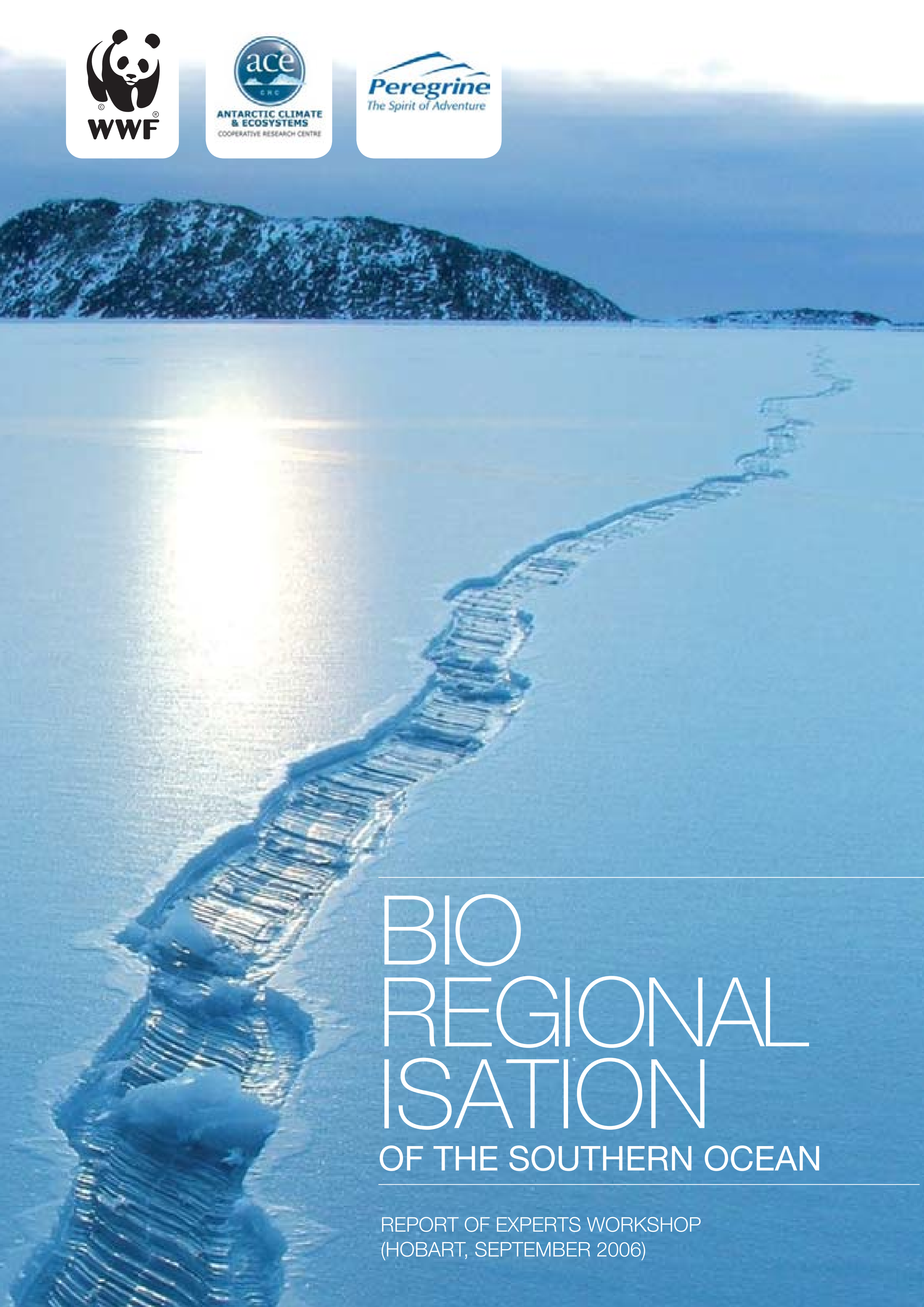

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BIO REGIONAL ISATION

OF THE SOUTHERN OCEAN

REPORT OF EXPERTS WORKSHOP
(HOBART, SEPTEMBER 2006)

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This report should be cited as:
Grant, S., Constable, A., Raymond, B. and Doust, S. (2006) Bioregionalisation of the Southern Ocean: Report of Experts Workshop, Hobart, September 2006. WWF-Australia and ACE CRC.

The CD attached to this report includes appendices, analysis tools, data and maps (including a GIS database) referred to in the report.

ISBN: 1 921031 16 6

Acknowledgements:

This report presents the outcomes of an Experts Workshop on Bioregionalisation of the Southern Ocean, held in Hobart, Australia, 4-8 September 2006, hosted by WWF-Australia and the Antarctic Climate and Ecosystems Cooperative Research Centre.

This workshop, and the preparation and publication of the report, was made possible through the generous support of Peregrine Adventures, which operates expedition-style voyages to the Antarctic Peninsula, the Falkland Islands and South Georgia. Peregrine supports WWF-Australia with funds raised through passenger and staff donations on board their ships, the Peregrine Mariner and Peregrine Voyager.

Responsible Tourism is a fundamental platform of Peregrine's operations. In line with this principle of sustainability, Peregrine has funded this report in the belief that it provides a foundation for the understanding and long-term conservation of Antarctica's important habitats and wildlife.

Additional support was provided throughout the project by WWF-Australia and the Antarctic Climate and Ecosystems Cooperative Research Centre.

The authors wish to thank all of the participants in the 2006 Experts Workshop, whose expertise and thoughtful input provided the material and outcomes for this report, as well as reviews of the manuscript. A full list of participants can be found at the end of the report.

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Acronyms and abbreviations

ACC	Antarctic Circumpolar Current
ATCM	Antarctic Treaty Consultative Meeting
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CEP	Committee for Environmental Protection
CPR	Continuous Plankton Recorder
LME	Large Marine Ecosystem
MPA	Marine Protected Area
PAR	Photosynthetically active radiation
PF	Polar Front
SACCF	Southern Antarctic Circumpolar Current Front
SAF	Subantarctic Front
SC-CAMLR	Scientific Committee for the Conservation of Antarctic Marine Living Resources
SSH	Sea surface height
SST	Sea surface temperature
STF	Subtropical Front

Executive Summary

In September 2006, twenty-three scientists from six countries attended an Experts Workshop on Bioregionalisation of the Southern Ocean held in Hobart, Australia. The workshop was hosted by the Antarctic Climate and Ecosystems Cooperative Research Centre, and WWF-Australia, and sponsored by Peregrine. The workshop was designed to assist with the development of methods that might be used to partition the Southern Ocean for the purposes of large-scale ecological modelling, ecosystem-based management, and consideration of marine protected areas. In 2005, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) and its Scientific Committee (SC-CAMLR) considered that a bioregionalisation of the Southern Ocean was needed to underpin the development of a system of marine protected areas in the Convention area.

The aim of the workshop was to bring together scientific experts in their independent capacity to develop a ‘proof of concept’ for a broad-scale bioregionalisation of the Southern Ocean, using physical environmental data and satellite-measured chlorophyll concentration as the primary inputs. Work included presentation of background information, computer-based analysis undertaken in small groups, and plenary discussion on the methods, data and results. Workshop participants are listed at the end of this report.

At the conclusion of the workshop, a method had been agreed upon that could be used to take the bioregionalisation work forward. Consensus was achieved on a draft physical regionalisation, and progress was made in determining how to include additional (e.g. biological) data for a more complete bioregionalisation. This report outlines the key results of the workshop, and highlights some of the issues discussed.

An understanding of the spatial characteristics of large ecosystems such as the Southern Ocean is important for the achievement of a range of scientific, conservation and management objectives. Bioregionalisation is a process that aims to partition a broad spatial area into distinct spatial regions, using a range of environmental and biological information. The process results in a set of bioregions, each with relatively homogeneous and predictable ecosystem properties. The properties of a given bioregion should differ from those of other regions in terms of species composition as well as the attributes of its physical and ecological habitats.

Classification of regions based only on biological data is often impractical at larger scales because of insufficient geographic coverage, even though there may be sufficient data to subdivide smaller-scale portions of those regions. Physical and satellite-observed data generally have better spatial and temporal coverage and greater availability than biological data. These can be used to help characterise regions on the basis of environmental properties, physical processes, primary production, and habitat type.

Initial discussions during the workshop focused on defining the major physical processes in the Southern Ocean, and their relationships with ecological processes. A key aspect of undertaking an ecologically meaningful regionalisation is to understand how important ecological processes correspond to the physical and satellite-observed parameters, and whether these parameters are appropriate for use as proxies or surrogates. This may depend in part on the end-use application of the analysis, and the scale at which the analysis is being undertaken.

Environmental data used as the primary input for analysis during this workshop were chosen based on their spatial coverage across the Southern Ocean. The datasets considered included bathymetry, sea ice concentration and extent, sea surface temperature, sea surface height, chlorophyll *a* concentration, nutrient data (silicate, nitrate and phosphate), and insolation (photosynthetically active radiation - PAR).

A series of presentations on approaches to bioregionalisation that have been undertaken elsewhere (terrestrial Antarctica, Australia, New Zealand) allowed detailed consideration of the relative benefits of different methods. The analytical methods used by Lyne and Hayes (2005), Leathwick et al. (2006a) and Raymond & Constable (2006) were used as starting points for the analysis during the workshop. These methods were refined into a single methodology, In September 2006, twenty-three scientists from six countries attended an Experts Workshop on Bioregionalisation of the Southern Ocean held in Hobart, Australia. The workshop was hosted by the Antarctic Climate and Ecosystems Cooperative Research Centre, and WWF-Australia, and sponsored by Peregrine. The workshop was designed to assist with the development of methods that might be used to partition the Southern Ocean for the purposes of large-scale ecological modelling, ecosystem-based management, and consideration of marine protected areas.

Photographer: Wayne Papps, Australian Government Antarctic Division, © Commonwealth of Australia

following workshop discussions and practical explorations of the methods.

Issues examined included the choice of data and extraction of relevant parameters to best capture ecological properties, the use of data appropriate for end-user applications, and the relative utility of taking a hierarchical, non-hierarchical, or mixed approach to regionalisation. The final method involved the use of a clustering procedure to classify individual sites into groups that are similar to one another within a group, and reasonably dissimilar from one group to the next, according to a selected set of parameters (e.g. depth, ice coverage, temperature). This approach shared strong similarities to several previous regionalisation methods, including Lyne and Hayes (2005) and Leathwick et al. (2006a).

The workshop established a proof of concept for bioregionalisation of the Southern Ocean, demonstrating that this analysis can delineate bioregions that agree with expert opinion at the broad scale. Consensus was reached on which of the trial bioregionalisations were the most ecologically and statistically meaningful according to expert opinion.

The workshop concluded that a statistical, hierarchical approach was the most useful in displaying the different levels of similarity and providing choices on the degree to which the region might be subdivided on the basis of the chosen datasets. The datasets were divided into primary and secondary datasets, reflecting

the primary properties of the region and the secondary environmental properties that might provide smaller-scale subdivisions to reflect the spatial heterogeneity of the Southern Ocean ecosystem.

The primary datasets used in this analysis were depth, sea surface temperature, silicate and nitrate. These highlighted the different environmental characteristics of large regions including the continental shelf and slope, frontal features (Subantarctic Front, Polar Front, Southern Antarctic Circumpolar Current Front), the deep ocean, banks and basins, island groups and gyre systems. Other primary datasets that could be usefully considered in future analyses were identified by the workshop, and included sea surface height and insolation.

The secondary datasets used in the analysis were ice concentration and mean chlorophyll *a* values. The addition of these datasets suggested smaller-scale spatial heterogeneity within the regions particularly in the continental shelf and slope areas, and the seasonal ice zone. These results highlighted the need for further analysis at the secondary level.

The final stages of the analysis included discussion on how well the defined regions corresponded to our present knowledge of the Southern Ocean. Experts provided information on the patterns and features that they would expect to see, according to current observations and understanding, and these largely concurred with the outcomes of the analysis.

Finally, workshop participants discussed priorities for future work, including the development of further methods to deal with uncertainty, understanding of inter- and intra-annual variation, validation of results, the incorporation of additional data (particularly biological datasets) and finer-scale analysis of particular areas of interest.

This workshop established a 'proof of concept' for bioregionalisation of the Southern Ocean. Continuation of this work will be an important contribution to the achievement of a range of scientific, management and conservation objectives, including large-scale ecological modelling, ecosystem-based management, and the development of an ecologically representative system of marine protected areas.

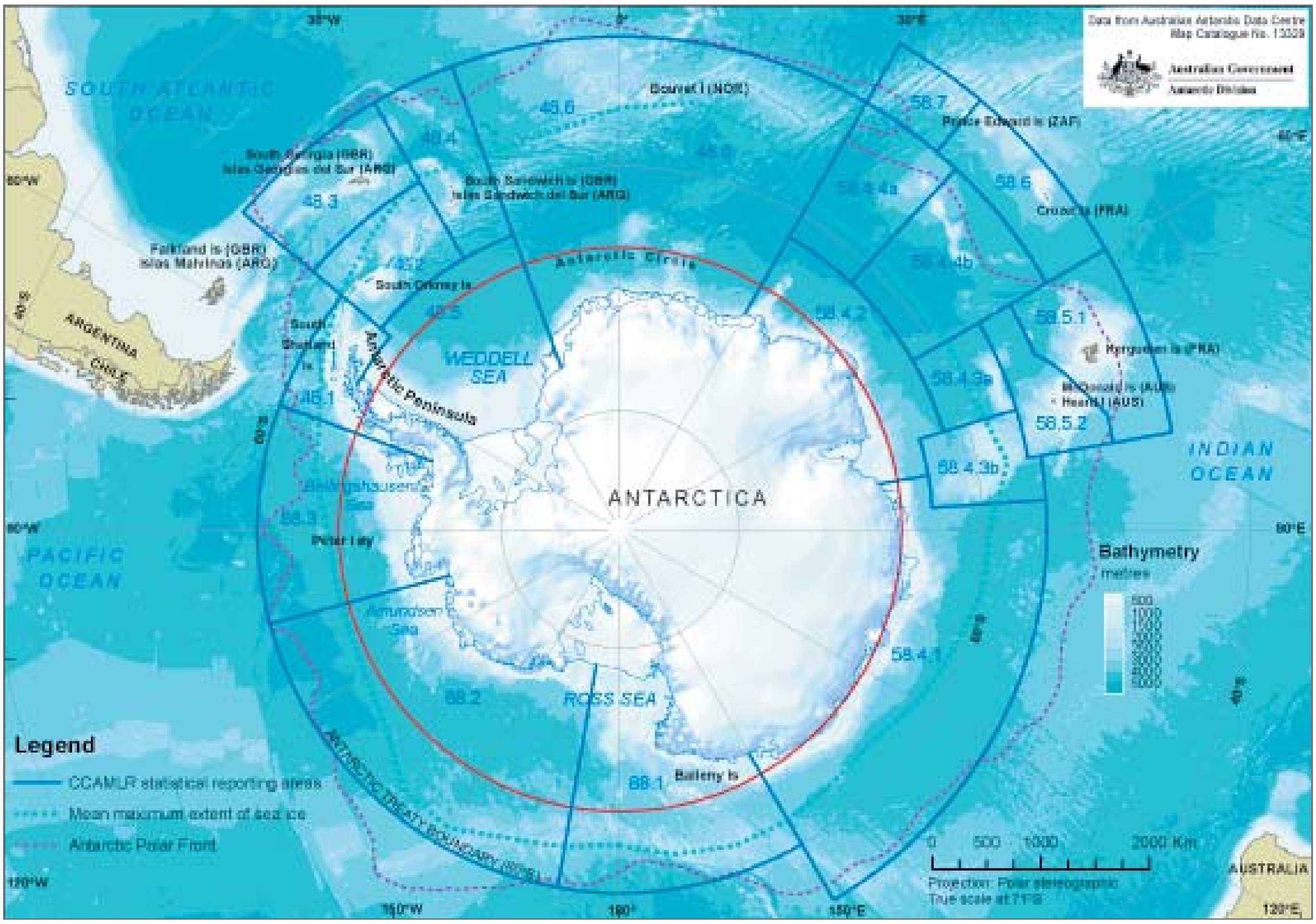

FIGURE 1: Map of Antarctica and the Southern Ocean. (Data from Australian Antarctic Data Centre)

1. Introduction

The Southern Ocean covers around 10% of the world's ocean surface, and includes some of the most productive marine regions on Earth. Although they are among the least-studied, the seas around Antarctica are a critical component of the global climate system and marine ecosystem.

An understanding of the spatial characteristics of large ecosystems such as the Southern Ocean is important for the achievement of a range of scientific, management and conservation objectives including ecological modelling, ecosystem-based management of living resources, and the establishment of an ecologically representative system of marine protected areas.

Bioregionalisation is a process that aims to partition a broad spatial area into distinct spatial regions, using a range of environmental and biological information. The process results in a set of bioregions, each with relatively homogeneous and predictable ecosystem properties. The properties of a given bioregion should differ from those of other regions in terms of species composition as well as the attributes of its physical and ecological habitats. Bioregionalisation can assist in providing information on the location and distribution of species and their habitats, and is an important foundation for efforts to further understand, conserve and manage activities in the marine environment.

Attempts to classify large ocean areas into meaningful management units have been carried out for coastal and shelf areas worldwide, for example in the definition of Large Marine Ecosystems (LMEs) (Sherman and Alexander, 1986; Sherman and Duda, 1999), Marine Ecoregions (Spalding et al., 2006), and the use of LMEs together with biogeochemical provinces (Platt and Sathyendranath, 1988; 1993; Longhurst, 1998) to define global regions for ecosystem-based fisheries management (Pauly et al., 2000).

In 2005, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) and its Scientific Committee (SC-CAMLR) identified a series of key tasks to assist in developing a comprehensive and ecologically representative system of marine protected areas (MPAs) (SC-CAMLR-XXIV, 2005). A broad-scale bioregionalisation of the Southern Ocean was identified as an important first step in this process. CCAMLR agreed that this process will need to be undertaken in cooperation with the Committee for Environmental Protection (CEP), which reports to the Antarctic Treaty Consultative Meeting (ATCM).

In 2006, WWF initiated a project to undertake some of the initial work towards a broad-scale bioregionalisation, in partnership with the Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC, Australia) and sponsored by Antarctic expedition cruise operator, Peregrine. The aim of this work has been to develop a 'proof of concept' for a broad-scale bioregionalisation of the Southern Ocean based on synoptic environmental data in the first instance.

As part of this work program, an Experts Workshop was held in Hobart, 4-8 September 2006, to review and expand upon the initial developmental work provided by Raymond and Constable (2006). This document provides a report of that workshop, detailing:

- background to the workshop and bioregionalisation in the Southern Ocean;
- an agreed approach to bioregionalisation;
- an example of a regionalisation for the Southern Ocean based on synoptic environmental data; and
- future work towards a bioregionalisation of the Southern Ocean.

An understanding of the spatial characteristics of large ecosystems such as the Southern Ocean is important for the achievement of a range of scientific, conservation and management objectives. Bioregionalisation is a process that aims to partition a broad spatial area into distinct spatial regions, using a range of environmental and biological information. The process results in a set of bioregions, each with relatively homogeneous and predictable ecosystem properties. The properties of a given bioregion should differ from those of other regions in terms of species composition as well as the attributes of its physical and ecological habitats.

1.1 What is bioregionalisation?

Large ecosystems can be partitioned at a range of spatial scales, according to their physical, environmental and biological characteristics. Variation in climate, topography and other physical factors forms different habitat types, which in turn support different species and communities. Biological diversity varies throughout this geographic space, and may be further influenced by factors such as the availability of nutrients and food, as well as human activities.

For example, forests, deserts and grasslands have different physical and environmental attributes, and contain different habitat types and communities of species. These different regions may occur adjacent to one another; however, each differs from the others in terms of physical and ecological characteristics. Some species may range across more than one region, whereas others will be more restricted in their range, according to their ability to live in particular habitat types or ecological conditions. For example, cacti are uniquely adapted to live only in desert conditions, while certain ubiquitous grasses are found in parts of the forest and the grassland, as well as the desert. Migrating birds may travel across all three regions, while deer inhabit the forest and the grassland but not the desert, and tree-dwelling mammals remain exclusively in the forest.

Boundaries between regions may be sharp, for example at the interface between a forest and adjacent alpine areas. Features such as the tree-line reflect the limit of tolerance by certain species to a particular set of physical conditions. However, boundaries may also be gradual, such as in the margins of a desert, where habitats and species from both the desert and the neighbouring grassland gradually blend across a wide transitional area. Transitional areas between adjacent ecosystems, regions or habitats are known as ecotones, and species may be found in decreasing numbers as they reach the edge of their range. Bioregionalisation provides a simplified interpretation of these physical and ecological boundaries. It endeavours to separate, say, desert, grassland and forest by drawing boundaries between them such that the attributes within each of the bounded areas are primarily desert, grassland and forest respectively.

This terrestrial analogy provides a simplified description of the bioregionalisation concept, and its utility in providing pragmatic solutions to complex ecological problems. Apart from the edges of rocky reefs, regional boundaries in the oceans are likely to be less sharp (or more 'fuzzy'), and they may be more mobile or variable because of the fluid nature of the marine environment. Regionalisation of marine ecosystems is also more complex because of their three-dimensional nature. However, marine ecosystems can nevertheless be partitioned using the principles described above to provide a simplified interpretation spatial differences in their environmental characteristics, habitat types and ecological boundaries.

Defining regions

Regions are generally defined using a combination of qualitative (expert opinion, descriptive data) and quantitative statistical analyses. A range of data on physical, environmental and biological properties can be incorporated into a regionalisation analysis, according to data availability and coverage, and specific end-use applications. Statistical procedures for undertaking a regionalisation attempt to partition a broad spatial area into discrete regions, each with relatively homogeneous and predictable ecosystem properties, but sometimes occurring in more than one geographic location (Leathwick et al. 2003). The properties of a given region (both species composition as well as attributes of the physical and ecological habitats) should differ from those of adjacent regions.

Regions can be defined according to the range of species or communities that inhabit them. Indicator species may also be used, where individual species are known to exclusively inhabit a certain type of region. For example, certain species of desert snake, grassland lizard and forest frog might be used as indicators to define these regions.

Alternatively, physical and environmental information can be used to define regions using qualitative methods (e.g. Bailey, 1996). Topography, altitude, substratum and temperature are among the variables which influence the characteristics and structure of habitats and their associated species and communities. An understanding of the spatial extent of different environmental conditions and physical habitats can provide further information on the ecological properties likely to be found in each area, and thus the types of communities or species which might occur there. As a simplified example, the distribution of freshwater habitats may give some indication of where frogs are likely to be found. This is particularly useful where biological information is unavailable. Information on the distribution of frogs over a large area may be impractical to obtain, however freshwater ponds could

be more easily identified using aerial photography.

Approaches to defining regions may also vary according to the particular application of a bioregionalisation analysis. For example, a manager interested in the conservation of reptiles may choose to define regions according specifically to the distribution of snakes and lizards, whereas an agricultural scientist might be more interested in the division of regions according to substratum type and topography.

Bioregions may also be defined at different spatial scales, according to the biological, physical or environmental characteristics of interest, and the scale of the data being used in the analysis (e.g. Bailey, 1996). The forest, grassland and desert may be encompassed within a much larger unit; for example all of these regions would be found in southern Africa. Within a particular region, there may also be finer-scale ecosystem divisions. For example, within a forest region, a mountain will support different vegetation with increasing altitude. Different forest communities may be found higher up the mountain, reflecting changes in topography and climatic conditions. At an even finer scale, features such as mountain streams, valleys and rocky outcrops may result in different forest communities occurring at the same altitude. Smaller scale ecosystems or regions can be seen as nested within ecosystems of a higher order, thus occurring within a hierarchical system.

Clearly, the final regionalisation will be dictated by the spatial detail required and the specific attributes needing to be captured in the subdivision. Nevertheless, a regionalisation needs to show generally how those attributes are nested within the larger scale heterogeneity of the system. This helps to appreciate whether areas with similar properties but separated in space may be influenced by different external environmental and ecological drivers at their boundaries.

Approaches to bioregionalisation in the marine environment have included the use of physical oceanographic parameters (e.g. ocean water masses, fronts, gyres and wave energy), geomorphology (e.g. depth, substratum, sediment characteristics and disturbance regimes), biological oceanography (e.g. primary and secondary production), fish stock distribution and abundance (e.g. areas of aggregation and fishing patterns), benthic communities (e.g. distribution and community structure) and marine mammals and birds (e.g. primary feeding and breeding locations).

Classification of regions based only on biological data is often impractical at larger scales because of insufficient geographic coverage, even though there may be sufficient data to subdivide smaller-scale portions of those regions (Belbin, 1993). Physical and satellite-observed data generally have better spatial and temporal coverage and greater availability than biological data. These can be used to help characterise regions on the basis of environmental properties, physical processes, primary production, and habitat type.

An important aspect of undertaking an ecologically meaningful regionalisation is therefore to understand how important ecological processes correspond to physical parameters, and whether those parameters are appropriate for use as proxies or surrogates. This may not require much ecological detail in the first instance, since physical and environmental data can provide an understanding of environmental heterogeneity which will inevitably affect the ecology of a region.

Photograph © Roger Kirkwood, courtesy Australian Government Antarctic Division

1.2 Bioregionalisation in the Antarctic context

Bioregionalisation of the Southern Ocean has relevance in a variety of applications within different scientific fields and for conservation and management across the Antarctic Treaty System. An understanding of spatial ecosystem characteristics is necessary to achieve a range of objectives in the Antarctic context, including:

- ecosystem modelling;
- ecosystem-based management of marine living resources;
- effective and systematic planning and management of other human activities;
- identification of biodiversity units and areas of high conservation value;
- establishment of a comprehensive and ecologically representative system of MPAs; and
- directing further research.

Recent discussions within the CCAMLR Scientific Committee (SC-CAMLR-XXIV) and the Committee for Environmental Protection (CEP IX) have agreed the importance of undertaking a bioregionalisation of the Southern Ocean, and highlighted the need to work together in achieving this common objective.

CCAMLR

The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) applies to all marine living resources within the area south of a line approximating to the Polar Front. The Convention Area is divided into three sectors corresponding to the adjacent Atlantic, Indian and Pacific oceans. These sectors are referred to as Statistical Areas 48, 58 and 88 respectively, and each is further divided into statistical subareas for catch reporting and management purposes (see Figure 1). Statistical subareas were defined on the basis of ocean characteristics, fish stock distributions and the location of fishing activities (Everson, 1977; Kock, 2000), thus providing one example of an existing bioregionalisation of the Southern Ocean. Subareas are used in catch reporting, and enable the implementation of conservation and management measures regionally or for individual stocks.

The primary objective of CCAMLR is the conservation of Antarctic marine living resources, where conservation includes rational use. CCAMLR has pioneered a precautionary, ecosystem approach to marine living resource management, and defines the Antarctic marine ecosystem as "the complex of relationships of Antarctic marine living resources with each other and with their physical environment".[1]

In 2005, the CCAMLR Workshop on MPAs considered the scientific work required for development of a system of protected areas to assist CCAMLR in achieving its conservation objectives. A broad-scale bioregionalisation of the Southern Ocean was identified as an important first step in this process (SC-CAMLR-XXIV, 2005).

CCAMLR has identified a series of key tasks to be undertaken towards bioregionalisation:

- collation of existing data, including benthic and pelagic features and processes;
- determination of statistical analyses required to facilitate a bioregionalisation, including use of empirical, model and expert data;
- development of a broad-scale bioregionalisation of the Southern Ocean, based on existing datasets; and
- delineation of fine-scale provinces within regions, where possible.

As part of this ongoing work, CCAMLR will hold a workshop in 2007 with the aim of providing advice on a bioregionalisation of the Southern Ocean, including, where possible, advice on smaller-scale delineation of provinces and potential areas for protection to further the conservation objective of CCAMLR. This workshop will involve members of both the CCAMLR Scientific Committee and the CEP, as well as external experts (SC-CAMLR-XXIV, 2005).

Committee for Environmental Protection

The Antarctic Treaty and its Protocol on Environmental Protection apply to the area south of 60°S, thus covering a smaller marine area than CCAMLR. The Environmental Protocol deals with environmental impact assessment, conservation of Antarctic flora and fauna, waste disposal and management, prevention of marine pollution, and area protection and management. The Committee for Environmental Protection (CEP) provides advice and recommendations to the ATCM in connection with the implementation of the Environmental Protocol.

Annex V of the Environmental Protocol states that Parties shall seek to identify a series of Antarctic Specially Protected Areas (ASPAs) (including marine and terrestrial areas) within a 'systematic environmental-geographic framework'[2]. This term has been defined as: "a method of classifying or organising subsets of environmental and geographic characteristics such as different types of ecosystems, habitat, geographic area, terrain, topography, climate, individual features and human presence into geographic regions. Each region would be distinctive or in some way different from other regions but some might have characteristics in common." (ATCM XXIV/WP012, 2001).

The bioregionalisation work proposed by CCAMLR corresponds closely to current efforts by the CEP to elaborate a systematic environmental-geographic framework, in particular through the terrestrial Antarctic Environmental Domains Analysis being undertaken by New Zealand for the Antarctic continent (Morgan et al., 2005).

In outlining the work programme for bioregionalisation, CCAMLR recognised the relative expertise of the CEP, and suggested that the CEP should be invited to undertake the initial work necessary to develop a bioregionalisation of the coastal provinces, as an extension of its terrestrial bioregionalisation work. At its meeting in 2006, the CEP undertook to engage fully with CCAMLR on this work, and agreed on the importance of such an analysis in contributing to its conservation and management objectives (CEP IX, 2006). ■

[1] CCAMLR, Article 1
[2] Protocol on Environmental Protection, Annex V, Article 3(2)

1.3 Antarctica and the Southern Ocean

Southern Ocean characteristics

The Southern Ocean extends across a total area of almost 35 million km^2, and consists of distinct provinces that differ physically and chemically (e.g. temperature, sea ice, nutrients and currents), as well as ecologically. It is characterised by deep basins, separated by large, mid-oceanic ridges and containing prominent plateaus and island groups.

Two major currents dominate the Southern Ocean system. The Antarctic Circumpolar Current (ACC) (or "West Wind Drift") flows eastwards around the continent, driven by the prevailing westerly winds. The ACC forms a unique link connecting all of the world's major oceans through an unbroken water mass surrounding the Antarctic continent, (Orsi et al., 1995). However, its path is influenced by topographic features such as the Kerguelen Plateau and the Scotia Arc, which deflect fronts and generate eddies. Closer to the continent, easterly winds form a series of clockwise gyres (the largest of these being in the Ross Sea and Weddell Sea) that combine to form the westward flowing Antarctic Coastal Current, also known as the "East Wind Drift".

The Subtropical Front (STF) marks the northernmost extent of the ACC, separating warmer, more saline subtropical waters from fresher, cooler subantarctic surface waters (Orsi et al., 1995). Further south, the majority of ACC water is transported in the Subantarctic Front (SAF), and also in the Polar Front, which marks the transition to very cold and relatively fresh Antarctic

Surface Water, and separates Southern Ocean waters from the Atlantic, Pacific and Indian oceans to the north. The Polar Front also marks the northerly limit of many non-migrating Antarctic species (Knox, 1994), including Antarctic krill (*Euphausia superba*), the staple food of many of the Southern Ocean's seabirds, marine mammals and fish. Closer to the Antarctic continent, upwelling of very dense, cold abyssal waters occurs at the southern boundary of the ACC.

The Southern Ocean plays an important role in the global ocean circulation system. Figure 2 shows the relationships between the frontal systems and the greater patterns of ocean circulation. Of note are the extremely cold winds blowing off the Antarctic Ice Sheet which cool the coastal waters. In certain recurrent locations (coastal polynyas), these create high rates of sea ice formation. This in turn leads to the formation of cold, dense saline water that sinks to form Antarctic Bottom Water. This complex system also sees a continual surface expression in the Southern Ocean of the global ocean's normally deep nutrient layer, which is the primary reason for the sustained high productivity in the region. In the tropics, this nutrient layer only reaches the surface through upwelling.

The continental shelf surrounding Antarctica is unusually deep compared to elsewhere in the world, as a result of scouring by ice shelves and crustal depression caused by the weight of continental ice (Clarke, 1996). The continental shelf is generally narrow, except in large embayments such as the Ross Sea and Weddell Sea.

The Southern Ocean is covered by a band of largely seasonal sea ice that extends from a maximum southerly extent of ~75^{o}S northwards as far as ~55^{o}S at its maximum extent. The width of this band is highly variable, ranging from a few hundred kilometres in the Indian Ocean sector to ~1600 km in the Weddell Sea. Given the relatively narrow width of the continental shelf surrounding the Antarctic continent, a large proportion of the Antarctic ice cover occurs over deep ocean, where it is exposed to a zone of strong cyclone activity and ocean waves and swell. The latter create a well-developed circumpolar marginal ice zone, which effectively protects the inner pack from incoming ocean wave energy.

The coastal zone is complex, with sea ice distribution and characteristics (of both pack and fast ice) being affected by coastal configuration and the presence of grounded icebergs, which are in turn closely linked to bathymetry (Massom et al., 2001). Coastal

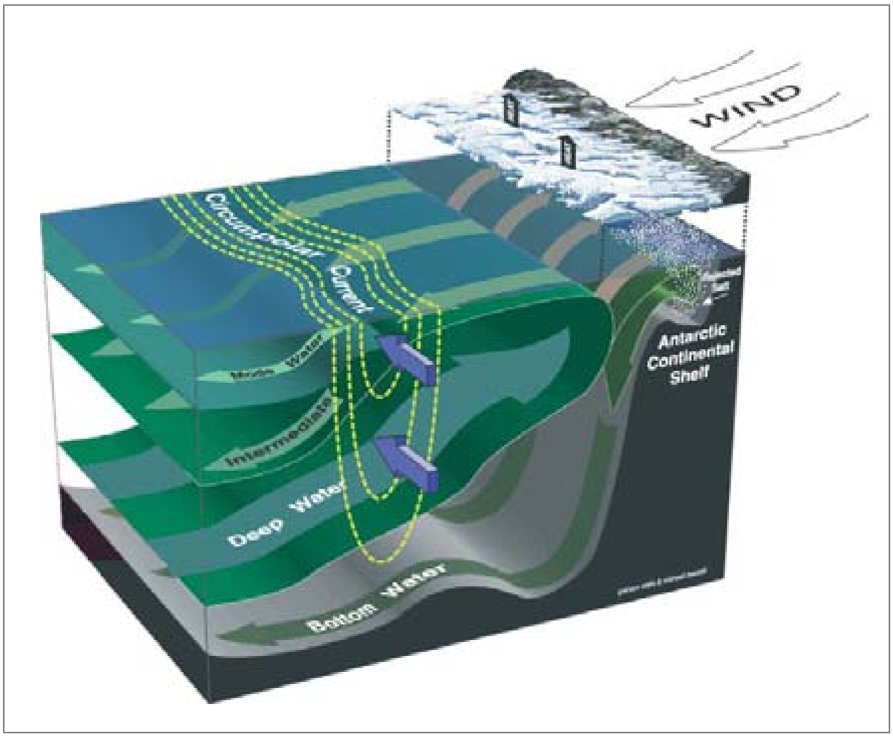

FIGURE 2: Three-dimensional structure of water masses, showing relationship between the ACC and deep water (Figure reprinted with permission from: Rintoul, 2000).

polynyas (large areas of open water) occur around the continent (Arrigo and van Dijken, 2003), and there are also two deep water polynyas in the Weddell and Cosmonaut seas (Morales Maqueda et al., 2004). Polynyas constitute major regional sea ice "factories", sites of major water-mass modification and, in places, enhanced biological activity.

The seasonal cycle of sea ice advance and retreat is one of the major drivers of physical and ecological processes in the Southern Ocean. On the hemispheric scale, the sea ice cover in winter interacts with key oceanic and biological boundaries such as the continental shelf break, the southern boundary of the Antarctic Circumpolar Current (Tynan, 1998) and the Antarctic Divergence, the latter being an important zone of upwelling. The areal extent of Antarctic sea ice varies annually by a factor of ~5, from a maximum of 18-20 x 10^6 km^2 in September-October to 3-4 x 10^6 km^2 each February. As such, it is predominantly a seasonal sea ice zone, although large regions of perennial ice persist in the western Weddell Sea, Amundsen Sea and Ross Sea and southwest Pacific Ocean though summer (Gloersen et al., 1992).

The major features driving the dynamics of sea ice are shown in Figure 3.

The Antarctic Peninsula region is the only Antarctic sector to have experienced a rapid warming trend over the past 50 years, of ~0.5^{o}C per decade (Vaughan et al., 2001). Moreover, the West Antarctic Peninsula (WAP) region is the only Antarctic sector to have experienced a statistically significant decreasing trend in sea ice areal extent since 1978 (see inset in Figure 3, from Kwok and Comiso, 2002). Recent results imply that this change may result from changes in dynamic (i.e., wind-driven) forcing (Massom et al., 2006). These factors, combined with the profound impact of the Antarctic Peninsula as a meridional blocking feature that extends to low latitudes and oceanic characteristics, suggest that the WAP region should be treated as a separate regime.

Forming an important habitat for a wide range of organisms specifically adapted to its presence, sea ice plays a dominant defining role in structuring high-latitude marine ecosystems (Ackley and Sullivan, 1994; Brierley and Thomas, 2002; Eicken, 1992; Lizotte and Arrigo, 1998; Nicol and Allison, 1997), and on a variety of scales. The most productive areas of the Southern Ocean lie in the Seasonal Ice Zone, between the maximum northern extents of sea ice in winter and summer. Here in particular, Antarctic krill and other planktonic organisms support an abundance of fish, birds, seals and whales. In addition, the ice edge is typically a region of enhanced biological activity during the melt season in particular (Nicol and Allison, 1997; Smith and Nelson, 1986; Smith et al., 1988; Sullivan et al., 1993).

Although in the past characterised as simple, the Antarctic food web involves complex relationships between primary producers and higher predators, as well as abiotic factors. The Antarctic ecosystem is characterised by

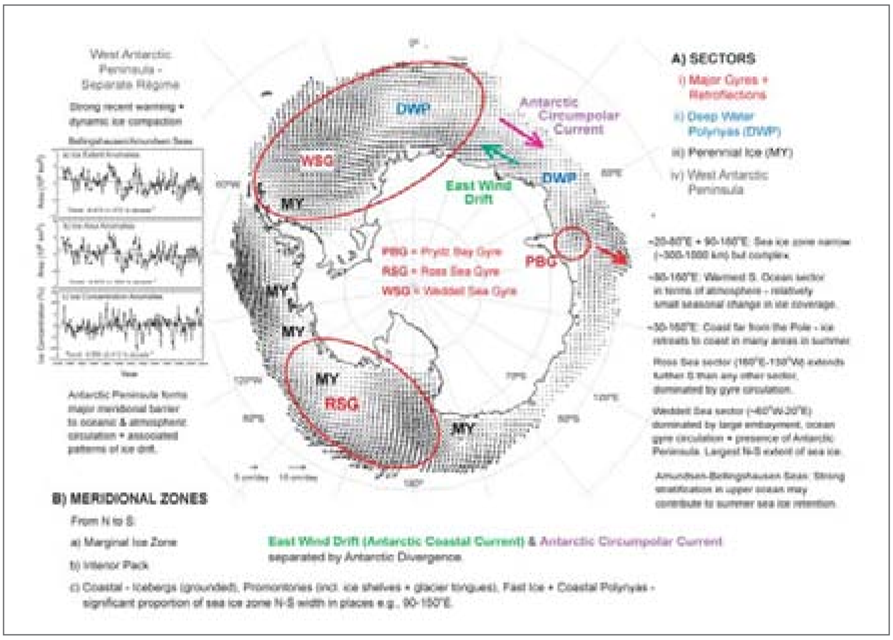

FIGURE 3: Map of climatological (mean) satellite-derived sea ice motion for 1997 (courtesy US National Snow and Ice Data Center; Fowler, 2003), with broad-scale sea ice sectors superimposed. Explanations are provided in the figure. The motion vectors are projected to a 25 x 25 km resolution grid. Dominant features in the climatological ice drift pattern are 3 major ocean gyre systems, the westward-drifting Antarctic Coastal Current and eastward flowing Antarctic Circumpolar Current, with regions of retroflection associated with the ocean bathymetry i.e., ocean bathymetric "steering". Figure by R. Massom.

strong seasonal cycles and major food-web differences that are intimately related to the annual sea ice growth-decay cycle and sea ice conditions, as well as associated ocean dynamics (mixing), water density and nutrient availability (Garrison and Mathot, 1996; Legendre et al., 1992; Lizotte, 2001).

Existing regionalisations for the Southern Ocean

The Southern Ocean has been divided into large-scale regions before, primarily based on physical characteristics such as frontal features (Orsi et al., 1995; Longhurst, 1998) and ice dynamics (Tréguer and Jacques, 1992). Information on the distribution of species has been used in biogeographic classifications of benthic fauna (Ekman, 1953; Hedgpeth, 1970; Dell, 1972), and also by CCAMLR in the definition of statistical subareas on the basis of fish stock distribution (Everson, 1977) (see Figure 1).

In the southern Indian Ocean, some smaller scale regionalisations have been attempted in the development of a bioregionalisation in Australian waters to assist in regional marine planning (Lyne et al. 2005), the designation of marine reserves (Meyer et al. 2000), and benthic habitat mapping (Beaman and Harris, 2005).

Early biogeographic classifications for the Southern Ocean delineated large-scale provinces according to the distribution of benthic fauna (Hedgpeth, 1970; Dell, 1972). More recent studies have largely confirmed these broad-scale patterns regions, although there are now thought to be significant differences between the benthic faunas of East and West Antarctica (Clarke and Johnston, 2003). A recent study on the biodiversity and biogeography of subantarctic mollusca (Linse et al., 2006), using species from the continental shelf areas (0-1000 m), identified the following distinct sub-regions in the Southern Ocean: Antarctic Peninsula, Weddell Sea, Dronning Maud Land, Enderby Land, Wilkes Land, Ross Sea, and the independent Scotia arc and subAntarctic islands (Figure 4). These divisions have also been used by WWF and The Nature Conservancy (TNC) in a study to synthesise existing classifications into a system of Marine Ecoregions of the World (Spalding et al., 2006).

Tréguer and Jacques (1992) defined five functional units south of the Polar Front on the basis of ice and nutrient dynamics. This work demonstrated the role of ice dynamics in controlling phytoplankton initiation and growth, and the nutrient regimes that discriminate each of these units. Defined units include the Polar Front Zone, located between approximately 60°S and 55°S, and the Permanently Open Ocean Zone which lies between the Polar Front and the maximum northern extent of winter sea ice. The Seasonal Ice Zone is located between the northern limits of the pack-ice in winter and in summer, while the Coastal and Continental Shelf Zone is adjacent to the Antarctic continent. The Permanent Ice Zone incorporates ocean areas under ice shelves.

Orsi et al. (1995) described large-scale frontal features of the ACC, based on historical hydrographic data. Gradients in ocean surface properties were used to define three major fronts within the ACC which separate water masses and flow characteristics. These are shown in Figure 5.

Longhurst (1998) proposed a global system of ocean classification based on a simple set of environmental variables (sea surface temperature, mixed layer depth, nutrient dynamics and circulation) together with planktonic algal ecology. In this classification scheme (Figure 6) the Southern Ocean includes two provinces in the Westerly Winds Biome between approximately 40ºS and 50ºS (South Subtropical Convergence Province and SubAntarctic Water Ring Province) and two in the Antarctic Polar Biome between 50ºS and the continental coast (Antarctic Province and Austral Polar Province).

The LME classification system defines the Southern Ocean as a single unit (Sherman and Duda, 1999), while several other classifications define only a small number of concentric rings around the continent. However, the Southern Ocean has a variety of distinct provinces within these larger regions which differ in their chemical, physical and ecological characteristics, and which show considerable longitudinal, as well as latitudinal variation. Improved data coverage and availability through satellite imaging, and improved understanding of ocean characteristics through ecosystem modelling makes it now possible to elaborate on these previous regionalisations using a wider range and broader coverage of data.

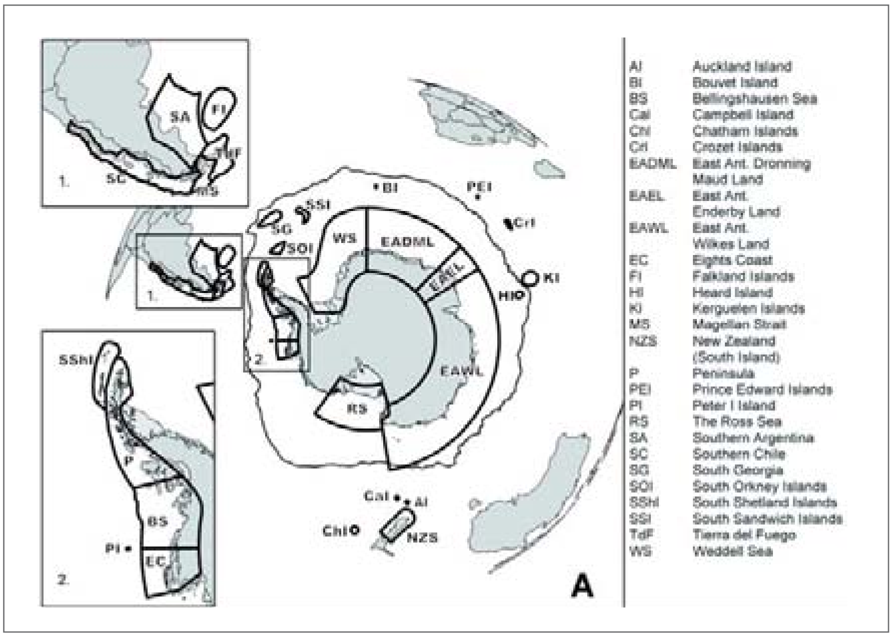

FIGURE 4: Biogeographic areas of the Southern Ocean defined by Linse et al. (2006), using distribution records for shelf (0-1000 m) species of shelled gastropods and bivalves
(Figure reprinted with permission from: Linse *et al*, 2006)

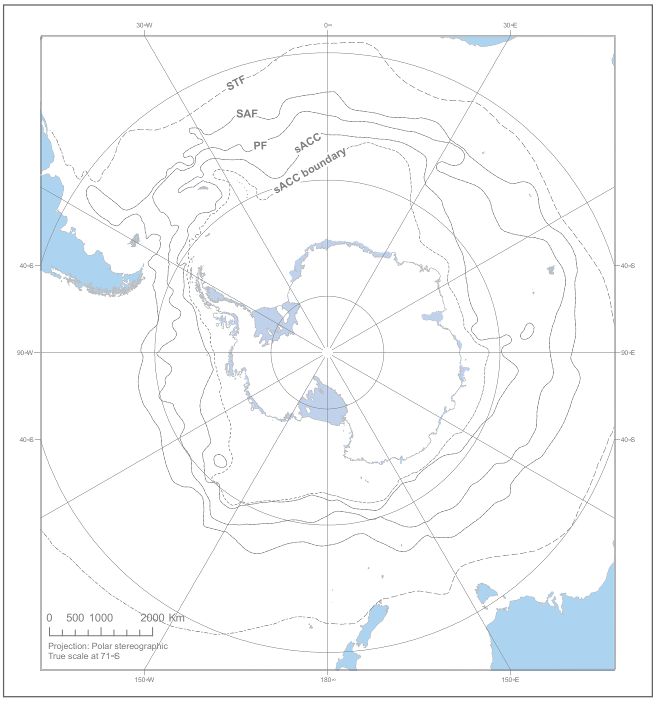

FIGURE 5: Fronts of the Southern Ocean, as defined by Orsi et al. (1995)

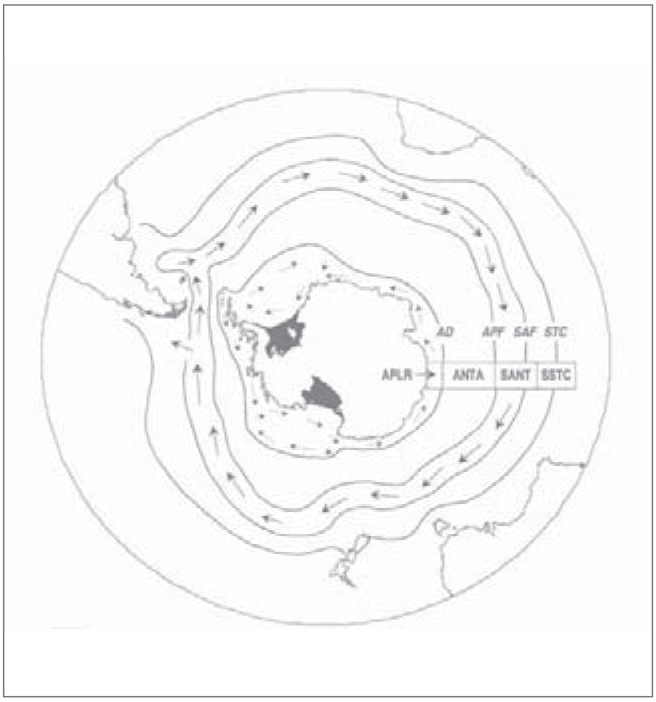

FIGURE 6: Classification of the Southern Ocean, Longhurst (1998)
(Reprinted from: Ecological Geography of the Sea, A.R. Longhurst. Copyright (1998), with permission from Elsevier)

1.4 Experts Workshop

The aim of the Experts Workshop was to review the methods for identifying major provinces, collate available synoptic datasets, and to gain input and recommendations from experts on the process and the results. In particular, the workshop aimed to develop a "proof of concept" for a broad-scale bioregionalisation of the Southern Ocean, using physical and environmental data as the primary input.

A list of the workshop participants is provided at the end of this report.

Specific objectives of the workshop were to:

- review and assess the processes developed to date and the proposed methods;
- discuss and make recommendations on data types to be included in a broad-scale bioregionalisation;
- collate appropriate datasets;
- apply the approved method(s) to the Southern Ocean using available datasets, to test and validate the process and produce a 'proof of concept' including maps of the defined broad-scale provinces;
- assess preliminary results and broad-scale provinces, given present knowledge of the Southern Ocean.
- provide recommendations on products to be developed, including the final report, maps, illustrations, datasets and a GIS (or other) database; and
- provide recommendations on datasets and/or method(s) that might be used to develop further fine-scale bioregionalisations.

The workshop was held over five days, and included background presentations, plenary discussion, and computer-based analysis in small groups.

At the start of the workshop, background presentations were given on some of the major physical processes in the Southern Ocean, and initial discussion focused on the relationships between physical and ecological processes. A series of presentations were also given on approaches to bioregionalisation that have been undertaken elsewhere, which allowed detailed consideration of the application of different methods.

Participants then investigated different aspects of data analysis and refinement of methods in small groups, focusing initially on their regions of particular expertise (e.g. South Atlantic, East Antarctica, Ross Sea) and later looking at the Southern Ocean as a whole. Selected physical datasets were provided for use in the initial analysis, and others were made available by participants during the week. The analytical methods used by Lyne and Hayes (2005), Leathwick et al. (2006a) and Raymond and Constable (2006) were used as starting points for the analysis during the workshop. These methods were refined into a single methodology, following workshop discussions and practical explorations of the methods. Appendix I gives further details on the background and technical aspects of each of these methods.

The final stages of the workshop included discussion on how well the defined regions corresponded to our present knowledge of the Southern Ocean. Priorities were identified for further work on issues including uncertainty, understanding of inter- and intra-annual variation, validation of results, the use of additional data (particularly biological datasets) and finer-scale analysis of particular areas of interest.

The Southern Ocean covers around 10% of the world's ocean surface, and includes some of the most productive marine regions on Earth. Although they are among the least-studied, the seas around Antarctica are a critical component of the global climate system and marine ecosystem.

2. Approach to bioregionalisation

This section describes the approach to bioregionalisation that was used as a starting point for the workshop discussions and analysis. Descriptions of each step are presented here, together with background information on issues that must be considered. Further technical detail is provided in Appendix II. A summary of the final method adopted is presented in Section 3.

The regionalisation process can be partitioned into the following steps:

1. Identify the ecological patterns and processes that have relevance to the end-use application of the regionalisation
2. Identify the major environmental drivers or properties that control these patterns and processes, and extract relevant parameters describing those properties
3. Pre-process the data (e.g. normalise, transform, smooth)
4. Compile a data matrix of individual sites (rows) by properties (columns)
5. Apply a clustering procedure to group sites with similar properties
6. Post-process the clusters to meet any application-specific constraints on the regions (e.g. minimum size)
7. Expert review of the regions to ensure suitability for the application.

This process can be iterative. Ideally, the initial process will establish the mechanisms by which new data and/or knowledge could be incorporated into revisions of the bioregionalisation, although this would be expected to assist more in establishing or revising smaller scale subdivisions rather than altering the higher level bioregionalisation.

Figure 7 is a schematic representation of the bioregionalisation process, illustrating how data selected to reflect ecological processes can be used to define bioregions.

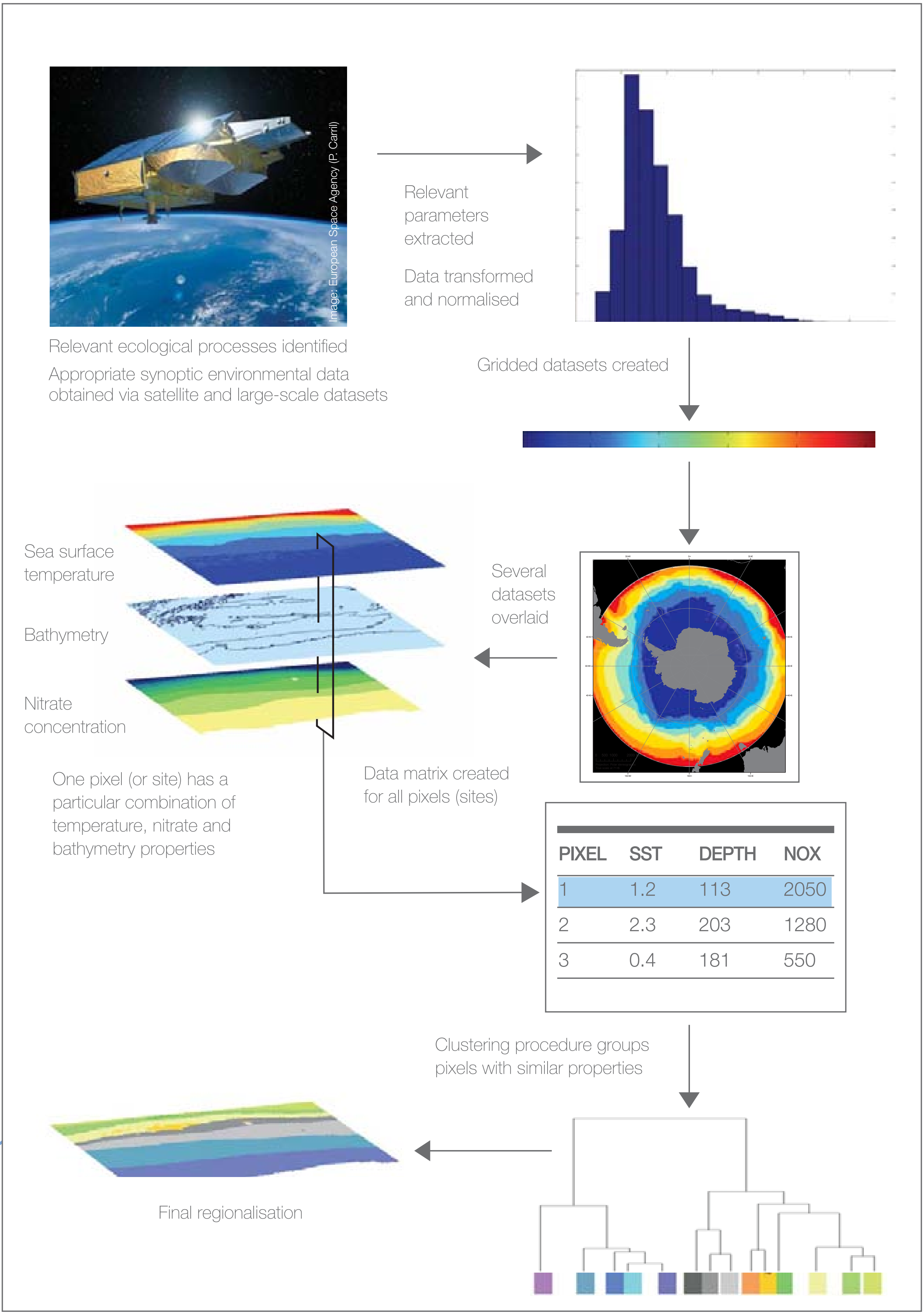

FIGURE 7: Schematic representation of the bioregionalisation process

2.1 Identifying properties to be captured

An important first step in the bioregionalisation analysis is to identify distinct ecological processes and their defining properties. The identification of ecological processes to be captured in the regionalisation is likely to be driven by the requirements of a particular end-use application.

Ideally, a bioregionalisation would delineate units that, depending on the scale, clearly separate habitats, communities and ecosystems. In this ideal world, populations would reside wholly within these areas. In reality, there is considerable complexity that needs to be addressed because of the different relationships that species have with the environment and other biota (Andrewartha & Birch 1984). A bioregionalisation aims to capture the properties of the important relationships rather than, necessarily, simply trying to circumscribe the distributions of whole populations of species.

This concept is illustrated in Figure 8. Some species will be found closely aligned with environmental gradients. Other species will appear in areas with high levels of perturbation, such that environmental factors are mixed and ever changing in their relative distributions. Yet others will exploit the diversity of patches in fringing habitats and ecotones. For mobile species, some taxa will be found across most areas but only some areas will be important to them as feeding or reproductive areas. An important step in the process is to determine how to accommodate environmental gradients and overlaps in the regionalisation.

The marine environment comprises three dimensions – geographic space and depth. Distribution of biota in the pelagic environment is mostly determined by the potential productivity in the water masses and the movement of those water masses in space and depth. The benthic environment has additional features reflecting variation in the depth, substratum types and roughness of the seafloor, and the degree to which this promotes interaction with the pelagic realm. These features are often considered to the primary drivers of environmental heterogeneity. Secondary drivers are more ephemeral or changing over time. In the Antarctic, they would also include other features of the environment such as the annual cycle of advance and retreat of the sea ice zone.

A bioregionalisation would generally try to represent the heterogeneity in ecosystem structure and function, which primarily would subdivide areas according to the magnitude of productivity and its predictability in time. Further subdivision would relate to the diversity of habitats and the relationships of species and food-webs to those habitats. The process will need to differentiate between areas with relatively constant features from those that are highly variable, even though they may have similar mean values. This is because a region with a large amount of disturbance can accommodate different assemblages involving opportunistic species as well as those that require long-term stability. Some areas in a bioregionalisation may need to represent large areas of habitat discontinuity or disturbance, which could be important regions in themselves. As a result of these considerations, a goal for a bioregionalisation is to capture not only the differences in diversity and the suite of ecosystem relationships, but also the potential differences in environmental stability.

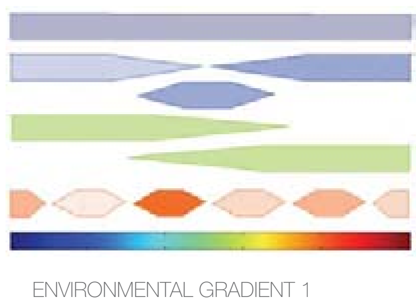

FIGURE 8(a): distribution of species with respect to a single environmental gradient, say temperature. Each polygon represents a different taxon, colours represent similar taxa. Width of bars represents relative abundance for a taxon.

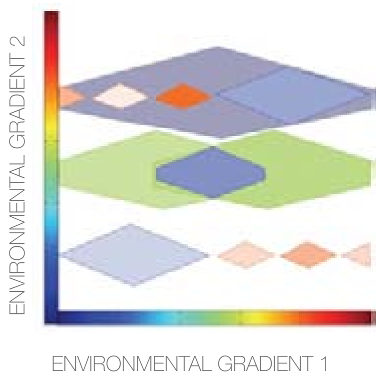

FIGURE 8(b): as for (a) but with distributions relative to two environmental gradients - distributions on gradient 1 are as in (a). A general discontinuity between species distributions in (a) might be roughly at the midpoint (green on the environmental gradient). In (b) the separation between groups of taxa becomes clearer on the second gradient.

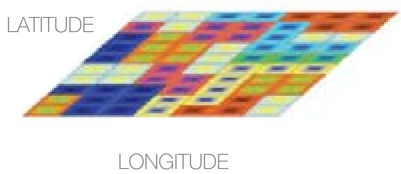

FIGURE 8(c): The environmental conditions form a patchwork in geographic space which can result in regions of similar environmental conditions being separated geographically. Here, parallelograms represent spatial areas with colours representing two environmental parameters (outer colour is from environmental gradient 1 and inner colour is from gradient 2). Each area is expected to have a species composition consistent with that composition at the intersection of two respective environmental gradient colours in (b).

FIGURE 8: Conceptual diagram illustrating potential relationships between species along gradients of environmental parameters.

2.2 Classification method

The intent of a regionalisation is to partition the study area into a set of discrete spatial regions, each with relatively homogeneous ecosystem properties. In the bioregionalisation analysis, regions are selected by grouping sites with particular characteristics. In some cases there may be specific, known characteristics that can be used to delineate region boundaries, such as water temperature changes across oceanic fronts. Another example is to separate the continental shelf from the continental slope by choosing an appropriate bathymetric contour, say 1000 m. Generally, however, the expectation is that the regions will reflect a natural clustering of the environmental or biotic data.

Clustering algorithms are well suited to bioregionalisation analysis, as they are designed to partition a large data set into a number of subsets, each with relatively similar properties that differ from those of the other subsets. In the context of a regionalisation, the clustering process takes sites (or cells) from a grid in geographic space. Each site has associated ecological properties (physical and/or biotic data) and this information is used to group together sites with relatively similar ecological properties. Those groupings (which are calculated in 'environmental space', i.e. based only on environmental properties, and ignoring spatial information) are then projected back into geographic space in order to find the spatial extents of the resulting regions. Thus, the regions are discrete in environmental space, but may be scattered or fragmented in geographical space (i.e. there may be several regions with the same properties located in different geographic areas).

Choosing clustering algorithms

There are a large number of clustering algorithms that could potentially be used, all of which have assumptions or limitations that may preclude their use in particular circumstances or with particular types of data. Thus, the outcomes of the bioregionalisation could be influenced by the choice of the algorithm. The aim is to develop a clustering process that is consistent with the data and for which the results are likely not to change much with alternative clustering algorithms. Consideration will need to be given, inter alia, to algorithm assumptions, complexity, and accuracy.

It is important to make the distinction between the clusters that are produced by a clustering algorithm, and the regions that are formed from those clusters. A cluster is a group of sites that are considered to have similar environmental properties. However, because the clustering process is based on environmental similarity (and not spatial information), a single cluster may contain sites that are spatially separated. A region is thus considered to be a group of sites that belong to the same cluster, but which also form a contiguous spatial area. A single cluster may produce a number of regions, each of which have the same general properties, but which are spatially distinct.

Clustering algorithms are often based around the concept of a dissimilarity metric, which (in the context of a regionalisation) is used to calculate how dissimilar two sites are, given their ecosystem properties (physical or biological data). The clustering of sites into regions is carried out in such a way that the intra-region dissimilarity of sites is low (i.e. sites within a region are similar to each other) relative to inter-region dissimilarities. Dissimilarity-based clustering methods can be broadly divided into hierarchical or non-hierarchical schemes. Further information on these schemes, and the issues related to selecting clustering algorithms, is provided in Appendix II.

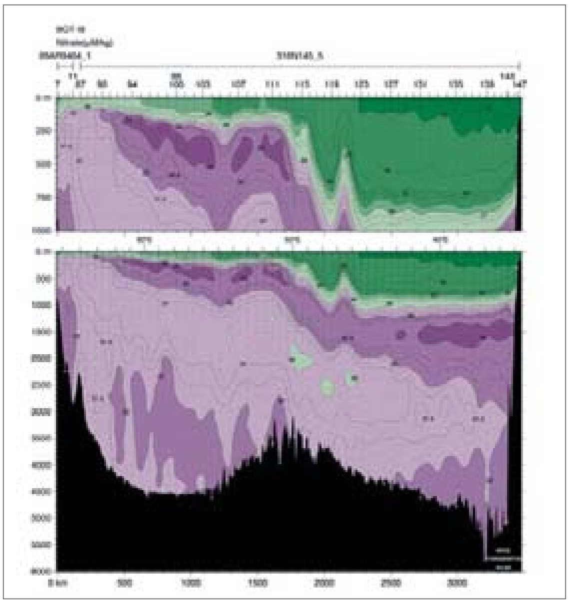

FIGURE 9: Water mass profile of nitrate concentration from Antarctica to the tropics, showing surface expression of the nutrient layer in the Southern Ocean. (Figure from http://woceSOatlas.tamu.edu. Orsi and Whitworth, 2005)

2.3 Variables that capture properties

Once the relevant physical properties have been identified, appropriate data must be selected to be included in the analysis. The data that are used in the clustering method should be matched to the ecological patterns and processes and spatial and temporal scales that are important to the end-use application. However, there is considerable latitude for choice within this broad guideline. Importantly, the data used in the clustering procedure will not necessarily be the raw observations from field sampling. The data may be transformed or be analysed within a model (processing algorithm) to provide the necessary inputs to clustering. For example, ice concentration maps can be routinely obtained from satellite passive microwave data (since 1978). However, daily ice concentration or mean concentration over time might not alone be indicative of the ecological processes of importance. The amount of time an area is free of significant concentrations of sea ice over the course of a year may be more important in terms of productivity in an area or the amount of time the area might be open to feeding activity of birds, seals and whales. Data availability and the choices of subsequent processing algorithms may impose some constraints on the types of data that can be used.

Figure 9 demonstrates how a particular variable (nitrate concentration) can capture environmental properties (surface expression of nutrients) across a broad spatial area.

Once relevant data have been collated, the study area is divided into a grid of sites (or interpolated from point observations), at a sufficiently fine spatial scale to enable appropriate resolution of the final areas. Descriptive statistics – such as means, variances, and other ecologically relevant information, including rates of change of parameters – are computed from the input data at a site level. Site data may be further processed if necessary. This might include spatial or temporal smoothing of the data in order to ensure that the data provides information at an appropriate scale for the regionalisation. The algorithms for selecting areas often also require data to be normalised so that variables with different measurement units can be statistically combined.

Variables of comparable type but measured on different scales are often normalised to a similar scale, say 0 to 1, while preserving the rates of change between different levels of the variable that need to be maintained in the analysis. Alternatively variables might be transformed where biological changes are greater in one part of the gradient, e.g., a log transformation might be used with ocean depth, given that rates of biological turnover are rapid near the ocean surface, but decrease with progression to deeper waters. Care needs to be taken to ensure that the properties of the variables and their relationships to other variables are not altered in the process. Variables that influence multiple ecological processes will reflect different aspects of those processes depending on how they are incorporated into the analyses.

The spatial and temporal scales of the data should be appropriate to the desired scale of the areas. Data with fine-scale spatial or temporal structure may need to be smoothed for use in broad-scale regionalisations. For pelagic applications, the selection of spatial regions is complicated by the depth structure of the water column and temporal variability at seasonal and longer timescales. A hierarchical approach is often used to assist in resolving problems of scale. The levels of the hierarchy can represent either spatial scales, or different ecological processes. A process-oriented hierarchy often has an approximate spatial structure due to the spatial scales of the processes.

To illustrate the concept of temporal variability at seasonal timescales, Figure 10 shows the mean monthly chlorophyll *a* concentrations for each month during summer (December to March). The seasonal variability of this property must be taken into account when using such data to capture ecological processes. Nevertheless, Figure 10 shows that certain areas maintain high levels of chlorophyll *a* concentration throughout this period, and thus a summer mean value may be appropriate for use in a bioregionalisation analysis.

Further information on scaling and weighting of variables is provided in Appendix II.

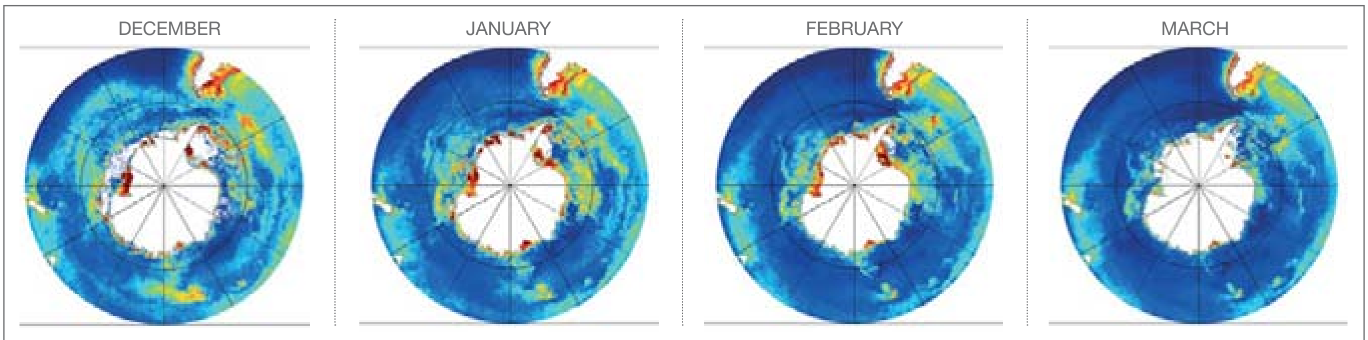

FIGURE 10: Mean monthly chlorophyll *a* concentrations for each month during summer (Dec-Mar) (Images provided by the SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE)

2.4 Uncertainty

A regionalisation requires an assessment of the uncertainties in the locations of the boundaries between areas. In addition, as assessment should be made of whether the heterogeneity within an area is not sufficiently great that the area should not be differentiated from one or more of its neighbours.

Here, the term “uncertainty” is used to describe the effects of a number of different processes, including imprecision in data (for example measurement error, and bias due to incomplete or unbalanced observations), model uncertainty (uncertainty within models that have been used to derive one variable from others, such as climatologies or primary productivity models), and epistemic uncertainty (lack of knowledge of how to go about the regionalisation process; Raymond and Constable 2006). Each of these can affect the resulting region boundaries. Note that stochastic, seasonal, or other temporal or spatial variability in data represents the temporal or spatial variability of the underlying ecosystem processes, and is not treated as uncertainty. However, if it is not clear how this variability should be incorporated into the regionalisation (e.g. should summer or annual means be used?) then this would, in turn, be a source of uncertainty.

A key output of an uncertainty analysis would be an assessment of the uncertainty in region boundary locations. This would indicate to end-users where they might expect the region boundaries to change if the data or analysis methods were to be updated or changed. ■

Photograph by John Kelly, Australian Government Antarctic Division © Commonwealth of Australia

Photograph by Grant Dixon, Australian Government Antarctic Division © Commonwealth of Australia

3. Physical regionalisation

3.1 Summary of adopted method

The classification method adopted during the workshop was a mixed non-hierarchical and hierarchical approach. The classifications were performed on a 1/8th degree grid, covering the marine area from 80°S to 40°S. The full set of 720,835 grid cells was subjected to a non-hierarchical clustering to produce 40 clusters. The mean data values for each of the 40 clusters was calculated and a hierarchical classification was then performed to produce a dendrogram and the final clustering.

Sites with missing data were excluded from the analyses. These were principally sites shallower than 200 m depth, for which the chosen nutrient data did not apply. These excluded sites are shown in the maps as white. Future work will need to fill in these missing cells, for example by considering their other attributes.

Primary regionalisation

The primary regionalisation used the following datasets:

- bathymetry (log10 transformed)
- sea surface temperature (SST)
- nitrate (NOx) concentration
- silicate (Si) concentration

Descriptions of each of these datasets are provided in Appendix III.

The workshop agreed that the ocean water masses combined with topography of the ocean floor were likely to define the primary features of the Southern Ocean and coastal Antarctic systems. Sea surface temperature was included as a proxy for the different water masses of the Southern Ocean (Figure 11). Topography (captured by bathymetric data) was included because of the clear ecological differentiation of the shelf, slope and abyssal regions as well as its influence on upwelling, eddying and as a potential source of iron. Bathymetry (Figure 12) was transformed (log10) to give most weight to the shallower areas less than 2500 m with a greater opportunity to differentiate the shelf break and slope.

Silicate and nitrate concentrations (Figures 13 and 14) were included to provide information on nutrient characteristics. Silicate concentration also provides a measure of actual primary production (particularly in diatom-dominated areas), since silicate is taken up during photosynthesis in the production of diatom shells. The silicate layer was found to be particularly useful for accurately differentiating water masses reflecting plankton communities in deeper water and along the various fronts. The nitrate and silicate climatologies at the 200 m depth layer were used rather than the surface layer as this is a better indicator of available nutrients, whereas surface nutrients are likely to be depleted in areas of nutrient-limited productivity. However, the use of the 200 m depth layer resulted in missing data in the shelf areas of less than 200 m depth.

Sea surface height (SSH) and insolation (mean summer climatology of photosynthetically-active radiation (PAR) at the ocean surface) were considered as additional primary variables that would have utility in defining frontal systems and productivity respectively, however they were not used at this stage because of insufficient time, and because the currently available datasets were incomplete. These datasets should be considered in future analyses.

Physical environmental data used as the input for analysis during the workshop were chosen based on their spatial coverage across the Southern Ocean. The datasets considered included bathymetry, sea ice concentration and extent, sea surface temperature, sea surface height, chlorophyll *a* concentration, nutrient data (silicate, nitrate and phosphate), and insolation (photosynthetically active radiation - PAR).

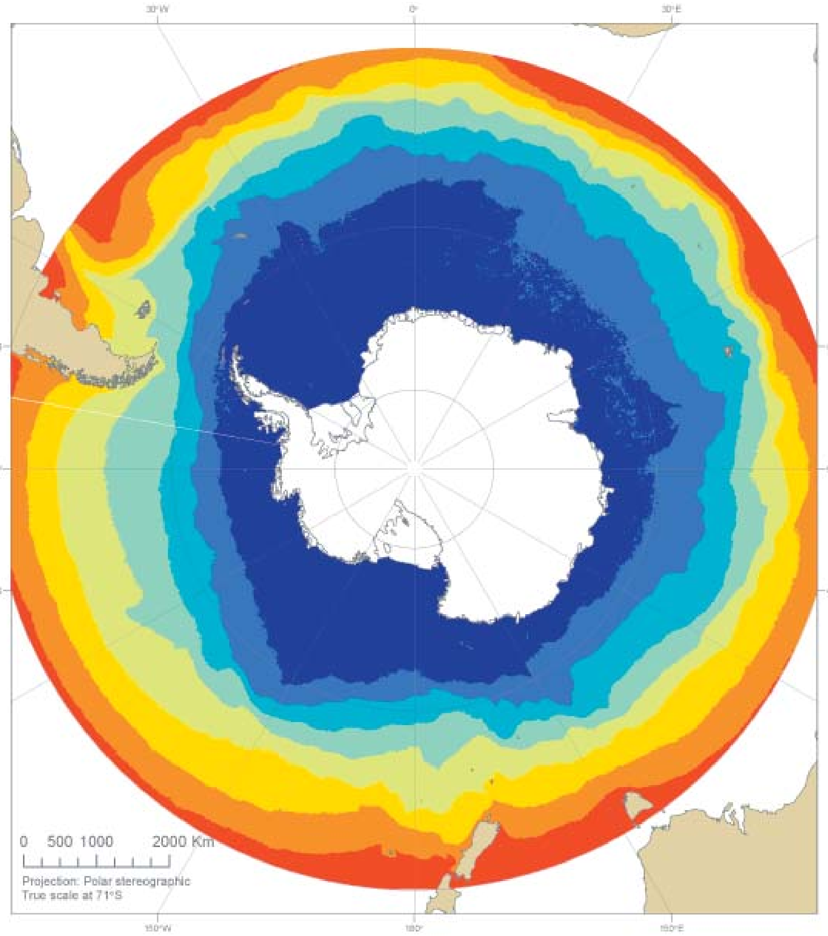

FIGURE 11: Mean annual sea surface temperature (SST). Monthly values from NOAA Pathfinder satellite annual climatology, averaged over the period 1985-1997 (Casey and Cornillon 1999)

Temperature (°C)

- -1.95 - -0.13
- -0.12 - 2.01
- 2.02 - 4.46
- 4.47 - 6.83
- 6.84 - 9.05
- 9.06 - 11.18
- 11.19 - 13.40
- 13.41 - 18.22

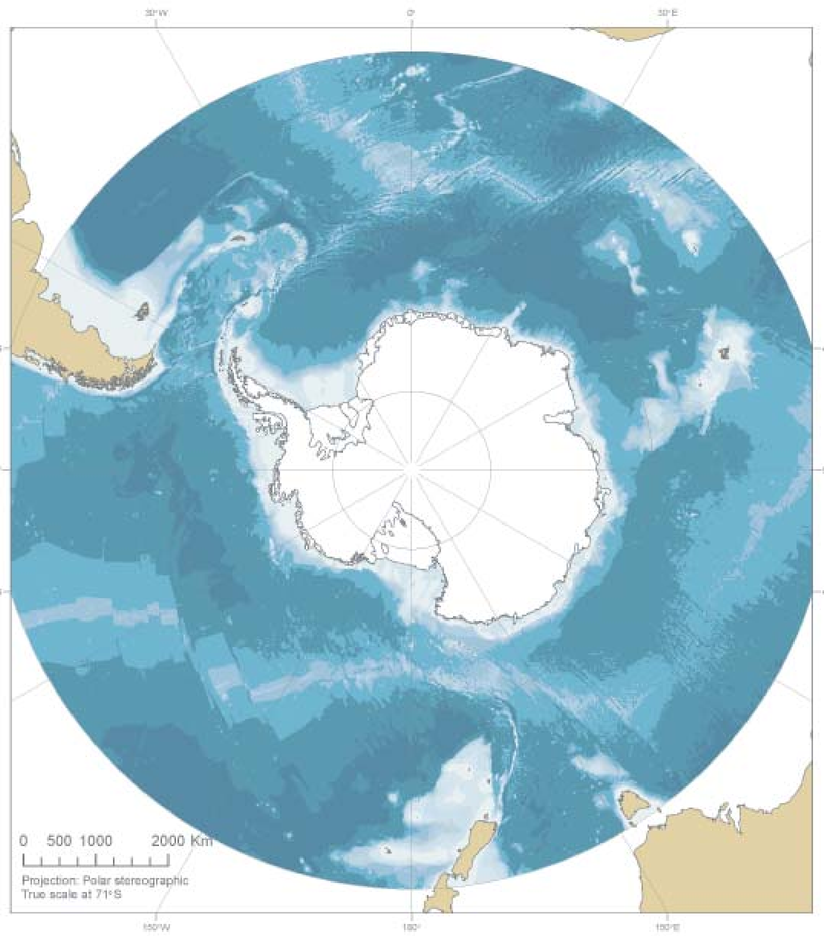

FIGURE 12: Bathymetry of the Southern Ocean. Depth data from the GEBCO digital atlas (IOC, IHO and BODC, 2003).

Depth (metres)

- 0 - 500
- 500 - 1000
- 1000 - 1500
- 1500 - 2000
- 2000 - 2500
- 2500 - 3000
- 3000 - 4000
- 4000 - 5000
- > 5000

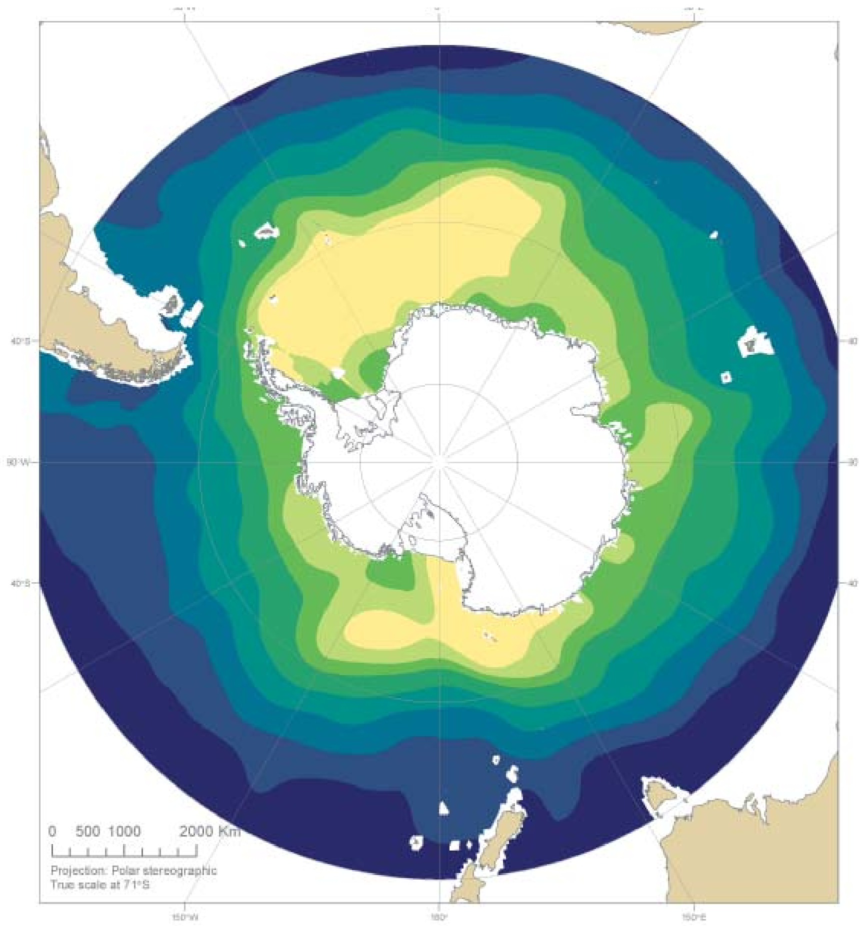

FIGURE 13: Silicate concentration (at 200 m depth). Climatology from the WOCE global hydrographic climatology (Gouretski and Koltermann, 2004)

Si (umol/kg)

- 2.47 - 4.58
- 4.59 - 7.96
- 7.97 - 18.08
- 18.09 - 38.76
- 38.77 - 64.93
- 64.94 - 76.74
- 76.75 - 86.87
- 86.88 - 110.08

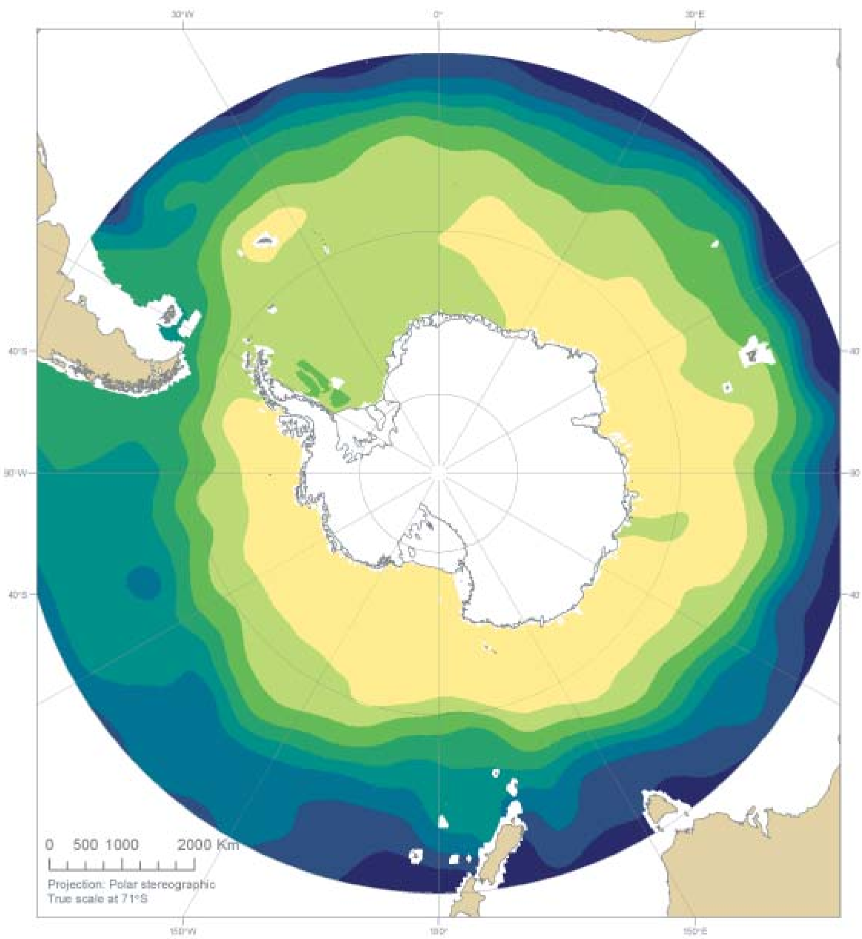

FIGURE 14: Nitrate concentration (at 200 m depth). Climatology from the WOCE global hydrographic climatology (Gouretski and Koltermann, 2004)

NOx (umol/kg)

- 5.55 - 12.40
- 12.41 - 15.58
- 15.59 - 18.65
- 18.66 - 21.72
- 21.73 - 25.38
- 25.39 - 29.27
- 29.28 - 32.34
- 32.35 - 35.65

Secondary regionalisation

The Workshop agreed that the bioregionalisation should ideally differentiate first between the main divisions of coastal Antarctica (shelf and slope areas), sea ice zone and northern open ocean waters before further subdividing according to secondary features. Nevertheless, two potential components of a secondary classification were explored to determine if there is sufficient spatial heterogeneity to warrant a further subdivision.

Sea ice was considered to modify the pelagic environment both in terms of the potential for primary production as well its influence on the distribution of marine mammals and birds. The impact of sea ice on the environment was explored using a data layer comprising the number of days an area was covered by at least 15% concentration of sea ice (Figure 15).

The concentration of satellite-observed sea surface chlorophyll was explored using a data layer comprising log transformed chlorophyll *a* densities (Figure 16). The chlorophyll distribution was truncated at 10 mg.m^{-3} (where all values greater than 10 were made equal to 10), because the variability in higher order productivity most likely results from variability in the range from 0-10 mg.m^{-3}. While chlorophyll *a* concentration may not reflect primary production absolutely, it was considered to be a suitable proxy for the purposes of exploring spatial heterogeneity in primary production at the large scale.

Descriptions of each of these datasets are provided in Appendix III.

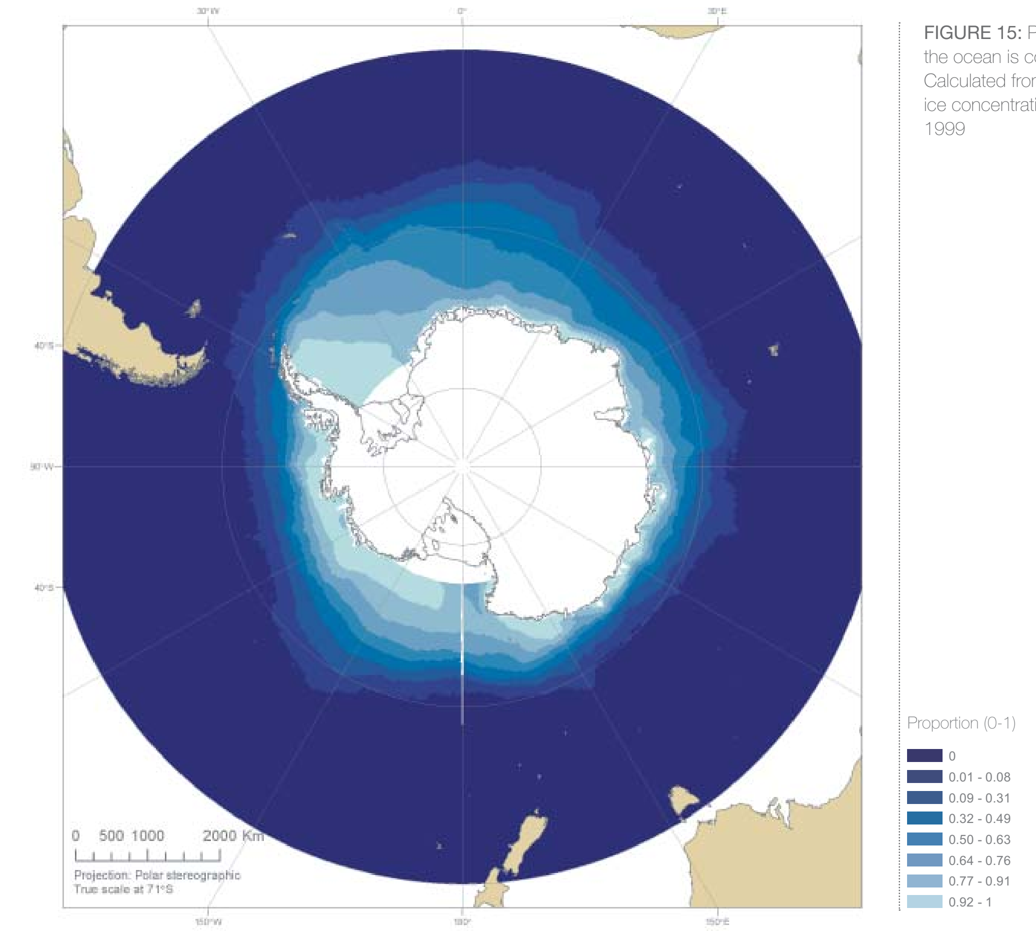

FIGURE 15: Proportion (0-1) of the year for which the ocean is covered by at least 15% sea ice. Calculated from satellite-derived estimates of sea ice concentration spanning 1979–2003. (Comiso, 1999

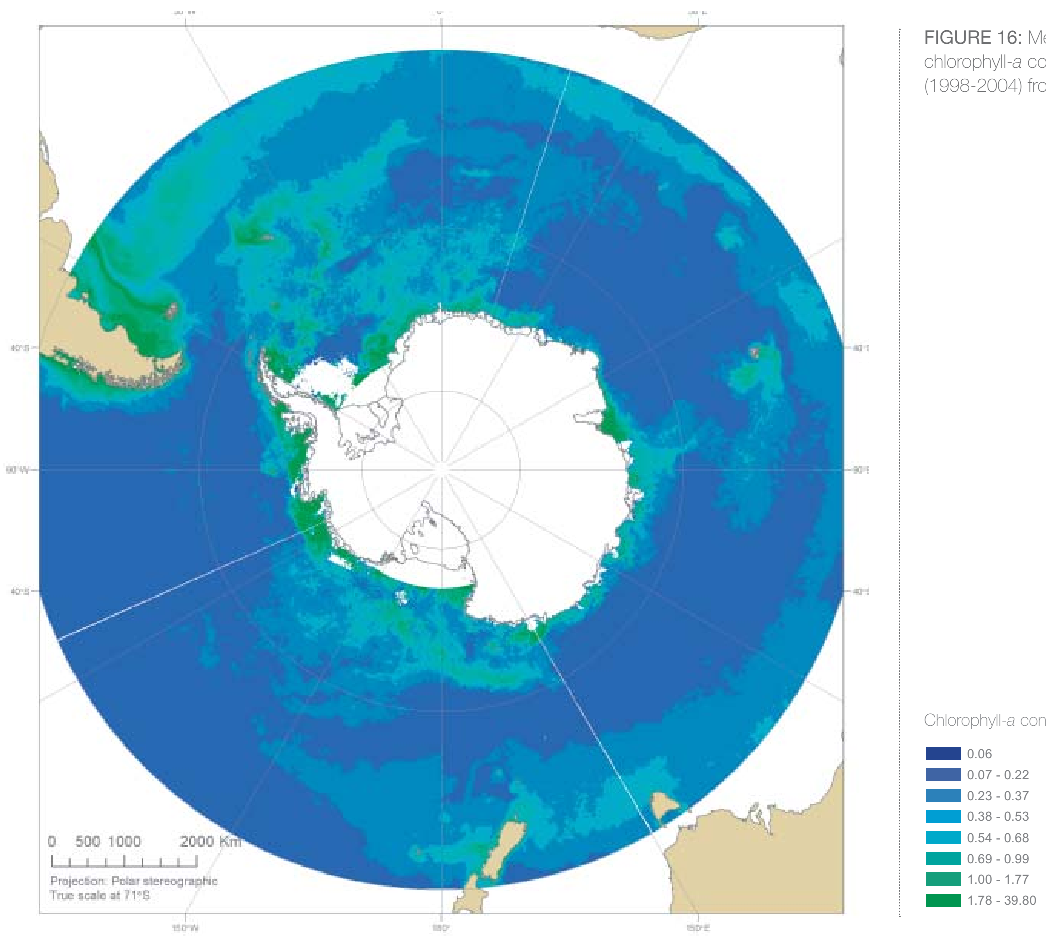

FIGURE 16: Mean summer (DEC-FEB) surface chlorophyll-*a* concentrations. Summer means (1998-2004) from SeaWiFS.

Photograph by Nick Gales, Australian Government Antarctic Division © Commonwealth of Australia

3.2 Results of Southern Ocean bioregionalisation

Primary regionalisation

The results of the primary regionalisation are shown in Figures 17 (dendrogram) and 18 (map). The physical properties of each region are shown in Table 1. This regionalisation clearly differentiates, at the highest levels, between coastal Antarctica (including embayments), the sea ice zone and the northern open ocean waters. The analysis highlights the different environmental characteristics of large regions including the continental shelf and slope, frontal features (Subantarctic Front, Polar Front, Southern Antarctic Circumpolar Current Front), the deep ocean, banks and basins, island groups, and gyre systems.

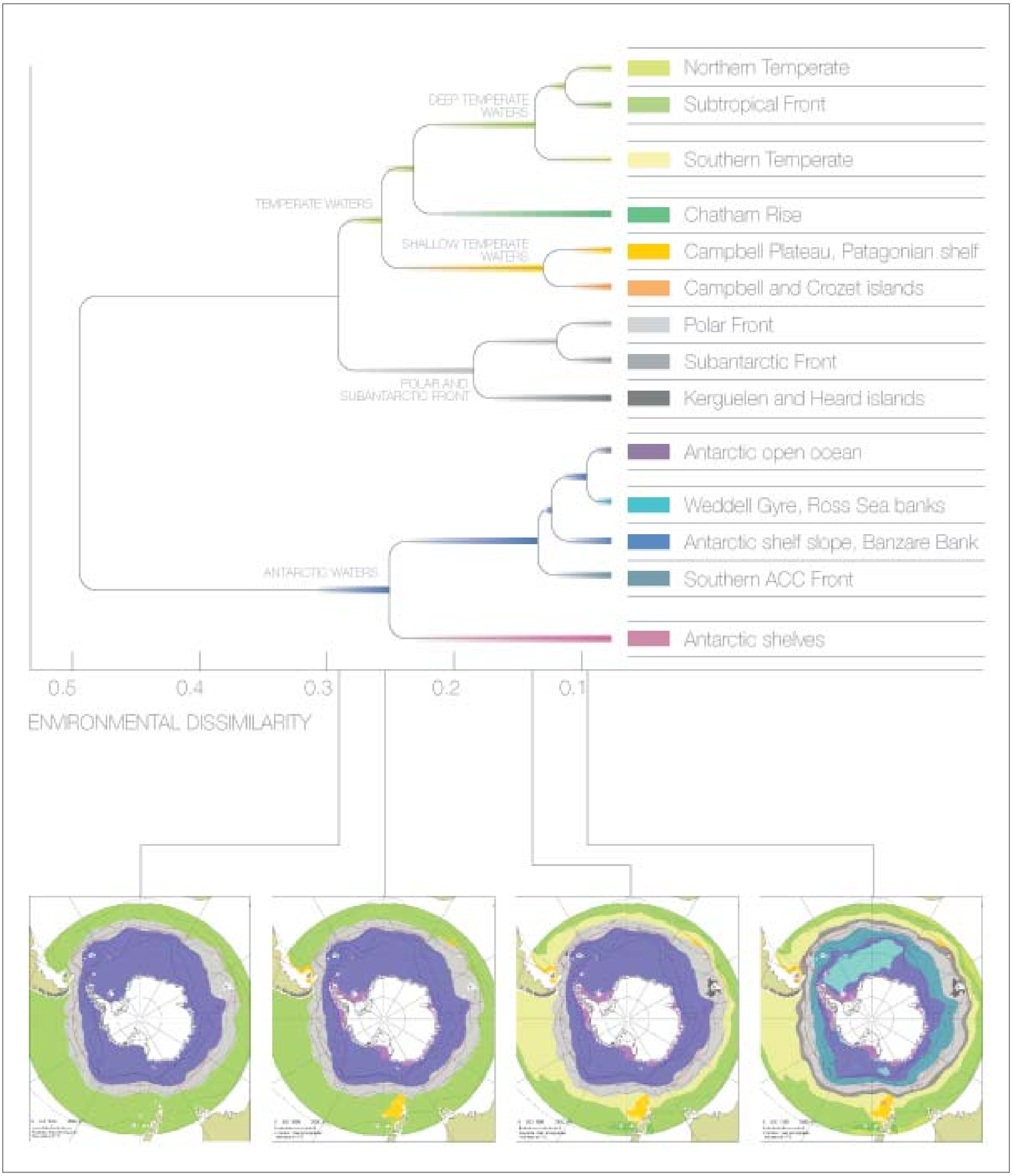

FIGURE 17: Dendrogram for primary (14-cluster) regionalisation, with thumbnail maps showing regionalisations at different stages of the hierarchy

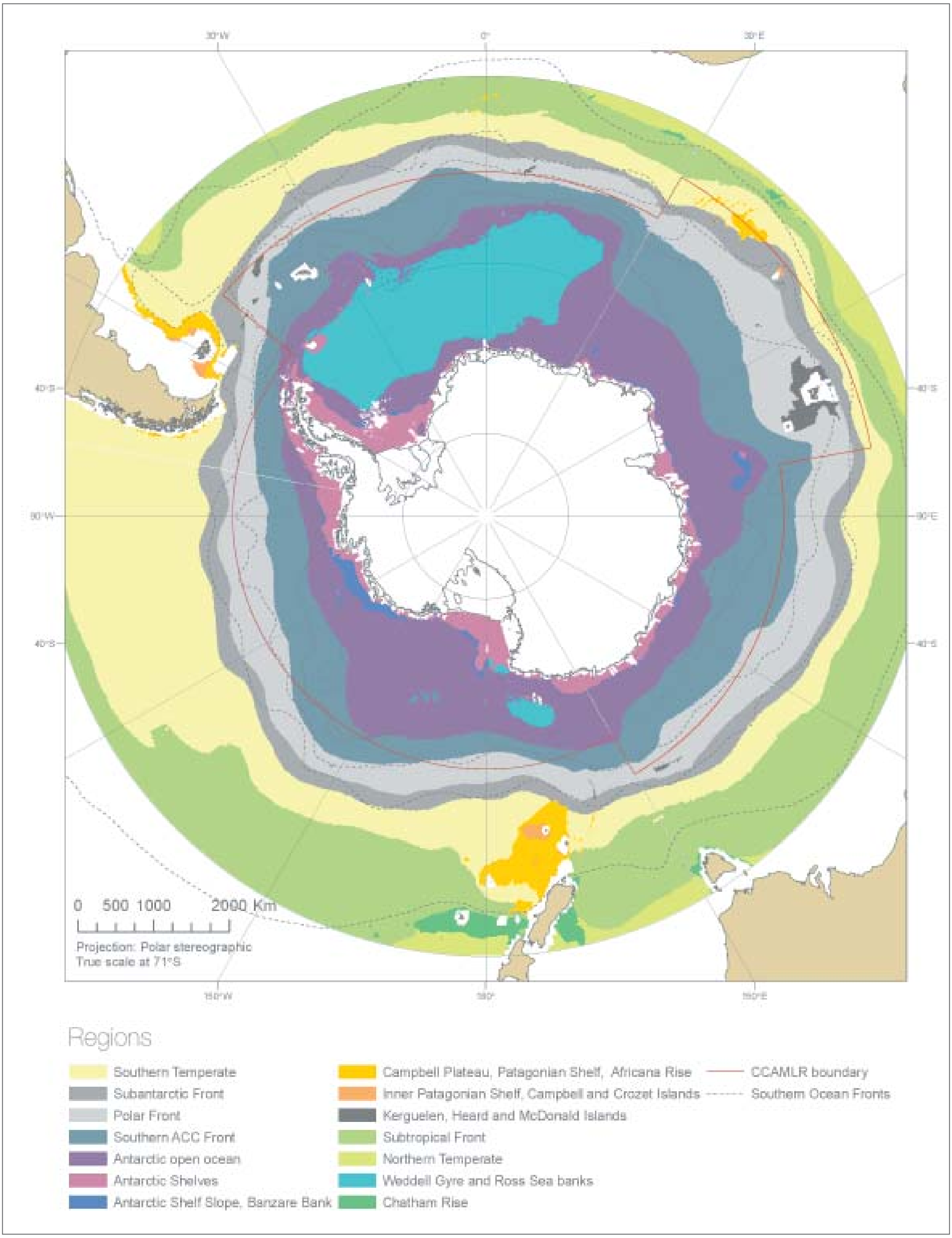

FIGURE 18: Primary regionalisation of the Southern Ocean based on: depth, sea surface temperature (SST), silicate (Si) and nitrate (NOx) concentrations (14 cluster groups) (white areas represent cells with missing data that were not classified in these analyses).

TABLE 1: Physical properties (mean and standard deviation of data values) of regions shown in Figure 18 (14 cluster groups based on primary datasets)

REGION NAME	Number of grid cells	Depth mean (m)	Depth SD	SST mean (°C)	SST SD	Si mean (µmol/kg)	Si SD	NOx mean (µmol/kg)	NOx SD
Southern Temperate	110567	-4119.952	821.342	8.681	1.854	7.998	2.402	20.919	1.616
Subantarctic Front	40180	-3917.738	921.884	5.840	0.791	15.231	2.582	25.158	1.052
Polar Front	83006	-4134.095	732.582	3.539	0.999	28.382	6.492	29.236	1.815
Southern ACC Front	108053	-4109.261	818.366	0.945	0.872	56.089	9.814	32.370	1.503
Antarctic Open Ocean	136360	-3612.533	897.680	-0.682	0.535	79.593	5.804	33.169	1.374
Antarctic Shelves	30767	-520.048	213.352	-1.149	0.380	82.044	9.211	32.356	1.821
Antarctic Shelf Slope, BANZARE Bank	6508	-1455.466	389.636	-1.227	0.434	79.961	2.946	33.599	1.343
Campbell Plateau, Patagonian Shelf, Africana Rise	7451	-1034.451	427.437	8.453	1.129	7.876	2.582	20.898	1.735
Inner Patagonian Shelf, Campbell & Crozet islands	913	-343.482	109.436	7.742	0.827	8.084	2.233	20.857	1.427
Kerguelen, Heard & McDonald Islands	2294	-1270.202	734.782	3.360	0.818	25.846	4.024	29.279	1.318
Subtropical Front	94234	-4461.472	788.887	11.804	1.511	4.607	1.235	15.257	2.062
Northern Temperate	9946	-4163.621	951.003	15.496	0.774	4.336	0.727	10.154	1.667
Weddell Gyre & Ross Sea banks	52905	-4466.641	762.290	-0.680	0.333	98.163	5.615	31.965	0.553
Chatham Rise	3025	-1568.439	858.953	14.361	0.802	4.112	0.610	12.061	1.453

Uncertainty

The time available to the workshop did not permit a rigorous analysis of uncertainty. However, a limited analysis was undertaken to investigate the uncertainty associated with the clustering algorithm. Figure 19 illustrates this uncertainty. Uncertainty was computed by first calculating the difference between the environmental characteristics of a grid cell and the average environmental characteristics of the cluster to which it was assigned. (Each grid cell is assigned to the cluster to which it is most environmentally similar). A second difference was then computed, this time between the environmental characteristics of a grid cell and the average environmental characteristics of the next-most similar cluster. The first difference value was then divided by the second. Thus, high uncertainty values (red, close to 1) indicate that a grid cell lies on the environmental boundary between two different clusters, and so its allocation to one or the other is less certain than for a grid cell that is strongly typical of the cluster to which is has been allocated. Note that this uncertainty analysis considers only a specific subset of the possible sources of uncertainty in the regionalisation (specifically, to do with the allocation of grid cells to particular clusters).

Secondary regionalisation

The secondary regionalisation incorporated two additional datasets to reflect properties that further modify the marine environment. The impact of sea ice on the environment was explored using a data layer comprising the proportion of the year (0-1) that an area was covered by at least 15% concentration of sea ice. The concentration of satellite-observed sea surface chlorophyll was explored using a data layer comprising log transformed chlorophyll densities.

The ice and chlorophyll data were incorporated both separately and in a single classification, and the results of these analyses are displayed in Appendix IV. The preliminary results of this analysis using a large number of clusters, based on both ice and chlorophyll, are presented in Section 3.3 for three sectors of the Southern Ocean. This exploratory classification is of use in illustrating the heterogeneity arising from these properties at a smaller scale than that of the primary regionalisation, however further work is needed to identify the appropriate level of regional separation using these secondary datasets, and to determine whether other datasets could be used to assist this process.

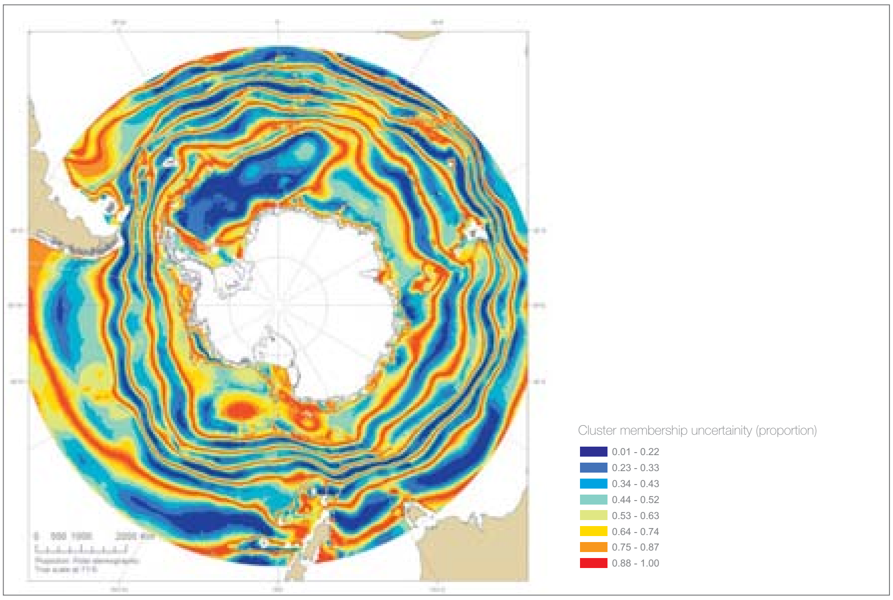

FIGURE 19: Map showing scaled uncertainty for the primary (14-cluster) classification

3.3 Expert review of bioregionalisation results

An assessment of the final results was carried out by expert review to determine if the defined regions were consistent with present knowledge of the ecosystem. The following sections describe the defined regions in further detail, focusing separately on the Atlantic, Indian and Pacific ocean sectors (CCAMLR Statistical Areas 48, 58 and 88, respectively). For each sector, a map of the regions defined by the primary regionalisation is overlain with information on known large-scale physical and ecological features such as fronts, gyres, seamounts and maximum sea ice extent. In addition, maps showing an example of a secondary regionalisation (using ice and chlorophyll data to define 40 clusters for the Southern Ocean) illustrate the high degree of smaller-scale heterogeneity arising from patchiness in chlorophyll and sea ice concentrations, particularly in shelf areas and the seasonal ice zone.

South Atlantic (Area 48)

The Atlantic sector is characterised by the narrowing of the ACC as it passes through Drake Passage between South America and the Antarctic Peninsula. In the west, strong currents, eddies and mixing associated with the ACC and the Weddell-Scotia Confluence (WSC) occur in the vicinity of the Scotia Arc. In the central and eastern areas, there is a greater contribution of the Weddell gyre and a broadening of the ACC. A large continental shelf area is present in the great embayment of the Weddell Sea, along with a number of ice shelves. These features are captured well in the primary regionalisation. The Atlantic sector is also dominated by strong seasonal cycles, manifest by changing irradiance and seasonal sea-ice cover. The bathymetry of the southwest Atlantic steers the flow of the ACC northwards, carrying polar waters to more northerly latitudes than elsewhere in the Southern Ocean. This transport is critical to the local marine systems around some of the more northerly SubAntarctic island groups where large colonies of many land-based predators breed.

The southwest Atlantic is possibly the most studied of all the areas in the Southern Ocean. It has higher productivity than other areas. Extensive summer phytoplankton blooms, particularly around some of the island chains, probably result from the mixing of micronutrients with surface waters through the flow of the ACC and the WSC as they pass over the Scotia Arc. A range of zooplankton species including Antarctic krill (*Euphausia superba*), consume this primary production. In turn, these taxa are consumed by numerous species of nekton, seabirds and marine mammals. The resulting biodiversity is possibly higher than elsewhere in the Southern Ocean.

Zooplankton community structure in the southwest Atlantic appears to be dependent upon the timing of the seasonal sea-ice retreat (Ward et al., 2003). Sea-ice influences the timing of reproduction; a late retreat delays reproduction and reduces population sizes of a number of zooplankton species. During years of normal sea-ice retreat copepods are more advanced, and there are also higher abundances of krill larvae. This implies that the seasonal environment critically influences the biogeography of zooplankton communities in the southwest Atlantic. As a consequence, multi-year datasets that encompass years of differing environmental

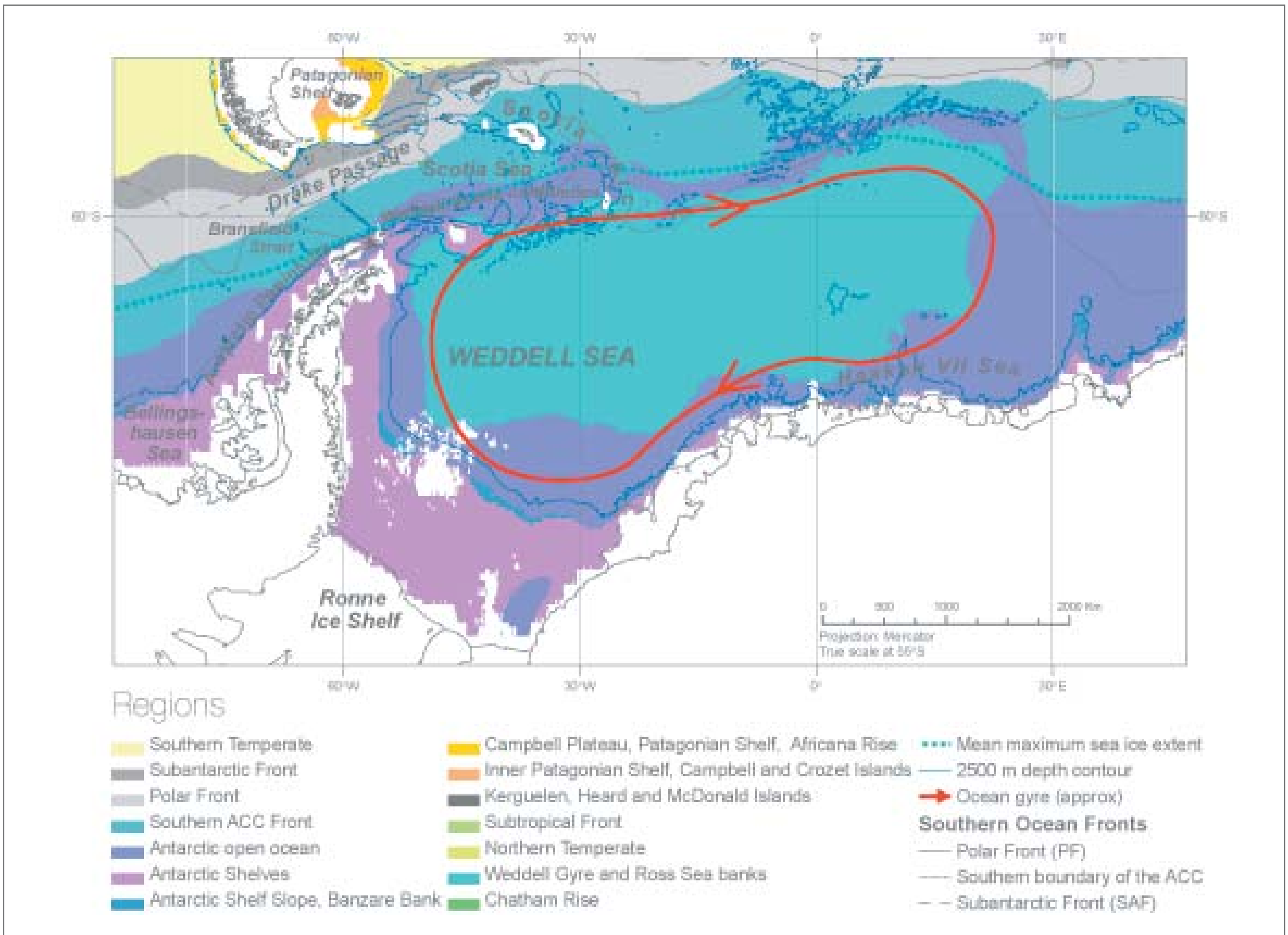

FIGURE 20: Map showing primary regionalisation for the South Atlantic sector (Area 48), with major physical features

conditions are likely to provide broader and more generic descriptions of community structure in the southwest Atlantic than do single year synoptic surveys.

A number of such analyses are now available, which reveal that (multi-year) sampling of zooplankton species across the ACC to the northwest of South Georgia form four community groupings, and that these are geographically consistent with the different water masses identified on the basis of temperature and salinity properties. Copepods are the largest contributors to total abundance within these groupings. All groups can be characterised by varying proportions of a relatively small subset of species, many of which are present throughout the region. Other species are characteristic of particular groups. The close physical and biological coupling observed across the ACC confirms that frontal zones, and particularly the Polar Front, are features across which community properties change in the Atlantic sector.

Small and mesopelagic zooplankton species also play a major role in the southwest Atlantic. Small copepods form approximately 75% of total copepod abundance in the upper ocean layers across all major oceanographic zones. These species show a continuum of temperature ranges, and there is no evidence that the Polar Front is a major biogeographic boundary to their distribution. Indeed, several important species reach maximum numbers in this area. Total copepod abundance is thus higher in the vicinity of the Polar Front than in any other region (Atkinson and Sinclair, 2000).

Larger zooplankton species such as Antarctic krill and salps (mainly *Salpa thompsoni*) are also major grazers in the Southern Ocean and particularly in the productive southwest Atlantic sector where krill biomass forms more than 50% of Southern Ocean krill stocks. Spatially, summer krill density correlates positively with chlorophyll *a* concentrations. Temporally, within the southwest Atlantic, summer krill densities correlate positively with sea-ice extent the previous winter. Summer food and the extent of winter sea ice are thus key factors in the high krill densities observed in the southwest Atlantic Ocean. Salps, by contrast, occupy the extensive lower-productivity regions of the Southern Ocean and tolerate warmer waters than krill (Atkinson et al., 2004).

The secondary regionalisation shows the patchiness in primary production and ice cover around the coastal region as well as the patchiness in primary production in the oceanic areas and around the islands of the Scotia Arc. The pattern of clusters from Antarctic Peninsula area to South Sandwich Island area matches well with the spatial distribution of krill length composition cluster groups observed during CCAMLR-2000 survey (Figure 5 of Sigel et al. 2004). Also, the influence of the Weddell Gyre on the productivity and water properties of the Bransfield Strait (Amos, 2001) is apparent.

Figures 20 and 21 show the primary and secondary regionalisations for the South Atlantic sector. (Note that the colours used in the secondary regionalisation do not relate to those in the primary regionalisation).

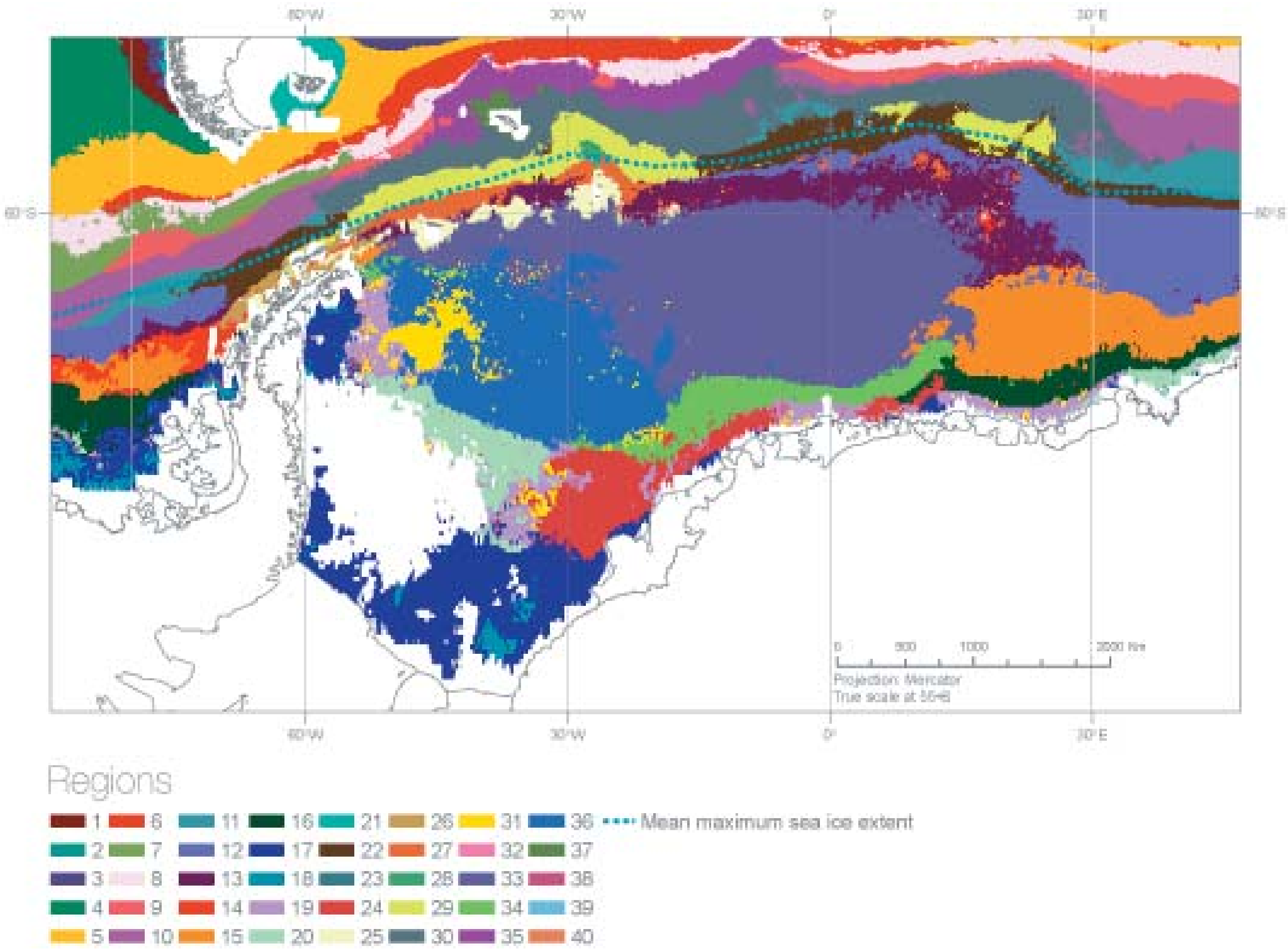

FIGURE 21: Map showing secondary regionalisation for the South Atlantic sector (Area 48)

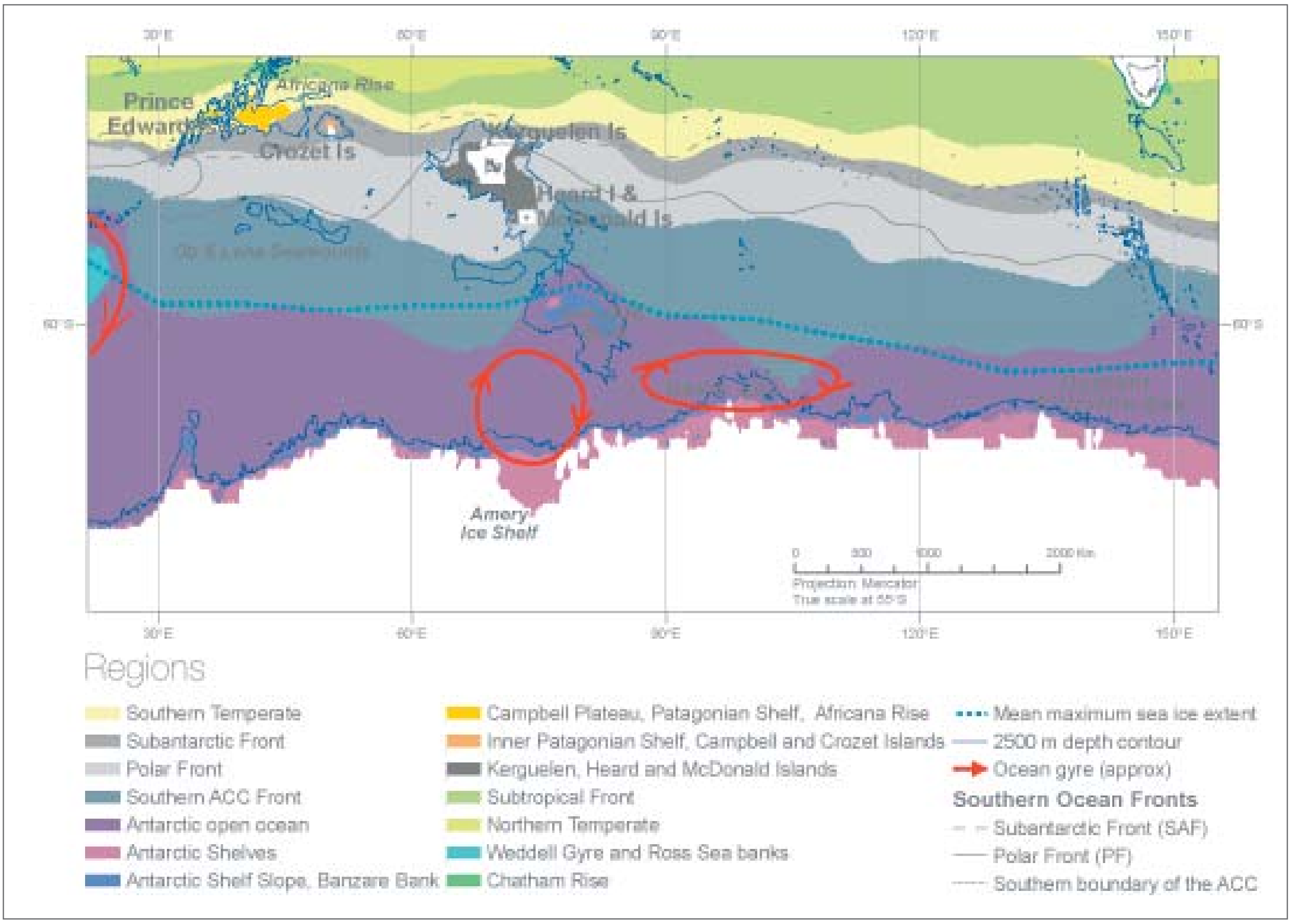

FIGURE 22: Map showing primary regionalisation for the Indian Ocean sector (Area 58), with major physical features

Indian Ocean (Area 58)

The Indian Ocean sector extends in the west from the eastern margins of the Weddell Gyre across the Indian Ocean with a gradual movement of the Polar Front from the north to the south. The flow of the ACC is disrupted by the greater Kergeulen Plateau, including BANZARE Bank, causing formation of many branches of the fronts. A set of subantarctic islands and banks are found in the western part of the sector between 45°S and 55°S. Gyres are present close to the small embayment of Prydz Bay, and also east of BANZARE Bank. These general features are evident in the primary classification.

Ice shelves are present along the coastal margins, including in Prydz Bay. Also, a number of polynyas occur along the coast (Arrigo and van Dijken, 2003; Massom et al., 1998), some of which are substantial contributors to production of sea ice and deep water formation. The annual progression and retreat of sea ice is uninterrupted in this region, extending to 60°S, although the winter sea ice extent is greater in the west than in the east.

Most research has occurred to the west of 60°E, although a recent survey of krill and associated environmental parameters (Jan-March 2006 - 30°E to 80°E) completed synoptic coverage of the coastal region from 30°E to 150°E (Nicol et al., 2000; 2006). These surveys suggest that productivity is higher and, along with Antarctic krill, *Euphausia superba*, extends further to the north in the area to the west of approximately 115°E (south of 60°S) compared to east of this longitude. Salps are found to the north of this krill distribution. This is evident in the secondary classification with a greater diversity of regions in the area of higher productivity between 115°E and Prydz Bay. This is also coincident with the evidence for an eastern gyre hypothesised by Nicol et al. (2000). The pattern of clusters around 30-80°E (south of 60°S) matches well the spatial pattern of krill length composition cluster groups found in recent surveys (Figure 12 of Nicol et al., 2006). These surveys also identified the higher densities of Antarctic krill, *Euphausia superba*, associated with the shelf break. This region also is indicated well in the secondary classification. The neritic community over the continental shelf is dominated by the crystal krill *Euphausia crystallorophias*, which are never found as adults to the north of the shelf break.

A number of studies have characterised the zooplankton assemblages in the Southern Indian Ocean and their association with fronts (e.g. Hosie 1994a; 1994b; Hosie et al., 1997; Chiba et al. 1999; 2001; Hoddell et al., 2000; Hosie et al., 2000; Hunt and Hosie, 2003; 2005; 2006a; 2006b). Continuous Plankton recorder (CPR) monitoring, primarily between 60 and 160°E from spring to autumn, have identified a number of breaks in the distribution of zooplankton taxa with fronts identified by Orsi et al. (1995). The SAF is a major biogeographic boundary for plankton with separate communities north and south of the front (Hunt and Hosie, 2003). Some changes in composition occur at the Polar Front, in particular the northern branch of the PF. A number of distinct zooplankton assemblages can also be defined south of the PF-N. These assemblages are identified more by subtle variation in the abundance or proportion of species rather than changes in species

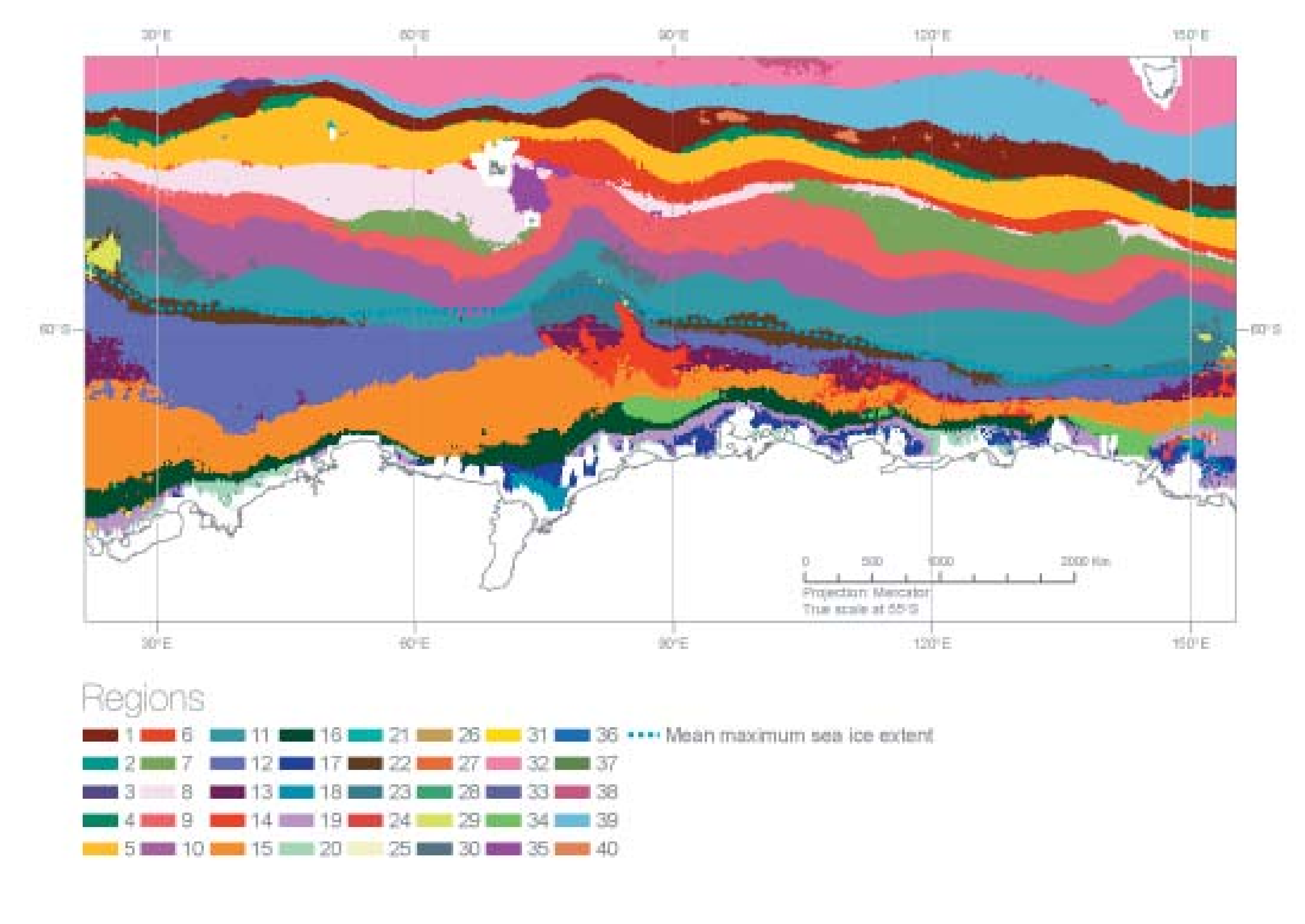

FIGURE 23: Map showing secondary regionalisation for the Indian Ocean sector (Area 58)

composition (Hunt and Hosie, 2005). The Polar Fontal Zone (SAF and PF) is often reported as an area of elevated primary production which then declines south of the PF. This is probably true for phytoplankton, and certainly many vertebrate predators forage in this area. However, the CPR survey has consistently shown that zooplankton abundance increases substantially south across the SAF and remain high though the Southern Ocean to a point between 60 to 62°S where zooplankton abundance declines suddenly (Hosie et al., 2003). The upper 20 m of the water column in the area further south usually remains almost devoid of zooplankton. This decline approximates the position of the SACCF (Orsi et al., 1995) although a link is yet to be established. Overall, the patterns displayed in the secondary classification correspond to the patterns of zooplankton described here.

Figures 22 and 23 show the primary and secondary regionalisations for the Indian Ocean sector. (Note that the colours used in the secondary regionalisation do not relate to those in the primary regionalisation).

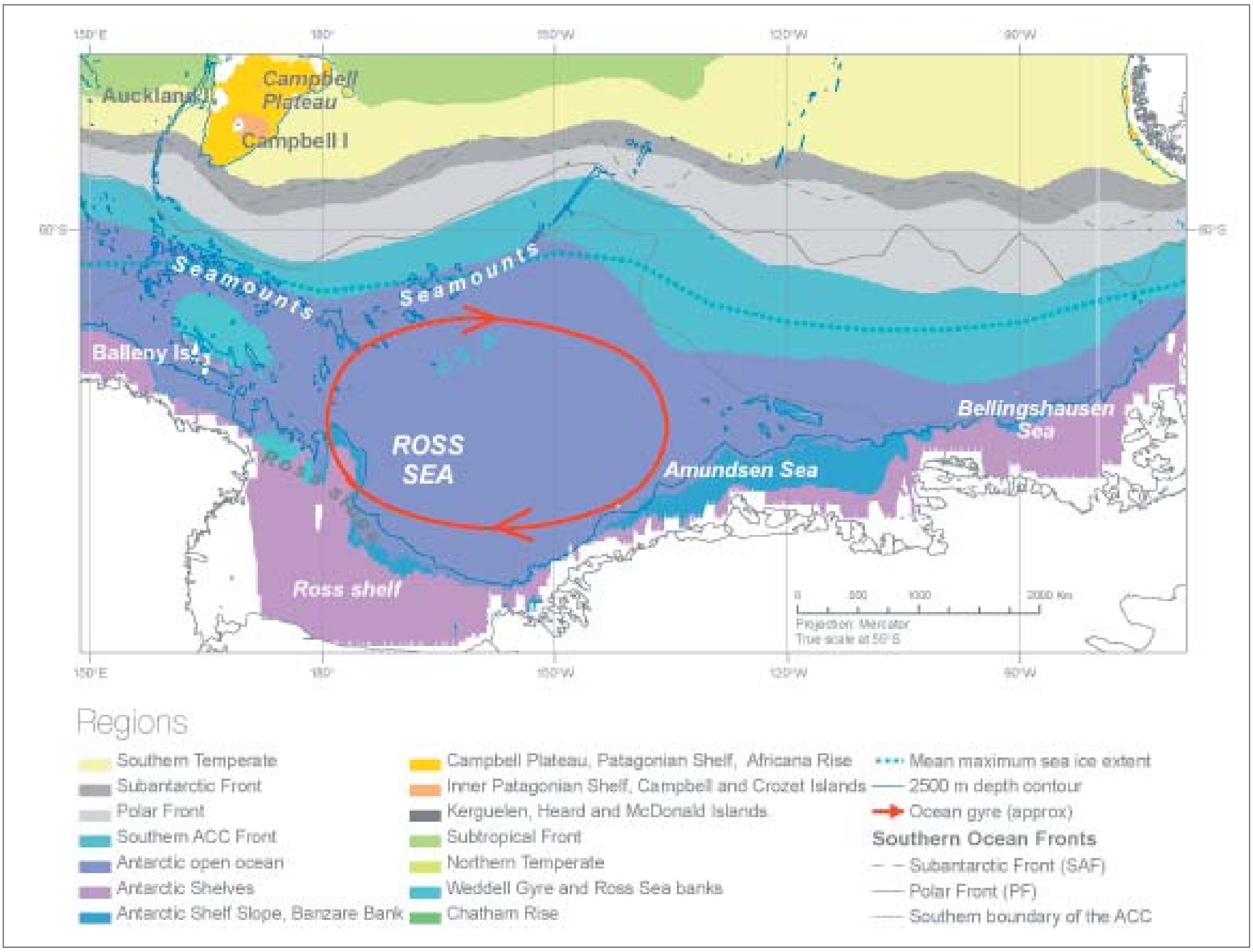

FIGURE 24: Map showing primary regionalisation for the Pacific Ocean sector (Area 88), with major physical features

Pacific Ocean (Area 88)

The Pacific sector is similar in ocean characteristics to the Indian Ocean sector except for the interaction with Ross Sea and its associated gyre. The inner Ross Sea over the continental shelf has characteristics distinct from those of the ACC. The western part of the Ross Sea has a complex shelf and slope area along with the Balleny Islands and ridges of seamounts extending to the north (the Macquarie Ridge extending to the Campbell Plateau) and to the east. A clockwise current flows within the area shallower than the 500 m isobath, and the East Wind Drift current flows in the opposite direction along the continental shelf break. Upwelling of Circumpolar Deep Water also occurs along this shelf break (Ainley, 2002). Seasonal polynyas in the western shelf area play an important role in the distribution of phytoplankton, zooplankton, fish, birds and seals. The concentration of top predators in the Ross Sea coincides with the marginal ice zone that rings the Ross Sea Polynya. This area is dominated by diatoms, while the central, open water portion of the polynya is dominated by Phaeocystis (Ainley et al., 2006). The primary classification identifies the Ross Sea shelf and slope areas. Features such as the Ross Sea polynya are not captured in the primary classification, but these may be reflected in the heterogeneity of the secondary classification.

Further to the east in the Pacific Sector is a narrowing of the ACC towards the Drake Passage. Also, the seasonal sea ice zone narrows in the eastern part of the Bellingshausen Sea. The primary classification captures the major ocean and coastal features, although it does not reflect the ocean ridges in the eastern part of the sector.

The separation of subtropical and subantarctic waters as well as distinguishing the Campbell Plateau from the ocean environment is supported by research on productivity of the region (Boyd et al. 1999; Murphy et al. 2001) and fish assemblages (Bradford-Grieve et al. 2003). Although these general differences are retained in the secondary classification, the wider Campbell Plateau is not differentiated from the southern temperate waters. This may be because of the lack of differentiation in the chlorophyll data used here.

The secondary classification does identify the heterogeneity of the environment associated with the island and ridge system in the eastern part of the sector. It also identifies the expected complexity in the Ross Sea Gyre and its relationship to the coastal system. These results reflect studies documenting the variation in diversity and ecological processes in the region (Bradford-Grieve and Fenwick 2001; Pinkerton et al., 2006; Sharp, 2006). For example, *Euphuasia superba* is found to the north of the shelf break while the neritic fauna is dominated by *Euphausia crystallorphias* and *Pleuragramma antarcticum*.

Figures 24 and 25 show the primary and secondary regionalisations for the Pacific Ocean sector. (Note that the colours used in the secondary regionalisation do not relate to those in the primary regionalisation).

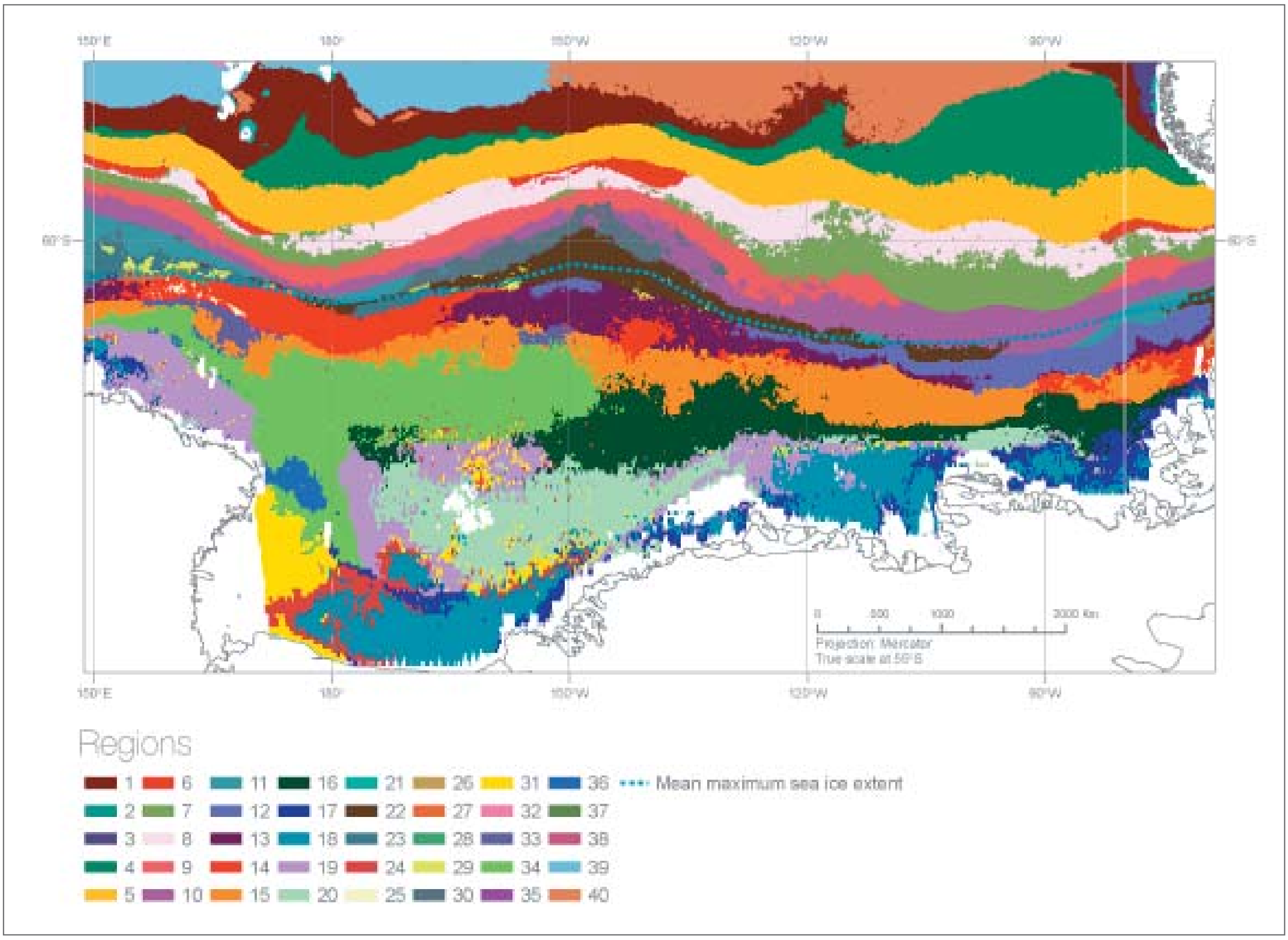

FIGURE 25: Map showing secondary regionalisation for the Pacific Ocean sector (Area 58)

The primary regionalisation of the Southern Ocean highlights the different environmental characteristics of large regions including the continental shelf and slope, frontal features (Subantarctic Front, Polar Front, Southern Antarctic Circumpolar Current Front), the deep ocean, banks and basins, island groups and gyre systems. The addition of secondary datasets suggests smaller-scale spatial heterogeneity within the regions, particularly in the continental shelf and slope areas, and the seasonal ice zone.

4. Future work

The workshop identified a range of areas in which future work might be directed in order to produce a final bioregionalisation for the Southern Ocean. Priorities included the incorporation of additional (particularly biological) datasets, and finer-scale analysis of particular areas of interest. It also identified that the statistical methods might be refined further. However, the workshop was satisfied that the proof of concept developed is sufficient to undertake the tasks identified by CCAMLR and the CEP.

Further data could be used to update or refine the draft broad-scale primary regionalisation (for example using additional datasets such as insolation (PAR) and sea surface height). Datasets used in this analysis might also be refined, for example using derived datasets such as a 'silicate depletion' data layer (reflective of primary production) derived by subtracting silicate at the surface from silicate at 200 m depth.The remotely-sensed PAR data are confounded by the inability to distinguish ice cover from cloud cover, however they might be transformed to represent biologically relevant variation in available light, by combining PAR data and ice data.

The addition of sea ice and chlorophyll *a* datasets in the exploratory secondary classifications illustrated the high level of heterogeneity arising from these parameters. Refinement of the analysis and data used at the secondary classification level is needed to identify the appropriate level of regional separation at a smaller scale using these secondary datasets, and to identify whether other datasets could be used to assist this process. In particular, sea ice is a major driver of ecosystem processes in the Southern Ocean (see Section 1.3), and the inclusion of variables representing sea ice dynamics will be important in finer-scale regionalisation analyses.

The draft regionalisation presented in this report is pelagic, however it may also be necessary to undertake a benthic regionalisation. Further consideration should be given to the relationships between the benthic and pelagic systems, and the utility of separating the two systems in the context of bioregionalisation analysis.

A range of potential biological datasets (for use in future analyses) were identified during the workshop (see Appendix V), but it will be necessary to identify which of these would be of most value. Data 'compendia' may be of assistance in providing information on inter-annual and seasonal variability, which can then be further analysed according to the defined objectives. Indicator species might also be investigated for their potential utility in providing further input to the analysis. In the longer term, the compilation of comprehensive biological data sets may allow the use of more sophisticated analytical approaches such as Generalised Dissimilarity Modelling (GDM – Ferrier et al. in press). This performs an integrated statistical analysis of biological and environmental data, using information on species turnover rates to identify the optimal weighting and transformation of environmental variables to be used in defining the classification.

It may be important to consider stochastic, temporal or spatial variability in defining bioregions in order to ensure that the outcome is robust to uncertainties and variability. Further work towards understanding (and, where possible, reducing) different types of uncertainty in the data, models or methods will help the classification process.

A bioregionalisation will inevitably be based on the best scientific evidence available at the time. Further refinement could be achieved by adding biological and environmental data as it becomes available, thereby reducing uncertainties. One source of refinement will be to add more biological data to test the relationship between physical and environmental surrogates and the ecological processes they are thought to represent. This is likely to be needed at finer-scale resolution of the bioregionalisation.

The most important avenue for further work will be to undertake a finer-scale regionalisation than that presented here. This might initially be focused in areas where more data is available, such as in the southwest Atlantic. The addition of datasets on chlorophyll *a* and sea ice extent illustrated the complexity of the coastal, shelf and seasonal ice areas, in relation to these parameters. These regions are likely to have additional complexity corresponding to other ecological processes and species distributions, and should be a priority for further research.

5. Conclusions

This workshop established a 'proof of concept' for bioregionalisation of the Southern Ocean. Further work within the frameworks of CCAMLR and the CEP will be an important contribution to the achievement of a range of scientific, management and conservation objectives, including large-scale ecological modelling, ecosystem-based management of human activities in the marine environment, and the development of ecologically representative protected area systems. Continuing work on this topic also has the potential to inform and contribute to the further development of bioregionalisation analysis as a tool for conservation and management in the global context.

List of Appendices (provided on CD)

APPENDIX I: Approaches to bioregionalisation – examples presented during the workshop

- Antarctic Environmental Domains Analysis (Harry Keys and Fraser Morgan, Department of Conservation, New Zealand)
- CCAMLR Small-Scale Management Units for the fishery on Antarctic krill in the Southwest Atlantic (Roger Hewitt, NOAA, USA)
- Australian National Bioregionalisation: Pelagic Regionalisation (Vincent Lyne and Donna Hayes, Department of the Environment and Heritage and CSIRO)
- Selecting Marine Protected Areas in New Zealand's EEZ (John Leathwick, NIWA, New Zealand)

APPENDIX II: Technical information on approach to bioregionalisation

APPENDIX III: Descriptions of datasets used in the analysis

APPENDIX IV: Results of secondary regionalisation using ice and chlorophyll data

APPENDIX V: Biological datasets of potential use in further bioregionalisation work

APPENDIX VI: Details of datasets, Matlab code and ArcGIS shapefiles included on the CD

List of workshop participants

PARTICIPANT	EXPERTISE	AFFILIATION
Dr. Ian Ball	Mathematical modelling, MPA selection	ACE CRC, AGAD, Australia
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Dr. Susan Doust	Support, CCAMLR	AGAD, Australia
Dr. Susie Grant	Support, marine protected areas, CCAMLR, CEP	UK
Dr. Roger Hewitt	Krill biology, ecosystem ecology	SW Fisheries Centre, NOAA, USA
Dr. Graham Hosie	Zooplankton ecology; CPR program	AGAD, Australia SCAR representative
Dr. So Kawaguchi	Krill biology, ecosystem ecology	ACE CRC, AGAD, Australia
Dr. Harry Keys	Bioregionalisation, Antarctic regional classification	DOC, NZ
Dr. John Leathwick	Statistical modelling, bioregionalisation, MPA selection	NIWA, Hamilton, NZ
Dr. Gilly Llewellyn	Support, classification, regionalisation, marine protected areas	WWF-Australia
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Dr. Matt Pinkerton	Ecosystem modelling, remote sensing	NIWA, NZ
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Dr. Steve Rintoul	Physical oceanography, remote sensing	ACE CRC, Australia
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Dr. Pete Strutton	Primary production, remote sensing	Oregon State University, USA
Dr. Phil Trathan	Ecosystem and predator ecology, CCAMLR	BAS, UK

Glossary of terms

Bioregionalisation (or Regionalisation)

A process that aims to partition a broad spatial area into distinct spatial regions, using a range of environmental and biological information. The process results in a set of bioregions, each with relatively homogeneous and predictable ecosystem properties. The properties of a given bioregion should differ from those of adjacent regions in terms of species composition as well as the attributes of its physical and ecological habitats. The term regionalisation may be used interchangeably (or sometimes to refer to an analysis undertaken using only physical data).

Bioregion (or Region)

A spatial compartment defined on the basis of its biological and/or physical properties. Each bioregion (or region) reflects a unifying set of major environmental influences which shape the occurrence of biota and their interaction with the physical environment. The term region may be used interchangeably (or sometimes to refer to spatial compartments which have been defined using only physical data).

Classification

The process of partitioning a broad spatial area into distinct regions. Also used to refer to the specific step within that process during which the actual allocation of sites to regions occurs, usually through a statistical process such as cluster analysis

Ecological process

In the context of this report, an ecological process is any process that affects the dynamics of a species

Hierarchy (spatial and statistical)

In the context of bioregionalisation, this term may be used to refer to spatial or ecological hierarchy, or statistical hierarchy.

Spatial or ecological hierarchy refers to the different levels of scale or ecological processes within a large area. A hierarchy may be nested, whereby smaller scale units or processes are nested within large scale units.

Statistical hierarchy has relevance in dissimilarity-based clustering methods, where an iterative approach is undertaken to group sites together into regions. All sites are initially allocated to their own regions. At each iteration of the process (or each step down the hierarchy), the two most similar regions are merged together, until at the end of the process there is only one region, which contains all of the sites. This is often displayed in dendograms.

Parameter

Information extracted from data. For example, sea ice concentration is a variable from which the parameters of ‘proportion of year when the ocean is covered by at least 15% ice’ or ‘areas with greater than 50% ice coverage’ can be extracted.

Property

This term is used here to describe the defining characteristics or attributes of a particular ecological process, or of a given region.

Proxy

A parameter that can be used to provide similar information or patterns to another parameter or variable, usually used when desired data (e.g. the distribution of species) are unavailable, or where one parameter can be used in the place of several others in order to simplify the analysis.

Site

In the context of bioregionalisation analysis, a site is the smallest unit of analysis. The study area is divided into a grid of sites, at sufficiently fine scale to enable appropriate resolution of the final areas. Each site will have a particular set of parameters, according to the input data.

Synoptic

This term is used to describe data that have broad and continuous spatial coverage (e.g. across the entire Southern Ocean). Here, synoptic data may also refer to summaries of the observed conditions over time (e.g. mean monthly values averaged to obtain an annual mean). Synoptic data may be obtained through satellite remote-sensing, or through model climatologies generated from observed values.

Uncertainty

In the context of bioregionalisation analysis, uncertainty refers to the effects of imprecision in data (e.g. measurement error), uncertainty within models used to derive variables (e.g. climatology models), and epistemic uncertainty (potential errors in the chosen method). Each of these types of uncertainty can affect the resulting region boundaries.

Variable

Variables are physical or environmental data from which specific parameters can be extracted. For example, sea ice concentration is a variable from which the parameters of ‘proportion of year when the ocean is covered by at least 15% ice’ or ‘areas with greater than 50% ice coverage’ can be extracted.

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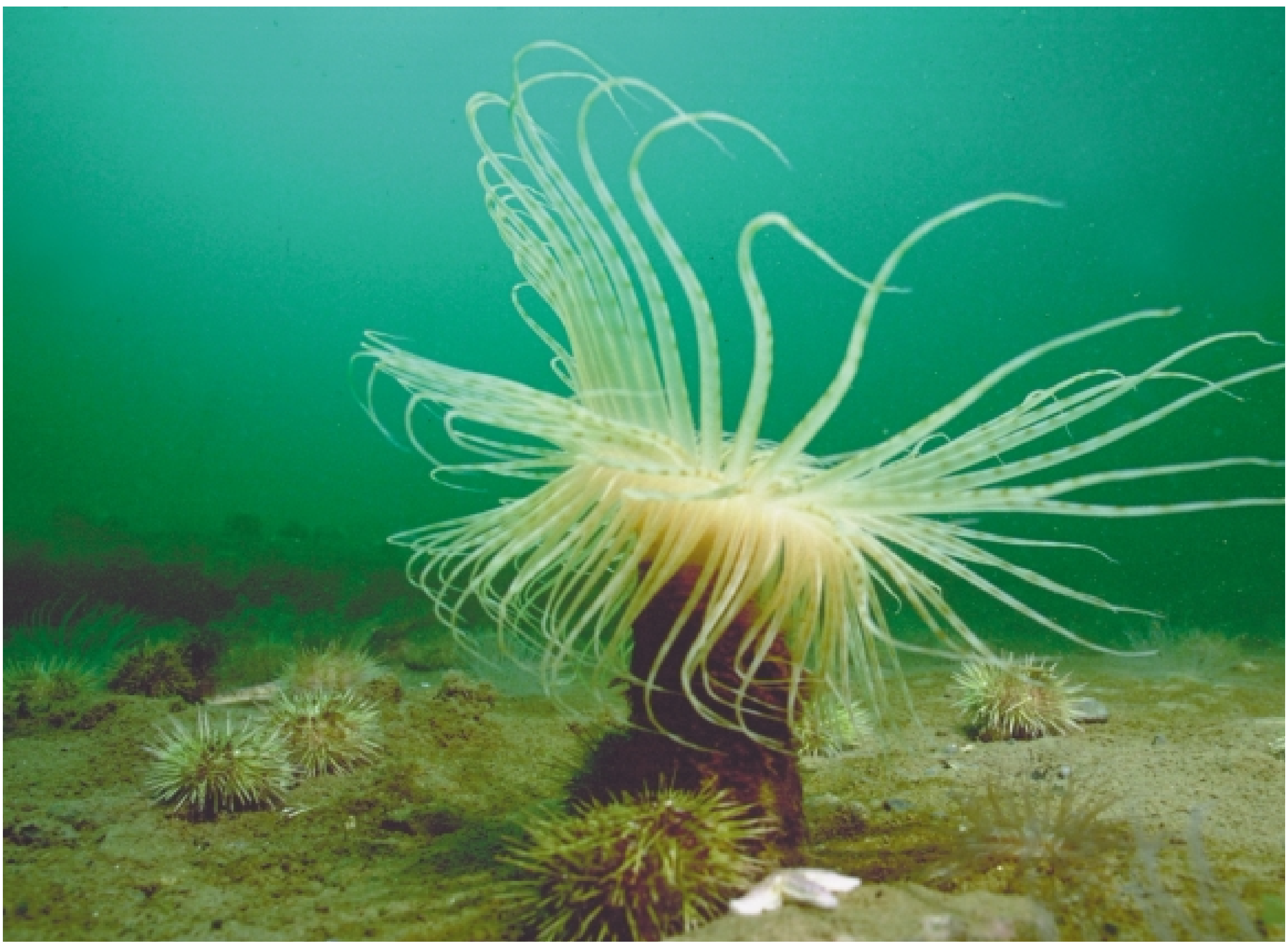
Planning for Representative Marine Protected Areas

A Framework for Canada's Oceans



Planning for Representative Marine Protected Areas
A Framework for Canada's Oceans

Written by Jon Day and John Roff. April 2000.
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Published April 2000 by World Wildlife Fund Canada (WWF).

Citation: Day, J.C. and Roff, J.C. 2000. Planning for Representative Marine Protected Areas: A Framework for Canada's Oceans. Report prepared for World Wildlife Fund Canada, Toronto.

Cover photo © M. Strong and M. Buzeta

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ABBREVIATIONS

The following abbreviations have been used in this report:

CNPPA	Commission on National Parks and Protected Areas (of IUCN)
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CWS	Canadian Wildlife Service
DFO	Department of Fisheries and Oceans
EEZ	exclusive economic zone
GBRMP	Great Barrier Reef Marine Park
GBRMPA	Great Barrier Reef Marine Park Authority
GIS	geographic information system
GPS	global positioning system
ICM	integrated coastal management
IMO	International Maritime Organization
IUCN	World Conservation Union
MPA	marine protected area
NMCA	National Marine Conservation Area
OMS	Oceans Management Strategy
UNCLOS	United Nations Convention on the Law of the Sea
UNEP	United Nations Environment Program
WCMC	World Conservation Monitoring Centre
WWF	World Wildlife Fund

Introduction

IN RECENT YEARS, there has been a growing realization that to best conserve biodiversity, we should be identifying and conserving representative spaces in conjunction with preserving individual species. If we can identify the appropriate representative spaces to be protected, then these will contain species we wish to conserve, as well as a suite of factors necessary for the health of those species, such as habitat and community structure. Furthermore, representative protected spaces can serve to protect a broad range of organisms, therefore helping to slow the alarming rate of species decline. Considering that perhaps as many as two-thirds of all species have yet to be catalogued, establishing representative protected spaces seems essential. Considerable efforts are also being directed worldwide to establishing marine protected areas (MPAs). However, choosing which areas to protect has historically been driven "more by opportunity than design, scenery rather than science" (Hackman 1995). Certainly many existing MPAs have been selected primarily on the basis of their local biological characteristics or scenic coastal features. A network of MPAs should not be restricted to sites about which the most is known or to those that are the easiest to declare.

A carefully planned, scientifically based network of representative natural areas, that protects the habitats and ecological processes on which species depend, can help ensure that marine biodiversity is conserved. The systematic identification of marine habitat types and the delineation of their boundaries in a consistent classification is a basis for selecting examples of Canada's marine areas that can contribute to a representative network of MPAs.

Therefore, we have developed a hierarchical framework for MPA planning. This framework is firmly based on ecological principles and on the enduring and recurrent geophysical and oceanographic features of the marine environment. The framework uses an ecologically based hierarchical classification of marine environments to determine the diversity of physical habitat types and, when followed to its logical conclusions, reflects the range of conditions that influence species distribution in Canadian waters. It is basically a community-level analysis of marine systems and differs from classifications previously developed (e.g., Harper et al. 1993) in a number of ways:

- The classification described in this report uses physical attributes alone and essentially predicts the expected species assemblages on the basis of documented enduring or recurrent geophysical characteristics. A major advantage of this approach is that the range of conditions that influence the distribution of organisms can be delineated into geographic units (referred to here as seascapes) by using already mapped geophysical features or by using remote sensing of appropriate surrogate variables. Most importantly, boundaries between habitat types can be defined, even where we lack detailed biological data.
- This classification recognizes and classifies the two major marine environments (the pelagic realm and the benthic realm), which have fundamentally different communities and are driven by different ecological processes.

- By relying on enduring and recurrent geophysical features, this classification identifies "natural" habitat types even in areas heavily affected by human use. Biodiversity in these highly disturbed areas might be impoverished or, at least, very different from that which occurred previously, but could recover over time if the source of the disturbances was removed.

The strengths of the framework are its abilities to do the following:

- Provide a defensible marine classification for Canada's oceans based on a minimal set of key physiographic and oceanographic factors
- Systematically identify habitat types relating to marine communities and delineate their boundaries in a consistent classification, ensuring that the full range of examples depicting Canada's marine diversity are properly identified
- Provide a hierarchical system that both has a global perspective and considers the differences between benthic and pelagic systems, enabling the identification of various finer levels of seascapes down to the delineation of habitats
- Define a rational and attainable goal for a system of MPAs in Canada
- Provide a mechanism with which to evaluate and assess the contribution to the system of all candidate MPAs, including those identified for reasons other than representation (e.g., unique features, endangered species habitat, fisheries management)

No other approach to marine classification systems provides all of these advantages. The framework proposed here should capture, in a network of systematically selected MPAs, a greater level of biodiversity than other conservation approaches based solely on geography, indicator species, distinctive communities, and so on.

As a systematic and logical framework that all agencies and jurisdictions can use for their own purposes, the framework has a variety of potential applications. It can be used as the following:

- A common basis in the first step to determine representative MPAs or to assess MPA proposals from an ecological perspective
- A framework within which to plan and manage Canada's marine environment
- A framework to monitor and report on the state of Canada's network of MPAs

Similar frameworks for the hierarchical classification of all other aquatic habitats (estuaries, streams, rivers, lakes) could also be developed on the basis of the same fundamental principles and similarly selected geophysical factors. This has not been done here because each type of aquatic habitat would require a different array of factors in its own hierarchical classification.

The following arguments may be put forward against using this classification and the framework to determine a representative system of MPAs:

1. Why not just choose distinctive or special areas for MPAs? Such an approach would mean that MPAs would comprise only those communities about which we have some information. This approach ignores the importance of including representative areas within MPAs, and it also assumes that the important species and areas are the ones we currently know about.

2. There is not enough correlation between the biological communities and the physical factors. In this report, we advocate that the physical approach is essentially the only practicable approach in Canadian oceans where biological data are lacking over broad areas. A biological framework is not easily transportable to or reproducible across regions or coasts, and thus would not provide a consistent national framework for a country such as Canada, with its vast coastline along three different oceans. *However, wherever biological data do exist, this information should be used in conjunction with the framework to optimize any decision making.*

The framework was developed through the collaborative efforts of World Wildlife Fund Canada and various academic and agency personnel.

This report is divided into four parts:

1. Part 1 is primarily about Canada's marine biodiversity and the potential role of MPAs in conservation. Part 1 includes an outline of WWF Canada's Endangered Spaces Campaign.

2. Part 2 compares physical and biological influences on marine ecosystems. It provides the rationale and establishes the parameters for the physical approach to the framework outlined in Part 3.

3. Part 3 outlines the general principles for designing a hierarchical framework and outlines the proposed national framework for marine conservation, as well as the various assumptions, limitations and caveats that also need to be considered.

4. Part 4 describes how the framework may be used to select and assess candidate MPAs.

Appendix 1 is a practical example of applying the classification framework developed in this report to the Scotian Shelf on Canada's east coast.

1

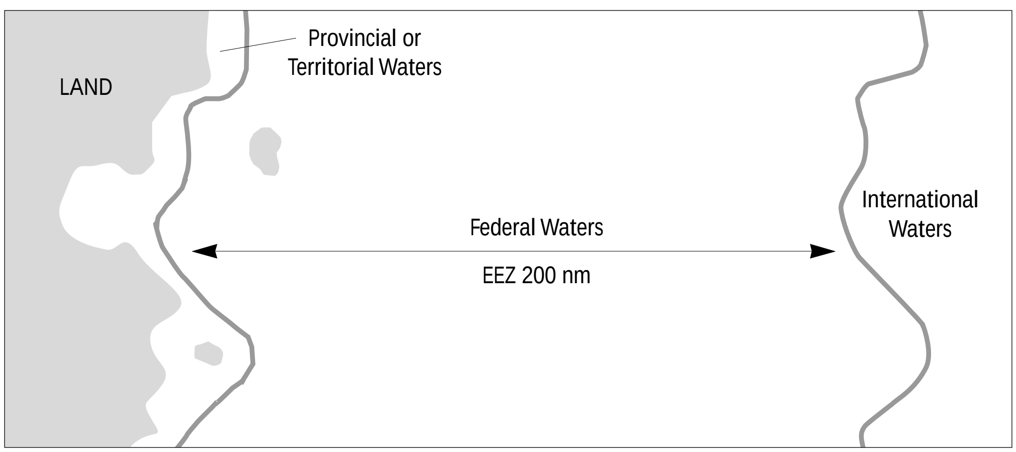
Canada's Marine Biodiversity and the Need for Marine Protected Areas

1a Canada's Marine Biodiversity

Introduction

Canada is a maritime nation bordered by three oceans; 11 of the 13 provinces and territories have coastal components. Canada possesses the longest coastline in the world (almost 244,000 km when the coastlines of most islands are included), the largest archipelago and the second largest continental shelf (3.7 million km^2) of any country in the world (DFO 1997). Canada's marine environment extends from the coastline to the boundary of the 200-nautical-mile (nm) exclusive economic zone (EEZ) and covers an area of approximately 5.08 million square kilometres (an area equivalent to 53% of Canada's land area); this marine area also represents approximately 1.3 per cent of the surface area of the world's oceans. Various jurisdictional zones of Canada's marine environment are shown in Figure 1.

Figure 1. **SCHEMATIC MAP OF CANADA'S MARINE REALM**



Canada has three marine regions:

- **The Arctic.** The Arctic region of Canada contains the longest of the three Canadian coastlines (162,000 km representing two-thirds of the country's total coastline). The arctic and subarctic seas of Canada cover a vast area, from the Beaufort Sea in the west to Baffin Bay in the east, and from north of Ellesmere Island to Hudson Bay in the south. The fragile environment of these arctic and subarctic regions supports vastly different species and a lower species diversity than those of the south. Characterized by its remoteness (it is Canada's least developed frontier), harsh climatic conditions and ice cover, which is present most of the year, the Arctic Ocean is the largest water body in the north.

The pack ice rotates slowly in a clockwise direction, and there are a half-dozen areas of restricted size, called "polynyas," within the archipelago where, due to the anomalies of three-dimensional ocean circulation and winds, the sea is free of ice for most of the year. These highly productive areas are of vital importance to arctic marine life. Extensive open-water areas develop in late summer off the west coast of Banks Island, in the Beaufort Sea (NABST 1994) and within Hudson Bay.

An arctic marine workshop in 1994 produced a good compilation of scientific information available at that time, highlighting areas of special interest (Parks Canada 1994).

- **The Atlantic.** A prominent feature of the Atlantic seaboard is the massive continental shelf of which the eastern section is known as the Grand Banks. The width of the continental shelf varies from 110 to 520 kilometres, and its depth varies from 183 to 366 metres at the outer edges (NABST 1994). Historically, the continental shelf has been a rich source of valuable biological resources such as fish, crustaceans, marine mammals and seaweed. While some areas of the continental shelf have supported fisheries for at least 500 years, today many of these fisheries are severely depleted. Northern cod provides the most striking example, as the spawning stock is estimated to be only 5 per cent of its historical average.

- **The Pacific.** Canada's west coast stretches some 29,000 kilometres, just over 11 per cent of the country's total coastline. The west coast has a narrow continental shelf (less than 50 km wide) and a complex shoreline of rugged mountains, productive estuaries and inlets, deep fjords and some 6500 islands. British Columbia has one of the most productive coastal environments in North America, with ocean activities contributing about 4.5 per cent of the total provincial gross domestic product (GDP) (about twice the value of the mining or forestry sector). The coastal and marine ecosystems are also of primary importance to tourism and recreational users (British Columbia 1996). British Columbia also has some of the richest and most diverse marine flora in the world, but some of these species are rare and in need of protection (Hawkes 1994). Austin (1992) has identified over 7000 marine species of flora and fauna, including some 1570 crustaceans (crabs, barnacles, etc.), 785 molluscs (snails, clams, etc.), 616 annelids (segmented worms), 340 cnidarians (sea anemones, etc.) and 270 sponges; however, he estimates that at least twice this number of species occur in British Columbia waters.

Within each of the above marine/coastal environments, a wide range of habitats and biological communities occurs, encompassing both high-energy and low-energy zones and ranging from exposed rocky shores, sandy beaches, algal reefs, kelp forests, coral reefs, estuaries, bays, sea-grass beds and coastal marshes and mudflats of the temperate waters to the ice-covered environments in the north Arctic. These ecosystems are home to a remarkable diversity of species, from commercial fish to marine mammals to a variety of invertebrate species and plants.

The extent and diversity of Canada's marine environments have resulted in some of the most spectacular marine life in the world: all major groups of marine organisms are represented in Canadian waters, and many species are endemic or unique to them. For example, half the world's population of narwhal, "the unicorn of the sea," summers in Prince Regent Inlet, Nunavut.

Approximately 1100 species of fish are recorded in Canadian waters (Ocean Voice International 1996), and a wide variety of marine mammals occur, including beluga and narwhal, and gray, bowhead, minke, humpback and killer whales, as well as sperm, northern bottlenose, blue and right whales farther offshore. Many other marine mammals such as dolphins, porpoises, seals, walruses, sea lions and sea otters can also be found in Canadian waters.

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) lists over 50 marine-associated species as extinct, endangered, threatened or vulnerable (COSEWIC 1999). Species listed as endangered include the beluga and the bowhead and northern right whales. Threatened species include the harbour porpoise, sea otter, humpback whale and beluga (eastern Hudson Bay population). Some marine mammal populations that were once exploited commercially and some that are traditionally used by Aboriginal people are experiencing difficulty in recovering to viable or manageable levels. Some species were affected in the past by whaling or fur hunting; pollution, collisions with ships, fishing practices and other human activities continue to affect them today. Many endangered and threatened species in need of protection are key to ecosystem functioning and are also valuable from an economic or a social perspective.

What Is Biological Diversity and Why Protect It?

Biodiversity is, put simply, the richness and variety of life in the natural world. The international Convention on Biological Diversity (UNEP 1994) defines biodiversity as "the variability among living organisms from all sources, including ... terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems." The term "biodiversity" therefore encompasses genetic, species and ecological diversity, as well as the variety of responses to environmental change.

The Convention on Biological Diversity refers to endangered species, threatened habitats and ecosystem management in specific sections on the following:

- Conserving biodiversity by establishing protected areas (Article 8)
- Recovering endangered species and degraded ecosystems (Article 8)
- Protecting the traditional knowledge of Aboriginal people (Article 8)
- Integrating principles of sustainable use into decision making (Article 10)
- Applying economic and social incentives for conservation (Article 11)

The reasons for protecting biological diversity are complex, but they fall into three major categories (The Nature Conservancy Great Lakes Program 1994):

1. Loss of diversity generally weakens entire natural systems. Every species plays a role in maintaining healthy ecosystems. When simplified by the loss of diversity, ecosystems become more susceptible to natural and artificial perturbations.

2. Biological diversity represents one of our greatest resources. Our marine areas contain innumerable raw materials that could provide new sources of food, fibre and medicines, and new discoveries continually contribute to scientific and industrial innovations. The pharmaceutical potential of thousands of yet-to-be-discovered marine products to provide lifesaving or commonly used drugs is almost untapped. Nature has repeatedly proved to be a much better chemist than humans—over 60 per cent of all anti-tumour agents and anti-infection agents introduced worldwide over the last 15 years have had a natural product structure in their background (Newman 1998). Only over the last couple of decades has the immense potential of the marine environment as a source of undiscovered chemical structures begun to emerge. For example, recent research indicates that the synthesis of a protein produced by mussels (which in nature helps the shellfish stick to rocks) may be useful for closing wounds that otherwise would require stitches. Given that we know so little about our marine resources, the potential for lifesaving or beneficial pharmaceuticals is enormous and is expanding every year.

3. Humans benefit from natural areas and depend on healthy ecosystems. The natural world supplies our air, water and food, and supports human economic activity. Furthermore, species and natural systems are intrinsically valuable.

Threats to Marine Biodiversity and How MPAs Might Help

Many marine areas have a range of biota rivalling or exceeding that of tropical forests. However, the diversity of life in our oceans is now being altered dramatically by rapidly increasing human activities. Although there are differing views of present and potential threats to coastal and marine biodiversity, those shown in Table 1 are among the most important.

It must be stressed that MPAs alone will not save biological diversity in the oceans. However, MPAs are very effective in conserving habitats and biological communities, especially if such MPAs have been chosen using a science-based representative framework. For example, coral reefs are particularly well suited to protected area status because they are physically defined areas harbouring a characteristic diversity of species (Thorne-Miller and Catena 1991). Other benthic communities may also receive adequate protection from an MPA, but pelagic communities are less amenable to such methods. Similarly, if MPAs are likely to be significantly influenced by impacts originating outside the MPA (e.g., pollution from mainland runoff), then the MPA status may have only partial benefit.

Table 1. **THREATS TO MARINE BIODIVERSITY**

Risk or Speed of Degradation of Biodiversity	Threatening Process	Can the Risk to Biodiversity Be Reduced by an MPA?
High	Physical habitat destruction (e.g., dredging)	Yes
	Blast fishing using explosives	Yes
	Toxic pollution (e.g., chemical spills)	Maybe
	Chemical fishing (e.g., using cyanide)	Yes
	Introduction of exotic organisms	Maybe
	Loss of genetic variability	Yes
	Biological invasions	Maybe
	Overexploitation/overfishing	Yes
	Bioaccumulation of noxious materials (e.g., heavy metals)	Maybe
	Indirect pollution (e.g., pesticides, herbicides in runoff)	Maybe
	Disease/parasite infection	Maybe
	Depletion of spawning sites	Yes
	Sea dumping of dredge spoil	Yes
	Incidental take/by-catch	Yes
	Destruction of adjoining watersheds	Maybe
	Impacts of adjacent land-use practices (e.g., aquaculture)	Maybe
	Effluent discharge (e.g., sewage, pulp/paper mill effluent)	Maybe
	Natural events (e.g., cyclones, tsunamis)	No
	Direct marine pollution, ocean dumping	Yes
	Downstream impacts from dams, dikes, etc.	Maybe
	Net/debris entanglement	Maybe
	Siltation	Maybe
	Noise pollution	Maybe
	Toxic blooms/red tides	Maybe
	Thermal pollution	Yes
	Rising sea temperatures (climatic change)	No
	Rising sea level (climatic change)	No
	Salinity changes	No
Low[a]	Take by Aboriginal people	Maybe

[a] The high–low scale on the left side of this table is approximate; it seeks only to indicate that some threatening processes have a higher risk and/or speed of degradation of marine biodiversity than others. Moreover, the relative order of the various threatening processes on this scale is open to conjecture. However, it is important to note that MPAs are able to address only some of these issues.

The effectiveness of the protection afforded by an MPA to marine animals and plants that occur within it will therefore depend largely on these factors:

- The size of the area protected
- The activities that are restricted and allowed within the MPA boundaries
- The MPA designation and whether it restricts polluting activities that occur outside the MPA but that threaten life within the MPA

In protecting and conserving marine biodiversity, it is important to recognize that biodiversity can be understood, conserved and managed along a range of spatial and temporal scales. Biodiversity occurs at the scale of large marine ecosystems, such as major oceanic ecosystems, and may be defined by broad-scale processes such as oceanography (i.e., currents and upwellings) and trophodynamics, as well as coastal and oceanic physiography and topography. Biodiversity also occurs at other scales, whether considered as communities, habitats or specific sites. At these finer scales, patterns in biodiversity may be dominated by physical processes, such as cyclones, storm events, the tidal range, changes in wave exposure, and the type of substratum, or by biological processes, such as competition and predation.

1b MPAs and a Representative System

Introduction to MPAs

Compared to protected areas for terrestrial conservation and management, MPAs are a recent concept. Some countries had established MPAs prior to the first World Conference on National Parks in 1962, but this conference was probably the first time the need for protection of coastal and marine areas was recognized internationally. However, the need for a systematic and representative approach to establishing protected areas in marine environments was not articulated clearly until the International Conference on Marine Parks and Protected Areas, convened by the World Conservation Union (IUCN) in Tokyo in 1975 (Kenchington 1996).

Today, there are over 1300 MPAs in more than 80 countries. These MPAs range in size from several hundred square metres to 339,750 square kilometres (the largest being the Great Barrier Reef Marine Park in Australia). This wide range of MPAs has been established for a variety of purposes:

- To preserve natural communities and free them from exploitation
- To help preserve important fisheries
- To protect historical and cultural resources
- To establish parks for diving

In Canada, there are approximately 155 protected areas with a marine component, 106 in British Columbia (MLSS nd) and 49 in the northwest Atlantic and Arctic areas (Kelleher et al. 1995). These MPAs may be designated as any of the following:

- National wildlife areas, declared under Canadian wildlife legislation
- Migratory bird sanctuaries, declared under Canadian wildlife legislation
- National parks and reserves, declared under national parks legislation
- National marine parks, declared under national parks legislation
- Provincial parks, declared under provincial legislation

Most of these MPAs have been established to conserve habitat for endangered species or to protect significant features. However, it is not clear to what extent these MPAs contribute to the protection of Canada's marine diversity, as many are extremely small and offer little protection or limited enforcement. It is virtually impossible to determine their contribution to an overall system without an ecological context in which to assess them, that is, a representative framework that also considers the ecological processes that are essential to maintain their long-term viability.

What Is a Representative System of MPAs?

Hundreds of articles and texts have been written about MPAs throughout the world, and many of these works refer to the importance of MPAs in representing marine biodiversity and preserving ecological processes. Few of these works, however, actually define a representative MPA system or provide a framework for determining how a representative system should be identified and how MPAs should be located to achieve ecological representation or to maximize marine biodiversity.

A representative system of MPAs is one that samples the full range of environmental gradients, or habitat types, at a given scale. Declaring MPAs in the right place and of the right size and the right configuration will most efficiently complete a representative system and help protect biodiversity over the long term. The Canadian Environmental Advisory Council (1991) stated:

> Priority must be placed on protecting representative natural areas. They are the cornerstone of a network of protected areas because of their significant contribution to conserving biological diversity and sustaining ecological processes.

There needs to be a systematic, science-based framework within which to choose MPAs and assess progress toward a representative system. The purpose of this report is to develop a framework that provides the basis for mapping Canada's oceans down to the level of habitat types, referred to here as seascapes. The representative system would be complete once all the seascapes have been sampled, or captured within a set of MPAs.

However, MPAs chosen on a representative basis will not automatically include all the unique and special marine features we might want to protect. These features can be identified and MPAs designed to incorporate them. In other words, not all MPAs need to be selected strictly by representation criteria. MPAs that are chosen to protect special marine features can still contribute to completing a representative system provided that they meet ecologically based protection criteria (e.g., size, level of protection, connectivity). An analysis of what these MPAs contribute to the representative system can be completed in hindsight. It must be said, however, that this approach will not achieve a complete representative system in the most efficient manner.

This part of the report describes in more detail the broader concept of MPAs declared for a wide range of reasons and outlines the role of representation within this broader context. A clear distinction between MPAs chosen for representation and those chosen for other values is important for a number of reasons:

1. While ecological representation is an important concept and is a sound basis upon which to plan MPAs, not all government agencies with responsibility for MPAs have representation as a mandate.[1]

2. The majority of existing MPAs in Canada, while providing varying degrees of ecological protection, nonetheless do contribute to marine conservation even if only by increasing public awareness.

3. Given the legislative mandate of those agencies that are able to declare reserves in marine areas, it is important to understand how the determination of a representative framework provides a systematic basis against which the role of existing MPAs may be assessed.

A representative approach to planning MPAs is not a new concept, but it has yet to be widely accepted or implemented. Before explaining how the representative framework can be used to further the network of MPAs in Canada, it is important to first outline the broader concepts of MPAs as historically viewed and implemented by agencies.

The Broad Context of MPAs

One definition of an MPA that is commonly used throughout the world is that of the IUCN (Kelleher and Kenchington 1992):

> [An MPA is] any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment.

Some users have found certain difficulties in applying this definition; for example, Nijkamp and Peet (1994) have these objections:

- The IUCN definition refers primarily to terrain rather than to marine waters, which seems to emphasize the value of the seabed rather than the value of the overlying water or associated flora and fauna.
- The reference to fauna and flora is too restrictive as it might exclude such marine features as ocean vents, upwelling areas, and so on.
- An area that is reserved by law is not necessarily protected by law.

[1] Currently, the federal government has three formal programs for MPAs; these programs have distinct but complementary purposes and are the responsibility of one of the following agencies: Parks Canada (Canadian Heritage), Canadian Wildlife Service (Environment Canada), and Department of Fisheries and Oceans (DFO).

The AIDEnvironment study (Nijkamp and Peet 1994) therefore suggests a modified definition of an MPA:

> [An MPA is] any area of sea or ocean—where appropriate in combination with contiguous intertidal areas—together with associated natural and cultural features in the water column, within, or on top of the seabed, for which measures have been taken for the purpose of protecting part or all of the enclosed environment.

By either definition, a plethora of areas throughout the world could be termed MPAs. Ballantine (1991) cites some 40 names in common use around the globe for areas currently set aside for the protection of parts of the sea. He includes the following:

- Marine park
- Marine reserve
- Marine nature reserve
- Marine habitat reserve
- Marine protected area
- National seashore
- Marine wildlife reserve
- Marine wilderness area
- Maritime park
- Marine sanctuary
- Marine life refuge
- Marine conservation area

The varying definitions and multitude of labels may add to the debate by causing misunderstanding and uncertainty. MPAs also range from small, highly protected "no-take" reserves that sustain species and maintain natural resources to very large, multiple-use areas in which the use and removal of resources is permitted but controlled to ensure that conservation goals are achieved. The intention underlying the use of specific terminology must be clarified.

Definitions

For the purposes of this report, let us assume a very basic and generic definition of an MPA:

> An MPA is any marine area set aside under legislation to protect marine values.

Within this definition, the "marine values" may be virtually anything, including one or more of the following:

- Conservation values
- Commercial values
- Enhancement of special species
- Scientific importance
- Historic features
- Recreational values
- Scenery/aesthetics
- Unique features
- Cultural values
- Traditional uses

Given that many types of MPAs exist and that confusion has resulted from terminology being used in different ways in different documents, the terms used in this report are defined as follows:

- **A multiple-use MPA** is an MPA in which the use and removal of resources may be permitted, but such use is controlled to ensure that long-term conservation goals are not compromised. Multiple-use MPAs generally have a spectrum of zones within them, with some zones allowing greater use and removal of resources than other zones (e.g., no-take zones are commonly designated as one of the zones of a multiple-use MPA).
- **A no-take MPA** is a special type of MPA (or a zone within a multiple-use MPA) where (a) any removal of marine species and modification or extraction of marine resources (by such means as fishing, trawling, dredging, mining, drilling) is prohibited, and (b) other human disturbance is restricted.
- **A biosphere reserve** is a protected area, generally large, that has highly protected core areas surrounded by partially protected buffer areas and an outer transition zone. Both the buffer zone and the outer zone may allow some ecologically sustainable use of resources (e.g., low-impact use and traditional use) and also should have facilities for research and monitoring; such activities within these areas should not compromise the integrity of the core area. The biosphere reserve concept was developed for terrestrial reserves but is considered by some[2] also to have application for marine environments and hence MPAs (Price and Humphrey 1993).

As outlined below, MPAs may be created to preserve a wide range of values, and the goal or purpose of an MPA will influence the type of MPA and consequently its design and selection and, ultimately, its name.

What Are the Potential Benefits of MPAs?

MPAs can provide a wide range of benefits, some of which are noted in Box 1.

Numerous publications have expanded on the wide range of benefits of MPAs; for example, at a workshop at the University of British Columbia in February 1997, the advantages of no-take marine reserves were comprehensively discussed (Pitcher 1997). Box 2 summarizes the benefits that can reasonably be expected with an appropriate system of no-take marine reserves (which should be accompanied by other marine management measures).[3] These benefits can be grouped as follows:

1. Protection of ecosystem structure, function and integrity
2. Increased knowledge and understanding of marine systems
3. Improved nonconsumptive opportunities
4. Potential fishery benefits

[2] Various authors (Batisse 1990; Kenchington and Agardy 1990) suggest that if the UNESCO Biosphere Reserve Program were to be redesigned and properly planned and implemented, it would provide a very useful tool for the wider aspects of marine conservation.

[3] Adapted from a listing produced by the Center for Marine Conservation in 1995 (Sobel 1996).

Box 1. **POTENTIAL BENEFITS OF MPAs**

- Protect many different kinds of habitat in all marine and aquatic regions of Canada.
- Protect critical habitat for rare and endangered species, such as the northern right whale and the beluga.
- Help protect key ecological functions and processes, such as upwellings, which are the "engines" of marine and freshwater systems.
- Serve as source or seed-bank locations for the production of eggs and larvae of commercial and recreational species, which may then move from MPAs to "seed" adjacent marine areas.
- Prevent overfishing by providing refuges to an intensely harvested species.
- Provide alternative and supplementary economic opportunities through such activities as whale watching, scuba diving, boating, sightseeing and ecotourism.
- Serve as natural laboratories for the study of marine systems and as ecological benchmarks against which human impacts and environmental trends can be monitored and measured.
- Serve as storehouses for currently undiscovered marine products that may one day lead to the discovery and production of new food sources or lifesaving drugs.
- Lessen the effects of future management errors, accidents or unfavourable environmental changes, such as changes in sea temperatures.
- Assist in the reestablishment of linkages between species that have been depleted or suppressed by exploitation (e.g., overfishing) and thus help reestablish, at least locally, ecological integrity.
- Fulfill Canada's international obligations as a signatory to the Convention on Biological Diversity.

When the information shown in Box 2 was first developed by Sobel (1996), he qualified the benefits of marine reserves with the following observations:

- The benefits grouped under ecosystem protection were among the most important and best documented by the panel of experts.
- The priority placed on ecosystem protection reflects the view that ecosystem protection is necessary, if not sufficient, to deliver the other listed benefits.
- Some categories overlap.
- Many benefits would accrue even from imperfectly designed marine reserves.
- The broad definition of ecosystem protection parallels the needs of biodiversity conservation as recognized elsewhere.
- Certain benefits to fisheries might be more sensitive to design but need additional testing in countries with a strong research capacity.

Box 2**. EXPECTED BENEFITS OF AN APPROPRIATE SYSTEM OF NO-TAKE MARINE RESERVES**

Protection of Ecosystem Structure, Function and Integrity

- Protect the structure of physical habitat from damage by fishing gear and from other anthropogenic and incidental impacts.
- Maintain high-quality feeding areas for fish and wildlife.
- Protect biodiversity at all levels.
- Restore population size and age structure.
- Restore community composition (species presence and abundance).
- Promote ecosystem management.
- Protect the genetic composition of populations from direct and indirect selection by fisheries.
- Encourage a holistic approach to management.
- Allow the distinction between natural and anthropogenic changes.
- Protect ecological processes, including keystone species, cascading effects, threshold effects, second order effects, food web and trophic structure, and system resilience to stress.

Increased Knowledge and Understanding of Marine Systems

- Provide long-term monitoring sites.
- Provide focus for study.
- Provide continuity of knowledge in undisturbed sites.
- Reduce risks to long-term experiments.
- Provide opportunity to restore or maintain natural behaviour.
- Provide experimental sites that require natural areas.
- Provide natural reference areas for assessing anthropogenic effects (including fisheries).

Improved Nonconsumptive Opportunities

- Enhance and diversify economic opportunities and social activities.
- Provide wilderness opportunities.
- Enhance aesthetic experiences.
- Promote ecotourism.
- Enhance spiritual connection.
- Improve appreciation of conservation.
- Enhance educational opportunities.
- Enhance nonconsumptive recreation.
- Diversify the economy.
- Increase opportunities for sustainable employment.
- Create public awareness about the environment.

Potential Fisheries Benefits

- Increase abundance of overfished stocks within the reserve.
- Export juveniles, eggs or adults to fisheries outside of the reserve.
- Provide resource protection even when data are lacking.
- Provide undisturbed spawning habitats and conditions.
- Simplify enforcement and monitoring.
- Reduce by-catch mortality.
- Provide control areas for research on fisheries management.
- Reduce conflict within and between sectors.
- Restore natural community structure in the reserve (e.g., age structures and predator–prey distributions).

How MPAs Can Benefit Endangered, Threatened or Rare Species

The following sections on various aspects of conservation are adapted from a DFO discussion paper (1997), which outlines the conservation role of MPAs.

CONSERVATION OF KEYSTONE SPECIES

MPAs can assist in maintaining or reestablishing keystone species by protecting them from activities that affect their populations. The disappearance of a keystone species can alter or disrupt the species structure and the functioning of an entire community, as occurred, for example, following the exploitation of sea otters along the Pacific Coast. "As the populations of sea otters declined because of trapping, their prey, the sea urchin, exploded in numbers. Sea urchin food (kelp) disappeared, leaving 'sea urchin barrens,' a dramatically diminished habitat and a drastically changed community" (DFO 1997).

In this case, the damage was done before scientists and managers were aware of the keystone role of the sea otter. Reintroduction of the sea otter by conservation agencies in recent decades has reversed the ecological processes and led to a return of the kelp along with other algal species, crustaceans, squid, fish and other organisms (Wilson 1993). Remote natural refuges offered protection that ensured the survival of the sea otter and provided the opportunity to reintroduce them to their former ranges.

CONSERVATION OF VALUABLE SPECIES

The DFO discussion paper (1997) notes the following:

> Oceans contain innumerable raw materials that could provide new sources of food, fiber and medicines, and that could contribute to scientific and industrial innovations. … We cannot know in advance which species are likely to be important. For example, species such as sea urchins, sea cucumbers, rock crabs and Jonah crabs were once thought to be of no commercial value, but have developed into locally significant fisheries.

As has already been pointed out in this report, the pharmaceutical potential of our oceans is virtually unknown, and only in recent decades has it begun to be explored.

CONSERVATION OF MARINE MAMMALS

Many marine mammals and their critical habitats can benefit from MPAs; consequently, such species and habitats are specifically identified in the Oceans Act as being worthy of special protection through the establishment of MPAs. To limit the impact of detrimental activities, the "design of an MPA must consider the temporal and other special requirements related to calving and feeding grounds, which can change over time. For example, highly migratory species such as whales require national or even international networks of MPAs to protect them throughout their ranges" (DFO 1997).

CONSERVATION OF UNIQUE HABITATS

MPAs designed to protect unique habitats have various benefits. "If a unique habitat has a rare species which is endemic to an area, protection of that habitat is a means of preventing the extinction of a species" (DFO 1997). For example,

> some benthic communities are associated with specialized environments such as hydrothermal vents, isolated seamounts, and oceanic trenches or canyons. These unusual and isolated habitats result in confined ecological communities. The species endemic to these habitats may be at risk because of their limited means of dispersing to recolonize other areas. (DFO 1997)

Much remains to be learned about patterns of marine endemism; growing scientific evidence indicates that many marine species are far less widely distributed than was previously thought (Norse 1993). Many offshore benthic organisms, for example, are relatively restricted in range.

Unique habitats can also be seen as having intrinsic value—that is, they are valuable because they are unique. Again, it is important to stress that a representative framework will not automatically include such unique or distinctive communities; these need to be identified separately to ensure they are protected in MPAs.

CONSERVATION OF BIODIVERSITY AND PRODUCTIVE ECOSYSTEMS

MPAs can provide an important tool for protecting marine biodiversity, as well as for maintaining productive marine ecosystems. Marine biodiversity can be adversely affected in numerous ways, including exploitation and overharvesting (particularly overfishing), physical destruction of habitats, pollution, incidental take and the introduction of exotic organisms.

A number of highly productive ecosystems will benefit from the protection afforded by an MPA:

> For example, many estuaries are highly productive, providing critical habitats for the life stages of a variety of fish and other species. Estuaries are under considerable stress throughout Canada, requiring greater levels of protection from both ocean and land-based activities. Similarly, upwelling and mixing areas typically have high productivity and support the life stages of a variety of fish, mammal, and other species. Upwelling occurs under specific conditions in coastal locations, such as the west coast of Vancouver Island, in the St. Lawrence Estuary (at the mouth of the Saguenay River), and on the Atlantic offshore. Other highly productive and diverse ecosystems include offshore banks, kelp forests, and deep sea features such as sea vents. (DFO 1997)
>
> Through strategic ecosystem-scale management and the judicial placement and management of MPAs, the impacts of human use and activity can be regulated so that they do not exceed the sustainable self-repair capacity of biodiversity and natural systems.

> However, to protect areas of high biodiversity and highly productive ecosystems, an MPA typically needs to be large—encompassing a variety of critical ecosystem components. This presents a unique management challenge, since it is often necessary to coordinate protection objectives with a variety of human activities. Consequently, the wide variety of factors and influences affecting productivity and biodiversity need to be considered in the development of MPAs for this purpose. Often "no take" areas or zones are required in order to ensure that critical ecosystem functions and key species and communities are maintained. (DFO 1997)

CONSERVATION OF INTANGIBLE VALUES

Although intangible values are not quantifiable, many people believe that biodiversity has intrinsic value and consider the loss of any species to be ethically unacceptable.

> Studies show that, in considering habitat restoration, people place a higher value on the existence of a species than on its potential for use (Vain and Bromley 1994). MPAs provide an opportunity to protect species and habitats that are considered valuable from these perspectives. (DFO 1997)

Benefits of MPAs for Scientific Research[4]

The establishment of MPAs provides opportunities to achieve other benefits, including those resulting from marine scientific research. While such research may involve the testing of management approaches, the greatest value of research is in studying relatively untouched marine areas and in comparing them with others that have been subject to human use and activities.

The Oceans Act (sections 35 and 42) enables the establishment of MPAs for marine scientific research. Such research can

> further our understanding of how ecosystems function and how conservation strategies contribute to the recovery of marine species and communities.… Improved scientific knowledge will aid in coastal management and fisheries management. It can also address major gaps in our current understanding, reduce uncertainty, and provide a basis for adaptive management and future planning. (DFO 1997)

Global Recognition of MPAs

MPAs are now recognized internationally as being an essential and fundamental component of marine conservation and are referred to within many international agreements, including the following:

- The United Nations Convention on the Law of the Sea (UNCLOS)
- The Convention on Biological Diversity and the accompanying Jakarta Mandate on Marine and Coastal Biological Diversity

[4] Adapted from DFO 1997.

- The Global Program of Action
- MARPOL 73/78 and the more recent International Maritime Organization (IMO) guidelines
- The World Heritage Convention

Why Have So Few MPAs Been Declared in Canada?

As Sobel (1996) states, "Despite overwhelming scientific evidence, empirical observations and common sense, many people remain unconvinced or unaware that significant marine biodiversity losses have already occurred, are continuing to occur and will continue to occur." There is, therefore, a real and urgent need to do something to remedy the paucity of Canadian MPAs. Many reasons are given by those who oppose MPAs or by those who are cautious about the declaration of MPAs:

- There is no scientific proof that reserves work.
- MPAs may be effective elsewhere, but that doesn't mean they will work here.
- The concept makes sense, but not enough information exists to properly design the perfect system.
- The resources aren't really in trouble; it's just a natural cycle.
- The resources are in trouble, but the problem is due to some other factor such as global warming or outside influences over which we have no control.
- The principle is good, but put them somewhere else (i.e.,"not in my backyard").
- Fishing is already heavily regulated; the regulations just need time to work.
- It is not economically viable to reduce the area available for fishing.

There are encouraging signs that the federal government has recognized the need to declare some MPAs quickly and at the same time is beginning to design a comprehensive plan for a system of MPAs:

> There is a balance to be sought between the need to act on critical areas immediately and the need to be systematic in looking at an overall MPA network. The judgment of government staff and users in discussions has been that we do not need to wait for full network systems plans to identify some of the known high priority areas. Indeed, waiting for such plans can delay overdue action. Typically, certain important areas are designated in advance of a systems plan. The best approach is to begin consideration of priority areas while at the same time proceeding on a systematic basis, conducting overviews of marine regions to identify candidate MPAs. (DFO 1997)

How Many Benefits Can a Representative System of MPAs Provide?

It is clear that MPAs provide a wide range of benefits, all of which are important for marine conservation. The extent to which an MPA offers benefits in addition to its contribution to representation (i.e., which seascapes it has sampled) will depend on the size and location of the MPA and various other factors. A carefully planned, scientific analysis of seascapes is a sound basis for conserving marine biodiversity for the following reasons:

- The systematic identification of marine habitats and the delineation of their boundaries in a consistent classification can ensure that the full range of Canada's marine habitat types are properly identified and can be protected, not just those areas about which we know the most.
- A representative system of MPAs can help ensure that all the essential elements of marine community diversity in Canada are secured by protecting a sample of all the habitats and the ecological processes on which species depend. This is something that no other approach to determining MPAs can ensure.

There are three essential steps in completing a national system of MPAs that will most effectively conserve marine biodiversity:

1. There must be a rational approach to determining ecological representation. The purpose of this report is to provide the framework necessary for this first step.
2. There must be a method to systematically choose a network of candidate MPAs that samples all habitat types identified in step 1.
3. There must be further assessment of candidate MPAs to ensure, wherever possible, that other important, unique or distinctive ecological features are incorporated. Candidate sites must also be further assessed using other non-ecological criteria (e.g., economic, political, social, legal or pragmatic reasons). If, for valid reasons, the candidate MPAs initially chosen are deemed inappropriate, then other candidate MPAs are similarly assessed, leading to finalization of acceptable MPAs and ultimately to a representative network of MPAs.

1c

Canada's Biodiversity Strategy and the Role of MPAs

Introduction

Large areas of the world's coastal and marine environment are under considerable ecological stress due to a number of threats, the most significant being pollution, overfishing and habitat destruction resulting from the physical alteration of the seabed or the coastline (Kelleher 1994). More pollution, including agricultural runoff, sewage, sediments from construction and deforestation, and airborne emissions, enters marine waters from land-based activities than from any other source (World Resources Institute 1994).

Canada's Biodiversity Strategy

Mathews-Amos (1997) describes the status of marine conservation:

> Clearly something needs to be done because current efforts at protecting biological diversity—both marine and terrestrial—are not enough. Marine conservation biology efforts are at least two decades behind terrestrial efforts, but, like a mythical sea monster emerging from the deep ocean, the mysterious marine problems now showing their faces are too alarming for scientists and policy makers to ignore any longer.

Canada's response to the international Convention on Biological Diversity was the development of a national strategy—the Canadian Biodiversity Strategy—which has six goals (Environment Canada 1995). The six goals of the Canadian strategy are as follows:

1. Conserve biodiversity by
   - maintaining populations of native flora and fauna in their functioning ecosystems;
   - establishing and managing protected areas;
   - using biological resources and ecosystems sustainably.
2. Improve understanding of ecosystems and increase capability to manage resources by
   - undertaking appropriate research and using traditional knowledge;
   - undertaking integrated planning and ecological management;
   - improving information and data management systems and monitoring.
3. Promote conservation and sustainable use.
4. Maintain or develop incentives and legislation to achieve conservation.
5. Cooperate with global partners in conservation.
6. Assist Aboriginal communities in implementing the biodiversity strategy.

The Role of MPAs

While MPAs might provide protection for valuable features in specific areas, the traditional approach for MPAs usually meant that the surrounding and connecting seas and upstream land areas remained subject to resource extraction, harvesting and management by other resource agencies or, in some cases, subject to no management at all. Thorne-Miller and Catena (1991) suggest five requirements for the effective protection of marine biological diversity:

- Regulation of land-based and maritime sources of pollution
- Coastal zone management
- Direct regulation of marine resources
- Establishment of MPAs
- Use of economic incentives and disincentives

These five requirements are discussed below.

1. **Regulation of land-based and maritime sources of pollution**. While this requirement does not provide for direct protection of species, it attacks the single greatest threat to marine species and marine ecosystems, particularly pollution that causes long-term damage. By far the greatest source of pollution of the sea is land-based human activity; mainland environmental problems are usually reflected in marine problems (e.g., soil erosion results in suspended particles, often with nutrients attached as ions, being conveyed to the sea).

   As well, spills of hazardous materials such as oil are a continuing threat. No country in the world has the capacity to combat a major oil spill adequately. While avoiding spills is far more important than preparing for their cleanup, such spills are inevitable, so adequate preparation for dealing with them is crucial.

2. **Coastal zone management.** This requirement recognizes the interrelated functions of the coastal zone and the need to avoid segregated "sector" management, which regulates particular activities without taking into account other activities affecting the same resources. Since it is not always possible to set aside totally protected areas, integrated coastal management is becoming increasingly accepted as the most effective means of dealing with such complex issues and areas.

3. **Direct regulation of marine resources.** The regulation of fisheries and other harvesting activities in the oceans is becoming increasingly critical as overfishing by commercial and recreational interests becomes more prevalent. Virtually every international marine fishery is considered by most experts to be inadequately managed for ecological sustainability (Kelleher 1994). Regulations need to cover more than just catch limits on target species; regulations regarding nontarget species (or by-catch)—including fish species, marine mammals and turtles—are necessary. In addition, a range of other fishery management techniques (e.g., species quotas; gear restrictions; and regulation of times, areas and numbers of licences) should be applied.

4. **Establishment of MPAs**. MPAs will make a key contribution to the long-term viability and maintenance of marine ecosystems if the network of MPAs has a representative basis and if the MPAs are adequate in size and connectivity. However, as outlined above, MPAs should be regarded as only part of integrated marine or coastal management. MPAs should exist within the context of large sustainable-use management areas, rather than as isolated, highly protected enclaves within heavily used areas.

5. **Use of economic incentives and disincentives.** Frequently, both regulatory and management approaches fail to maintain the necessary level of biological diversity. Until recently, governments have used economic incentives to encourage the exploitation of natural resources, often well beyond their natural capacity to replenish themselves. Those economic policies can be altered so that the sustainable use of resources becomes the guiding principle for economic incentives. McNeely (1988) and Thorne-Miller and Catena (1991) both suggest such methods at the community, national and international levels.

The Oceans Management Strategy (OMS), Part II of Canada's Oceans Act, identifies three complementary initiatives that will be part of a national strategy for managing Canada's oceans. These legislated initiatives include MPAs; integrated management of activities in estuaries, coastal waters and marine waters; and marine environmental quality. The OMS will provide the basis for incorporating MPAs into a broader national planning framework for the coastal zone. At the same time, stakeholders will participate in developing the overall vision of MPAs for Canada.

The Oceans Act also states that the national strategy will be based on the principles of sustainable development, integrated management and precautionary approaches. Consequently, the application of these principles will be an integral part of developing and implementing the MPA program.

In recent years there has been increased focus on defining goals and principles for the management of natural systems (e.g., Agee and Johnson 1998; Kessler et al. 1992; Norton 1992; Grumbine 1994). Edyvane (1996) identifies several dominant themes that must be understood before natural systems can be managed:

- The hierarchical nature or structure of ecosystems (i.e., the need to adopt a systems perspective)
- The definition of ecological boundaries (which inevitably do not correspond to artificially determined administrative or political boundaries)
- The maintenance of ecological integrity (protecting biodiversity, patterns and processes; maintaining viable populations and natural disturbance regimes; and facilitating species reintroductions)
- The importance of data collection, monitoring and adaptive management
- The need for interdisciplinary research (e.g., bioeconomic analysis)
- The importance of scenario modelling and decision support systems

- The role of spatial modelling and geographic information systems
- The need for interagency cooperation and organizational change
- The need to investigate human effects on ecosystem structure and function
- The importance of human social values

MPAs are an integral and critical component of the management of coastal and marine resources. To achieve a viable system of MPAs, however, the effects of surrounding marine and terrestrial areas must be recognized and managed. Therefore, the quality, quantity and accessibility of ecological data and human-use information available to decision makers must be improved.

1d

WWF Canada's Endangered Spaces Campaign

The goal of WWF Canada's Endangered Spaces Campaign has been the completion of a national network of protected areas that will adequately represent all of Canada's terrestrial natural regions by the year 2000, and marine natural regions (including the Great Lakes) by the year 2010. The importance of completing such a representative network of protected areas has won international acceptance in conservation planning fora. Furthermore, the Convention on Biological Diversity commits Canada to establishing a system of protected areas.

Underlying the WWF Canada goal is the belief that conservation of biodiversity will not be achievable without a well-planned, science-based system of properly protected areas.

As in the methodology for identifying terrestrial protected areas published by WWF Canada in 1995, the methodology for identifying representative areas in marine systems should be based on ecological principles and should identify a distinct goal. It is important to remember that the focus of the WWF Canada campaign is on ecological representation rather than on protecting some arbitrary percentage of the country's marine areas.

WWF Canada's objectives for this report are to do the following:

- Develop a nationally consistent framework for the planning and establishment of a nationwide system of ecologically representative MPAs to ensure that they address marine representation within Canada's three oceans.
- Increase awareness among relevant governments, agencies, interest groups and the Canadian public regarding the objectives of and needs for developing a representative network of MPAs.

WWF Canada has the view that, in terms of the level of environmental protection they afford, many MPAs currently existing in Canada are inadequate due to the types of activities that may be allowed within them (that is, the existing legislation does not prohibit certain activities considered incompatible with the goals of an MPA). For this reason, WWF Canada has determined the minimum protection standard it considers necessary for an area to be deemed an effective MPA. This standard is described in Box 3.

Box 3. **WWF CANADA'S MINIMUM PROTECTION STANDARD FOR MPAs**

WWF Canada recognizes MPAs in which large-scale habitat disturbance by industrial activities or commercial resource extraction (i.e., dredging, mining, oil or gas development, drilling, bottom trawling, dumping, dragging, finfish aquaculture or any other activity that severely affects the benthos or jeopardizes the ecological integrity of the MPA) is not permitted but within which certain fishing practices are allowed.

This standard does not prohibit fishing practices that do not cause habitat disturbance or do not result in the widespread extraction of marine resources. Other fishing activities should be considered on a case-by-case basis, depending on the ecological sensitivity of the area and the specific conservation objectives of the MPA.

This standard is suggested by WWF Canada to be the minimum for any MPA that is declared in Canada. An MPA must meet this standard to be considered by WWF Canada as contributing to its ecological representation targets.

Of the approximately 155 MPAs established in Canada, the majority[5] do not meet the WWF Canada minimum protection standard and therefore are vulnerable to industrial activities.

WWF Canada monitors progress toward the goal of a representative MPA system by reviewing the selection of candidate areas on the basis of ecological representation. All future MPAs declared in Canada will be assessed against the minimum protection standard, as well as the representation framework developed in this report.

[5] Only three existing Canadian MPAs (i.e., Fathom Five National Marine Park, Pacific Rim National Park Reserve and Saguenay–St. Lawrence Marine Park) meet the WWF Canada standard. All other Canadian MPAs either allow resource extraction or have no policy on the issues of habitat disturbance or widespread resource extraction; of the 106 MPAs in British Columbia, MLSS (nd) maintains that 90 per cent provide little or no ecosystem protection.

2

Marine Science and Ecosystems

2a

Comparison Between Marine and Terrestrial Ecosystems

Introduction

> Of all the species known to science, about 80 per cent are terrestrial, but there are more orders and phyla in the sea. In fact, all phyla of animals are found in the sea, a majority of these in benthic environments, and one third of the phyla are exclusively marine. If plants and protista [bacteria, fungi, algae and protozoa] are also considered, at least 80 per cent of all phyla include marine species. In addition, the relative abundance of marine species may be greater, since most marine species are unknown. (Thorne-Miller and Catena 1991)

For marine conservation to be successful, the similarities and differences between marine and terrestrial ecosystems need to be understood. Any attempt to protect marine biodiversity simply by applying terrestrial conservation methods will encounter difficulties. Marine ecosystems are more connected than terrestrial ecosystems, and therefore physical influences tend to propagate over a broader area and over longer periods of time. Unlike in terrestrial ecosystems, the fundamental attributes, biological characteristics and even the species of marine ecosystems are not directly observable.

Similarities Between Terrestrial and Marine Ecosystems

At a very broad conceptual level, marine and terrestrial ecosystems have many similarities:

- Both are composed of *interacting physical and biological components*, with energy from the sun driving most systems.
- Both are complex *patchworks of differing environments* that are occupied by different communities and species.
- Both marine and terrestrial species show a *gradient in diversity with latitude*—that is, species diversity generally increases with decreasing latitude (Thorne-Miller and Catena 1991).
- In both ecosystems, the primary zones of biological activity tend to be concentrated nearer the surface (i.e., the land–air and the sea–air interface).

Differences Between Terrestrial and Marine Ecosystems

Many differences exist between marine and terrestrial ecosystems. These differences can be found in such variables as space and time scales of physical processes; mobile versus sessile life styles; and size, growth rate and factors relating to trophic position (Steele et al. 1993; Steele 1995). Differences are also related to the fundamental physical properties of water itself (e.g., Sverdrup et al. 1942).

PHYSICAL AND BIOLOGICAL DIFFERENCES

Size: The combined seas are far larger in area than the combined land masses. The Pacific Ocean alone could easily contain all the continents. Even more important is the difference in volume between marine and terrestrial habitats. Life on land extends roughly from the tops of trees to a few metres below ground—a vertical extent of about 30 to 40 metres. Although birds, bats, arthropods and bacteria may periodically rise above these heights, the area above the treetops is more properly seen as one suited to temporary dispersal, rather than as an essential habitat, since species must return to the ground or trees for resources, reproduction and shelter. The average depth of the oceans is 3800 metres, all of it containing living creatures. The sea's habitable volume is therefore hundreds of times greater than that of the land.

Viscosity and density: Terrestrial and marine ecosystems differ markedly in their physical properties. For example, the water overlying the seabed is 60 times more viscous than air and has greater surface tension than the air overlying the land. Water is also about 850 times denser than air; this property provides buoyancy, allowing organisms, many of them very different from organisms existing on land, to survive without the need for powerful supporting structures. Seawater's buoyancy and viscosity keep food particles suspended and result in an environment—the pelagic realm—without analogue in the terrestrial environment. Specialized subcomponents of this realm, just beneath or at the sea–air interface, are the plueston and neuston.

Temperature: The strong seasonal and long-term temperature fluctuations in the terrestrial climate contrast with the moderate temperature fluctuations in the marine environment. Seawater has a much greater heat capacity than air, therefore temperatures change more slowly in the sea than they do on land. The higher viscosity of seawater makes it circulate more slowly than air.

Benthic and pelagic realms: The oceans contain two distinct realms, each with its own communities: the pelagic realm (the water column from the surface to the bottom) and the benthic realm (the seabed and the layer of water immediately above it). Even within the pelagic realm, conditions vary dramatically with depth, which affects community structure. For example, due to changes in pressure and available light and nutrients, the communities inhabiting the top 20 metres of the ocean are very different from communities 1000 metres below the surface. The benthic realm can be compared to terrestrial ecosystems, where species either live on the ground (or seabed) or are dependent on it for habitat and resources.

However, a significant difference between the benthic realm and terrestrial ecosystems is that most of the benthic realm is below the photic zone, that is, below the depth where enough light penetrates for photosynthesis to occur. Therefore, unlike in most terrestrial ecosystems, most of the benthic community does not have primary producers but must rely on resources that settle from the upper pelagic zone. The pelagic realm has no counterpart in terrestrial ecosystems as there are no terrestrial species (let alone whole communities) that are completely independent of the ground or ground-based resources.

Mobility and fluidity: The fluid nature of the marine environment means that many marine species are widely dispersed, and individuals can be far ranging. In addition to enhancing cross-fertilization and dispersal, water motion also enhances the migration and aggregation of marine species (especially those in pelagic systems). Water also dissolves and circulates nutrients (Denman and Powell 1984; Mackas et al. 1985; Thorne-Miller and Catena 1991). Even marine species that can be considered static as mature forms (e.g., many molluscs and seaweeds) usually have highly mobile larval or dispersive reproductive phases, and their populations may be controlled by mobile predators. This means that it may be extremely difficult for such species to be managed as spatially defined populations. Similarly, the sediments of the substrate are themselves often so mobile that land erosion cycles seem slow and mild in comparison (Ballantine 1991).

Circulation: Although both terrestrial and aquatic environments exhibit patterns of circulation, that is, circulation of the water in the oceans and of the atmosphere above land and water, the two are not strictly comparable. In the oceans, the medium—water—contains the organisms themselves; aquatic organisms live in the medium, flow with it and are dominated by it. In contrast, the presence of organisms in the atmosphere is strictly temporary. Thus, in the ocean, recruitment failure in one region may be reversed by passive recruitment from another area. On land, a similar process generally requires active migration (National Research Council 1994). Even for benthic communities, movements of the overlying waters are essential for the transport of food resources; the atmosphere does not fulfill a similar function for terrestrial communities.

Light: Compared to the terrestrial realm, a far greater portion of the marine realm does not receive light. Light is necessary for primary production through photosynthesis, except at hydrothermal vents, which are dependent on their own chemosynthetic producers. Therefore, essentially no organic matter is produced in the vast, unlit depths of the ocean (the dysphotic and aphotic zones), and species in these dark areas must depend on the flux of organic matter from the productive surface layer.

Primary production: The most obvious biological difference between terrestrial and marine ecosystems may be in the types and source of primary production (Steele 1991b). In terrestrial ecosystems, primary producers (mainly vascular plants such as trees and grass) constitute the great majority of biomass, and individuals are often large. In contrast, the dominant primary producers in marine ecosystems—the phytoplankton—are generally microscopic and can reproduce rapidly. Consequently, they have much higher turnover rates compared to the forests or prairies of terrestrial ecosystems.

In terrestrial ecosystems, the biomass of primary producers tends to be highly conserved (e.g., in woody plants). In contrast, in marine ecosystems the biomass of primary producers is rapidly processed, either by consumers or reducers. Therefore, marine sediments are typically much lower in organic carbon than terrestrial soils and become progressively lower still with increasing depth. Even marine macrophytic plants (e.g., algae and sea-grass angiosperms), though often perennial, have short generation times compared to terrestrial plants. No marine plants have the longevity of terrestrial gymnosperms and angiosperms. At lower latitudes, the partially seawater-adapted mangroves (emergents) are recent reinvaders of marine waters.

Ecological response to environmental change: Other important differences between terrestrial and marine ecosystems result from—or are associated with—the temporal and spatial scales of ecological response to changes in the physical environment (Steele 1974, 1985, 1991a, 1991b; Parsons 1991; Longhurst 1981; Cole et al. 1989) and are related to the fundamental differences in the communities of primary producers and to the properties of water. The high storage of biomass in terrestrial organisms and organic detritus tends to decouple biological and physical processes to some degree. In the oceans, however, the space and time scales of physical and biological processes are nearly coincident; biological communities can respond rapidly to physical processes. Spatial variation and distribution of primary producers on land are largely related to topography and soil; such processes occur more slowly on land than in marine ecosystems. On land, largely as a function of the longer generation times of larger organisms, population and community cycles may depend more on biological than on immediate physical processes (Steele et al. 1993). However, at all spatial scales, physical changes in the atmosphere are faster than in the ocean. Cyclonic systems in the atmosphere have typical diameters of about 1000 kilometres and last for about a week. Equivalent eddies in the ocean have diameters of about 100 kilometres and can last for months or years (Steele 1995). Thus we have the apparent paradox of “slowly responding” terrestrial communities buffeted by a faster moving atmosphere, while in the oceans we have “quickly responding” communities within a slowly reacting and insulating ocean!

Bedrock type: Unlike in terrestrial ecosystems, bedrock type and geological composition apparently have little influence on the biota of the marine benthos. This is at least partially a function of the global constancy of the composition of seawater. Within the intertidal and subtidal euphotic zone, macrophytic algae are attached to rocks of all types. Within these same zones where soft substrates exist, it is tidal velocity and wave motion that determine substrate grain size and together they become the main determinants of community composition.

Ecological boundaries: Terrestrial environments have more pronounced physical boundaries between ecosystems. Especially at finer scales, it may be difficult to identify distinct boundaries between marine ecosystems because they are so dynamic and because pelagic and benthic realms require separate consideration. This does not mean there are no distinct marine ecosystems, but generally the boundaries are more transitional. Nevertheless, it is still appropriate to examine the broad marine ecological characteristics and to define representative habitat types in terms of their related enduring geophysical factors or recurrent processes.

Longitudinal diversity gradients: In addition to the latitudinal gradients observed in both terrestrial and marine environments, a longitudinal diversity gradient exists in the marine environment, decreasing from west to east in both the Atlantic and Pacific Oceans. As well, fauna in the Pacific Ocean (e.g., coral reefs) are more diverse on the whole than in the Atlantic Ocean (Thorne-Miller and Catena 1991). The greater diversity in the western part of these oceans can be related to the eccentric circulation pattern within them, whereby the western part receives water from low latitudes (with higher species diversity) at high velocity (e.g., the Gulf Stream in the Atlantic Ocean and the Kuroshio, or Japanese Current, in the Pacific Ocean), while the eastern part receives water at lower velocity from higher latitudes (with lower species diversity). The greater overall species diversity of the Pacific Ocean is generally explained in terms of its greater geological age.

Faunal diversity at higher taxonomic levels: At higher taxonomic levels, the diversity of marine fauna is much greater than the diversity of terrestrial fauna (Ray and McCormick-Ray 1992); all phyla of animals are represented in the oceans. Some taxa, for example, the fishes, are extraordinarily diverse; others are less diverse, although in "lower" phyla undoubtedly many species remain to be described.

Life span and body size: In the open ocean, there is a regular increase in life span and in body size with increasing trophic level (Sheldon et al. 1972), whereas in terrestrial systems these patterns are not so clear (Steele 1991b).

Human Perspectives and Considerations

Observability of marine ecosystems: A very basic difference between marine and terrestrial ecosystems is that most of the marine environment is hidden from human sight, resulting in major differences in our knowledge and understanding of these ecosystems. Our "out of sight, out of mind" mentality and the vastness of our oceans have both contributed to the misguided belief that the oceans can harmlessly absorb whatever we drop into them. Similarly, because the sea is remote and is an alien environment, demonstrating the need for marine protection has been difficult. The collapse of commercial fisheries in many areas of the world has begun to raise awareness of the need for marine conservation.

Difficulties of marine research: Research and monitoring are far more difficult in and under the water than they are on land. The exponential increase in the cost of obtaining data from increasing water depths explains why so little is known about the sea, especially the deep oceans. The difficulty and expense of maintaining even moderately stable working conditions at sea are so great that most marine research and management is virtually "hit and run," after which the researchers and managers come home to land. Furthermore, far fewer people are employed to investigate or manage marine ecosystems, yet the marine areas to be investigated and administered are far greater than terrestrial areas.

Known extinction rates: While current estimates of species loss in terrestrial ecosystems are frightening, because of the lack of study little is known about, or even predicted for, species extinctions in marine ecosystems. Canada is not without examples, though, which include the extinction of the great auk, Labrador duck and eelgrass limpet and, more recently, the near disappearance of the barndoor skate. Recent evidence shows that many marine species worldwide are in dire straits, especially those with commercial value (e.g., whales, sea turtles, dugongs and many fish species).

Ownership: Until very recently, it was commonly accepted that no one owned a piece of the sea or any of its resources (this is now changing following successful sea claims by Aboriginal people). Certainly in the more developed countries, it has long been felt, and generally still is, that marine resources were there for the taking or using by anyone who had the skill and initiative to do so (Ballantine 1991). Today, governments are taking on specific responsibilities for some marine areas, but unfortunately most marine environments remain subject to the "tragedy of the commons." Responsibility for international waters is hampered by the mobility of water masses and connectedness of oceanic and territorial seas.

Resource extraction: During terrestrial resource extraction, the physical landscape is often altered dramatically and visibly. It has recently been realized that the harvesting of marine resources can also dramatically alter the sea floor on a large scale. Much of the floor of the North Sea, for example, resembles a plowed field due to trawling activities. Marine conservation requires regulation of all types of resource extraction, including those that directly disrupt the physical seascape (e.g., oil drilling and mining), and activities, such as commercial harvesting (e.g., bottom dredging, bottom trawling and dragging) and aquaculture that perturb the sea floor at smaller scales but over broad areas.

Delineating park boundaries: On land, it is easy to mark park boundaries using signs or natural features. At sea, the absence of obvious geographical features makes it difficult for marine users to determine if they are inside a protected area and when to curtail their harvesting activities. However, it is hoped that the increasingly common use of global positioning systems (GPS) makes this a diminishing concern.

Biogeochemical Linkages

The sea is biogeochemically "downstream" from the land; thus virtually any substance released into the ecosphere is carried seaward. This has obvious implications for marine pollution as many inputs into marine systems have terrestrial origins.

The natural hydrological cycle flows from the land to the sea. Water is returned via the atmosphere to precipitate on land. Erosion of the earth's crust is therefore a one-way process from land to receiving waters. The assumption generally made is that, over geological time, inputs to lakes and oceans are balanced by "output" in the form of sedimentation. The ocean sediments, in turn, move laterally with the spreading sea floor and eventually are subducted at tectonic plate margins to form new crustal rocks.

Because of these natural cycles and processes, it is often assumed that lakes and oceans are, in fact, dependent on such inputs from land, especially the input of plant nutrients to drive biological production. This is only partially true for lakes and is not true for the oceans as a whole. Inputs to lakes and oceans come from drainage basin runoff, the atmosphere, internal recycling and animal migrations.

Discussion

It is obvious that marine ecosystems are significantly different from terrestrial ones, and serious problems can arise if it is assumed that knowledge gained from terrestrial ecosystems can be applied directly to marine contexts (as Rice [1985] warned, "marine ecosystems are not simply wet salty terrestrial ones"!). The principles used in designing marine reserves will often be very different from principles that have been derived from experience on land.

Management of marine areas or marine species is exceedingly complex and will likely require a knowledge of both terrestrial and marine environments. For example, some marine species also spend time in terrestrial environments; furthermore, many species spend large parts of their life cycle outside protected areas. Consider, for example, the green turtle. Within the Great Barrier Reef region of Australia, green turtles lay their eggs on the mainland or islands (i.e., outside the marine ecosystem). Once the young emerge from the eggs (and if the young survive), they move into nearshore marine areas where they feed on seaweed and sea grasses. They then migrate thousands of kilometres in the open sea to other countries where they are frequently hunted and caught; those females that survive return every two to eight years to nest on the same stretch of beach in Australia where they were born. This behaviour means that, for effective conservation of this species alone, state jurisdictions (both terrestrial and marine) and federal jurisdictions, as well as a number of international jurisdictions (both those governing the open sea and those within other countries) must be considered. Furthermore, the world's largest MPA is still not large enough to encompass the full life cycle of the green turtle.

While there are many similarities between terrestrial and marine systems, the concluding remarks by Rice (1985) are appropriate advice for those proposing to make decisions about marine areas:

> When I began to work with marine ecosystems, my serious problems arose not through lack of understanding of the ecosystem (although I often did—and may still—lack that understanding). The most serious problems arose when I assumed some knowledge I had gained in other contexts would transfer readily to marine contexts. It is NOT the case so often that one is better off assuming it is never the case, and occasionally being pleasantly surprised.

The next section examines the ecological factors, many of which are unique to the marine environment, that influence the distribution of marine species and community structure.

2b

Defining Enduring and Recurrent Features in the Marine Environment

Introduction

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 most appropriate spaces for protection. In terrestrial ecosystems, the term “enduring features” has a specific meaning—the enduring elements of the landscape; in terms of human life spans, these elements 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). These stable abiotic features primarily define landforms that have been demonstrated to play a significant role in the distribution and diversity of flora and fauna at small to medium scales. Furthermore, landforms can be readily mapped, and, in Canada, considerable information at various scales is available to accomplish such mapping.

Using the terrestrial representation paradigm (Hills 1961) as a starting point, Geomatics (1996) deduced the equivalent key abiotic attributes of the marine environment, including both *oceanographic* and *physiographic* factors, that control biotic responses and hence marine biological communities. These attributes are those abiotic components of the ecosystem that are observable and measurable, that are presumed to control the distribution and diversity of marine species and communities (though sometimes in a dynamic fashion) and that collectively define physical habitat types, and could serve as surrogates for the various types of biological communities. These attributes are used to identify major ecological units, referred to as seascapes.

Such seascapes were considered to be the most useful way to define the basic ecological unit for two reasons:

1. Seascapes are basically stable, recurrent or predictable in time and space and generally are not subject to human or natural disturbances.
2. Seascape parameters have been mapped at a variety of scales for most of Canada, whereas biological mapping is incomplete and inconsistent in its format.

We realize that biological communities must ultimately be recognized on the basis of their species composition. However, because physical characteristics alone are considered to be sufficiently reliable indicators of the major types of biological communities, physical characteristics can be used to separate representative areas at the higher levels of the hierarchy of classification.

An examination of the marine ecological literature shows that many factors have been invoked to explain the nature and distributions of marine biota. These factors can be broadly grouped into three categories:

- Biological factors
- Oceanographic factors
- Physiographic factors

Undoubtedly, some combination of biological and physical parameters will normally be required to explain where a particular species, or community, is found. It is often assumed that the fundamental niche of any species (i.e., the theoretical multidimensional space that it could occupy) can be described largely in terms of the physical environmental and resource requirements of that species. It is usually further assumed that the actual or realized niche of that species is constrained within this fundamental niche, predominantly due to restrictions imposed by biological interactions (e.g., competitors, predators). Recognizing the fundamental niche will be crucial when considering areas heavily altered by human activities (e.g., most of the continental shelf). Simply mapping where species are today would not reflect their historical distributions. For example, bottom trawling has been an ongoing activity on the Scotian Shelf for nearly 100 years and has significantly altered the benthic community structure and composition by not allowing the development of later seral stages. Current species distributions and densities are likely to be very different from those that would be there if the environment were allowed to recover from these human-related disturbances.

A parallel argument can be made for the real distribution of a species in terms of the *habitat* that it actually occupies, which is likely to be determined by some combination of physical and biological constraints. Nevertheless, the correlation between the distribution of species (or communities) and physical factors is sufficient to permit description of their distributions from a knowledge of the physical factors alone.

Several biological, physiographic and oceanographic characteristics that could be considered to either determine or be correlated with the distribution of marine biota are presented in Table 2. The various roles of these characteristics in shaping marine communities and their suitability for classifying marine enduring features or recurrent processes are discussed in the remainder of Part 2.

Table 2. **FACTORS DETERMINING, CORRELATED WITH OR CONTROLLING THE NATURE AND DISTRIBUTION OF MARINE BIOTA**

Biological Factors	Oceanographic Factors	Physiographic Factors
Predation	Water masses and salinity	Geological activities
Resources (nutrients and food)	Temperature	Geographical position and latitude
Competition	Temperature gradients, temperature anomalies and upwellings	Geological history of the ocean basin
Life-history patterns	Ice cover and ice scour	Water depth
Mutualisms	Segregation of benthic and pelagic realms	Relief (slope)
Recruitment mechanisms	Water motions	Substrate (sediment) particle size
Migrant species	Convergences and divergences	Basin morphometry (topography)
Larval dispersal	Stratification, mixing and nutrients	Geology (rock type)
Buoyancy and sinking	Light penetration and turbidity	
Desiccation resistance	Depth and pressure	
Osmotic tolerance	Tidal amplitude and currents	
Spatial use	Exposure to atmosphere and waves	
Patchiness	Tsunamis, storm surges, hurricanes and water spouts	
Seasonal cycles		
Biological succession		
Human activities		
Productivity		

Note: Some factors may be relevant to more than one category.

Biological Factors

Although biological factors are obviously important in determining local species compositions, generally these factors are not a reliable or informative basis for an overall synthesis of the factors that shape marine biological community types or their distributions. In short, we have a poor understanding of the way these factors operate at larger ecological scales. Three essential questions need to be answered:

- How do these factors operate to shape marine communities?
- How can we predict the effects of these factors?
- How can we measure and map these factors in space and time?

The distribution of a species may often be limited by some combination of *predation* and availability of *resources*, or by *competition* with other species. Rarely do we know the actual situation, and it is to be expected that biological factors limiting the distribution of a species will fluctuate in space and time. There is still considerable debate, for example, as to whether competition or predation is the major biological factor in determining community composition. We have no overall theory that we could apply to marine communities as to how these two major factors may interact or how each might become dominant or secondary in space and time. Therefore, we cannot hope to find in these factors any general relationships on which to base a conservation strategy.

Similar arguments apply to *life-history patterns.* Although the strategies underlying several life-history types are becoming understood (e.g., Roff 1992), such theory will not yet form a foundation for defining seascapes. To some degree, life-history patterns should be correlated with the various types of seascapes, although this correlation largely remains to be investigated and documented. Life-history patterns, *mutualisms, recruitment mechanisms*, use of the environment by *migrant species*, and *larval dispersal* will all need to be assessed as part of the process of selecting MPAs; these factors, however, cannot contribute meaningfully to the definition of seascapes. By migrant species we mean those vertebrates (birds, mammals and fish) and invertebrates that either use marine resources in more than one geographical area or use other environments (i.e., freshwater or terrestrial environments) for part of their life cycle. The congregation of migrants at certain seasons of the year may indicate a local surge of biological productivity that is related to temperature anomalies or other physical parameters. Such considerations are important criteria for the selection of MPAs.

Biological factors such as *buoyancy and sinking, desiccation resistance* and *osmotic tolerance* are properly considered both to be a function of the physical environment and to be physiological properties of the organisms themselves. Therefore, we can capture the habitat types for organisms possessing these different physiological abilities by mapping mixing versus stratification of the water column, extent and type of the intertidal zone, and so on.

The next five biological factors listed in Table 2 also involve complex interactions between organisms and the geophysical environment. It should be noted that the list in Table 2 is by no means complete—ongoing research is exploring the multitude of ways in which organisms make *spatial use* of or are spatially constrained by their environments. We recognize the major distinction between how pelagic and benthic organisms make spatial use of their environments (see the discussion of physiographic factors below).

Patchiness (e.g., overdispersion, heterogeneity in population distributions) is a well-known and extensively documented phenomenon, in both pelagic and benthic realms, that results from the complex interplay of biological and physical factors. Patchiness is a pervasive feature of the distribution of life on the planet and is fundamental to the trophodynamic functioning of aquatic ecosystems. Nevertheless, because patchiness is prevalent at all spatial scales, we cannot use it as a factor in our classification system.

The phenomena of *seasonal cycles* and *biological succession* (e.g., seasonal, interannual and interdecadal succession) in marine communities are still poorly understood. The factors involved often can be separately identified, but the subtleties of their interactions have usually defied analysis, even at a relatively crude taxonomic level; for example, the often inverse seasonal relationships between phytoplankton growth and macrophytic algal growth have been analyzed only in a general way (Mann 1976).

Human activities can extensively alter the local species composition of marine communities. However, the purpose of the classification system presented in this report is to recognize and distinguish between the fundamental marine community types, irrespective of human actions. A biological classification system based on current species assemblages will not identify the potential of areas intensely affected by human impacts to regain their native assemblages if those impacts were removed. The identification of pristine habitats, especially where the species themselves provide habitat structure (e.g., kelp forests, deep-water corals or eelgrass beds), might be very helpful in the selection of individual MPAs.

Productivity could be used as an index of seascapes. We can judge animal productivity only crudely in spatial terms, and only for a very few species, essentially as yields of commercially important species of fish, invertebrates and marine mammals. For phytoplankton and intertidal macrophytic algae, we can assess, by remote or airborne sensing, the instantaneous biomass (an index of production) over broad geographical areas. However, the productivity of both primary producers and fish can be qualitatively linked to the mixing regime of the water column (Pingree 1978), which has already been indexed by mappable oceanographic and physiographic factors, specifically to depth and the stratification and mixing regime.

Interestingly, in marine environments biological diversity tends to vary inversely (though weakly) with productivity. Thus *areas of high productivity tend to be areas of lower species diversity* and vice versa.

FAILINGS COMMON TO ALL SPECIES-LEVEL APPROACHES TO MARINE CONSERVATION

All species-level approaches to marine conservation suffer from the same kinds of deficiencies:

- Any individual species may become extinct locally, thereby depriving us of our classification criterion.
- Any classification based on a species-level approach requires that the distributions of those species be known in some detail over broad geographic areas.
- Different species will be “indicators” or “umbrellas” for each region. Therefore, any classification system based on such criteria automatically would be applicable to that area alone, and hence would have no broad geographic applicability.
- Because of ongoing human-related disturbance, current species data often are not reflective of historical distributions.

Furthermore, various groups of biologists, naturalists, conservationists or environmental managers are likely to have a particular interest in or responsibility for selected taxonomic groups of plants or animals. In the marine environment, the taxonomic groups of predominant economic or conservation interest typically are birds, marine mammals and fish. The first two groups, at least, are unlikely to be efficient indicators of seascapes for several reasons. Birds and marine mammals are migratory or seasonal in occurrence, and therefore their use of the marine environment varies spatially and at different times of the year. They are likely to aggregate or be more common in regions of high productivity (e.g., tidal mud flats, marshes, upwelling areas, gyres and frontal systems), which themselves are typically of lower than average species diversity.

If we simply proceed in this way, selecting MPAs on a case-by-case basis, we leave the whole issue of conservation of other taxonomic groups (i.e., the vast majority of species that are neither birds nor marine mammals) completely unaddressed in any systematic way. As noted above, there is little evidence to suggest that these groups of charismatic megafauna can act as efficient umbrella groups for the conservation of other species. Although we accept that classification systems used for conservation purposes must ultimately correspond to species distributions, attempts to achieve such classifications by *working directly at the species level* are not an efficient way to proceed. Note that the dynamics of individual species populations (e.g., their migrations) will need to be considered again in the process of selecting MPAs.

Oceanographic Factors

Numerous oceanographic factors (characteristics of water and water movement) may be involved in defining marine habitats. Those given in Table 2 by no means constitute a complete list; they are, perhaps, the factors about which most is known. Some of these factors, specifically a variety of types of water motion, may prove problematic or impossible to derive from mappable or remotely sensed data. However, for most of the important factors, correlated or surrogate variables should suffice.

WATER MASSES AND SALINITY

Water masses are recognized and mapped on the basis of their combined salinity and temperature characteristics. There is no functional relationship between temperature and salinity, but certain usual or "preferred" combinations do occur, and the distribution of such associations can be traced over wide areas of the oceans. At the broadest geographic scales water masses are well correlated with major differences between biological community types in both the pelagic and benthic realms. However, outside estuarine habitats, salinity has little direct biological significance in the open oceans, and temperature is the operative variable in biogeographic distributions.

Water masses can, in some respects, be considered as analogues of the major climatic regions of terrestrial environments. Both temperature (which is important biologically) and salinity need to be identified to define the origins, movements and extent of the distribution of water masses. A water mass will change in temperature seasonally by atmospheric interactions (salinity is far less seasonally variable).

TEMPERATURE

Temperature is a major determinant of oceanic communities because of its positive relationship to growth and its frequent inverse relationship to biodiversity and nutrient supply (see the discussion of upwellings below). Temperatures are relatively stable within the oceans and far less seasonal fluctuation occurs there than in terrestrial systems. Furthermore, in terrestrial systems no precise analogue exists for the differing role of temperature on pelagic and benthic marine systems:

- In the pelagic realm, temperatures often *dictate* what occurs.
- In the benthic or demersal realm, temperatures *contribute* significantly to what occurs.

The temperatures of bottom waters may be quite different from those at the surface because of ocean currents, upwellings and tidal effects on inshore areas. Water temperatures associated with the benthos are more constant than those of surface waters, except at the relatively shallow depths in the littoral and sublittoral zone. Water temperatures in deeper waters may be influenced significantly by ocean currents. Bottom topography also has an influence on water temperature, with pockets of warmer (but more saline) waters often being trapped for periods in large basins (e.g., Emerald Basin off the coast of Nova Scotia). Since temperatures of bottom waters may not be congruent with temperatures of surface waters, we have another argument for treating pelagic and benthic realms separately.

Because large areas of the oceans experience approximately the same seasonal averages and range of temperatures, temperature itself will be a discriminant between community types primarily at the largest scales. However, temperature may also be a discriminant at finer scales, for example, within sheltered coastal waters and estuaries, where local temperatures may exceed those in surrounding waters (see the discussion of temperature gradients and temperature anomalies below).

Note that because marine waters are continuous, any limits set by temperature intervals must have some element of arbitrariness. In the relevant literature, there is some discussion about the most useful temperature parameters to use: maximums, minimums, means or seasonal ranges.

TEMPERATURE GRADIENTS, TEMPERATURE ANOMALIES AND UPWELLINGS

A common feature of marine areas exploited by migrant species is high productivity of resources. The common link between such areas is some sort of temperature anomaly or sharp temperature gradient. Thus areas characterized by upwellings, which carry nutrient-rich waters to the surface, will also be characterized by temperatures that are lower than those of the surrounding waters. During the summer months, rich intertidal mud flats will generate temperatures higher than those of surrounding marine areas, thus heating overlying waters. Productive frontal systems between stratified and nonstratified waters (see the discussion of stratification below) also show strong horizontal temperature gradients.

Temperature anomalies are well documented as being associated with upwellings, areas of high productivity where cold, deep water is driven to the surface by oceanic circulation forces or by topographic obstructions to the flow of water. Such upwellings stimulate primary production while retaining the cold water anomaly. The waters off southwest Nova Scotia may be an example of this phenomenon. Many other examples are associated with the world’s major fisheries (e.g., those along the coast of Peru and Chile). An upwelling of cold water due to mechanical or topographic features may bring small fish and other organisms to the surface, providing rich feeding areas (e.g., the waters off Briar Island in the Bay of Fundy) for migrant species such as birds, mammals and fish.

High production is also well documented as being associated with the temperature anomalies of frontal regions, which are defined as the transition areas between well-mixed, cold waters and stratified, warmer waters. Mixed water means high nutrients but poor light conditions; stratified water means good light conditions but limited nutrients. The frontal zone is a region of high production due to the compromise between adequate light and adequate nutrients.

Areas of upwellings generally are productive regions, and plant growth is stimulated because of the rich nutrients supplied from the cold waters. The following can be used to map such areas:

- Temperature anomalies
- Models of the stratification parameter (see the discussion of stratification below)
- Direct observations of lack of stratification

While the geographic location of upwellings is predictable, their timing may not be and may depend on unpredictable meteorological events. The development of upwellings varies seasonally and annually. The water column typically is mixed, and stratification is weak or absent.

ICE COVER AND ICE SCOUR

Ice cover may be permanent, seasonal, variable or absent; its extent will be a discriminating factor over the broadest geographical areas. The presence of permanent ice greatly restricts marine productivity, but except for inshore areas—or in the Arctic, where effects of ice can reach to considerable depths—ice does not have an impact on the subtidal benthos. The physical effects of ice scour and glaciers have the greatest impact on shallow-water marine communities, especially in intertidal regions, primarily by reducing community diversity or restricting some organisms to crevices. Seasonal ice (as a reflection of temperature) has a major impact in seasonally eliminating or enhancing production; again, the seasonal extent of ice cover will be a discriminating factor only at the broadest geographical extent.

SEGREGATION OF BENTHIC AND PELAGIC REALMS

As noted already, the marine environment is significantly different from the terrestrial environment in that the former has two distinct realms; this has no recognized analogue in terrestrial systems. Benthic and pelagic realms, each of which has functionally different communities, can be distinguished in marine waters. At the scale of mapping used in this study, the demersal layer is effectively benthic, and hence only two levels are mapped.

From the perspective of ecological representation, differences between the pelagic and benthic environments in terms of physical, oceanographic and biological conditions are highly significant. The principles controlling pelagic species can be different from those controlling benthic ones. This is one reason for separating oceanographic and physiographic parameters and for separate consideration of pelagic and benthic communities. Oceanographic factors will be of significance to both pelagic and benthic communities, whereas physiographic factors will be of significance primarily to benthic communities. Species and, indeed, whole communities occupy the pelagic realm and have no reference to the underlying benthic realm for any of their life cycle (and vice versa). Conversely, many benthic organisms use the pelagic zone for dispersal stages, and pelagic species may use some aspect of the benthos for reproduction.

WATER MOTIONS

Natural bodies of water show motions of several types. Water motion is an essential feature of the oceans, and a proper perspective on the scale of water movements is essential to an understanding of aquatic ecosystem functioning. Ultimately, three forces cause all motion of the earth’s water bodies: the sun’s radiation, the earth’s rotation on its own axis and the gravitational effects of the sun and the moon. Geological and atmospheric effects, which cause tsunamis, storms, and so on, constitute a minor fourth factor. Water motion may be generated by winds, tides or currents. The frequency and strength of the movement of water have a profound effect on biological communities.

Water movements vary in scale from molecular diffusion to entire oceanic circulation. The list of observable and distinguishable phenomena is quite extensive, and only the major phenomena resulting from water motions (rather than the mechanisms causing these phenomena) are associated with differences in community types and will be considered here. Major ocean currents, such as the Gulf Stream or Labrador Current, are predictable currents, as are the diurnal tides that flush the inshore waters along the coast.

CONVERGENCES AND DIVERGENCES

The locations where oceanic water masses meet (convergences) or rise to the surface and disperse (divergences) are extraordinarily important to the overall productivity. Convergences and divergences typically are regions of much higher than average productivity at trophic levels from phytoplankton to fish. However, these regions are much more clearly defined in the tropics, subtropics and southern oceans than they are at northern latitudes, and convergences and divergences typically are restricted to oceanic waters. Therefore, although global marine conservation initiatives would certainly need to include these phenomena in a seascape framework, they will not feature in a Canadian framework.

STRATIFICATION, MIXING AND NUTRIENTS

Within the pelagic realm, phytoplankton have two main requirements for growth that fundamentally are at odds with one another: light and nutrients. To obtain sufficient light, phytoplankton must be retained within the upper water column (the photic, or euphotic, zone). For this retention within the euphotic zone to occur, the water column should be stratified so that phytoplankton remain in the euphotic zone and do not get moved into deeper zones where light is insufficient. However, replenishment of nutrients within the euphotic zone requires deep mixing of the water column. Nutrient replenishment is impeded by stratification, and deep mixing removes phytoplankton from the euphotic zone. The temporal and spatial changes of the water column between deeply mixed and strongly stratified are, therefore, fundamental to marine productivity.

Arctic waters typically mix in early summer and then become stratified, mainly as a result of vertical differences in salinity. In subarctic waters, stratification can be due to a combination of salinity and temperature effects. In temperate and subtropical waters, stratification of the water column is primarily due to temperature, but it may also result from a change in salinity. In coastal waters, stratification may be associated with seasonal freshwater runoff from land that in turn may also be related to the cycle of primary production (see the discussion of nutrients below). Seasonally ice-free areas of the Arctic Ocean experience such effects (Roff and Legendre 1986), as do coastal waters with high runoff (e.g., Hallfors et al. 1981; Kullenberg 1981), for example some areas of the Pacific coast. Locations may be predictable from a combination of terrestrial landforms (mountains), rainfall distribution and drainage basin outflow to the sea.

All temperate oceanic and fresh waters typically mix vertically in spring and fall, but they may, or may not, become stratified in the summer. Two forces cause near-surface water mixing: tides and winds. The effects of wind mixing are difficult to formulate, but they are more uniformly distributed than the effects of tides. In the oceans, when the depth of the water column exceeds about 50 metres, winds cannot prevent the water column from stratifying during the annual heating cycle, but tidal action can.

Mixing and stabilization regimes are largely determined by two factors, the stratification parameter and the water depth. The stratification parameter measures the tendency of the water column to stabilize under the influence of a surface heat flux, in the presence of mixing due to tidal stirring. This parameter is defined as the ratio of potential energy from the sun, which tends to stratify the water column, to the rate of tidal energy dissipation, which maintains well-mixed conditions in the water column. The length of the mixing period and the timing and intensity of stratification during the seasonal heating cycle can be effectively described by the stratification parameter, S, where S equals log10[|H|/Cd . U3] and |H| is water depth, U is the averaged tidal current velocity and Cd is friction/drag coefficient (Pingree 1978).

Pingree (1978) argued that the critical value of the stratification parameter, which is when S equals 1.5, will determine the position of summer boundary fronts separating well-mixed waters from well-stratified waters. Wind-generated waves are never strong enough to prevent stratification at values of S greater than 1.5 (Pingree 1978). Infrared satellite images of sea surface temperatures, as well as measurements at sea, provide confirmatory evidence of the importance of the tidal stratification parameter as an index of mixing on the continental shelf. Thus regions characterized by high values of the stratification parameter may be associated with well-stratified water conditions in the summer months, whereas low values characterize areas where the water column remains mixed throughout the year. The stratification scale spans, in effect, a range of conditions from those in which mixing and stabilization are dominated by weather to those in which they are dominated by tidal stirring.

The stratification parameter appears to be the only parameter that delineates pelagic communities horizontally at a scale below that of water masses and that is reproducible and mappable from remotely sensed or modelled data. Stratification and light penetration are also the only parameters available to delineate pelagic communities vertically. This vertical stratification of a water column separates its communities both spatially and temporally. Although the phytoplankton community varies substantially through an annual cycle at any location, the broad features of its character can be captured by the stratification parameter. Stratified and nonstratified 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). Where data are directly available, the intensity of stratification is the rate of change of density with depth.

Values of the stratification parameter are almost fixed geographically and are annually reproducible, leading to a defined spatial pattern of development of seasonal thermoclines. For open waters, although the rate of change of density with depth is a direct measure of the intensity of water column stratification, it must be measured in situ. Frontal systems (where S = 1.5) are identifiable from their temperature gradients in satellite images (see the discussion of temperature gradients and anomalies above). Frontal systems that separate stratified and nonstratified waters are highly productive because they represent areas of compromise between sufficient light and sufficient nutrient supply for pelagic plants. Though they may vary from year to year and change in intensity, frontal systems can nevertheless be considered recurrent oceanographic features.

The stratification parameter also appears to define population boundaries, recruitment cells, gyral systems and migration limits for at least some pelagic species (Bradford and Iles 1992; Iles and Sinclair 1982). In the North Sea, for example, the spatial pattern of the ultimate predator, the European fishing fleets, closely reflects the distribution of the stratification parameter (Pingree 1978). Very conspicuous is the large, relatively unfished region of the central and northern North Sea, which approximates the well-stratified deep regions where S is greater than 2. Also noteworthy is the region of most intense fishing activity, which generally corresponds to the shallow areas where S is less than 2.

Stratification is also significant in the demarcation of benthic communities (Wildish 1977). Dyer (1973) and Pritchard (1955) describe high-current areas as increasing the availability of nutrients to sessile organisms, since high-current areas are almost always well mixed, resulting typically in areas of high biological productivity (Zacharias and Howes, in prep.).

LIGHT PENETRATION AND TURBIDITY

Light provides the energy for photosynthesis and primary production in most marine ecosystems. The penetration of light into the water column is attenuated with depth and turbidity, and both parameters are important determinants of the vertical distribution of pelagic and benthic vegetation. The euphotic, dysphotic and aphotic zones are functional zones that limit the development and types of biological communities. The division between the euphotic (where photosynthesis can occur) and nonphotic zones is more significant than the further subdivisions (dysphotic and aphotic) within the nonphotic zone because beyond the limits of the euphotic zone we find communities that cannot photosynthesize. At these depths, energy for consumers is imported from other areas, predominantly by vertical settling of detritus. Consequently, the whole trophic structure of communities below the euphotic zone is different from those within it.

The compensation point is defined as the depth at which the rate of photosynthesis exceeds the rate of respiration. The measurement of this depth is highly variable between inshore and offshore waters and at different times of the year. For example, in estuaries, the euphotic zone may be less than 2 metres in depth, while in oceanic waters, it may exceed 200 metres. Similarly in the Arctic Ocean, the euphotic zone may exceed 100 metres in depth during the spring and suddenly decrease to only a few metres in depth during the summer phytoplankton bloom. For the purposes of this study, 50 metres was chosen as a reasonable depth to separate the euphotic zone from the dysphotic zone; the euphotic zone, therefore, includes all the littoral regions and shallow banks and shoals to a depth of 50 metres. However, it should be realized that the actual depth of the euphotic zone increases with water depth itself, from the coast toward the edge of the shelf into oceanic waters.

The biomass and productivity of phytoplankton can be estimated from ocean colour and water clarity (e.g., Bukata et al. 1995). Within the benthic euphotic zone (i.e., all nearshore and shelf areas that are shallower than 50 m), productivity is largely reflected in the biomass of the attached macrophytes or interstitial microphytes.

DEPTH AND PRESSURE

The increase in pressure with water depth has a significant impact on organisms. With every 10 metres of depth, the water pressure increases 1 atmosphere (with the greatest change from 0 to 1 atmosphere occurring in the top 10 m). With increasing depth, the amount of food available declines exponentially as a function of surface productivity. Additional physical, chemical and biological changes lead to a decrease of dissolved oxygen and an increase of dissolved carbon dioxide.

Both the pelagic and benthic realms can be divided into three classes (distinguished by the prefixes epi-, meso- and bathy-) that are also defined by depth but in which the controlling physical factor for organisms is probably water pressure rather than the presence or absence of light. The epipelagic realm is essentially within the uppermost part of the water column and is characterized by communities of plankton and fish. Organisms that live in the mesopelagic and bathypelagic regions have evolved in response to the enduring factor of pressure and are adapted to the physical conditions and dilute resource concentrations of these regions; these organisms rarely move into the epipelagic region. However, some fish and invertebrates in the bathypelagic zone (such as the sergestid prawns and myctophid fishes) do migrate into the upper two layers of the water column at night. Where bathypelagic zones are occupied by specially adapted fish or invertebrates, the actual populations may be low except in areas where food is more abundant, such as around sea mounts.

TIDAL AMPLITUDE AND CURRENTS

Local currents can derive from several oceanographic processes, including general oceanic circulation, water masses and tides. In coastal waters, currents due to tides are generally the most predictable and best-documented currents. Tidal amplitude, together with bottom slope, determines the vertical and horizontal extent of the intertidal zone. Tidal currents and bottom slope determine, in part, the type of substrate, which in turn acts as a determinant of benthic community type.

Water movement determines the following major substrate types and their associated benthic communities:

- Erosional areas, where high current speeds remove particles from the substrate, leaving a hard bottom of rock, boulders and gravel
- Depositional areas, where water movement is slow enough to allow suspended particles to settle, leaving a soft bottom of mud and silt

Water movements caused by tides, ocean currents and waves are also associated with the degree of exposure of littoral communities, and this is of major importance to the development of the various community types in both intertidal and subtidal regions (see the discussion of exposure below). In areas of high-energy water motion, the water motion tends to wash sediments out of the littoral zone into areas with lower-energy regimes, either those that are in deeper water or those that are more protected, such as bays or gullies. Below the littoral zone, sediment movement is still affected by high-energy currents.

EXPOSURE TO ATMOSPHERE AND WAVES

Exposure occurs in two ways:

- Through wave action
- Through desiccation

Neither type of exposure is a discriminating variable for pelagic communities. Although wind-induced waves may have some influence on pelagic organisms, waves are unpredictable and random in space and time.

In the benthos, exposure is only significant for the intertidal and immediate subtidal regions. Coastlines that are highly exposed have different intertidal and nearshore biota from protected shorelines as a result of the mechanical wave action on the shore and the shallow seabed. The intensity of wave action that can develop is related to fetch, which is predominantly a function of the distance over which waves are propagated and the angle and development of the shoreline. Fetch can be determined from maps and meteorological records.

A different form of exposure for littoral communities is recurrent exposure to desiccation by the atmosphere during a tidal cycle. Exposure is strongly correlated with tidal amplitude, substrate slope and substrate particle size along a spectrum from bedrock to mud (Levinton 1982). Both types of exposure exert considerable influence on the type of benthic plant and animal communities that develop in a marine region.

TSUNAMIS, STORM SURGES, HURRICANES AND WATER SPOUTS

These massively destructive atmospheric events are now more or less predictable in terms of location of impact and scale of effect, at least at short time scales. Although considerable local destruction to coastal marine communities may result from these phenomena, over a period of years (for most intertidal communities) to decades (for coral reefs and mangroves), the local communities may generally become reestablished in approximately their original composition. Such phenomena, which have profound local effects on shaping marine communities, should be thought of as resetting the ecological "clock of succession." These phenomena should not be considered as belonging to the same category of determinants of community type as the oceanographic factors previously discussed, except in so far as they are recurrent within time scales and may determine whether certain community structures exist.

USING OCEANOGRAPHIC FACTORS IN A MARINE CLASSIFICATION

In the discussion on biological factors, we concluded that biological criteria are not an efficient method on which to build a broadly applicable marine classification. Many of the oceanographic factors discussed do consistently and predictably influence species distributions and are mappable on a broad scale, and therefore oceanographic factors can be appropriate factors to use in developing a classification. However, oceanographic factors by themselves do not determine community distributions; below we discuss the influence of physiographic factors on marine ecology.

Physiographic Factors

Physiographic characteristics are those features that can be recognized broadly as aspects of the "marine landform" and that in essence relate to the substrate and topography of the bottom of the sea. Included are certain geographical features such as position, which is a combination of latitude, longitude and the spatial relationships of land masses that separate oceans or areas of ocean.

The physiography of the shoreline and seabed determines the broad sweep of biological communities, though an overlying geological and geographical context is responsible for large-scale differences in biological communities. Therefore, the location of an area, whether in the Atlantic, Pacific or Arctic Ocean, affects the prevailing currents and winds and the connections with biota elsewhere. The physiography of coastlines and the sea bottom is one of the easiest components to map and, with satellite and airborne sensing technologies, considerable accuracy is possible.

GEOLOGICAL ACTIVITIES

Modern day geological activities do periodically affect marine communities, but not in any regular or predictable way that could be used to distinguish community types. One important exception is deep-sea vents, which have extraordinary communities. Deep-sea vents could be excellent MPA candidates, but the vents are so unusual, and clearly identifiable without using surrogates, that they are not helpful as criteria for determining broad-scale habitat types.

GEOGRAPHICAL POSITION AND LATITUDE

As was mentioned above, the geographical position and latitude of an area affect the prevailing currents and winds and the connections to biota elsewhere, and are therefore responsible for ocean-scale differences between community types. These major features form the basis for the two-factor separation of the Arctic, Atlantic and Pacific Oceans into regions defined largely by geographical position and temperature.

The latitude of an area is an indication of seasonal temperature and the amount of light available for primary production. However, at any given latitude in the marine environment, the temperature of the water mass may be significantly at variance with that predicted from local solar radiation. The Labrador Current and the Gulf Stream are good examples. Definition of broad-scale community features in terms of water masses is therefore more fundamental than their definition in terms of latitude. At a finer scale, stratification of water masses is also a better predictor of community type and of the timing of events than is latitude.

GEOLOGICAL HISTORY OF THE OCEAN BASIN

Any classification of the three oceans adjoining Canada must recognize that they have different geological and biological histories. Although there are profound differences in species composition among the oceans, it is evident that traffic of species between them is still occurring, and we can expect such changes in species distributions to continue over geological time and certainly to be accelerated by human actions. A fundamental axiom of this classification system is that, despite significant differences in the species assemblages observed in the three oceans, these species will be organized into (or can be recognized as belonging to) the same fundamental sets of biotopes. Thus ecological organization of species into functional assemblages (here termed "communities") follows essentially the same pattern in all oceans, irrespective of the absolute number of species or the exact identity of the species themselves.

WATER DEPTH

Water depth may be subsumed under relief (see the discussion of relief below) and vice versa. Depth itself is not a critical physiographic determinant of marine communities; however, depth is a surrogate for a variety of factors that all vary with depth in the vertical plane. Thus, light intensity diminishes exponentially with depth, which therefore defines the photic and nonphotic zones. Depth is also a surrogate variable for pressure. Temperature also decreases with depth, from ambient surface values to a nearly constant 0°C to 2°C in the deepest oceanic waters. Concentrations of particulate organic carbon (the detrital flux from the euphotic zone) also decrease exponentially with depth (Suess 1980), while oxygen concentrations decline and carbon dioxide concentrations increase with depth. Depth is therefore an index of a variety of concurrently changing physical and chemical conditions that collectively influence the nature of biological communities in both the pelagic and benthic realms.

Vertical changes in these biological communities are observable, but, especially in the pelagic realm where organisms form a series of overlapping distributions and vertical migration ranges, divisions should be regarded as typically gradual rather than distinct. Nevertheless, some communities, for example, the nektonic community forming the deep scattering layer, may show very significant coherence in their vertical distributions and in the extent and timing of their vertical migrations. Several schemes that vertically segregate the pelagic and benthic realms recognize divisions comprising the euphotic zone, depths covering the continental shelf (i.e., down to 200 m), depths beyond that to about 2000 metres and thence to hadal regions of 6000 metres and beyond.

The general trend in benthic communities is that both substrate type and community type become less variable with increasing depth. In the depths of the oceans, the zoobenthos tends to converge to only a few community types, and many species may be cosmopolitan. The tendency is for the bottom itself to be composed largely of silty mud, for current speeds to be low and for the community to become dominated by deposit feeders and scavengers.

RELIEF (SLOPE)

The relief or slope at the shoreline and within coastal and marine waters is highly variable. While slope intervals are sometimes mapped, slope is more often inferred from vertical changes in height in relation to horizontal distance (i.e., a steeper slope where bathymetric contours are closer together). Depth and hence slope generally are mapped in more detail in areas of navigable waters.

Areas of high relief tend to have irregular bottom morphologies and high elevation ranges; areas of low relief have uniform slopes with small elevation gradients (Zacharias and Howes, in prep.). Areas of high relief provide habitat for numerous species assemblages and generally indicate high species richness, diversity and biomass (Lamb and Edgell 1986); relief is also an indirect indication of mixing (Zacharias and Howes, in prep.). Sediment stability is dependent on slope and other variables, while the angle of repose of marine sediments depends on particle size and the degree of water motion. Marine slopes suitable for stable sediment accumulation are at much lower angles than are terrestrial slopes for similar particle sizes (mass movements of materials on marine slopes have been known to occur at angles as low as 1°).

The shoreline slope, in combination with local tidal amplitude, determines the extent of the intertidal zone. Slope and *exposure* also influence the substrate type in intertidal regions. Steep slopes and high exposure lead to bare rock, while intertidal mud flats occur at the opposite end of the slope and energy spectrum.

Relief and slope generally are considered to be secondary diagnostics when compared to such factors as substrate type, current speed and exposure. Relief and slope may, however, become useful as predictors of local substrate type under some circumstances in which direct data on substrate type is not available (e.g., in regions of the Arctic). In most cases where substrate type and current velocities are known, relief and slope may add little information concerning biological community types. These two characteristics may be useful diagnostics, however, at the edge of the continental shelf where the change in substrate slope itself, in concert with current activity, may enhance local benthic production by processes not yet well understood.

SUBSTRATE (SEDIMENT) PARTICLE SIZE

Substrate or sediment particle size is a dominant influence on benthic and demersal communities. The type of marine benthic community and the types of organisms that can live within or on the substrate are substantially determined by particle size along a spectrum from solid rock to mud (Levinton 1982). These distinctions between the communities of hard versus soft substrates have been recognized for many years; indeed, whole ecological volumes are devoted solely to one type of community or to the other (e.g., Stephenson and Stephenson [1972] for rocky shores; Eltringham [1971] for communities on soft substrates). Communities on hard substrates, in both intertidal areas and immediate subtidal areas, generally are dominated by macrophytic algae and a variety of epibenthic molluscs and crustacea, with few species managing to burrow successfully into the substrate itself. In sharp contrast, communities on soft substrates are dominated by burrowing species of worms and molluscs, and plant life may be restricted to microphytic algae on the sediment itself. Although there are various gradients between these extremes of community type, and mixtures may be found in regions where the substrate itself is mixed in character, nevertheless, these major community types are readily recognizable.

Below the water level, slope and current speed interact to determine substrate particle size and sediment and community type. In high-energy (erosional) areas of higher slope and current speed, exposed substrate or coarse sediments (e.g., stones and gravel) will predominate. In lower energy (depositional) areas having lower slope and current speed, finer mud and silts will be found. In the deep regions of the sea, away from the influence of surface currents, wave motion and tidal effects, the velocities of currents are low and sedimentation of fine materials is the norm. Different biological community types are therefore associated with erosional and depositional areas.

Sediments may be mud, sand or gravel, and they may be transported considerable distances along a coast or within an estuary prior to settling on the bottom. Sediment transport rates are dependent on the direction and velocity of the current, as well as on grain size. Sediment stability is dependent on slope (see the discussion of slope above) and other variables, while the angle of repose of marine sediments depends on particle size and the degree of water motion. The substrate type at the extremes of the erosional and depositional regimes tends to be relatively constant, although there may be very significant changes in sediment accumulation or erosion over the years as the result of storm activity in coastal waters. Thus, sand and gravel environments typically experience the greatest changes in sediment quantity and mobility over the years. For this reason, the species diversity of plants and animals tends to be highest on rocky shores and again on muddy shores, with the more mobile sandy or gravel substrates typically showing much lower species numbers.

This important distinction between community types is strongly related to the sedimentary regime and water motion. Thus communities characterized by suspension feeders, which take particles directly from the water column, dominate in areas of relatively coarse sediments and high current velocities (which bring food to the zone). In contrast, communities characterized by deposit feeders dominate in regions of fine sediments and low current velocities, where fine particulate matter settles directly onto the bottom (Wildish 1977). The predictable current speeds are predominantly tidally generated (Pingree 1978; Eisma 1988).

Information on sediment composition is available directly or can be derived as a surrogate from slope, bottom morphology and geological characteristics. Substrate particle size is frequently classified according to a “Wentworth,” or mean particle size, scale, which can be reduced and simplified to the following categories:

- Clay or silt—0.0 millimetres to 0.5 millimetres
- Sand or pebble—0.5 millimetres to 30 millimetres
- Cobble or boulder—greater than 30 millimetres

BASIN MORPHOMETRY (TOPOGRAPHY)

The general morphometry or topography of a region (e.g., an estuary, inlet, basin) can exert a significant effect on the character of a coastal region. At a large scale, an entire basin may have a natural period of oscillation that reinforces that of the local tidal frequency. In such a case, resonance occurs, and very high tides and rapid tidal currents are observed. A prime example of this in Canadian waters is the Bay of Fundy. In such conditions, the high tidal range and fast currents may determine that the local substrate consists of coarse particles or even bare rock for considerable distances. At the opposite extreme, where a local basin experiences low tides, sedimentary areas may predominate. However, because the tidal amplitude and nature of the substrate can be independently obtained, and because substrate type is also a function of wave action, these factors should be assessed directly rather than be interpreted from morphometric characteristics.

GEOLOGY (ROCK TYPE)

Unlike in the terrestrial environment, where local geology can have significant effects on the vegetation type and resultant animal communities, in the oceans the geological rock type is generally not a significant factor in the development of community type. The major exception to this is that different geological types may generate different substrate particle sizes (see the discussion of substrate particle size above). Rock type may be sedimentary, metamorphic or igneous and may include granite, hard and soft sandstone, limestone, shale, and so on. The erosion potential of the parent material has an effect on the particle size of the substrate of shorelines and, in turn, on the type of associated benthic organisms. Sedimentary bedrock is most likely to be affected by erosional processes while the crystalline igneous and metamorphic materials are more likely to be resistant to them.

There is no strong correspondence between rock type and community composition mainly because the major marine angiosperms are rooted in soft sediments. Here they are buffered by the composition of seawater itself, the effect of which overshadows any residual effects of substrate particle type. Macrophytic algae possess holdfasts that anchor them to the hard substrate, irrespective of its geological type, and their resources are derived from the water itself. The same is true of the various invertebrates of rocky shores.

Below the low-tide levels, and with a few exceptions of solid rock, virtually all the seabed consists of some form of sediment (see the discussion of substrate particle size above). Consequently, bedrock and geology have minimal influence on aquatic organisms (in contrast to the determining role of geology and landforms in terrestrial ecosystems).

USING PHYSIOGRAPHIC FACTORS IN A MARINE CLASSIFICATION

Physiographic factors, like oceanographic factors, influence species and community distributions. Furthermore, physiographic factors are more easily mapped than either biological or oceanographic factors. Physiographic factors, though not sufficient on their own, are ideal criteria to use in building a marine classification. Part 3 of this report outlines which combination of physiographic and oceanographic factors were chosen to create a classification of marine habitat types.

Conclusions

We should recognize that any community type will vary in its species composition depending on the relative influences of many biological factors. Thus the presence or absence of a keystone species may have dramatic effects upon the relative abundance of other species within a community. For example, the subtidal community of temperate rocky shores can vary greatly in relative species composition from dominance by macrophytic algae (Laminarians) to dominance by sea urchins to almost bare rock, depending on local predator–prey dynamics. However, all these apparently different communities are, in fact, phases of evolution of the same community type—the same biotope shifted along the axis of relative species composition. Such variations in relative abundance of component species must not distract us from the recognition of fundamental biotopes.

Marine community types (as opposed to communities of specific species) are recognizable across widely separated geographical areas. Thus, we can recognize subtidal communities dominated by macrophytic algae in the Atlantic, Pacific and Arctic Oceans. In each geographical region, the species present and the species assemblages are different, *but the same types of communities with different species playing equivalent ecological roles are recognizable, irrespective of the specific geographical location.* This is precisely what we need to specify the various types of seascapes in a hierarchical classification that can be used irrespective of geography.

2c A Review of the Correspondence Between Biological and Geophysical Factors

The close association between physiographic and oceanographic characteristics and biological community types in the oceans has been realized for many years. Hedgpeth (1957) and Thorson (1957) were among the earlier authors to compile data and describe relationships between the phyto- and zoobenthos and physiographic features in the marine environment. More recently, Warwick and Uncles (1980) and Hiscock (1995) have further explored and codified these relationships statistically and systematically. There is now little doubt that we can, in many circumstances, extrapolate reliably from a knowledge of geophysical properties to the expected type of benthic community (i.e., the local biotope).

In the case of intertidal communities, the stark differences between the communities of hard rocky substrates and soft muddy substrates are evident even to the casual observer. Photosynthetic productivity in fringing communities is high in the macrophytic algae of rocky shores, low in sand and gravel, and then high again in mud flats with either microphytic algae or the angiosperms of salt marshes. In deeper waters, the predominant difference is between communities in areas of high currents and coarse substrates, which consist predominantly of suspension feeders (Levinton 1995), and communities inhabiting regions of slower currents, which consist predominantly of deposit feeders. These relationships, though codified in many studies, are still imperfectly understood in process terms, and differences in community structure may well be related to the degree or seasonality of pelagic–benthic coupling (e.g., Chevrier et al. 1991).

There has long been an appreciation that community composition and structure in the pelagic realm is related to the origin and character of water masses, which are described fundamentally by their salinity and temperature. Some of the earliest statistical analyses of such relationships were undertaken by Colebrook (1964) and Fager and McGowan (1963). More recent analyses confirm the broad-scale relationships between water masses and several groups within planktonic communities, including the confounding factors of depth and distance from shore (Thorrington-Smith 1971; Tremblay and Roff 1983; Roff et al. 1986). Within these temperature and salinity regimes, the presence or absence of stratification of the water column also contributes to the character, seasonal cycle of production and community structure of the plankton, although less attention has been paid statistically to the local analyses of these relationships. However, it is clear that the fundamental differences in production regimes between stratified and unstratified regions can affect the fisheries.

Thus Pingree (1978) has shown a close relationship between the distribution of the top predator in the North Sea (i.e., the fishing fleets), quantitative fish distributions and the seasonal patterns of water-column stratification. It is clear that these patterns of seasonal stratification also delimit the mixing regimes of contiguous water masses and can define genetically distinct subpopulations of fish (e.g., Iles and Sinclair 1982).

Whereas planktonic communities drift within the water column and benthic communities are largely fixed within or on top of the substrate, fish are capable of independent movement. Relationships between the fish community and geophysical factors are therefore more complex, and, at the very least, we should recognize that fish can be predominantly pelagic or predominantly demersal (i.e., species that are bottom referenced, even if they do not live in contact with the bottom) or may exhibit tendencies to move between the two realms. In addition, associations between fish communities and physical factors may be undertaken to investigate biodiversity and productivity or to document environmental degradation. Nevertheless, relationships between species assemblages and physiographic and oceanographic factors are still evident, although these associations may change over the years (perhaps as a function of climate changes) and through developmental stages and fish ages. Thus spawning areas, nursery areas and areas of adult distributions may all be different (e.g., Haegele and Schweigert 1985). Analyses of demersal fish communities clearly show the same sorts of relationships between geophysical factors and distributions that are seen in the planktonic and benthic communities (e.g., Swartzman et al. 1992; Mahon and Sandeman 1985). However, the assemblages identified may exhibit more complex distribution behaviours when analyzed over time, due to such factors as seasonal migrations and fishing impacts.

3

A Classification for Marine Conservation

3a

General Principles of a Hierarchical Classification for Marine Conservation

Summary of Key Points

The previous sections of this report outlined the key ecological factors that influence species distributions and community structure. These factors will be used in this section to design a classification system for Canada's oceans. This classification system can be used as a basis for marine planning, including designing a representative network of MPAs. The following summarizes the key concepts discussed so far:

1. Marine systems are basically different from terrestrial ones but, like them, consist of interacting physical and biological components, which, at least theoretically, can be used as indicators in separating seascapes.

2. Marine systems exhibit more complex spatial–temporal relationships than terrestrial systems; this has made the development of comparable frameworks for MPA planning more difficult.

3. Using stable, enduring features as a basis for delineating marine natural regions is difficult because two very different communities—the pelagic and the benthic—exist and can be either strongly coupled or largely independent.

4. 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.

5. In marine environments, we can recognize two broad sets of ecological attributes:

   - Enduring physiographic features (the closest analogue of terrestrial enduring features)

   - Recurrent oceanographic features or processes that may not be permanent but may reoccur daily, monthly, seasonally or yearly in a predictable fashion in the same geographical area

6. The advantage of using physical parameters to delineate marine natural regions is that, certainly at coarse to medium scales of analysis, they control the distribution of organisms. Thus while individual species are locally prone to population changes, invasions or extinctions, the larger assemblages or communities will persist and can be represented by their enduring or recurrent physical correlates.

7. Because marine systems are so dynamic, it is difficult to identify distinct boundaries within them, particularly when using traditional mapping techniques. Nevertheless, it is still appropriate to examine marine ecological characteristics and to define habitat types 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 such as hurricanes, communities generally reestablish themselves in due course on the basis of the enduring physiographic and recurrent oceanographic factors.

Guiding Design Principles

The identification of appropriate guiding principles for the design of a classification system for marine ecosystems is fundamental to the success of this project. The identification of these principles is similar to the preparatory work conducted by Peterson and Peterson (1991) in their terrestrial representation study. A set of key design principles is necessary to do the following:

- Guide the development and implementation of the marine representation methodology and framework
- Guide the ecological integrity requirements for marine endangered spaces and develop a network of MPAs
- Enable a gap analysis approach to identify those areas that best sample the seascapes required to complete a system of MPAs

The following principles were used to guide our classification of seascapes:

1. An approach based on marine enduring features should be used to classify marine habitat types that directly or indirectly determine the distribution of marine biological diversity.
2. Data describing marine enduring features used to delineate seascapes should be available, either directly or via suitable surrogates at comparable scales, for all areas to be evaluated to ensure consistency of interpretation and comparison.
3. A community-level analysis of biological diversity should be done for all areas.
4. The marine enduring features should include a range of fundamental physiographic and oceanographic factors.
5. The classification of seascapes should be hierarchical so that description occurs on different spatial scales, allowing for the identification and ultimate protection of lower-level classification units in the system (Watson 1997).
6. The classification system should have a global perspective in which the higher levels of classification are defined by global processes (Watson 1997).

7. The classification system should be constructed so that the upper levels of the hierarchy discriminate between the most broadly different community types and the lower levels of the hierarchy discriminate between more closely related community types.

8. The classification system must have predictive power and describe the relationships between physical environments and biotic communities (Watson 1997).

9. The classification system should be logical, easy to use and stable (or naturally adaptable) through time.

10. The classification system should clearly delineate repeating community or habitat types based on scalable and nonscalable marine enduring features, incorporating a minimal set of key physiographic and oceanographic factors.

11. Given the obvious and profound differences between pelagic and benthic communities, it will be necessary to consider these realms separately and subsequently to combine these "layers" to assist in determining MPAs.

12. Selection of MPAs will require a separate analysis of further ecological information, for example, of individual species at the population level and ecological processes at the ecosystem level. This second step will also require socioeconomic evaluation of alternatives. MPAs may be contained within a seascape or may contain several seascapes.

3b

A National Classification System for Marine Conservation

To produce a useful planning tool for MPA planners and fisheries managers, the extent and delineation of seascapes must be known. By designing and applying a theoretical construct using the factors described in Part 2 and using available data sources and appropriate surrogates for each factor, we can delineate geographic units that represent habitat types. Table 3 outlines the national marine classification system; the specific parameters used to define seascapes and the rationale for specific categorization of parameters are described in the following sections.

The factors chosen as the basis for this classification system were considered to be the most appropriate at each level in the hierarchy. To create the most stringent classification system, a variable is used at only one level in the hierarchy. This implies that the variable controls processes at that particular level. While physical parameters are best used at coarser scales of resolution, biological parameters can be used at finer scales for local verification of physical correlates (Maxwell et al. 1995). Physical environmental parameters and biological community types can be expected to converge at the finest scales as joint descriptors of species distributions.

The hierarchy itself is constructed in such a way that the upper levels discriminate first between the most broadly different community types. At the lower levels of the hierarchy, community types are progressively more closely related. Thus our hierarchy is analogous to the Natural System of Classification which is used for the taxonomic classifications of organisms. Inevitably, it may not always be possible to judge the precise sequence in which factors should enter the classification system as discriminators of differences among communities. Only a rigorous statistical analysis (i.e., a variant of the taxonomic cladistic analyses) will reveal whether the most appropriate sequence of descriptors has been selected.

Using GIS software, each level of the hierarchy is merged with the others to produce seascape-level boundaries. At the lowest level of the hierarchy (Level 8), seascape units are defined.

At Level 6, we can distinguish natural regions. Natural regions are here defined as broad oceanographic and biophysical areas characterized by similarities in water-mass characteristics and sea-ice conditions. Theoretically, the pelagic and benthic environments themselves are ecologically distinct at broad enough levels to be classified as individual natural regions. The result would be a column of water with anywhere from two to five vertically segregated natural regions. For visual display and for planning purposes, these separations are not defined or delineated during mapping. Therefore, the entire water column from surface to substrate forms one functional zone defining a natural region.

At the lower levels of the hierarchy, the criteria of stratification, slope, exposure and substrate are merged into the GIS within the natural region boundaries. The combination of a pelagic layer overlying a benthic layer forms ecologically unique sets of conditions. Each set of unique conditions defines a seascape, creating the basic functional unit of the hierarchy. Each seascape, therefore, has a unique set of characteristics derived from the higher levels of the hierarchy. It is important to stress that a seascape is a combination of pelagic and benthic habitat types, and that a seascape can be identified anywhere that a defined set of ecological conditions recurs. In other words, while the set of ecological conditions defining a seascape is unique, there will often be several locations where that set of conditions (i.e., that seascape) can be found.

Table 3. **A NATIONAL FRAMEWORK FOR MARINE CLASSIFICATION**

LEVEL 1 Environment Type	**LEVEL 2 Geographic Range**	**LEVEL 3 Temperature**	**LEVEL 4 Sea-Ice Cover**
Lotic (streams and rivers)	Not considered in this framework		
Lentic (lakes)	Not considered in this framework		
Estuarine	Not considered in this framework		
Marine	Arctic Ocean basin	Arctic (avg. temp. < 0°C, ice 9–12 months)	Permanent
	Atlantic Ocean basin	Subarctic (avg. temp. > 0°C, ice 6–9 months)	Seasonal (90% frequency of occurrence)
	Pacific Ocean basin	Boreal (avg. temp. > 0°C, ice 1–6 months)	Variable (25–90% frequency of occurrence)
		Temperate (avg. temp. > 0°C, < 18°C, ice < 1 month)	Absent (includes polynyas)
		Subtropical (avg. temp. > 6°C winter, > 18°C summer)	

Level 1: Environment Type

Any classification framework for aquatic environments must recognize the fundamental similarities and differences among them. This analysis will concentrate on physical–chemical differences among these environments, but major biological differences will also be discussed.

Natural bodies of water can be categorized as belonging to the following types of environments:

- Freshwater lotic (streams and rivers)
- Freshwater lentic (lakes)
- Estuarine (junctions of fresh and marine waters)
- Marine (seas and oceans)

LEVEL 5 **Segregation of Pelagic and Benthic Realms**	**LEVEL 6** **Vertical Segregation**	**LEVEL 7** **Mixing and Wave Action**	**LEVEL 8** **Benthic Substrate**
Pelagic	**Pelagic**	**Pelagic–Stratification**	
	Epipelagic (0–200 m)	Stratified epipelagic (S > 2)	
	Mesopelagic (200–1000 m)	Nonstratified epipelagic (S < 1)	
	Bathypelagic (1000–2000 m)	Frontal epipelagic (1 < S < 2)	
	Abyssal/hadal (> 2000 m)		
Benthic	**Benthic**	**Benthic–Exposure**	**Benthic–Sediments**
	Euphotic (0–50 m)	Exposed: fetch > 500 km (euphotic)	Clays/silts (0.0–0.5 mm)
	Dysphotic/aphotic (50–200 m)	Moderately exposed: fetch > 50 km, < 500 km (euphotic)	Sand/pebbles (0.5–30 mm)
	Bathyal (200–2000 m)	Sheltered: fetch < 50 km (euphotic)	Cobble/boulders (> 30 mm)
	Abyssal/hadal (> 2000 m)		
		Slope	
		Low slope < 1° (> 50 m depth)	
		High slope > 1° (> 50 m depth)	

While the above aquatic environments have many features in common, each has its own unique set of properties and its own suite of relationships between geophysical characteristics and biological communities. Although some relationships may traverse the boundaries of environment type, it would be a mistake to extrapolate relationships uncritically from one environment type to another. Thus, while a similar framework for the hierarchical classification of each of these groups of aquatic environments could be developed on the basis of the same fundamental principles, each would require a different array of factors in its own hierarchical classification. This has not been done here, but a classification framework for the Great Lakes is currently in development.

This report and framework outlines a classification system only for the marine environment. There is no perfect definition of what constitutes the marine environment. Since it dominates our planet, a more relevant question might be, What does not constitute part of the marine environment? For the purposes of this framework, the marine environment is considered to include oceans, seas, bays and the outer reaches of estuaries where the ambient salinity exceeds about 30 parts per thousand. Thus we are considering all those marine waters of full-strength salinity or where dilution by fresh water amounts to only about 10 per cent.

Level 2: Geographic Range

Each of the three oceans surrounding Canada contains its own distinct complement and diversity of species. These species, however, are arrayed within the same recognizable sets or assemblages of species (i.e., communities). Although the species themselves differ, we can still recognize the same community types. We can also recognize the same ecosystem-level dynamics in all three oceans. The Pacific Ocean, with its longer evolutionary history, has a richer species diversity and more distinct species assemblages than the Arctic and Atlantic Oceans. The Atlantic coast of Canada is strongly affected by the westward-intensified currents of the subpolar and subtropical gyres—the Gulf Stream and the Labrador Current respectively. In contrast, the Pacific coast of Canada lies under the eastern waters of corresponding gyres, with weaker currents producing a temperate area that is transitional in character between arctic and subtropical waters.

The exchange of water between the Arctic and Atlantic Oceans is substantial, with deep Atlantic Ocean waters reaching to the mouth of Hudson Bay and surface Arctic Ocean waters affecting the Scotian Shelf. Thus the division between these oceans is as much a vertical as a horizontal phenomenon. In contrast, in the Pacific Ocean, the narrow and shallow Bering Strait substantially reduces the exchange between the Arctic and Pacific Oceans.

The division between the Arctic and Atlantic Oceans used in this framework is based on sea-ice frequency and the previously defined extents of the Arctic and Atlantic basins (Dunbar 1968; Brown et al. 1975).

Level 3: Temperature

The third level of the hierarchical classification is based on a combination of temperature and sea-ice frequency. In this step, the differences between the Pacific, Atlantic and Arctic Oceans are recognized and are further subdivided into definable thermal regimes.

Temperature is often regarded as the most important single factor governing the distribution and behaviour of organisms on earth (e.g., Gunter 1957). It will become clear that temperature is an important determinant of communities at both broad and local spatial scales. Very few species have geographical ranges covering the entire range of observed aquatic temperatures. Those that apparently do, so-called cosmopolitan species, will probably be found to consist of species complexes.

Within the oceans, the distributions of temperature and salinity are partially confounded and are often used in combination to describe the origins and movements of water masses and their associated fauna and flora. However, temperature alone can serve as an indicator of water masses, at least for surface waters over a restricted geographic range (e.g., the Canadian coastline).

In physical terms, the Arctic Ocean has the lowest salinity, largely as a consequence of the huge amount of seasonal freshwater runoff that, due to the surrounding land masses, cannot easily escape. Stratification in the Arctic Ocean is, therefore, at least as much a consequence of salinity as it is of vertical temperature gradients. The greater ice cover of the Arctic Ocean also tends to uncouple it from (at least) seasonal interaction with the atmosphere; perhaps surprisingly, however, it has become clear that atmospheric transport is a major source of pollutants in the Arctic.

Temperature regimes are distinctly different between the three oceans, and this factor forms part of the rationale for their separation at Level 3. Arctic waters vary in temperature from below to just above 0˚C. The Canadian Atlantic Ocean exhibits a far greater range of temperature than the Canadian Pacific Ocean, a consequence of the larger pattern of circulation in these two oceans.

In the ecological literature, it is often stated that arctic communities are mainly physically accommodated, whereas tropical ones are predominantly biologically accommodated. This is generally deduced from the greater fluctuations in seasonal cycles of biological production and abundance in the Arctic compared to the temperate and tropical regions, which in turn is taken as evidence of a lack of strong biological control between trophic levels. However, temperature fluctuations themselves are no greater in arctic waters than they are in tropical waters. Rather, it is subtle and environmentally important processes of runoff and stratification that trigger the great seasonal production cycles of arctic and subarctic waters. It seems likely that the slower reproductive cycles of arctic marine fauna, compared to the faster ones at higher temperatures in tropical waters, cannot keep pace with these explosions of the primary producers. However, in advancing these comparisons, we should be aware that our perceptions are coloured by two things: first, there is considerable confusion between the Arctic proper and the subarctic region, and second, we have far greater understanding of terrestrial than of marine arctic biological processes. Most of our knowledge, in fact, derives from the terrestrial subarctic regions.

Subarctic, boreal and temperate waters typically support the greatest commercial fisheries. Production is lower in arctic waters because of lower temperatures, lower plant productivity and the short growing season. Production is typically lower in tropical waters because of permanent vertical stratification that prevents significant return of nutrients to surface waters.

ARCTIC WATERS

Separation of arctic and subarctic waters largely follows Dunbar (1968). In the Antarctic, polar and subpolar waters are readily distinguished; indeed, they are physically separated by a temperature discontinuity at the Antarctic convergence. Separation in the Arctic is not so dramatic, and characteristics of surface waters can be variable. Indeed, the subarctic zone has no true counterpart in the southern hemisphere. Arctic waters typically remain at or below 0˚C throughout the year. They generally remain vertically stratified throughout the year, predominantly as a result of salinity stratification. A large part of the Arctic Ocean remains ice covered throughout the year, and floating ice is typical throughout the year. Marine arctic waters have a lower productivity and lower species diversity than marine subarctic waters.

SUBARCTIC WATERS

Although ice generally forms at the surface during the winter, the water mass of the marine subarctic zone generally remains above 0˚C throughout the year. This zone is generally free of ice during the summer, except for adventitious floes and icebergs. The marine subarctic zone is more productive and displays greater species diversity than arctic waters. Subarctic waters may be highly productive during the summer months or where areas remain ice free, depending on the local regime of mixing and upwelling. Such mixing may be tidally or topographically induced, or prevented by the reduced salinity of surface waters. The sea-ice community itself (the epontic community) may be a significant source of fundamental nutrition for many migratory species of fish and marine mammals.

BOREAL WATERS

The boreal zone exhibits moderate ice frequency and generally low summer maximum temperatures. Ice is expected to occur for at least one month and last up to six months, and the average annual temperature is above 0˚C. This zone is unique due to colder arctic waters flowing from the north above warmer temperate waters flowing from the south. Boreal waters may be highly productive during the summer months. Fish and marine mammal species (or their subpopulations) may be widely distributed and range widely.

TEMPERATE WATERS

Temperate waters are generally free of ice throughout the year. They may approach 0˚C during the winter, but generally remain a few degrees above 0˚C. These waters may attain temperatures from 15˚C to 18˚C during the summer months. Higher temperatures develop only locally in sheltered bays with low tidal amplitudes. Whether these waters become stratified during the summer depends on local tidal amplitudes. Temperate waters generally have a higher diversity of species than arctic waters, and may show a unimodal cycle (one peak in midsummer) or bimodal cycle (peaks in spring and fall) of seasonal production, depending on the local mixing regimes (predominantly tidally controlled, but also subject to freshwater runoff).

SUBTROPICAL WATERS

Subtropical waters are advected to Canadian environments; they are not formed at Canadian latitudes. On the east coast, subtropical waters form part of the Gulf Stream system and typically are located off the continental shelf. Their mean boundary is approximately coincident with the continental shelf break, although subtropical waters can be advected onto the continental shelf itself in the form of Gulf Stream ring water. Subtropical waters can be defined as those attaining temperatures greater than 18˚C during the summer but not falling below 6˚C during the winter. This definition appears to apply well to the east coast. Subtropical waters show the highest biological diversity in most taxonomic groups, but generally lower annual production than other areas, except for the ice-covered Arctic. Subtropical waters are typically vertically stratified to some degree and at some depth throughout the year, thus preventing return of nutrients from deeper waters to the euphotic zone. On the Atlantic coast of Canada, numerous larval forms are advected north and many form temporary or distinctive communities in deeper basins.

Level 4: Sea-Ice Cover

Sea ice is important in defining primary productivity potential (Harper et al. 1993). In addition, ice cover substantially prevents vertical mixing of the water column, and therefore prevents resupply of nutrients to surface waters. Consequently, primary production in both pelagic and benthic communities is limited in regions of permanent ice cover. Unlike freshwater ice, which is transparent, sea ice is highly amorphous and crystalline and strongly attenuates the passage of light. However, sea ice develops a new community of primary producers (the diatoms of the epontic community), which supports an important food web of crustaceans, fish and marine mammals at high latitudes. The presence, duration and probability of ice cover is a surrogate for other temperature-related effects, such as overall species diversity, the magnitude of plant and fisheries production, and seasonal timing of many events, including spring-production blooms, reproductive cycles and timing of migrations. Many species have adapted to capitalize on the niche afforded by the characteristics of ice and its availability.

PERMANENT PACK ICE

Permanent pack ice is defined as the area where no regular breakup of ice occurs and where less than 25 per cent of the total ice mass is new ice. Very low levels of production are expected to occur in areas of permanent sea ice.

SEASONAL ICE

Seasonal ice is expected to occur annually with a probability of 9 out of 10 years at the outermost extent of the zone. The ice is expected to last five to six months per year at its limit. This zone contains a combination of pack ice and first-year drift ice. Slightly higher productivity is expected in this zone relative to areas of permanent pack ice.

VARIABLE ICE

Separation of variable ice from seasonal ice is important, since this zone of variable ice represents a transitional area with a high degree of variation in average annual temperature and potential ice cover. In this zone, the probability of ice forming in a given year is between 25 per cent and 90 per cent (i.e., on average, annual sea-ice formation occurs from 2.5 years out of 10 to 9 years out of 10). Moderate productivity is expected in areas of variable ice cover.

NO ICE

Areas where no sea ice occurs are contained within temperate and subtropical waters. The probability of sea ice forming in a given year is less than 25 per cent in these areas (i.e., on average, sea ice forms in fewer than 2.5 years out of 10). The absence of ice allows for greater productivity relative to areas where ice is present.

POLYNYAS

Polynyas are unique phenomena defined as enduring ice-free areas surrounded by ice. They are zones of much higher productivity relative to adjacent habitat.

Level 5: Segregation of Pelagic and Benthic Realms

Marine systems are significantly different from terrestrial systems in having two separate realms with functionally different communities:

- *Pelagic* communities encompass all those organisms that inhabit the water column itself.
- *Benthic* communities encompass all those organisms that inhabit the substrates of aquatic basins.

Note that at the scale of mapping used in this study, species that are demersal will be considered as effectively benthic.

This division is a fundamental distinction of community types recognized in all marine biology and marine ecology texts. Because of the fundamental differences between the organisms inhabiting the water column and those that live in or on the substrates, these realms need to be separated at an early stage in the classification. This separation into pelagic and benthic realms constitutes Level 5 of our hierarchical framework.

In most aquatic ecosystems, these two types of communities are virtually distinct, although they interact. Benthic communities are sometimes further subdivided (e.g., Hedgpeth 1957) into the following:

- Fringing communities (comprising the primary producers and consumers of the euphotic zones)
- Benthic communities proper (those below the euphotic zone, dependent on a detrital economy)

There are pros and cons to recognizing such a distinction. In our hierarchical framework, fringing and benthic communities are considered together to avoid artificial separation of producers and their attendant consumers.

Separation into pelagic and benthic realms represents the first step in the recognition of hierarchies of community types within each of these two major realms. It is probably fair to say that, to most people, separation into pelagic and benthic realms is not an immediately obvious division. Divisions into land versus water, then into the major environment types (freshwater, estuarine, marine), then into approximate thermal regimes (arctic, subarctic, boreal, temperate, subtropical) are likely to seem more natural and be considered to be at a higher level than division into pelagic and benthic realms. All these arguments are constituents of the decision to segregate spatially into pelagic and benthic realms at Level 5 of the hierarchy.

Pelagic and benthic communities are often spoken of as coupled. However, it is perhaps better to refer to them as interdependent because the degree of coupling varies in space and time. Typical pelagic and benthic communities do not share adult species members, except temporarily. However, there are significant two-way interactions between the communities, involving exchange of larvae and energy. Below the euphotic zone, benthic communities are entirely dependent on the rain of detrital material from the pelagic realm. The only exception to this is found in the extraordinary hydrothermal vent communities around the oceanic ridges, which are essentially independent of resources from the overlying water column and are self-reliant on a chemosynthetic sulphur economy.

It will become apparent that the number of hierarchical levels within the pelagic realm is smaller than the number of hierarchical levels within the benthos. We recognize this difference as being a simple consequence of the greater spatial homogeneity of community type within the pelagic realm as compared to the benthos. (Note that spatial heterogeneity in terms of abundance and distributions of organisms can be just as great within the pelagic realm as within the benthos.)

Level 6: Vertical Segregation

Within the water column, depth, pressure, light penetration and turbidity are all interrelated. From the shoreline to the continental shelf to offshore areas beyond the continental slope, water-column depth increases, light penetrates farther (because of greater water clarity and lower turbidity) and pressure increases. Along this continuum, we pass from coastal to neritic to progressively more oceanic communities.

PELAGIC REALM

Community structure changes greatly with depth as we pass below the euphotic zone and encounter the larger pelagic species whose populations may be concentrated into discrete layers but nevertheless become progressively less common with depth.

Water-column depth itself acts as a suitable discriminant of community type and also accounts for the correlated factors of light penetration and pressure. Seasonal thermal stratification is relevant only to the upper 200 metres of the water column. Below this, the water column almost always exhibits some form of stratification (due to changes in temperature and/or salinity), but seasonal variations become negligible due to the great homogenizing effects of ocean circulation and the high heat capacity of water.

The natural classification of the pelagic environment that emerges from these considerations is as follows:

1. Segregate the water column by *depth* intervals at Level 6.
2. Segregate the pelagic zone into *stratified*, *nonstratified* and *frontal* regions at Level 7.

The depth intervals chosen are those generally recognized in the biological oceanographic literature as separating communities that show clear differences in species composition.

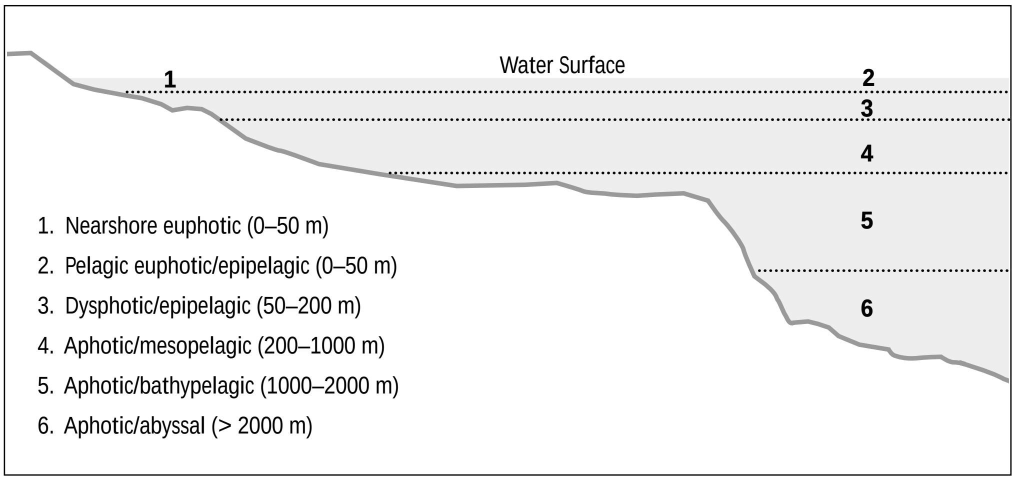
Two further points should be made:

1. Vertical migration by the animals of the pelagic realm obviously integrates trophodynamic processes within these communities in the vertical plane. Nevertheless, vertical structure in these communities is clearly defined and should be recognized as a correlate of increasing water-column depth.
2. We would hardly expect that an MPA would encompass only, for example, the 1000-metre to 2000-metre depth interval of the water column. However, separate recognition of these different communities as occupying different strata, their natural correlation with water depth and the parallel classification of benthic communities should make subsequent selection of MPAs a more orderly process.

BENTHIC REALM

At Level 6 of the benthic hierarchy, the factor that discriminates most significantly between community types is depth, which is a correlate of light and pressure. Depth is chosen as the simplest index of these interacting effects. Thus the intertidal community is typically rich in macrophytic and microphytic plants and shelters a wide diversity of organisms adapted to recurrent immersion and exposure. Below this, but still within the euphotic zone, lie well-recognized community types where plant growth (again either macrophytic or microphytic) can thrive. Below the euphotic zone, resources for animals are dependent on detrital inputs from the euphotic zone, and the coarsest substrates are generally lost in favour of finer sedimentary ones. Figure 2 illustrates the depth intervals of the pelagic and benthic zones.

Figure 2. **PELAGIC AND BENTHIC ZONES OF THE OCEAN**



Level 7: Mixing and Wave Action

Level 7 identifies the effects of water motion on both the pelagic and benthic realms. Tidal currents and wave action can cause stratified waters to mix, thus affecting nutrient supply and turbidity. Wave action also affects the substrate type, especially in exposed or high-slope areas. These effects of water motion play a significant role in the distribution of marine communities.

PELAGIC STRATIFICATION

At scales from metres to hundreds of kilometres, the pelagic realm may appear to be largely homogeneous until more closely examined. A major feature of the pelagic realm is its spatial heterogeneity, generally referred to as patchiness. However, specialized sampling apparatus is needed to reveal these quantitative heterogeneities. Pelagic species demonstrate a great diversity of body size, form and taxonomic type (i.e., a high diversity of phyla inhabit the pelagic realm), but species diversity itself tends to be lower than in the benthos, perhaps as a function of qualitative environmental homogeneity. The pelagic realm itself can be vertically subdivided, as discussed above.

Water motion is manifested in many phenomena over a continuum of scales; some phenomena are predictable or recurrent in time and space, and others are intermittent or unpredictable. Clearly, reference to predictable processes or factors is required for reliable identification of seascapes.

The only predictable factor available appears to be the stratification parameter, which distinguishes regions of the water column that become stratified during the seasonal heating cycle from those that remain vertically mixed. Frontal zones (where S ~ 1.5) between these two regions are highly productive areas that represent one type of temperature anomaly. Although the intensity and exact location of frontal zones may vary from year to year, they can nevertheless be considered as recurrent oceanographic features. The stratification parameter also describes the broad-scale type of summer nutrient regime—impoverished surface waters in stratified areas versus regions of vertical nutrient replenishment—and accounts for the effects of tidal amplitude within the pelagic realm. Note that the effects of major ocean currents will already have been accounted for in the distribution of temperature at Level 3 of the hierarchy.

BENTHIC EXPOSURE AND SLOPE

The next factors to discriminate in Level 7 are combined exposure and slope. Here, two factors are selected that interact with several others to determine community type. The degree of exposure (i.e., to some combination of atmosphere and water motion, such as high currents and wave action) will be of significance only in the intertidal and immediate subtidal regions, not extending below the depth of the euphotic zone (about 50 m). In both the intertidal and subtidal regions, exposure to water movements (predominantly tidal currents and wave action) can range from high (exposed) to low (sheltered). Such exposure, again, is not uniformly confounded with substrate type and particle size. Thus, exposed shores will have shores of solid rock or boulders, but sheltered shores may have any type of substrate, and shores of intermediate exposure will tend to have substrates of pebbles and sand. The type of community observed is closely correlated with the substrate type, as a function of exposure to water motion. The degree of exposure can be at least partially ranked as a function of fetch, which is in turn related to the distance over which winds can blow onto the shoreline. In general, to assess the degree of exposure we do not require direct measurements of tidal currents and wind speeds themselves, but only a measure of fetch.

Below the euphotic zone, exposure to wave action is irrelevant, but currents still play a role in determining substrate characteristics. Here, two basic types of benthic communities tend to develop: erosional communities on coarse substrates and depositional communities on finer substrates. Slope now becomes a confounding factor at Level 7. In the intertidal and subtidal regions, slope predominantly determines the extent of the zones (the lower the slope, the greater the horizontal extent, and vice versa). However, below the euphotic zone, slope is confounded with substrate type. Areas of low slope may have coarse or fine substrates, but regions of high slope will be found only with coarse substrates. This is because fine substrates are inherently unstable at high slopes, and even periodic disturbances will cause accumulated sediments to slump and dissipate. Such high-slope regions are typically associated with the edge of the continental shelf, with sea mounts that rise above the surrounding bottom and with canyons that descend below it. Typically, such areas also experience the effects of local currents more than the surrounding flat plains, and may develop benthic communities that differ significantly from those of regions of finer substrates at similar depths. Thus slope may sometimes act as a partial surrogate for substrate particle size.

Level 8: Benthic Substrate

Habitat types in Level 8 are discriminated according to substrate type. This factor itself is, of course, partially confounded with depth. In shallow waters, substrates span the size spectrum from solid rock to fine sediments, depending on the energy of local water motion. In deeper waters, the energy associated with water motion is greatly reduced and sedimentary substrates predominate. With increasing depth, the strong tendency is for sediments to become progressively finer in particle size and to have lower organic contents until, in the deepest parts of the ocean, sediments have become almost uniformly similar in mud and silt composition.

The increasing uniformity of substrate type with increasing depth means that in deep offshore areas the benthos tends to converge to only a few community types, and many species may be cosmopolitan. Typical species include a variety of deposit feeders, especially tube-building polychaete worms and bivalve molluscs and small epibenthic or burrowing crustaceans. Coarse-textured substrates are typically found in areas of stronger currents where suspension feeders predominate. Here, larger surface-dwelling bivalves and echinoderms may be most evident, along with a diversity of other taxa, such as sponges, sea stars, decapods and other motile forms. Medium-textured substrates often indicate conditions and community types intermediate between deposit-feeding and suspension-feeding communities, and may be heavily dominated by small clams, brittle stars or ascideans. Where such substrates are kept in motion by the action of currents, the abrasive forces may greatly reduce the local biological diversity of larger plant and invertebrate species.

3c Data Requirements for Determining Seascapes

Introduction

One of the strengths of a classification based on physiographic and oceanographic features is that data relating to these features tend to be more consistent and readily available at a national scale than do biological data. Table 4 outlines, to the best of our knowledge, where the data necessary for the classification of seascapes can be found. However, there may be instances, especially in the Arctic, where data are simply not available at the appropriate scale. In such cases, decisions will need to be based on the best available information, and an adaptive management approach should be adopted that allows better information to be incorporated as it becomes available.

Table 4. **DATA REQUIREMENTS FOR THE CLASSIFICATION OF MARINE SEASCAPES IN CANADA**

Factor	Location in Framework	Classes/Description Used in Framework	Source of Map/GIS Data
Environment type	Level 1	Marine—all oceanic waters subject to tidal influences, including the St. Lawrence River	Marine waters can be mapped using either topographic maps or hydrographic charts.
Geographic range	Level 2	Arctic Ocean Atlantic Ocean Pacific Ocean	The distinction between the Atlantic and Pacific Oceans is based on previously defined extents of the Arctic and Atlantic basins (Dunbar 1968; Brown et al. 1975).
Temperature	Level 3	Arctic Subarctic Boreal Temperate Subtropical	Arctic (avg. temp. < 0°C, ice 9–12 months Subarctic (avg. temp. > 0°C, ice 6–9 months) Boreal (avg. temp. > 0°C, ice 1–6 months) Temperate (avg. temp. > 0°C, < 18°C, ice < 1 month) Subtropical (avg. temp. > 6°C winter, > 18°C summer)
Sea-ice cover	Level 4	Permanent ice cover Seasonal ice cover Variable ice cover Absent (includes polynyas)	Use National Atlas of Canada sea-ice map.
Segregation of pelagic and benthic realms	Level 5	Pelagic Benthic	This is a theoretical and management principle and does not require spatial data to segregate realms.

Consideration of Scales for Environmental Management

Edyvane (1996) suggests a scale-adapted approach to environmental management. Such an approach requires an understanding of the spatial–temporal hierarchies of processes and patterns in natural systems and recognition of the scales of human impacts, management and monitoring in human–marine ecosystem interactions. Table 5 illustrates these processes, impacts and management scales.

Given that arbitrary boundaries can be drawn around any biogeographic unit or units, appropriate scales must be defined when applying this classification framework to determine representative MPAs. However, in the development of a representative system of MPAs, we must consider, from a practical viewpoint, the appropriate scale for planning and management.

For example, the following scales must be considered:

- Scales of 1:1 million to 1:3 million may be more appropriate for developing a national system of representative MPAs and reporting on the extent of the system on a national scale.

Factor	Location in Framework	Classes/Description Used in Framework	Source of Map/GIS Data
Vertical segregation	Level 6	0–50 m 50–200 m 200–1000 m 1000–2000 m > 2000 m	Use Canadian Hydrographic Service bathymetry series of charts to determine 0-, 50-, 200- and 2000-m bathymetric contours (note other contours will be required for slope — see below).
Mixing and wave action: Stratification	Level 7 Pelagic	Stratified (S > 2) Frontal (1 < S < 2) Nonstratified (S < 1)	These areas will need to be determined by DFO from maps or satellite images.
Mixing and wave action: Slope	Level 7 Benthic offshore (dysphotic)	Low slope (< 1°) High slope (> 1°)	Slope is considered a significant determinant only in waters > 50 m (other factors are more important in waters < 50 m). These slope classes will be calculated using the bathymetric contours obtained from the Canadian Hydrographic Service.
Mixing and wave action: Exposure	Level 7 Benthic nearshore (euphotic)	Sheltered: fetch < 50 km Moderately exposed: fetch > 50 km, < 500 km Exposed: fetch > 500 km	Wave exposure is significant only for the euphotic regions. Fetch can be calculated from knowledge of prevailing wind direction and distance over which the waves are propagated.
Benthic substrate	Level 8 Benthic	Clay or silt — 0.0 mm to 0.5 mm Sand or pebble — 0.5 mm to 30 mm Cobble or boulder — greater than 30 mm	The Surficial Materials of Canada map (1:5 000 000) is the best-known source that may be used to derive sediment type for Canada's marine waters. Gaps exist in the data from this source, and additional data may be available from Natural Resources Canada, Geodetic Survey Division.

- Scales of about 1:500 000 may be more appropriate at the level of provincial reporting.
- Scales of about 1:250 000 may be best for local planning and determining MPA boundaries.

A strong relationship exists between map scale and the complexity of mapping units. Therefore, the size of mapping units for ecosystem surrogates will accordingly affect the extent to which map units are represented in protected areas. An analysis of published reports and maps by Pressey and Bedward (1991) shows an inverse relationship between relative reservation status of map units and their scale (i.e., degree of subdivision). Representation is more comprehensive for coarse-scale homogeneous map units, where much of the internal variation may be unmapped but still captured by MPAs, than it is for more heterogeneous map units at a finer scale.

Table 5. **SCALES OF HUMAN–MARINE ECOSYSTEM INTERACTIONS**

Scale	**Ecosystem**	**Major Processes and Patterns**	**Human Impacts**	**Management and Monitoring**
Global	Biosphere	Topography (ocean basins) Oceanography Climate (large-scale)	Global warming Sea-level changes	International
1000s km	Bioprovince	Topography (large-scale) Oceanography (major currents, temperature) Climate	Global warming Sea-level changes Ecosystem stress Reduced biodiversity	International
100s km	Bioregion	Topography Oceanography (upwellings, small currents) Sediment supply	Pollution Habitat fragmentation Overfishing Species loss Ecosystem stress Reduced biodiversity	National/regional
10s km	Bio-unit	Topography Exposure Tides Storms Sediment supply	Pollution Habitat loss Overfishing Population loss Exotic introductions Ecosystem effects	Local
1–10 km	Habitat	Exposure Storms Community dynamics Tides Depositional processes	Pollution Habitat loss Overfishing Aquaculture Dredging Population loss Exotic introductions Ecosystem effects	Local
100s m	Site	Depth Predation Competition Storms	Pollution Habitat loss Aquaculture Dredging Population loss Exotic introductions	Local

3d Assumptions, Limitations and Caveats

Introduction

Frameworks and classifications provide a valuable and meaningful basis for aggregating information, depicting patterns, mapping marine representative areas and setting priorities. While the approach used here is flexible, repeatable and hierarchical, it is important, however, to understand what assumptions, limitations and caveats pertain to the overall framework and the resulting classifications.

Assumptions and Limitations

Assumption 1: The ecosystem- and species-level approaches frequently applied to marine conservation are inherently unworkable at broad (i.e., national) scales.

Limitation: These approaches to conservation have been adopted elsewhere. Two major challenges with such approaches for MPA planning are that natural boundaries between marine ecosystems generally cannot be consistently defined, and that there is no clear way to combine mapping data for individual species distributions. These challenges make it difficult to set goals or targets for completing an MPA system.

Assumption 2: The framework presented in this report is an ecological hierarchy of habitats; it is not a spatial hierarchy of habitats.

Limitation: Correspondence between habitat type and spatial scale is, therefore, unavoidably lost. The natural patterns of spatial organization of biological communities must be recognized in proceeding from seascapes to the selection of MPAs.

Assumption 3: By identifying habitat types, we can produce, as far as practicable, a systematic basis for helping to conserve marine biodiversity. If we can identify the appropriate range of habitat conditions, then these should contain a majority of the species we wish to preserve.

Limitation: By identifying and conserving habitat types, a systematic framework for conservation can be developed that represents, either directly or indirectly, biological diversity at the community level. However, the seascape framework does not necessarily capture distinctive, special or unique communities or population-level effects of habitats or species. These effects must be considered in combination with seascape representation when planning MPAs.

Assumption 4: The framework represents, either directly or indirectly, biological diversity at the community level.

Limitation: Seascapes are a convenient approximation of the complexity observed in the real world, but they have not been extensively or rigorously tested. Therefore, they may not yield precise answers in all situations, particularly in fine-scale work and applications involving individual species. Seascapes must be tested, refined and periodically revised as data become available.

Assumption 5: The oceanographic and physiographic factors are indicators of biotic responses and hence of marine biological communities.

Limitation: The advantage of using physical parameters is that, certainly at the larger scale of analysis, they control the distribution of biological organisms and hence are indicators of the major types of biological communities. However, biological communities must ultimately be recognized on the basis of their species composition; biological parameters may, therefore, be more appropriate at the finest scales and be used for local verification of physical correlates. For example, the benthic classification may contain various categories:

- Fixed animal and plant benthos: These species will dictate seascapes.
- Migratory species: These species should contribute to the setting of MPA boundaries.
- Demersal (e.g., flat fish, cod, hake): These species may need to be considered on a population basis (i.e., species by species) in the benthic classification and when determining or fine-tuning the boundaries of MPAs.

Assumption 6: Oceanographic factors will be of significance to both pelagic and benthic communities, whereas physiographic factors will be of significance primarily to benthic communities.

Limitation: This difference is one reason for separating oceanographic and physiographic parameters in the framework. Furthermore, while physiographic factors are (relatively) stable and easy to map (using remote sensing technologies), oceanographic factors are spatially and temporally variable during the year at any one location.

Assumption 7: Different relationships will exist between the identified seascapes and the candidate MPAs that may be selected in any area.

Limitation: Because this framework is an ecological hierarchy and not a spatial one, seascapes will vary considerably in size from one region to another and between realms, depending on the natural heterogeneity of a region and the organization of its representative community types. Thus it should be expected that in some areas a representative MPA will be contained wholly within a given seascape, whereas in other areas an MPA may contain several smaller seascapes. A prime example of the first case would be in pelagic areas or the deep-sea benthos, and a good example of the second case would be a section of coastline, that comprises rocky shores, sandy beaches and sheltered muddy bays. Thus, moving from deep to shallow waters, we would probably expect the following transition:

- Deep water: Several MPAs each contained within a seascape
- Shallow water: An MPA containing several seascapes

Assumption 8: Even when the seascape analysis is complete, a further process is required to proceed from seascapes to MPAs; distinctive areas, special needs and practicalities must be considered in this process.

Limitation: While a scientific rationale exists for the delineation of seascapes and candidate MPAs, the integration of further ecological, socioeconomic, legal and political aspects, and practicalities makes the final selection and design of MPAs subjective and more of an art than a science. Furthermore, processes at both the population level (e.g., migrant species) and the ecosystem level must be considered to determine what may have been missed at the seascape level.

Assumption 9: Certain oceanographic and physiographic data are available for mapping.

Limitation: The data used to derive seascapes are the best available to WWF Canada; where data are not available, surrogates have been used wherever possible. For some areas, all types of data (including surrogates) are limited or not available; in these instances, other approaches must be applied (e.g., modelling).

Assumption 10: Data must be available, either directly or via suitable surrogates at comparable scales, for all areas to be evaluated to ensure consistency of interpretation and comparison.

Limitation: Considerable effort has been invested in the interpretation of data and information used to determine seascapes. Some instances occur, however, in which the scale, type and number of attributes used, the temporal differences between data sets, and the different analytical methods used will affect the appropriateness of the data for comparison between areas (e.g., between oceans).

Assumption 11: The relationships between communities and their physical environment are the same in all three oceans, and equivalent community types consist of the same sets of "ecological species," that is, species guilds or trophospecies.

Limitation: Until more detailed information is known, this assumption can be made. Note that if we can verify that similar community types do, in fact, exist, we could answer questions such as, Is the greater species diversity of the Pacific Ocean reflected in a greater diversity of community types or simply a greater species diversity within them?

Assumption 12: The delineation of seascapes as described embodies a single framework that integrates both pelagic and benthic realms. It accounts for differentiation on the basis of pelagic and benthic communities and for differentiation of light regimes based on euphotic and aphotic zones.

Limitation: The benthic and pelagic regions have been identified on the basis of available knowledge, using a variety of approaches to delineate the boundaries. The fact that the benthic and pelagic classifications are separate requires some integration for the final depiction of seascapes. While this integration is assisted by overlaying the two classifications, some subjective interpretation is required to determine the final seascape boundaries. These integrated boundaries must continually be tested and validated using a range of regional and continental data sets and analytical tools.

Assumption 13: The degree of actual affinity between physical and biological attributes has not yet been rigorously tested for all communities.

Limitation: This affinity should be tested for all communities and the results used to refine the framework.

Assumption 14: The habitat types identified are discrete types as opposed to continuous ecological gradients. We have not considered whether gradients between habitat types are just as important as or more important than habitat types or whether such gradients should formally enter the analysis.

Limitation: The habitat types identified are not simply "fuzzy" boundaries around a disjunction. On the contrary, some of the ecotones may be as extensive as the core seascapes and must be recognized and managed as unique systems.

Assumption 15: There are minimal linkages between terrestrial and aquatic systems.

Limitation: While local estuaries, bays and nearshore areas may be strongly influenced by freshwater runoff and other interactions with the land, the same is not generally true of waters overlying the entire continental shelf. The influence of land on the oceans diminishes rapidly with increasing distance from the shore and increasing depth. A proper perspective, in both evolutionary and biogeochemical terms, is to view the terrestrial environment as a recent extension of the marine benthic environment rather than to examine marine dependencies on terrestrial systems.

Assumption 16: Natural environments are heterogeneous across the spectrum of physical and temporal scales (including seasonal patterns and long-term changes). This natural heterogeneity must be taken into account when designing MPAs.

Limitation: Any assessment of heterogeneity will be biased by the level of information available for a particular region. That is, well-studied regions will usually appear to be more heterogeneous than less well-known regions. The lines delimiting the seascape boundaries are approximations and may, particularly in offshore areas, vary by up to 100 kilometres, depending on a host of factors such as the seasonality of currents. Comparisons with other classifications may also be misleading if focused on the boundaries rather than on the inherent characteristics of the seascapes.

Assumption 17: The framework is naturally adaptable through time as more information becomes available and will become progressively more useful for decision making at finer scales.

Limitation: This framework will become more useful at finer scales if agreement can be reached as to the essential data sets that are both missing and required. Given that federal and provincial agencies are the custodians of the waters within their jurisdictions, any revision of the data sets for these waters should be the responsibility of the respective agencies.

Assumption 18: The seascapes potentially provide a meaningful framework for assessing and reporting on a wide range of natural resource–related activities, including planning, management, monitoring and research in marine and coastal environments.

Limitation: While this assumption is considered to be basically correct, the links between data and information-collection activities need to be strengthened in relation to the seascapes. Given that many potential users of the framework currently have limited understanding of the representative basis of seascapes, the full range of assumptions and caveats must be read in conjunction with the framework and classifications.

Caveats

1. Note that community compositions fluctuate over time. The relevant time span is basically that of the organisms within each community. In plankton, for example, a seasonal succession will occur within years; successive years can be expected to broadly repeat the same pattern of seasonal succession at any given location. In the benthos, as generational succession occurs over one to 20 or more years, we expect to see interannual and decadal succession patterns. In communities of kelp and sea urchins on hard substrates, for example, we may see fluctuations: sometimes these communities are dominated by plants and at other times they are dominated by sea urchins, with few plants occurring. We should regard these as natural changes within a community, not as changes from one community to another. If the region is left to itself, its composition will fluctuate naturally between the extremes of domination by plants or animals. In other areas, however, a natural succession from one community to another will occur, either within years, over several years or over decades. We need to understand when a change in the type of community has occurred and when a change within a community type has occurred.

2. Note that zonations within the littoral zones have not been presented as separate habitat types, although in fact they are such. Classification has not been done at this level because it is assumed that, for practical reasons, any MPA declared will encompass the full array of habitat types, vertically organized within the local intertidal region.

3. In constructing a hierarchical classification for the benthos on the basis of physiographic and oceanographic factors, we encounter three basic problems:

   - Many of these factors are confounded, repetitive of one another, correlated or can act as surrogates for each other under at least some conditions. For example, factors such as depth, degree of shelter or exposure, and wave action can all, in some combination, define substrate particle size.

   - The sequence in which factors should be placed in the hierarchy is not generally agreed on, and some hierarchies of classification are multidimensional.

   - No hierarchical system of classification has been adequately tested through some sort of analysis equivalent to a cladistic taxonomic analysis.

Nevertheless, there is little doubt that these factors *in some combination* are effective and efficient descriptors of habitat types for the benthos.

4

Planning a National System of Representative MPAs

4a

Guiding Principles for Designing a System of MPAs

Introduction

This framework was developed to provide a consistent physical classification system for the marine environment to guide the selection of MPAs. However, a classification system alone will not be sufficient to prescribe the location and design of MPAs. Even when the seascape analysis is complete, further exercises must be carried out to determine ecological integrity, to identify priority areas or special needs and to ensure that practicalities are considered before proceeding to the selection of MPAs.

While the major focus of this project was the development of a framework for seascape identification, the integrity of areas to be identified must also be considered subsequently. In terrestrial systems, this involves concepts of ecosystem structure and function, including aspects of size, naturalness and ecological disturbances. Separate identification guidelines or decision rules will be needed to rank areas in terms of importance within marine systems (e.g., sites for rare and endangered species).

It should be stressed that the first stage of the process—the recognition of seascapes—is a natural one in that all areas of marine environments are included in the classification and are separated by defined physical characteristics of the environment. In contrast, the second stage of the process—the selection of MPAs—is a more artificial process, requiring the input of data or information according to several somewhat arbitrary criteria related to conservation value and economic factors.

Especially in the early stages of designing an MPA network, MPAs of an almost endless combination of sizes and locations could sample all seascapes. Economic considerations, connectivity analyses and value judgments (e.g., about key habitat for endangered or commercial species) can be used in conjunction with seascape representation analysis to guide the specific placement of MPAs. The key point is that seascape representation defines the goal of a completed network and serves to balance common anthropocentric concerns that tend to concentrate on marine mammals and commercial fish species.

Part 4 of this report examines the criteria that can be used to move to the second stage, that of the selection and design of MPAs.

Basic Principles for the Selection and Design of MPAs

Thackway (1996a) has reinterpreted four broad principles that should guide the identification, selection and establishment of any MPAs (based on Salm and Price 1995):

1. **Recognize that goals will determine the identification and selection processes.** If the goal is to represent all communities within a biogeographic region, then a different set of identification and selection criteria would be used than if the goal is to protect critical habitat for a fishery species. An integrated goal that includes the needs of all sectors of society (e.g., those relating to conservation, fisheries, Aboriginal peoples, tourism) is obviously more complex, ambitious and controversial than a single-purpose goal.

2. **Be realistic and practical in defining goals and objectives.** There is a need for common sense, sensitivity and pragmatism regarding the aspirations and capacities of both the local community and the managing agencies, particularly with regard to ongoing resources for MPA management.

3. **Establish and manage selected areas as components of larger ecological systems.** The objectives of the MPA program determine the identification and selection processes and are important determinants of the criteria used. The representative approach outlined in this report addresses the wider ecological aspects. However, it is relatively simple to prove scientifically that a particular area is unique in one or more respects, and hence to develop a scientific case for its protection. In contrast, the concept of identifying and protecting representative areas is much more difficult to communicate.

4. **Maintain flexibility in designing a system of MPAs**. To establish viable MPAs requires consideration of the range of parameters that will determine the viability and the success or acceptability of the MPA in the local area and region. Once these risks and constraints are understood, the MPA can be designed and adapted accordingly. Although ecological criteria should be of primary importance in identifying candidate MPAs, economic and sociocultural priorities and issues cannot be ignored in the process of assessing the feasibility of MPAs and fine-tuning the final configuration; furthermore, such factors can make or break an MPA proposal.

Thackway (1996b) states the following:

> Provided the identification and selection of MPAs is based on the sampling of representative ecosystems (i.e., assumed to represent ecological processes and components of biodiversity) and they are adequate in terms of size and connectivity, they provide essential self-sustaining entities which act as safe-houses for reintroduction and rehabilitation in areas which are otherwise subject to minimal management controls and regulations.

Influence of the Goal of MPAs on Their Selection and Design

In most countries, government agencies are responsible for establishing MPAs. However, in some jurisdictions (including Canada), one or more natural heritage or conservation agencies, as well as fisheries management agencies, have legislative responsibility for establishing MPAs. The difference in the mandates of the agencies has implications for the selection and management of MPAs and the design of their boundaries.

When an agency's aim is to design MPAs for an identifiable economic benefit, the resulting network of MPAs will be different from one predicated solely on ecological criteria. For example, a fisheries agency may design and establish MPAs to provide "recharge" areas for recreational and commercial fish stocks in waters adjacent to the MPA that have been depleted of fish through harvesting. Similarly, a management philosophy of encouraging tourism may result in the selection of a different set of protected areas. In both instances, the economic benefits may pervade the agency's philosophy.

In contrast, if the key goal for an MPA is "to protect representative biological communities [and] to act as source areas, reference areas, and reservoirs of biodiversity and species abundance" (Great Barrier Reef Marine Park Authority 1994), then the selection and design criteria must consider different aspects. For MPAs based primarily on ecological criteria, Done (1996) endorses this goal as appropriate for the following reasons:

- Representation is not the sole end in itself.
- The goal embraces the concept that protected biological communities "serve" the broader biological system (through, for example, protection of "source areas" of spawning stocks of species fished outside the protected areas).
- The goal recognizes the importance of reference areas as a basis for monitoring the effectiveness of management.
- The goal addresses biodiversity conservation per se.
- The goal acknowledges that biodiversity conservation stands or falls on maintenance of viable species populations (species abundance).

Similarly, MPAs declared for the protection of threatened or endangered species will be different from those established for the conservation and protection of commercial or non-commercial species. MPAs designed for the protection of threatened or endangered species must provide enough suitable habitat and space to maintain the communities and the genetic pools that support viable populations of these species. The success of these MPAs also depends on the appropriate and complementary use of adjacent lands and waters.

Ill-defined objectives for MPAs often result in a dilution of the conservation effort. This is a concern particularly in multiple-use MPAs that aim to accommodate all users. If the primary purpose of an MPA is accepted as being a tool for the conservation of biodiversity, then ecological values must be given precedence over other values when selecting and designing an MPA (Inglis 1993).

In short, the mandate of the relevant agency will determine the primary purpose for developing MPAs, and this, in turn, will determine the selection criteria or targets that are used to achieve the best fit with that primary purpose. Different criteria are needed for evaluating ecological values versus socioeconomic values; however, Smith and Theberge (1986) note that ecological goals and socioeconomic goals are not mutually exclusive. Areas of high biodiversity are often also attractive for their conservation, resource use, tourism and cultural values. Such links between biological values and other social and cultural values cannot be ignored and often play a critical role in the success of any MPA (Kenchington 1990).

4b

Selection Criteria for MPAs

Much of the existing literature on MPAs includes various lists of criteria that may be applied in the identification and selection of MPAs. For example, Kelleher and Kenchington (1992) suggest selection criteria for MPAs grouped into eight categories, which have been adapted to the seven listed in Box 4. This list has been adopted by the IUCN and is often cited.

Box 4. **PROPOSED CRITERIA FOR ASSESSING THE SUITABILITY OF AN AREA AS AN MPA**

Naturalness

- Extent to which the area has been protected from, or has not been subject to, human-induced change

Biogeographic Importance

- Inclusion of rare biogeographic qualities or representation of a biogeographic type or types
- Inclusion of unique or unusual geological features

Ecological Importance

- Contribution to the maintenance of essential ecological processes or life-support systems (e.g., a source of larvae for downstream areas)
- Integrity
- Degree to which the area, either by itself or in association with other protected areas, encompasses a functional ecosystem
- Inclusion of a variety of habitats
- Inclusion of habitat for rare or endangered species
- Inclusion of nursery or juvenile areas
- Inclusion of feeding, breeding or rest areas
- Inclusion of rare or unique habitat for any species
- Preservation of genetic diversity

Economic Importance

- Existing or potential contribution to economic value (e.g., recreation, subsistence, use by traditional inhabitants, appreciation by tourists and others, use as a refuge nursery area or source of supply for economically important species)

Social Importance

- Existing or potential value to the local, national or international communities because of its heritage or historical, cultural, traditional, aesthetic, educational or recreational qualities

Scientific Importance

- Value for research and monitoring
- International or national importance
- Potential to be listed on the world or a national heritage list; to be declared as a biosphere reserve; to be included in a list of areas of international or national importance; or to be the subject of an international or national conservation agreement

Practicality or Feasibility

- Degree of insulation from external destructive influences
- Social and political acceptability and degree of community support
- Accessibility for education, tourism and recreation
- Compatibility with existing uses, particularly by local people
- Ease of management and compatibility with existing management regimes

To achieve a representative network of MPAs, the selection of sites could follow these steps:

1. Systematically classify all marine habitat types using a consistent framework.
2. Systematically choose a network of candidate MPAs using the framework to incorporate the representative patterns characteristic of each seascape.
3. Further assess the candidate MPAs, ensuring, wherever possible, that other important, unique or distinctive features are incorporated and that other non-ecological criteria (e.g., socioeconomic aspects) are considered. If, for valid or critical reasons, the candidate MPAs initially chosen are deemed inappropriate, then similarly assess other candidate MPAs until acceptable MPAs and, ultimately, a network of representative MPAs are identified.
4. Develop appropriate zoning for the MPAs chosen to ensure that all the essential elements of the ecological diversity of the marine communities remain adequately protected in perpetuity.

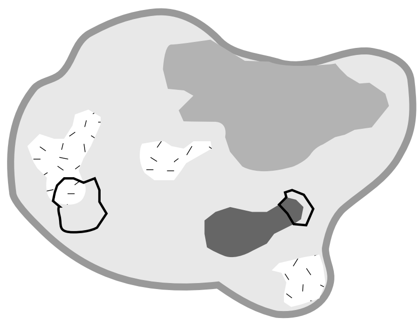
Figure 3 illustrates three options for designing a network of MPAs in a natural region, based only on seascape representation (i.e., the first two steps above).

Currently, most marine management agencies identify and select MPAs by a manual scoring based on a set of selection criteria (such as that listed by Kelleher and Kenchington 1992) or an iterative evaluation of similar criteria. Research by Pressey and Nicholls (1989) on the value of such scoring of selection criteria compared with systematic interactive computer-based algorithms showed that scoring methods were less efficient than interactive computer-based approaches. The major advantages of such computer-based approaches are that they provide flexibility for testing and comparing different design scenarios (or reserve options) and for comparing the costs and benefits of these different reserve options. However, not all agencies have access to the detailed GIS data required to use such methods.

When identifying and selecting MPAs, we need to consider the following points:

- If we are to trying to choose a set of MPAs that represent the marine biodiversity within an area, we will need to use a systematic ecological basis for the selection process. Decisions should be made within the context of an entire area, rather than by considering only small locations about which more details are known.
- Many agencies and jurisdictions apply these criteria largely in isolation of neighbouring jurisdictions and even agencies within the same jurisdiction. There is, therefore, a need to define and apply consistent and appropriate criteria and guidelines for the identification and selection of individual MPAs.
- Where there is a multitude of identification and selection criteria, it may be difficult to rate them all equally.

Figure 3. **CONCEPTUAL OPTIONS FOR A REPRESENTATIVE NETWORK OF MPAs IN A MARINE NATURAL REGION**



Option 1

No representation of seascape A

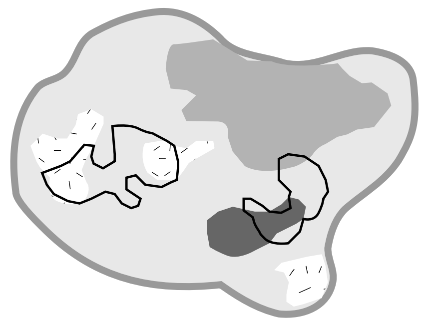
Moderate representation of seascape B

Partial representation of seascape C

Partial representation of seascape D

Assessment

Natural region partially represented.



Option 2

Partial representation of seascape A

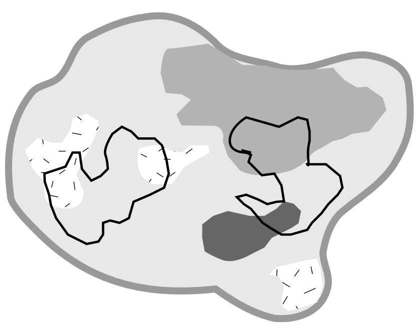
Adequate representation of seascape B

Moderate representation of seascape C

Adequate representation of seascape D

Assessment

Natural region moderately represented.

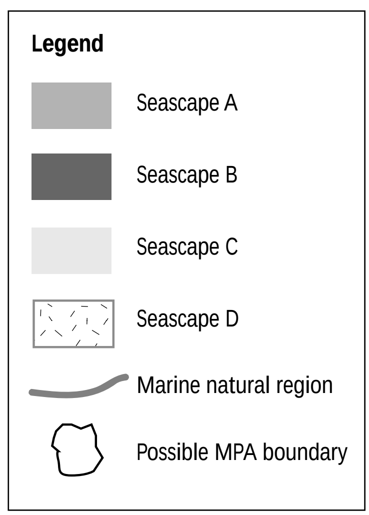


Option 3

Adequate representation of seascapes A, B, C and D

Assessment

Natural region adequately represented. This is the best option for representation because the candidate MPAs adequately represent each of the seascapes and have connections to surrounding seascapes.



Source: Adapted from Kavanagh and Iacobelli 1995.

4c Ecological Principles and Criteria for Designing a System of MPAs

When designing representative MPAs, we must consider additional ecological design criteria. The environmental connectivity of areas, the appropriate shape and size of a reserve, the level of natural heterogeneity, the ecological vulnerability and the need for replication are important considerations. There is no known order in which these ecological criteria should be applied; rather, an iterative approach is recommended when developing an MPA proposal. Furthermore, some criteria will be more critical than others, depending on the specific location or the circumstances.

A new principle also enters the process when proceeding from seascapes to MPAs. Whereas our analysis of seascapes was conducted at the community level, to proceed to the MPA level, we must take into account processes at the population level. In particular, we need to examine what populations (e.g., migrant species) we may have missed at the community level and how they exploit the environment spatially.

Reserve Size

The issue of whether a candidate protected area will be adequate in size is important, particularly in the case of fragmented or highly modified seascapes or in areas that are undergoing degradation. In most cases a precautionary approach would suggest that larger rather than smaller areas should be chosen and that strictly protected areas should have appropriate buffer zones. It is also preferable that strong conservation management principles be applied as much as possible outside and surrounding the areas of ecological importance.

The size of a candidate MPA may be influenced by the proposed management type (see the discussion of reserve management type below). Consequently, while an ecological basis should be the primary determinant of the size of a reserve, its future management may also determine the area likely to be socially and politically acceptable. In all cases, strong involvement of user groups and the community is required in setting up the system for it to be accepted and effective (Benzie 1996).

The principle of a buffer zone protecting a core site from human impacts is well established and, wherever possible, should be applied to all MPAs. However, since coastal and continental-shelf environments are often linear in nature and subject to established heavy use, buffering, although desirable, may be impracticable in some cases (Kelleher and Kenchington 1992).

From an enforcement perspective alone, MPAs should, as a general rule, be large and manageable rather than small and highly dispersed with complex zoning configurations.

If the goal of an MPA is primarily to protect a specific marine species, Shepherd and Brown (1993) maintain that reserve size must be determined in relation to the internal dynamics and size of the metapopulations in question. Small metapopulations will require the conservation of a much larger fraction of those metapopulations conserved than would large metapopulations with many interconnecting local populations. For example, South Australia's only long-term abalone reserve (West Island Reserve) failed to protect a metapopulation because it was too small and enforcement was inadequate for preventing poaching.

Reserve Networks

Ballantine (1991) stresses the need to consider the following issues when deliberating over reserve size and number:

- Many marine populations have dispersive phases and reproduction is decoupled from recruitment. It is rarely possible to identify the parental origins of any particular population or to specify which area(s) the offspring of one population will recruit. In any case, the answer is likely to be different for each species (with different reproductive seasons and length of planktonic phase) and often different in the same species for different years (owing to current variations, whether random or systematic). It follows, therefore, that a well-designed network of reserves (including spaced replicates) is much more effective in promoting recruitment (including to other reserves) than a few large ones.
- Present knowledge of the interactions between different marine habitats and communities is sufficient to show that these are common and self-sustaining, but it is not enough to specify the size of area that would be self-sustaining. Consequently, while reserves should contain as many representative habitats as possible, this should not override the principle of a network.
- The minimum area of biologically useful marine reserves may be as small as a few square kilometres (except where the entire system itself is smaller, e.g., a small estuary). However, in all cases, the addition of adjacent areas is highly desirable, since important interactions with such adjoining areas are very likely.

Central to the concept of a network of MPAs is the understanding that protected areas should operate as an interconnected group or system. The main requirement, then, is to design protected areas so that species can move readily from one reserve to another; this is not necessarily done by providing strips of habitat connecting larger habitat areas, but instead by providing habitat that maintains broad patterns of movement (Schmeigelow 1997). Other management strategies, such as temporal regulation of human activities, may also be critical for species movement or recruitment. Therefore, the following must be considered when configuring reserves:

- The type of movements important for population persistence (e.g., juvenile and adult dispersal, foraging, seasonal migration)
- The spatial and temporal scale of these movements
- The natural levels of connectivity in the system
- The broader context in which the MPAs are located (i.e., the surrounding management regimes)

Reserve Connectivity

Done (1996) explains that for MPAs to act as source areas and reservoirs of biodiversity and species abundance, they need connectivity. A good source area will be one chosen to maximize the probability that the propagules emanating from it will actually succeed. That is, they have a higher than average probability of arriving at an appropriate habitat (either another MPA or not) while still viable (Kelleher et al. 1994).

Done (1996) continues:

> Potential protected areas will vary in the degree to which they are self-seeding and the degree to which they rely on outside areas for replenishment of populations depleted due to natural attrition, harvesting or habitat degradation. There are two bases for this variability. First, there is great variability in the buoyancy and capacity for active swimming of the planktonic stages of different biota. Second, the current regimes to which the planktonic stages will be exposed are regionally variable.

The following lists a number of relevant aspects for connectivity if an MPA is specifically designed for a particular target species (based on Noss 1995):

1. Mobility or dispersal of the target species including the following:
   - Species-specific habitat preferences for movement
   - Dispersal distance or scale of resource utilization
   - Rate of movement or dispersal
2. Other ecological characteristics of the target species (e.g., preference for a particular structural feature; feeding requirements; mortality risks)
3. Seascape context: structural characteristics and the spatial pattern of the seascape
4. Distance between patches of suitable habitat
5. Interference from humans and predators

Computer simulations based on best available models of underlying oceanographic and biological bases have been used both to optimize site selection based on the best use of present knowledge (e.g., James et al. 1996) and to highlight the needs for filling gaps in data and understanding. However, the interest in the role of source and sink sites in determining recruitment and, therefore, their inclusion in MPAs may belie our actual capacity to identify these effectively, particularly as these factors vary from organism to organism and from time to time. Nevertheless, although a site may not be an important sink or source, it may still be important in terms of its representativeness.

Reserve Shape

A considerable number of theoretical approaches to the optimum shape for reserves exist; given the problems of the impacts associated with edge effects in terrestrial systems, the optimum shape for a reserve in such systems is frequently believed to be circular. However, because of the fluid and mobile nature of the marine environment, the issues associated with edge effects on boundaries are not as relevant as they are in terrestrial reserves. Furthermore, the optimum shape for marine reserves is not the circular shape depicted in many of the theoretical texts (i.e., a core area surrounded by concentric circles of buffer). Rather, the optimum shape for an MPA is dependent on criteria similar to those defined for the design of networks — such as juvenile and adult dispersal, foraging, seasonal migration, natural levels of connectivity — and the surrounding management regime.

The resulting optimum shape for an MPA (unless it is large and encompasses a broad area) will depend on the purpose of the MPA. If the goal is to maximize protection of a single species, the MPA should be parallel to the coast and/or the prevailing current. If the goal is to maximize biodiversity in the MPA, a cross-shelf configuration may be optimal. However, a number of practical aspects require consideration when determining the configuration of an MPA boundary. Spatial boundaries are relevant to only some facets of integrated management of marine biodiversity, and lines on maps have limited validity when it comes to open waters, particularly if those lines are based on seabed features.

Once the ecological determinants have been applied to a candidate area, the actual shape of a preferred MPA, as well as the management regimes within the MPA, can be determined on a pragmatic and socioeconomic–legal basis. For practical reasons, it is often necessary to align ecological boundaries with more distinguishable human-related features. Wherever possible, these boundaries should encompass the underlying ecological boundaries. Many pragmatic considerations can influence reserve shape:

- Recognizable boundary features and markers
- Ease of access
- Existing levels and types of uses
- Potential in terms of what might be legally declarable
- Potential in terms of what might be better for enforcement and surveillance

Reserve Management Type

Whether a small no-take area is better (from a conservation standpoint) than a larger multiple-use MPA will obviously depend on the specific circumstances. However, given that marine ecosystems are relatively large, fluid and interconnected, it follows that a network of reserves (including spaced replicates) could be more effective in promoting recruitment (including to other reserves) than would be a few large reserves (see discussion of networks above). More reserves and protected areas foster biological links that increase these advantages even further. For example, a few unexploited marine reserves are unlikely to have any general or widespread effects, however large the difference between their state and that of adjacent exploited areas. In contrast, a network of such reserves is likely to have such effects, even if we do not know, and may never know, which parts of the network achieved which results.

Many people consider the management model based on a large multiple-use MPA with zoning (e.g., the Great Barrier Reef Marine Park [GBRMP]) to be advantageous in that it can provide for an overall level of protection and for consistency in planning and management, as well as enable strategically placed, small, highly protected core areas. Such a model can serve both to preserve biodiversity and to help sustain ecosystem integrity and allow the use of marine resources within the larger managed area. Pressey and McNeill (1996) give the following argument in favour of multiple-use areas:

> The multiple use model allocates activities through zoning and is considered more effective than small, isolated, highly protected areas for several reasons:
>
> 1. Ecologically, it recognizes the temporal and spatial scales at which marine ecosystems operate;
> 2. Practically, it is easier to manage and potentially buffers and dilutes impacts of activities in areas adjacent to strictly protected areas; and
> 3. Socially, it helps to resolve and manage conflicts in the use of natural resources.

However, few MPAs of a size comparable to the GBRMP have been declared to obtain maximum benefit as outlined by Pressey and McNeill (1996).

Reserve Replication and Redundancy

Any large disturbance in marine systems, whether natural (e.g., cyclones) or man made (e.g., oil spills), can destroy the very qualities of an MPA—its intrinsic values as well as its connections—for which it was chosen. The need to plan for such disturbances is, therefore, well accepted in the field of protected area management. However, unlike in terrestrial systems, where the recommended goal is reservation of areas large enough to accommodate any disturbance, in marine systems replication or redundancy is considered a more prudent strategy. MPAs should, therefore, be configured to minimize the likelihood that the entire representation of a seascape would be degraded at any one time by natural or human disturbance.

For example, even if one metapopulation were to suffer decline due to disease, overharvesting or habitat destruction, the entire stock would be less at risk if other reserves existed to protect other metapopulations (provided these are unlikely to all suffer the same disaster at the same time). Essentially, the more MPAs that are declared, the greater the chance of a variety of benefits accruing.

Seascapes and candidate MPAs generally convey no information about the relative value or protection priority for each seascape. Pressey and McNeill (1996) therefore recommend a specific approach:

> More information on the relative value of planning units can be conveyed by analyses that show the irreplaceability of areas (Pressey et al. 1994). These analyses produce a map of all the individual areas being considered for reservation, indicating two things:
>
> - The likelihood that any particular planning unit will be needed as part of a representative reserve system
> - The extent to which the options for achieving a representation goal will be reduced if the planning unit is made unavailable for protection
>
> Irreplaceability puts a number on the obvious fact that there are no options for reserving some units but many options for reserving others. Some units are totally irreplaceable, either because they contain unique features or because they contain so much of one or more features that the reservation goal can no longer be achieved if the unit is not reserved. Other units are replaceable to varying degrees. A map of irreplaceability in a region is therefore a map of options for developing a representative reserve system.

Where the goal is to conserve biodiversity, it is necessary to identify and select priority areas on the basis of agreed biodiversity values.

4d Other Selection Criteria for MPAs

Decisions about whether any particular coastal or marine areas should be conserved, developed or left as they are ultimately hinge on arguments regarding the relative merits of ecological goals compared with socioeconomic goals. Whether to give greater weighting to ecological goals or to socioeconomic goals (including the decision whether to establish a conservation reserve) is primarily a political and social process like any other public policy decision.

In developing options for MPAs, planners initially need to define a number of candidate areas using ecological principles that recognize representativeness and that consider additional ecological determinants such as unique and special areas. However, planners also need to recognize that the decisions on final MPA configurations (e.g., locations, boundaries, size, type) will necessarily involve consideration of a much wider range of selection criteria and other determining factors. Consequently, once the above ecological criteria have been applied and a number of candidate MPAs have been identified, the extent of their boundaries must be optimized. To do this, a number of subordinate criteria must be considered; such economic, social, political, legal and cultural considerations are discussed below. However, it is important to realize that some of these additional criteria may also act to constrain the development of a representative system of MPAs by providing reasons why an area should not be included in an MPA.

It is rare that planners or managers have the luxury of determining an ideal boundary or configuration for any form of conservation reserve or MPA. Rather, the precise location and boundaries of an MPA are usually the collective decision of park planners, politicians and the public (Ballantine 1991) and are not based strictly on any scientific formula or checklist. Science may inform the debate and influence the outcome, but it will not be alone in making the final decision. Ultimately, there must be enough public and user support for MPAs to overcome the natural resistance of some special interest groups and decision makers so that they change the status quo.

In evaluating candidate MPAs, the approach used by Parks Canada in coordinating workshops of experts to provide the most accurate and current information on a particular location (e.g., Mercier 1995) is valuable, particularly for determining unique and special areas that also need to be considered when evaluating MPA proposals. Ideally, planners will use iterative approaches using GIS techniques, in conjunction with expert opinion.

At this stage, a review of the benefits of no-take MPAs versus multiple-use MPAs is appropriate.

MLSS (nd) summarizes some of the social and managerial benefits of harvest refugia (no-take MPAs) and multiple-use MPAs (noting that these can be used in complementary fashion).

Benefits of No-Take MPAs

1. Fairness and equity to user groups: No single group is favoured at the expense of others, as harvest refugia prevent use by all fisheries.
2. Simplified management and enforcement: Because harvesting is totally prohibited, management and enforcement are simplified. Violations can be detected easily by fisheries officers, volunteer wardens or the public. Similarly, it is easier to communicate the no-take regulations to all visitors.
3. Community involvement: Because harvest refugia can be relatively small, coastal communities can identify areas that need protection and request legal protection for those areas by governments.
4. Research and monitoring: No-take zones can be used to establish a baseline by which to assess change in unprotected areas.

Benefits of Multiple-Use MPAs

1. No-take zones: More often than not, some zones within a multiple-use MPA are likely to be designated as no-take zones.
2. Integration of human activity and conservation: Innovative solutions can dispel the myth that conservation and resource use are incompatible.
3. Adaptive management: Zones can be reviewed on a regular basis, allowing managers and scientists the flexibility to respond to changes in human activity and the environment (e.g., Great Barrier Reef Marine Park).
4. Development of management partners: As human activities are integrated in multiple-use MPAs, coastal communities and stakeholders become important long-term partners in planning and management.
5. Research and monitoring: Whereas no-take zones establish control sites for research, multiple-use MPAs can provide opportunities for researching and monitoring the sustainable use of an area.

Airspace Above an MPA

When most MPA proposals are evaluated, virtually all consideration is given to the marine aspects alone (pelagic and benthic). Little consideration is given to the airspace above an MPA, yet this is often a critical component for successful management of the MPA. For example, if the conservation of whales is a priority within an MPA and there are no controls over aircraft, such as controls on minimum flying heights, then aircraft can have major effects on such species, particularly if whale watching becomes a major tourist industry.

The use of hovercraft in sensitive areas today can have major effects if such use is not managed, yet it could be argued that hovercraft are operating over rather than within the marine environment. Furthermore, with rapid advances in technology, it is likely that in less than a decade some vessels will probably be surface assisted and extremely fast (i.e., operate more like extremely low-flying aircraft with the ability to cover huge distances quickly and easily). Consequently, an MPA should also extend some distance above the water surface; an example of airspace being part of an MPA is the Great Barrier Reef Marine Park, where protected airspace has been declared up to a height of 3000 feet above sea level. While the navigation of most aircraft is unimpeded in most zones of the park, this regulation provides managers with the ability to apply controls when and where necessary.

4e Special Areas

A representative approach to MPAs specifically does not identify special or unique sites for protection. Rare species and special sites need to be dealt with separately from ecologically representative sites.

The Oceans Act (section 35) has provision for "the conservation and protection of unique habitats." Other possible examples of unique areas cited in the DFO (1997) discussion paper include "breeding areas, spawning areas, nursery areas, genetic 'seed banks,' 'rare species' habitats, polynyas, estuary zones, tidal flats, kelp forests, offshore banks, permanent or seasonal upwelling or mixing areas, deep sea vents, sea mounts, salt marshes, or marine mammal habitat." Note that some of these areas are already captured at the community level by the delineation of seascapes; others, predominantly those at the population level, are not.

People generally are more likely to see the point of special status for special or distinct areas than they are to comprehend restrictions on existing uses of representative areas. It is therefore critical that the scientific values of representative MPAs be explained.

An example of a special community that warrants protection is given by McNeill (1996). McNeill discusses some of the biological characteristics of sea-grass beds, citing the design of various existing MPAs that in no way reflect an understanding of the critical processes structuring the sea-grass systems (e.g., spatial and temporal variability of species, recruitment, seasonality, life cycle requirements). McNeill justifies protecting the maximum area of sea-grass beds within estuaries and argues that their protection should override other considerations in the design of MPAs for the following reasons:

1. Maintenance of seagrass beds and their associated communities is critical for the long-term sustainability of coastal ecosystems.
2. Seagrass habitats, located within estuaries, are more vulnerable to damage and destruction from physical disturbance and adjacent land use than many other marine habitats.
3. Seagrasses lack resilience to disturbance; once destroyed, seagrass beds do not readily recolonise.

Many other special or unique areas might be important to include in a system of representative MPAs:

- Habitat for rare or threatened species
- Source areas for recruitment and replenishment
- Important corridors for migratory species
- Feeding, breeding or resting areas
- Nursery, juvenile or spawning areas
- Areas of unusually high species richness
- Natural or unspoiled areas
- Unique or unusual geological features
- Benchmark and reference sites
- Areas of cultural or traditional significance

A well-planned system of MPAs can be representative of all habitat types and still capture a wide range of these areas of special importance.

4f Summary: Guiding Principles for Choosing Individual MPAs

MPAs will often be chosen according to different ecological, economic and cultural priorities. However, there are some principles that can be used to guide the selection and design of all MPAs to maximize conservation gains.

1. MPAs should be chosen in relation to marine representation and not solely in relation to themes or species that are high in public profile.

2. The precautionary principle should be adhered to, which means that lack of scientific certainty about such aspects as where MPAs should be located, how large they should be or how many are needed should not be used as a reason for not establishing MPAs.

3. Information about special or unique biological communities, habitats or species, where available, should be used to enhance the selection of MPAs.

4. The following guidelines should be followed when determining the management plan to ensure that MPAs maintain ecological integrity:

   - Natural processes and disturbance regimes should be allowed to continue.
   - Viable populations of native species should be maintained in natural patterns of abundance and distribution.
   - Species dispersal should be maintained by functionally linked, core no-take areas.

5. No-take MPAs, or no-take zones within an MPA, should be established to provide ecological benchmarks and allow for naturally functioning population interactions.

6. The size and configuration of MPAs should be sufficient to do the following:

   - Incorporate a diversity of marine enduring features.
   - Maintain the long-term integrity of natural communities.
   - Include both resident flora and fauna, as well as relevant migratory species.

7. As far as practicable, representative samples of all communities in the MPA should be included within one or more no-take zones.

8. Significant breeding or nursery sites should be included either within no-take zones or within an appropriate seasonal closure (that is, given a high degree of protection on either a permanent or a seasonal basis).

9. Single zonings or regulatory provisions should surround areas with a discrete geographical description (i.e., if at all possible, single islands or reefs should not have multiple zonings or split zonings, which can have major implications in terms of public confusion and enforcement issues).

10. In the pattern of zones within a multiple-use MPA, sudden transitions from highly protected areas to areas of relatively little protection should be avoided. The concept of buffering should be applied wherever possible.

11. In the selection phase, all available information on human-use patterns, economic and social values, and Aboriginal cultural values should be considered.

12. Some habitat types can be sampled equally well by MPAs at a number of different locations. Furthermore, different configurations of a candidate area can sometimes satisfy similar ecological criteria. In these cases, the option that imposes the least short-term and long-term cost (where cost does not refer only to monetary value) to nearby communities and stakeholders should be adopted.

4g

Conclusion

WWF Canada's goal is the completion of a national network of MPAs by the year 2010. The goal is not to create a system for the sake of having a system; rather, the goal is one of a suite of essential actions that will help ensure the health of our oceans and Great Lakes, along with the sustainable use of areas outside MPAs and the proper regulation of pollutants and toxins.

A system of MPAs must be more than an ad hoc collection of sites with no overarching rationale or protection standards. Conservation of biodiversity will not be achievable without a network of well-planned and scientifically based protected areas, with strong protection standards, as part of good overall oceans management.

The framework developed here is meant to help provide an ecologically sound, consistent and transparent method to define the overall goal and to generate and assess candidate sites. Furthermore, this framework uses physiographic and oceanographic features that are, for the most part, readily available and that describe community diversity at a broad scale. No one knows with certainty how many MPAs are needed in Canada, where exactly they should be located or how large they should be to ensure conservation of our marine biodiversity. However, we don't have the luxury of waiting until all the information is at hand before we begin. We must make decisions based on the best available knowledge and incorporate new information as it becomes available. The sooner we begin and the more people that are involved, the more effective the system of MPAs will be.

Glossary

Glossary

abiotic. Without life.

abyss. The great depths of the oceans, usually considered to be depths of 2000 to 6000 metres, a region of low temperatures, high pressure and an absence of sunlight.

algae. The simplest plants; may be single-celled (such as diatoms) or quite large (such as sea weeds). Live in salt or fresh water.

anadromous. Of or relating to migratory fish species, such as the Atlantic and the Pacific salmon, that spawn in fresh water but spend most of their lives in salt water.

aphotic zone. The deepest part of the water column, where light does not penetrate.

archipelago. A group of islands.

assemblage. A neutral substitute for "community" but implying no necessary interrelationships among species; also called species assemblage.

baseline. The low-water line along the coast as marked on large-scale charts officially recognized by Canada; used for measuring the breadth of the territorial sea, except where the coastline is indented or where a fringe of islands is in its immediate vicinity, in which case straight baselines join appropriate points.

bathymetry. The measurement of depth in oceans, seas and lakes.

bathypelagic zone. The dark, deep part of the water column (1000–2000 m) below the euphotic (well-lighted) zone and mesopelagic (poorly lighted) zone but above the abysso-pelagic zone.

benthic. Of or relating to organisms, both plant and animal, that live on the substrate under a body of water; those living on the ocean floor are the epifauna, while those living within the sediments are the infauna.

benthos. The bottom of a sea or lake; the collection of organisms living on or in sea or lake bottoms.

biocenosis. An assemblage of species characteristically found together. Relationships to habitat type are not specified. A modern conception of this older term might be the biological recurrent group.

biodiversity. The diversity of life, often discussed in terms of three hierarchical levels: genetic diversity (diversity within species), species diversity (diversity among species) and ecosystem diversity (diversity among ecosystems). Also called biological diversity.

biogeographic region. A complex area of land and/or water composed of a cluster of interacting ecosystems that are repeated in similar form throughout. Biogeographic regions vary in size, with larger regions found where areas have more subdued environmental gradients.

biome. A major regional or global biotic community characterized chiefly by the dominant forms of plant and animal life and the prevailing climate.

bioregion. An area of land and/or water whose limits are defined by the geographical distribution of biophysical attributes and ecological systems.

biosphere. That part of the earth system (air, water and rock) that supports life.

biota. The organisms in a specified area.

biotic. Living or having to do with life or living organisms.

biotone. A zone of transition between core provinces. Biotones are not simply "fuzzy" boundaries but represent unique transition zones between the core provinces. Biotones are unique systems and need to be recognized for their contribution to explaining the marine environment.

biotope. An assemblage of species generally found together in a characteristic habitat.

catadromous. Of or relating to migratory fish species, such as eels, that breed in salt water but spend most of their lives in fresh water.

cetacean. Member of the order Cetacea, primarily marine mammals (a few freshwater cetacean species exist), with nostrils on the top of their heads. Whales, dolphins and porpoises are cetaceans.

coastal waters. Both benthic and pelagic ecosystems that are influenced substantially by the land.

community. A group of species that generally are assumed to be interdependent (though this is often not demonstrated). The term can be used in a variety of hierarchies. Communities at larger scales can be progressively subdivided, such as spatially, taxonomically and trophically, to finer scales: for example, the North Atlantic plankton community, the *Fucus* community of rocky shores and the zooplankton community.

contiguous zone. A zone that adjoins the territorial sea and over which Canada may exercise control, such as enforcing laws relating to customs and immigration. Canada's contiguous zone extends 24 nautical miles from the baseline.

continental margin. The submerged prolongation of the land mass of Canada consisting of the seabed and subsoil of the continental shelf, slope and rise but not the deep ocean floor.

continental shelf. The seabed and subsoil of the submarine area that extends beyond the territorial sea throughout the natural prolongation of the land territory to the outer edge of the continental margin where it is beyond 200 nautical miles, or 200 nautical miles where the margin is less than that distance; generally, the most productive part of the sea.

continental slope. The descent from the continental shelf to the deeper (abyssal) depths.

crustacean. Any of various predominantly aquatic arthropods of the class Crustacea, including lobsters and crabs, characteristically having a segmented body, a chitinous exoskeleton and paired jointed limbs.

demersal species. A fish (also called groundfish), cephalopod or crustacean that spends its time on or near the bottom, although it can swim.

diadromous. Of or relating to species that migrate between fresh water and salt water regularly during their life cycle.

dysphotic zone. The part of the water column, below the euphotic zone, that receives low levels of sunlight but insufficient to support plant growth.

ecoregion. In terrestrial ecological land classification terminology, an area of land "characterized by distinctive ecological responses to climate as expressed by vegetation, soils, water and fauna" (Wickware and Rubec 1989). Ecoregions are one of several hierarchical levels of classification and are mappable at scales of between 1:1 million and 1:3 million. Ecoregions are the fundamental units of representation for terrestrial and marine gap analysis.

ecology. The scientific study of the interaction between living things and their environment.

ecosystem. A definable part of the biosphere consisting of several interacting communities; it receives inputs from the surrounding land, water and atmosphere, and may create outputs to other locales. A much misused term, it is not synonymous with "habitat" or "community."

echinoderm. Any of numerous radially symmetrical marine invertebrates of the phylum Echinodermata, which includes the starfishes, having an internal calcareous skeleton and often covered with spines.

endangered species. A species whose global population has been reduced to a level that is close to or beneath the sustainable level for that species. Since they are in imminent danger of becoming extinct, endangered species are protected under laws recognized by many countries.

enduring feature. A landscape element or unit within a natural region characterized by relatively uniform origin of surficial material, texture of surficial material and topography or relief. *See also* **marine enduring feature**.

epibenthic. Living on the surface of bottom sediments in a water body.

estuary. An ecosystem in which a river or stream meets the ocean; characterized by intermediate or variable salinity levels and often by high productivity.

euphotic zone. The upper part of the water column that receives sufficient light to allow plant growth.

eutrophic. Of or relating to waters rich in plant nutrients that support high rates of plant growth.

exclusive economic zone (EEZ). An area beyond and adjacent to the territorial sea, subject to the specific legal regime of Canada, under which the rights and jurisdiction of Canada and the rights and freedoms of other coastal states are governed by the relevant provisions of the United Nations Convention on the Law of the Sea.

fauna. A broad term for animal life.

fetch. The distance travelled by unobstructed wind or waves.

fjord. A long, narrow, deep inlet of the sea between steep slopes. Also spelled "fiord."

flora. A broad term for plant life; the plants of a particular area, region or time.

gap analysis. A technique designed to evaluate existing protected areas with regard to their representativeness (of marine ecosystems), to determine what further representation is required and to identify where those additional protected areas are located.

gyre. A circular ocean current.

habitat. A space with definable physical characteristics and limits within which organisms live.

hadal. Pertaining to depths of the ocean greater than 6000 metres.

indigenous. Of or relating to any of the Aboriginal peoples of a particular region.

inshore. Of the near coastal waters extending from the coastline and estuaries out to 3 nautical miles.

intertidal zone. The area between the high-water mark and low-water mark that is submerged at high tide and exposed at low tide.

invertebrate. An animal without a backbone or spinal column (i.e., not vertebrate).

kelp. Any of various brown, often very large seaweeds of the order Laminariales.

littoral zone. *See* **intertidal zone**.

marine. Of or relating to the sea; native to, inhabiting or formed by the sea.

marine ecological principles. Statements designed to guide the development and implementation of a marine representation framework and methodology. The principles use marine ecological attributes along with representation, mapping and ecological integrity requirements for a network of marine protected areas.

marine enduring feature. An abiotic marine ecological attribute that is considered most representative of marine ecosystems, is observable and measurable, and exerts an organizing influence on the distribution and diversity of marine species and communities. Such features can be used to identify major representative units for the purposes of classification, mapping and gap analysis.

marine protected area. An area set aside under legislation to protect marine values.

mollusc. A member of a large phylum of invertebrate animals characterized by soft, unsegmented bodies and usually having a calcareous shell.

natural region. In the ocean, a broad oceanographic and biophysical area characterized by particular water-mass characteristics and sea-ice conditions.

nekton. An aquatic organism, such as fish and krill (euphausiids), that can swim powerfully enough to move against currents.

neritic. Pertaining to the water column overlying the continental shelf.

network. A group of sites related to each other or interacting on the basis of known or specified criteria so as to form a collective unity. Parts of the network should relate to or complement each other in some way.

neuston. The diversity of minute or microscopic organisms that inhabit the surface layer of a body of water.

niche. The range of environmental variables (such as temperature, salinity, nutrients) within which a species can exist and reproduce. The preferred (or fundamental) niche is the one in which the species performs best in the absence of competition or interference from extraneous factors.

nonphotic zone. The part of the water column where plant growth cannot occur. This zone includes the dysphotic zone (where light is insufficient for photosynthesis) and the aphotic zone (where there is no light at all).

offshore. Of the area of the exclusive economic zone extending from the border of the territorial waters to the limit of Canada's international marine boundary.

pelagic. Of, relating to or living in the water column of seas and oceans (as distinct from benthic).

phytoplankton. Microscopic free-floating algae that drift in sunlit surface waters.

pleuston. Organisms that float on the surface of the sea.

plankton. Small or microscopic aquatic organisms that are suspended freely in the water column; they drift passively and cannot move against the horizontal motion of the water.

polynya. An area of open water surrounded by sea ice.

precautionary principle. The guiding ecological principle that maintains that, when considering which activities to permit, only those that have been demonstrated not to damage ecological resources be permitted. Too often, however, activities are permitted *until* it has been demonstrated that they are harmful.

productivity. The rate of biological production in an ecosystem. *Primary productivity* is the rate of transformation of solar or chemical energy to living material (biomass).

protected area. An area of land and/or sea especially dedicated to the protection and maintenance of biological diversity and of natural and associated cultural resources, and managed under federal, provincial or territorial legislation for conservation purposes.

recruitment. The influx of new members into a population by either reproduction or immigration.

recurrent factor. An oceanographic process that is periodic or recurring on some spatial–temporal scale (e.g., tides). Also called recurrent process.

recurrent group. The lowest level of the community hierarchy; can be thought of as the community that constitutes the species assemblage within a habitat, and thus as a biotope.

representation assessment. The identification and delineation of the complex of marine ecological attributes that defines particular seascapes for purposes of characterizing marine ecosystems and undertaking gap analyses.

representative community. A community that is typical of its surroundings at some given scale.

representativeness. The extent to which sites identified for, or already declared as, protected areas reflect known biological diversity, environmental and ecological patterns and processes, and physical features at various scales.

sea mount. An underwater mountain rising from the ocean floor and having a submerged summit.

seascape/seascape unit. A marine area that has a distinctive combination of marine enduring features as defined at scales of 1:250 000 to 1:500 000; used in the same sense that landscapes or landscape units are used in the terrestrial gap assessment methodology. *See also* **marine enduring feature**.

seiche. A wave that oscillates in lakes, bays or gulfs over periods from a few minutes to a few hours as a result of atmospheric or seismic disturbances.

spawning ground. A favoured location where aquatic organisms produce eggs (frequently the same location each year).

species diversity. The number of species in a region; sometimes defined as both a function of the pattern of distribution and the abundance of species.

stratification. The formation of layers of different densities (formed as a function of salinity and/or temperature) within the water column.

taxon. A group of organisms or populations considered to be sufficiently distinct from other such groups to be treated as a separate unit. The plural is taxa.

terrestrial. Of or living on land (i.e., not aquatic).

tidal current. A current caused by tidal motion.

tidal range. The difference between high-water and low-water levels.

tide. The periodic variation in the surface level of the oceans and of bays, gulfs, inlets and estuaries caused by gravitational attraction of the moon and sun.

trophic level. The position of an organism in the food chain or “food pyramid,” determined by the number of transfers of energy that occur between the nonliving energy source and that level.

tsunami. A very fast moving wave, incorrectly called a tidal wave, that is initiated by an underwater disturbance, such as an earthquake, volcanic eruption or slumping.

upwelling. A process by which water rises from the lower depths into shallow waters, usually as a result of divergence or currents moving offshore.

water mass. A volume of water that has defined salinity and temperature characteristics; water masses might be considered to be analogues of the major climatic regions of terrestrial environments.

zooplankton. Small, sometimes microscopic, animals that drift in the ocean; protozoa, crustaceans, jellyfish and other invertebrates that drift at various depths in the water column are zooplankton.

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ACKNOWLEDGMENTS

The hierarchical framework described in the report is based largely on a contract undertaken by Geomatics International Inc. under the direction of Dr. Cheri Recchia of WWF Canada that led to the following reports:

National Framework and Methodology for the Determination of Marine Representation and Ecological Integrity, June 1996

Proposed Methodology for Determination of Marine Representivity—Scotian Shelf and Surrounding Waters Pilot Study, July 1997

Proposed Methodology for Determination of Marine Representivity—Lake Superior Pilot Study, August 1997

A number of people assisted in the preparation of this document. Unpublished manuscripts, reports and data were made available by the following people:

Mark Taylor, Geomatics International Inc., Burlington, Ontario

Mark Zacharias, Land Use Coordination Office, Victoria, British Columbia

Jane Watson, Malaspina University-College, Nanaimo, British Columbia

Richard Thackway and Sharon Pretty, Environment Australia

Peter McGinnity, Great Barrier Reef Marine Park Authority, Australia

Particular thanks go to Kevin Kavanagh and Korry Lavoie for their comments on draft sections of the manuscript. Other comments were also provided by Tony Iacobelli, Inka Milewski, Sabine Jessen and Arlin Hackman.

Research and publication of this report was made possible by MPH Graphics Inc.

Copy Editor: Sarah Weber
Design and Layout: Judie Shore
Printing: DTP International

Printed on 100% recycled paper
(30% post consumer)

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Recommendations for Effective Marine Planning Processes

Lessons Learned from Case Studies in Canada, the USA and Australia

Living Oceans Society

and World Wildlife Fund Canada

January 2005

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Introduction

Purpose of this Report

Multistakeholder decision making is often used in natural resources management and marine reserve design processes to provide advice on planning and management issues – the challenge is to make it work effectively.

This report has been commissioned by Living Oceans Society and World Wildlife Fund Canada to identify the principles that should be used in collaborative processes for planning Marine Protected Areas (MPAs). Since MPAs are often part of comprehensive marine planning processes, these principles also apply to broader marine planning initiatives.

There are many benefits to a good planning process. MPAs that are created through extensive consultation with local residents and stakeholders enjoy more public support and greater commitment to implementation. Processes designed to accommodate First Nations rights and title will go a long way to avoid costly court battles or lengthy delays.

On the other hand, poor planning that does not involve all stakeholders in the decision-making process can end up becoming cumbersome, expensive and mired in years of controversy and protest.

Public participation can vary widely in scope, issues, purpose and degree of involvement. However, by studying what has worked and what hasn't worked in several jurisdictions, this report provides British Columbia with a set of lessons that can be applied to future marine planning processes to ensure more stakeholder support, make the process more efficient, and increase the likelihood of success.

The key lessons and recommendations were based on case studies from British Columbia (Race Rocks), Nova Scotia (Eastern Scotia Shelf), Florida (Tortugas 2000), California (Channel Islands) and Australia (Great Barrier Reef).

The material is drawn from a 120-page document entitled *An Overview and Assessment of Marine Planning Processes: Case Studies in Canada, USA and Australia*, prepared for Living Oceans Society and World Wildlife Fund Canada by Dovetail Consulting Inc. in February 2004.

Methods

This report was developed through a literature review of five case studies and structured interviews with planners and stakeholders involved in the various marine planning processes.

The case studies were chosen based on the following criteria:

- were designed to address a wide range of marine use issues
- were designed to establish marine protected areas
- include stakeholder participation, including a fractured and complex commercial fishing industry
- address the rights and interests of aboriginal people

Process Structure Framework

This report uses a process structure framework adapted from the principles suggested by several well-known authors of multistakeholder decision making in natural resources management and marine reserve design. This framework can be used to *evaluate*, *design*, and *implement* a collaboration initiative. It consists of:

- A common purpose and definition of the problem and a commitment to collaborate
- Inclusive and effective representation of interested parties
- Effective process management
- Effective process design
- A structured and integrated decision-making framework
- Equal access to information

Please see Appendix C for more details.

Recommendations for BC

The following points summarize what conditions make a marine planning process successful, when a marine planning process is appropriate, and what conditions reduce the likelihood of a successful outcome, based on the common themes revealed in the five case studies.

What Makes a Process Successful

The following recommendations to ensure successful planning processes emerged from the five case studies:

Common Purpose

- *Build trust.* Some stakeholders will be concerned about the legitimacy of other stakeholder involvement in a process. Process managers must allow time at the outset to build the trust and respect between stakeholders.
- *Educate and build awareness about a marine reserve/planning proposal long in advance of a process* to avoid surprises, build knowledge, create interest, and increase the desire for ocean protection.
- *Take small steps.* Begin with a small, but useful, non-controversial reserve.
- *Address fears* of the floodgates opening by coordinating marine reserve proposals for places that make sense. Avoid enhancing the perception that reserves are ad hoc conservationist tools.
- *Ensure all members regard each other as legitimate participants*. This takes time and also involves many points listed in the Representation section below.
- *Demonstrate government support* through clear objectives, policies and financial and human resources. Top-down agency support and outside attention or profile lends significance to a process. If there are broader fisheries management policies and initiatives underway while a specific MPA process is deliberating, government should seek to provide clarity on the linkages between the two processes or policies.
- *Conduct pre-negotiation assessments.* Before commencing a collaborative process, conduct a feasibility study to assess the value of collaboration. For example, assess the utility of a multistakeholder marine planning process, the level of support and understanding among users regarding marine reserves, and the need for a marine reserve from a socio-economic perspective, as well as a biological perspective. Include research on the utility of other means besides marine reserves to address the issues.
- *Ensure clear purpose* through discussion and agreement.
- *Take an ecosystem approach.* Coordination between and within government agencies will promote the legitimacy of the process and engender trust and participant commitment.
- *Ensure law and policy exists* to mandate a marine planning process to develop and implement zoning. Legal mandates enhance fair, efficient, and consistent processes.

Inclusive and Effective Representation

- *Clarify who is to be involved in a process before starting the negotiation process* so that negotiations can begin with everyone working towards a solution together. Finding the right persons to be involved as representatives in a multistakeholder advisory group is one of the most difficult parts of the process and can take up to a year. Poor representation can mean delays in the process once it starts or once it has moved to the regulatory stage. Screen representatives for knowledge about the issues and make sure they won't seek a pre-determined agenda.
- *Make sure participants can be effective representatives* who are trusted and empowered by their constituency. This means spending time to manage complex or disorganized constituencies/sectors into caucuses or work groups.
- *Acknowledge the diversity of perspectives within a constituency* and ensure they are adequately addressed in a marine planning process. One commercial fisherman or sport fisherman cannot speak for the whole industry. Ensuring the right balance of representatives even from within one constituency enhances participant trust and respect in a process.
- *Spend a substantial amount of time at the start* of the process to become acquainted with all interested parties, both locally and beyond the region, and build relationships with them. Invite all interested parties into the process, but seek a balance of interests to avoid perception of power disparities. Engage average people from the various sectors and constituents, not only lobby groups or activists.
- *Consult First Nations communities* as traditional users of marine resources. Invitations and follow up calls are necessary to obtain initial contact. Honorariums to cover transportation costs may be necessary. Identify respected community leaders to be involved in the process. Seek to develop tripartite cooperative management arrangements to address First Nations rights and interests in the marine area being planned. Because there are difficulties inherent with territorial overlap between tribes, First Nations must be allowed to decide how they wish to be represented in a process.
- *Build time for outreach.* Design the process so that local representatives have the time and resources to plan and conduct outreach tasks. Develop a communication strategy that reaches out and informs widely (locally, regionally, provincially, nationally, internationally) and provide many opportunities for public input. Concerted outreach by process sponsors and grassroots activists targeting unorganized or alienated groups can help motivate people to attend public meetings and get involved in processes. Consider the creation of a Liaison Unit to engage with Indigenous coastal communities and identify and address Indigenous interests and concerns.
- *Involve community members and scientists as local expert stakeholders at the table* so that they are part of a team for discussion, negotiation, and information gathering and dissemination.
- *Training or experience in consensus-based negotiations* will enhance the effectiveness of representatives in a process.

Process Management

- *Provide clear leadership*, administration and facilitators. Ensure process managers are committed, neutral, and skilled in process management and communication. Government sponsors should focus on facilitating, coordinating, and supporting processes. Staff should have the skills to teach and enable fishermen, local interested persons, and other constituent representatives to lead or chair meetings, and design processes as well as give presentations (Lane 2001). Sponsors should also supply the necessary resources for a process.

- *Use tripartite (or cooperative) arrangements* to ensure successful planning and designation of MPAs. Involvement of First Nations must be government-to-government rather than as participants or stakeholders.
- *Employ impartial, expert facilitation to help structure and guide a process.* Ensure that the facilitator is neutral but knowledgeable of the substantive issues.
- *Ensure active communications up and down the decision-making hierarchy.* Keep advisory bodies as well as senior government and political decision-makers up to date with a community-based negotiation process.

Process Design

- *Provide clear terms of reference* for the overall process, even if they are drafts that require consensus amongst participants, to provide direction and help move the process forward. Then let participants refine the terms of reference and seek constituent feedback to ensure the process will fit the community's specific needs.
- *Ensure the scope and purpose of a process is made clear* to all participants in a process before proceeding with substantive discussions. It may take several meetings, but taking the time to clarify mandate, roles, responsibilities, overall process framework and purpose will enhance understanding and trust, as well as prepare participants for what lies ahead.
- *Clarify early stakeholder expectations* about outcomes of the process.
- *Be realistic about the amount of time required* to develop a planning process. It takes time to identify issues and needs before seeking agreement on process or structure. Nevertheless, establish some milestones to guide people's involvement. Ensure that a marine planning process works with the timelines of all stakeholder representatives involved in a process (e.g., check the fishing season so that fishermen can attend meetings). (Lane 2001)
- *Advisory Panels:* Ensure that the expert panels that provide technical advice have clear terms of reference to avoid issues with the legitimacy of advice they provide.
- *Create a clear set of consensus-based decision rules and a fall-back dispute mechanism* in case consensus cannot be reached. Resolve veto power by putting the onus on the person disagreeing to provide an alternative solution that will address their concerns and those of others. Do not place too much emphasis on the need for unanimity in a multistakeholder decision-making process. Something less than 100% will suffice for the process to still be considered consensus-based. The actual extent of agreement should be negotiated with the participants and not decided ahead of time by the process manager.
- *Take an ecosystem approach* to process design as well as to reserve design. An ecosystem approach in reserve design increases the substantive issues that can be addressed in marine reserve collaborations (social, ecological, economic); an ecosystem approach to process design provides the means for involving all the agencies and groups whose jurisdictions crisscross the boundary area. A

reserve therefore serves as a locus to coordinate and address interests and institutional responsibilities at all levels.

- *Avoid getting into mapping work* before the ground rules and the upfront groundwork is completed.

Structured and Integrated Decision-Making Framework

- *Use positive terminology* to explain MPAs to commercial fishermen – "fisheries management tools," for example, not "no-take zones" (Lane 2001).
- *Use various techniques to involve participants.* This will enhance meaningful and comprehensive involvement. Some people are uncomfortable with highly structured processes and may prefer time for open, frank, and less structured discussion (pers. comm. (15), 2001). Mixing small and large group discussions allows people to get to know one another at different levels, raises comfort levels, reduces fears and encourages the generation of ideas.
- *Develop a set of weighted selection criteria based on stakeholders' values* to help create better alternatives and assess how well those alternatives measure against the value-based criteria. Emphasize socio-economic considerations, not just the natural sciences of a reserve proposal. This is a foundation for process success, as well as the basis for the sustainability of the outcome.
- *Provide opportunities for the public to actively engage in workgroup discussions* and contribute their local knowledge. During breakout group sessions, encourage participants to seek the input of constituents and others who attend meetings.
- *Be wary of perceptions of "behind-closed-door" solutions* that may alienate participants.
- *Avoid independent review panels.* Ensure that ecological, social and economic concerns and information are integrated equally into the process. Not setting up "expert science" panels avoids the dichotomies that are created between science and consumptive user groups.
- *Check in with participants* during the process to identify how they perceive the meeting and whether any design parameters need to be changed.

Information Gathering and Dissemination

- *Schedule a number of community meetings* to ensure that all relevant communities and representatives are invited to voice their opinions.
- *Do not underestimate the amount of science that is needed* and the amount of time to acquire that knowledge. Information gathering is a good opportunity to build group relationships.
- *Invest resources and take the time to build user awareness* about impacts to the marine environment. Disseminate information about MPAs, marine reserves, and issues of concern to increase understanding and awareness. Disseminate credible research and monitoring results from the region and abroad.
- *Use third-party researchers who are trusted by locals* and who will follow protocols of confidentiality to obtain reliable socio-economic information.
- *Enlist locals to share their knowledge* of the marine region. Recognize that some commercial fishermen, divers and salvors may not have academic training but they know as much about marine ecosystems as scientists, if not more. .

- *Build fishermen's trust and respect*, as well as support, for the process and proposal - they may help with enforcement later on. Ensure fishermen understand the economic benefits available to them from protecting a particular site. If marine users are not informed about what the benefits (and the costs) are, they will be less supportive.
- *Learn about what matters to fishermen and coastal people.* Do not rush into a process before learning to speak their language. Take the time to identify their values and why they may be for or against marine reserves.
- *Identify whether marine reserves are the best option*. One result of joint fact-finding discovering whether it makes sense to protect an area or not as a marine reserve, or whether other marine planning means are more suitable.
- *Be sensitive to all users' views and educate the public* on both the pros and the cons of marine reserves for all user types so no single group feels it is being specifically targeted and impacted in the process.
- *Provide mapping technology* at standardized scales as a means of assembling large amounts of information and allowing comparisons across a range of values. Provide support staff to assist the participants with GIS technology and mapping work.
- *Assemble all of the written documentation in one resource binder* for each participant. Don't overload the working group. Provide information far in advance of the start of the process and update as necessary.

When a Process Should Proceed

A process should proceed if the following circumstances apply:

Common Purpose

- The agency has first considered whether an agreement-seeking approach is appropriate. For example, the feasibility of a marine planning process and the level of support for such an initiative have been assessed before commencing or announcing such an initiative.
- Key parties are committed to collaborate and are willing and able to participate.
- The issue will not require compromise of basic values and principles. (First Nations will take the time to be involved in a marine planning process if it is developed on the basis of cooperative management of traditional resources).
- The issue is "ripe" for discussion (e.g. a stalemate is unacceptable to several parties).
- Government is likely to implement the agreement reached. Public participation includes the promise that the participants' contribution will influence the decision.

Inclusive and Effective Representation

- Inclusive and effective representation is a key focus of the participation process; it seeks out and facilitates the involvement of those potentially affected.
- The process is coordinated with other government agency processes.
- The process design includes reaching out to the general public to help ensure inclusive representation.
- Stakeholder representatives demonstrate effective representation and maintain communication with their constituencies.
- Stakeholder representatives have negotiation skills to build bridges between sectors.

Process Management

- There is support from relevant decision-making agencies.
- A neutral third party facilitates discussions involving potentially high-conflict topics such as public lands, public waters, and natural resources.

Process Design

- Sufficient time is available to address the key issues.
- Consensus is sought for small steps in the process (e.g., problem statement, goals/objectives, management intentions), not just in the outcome.
- Participants help define how they participate.
- Ground rules are mutually agreed upon by all participants.
- There is a real possibility of success as defined by participants.

- Effective means of communication are used to reach constituents, including coordinating special gatherings, attending other meetings, chatting with people at local bars, connecting one-on-one, and going “down to the docks.”

Structured and Integrative Decision-Making Framework

- The process promotes an iterative approach to dealing with complex issues, develops decision criteria, highlights trade-offs, identifies options, and balances social, economic and environmental concerns in the decision-making structure.
- There is a chance to coordinate and integrate activities.
- Interest groups feel that the framework provides a means of addressing growing user conflict.

Information Gathering and Dissemination

- The process promotes knowledge equality amongst all interested parties and participants to a process, adding significantly to the general body of knowledge about marine reserves. This can involve having participants assist with information gathering, inviting expert speakers, sponsoring public sessions and special socio-economic and ecological forums, providing relevant and understandable documents, and producing other resources such as GIS mapping tools.
- The process provides feedback to participants on how their input was used.

When a Process Should Be Avoided

A process should be avoided in the following circumstances:

Lack of Common Purpose

- There is little or no incentive to solve a problem, meet a deadline, or engage adversaries because participants have other means to work out their issues, such as lawsuits or political pressure.
- The resource is too significant, sensitive, or otherwise unsuitable for negotiation.
- The key issues require legislative or legal determinations outside the scope of the group.
- The convening agency or authority lacks commitment to the process and to honouring process outcomes.

Poor and Ineffective Representation

- Participants lack the authority to make decisions on behalf of their constituency.
- Participation requires an organization to compromise fundamental values.
- Diverse representation is not available or key individual representatives cannot participate.

Ineffective Process Management

- Consensus rules are not enforced by the facilitator, creating a veto power.

Ineffective Process Design

- There is too high an emphasis on achieving a consensus agreement, putting too much pressure on representatives, especially if they are not empowered to negotiate agreements.
- Too little time is allowed for the collaborative process.

Poor Information Gathering and Integration

- Participants are unwilling or unable to accept new information and alter beliefs.
- There isn’t fair access to independent expertise on technical issues

Case Studies of Marine Planning Processes

United States: Tortugas 2000, Florida

This case study outlines the National Oceanographic and Atmospheric Administration's (NOAA) community-based process for establishing a network of marine reserves in the Florida Keys National Marine Sanctuary. The process for Tortugas 2000 and the designation of the Tortugas Ecological Reserve involved eleven years of marine planning.

The Florida Keys National Marine Sanctuary was designated by Congress in November 1990 to address drastic declines in coral reef health and fish species and the risk of ships grounding on the shallow reefs (Ogden 1997). The 2,900 nm^2 (9800 km^2) Sanctuary encompasses the marine waters surrounding the Florida Keys archipelago. Today it contains a network of 24 no-take zones, including the Tortugas Ecological Reserve.

In 1991, the Sanctuary began a public process to develop the management plan and formed the multistakeholder Sanctuary Advisory Council to help ensure public input. In 1995, NOAA proposed a draft management plan (DOC 1995) for public review that originally included an ecological reserve, as well as a boundary for a 110-nmi^2 no-take zone in the Tortugas area.

Despite the efforts of scientists and conservation organizations, local fishermen defeated the proposal for the Tortugas reserve (Ogden 1997). There was great misunderstanding and mistrust of the Sanctuary, lack of knowledge about marine reserves, and dissatisfaction with the public process the Sanctuary followed to develop the marine zoning system.

Subsequent drafts of the Management Plan proposed smaller and smaller sites, until finally, due to mounting public controversy, the Sanctuary eventually removed the Tortugas proposal from the plan completely (Ogden 1997).

However, Sanctuary officials did not give up on Tortugas. Local and international evidence was being published on the positive effects marine reserves were having on biodiversity and fisheries. Together with the National Park Service, they launched a collaborative process – *Tortugas 2000* – that brought together a group of stakeholder representatives to recommend more acceptable boundaries for the Tortugas area that would satisfy conservation concerns without ignoring socio-economic needs (DOC 2000).

Phase I (April 1998 to June 1999) involved the design of the reserve, including a series of public meetings to determine the range of issues to be considered. A Work Group of agency officials, representatives from user groups (such as commercial fishermen and the dive industry), environmental organizations, and other concerned citizens was then formed and charged with recommending a set of alternative boundaries for comment.

The Work Group agreed on an ecological reserve in two portions. The 91nm^2 Tortugas North, designed to protect coral reef resources, allows diving but no consumptive uses. The 60nm^2 Tortugas South, designed to protect a coral reef system, commercial fish species, and associated habitat, does not allow diving or consumptive uses.

Successes

There was a high level of participant support for the process, due partly to the perception that government had learned its lessons from the original, flawed marine zoning process and partly to a new, bottom-up approach. By 1998, the public could also see benefits of no-take zones locally and internationally. The Sanctuary Superintendent's long-term commitment, leadership, and local credibility were very important, as was a core staff that was critical in moving the process forward.

The Work Group made sure that missing interests were invited to the table, demonstrating commitment to an inclusive process. The process for selecting stakeholder representatives was considered clear, fair and comprehensive. Spending time on groundwork helped to build relationships and develop trust.

Integrating the scientists and the local traditional knowledge experts into the Work Group also built trust, and the wealth of knowledge that fishermen possessed was a great benefit. Use of GIS mapping to display ecological and socio-economic information was helpful in negotiating the location, size and allowable uses in the Tortugas Ecological Reserve. Disseminating research and monitoring results was critical in shifting pubic opinion. Likewise, constituent outreach was a key feature of ensuring effective representation.

Consensus decision making ensured that all concerns were addressed in the process, moving people away from extremes or positional bargaining (pers. com. (14) 2001) and achieving compromise. Considering a balance of the social and economic issues along with the ecological issues was fundamental to the success of the process. Finally, the process was designed so that common criteria were agreed on before the contentious discussions about maps, reserve locations or percentages occurred.

Challenges

The greatest opposition to the process came from national recreational fishing groups, who opposed the principle of closing any waters to recreational fishing. In addition, lack of clarity with the marine reserve objectives before the start of the process led to some confusion and mistrust, especially from the sport fishermen.

Finding the right Work Group participants was one of the most difficult parts of the process. Some participants couldn't openly represent and commit their constituencies at the table, and failing to secure a sport fishing representation early on was a problem, given the media coverage generated by sport fishing interests.

United States: Channel Islands, California

This case study outlines the National Oceanographic and Atmospheric Administration's (NOAA) community-based process for establishing a network of marine reserves in California's Channel Islands National Marine Sanctuary. The Sanctuary was designated in September 1980, and consists of 1,252 square nautical miles of open ocean and near-shore habitat approximately 25 miles off the coast of Santa Barbara.

In 1998 local citizens, fishermen and the Channel Islands National Park approached the California Fish and Game Commission with a proposal for a network of marine reserves within the Sanctuary. The result was a joint process to discuss MPAs in the Channel Islands area, including the appointment of a 17-member Marine Reserves Work Group (MRWG).

The MRWG included members of the Sanctuary Advisory Council (an advisory group of constituents), government agencies, and representatives of the public, commercial fishing, recreational fishing, sport and commercial diving interests, and non-consumptive interests. A Science Advisory Panel and a Socioeconomic Panel provided technical expertise, and input was gathered from public forums and comments.

While the MRWG did not reach consensus on reserve boundaries, it agreed on a problem statement, issues of concern, goals and objectives and implementation recommendations, producing the foundation for what has become the state-level network of MPAs and marine reserves, and what will soon become the federal waters portion of the network. During the nearly two-year process, the group developed over thirty potential marine reserve network maps which they whittled down to two, but ultimately they could not achieve consensus on the use of limited take, size, and the location of the reserves.

A series of bodies evaluated the MRWG's efforts: the Channel Islands Sanctuary Advisory Council, the Sanctuary Manager and staff, the Department of Fish and Game, and finally, the Fish and Game Commission. The MRWG's package of agreements and information gathered during process formed the basis of the Commission's final recommendation.

In October 2002, the Commission approved NOAA's and the Department's preferred alternative for a network of twelve marine reserves and various types of MPAs, ranging from limited to full protection, covering 142 nmi^2 of the Sanctuary.

Successes:

Reaching out to constituencies was critical to the process and to ongoing relationships. As a result of the MRWG, more fishing communities became interested and involved in the process of marine planning – not only in the MRWG but in the wider state process. The process was designed to directly involve representatives in meeting design, and consensus decision making encouraged a broad alliance of interests.

Gathering and disseminating information – including local knowledge – involved a great deal of time, money, and research, but was invaluable to the Sanctuary, the MRWG members and the general public.

Challenges

Poor choice of terminology and the lack of pre-negotiation assessment made it more difficult to build support and establish a common purpose. For example, terms like “no-take zones” and “over-fishing” often disengaged fishermen and other marine users.

There were several problems with representation. When one conservation representative withdrew, the open seat was not filled, which affected the perception of balance and the legitimacy of the process. Some representatives in the MRWG did not reflect the views of constituents, while others lacked the authority to make decisions for their constituents (Davis 2001). Some, like oil and gas and yachting interests, were missing entirely.

Some MRWG members felt that too much emphasis was placed on unanimity and that something less than 100% would have sufficed. Drawing lines on maps and discussing percentages created some of the greatest conflict in the process. In addition, the group was unsure how to address a reserve network in the Channel Islands with little knowledge about fisheries management outside of reserves.

Finally, there was too much pressure on the MRWG to deliver a recommendation within too short a time to prevent the state government from stepping in and making decisions. More time was needed to build relationships between divergent interests.

Australia: Great Barrier Reef, Queensland

This case study outlines the Great Barrier Reef Marine Park Authority’s process for involving Aboriginal and Torres Strait Islander peoples in the planning and management of Queensland’s Great Barrier Reef Marine Park and World Heritage Area. Two sets of property rights and responsibilities overlap in this region: Indigenous Australians’ native title rights, and national/state governance of the area as a multiple-use MPA (Innes and Ross 2001).

From the Authority’s perspective, one of the hardest issues to address has been the culturally appropriate and ecologically sustainable management of traditional hunting (GBRMPA 2003e). It therefore developed an Indigenous Policy and Liaison Unit to help address the legal issues and concerns of local Indigenous peoples (GBRMPA 2003a).

Under the Representative Areas Program, the Authority rezoned the Marine Park based on 70 distinct bioregions with community input. During the initial public consultation, the Liaison Unit informed and sought input from Aboriginal and Torres Strait Islander peoples, reference groups, land councils, community groups and corporations, leading to the development of a draft zoning plan for the Great Barrier Reef.

Next, 18 regional workshops on the reef-wide Traditional Hunting Framework were held with Indigenous communities (GBRMPA 2003f). Then the Draft Zoning Plan was released for public comment, one of the largest examples of public involvement in any environmental issue in Australia’s history.

As a result of the consultations, a new provision for Traditional Use of Marine Resource Agreements (TUMRAs) was introduced. TUMRAs are formal agreements with Aboriginal and Torres Strait Islander Traditional Owner groups who assert rights and interests in the Marine Park (GBRMPA 2003a). They provide a framework for addressing a range of Marine Park issues that Traditional Owner groups will help to manage.

Under the proposed management arrangements in the draft Zoning Plan 2003, traditional fishing and collection will not require written permission from the Authority in zones that allow fishing and collecting. Traditional Owners will continue to have access to all zones in the Marine Park for traditional activities that don't involve taking animals, plants or marine products. In more highly protected zones, traditional uses will be managed under TUMRAs.

The public and community consultations on the new Zoning Plan have resulted in 33 percent protection in highly protective no-take areas (GBRMPA 2003a).

Successes

Indigenous representation is the greatest success of the rezoning process. For the first time, Indigenous communities became more involved, visible, and represented at a reef-wide level. Aboriginal and Torres Strait Islander peoples are taking a proactive approach to addressing traditional use of marine resources, leading to the development of cooperative management arrangements (TUMRAs) in the Marine Park.

The Authority has played a key role in ensuring Indigenous involvement in Park management. Because of the wide and often remote distribution of the region's Indigenous population, an effective cross-cultural communication strategy has been critical.

Challenges

The main challenge arises when Traditional Owners oppose certain activities in a particular area of the sea country. The Liaison Unit can now respond with planning tools such as TUMRAs to support Traditional Owners' involvement in issue identification, cultural mapping, and cooperative management of their traditional area.

Canada: Race Rocks, British Columbia

This case study outlines First Nations involvement in Fisheries and Oceans Canada's X̌ʷayəŋ / Race Rocks Marine Protected Area planning process, particularly in the Race Rocks Advisory Board. X̌ʷayəŋ (pronounced *shwai'yen*) is the name given to the area by the Coast Salish Nations and means "swift waters."

Under the *Oceans Act 1997*, Fisheries and Oceans Canada (DFO) is responsible for coordinating marine protected area initiatives between agencies and between federal and provincial jurisdictions. It is also mandated to designate its own national system of MPAs[1] through collaboration and cooperation with other governments, agencies, affected First Nations organizations, and coastal communities. These should ideally be situated within integrated management plans based on an ecosystem approach. Special consideration is given to traditional activities in marine areas, and all decisions should be consistent with First Nations land claims agreements (DFO 1998).

[1] In this case study, the term "MPAs" refers to DFO's system of marine zoning designation under the *Oceans Act*. In the rest of the report, the term "MPAs" refers to the meaning defined in the glossary.

In 1980, the province designated Race Rocks as an ecological reserve, providing protection for the natural and cultural heritage values of nine islets and the ocean bottom. Eight years later, X̌ʷayəŋ /Race Rocks Ecological Reserve was declared an Area of Interest under the *Oceans Act* and the Federal–Provincial MPA Strategy and was selected as an MPA pilot. The next step was for DFO to assess whether it met the designation criteria and then identify and assess its ecological, technical and socio-economic merits.

To help in the process, a multistakeholder Race Rocks Advisory Board was established in 1999 that included government, First Nations and local stakeholder representatives. The Advisory Board reached consensus on recommendations to support an MPA designation, including provisions for the creation of a no-take zone and the establishment of a co-management regime involving First Nations, British Columbia and Canada (DFO 2000a).

The Minister of Fisheries and Oceans subsequently announced X̌ʷayəŋ as Canada's first MPA under the *Oceans Act* in September 2000. However, to date, the MPA was has not been formally designated due to complications in the regulatory process in Ottawa.

Successes

Thanks to creative problem solving, the Race Rocks Advisory Board was able to negotiate a no-take zone within the boundaries of the existing ecological reserve, gain First Nations' support for the creation of a Marine Protected Area, adopt a First Nations name for the area, and recommend co-management by local First Nations, B.C. Parks and DFO.

Challenges

Despite the Advisory Board's success in developing recommendations, once these recommendations were submitted, they were misrepresented in the proposal and in the federal government's regulatory approval process. Both the misrepresentation and the subsequent protest involved groups that were not part of the Advisory Board (LeRoy 2002).

DFO's proposal document excluded the possibility of First Nations being part of a tripartite cooperative management arrangement, which was agreed to by the Advisory Board.

The local First Nations Chiefs T'souke, Songhees and Beecher Bay opposed the proposed MPA, citing *Delgamuk*, infringement of rights, and lack of consultation, halting the final designation (LeRoy 2002). DFO learned that First Nations representatives on the Advisory Board did not have the support from local First Nations to negotiate on their behalf.

DFO has since consulted with the Chiefs and acknowledged that it did not engage with the First Nations effectively. The Chiefs responded with a letter of support for the MPA on the condition of true co-operation and acknowledgement of Douglas Treaty Rights.

Canada: Eastern Scotia Shelf, Nova Scotia

This case study outlines Fisheries and Oceans Canada's Eastern Scotian Shelf Integrated Management (ESSIM) process and the Gully Marine Protected Area process. As noted in the previous case study, Fisheries and Oceans Canada (DFO) is responsible for developing a national system of MPAs based on an integrated management approach.

The Eastern Scotian Shelf Integrated Management (ESSIM) Initiative is an ongoing collaborative offshore planning and management process for the Eastern Scotian Shelf Large Ocean Management Area being led by DFO. It was announced in December 1998 following the Sable Gully Conservation Strategy's recommendation to apply integrated management approaches to the offshore area surrounding the Sable Gully Area of Interest.

Key interests on the Shelf – an area of high biological diversity and productivity – include fisheries, offshore oil and gas, shipping, maritime defence operations, submarine cables, science, research and development, recreation and tourism, potential offshore minerals development, and marine conservation (DFO Maritimes Region 2001).

To date, an array of sectoral meetings have been held, background reports written, and two workshops conducted. An "ESSIM Forum" has been proposed along with a supporting administrative ESSIM Secretariat, and a Federal-Provincial ESSIM Work Group has been formed, along with other multistakeholder work groups.

Gully MPA

The Gully is a deep canyon ecosystem on the edge of the Scotian Shelf, near Sable Island, that has been the focus of conservation efforts since the early 1990s (Canada Gazette 2003).

A Work Group and an Advisory Committee have been formed to develop the MPA and management plan. Based on the Work Group deliberations, DFO developed a document in 2002 outlining the proposed MPA and management zone boundaries, and described the scope and intent of the regulations being developed. It was distributed to offshore industries, academia, government agencies, First Nations, environmental interest groups and other non-government organizations. DFO also gave presentations and held separate meetings with key interests during 2002–2003.

Although the Gully MPA is distinct from the broader ESSIM Initiative in terms of scale and scope, the two planning processes are nested together and involve many of the same interests and management issues. The ESSIM process will continue to support Gully MPA planning, as well as the identification and development of an MPA system plan for the Scotian Shelf (Canada Gazette 2003).

Successes

To date, the intent, objectives and processes proposed for the ESSIM Initiative have been received favourably by participants (DFO Maritimes Region 2001). Through ESSIM processes, DFO has demonstrated its willingness to collaborate, and although the process is taking longer than expected, there is a general belief that an integrated management plan will improve the situation on the Shelf.

Because DFO is a process sponsor instead of a process facilitator – meetings are co-chaired and workshops led by a neutral facilitator – it can focus on the discussion issues.

By integrating the Gully MPA process in the ESSIM Initiative, multiple uses and impacts beyond the MPA can be managed to meet the Gully's ecosystem protection requirements. The iterative cycles and feedback loops among the five stages allow the integrated management plan to be adapted to address the dynamic nature of the ecosystem and/or human uses of the ecosystem.[2]

Challenges

Some participants do not acknowledge the legitimacy of other stakeholders, and fishing interests are not always willing to discuss management in a multisectoral context. It will take more time to build trust and respect. As well, DFO suffers from some lack of public trust because it is seen as "the violator" of fisheries management on the East Coast.

Participants want DFO to take a greater leadership role and begin implementing some of the planning to date. There continues to be the perception that DFO is not well coordinated internally, and DFO staff does not have adequate resources to perform its Secretariat functions appropriately.

There are many different perspectives and interests involved within a constituency, making it difficult and undesirable for people to identify themselves as spokespersons for their constituency. It is also difficult to identify and engage all interests. In addition, some constituents can't afford to attend meetings regularly.

[2] Source: http://www.mar.dfo-mpo.gc.ca/oceans/e/essim/essim-reports-planningprocess-e.html.

Appendix A: Glossary

Collaboration: Collaborative processes include a mix of individuals representing often conflicting interests and views who come together either because of a shared vision (proactively) or because of conflict (reactively) to meet the goals of all the group members. Also called **multistakeholder decision making** and **natural resource decision making**.

Indigenous: In Australia the term Indigenous is used to refer to both Aboriginal and Torres Strait Islander peoples. This document will often use the term Indigenous to refer to both First Nations in Canada and Aboriginal and Torres Strait Islanders in Australia.

Integrated oceans and coastal management (IM): A comprehensive and coordinated approach to decision making, based on a balanced consideration of the full range of interests and associated ecosystem, social and economic objectives for a management area.

Marine Protected Areas: According to the World Conservation Union (IUCN), any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical or cultural features, which has been reserved by law, or other effective means, to protect part of the entire enclosed environment.

Marine reserves: Areas in the ocean where no take of living or non-living marine resources is allowed. Also called **no-take areas** or **no-take zones**.

Stakeholders: Anyone who is able to affect or be affected by an outcome of any negotiation, who is responsible for implementing its decision(s), and who has an interest in the issues. Also called **interested parties**.

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Appendix C: Process Structure Framework

The following table describes the process structure framework used in this report, adapted from the principles suggested by several well-known authors of multistakeholder decision making in natural resources management and marine reserve design.[3] This framework can be used to *evaluate*, *design*, and *implement* a collaboration initiative.

1. Common Purpose and Definition of Problem & Commitment to Collaborate	***a) Participants**:* Participants acknowledge the need for a consensus-building process and are committed to it, acknowledge the legitimacy of other stakeholders, and agree on a common definition of the issues at stake. ***b) Government:*** Government demonstrates leadership, commitment and integrity by establishing clear objectives, providing timely and clear policies, allocating financial and human resources, and acting on consensus recommendations; ensures coordination with existing policies and decision-making processes; and supports participation by its agencies and their representatives. Government assesses the appropriateness of negotiation prior to the start of process.
2. Inclusive and Effective Representation of Interested Parties	***a) Inclusive representation:*** Everyone who is able to affect or be affected by the outcome of any negotiation, who is responsible for implementing decisions, and who has significant interest in the issues should be involved in the negotiations. The wider public is kept informed through outreach methods. The process involves local, government and First Nations interests as needed. Inclusion is a process of continual adaptation with differing levels/roles for representatives. Complex constituencies are managed into caucuses. The set and number of stakeholders reflect the complexity of the problem. ***b) Effective representation:*** All participants are committed – they attend regularly, participate in good faith, are knowledgeable, communicate openly and share ideas. Representatives are trusted by their constituents and empowered to represent them and make decisions on their behalf; they maintain communication with and inform their constituencies. Government representatives can speak for their organization, are available for consultation, are skilled in communication and public processes, listen to participants, are technically knowledgeable, understand planning, work well with people, and share power with public representatives.
3. Effective Process Management	Process managers include convenors, co-ordinators, administrators, and facilitators. In addition to having the attributes described under *Effective Representation*, process managers are committed, neutral, skilled in process management and communication, knowledgeable about issues; and available for consultation with participants. Stakeholders must believe process managers have legitimate authority. Leadership and constructive management throughout the process are critical to success. High interdependence in a group requires powerful convenors. High-conflict situations suggest the need for professional facilitators.

[3] The main authors are: Dukes and Firehock 2001; Duffy, Hallgren, Parker, Penrose, and Roseland 1998; Gray 1989; Cormick, Dale, Edmond, Sigurdson and Stuart 1996; Roberts and Hawkins 2000.

4. Effective Process Design Effective process design requires clear terms of reference to guide the process, participant involvement in the process design, and a comprehensive set of procedural ground rules.	***a) Clear terms of reference:*** The mandate, roles, responsibilities, and authority are clear to all participants. Clear terms of reference also involve a clear purpose of process; clarity of stakeholder expectations about outcomes; clear organization, roles and authority of subgroups; clear ground rules; and realistic timeframes. The process is flexible and adapts to changing circumstances; a fall-back dispute mechanism exists if consensus is not reached. The geographic scale is appropriate. Meeting logistics are clear, and a media policy is agreed upon. ***b) Participatory design:*** Participants are involved in tailoring their mandate, process, issues, and agenda. The agenda is designed to accommodate all interests and includes ground rules for operating together. Mechanisms are in place to allow participants to provide feedback and to facilitate change to the process design. There are trade-offs between the number of stakeholders and the ease of managing a process. ***c) Ground rules:*** The rules of procedure must be clear to establish boundaries for participant behaviour as well as the procedure and substance of the discussions (e.g., organization, conduct and logistics of meetings). Ground rules cover participant interactions, issues up for discussion, parties at the table, information sharing, facilitation, dispute settlement process, decision rules, and consensus rules. Without agreement on these matters there can be no process. The process design is effective only if stakeholders adhere to procedural agreements.
5. Structured and Integrative Decision-Making Framework Providing structure to the decision process creates opportunities for meaningful involvement of all participants in deciding the substantive issues through the achievement of each of the following sub-sections, in development, evaluation and selection of decision alternatives.	***a) Structured decision-making framework:*** The decision-making framework is rigorous, uses an iterative approach to deal with complex issues, and highlights trade-offs. It manages the complexity of substantive issues through explicit decision criteria used to explore options, clarify decisions, and monitor and evaluate decisions. Inventing options of differing strength increases the number of potential solutions. ***b) Creative approaches to problem solving:*** Creative approaches to promote teamwork and effective problem solving are utilized; e.g., small group sessions, plenary or roundtable discussions, forums, speakers, and mapping tools. Sub-groups/sub-committees or a neutral third party can help present and scrutinize multiple options. Time is built into the process to understand differences. Trust is built by working to achieve the principles in this framework, by ensuring interest-based negotiations, by holding specific workshops to address barriers between groups and develop skills, and by exploring options and making trade-offs together. ***c) Comprehensive and integrative framework:*** The process promotes decisions that consider balancing social, economic and environmental impacts, issues, and concerns.
6. Equal Access to Information	***a) Equal access to information:*** "Knowledge equality" improves the balance of power and ensures all participants, including government agency staff, can participate meaningfully. This means providing resources to assemble information and providing access to, and dissemination of, information and expert knowledge. Expertise includes local and traditional knowledge. Information is the best available, credible, understandable, timely, not rushed or late. Experts are made available to explain and interpret information and assumptions. ***b) Joint information search:*** Joint fact finding allows all participants to mutually gather, examine and share information relevant to decisions. Together, participants assign tasks or teams or invite panels of experts to synthesize complex and controversial data (social, economic, scientific, layperson/traditional/local knowledge) to help stakeholders understand. Third parties can be contracted to research information that is missing or difficult to obtain.