retention, thus influencing local deposition. Its steep slopes make it an area where internal wave activity may be enhanced, leading to stronger local mixing, nutrient transport to surface waters and to increased local primary production. Patterns of circulation and flow strengths also contribute to the distribution and nature of surficial sediments; circulation and sediment type, in turn, influence the distribution, abundance and community structure of the benthos.

Locally enhanced primary production can provide energy for zooplankton in the water column and/or for benthic filter-feeders when transported to depth as phyto-detritus. The zooplankton are in turn an important food source for larval finfish and invertebrates which are consumed by adult pelagic finfish, seabirds and marine mammals. The benthic communities are an additional food source for marine mammals and for demersal finfish. The diversity of feeding types of cetaceans found in the Gully suggests that the food sources which support their activity are likewise diverse.

Besides providing a localized food source, submarine canyons may also provide refuge for a variety of organisms from plankton to mammals. These and the deep basins that are found on the Scotian Shelf, for example, are known to harbour large populations of over-wintering meso and macrozooplankton, *e.g.* krill. The steep and complex bathymetry of submarine canyons also provides for high substrate (habitat) diversity which is associated with high biodiversity. The Science Review has documented, for example, that the Gully is a region of strong demersal ichthyiofaunal boundaries and that their diversity is high compared to the eastern Scotian Shelf as a whole. High benthic species diversity has been noteworthy in studies of other canyon features along the North Atlantic coast.

It is not unreasonable, therefore to conclude that the aggregation of fish, seabirds and mammals within or in proximity of submarine canyons can be explained by: (1) an enhanced supply of food mediated by processes which favor localized production and its retention there and (2) a diversity of habitats, providing both substrate and shelter to support a complex array of biotic communities within a geographically confined region. The extent to which the Gully conforms to this generic view of submarine canyon ecosystems can only partially be evaluated at present; more (multidisciplinary) research in the region will be required to fill the critical knowledge gaps and quantify the key processes and interactions.

Submarine Canyons

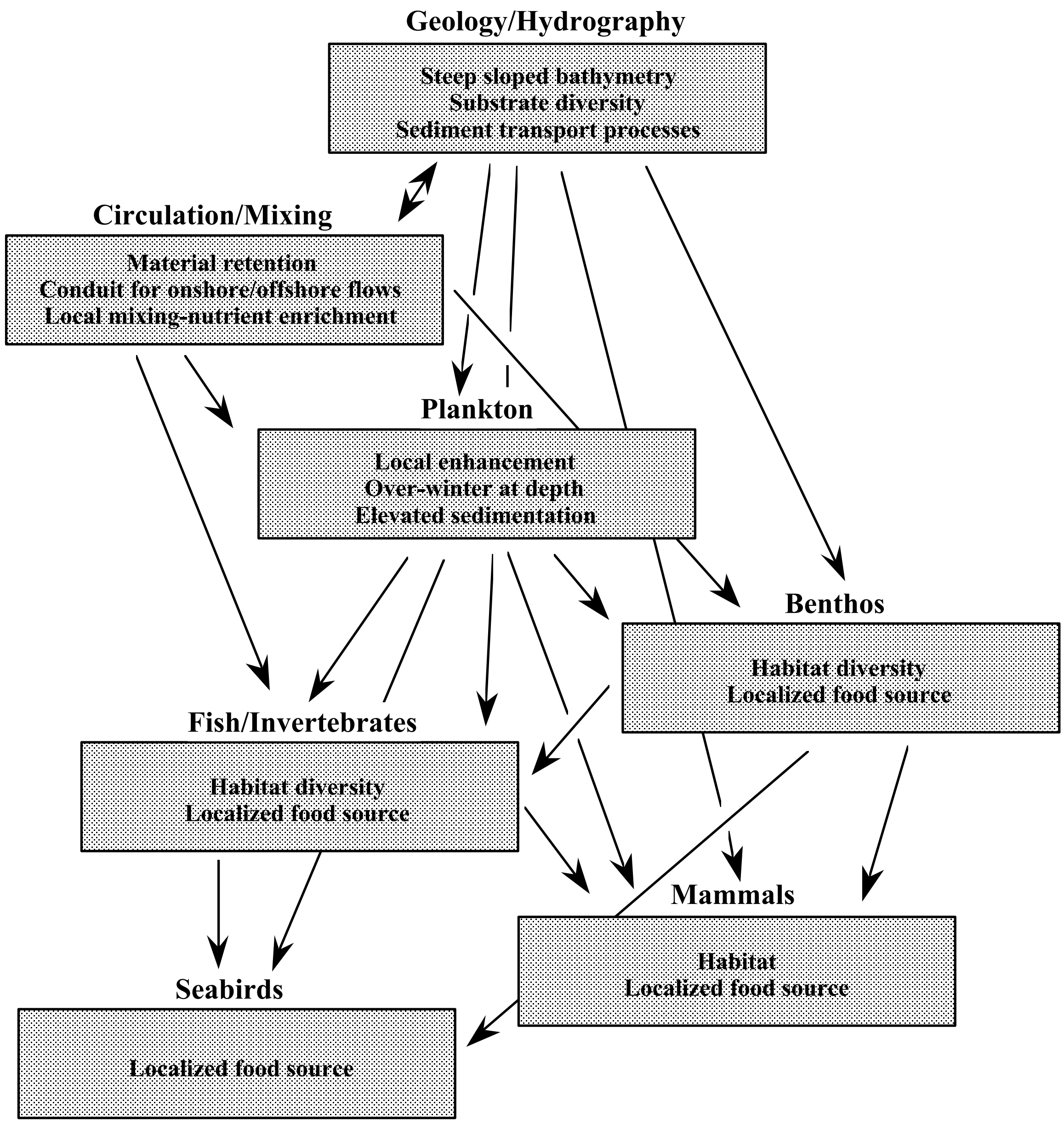

Fig. 12.0.1. Linkages among the major environmental and ecosystem components of submarine canyons.