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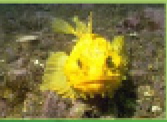
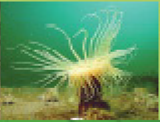
Marine Ecosystem Conservation for New England and Maritime Canada: a Science-Based Approach to Identifying Priority Areas for Conservation

Conservation Law Foundation - USA
WWF-Canada

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Marine Ecosystem Conservation for New England and Maritime Canada:
a Science-Based Approach to Identifying Priority Areas for Conservation

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Acknowledgments

This project and the production of this document are the culmination of a substantial 6 year collaboration between the Conservation Law Foundation (CLF) and WWF-Canada. This project benefited from the critical input and cooperation of a large number of people over the course of its life. Many scientists from government and academic institutions made essential contributions by providing access to data, analysis and interpretation, and guidance on design. We have tried to recognize individuals within specific chapters of this report where their contributions were greatest. The project also benefited enormously from the input of scientists who were convened for several peer reviews of the project, and we are indebted to these individuals for their essential contributions. Names of peer review team members are provided in Appendix A.

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Document preparation

The principal authors of this report are John D. Crawford, Senior Scientist, Conservation Law Foundation, and Jennifer Smith, Manager, GIS and Conservation Planning, WWF-Canada. Hussein Alidina and John Roff provided an early draft of the material on seascapes (Chapter 8). Ken Larade, WWF-Canada, produced many of the analyses, tables, and figures. We are grateful to Petra Halsema, Christina Kaba, Elliot Rector, Kate Zultner, and Scott Sneddon at CLF, and Marty King at WWF-Canada, for their help in producing this report. We are indebted to John Morrison, Deputy Director, Conservation Science, WWF-U.S., for a comprehensive review of a near-final draft of this document, in the fall of 2005. Kathi Hagan made substantial improvements to the report through professional editing. Kyle Ferguson and Wendy Douglas of WWF-Canada assisted with production of the report. Design and layout by Mystique Creative Inc. Printing by Bowne of Canada, Ltd.

Summary

In this report the Conservation Law Foundation and WWF-Canada present a method for identifying a network of priority areas for conservation and call for the implementation of a large-scale network of protected areas to help restore marine ecosystems and conserve biodiversity in New England and Maritime Canada.

The marine ecosystems of the Gulf of Maine, Georges Bank, and the Scotian Shelf are legendary for their productivity, and marine life has played an important role throughout this region's history. However, due to the depletion of populations of many fishes, whales, turtles, and seabirds, and due to habitat loss and water pollution, these once-plentiful waters are in peril. Scientific research points not only to dwindling populations of marine life, but also to fundamental changes in the characteristics of populations and complex ecological systems. To date, the stewardship of the region's marine ecosystems has been inadequate, and further losses in terms of biodiversity and the valuable goods and services provided by healthy ecosystems are to be expected. Failed fisheries and unemployment testify to these problems and mark the changing face of coastal communities throughout our region.

A host of scientific, conservation, and governmental bodies have recognized that effective marine ecosystem conservation must include carefully designed networks of marine protected areas that are representative of habitat types and the full spectrum of marine life. These networks must receive enduring protection to ensure that biodiversity is preserved for current and future generations. As a starting point, the Conservation Law Foundation and WWF-Canada are working to promote the implementation of a network of marine protected areas within the shelf waters of the Gulf of Maine, Georges Bank, and the Scotian Shelf, an ecological region encompassing 277,388 km^2 (80,886 nmi^2; 107,100 mi^2). Here we present a method for identifying a network based on the best-available scientific data for the region. We illustrate the utility of the method and describe a network of priority areas for conservation.

The priority areas for conservation presented here were designed to simultaneously achieve three objectives essential to marine biodiversity conservation.

1. *Represent habitat types*. To achieve habitat representation, a significant sample of each of the coarse-scale habitat types or seascapes was included. Habitat was classified on the basis of non-living (abiotic) features including seafloor type, seawater depth, temperature, salinity, and stratification, all of which are features known to influence the distributions of marine organisms.

2. *Include biologically distinctive areas*. Biologically distinctive areas were identified from an ecologically diverse suite of marine life forms (i.e., biological conservation features). Distinctive areas were determined by patterns of species richness and abundance of bottom-living fishes (i.e., demersal fishes), distributions of whales and dolphins, and the distribution of primary producers as estimated from surface chlorophyll concentrations. We used this suite of biological conservation features to facilitate the inclusion of ecologically important areas and a diversity of community types.

3. *Recognize biogeographic areas*. Goals for representing habitat and for distinctive biological areas were achieved within each of three biogeographic areas making up the analysis region, to ensure that differences in faunal assemblages at the scale of biogeographic areas were captured within the network of priority areas for conservation.

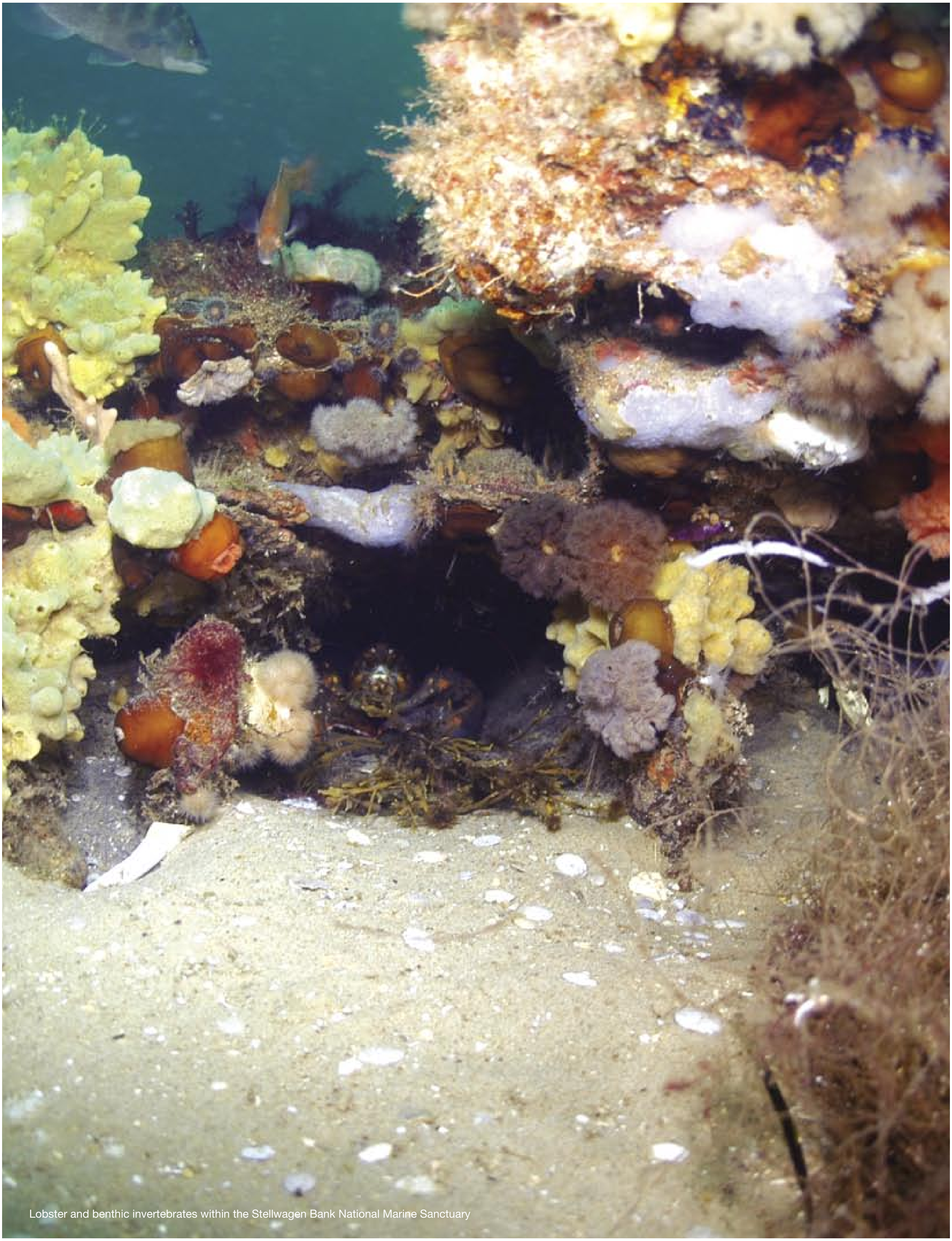
Site selection was undertaken with MARXAN, a computer program that has been applied to a variety of marine planning problems around the world. We provided MARXAN with explicit goals for each of the conservation features and several other instructions that influenced the form of the solutions, or networks of areas. MARXAN evaluated the performance of thousands of different combinations of planning units in terms of how efficiently and to what degree the goals could be met. In this manner the program identified many networks that were good at meeting the goals. Of these, the top-performing network – *the best network* – consisted of 30 individual priority areas that covered one-fifth of the region. We call this a network of priority areas for conservation. Seven of the areas included portions of Georges Bank; 11 areas were selected in the Gulf of Maine, some of which extended into adjacent biogeographic areas; and 16 areas were located on the Scotian Shelf. The priority areas making up the network were complementary, i.e., each made a particular contribution to some or all of the conservation goals such that all of the goals were met by the network. A number of the areas of the network coincided with areas of previously recognized ecological significance, including Stellwagen Bank, historic cod spawning areas in the Gulf of Maine, and critical areas for whales on the Scotian Shelf.

Our method can be readily extended in a number of ways, and this point is as important as the specific results. For example, new survey data or traditional knowledge can be added to the site-selection process if they become available, and particular places can be incorporated if there is agreement that this is well justified. The method is also valuable because it can identify more than one viable network within the constraints of a given set of data and conservation goals; it thus provides planners and policymakers with options.

We acknowledge that the data for large-scale marine conservation planning are not perfect – much is unknown about the greater Gulf of Maine and Scotian Shelf ecosystems, but this will always be the case. Nevertheless, the data we used have proven sufficient, and we know this because the resulting network identified a number of priority areas that coincided with places that are already well known for their ecological significance, in some cases dating back to the earliest historical accounts of the region. Our site-selection process was strengthened through the integration of a number of data layers.

What is certain is the seriousness of the effects humans have had on our marine ecosystems, as is the urgency of implementing new approaches to marine conservation. The marine conservation problems in the northwest Atlantic Shelf region are significant. Solutions are urgently needed, and planning should not be delayed.

Embracing the challenge of guiding marine activities by using the best-available science in a public process for implementing a well-planned system of marine protected areas, including fully protected zones, has been recommended by a diverse cross-section of the community including marine scientists and the public. We are confident that our method of identifying a network of priority areas for conservation is a sound, science-based foundation for conserving the biodiversity and ecosystems of the northwest Atlantic Shelf region. As such, it should be integral to a public process for developing an improved program of marine stewardship for the ecological regions shared by New England and maritime Canada. We cannot afford to wait.



Lobster and benthic invertebrates within the Stellwagen Bank National Marine Sanctuary

Chapter 1

Background

Complex webs of life: importance of marine ecosystems

Marine ecosystems are composed of vast numbers of organisms, from microscopic bacteria and photosynthetic plankton to the largest predatory fishes and whales. These life forms interact through highly complex webs, including direct predator-prey interactions and many indirect interactions. The species are distributed throughout a myriad of habitats, and each is adapted to some particular set of physical and biological circumstances characteristic of distinct ecological communities of organisms. Familiar species, seafood for example, comprise a minute fraction of all the species. They are products of an ecosystem and consequently rely, albeit indirectly, upon a very large web of species and habitats.

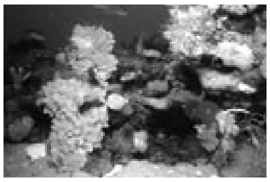
The extraordinarily diverse and abundant marine life of the northwest Atlantic Shelf region – which includes the Gulf of Maine, the Bay of Fundy, Georges Bank, and the Scotian Shelf – has supported indigenous peoples for millennia, and in more recent centuries has been a significant factor in the influx of immigrants to the region (Figure 1-1).

Figure 1-1. Map of the northwest Atlantic Shelf region, including the Gulf of Maine, Bay of Fundy, Georges Bank, and the Scotian Shelf.

However, today, the ecosystems that yielded this bounty are seriously at risk. Fundamental aspects of ecological structure have been altered through habitat destruction, over-harvesting, and other human activities. In addition, the effects of a rapidly changing global climate are just beginning to manifest themselves in the already stressed marine environment, and the repercussions are likely to be severe.

Populations of many commercially valuable species are dangerously depressed, major fisheries have vanished, and some marine animals are extinct. Fish and whale populations are a mere shadow of what they were historically (Rosenberg et. al. 2005) and many human communities along the coasts have suffered as a result. Some species, such as Atlantic cod and the north Atlantic right whale, have failed to respond to management efforts aimed at restoring their numbers. Others, such as the great auk, sea mink, and gray whale are gone forever.

Humans have an enormous dependence on the integrity of the sea's intricate web of life, yet humankind is at risk of losing major components of marine biodiversity before the ecological roles or resource values of these components are fully understood (Pew Oceans Commission 2003). Therefore new approaches to implementing and managing marine habitat protection are desperately needed to permit the recovery and conservation of marine ecosystems.



Current state of marine habitat protection

As on land, networks of strategically selected protected areas are an essential component of effective marine stewardship (Science and Management of Protected Areas Association 2000; National Research Council 2001; Partnership for Interdisciplinary Studies of Coastal Oceans 2002; Pew Oceans Commission 2003). Of the protected areas in our region, almost none are fully protected, and the level of protection in the remainder is inadequate for biodiversity conservation (Recchia et al. 2001; Pew Oceans Commission 2003; Sobel and Dahlgren 2004).

The Gully, on the edge of the Scotian Shelf, was recently designated for conservation of marine biodiversity, and at about 1,500 km^2 is large enough to make a significant contribution to regional ecological integrity. It includes a fully protected core zone. The Stellwagen Bank National Marine Sanctuary within the Gulf of Maine is of similar size and is also designated for conservation of marine biodiversity, albeit nominally; unfortunately, few protections for marine life are in place within the Stellwagen Sanctuary. Fishing occurs throughout the sanctuary, and includes bottom-trawls, mid-water trawls, hook and line, purse seines, lobster traps and harpooning of tuna.

Many protected areas – i.e., fisheries closures – have been designated for commercial fisheries management in the United States and Canada. However, most of the areas are not fully protected. They allow some forms of fishing and they can be re-opened when resource values within them increase. Additionally, a number of these areas are protected for only a part of each year. Overall, the areal extent and degree of protection in our region falls well short of what has been recommended by the scientific community (National Research Council 2001).

Marine protected areas

A protected area in the ocean is often called a marine protected area (MPA). The term is broad in that it applies to very small areas as well as large ones, and it refers to areas that are protected from all activities (i.e., marine reserves) as well as areas that receive minimal protection (e.g., locations where the only restriction is that sand and gravel cannot be removed). The definitions of marine protected areas have been discussed by many authors (Shackell and Willison 1995; Kelleher 1999; Atkinson et al. 2000; National Research Council 2001; WWF-Canada 2006), and the following definition is currently used by the World Conservation Union, International Union for the Conservation of Nature and Natural Resources (1994): "... an area of inter-tidal or sub-tidal 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 ..." With such broad and varied definitions, there are many areas that are identified as marine protected areas but few that are rigorously designed and sufficiently protected to achieve biodiversity conservation.

Marine protected areas in Australia, New Zealand, the Caribbean, the Pacific islands, the United States, and Canada have demonstrated the value of comprehensive protection, not only for marine life within the protected areas themselves but also for marine life in surrounding areas. The benefits of marine protected areas are greatest when all extractive activities are excluded, as is the case in reserve areas. Typically, total biological production (i.e., biomass) increases inside protected areas (Partnership for Interdisciplinary Studies of Coastal Oceans 2002; Halpern 2003). Once pressure from resource extraction is reduced, the number and average size of individuals often grows. Within populations for particular species the size-structure can return to a more natural state, so that it includes a greater proportion of older and larger individuals.

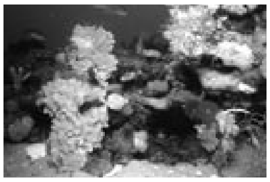
This is important in the case of fishes, for example, because older females produce eggs of higher quality and produce vastly more of them than younger individuals (Trella 1998; Berkeley et al. 2004). This improvement in reproductive output contributes to the growth of the population within the protected area and can also contribute to the re-population of surrounding areas (spillover) through the export of eggs and larvae, and through emigration of adults driven to areas of lower intra-specific competition (Roberts et al. 2001; Stevens and Sulak 2002).

As the populations of previously extracted species recover, so do other components of ecological communities. With reduced damage to the seafloor, slow-growing animals such as corals, bryozoans, and sponges that live on the ocean bottom increase in size and abundance and, in so doing, enrich the habitat for juvenile fishes and other animals (Collie et al. 1997; Collie et al. 2000; Hermsen et al. 2003; Collie et al. 2005).

For these reasons, many in the scientific and conservation communities have recognized the vital importance of placing more of the world's marine environment under effective long-term protection. Marine areas designated for long-term protection have been established around the world and they have well-known benefits for conservation (Agardy 1997; Halpern 2003; Lubchenco et al. 2003; Sobel and Dahlgren 2004), and for ecosystem-based fisheries management (Kaufman et al. 2004). Unfortunately, at <1% both globally and regionally, the portion of marine waters designated for comprehensive ecosystem protection is vastly inadequate.

The call for protected areas

The need for establishing marine protected areas as part of marine stewardship has been recognized by diverse sectors in Canada, the United States, and around the world. The Oceans Act (Canada, Parliament 1996), Canada's Oceans Strategy (Fisheries and Oceans Canada 2002), and Canada's Oceans Action Plan (2005) together provide a mandate for marine protected areas as part of Canada's integrated approach to ocean management (Smith et al. 2006). Canada was one of the first countries to ratify the Convention on Biological Diversity and subsequently agreed to the Convention's Jakarta Mandate on Marine and Coastal Biodiversity (Secretariat of the Convention on Biological Diversity 1995). At the World Summit on Sustainable Development in 2002, Canada committed to completing a national network of marine protected areas by 2012. In 2003 Canada ratified the United Nations Convention on the Law of the Sea (United Nations 1982), which included the commitment to conserve and manage marine resources (Breide and Saunders 2005). Despite these important steps, at present only about one half of one percent of Canada's marine waters (within the Exclusive Economic Zone 200-nautical-mile boundary) are under protection (based on MPA Global database: http://www.mpaglobal.org)[1].



In the United States, an executive order calling for a national system of marine protected areas was issued in 2000 (Presidential Documents 2000). It led to the establishment of a federal marine protected area center that has provided outreach and education, but which does not have the authority to implement marine protected areas. The National Marine Sanctuaries Act (United States House of Representatives 1972) has resulted in the creation of 13 sanctuaries in the United States, including the one at Stellwagen Bank. However, these sanctuaries occupy less than half a percent of the area of United States waters (i.e., those within the Exclusive Economic Zone 200-nautical-mile boundary) and, with few exceptions, offer little protection for marine life (Chandler and Gillelan 2005). In its current form the National Marine Sanctuaries Act does not provide an adequate legal mandate for creating a network of protected areas in the Gulf of Maine region, or elsewhere in the United States.

The National Academy of Sciences (National Research Council 2001), the Pew Oceans Commission (Pew Oceans Commission 2003), and a broad spectrum of scientists (National Center for Ecological Analysis and Synthesis 2001; Partnership for Interdisciplinary Studies of Coastal Oceans 2002) and conservation organizations (Sobel and Dahlgren 2004) have all recommended the designation of networks of protected areas as one of the essential tools for preserving threatened marine ecosystems. The United States Commission on Ocean Policy (2004) has also identified marine protected areas as an important conservation tool.

[1] Louisa Wood, Doctoral Candidate, Fisheries Science Centre, University of British Columbia; personal communication, 2005.

Moving forward: an approach for identifying marine conservation areas

It is clearly time for Canadian and American stakeholders associated with the northwest Atlantic Shelf region to move forward with a science-based approach to conserving our shared marine ecosystems and biological populations. To address these needs, WWF-Canada and the Conservation Law Foundation in New England (CLF) have worked together for over 5 years to bring innovative conservation science to the urgent problem of improving the marine stewardship of our region. The result is a science-based method for identifying marine conservation areas.

Effective marine stewardship must include comprehensive habitat protection that is designed to support all forms of biological diversity as well as sustain ecosystem integrity (Auster 2000; Lindholm and Auster 2000; Margules and Pressey 2000; Roberts and Hawkins 2000; Partnership for Interdisciplinary Studies of Coastal Oceans 2002; Groves et al. 2002; Roberts et al. 2003). This requires that scientific information be used to select marine conservation areas that are representative of all the habitat types in a region and are of sufficient scale to support ecosystem functions (Day and Roff 2000; Roberts and Hawkins 2000). Multiple areas are required to form a network because no single area can achieve these goals. The areas in a network complement one another, with each contributing to some sub-set of the conservation goals (i.e., the areas are complementary). The distributed areas of a network offer a number of additional benefits, including insurance against localized environmental disasters (Roberts et al. 2003).

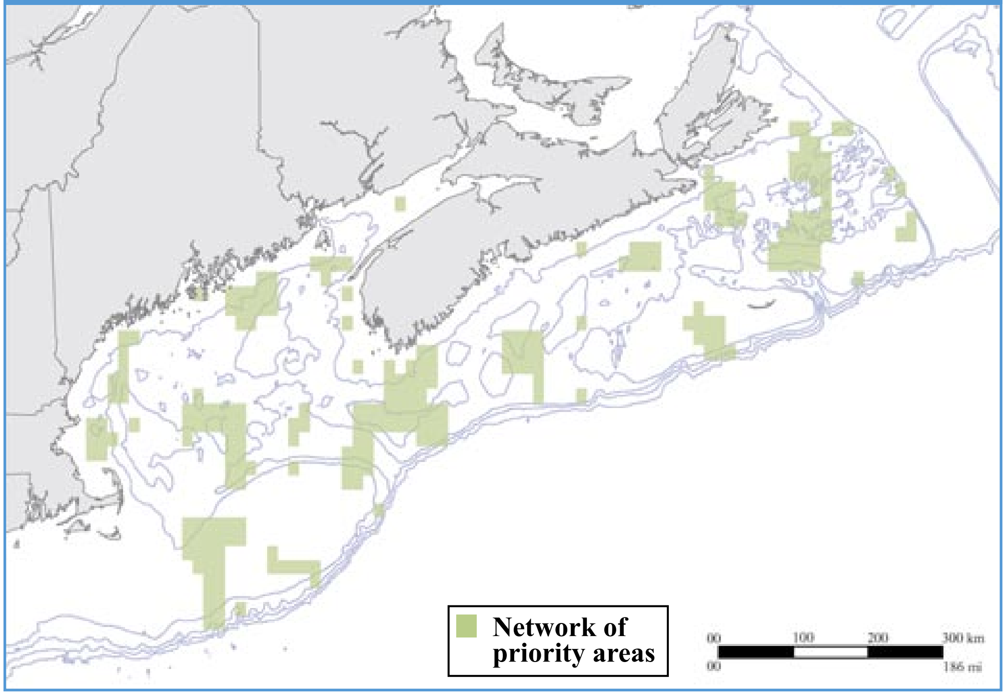
It is clear to many scientists and others that establishing substantial networks of marine conservation areas is crucial for sustaining biodiversity in the region (Recchia et al. 2001). We believe that our method of identifying a network of priority areas for conservation in the northwest Atlantic shelf region provides an objective, science-based starting point for developing an ecoregional marine stewardship plan for ecosystem conservation.

Overview of the method

This document describes scientific methods for identifying a network of priority areas for marine conservation (Figure 1-2). The document focuses on network design; actual management practices are not analyzed.

We present an objective method, based on the best-available survey data, to identify a network of marine areas that represents a portion of each habitat type and which includes distinctive areas for our region's biological diversity. The analysis is based upon information that describes the physical characteristics of marine habitat and the distributions of a variety of forms of marine life. All of the data and decision criteria are fully specified in order to make the procedures as transparent as possible.

Figure 1-2. A network of priority areas for conservation. The network is representative of marine habitats and includes biologically distinctive areas.

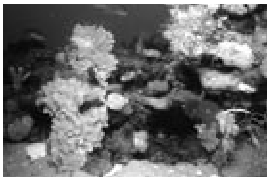


Our method can be readily extended in a number of ways, and this point is as important as the specific results. For example, new survey data or traditional knowledge can be added to the site-selection process if they become available, and particular places can be incorporated if there is agreement that this is well justified. The method is also valuable because it can identify more than one viable network within the constraints of a given set of data and conservation goals; it thus provides planners and policymakers with options.

Although we did not address human uses in our own analysis, the method is designed so that such information can be incorporated. Addressing human uses would be essential to any public process that would be carried out in designing and implementing a network of conservation areas.

To the best of our knowledge, the work presented here constitutes the first effort to develop a large-scale marine conservation plan for the northwest Atlantic region. We hope our methodology will be the catalyst that allows policymakers to engage in new approaches to marine biodiversity conservation, and thus lead to the improved stewardship that is urgently needed.

It should be noted that much of the foundation for the work described here has been presented previously by WWF-Canada (Day and Roff 2000), the Conservation Law Foundation (Atkinson et al. 2000), and many others in the scientific and conservation communities (Roberts and Hawkins 2000; Partnership for Interdisciplinary Studies of Coastal Oceans 2002; Lubchenco et al. 2003; Sobel and Dahlgren 2004).



Report overview

Chapter 2 provides an overview of our method and rationale, and Chapter 3 describes the analysis region. A detailed explanation of computer-assisted site selection appears in Chapter 4. Chapters 5 to 8 describe the types of information we have used to identify priority areas for conservation, and, finally, Chapter 9 explains how we used the method to identify a network of priority areas for conservation for the northwest Atlantic Shelf region. A glossary of terms is provided in Appendix B.

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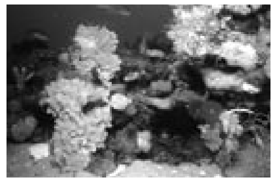

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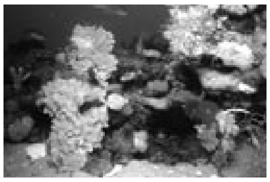
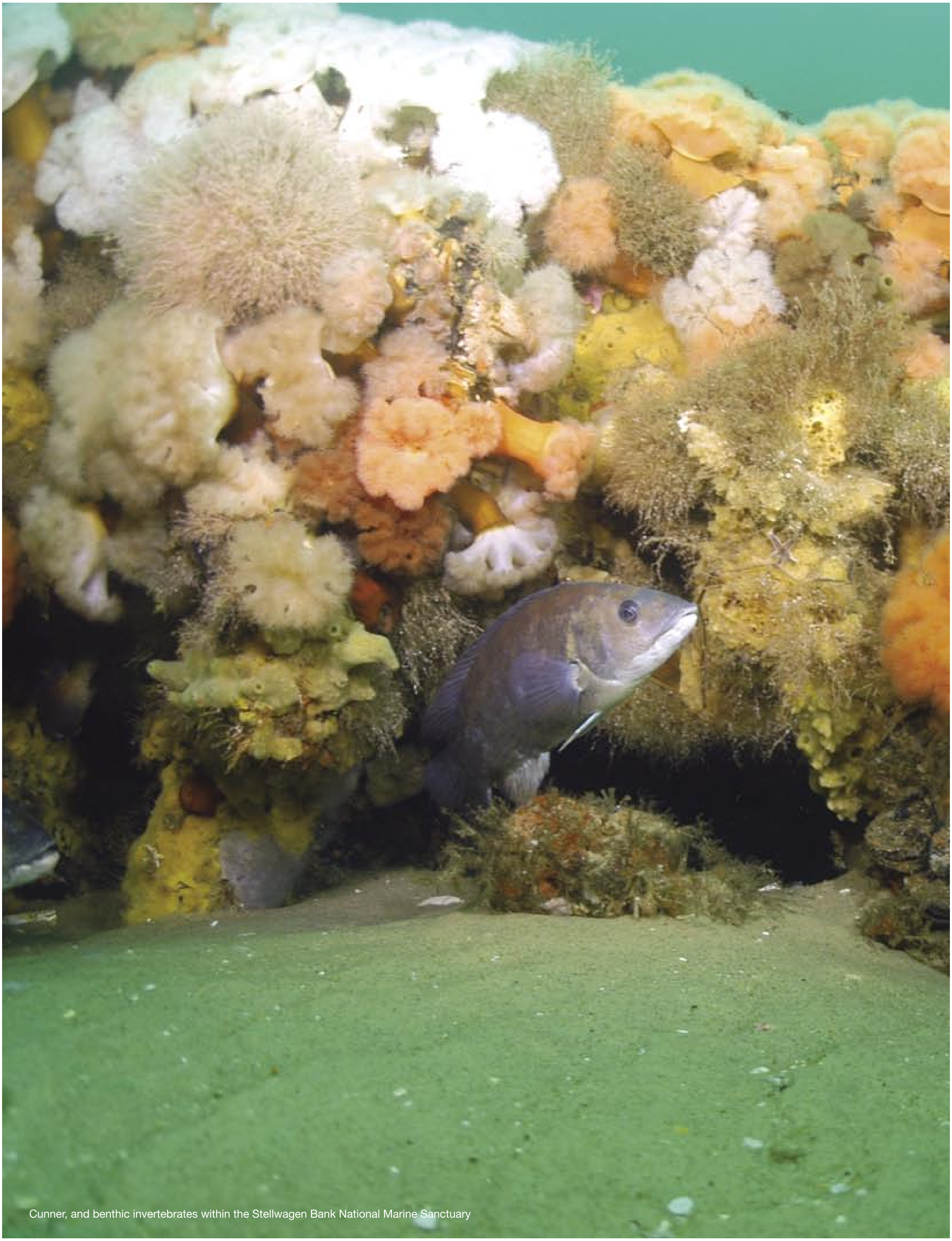




Cunner, and benthic invertebrates within the Stellwagen Bank National Marine Sanctuary

Chapter 2

Overview of rationale and methods

Habitat representation as a strategy for biodiversity conservation

Whether plans for biodiversity conservation are intended for land-based or sea-based ecosystems, developing them is challenging because knowledge of the components of the diversity (e.g., the distributions of species and/or communities) is almost always incomplete, ecosystems are dynamic and complex, and the requirements of target populations are often poorly understood.

Representation is a widely accepted strategy for countering this uncertainty in planning for biodiversity conservation (Noss 1983; Belbin 1993; Olson and Dinerstein 1998; Soule and Terborgh 1999; Ward et al. 1999; Groves et al. 2000). A systematic effort to conserve high-quality and enduring examples of the full range of communities, habitats, environmental gradients, and ecological processes in a region – not just those areas about which we know the most – is a substantial step toward protecting the majority of the diversity of marine plants and animals in the places where they live, as well as the natural processes that sustain them (Anderson et al. 1999). A representative approach is a means of sampling ecological processes and critical life history areas, thus ensuring that management failures in the wider planning region are less likely to result in irreversible biodiversity loss (Hunter 1991; Secretariat of the Convention on Biological Diversity 2004). It is a precautionary approach.

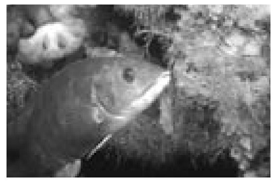
An ecosystem that includes a representative network of protected areas may be better able to withstand shock without fundamental change – to cope, adapt, or re-organize without sacrificing the provision of ecosystem services – because the components needed to rebuild persist (World Commission on Protected Areas/International Union for the Conservation of Nature and Natural Resources in press). Conserving a range of environmental gradients and potential temperature refugia also enhances resilience in the face of projected climate change impacts.

Physical habitat mapping – which is based upon various types of information, including vegetation and substrate types, altitude, grade, rainfall, temperature, and, in the marine environment, salinity, and water depth, temperature, and stratification – allows planners to design networks that include some minimum amount of each habitat type when comprehensive data on the distribution of biological communities is lacking (Leslie et al. 2003; Roff et al. 2003; Soule and Terborgh 1999). In principle, good habitat mapping should lead to representative networks that include all the types of areas needed by various ecological communities. This approach, which is sometimes called a coarse-filter approach, has been used for both terrestrial and marine conservation.

The diversity of species and their habitat requirements are great, and the variables chosen to define habitats will be more suitable for some species than for others. Consequently, using habitat representation as a strategy for biodiversity conservation is best when integrated with information about the distributions of key species or biological communities (Hunter 1991; Day and Roff 2000; O'Connor 2002; Meir et al. 2004; Stevens and Connolly 2004).

As an example, consider the distribution of a particular fish species, and the community of which it is a part. Sea water depth and salinity, and seafloor type, may strongly influence distribution. However, within all areas meeting the requirements for these variables, the fish may also be influenced by other variables, such as the availability of a particular bottom-living invertebrate. Should the invertebrate be unevenly distributed, the fish might occupy only some portion of the "habitat" that was otherwise suitable; a representative approach based only on habitat could therefore miss these areas. Additionally, even in a case where the set of variables used for habitat definition is perfectly matched to a given species, that species may fail to fully saturate all the available habitat (O'Connor 2002). Conservation planning that is based upon both representation of habitat and upon the distributions of life forms is less susceptible to these pitfalls, and thus more powerful than if based on only one or the other.

The value of a well-designed representative network for conservation planning at large scales has been discussed by a number of authors (Anderson et al. 1999; Day and Roff 2000; WWF-Canada 2006), and the representative approach has become fundamental in conservation theory and practice (Noss 1987; Franklin 1993; Pressey et al. 1993; Noss and Cooperrider 1994; Maybury 1999). The work of Day and Roff (Day and Roff 2000; Roff and Evans 2002) served as an important foundation for our own approach to deriving priority areas for marine conservation.



Day and Roff (2000) set out a framework for designing networks of marine protected areas that included a case study for the Canadian portion of the northwest Atlantic Shelf region. They outlined the use of what they called "enduring and recurring" environmental features for habitat classification as a basis for achieving representation. These features were non-living – or abiotic – and described sea water conditions and the seafloor.

Importance of distinctive areas

Day and Roff also highlighted the need to consider distinctive areas in the development of marine conservation plans (see also Roff and Evans 2002). A distinctive area is distinguished by the presence of one or more unique biological or physical attributes, such as a known spawning area for a fish, a known feeding ground for an endangered whale, a location where cold-water corals survive, or a rare habitat such as a seamount or a particular submarine canyon.

The integrated approach used here

Our integrated approach to planning for biodiversity conservation involved combining coarse-scale habitat representation with data depicting distinctive areas for an ecologically diverse set of marine life, i.e., the biological conservation features (Table 2-1).

Habitat representation was achieved on the basis of a suite of abiotic characteristics that were known to be fundamental components of habitats for a wide diversity of marine life, and for which adequate spatial data were available (Day and Roff 2000; Etnoyer et al. 2004; Roff and Evans 2002; Roff et al. 2003). Maps of marine habitat, referred to as seascapes (Day and Roff 2000; Roff et al. 2003), were derived from physical parameters that describe the sea water (temperature, salinity, stratification, depth) and the seafloor (substrate type).

Table 2-1. Conservation feature classes and goals for designing a network of priority areas for conservation.

Conservation feature classes	Description and data source[a]	Goals
Primary production	Areas of persistently high chlorophyll concentration – SeaWiFS satellite images.	20% of those planning units classified as exhibiting persistently high chlorophyll concentrations. See Chapter 5.
Demersal fishes		
Species richness	Number of species per trawl, average by planning unit – NMFS and DFO research surveys.	20% of the richness contained in those planning units at or above the mean for the biogeographic area See Chapter 6
Juvenile abundance	Number of individuals per trawl, average of log normalized counts by planning unit – NMFS and DFO research surveys.	20% of the relative abundance contained in those planning units at or above the mean for the biogeographic area, goals set by species. See Chapter 6.
Adult abundance	Number of individuals per trawl, average of log normalized counts by planning unit – NMFS and DFO research surveys.	20% of the relative abundance contained in those planning units at or above the mean for the biogeographic area, goals set by species. See Chapter 6.
Cetacean abundance	Number of sightings per 1,000 km of survey transect, average of log normalized counts by planning unit – NARWC database.	20% of the relative abundance contained in those planning units at or above the mean for the biogeographic area, goals set by species. See Chapter 7.
Seascapes	Habitat types classified from abiotic data, benthic and water	20% of each seascape, goals set by seascape type. See Chapter 8.

[a] *See Appendix D for a list of abbreviations.*

Although our particular suite of biological features was diverse, it was not perfect. It was not likely to lead us to every ecological community and associated habitat in the region (Su et al. 2004). Additionally, some of the species we used could have been absent from particular areas during sampling, due to fishing or other impacts. The exploitation of various habitat types is also density dependent in some species (O'Connor 2002), so the distribution throughout the seascape mosaic would be different if a reduction in population size were to occur. Thus, some areas – areas that could again support abundant marine life – might have been missed based on the biological conservation features alone. These possible problems with the suite of biological conservation features may be avoided by also basing site selection on seascapes, i.e., in order to ensure representation. Conversely, weakness in the seascape classification may also be mitigated by the biological conservation features.

We selected networks that met goals for the representative and distinctive conservation features simultaneously. Thus, we developed networks that were representative of the seascapes but the selection of areas was in essence guided by the biological conservation features. The resulting networks were representative and included distinctive areas for each of the biological conservation features. Many locations in a network contributed to meeting objectives for both habitat and biological conservation features. It was also expected that some areas might be selected primarily because they were essential to meeting goals for particular biological conservation features, or because they were only required for achieving goals for representation of the seascapes.

■ Using seascapes to achieve habitat representation

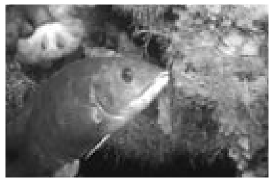
On land, it is common to think of regions as being made up of a mosaic of habitat types. Similarly, we have made a coarse-scale classification of the mosaic of seascapes within the northwest Atlantic Shelf region.

Some attributes of a seascape are like those used to describe a landscape, such as topography of the seafloor (i.e., depth) and soil type (i.e., substrate). Other attributes are less familiar but are important from the perspective of many marine organisms. For example, the discontinuities between water masses in terms of temperature, salinity, or stratification can have a profound influence on the distributions of marine animals. Thus, in defining seascapes we have included these less familiar dimensions, and have recognized that the seafloor (benthic realm) and water column (pelagic realm) each display distinct seascape mosaics.

■ Using biological conservation features to identify distinctive areas

Biologically distinctive areas were identified in our analysis from data on marine life. These constituted the biological conservation features and described relative abundance and/or species richness for a number of cetacean and fish species, and phytoplankton. Areas that were high-scoring based on these measures were classified as distinctive (see details in the following chapters). For example, the distinctive areas for particular fish and whale species were defined as those areas where abundance was at or above the average for the species. Areas of high species richness for fishes were similarly selected, and locations where chlorophyll concentrations were persistently in the top 10% were taken as distinctive for primary production (Table 2-1).

We used a set of species that participate in a diversity of ecological communities. Thus, these features are expected to function as ecological indicators, serving as “umbrella species” for other components of the ecosystem (Primack 2002). We did not include geologically distinctive areas, nor did we include localities known to be biologically distinctive but for which a systematic survey covering most of the region was not available to us (e.g., isolated coral areas). It was our judgment that such localized areas could be added in the future, during the further development of a conservation plan. The decisions about which particular localities to include ought to be made through a broader and more participatory process than we have carried out here.



Defining habitat

■ Variables

Because biodiversity conservation and habitat protection are inextricable, much of our discussion here focuses on habitat, a term that can be used in a variety of ways. For our analyses, we have used abiotic variables that have repeatedly been found to influence the distributions of a variety of marine taxa for coarse-scale habitat mapping. We have also used the distributions of selected species to identify biologically distinctive habitat areas, but again at a coarse scale.

■ Scale

Scale is a critical aspect of habitat, population viability, and conservation planning, with mere centimeters being relevant to some of the smallest organisms, and hundreds of kilometers being important for highly mobile species like pelagic fishes and whales. The issues around defining habitat on scales that are appropriate for particular species are important and complex (Wiens 1989; Ludwig et al. 2000; Scott et al. 2001; Warman et al. 2004), and they relate to the complicated question of how much habitat is needed to attain the broad goals of ecosystem conservation associated with a network of marine protected areas. Under the best of circumstances, one can begin to get at this question through the analyses of particular target species. However, we have not undertaken such analyses here.

Our analysis is not directed at a detailed classification of habitat for particular species. Rather, ours is a coarse-scale analysis aimed at capturing a broad spectrum of habitat types and the associated biodiversity, to the extent possible with currently available data.

In our classification of habitat, the grain of our analysis had a minimum resolution determined by the size of our seascape grid (i.e., 5 geographic minutes on a side, or about 58 km^2) and planning units (10 geographic minutes on a side, or about 234 km^2). These limitations on grain were determined by the data available at an ecoregional scale. When we discuss the identification of habitat, we are referring to relatively large areas that are dominated by habitat conditions of the specified type, but these areas were not assumed to be exclusively one habitat type throughout. At the coarse grain of our analysis it was expected that individual squares would often contain a variety of conditions that would be revealed if a finer-grained analysis was possible.

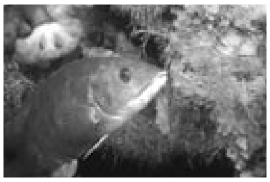
■ Steps in identifying habitat

Habitat is most commonly defined by the characteristics of those places where a particular species lives, both abiotic (e.g., water depth) and biotic (e.g., predominant kelp type where a species of fish lives). Thus, the first step in understanding the habitat for a given species is to examine where that species is found. Thus, maps in this document that show where particular species were found are a form of coarse-scale habitat map. The next step – describing *what* defines the habitat – is more difficult and has been attempted for relatively few species. In the absence of experimental work on habitat selection, we were left with correlations between abundance and those attributes of the environment that scientists have had the ability, or forethought, to measure (e.g., seafloor type, depth, salinity). Some of the attributes may not directly determine where a given species is found, and some of the factors that do directly influence distribution may be missing. In order to include as much biodiversity as possible within our networks, we have combined maps based on several key marine habitat parameters with maps of a diversity of life forms.

Areal extent of the network

We relied on guidance from the scientific community to determine the areal extent of our network of priority areas for conservation. Areal extent is a complex issue that has been examined by the National Academies of Sciences (National Research Council 2001), by the Great Barrier Reef Marine Park Authority Scientific Steering Committee (Great Barrier Reef Marine Park Authority 2002) for the Representative Areas Program, and in a variety of scientific publications.

There is no simple answer to the question of how much is enough, in terms of the sizes of individual areas making up a network, the total number of areas, or the overall spatial extent of a network. However, based on what is known, we focused on a network design that includes approximately one-fifth of each of the three biogeographic areas.



A network of this scale is expected to meet the requirements of much of the region's biodiversity, but possibly will contribute more to the less mobile (usually smaller) species than to highly mobile species. However, even highly mobile species will benefit from the protection of areas where they spend part of their life cycle, for example through increased availability of smaller prey species or of areas where behavioral disturbance is minimal. We have sought to balance the benefits that emerge from achieving conservation objectives through a network of distributed areas (Roberts et al. 2003) against the potential costs of including some areas that may be too small to support some of the mobile species.

Site selection

The task of identifying a network of priority areas for conservation based upon many types of information was complex. We needed to meet a large number of goals efficiently yet keep the overall area to a minimum. We accomplished this by using MARXAN, a powerful computer-based site-selection program (Possingham et al. 2000).

MARXAN performs site selection based on a set of conservation features, with a quantitative goal specified for each. We set a goal of including a representative proportion of each of the seascape classes (i.e., 20% of each habitat type). We set goals similarly for the biological conservation features, including a proportion of the high-abundance areas identified for each whale species, for example.

MARXAN then repeatedly searched through all of the information provided to it, seeking combinations of areas that attained the goals in a spatially efficient manner. Not surprisingly, the program could achieve the goals in a variety of ways because most habitat types and marine life were found in a number of locations, and each network of areas needed to capture only some portion of each. MARXAN allows the performance of each network to be evaluated with respect to the specified conservation goals and degree of spatial efficiency and thereby identify the best performer. Because the method can generate several networks that perform reasonably well, it has the added benefit of providing planners with a choice of viable networks. As noted in Chapter 1, knowing the alternatives can be essential in a public planning process.

The full details of using MARXAN for site selection appear in Chapter 4.

Operating principles

The following operating principles guided us in developing a method for identifying a network of priority areas for conservation:

- *Engage in conservation planning at an ecoregional scale*. Our ecologically unified analysis region covers the shelf waters ranging from Cape Cod, Massachusetts to Cape North, Nova Scotia, an area of some 277,388 km^2 (80,886 nmi^2; 107,100 mi^2).

- *Recognize biogeographic areas*. The analysis region includes three biogeographic areas – the Gulf of Maine (including Bay of Fundy), Georges Bank, and the Scotian Shelf – which we distinguished based upon studies of biological communities and ecologically significant habitat features (e.g., water temperature, currents). We have explicitly recognized these three areas as distinct biogeographic areas by setting area-specific conservation goals.

- *Use the best-available spatial data for biological conservation features*. We included an ecologically diverse set of biological conservation features while maintaining standards for region-wide sampling. We excluded data that did not have sufficient spatial extent or resolution for assessing large-scale distributional patterns. Isolated areas known for their ecological significance (e.g., localities for hard corals) were not included as explicit conservation features, but we recognize that it may be desirable to add such localities to future analyses.

- *Use the best-available abiotic data for classification of marine habitat or seascapes*. We selected data for defining benthic and pelagic seascapes that are based on: (1) variables of demonstrated ecological significance, and (2) datasets that have adequate spatial resolution and extent for the analysis region.

- *Use biological and abiotic data simultaneously to design a network that is representative of habitat and includes biologically distinctive areas.*

- *Design a network of a size that is sufficient for meeting objectives for biodiversity conservation and for playing a role in sustaining the region's ecosystems.*

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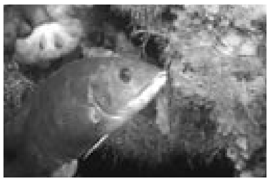

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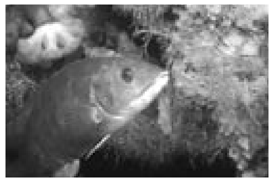
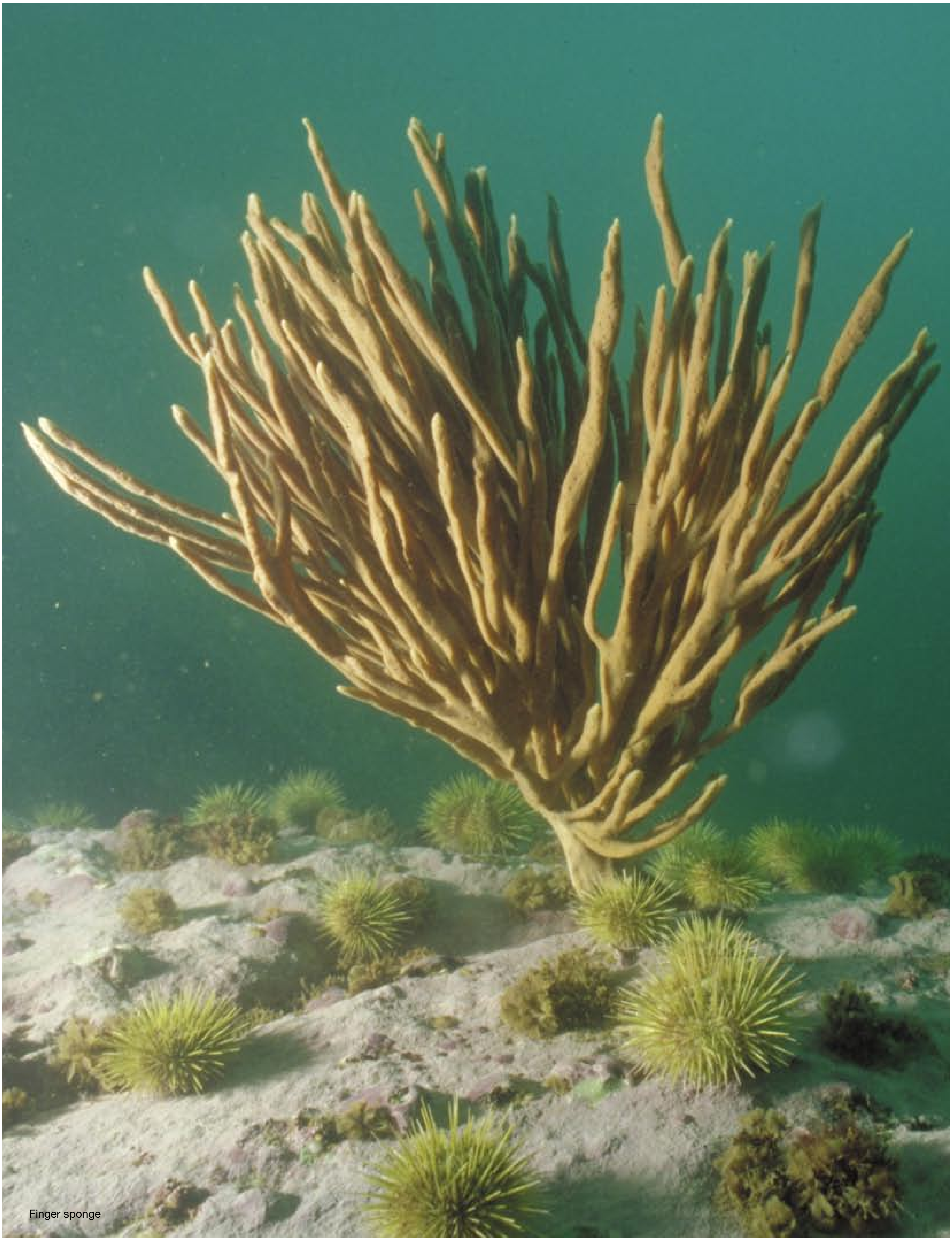



Finger sponge

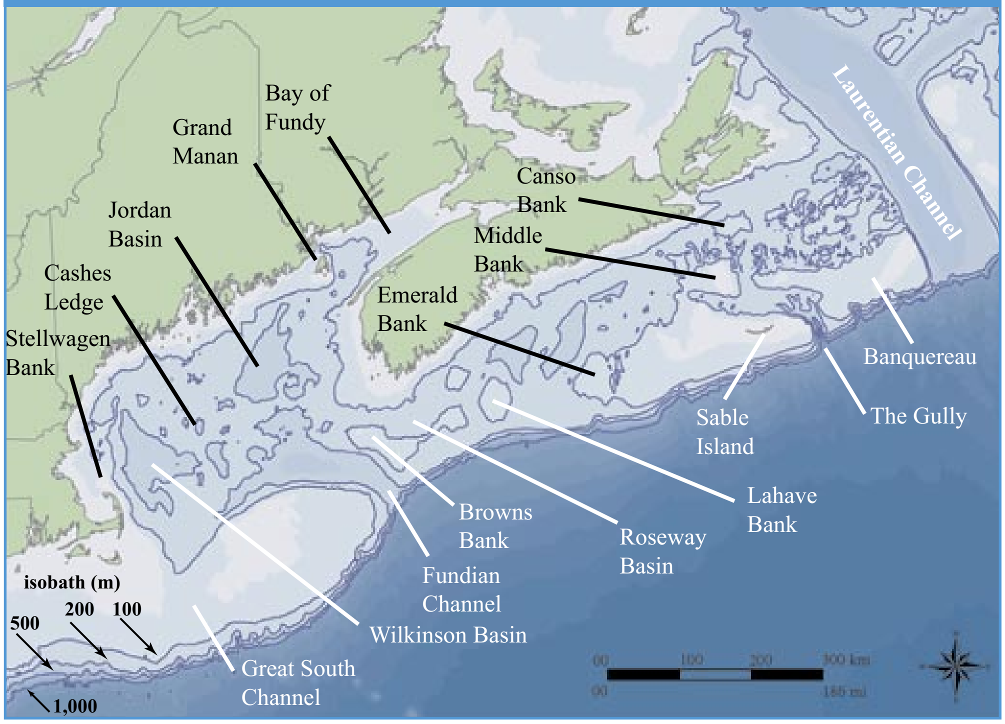
Chapter 3

Ecological region and biogeographic areas

Boundaries of the analysis region

We have used ecological boundaries to determine our analysis region (Olson and Dinerstein 1998; Groves et al. 2000), and have not structured our analysis to consider the Hague Line, which is the maritime boundary between the United States and Canada, nor any other political boundaries. Our work focused on the region of continental shelf waters defined by a seaward boundary extending from Cape Cod through the Great South Channel to the seaward edge of Georges Bank, and extending northeast along the edge of the Scotian Shelf to the Laurentian Channel (Figure 3-1; Table 3-1). The total area of the region is approximately 277,388 km^2 (80,886 nmi^2; 107,100 mi^2).

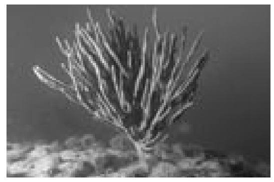
Figure 3-1. Analysis region with some of the prominent marine features.



The Great South Channel in the southwest provided a natural faunal break, as did the Laurentian Channel which is to the northeast between Cape Breton Island and Newfoundland (Figure 3-1). The faunal composition of this region can be distinguished from that of the warmer waters to the south and of the colder boreal waters to the north, though many species from within the region range beyond these boundaries. On the seaward side, the ecological region was demarcated by the shelf edge (200-m isobath) beyond which deep-water communities characteristic of the slope and abyss predominate. The coastal and estuarine zones of the inshore were excluded by means of a shoreline buffer.

Table 3-1. Number of planning units and size of biogeographic areas.

Biogeographic area	Area			
	Planning Units	km^2	nmi^2	mi^2
Georges Bank	153	42,343	12,347	16,349
Gulf of Maine	329	87,156	25,415	33,651
Scotian Shelf	575	147,889	43,124	57,100
Total	1,057	277,388	80,886	107,100



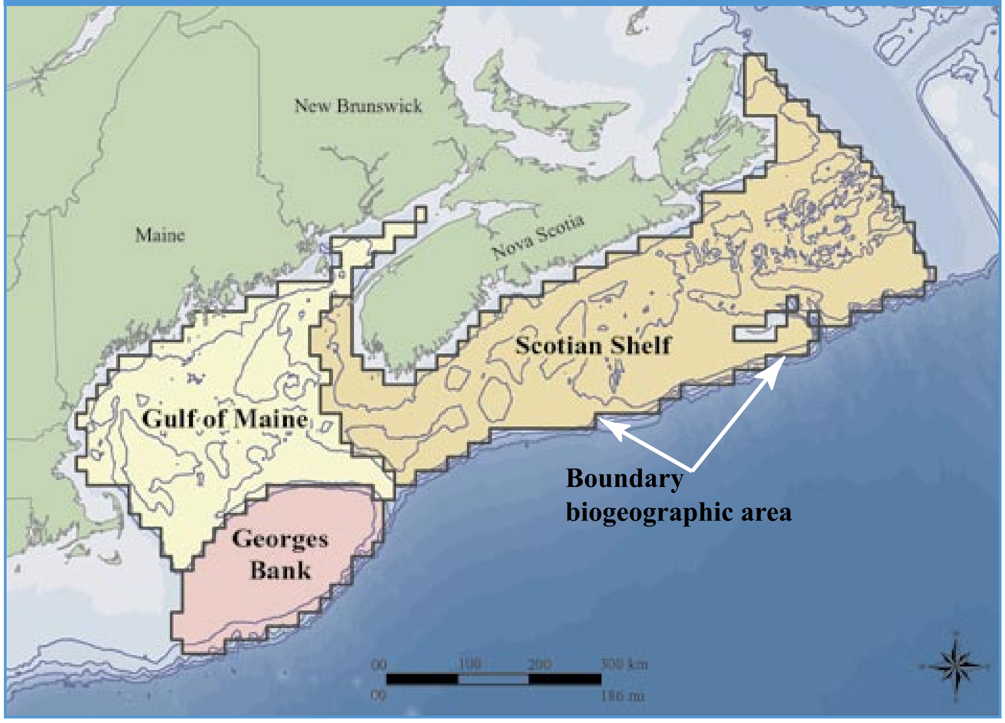
According to some scientists, our analysis region is part of a larger division of the northwest Atlantic (Longhurst 1998; Olson and Dinerstein 1998). Nevertheless, we felt that our boundaries were justified by the region's ecology and the presence of biogeographic subdivisions within it, and by the fact that the scale was appropriate relative to our marine ecosystem conservation goals.

Biogeographic areas

■ Why we used biogeographic areas

The use of biogeographic areas was essential to our goal of achieving the best representation of habitat and marine biodiversity possible because such areas are, by definition, characterized by distinct floral and faunal assemblages (Roberts et al. 2003a). Areas that may appear to be similar based on conspicuous habitat features but are situated in different biogeographic areas often support different ecological communities, species, subspecies, or genetically distinct subpopulations. A conservation plan must account for these differences in order to attain conservation goals. Achieving conservation goals for each biogeographic area is expected to provide some insurance against possible failure to capture important variation in population structure and species distributions. Distributing protection amongst biogeographic areas, and amongst multiple areas within biogeographic areas, may also contribute to overall resilience and connectivity of the network, and provide additional insurance against localized disasters (Roberts et al. 2003b).

Figure 3-2. Analysis region and biogeographic areas. Area boundaries are demarcated by black lines following planning unit edges here (arrows) and in other figures.



■ Defining biogeographic areas

We based our biogeographic areas on a synthesis of a somewhat complex body of literature on the region's biogeography, which includes varied conclusions about biogeographic boundaries (Ekman 1953; Hazel 1970; Briggs 1974; Ingham 1982; Sherman et al. 1996; Mondor 1997; Theroux 1998). Our biogeographic areas are close to those adopted recently by Cook and Auster (2005).

In deriving a network of priority areas for conservation we recognized three biogeographic areas: Georges Bank, the Gulf of Maine (including Bay of Fundy), and the Scotian Shelf (Figure 3-2).

- *Georges Bank* (42,343 km^2). The Georges Bank biogeographic area is ovoid in shape, with its most southwesterly point bounded at the Great South Channel and its northeasterly tip bounded at the Northeast Channel. The northern boundary separating this biogeographic area from the Gulf of Maine extends in a northeasterly direction from the Great South Channel at depths ranging from 50 to 100 m. The boundary shifts to an easterly course and extends to the western margin of the Northeast Channel, rounding the Northeast Peak and following the shelf edge (200-m isobath) back to the Great South Channel (Theroux 1998). Georges Bank is one of the most productive fishing areas of the northwest Atlantic and is characterized by currents that retain biological material including primary producers and larval fishes (Backus and Bourne 1987).

- *Gulf of Maine* (87,156 km²). The Gulf of Maine biogeographic area is an irregularly shaped area that includes the Bay of Fundy and the Northeast Channel, and which is bounded by the Scotian Shelf and Georges Bank biogeographic areas. The Gulf of Maine area is separated from the waters to the southwest (i.e., the southern New England biogeographic area, not included in the present analysis) by a boundary that extends from the southwestern end of Georges Bank toward the tip of Cape Cod, along the deepest part of the Great South Channel. A 15-km shoreline buffer was applied to separate the Gulf of Maine biogeographic area from the inshore zone. This buffer was also used around Grand Manan and Mount Desert Islands, but not around the smaller islands of Penobscot Bay.

- *Scotian Shelf* (147,889 km²). The Scotian Shelf biogeographic area is a large elongate area extending from the waters off southwestern Nova Scotia northeast to the Laurentian Channel. At the southwestern end the area is separated from the Gulf of Maine by the 100-m isobath along the northern side of the Northeast Channel. Near shore, the edge of the Scotian Shelf is defined by the 15-km buffer, and the seaward edge by the 200-m isobath. A 15-km buffer was also applied around Sable Island in the northeastern part of this area.

Although some of the biogeographic areas proposed in the literature are based on direct analysis of specific assemblages of fauna, additional biological research would clearly improve scientists' overall understanding of the region's biogeography (Longhurst 1998). Much of the available literature is based on inferences from studies of oceanographic features that are known to influence the distributions of biological communities, such as ocean currents, water temperature, salinity, stratification, depth, and substrate types.

The differences in biota among these biogeographic areas are probably substantial, scientists have nevertheless only begun to elucidate this biological diversity. Theroux and Wigley (1998) have examined the region's biogeography based on oceanography and a survey of the macrobenthic invertebrate fauna. They provide a literature review and discuss the subregions we have employed.

Research on demersal fishes indicates that winter and yellowtail flounder have distinct subpopulations within Georges Bank, off southern New England, and in the Gulf of Maine, and fisheries managers treat these species as consisting of distinct stocks within these areas (Nitschke et al. 2000; Cadrin 2002; Collette and Klein-MacPhee 2002; United States National Marine Fisheries Service 2003). Additionally, two stocks of yellowtail flounder are recognized within the Scotian Shelf subregion (Collette and Klein-MacPhee 2002), which suggests even finer regional subdivisions than we have employed here. Genetic analyses of Atlantic cod (*Gadus morhua*) have revealed subpopulations in the northwest Atlantic (Ruzzante et al. 1998; 2000) and, again, fisheries managers recognize regional stocks for Georges Bank and the Gulf of Maine. Our analysis of demersal fish distributions, presented in Chapter 6, also illustrates differences between areas in species composition.

Although further analysis of the biogeography of this region is clearly needed, it is our view that incorporation of these biogeographic areas will improve the efficacy of our conservation planning.

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Pink hearted hydroid

Chapter 4

Computer-based site selection

Overview

■ Why we used computer-based site selection

We chose to use a computer-based site selection method because large-scale, systematic marine conservation planning is a difficult task that demands many goals be met simultaneously and efficiently. Powerful site-selection tools are available and have been applied successfully to complex planning problems in both terrestrial (Davis et al. 2004) and marine settings (Beck and Odaya 2001; Leslie et al. 2003). Solutions are generated in the form of networks of complementary conservation areas (or sites) distributed throughout an analysis region. The networks can be evaluated quantitatively so that in addition to the best performing network, a number of other networks that meet the conservation goals can also be identified. These networks can serve as alternatives during a planning process (Kelleher and Kenchington 1992; Prendergast et al. 1999; Pressey and Cowling 2001). With computer-based site selection, data are used objectively by a program that follows fully specified rules, making the method of network design transparent.

■ Planning units

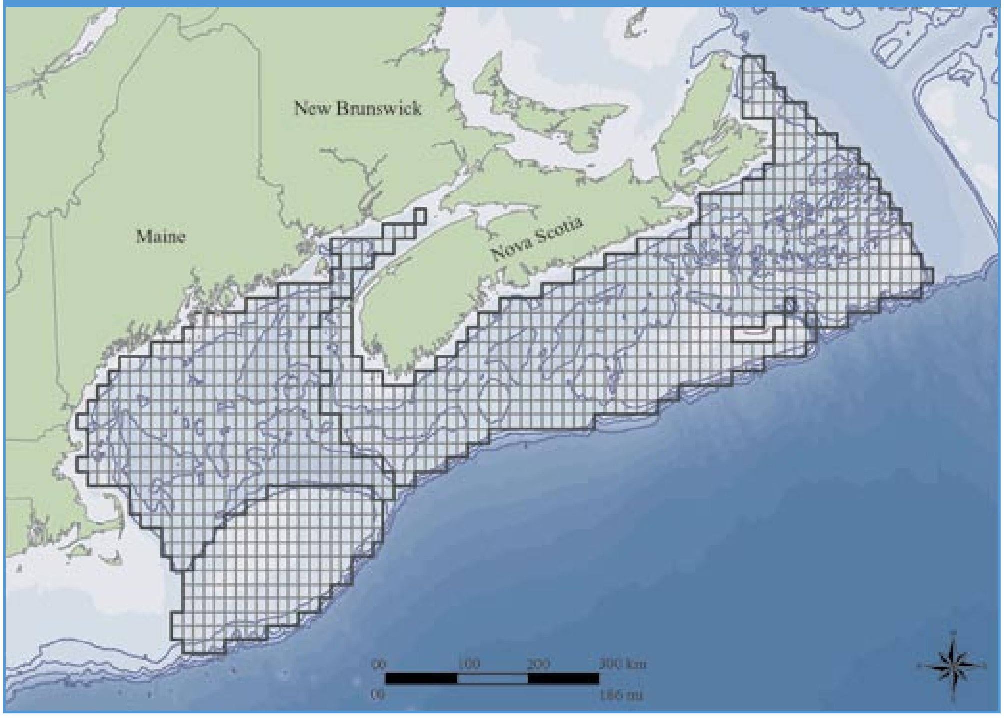
In addressing a conservation planning problem, one often begins by partitioning the analysis region into manageable geographic planning units. Planning units may take on any geographic size or shape, but squares of 10 geographic minutes (i.e., 10-minute squares that are approximately 16 km per side) have often been used for coarse-scale planning. In large-scale ecoregional planning a great many such units – hundreds or even thousands – might be involved.

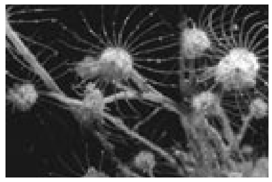
Each planning unit is characterized in terms of a list of conservation features. In our work, these included habitat features such as depth and seafloor type, and biological features such as abundance of fish and whale species, as proxies for ecological community types. Conservation networks are developed by evaluating different combinations of planning units in terms of these conservation features and goals. A conservation planner must decide which combinations of planning units will be the most effective in meeting all the goals. However, even in relatively simple problems, the possible combinations of planning units that could be considered number in the thousands. Computer-assisted site selection is thus essential.

■ Choice of conservation features

For the conservation planning reported here we chose a diverse set of conservation features that corresponded to habitat characteristics (i.e., seascapes) and marine life (i.e., biological conservation features). Each feature was quantified and represented as one or more maps of the analysis region. These data layers are described in detail in the following chapters. The analysis was based on 10-minute squares (Figure 4-1).

Figure 4-1. Analysis region showing grid of ten minute square planning units.





Chapter **4**
Computer-based site selection

Using MARXAN to identify a network

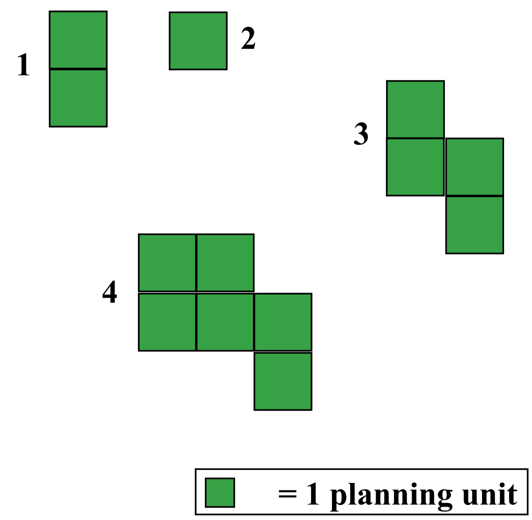
■ Background

We utilized a site-selection program called MARXAN (MArine Reserve Design by Spatially EXplicit ANnealing) to design conservation networks. MARXAN is based upon simulated annealing (Possingham et al. 2000; Leslie et al. 2003). Network design based on MARXAN is superior to other methods because it finds multiple networks for a given set of conservation features and goals, and it produces efficient networks by holding area to a minimum (Evans et al. 2003).

MARXAN has been used for marine conservation planning in a number of other regions including the Great Barrier Reef in Australia (Stewart and Possingham 2002; Day et al. 2003; Leslie et al. 2003), the coast of California (Airame et al. 2003), the Florida Keys (Leslie et al. 2003), and the northwest Altantic (Cook and Auster 2005). The program and its uses are described on several websites, e.g., http://www.ecology.uq.edu.au/marxan.htm and http://www.mosaic-conservation.org/cluz/marxan1.html.

We used MARXAN to design networks of priority areas for conservation. In site selection, the sites selected are the areas that make up a network. Each network consists of multiple areas, and each area is composed of one or more planning units. Figure 4-2 shows a hypothetical network comprised of four priority areas and 13 planning units. The priority areas within a network are complementary, which is a property of all networks produced with MARXAN. That is, the priority areas, taken together, meet all the goals but individual priority areas do not. Thus, if only a subset of the priority areas comprising a network were to be protected, the conservation goals would not be fully achieved.

Figure 4-2. Hypothetical network of priority areas for conservation. For simplicity, only the planning units that were selected for the network are shown.



MARXAN can identify multiple networks because particular species and habitats are found in multiple places. Because only a portion of these places is included in any given network, it follows that different combinations of areas might be used to accomplish the same objectives (Figure 4-3). The networks identified by MARXAN are evaluated based on how well goals are met and on other factors that have to do with spatial efficiency. A single best network emerges from the evaluation process, as well as other networks that do not perform quite as well. Often, a number of networks are very nearly as good as the best one and these serve as viable alternatives. The alternative networks usually overlap with the best network to some degree.

Figure 4-3. Two networks from a simple hypothetical MARXAN analysis, each of which meets the goals for habitat and biological conservation features: networks are comprised of the outlined planning units.

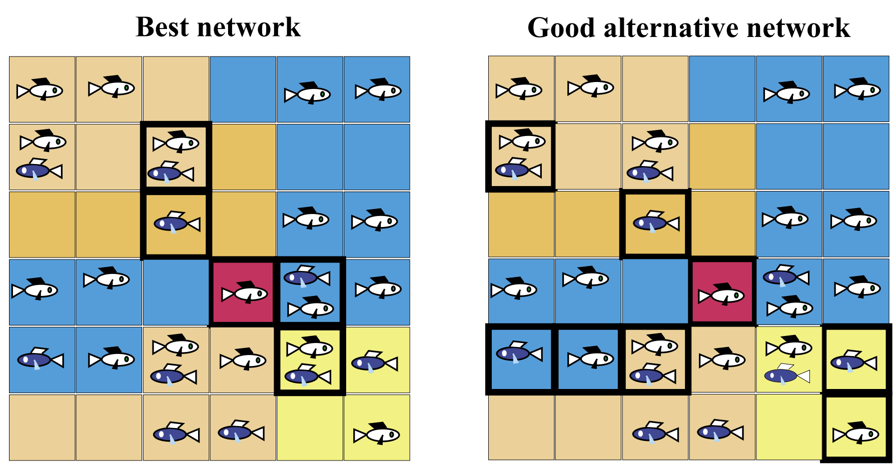
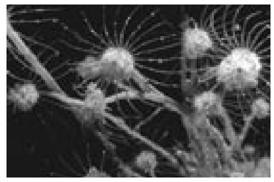


Figure 4-3 shows two networks from a simple, hypothetical MARXAN analysis; each network meets the goals for habitat and biological conservation features. The five different habitat types (or seascapes) are depicted by the colors of the 12 planning units spanning the analysis region. In this simple example, MARXAN was instructed to include at least one planning unit for each habitat type (i.e., the goal is one planning unit), and at least four blue fish and four white fish. The most efficient networks use planning units where both species of fish occur, use the minimum number of planning units, and use planning units that share edges whenever possible. The good alternative network meets or exceeds all the habitat goals – i.e., all five habitats are represented – and it meets all the goals for the biological conservation features. However, the good alternative network uses 40% more planning units and is therefore not as efficient as the best network (note that in more complex, realistic scenarios, the differences between networks are typically much smaller). The good alternative network has a substantially greater boundary length (25 vs. 14) while the best network has more aggregation of planning units and includes more planning units where both species of fish are found. The blue habitat type is the most widely distributed, and thus offers flexibility during site selection. In contrast, the central planning unit – which holds the only example of the red habitat – is irreplaceable and must be included in all networks.



■ Input and assumptions

MARXAN simply takes the set of geographically referenced data it is given (i.e., maps), follows the instructions provided, and uses an explicit mathematical function to find solutions (i.e., networks) to a given planning problem. MARXAN makes no assumptions about how an ecosystem works. It is not used to make predictions, and it is not a model. We make some assumptions in our conservation planning about, for example, how the identified networks relate to regional ecology and about the performance of biological features as ecological indicators, but these assumptions have little to do with MARXAN itself. Moreover, these kinds of assumptions apply no matter what site-selection method is used to meet broad ecological and biodiversity conservation goals.

The network of priority areas for conservation we identified with MARXAN was based on all of the different biological conservation features and seascapes. In addition, we used MARXAN to identify networks of areas based only on the individual component data layers (i.e., whales, fishes, and seascapes) in order to provide insight into these layers and how site selection proceeds based on these layers in isolation. These exploratory MARXAN analyses also provided an opportunity to compare the resulting networks with the network of priority areas for conservation based on all of the different types of data (Chapter 9).

■ The objective function

MARXAN finds individual networks through a process of iterative improvement that uses an equation known as the objective function. Note, to find multiple networks, the iterative process described here must be carried out multiple times.

The objective function is shown below in the form in which we used it. It is described in further detail by Ball and Possingham (2000).

$$\mathbf{Score} = \underbrace{\sum_{i=1}^{n} \mathbf{cost}_i}_{\mathbf{A}} + \underbrace{\mathbf{BLM} \times \sum_{i=1}^{n} \mathbf{boundary}_i}_{\mathbf{B}} + \underbrace{\sum_{i=1}^{n} \mathbf{CFPF}_i \times \mathbf{penalty}_i}_{\mathbf{C}}$$

The objective function not only evaluates the success with which combinations of planning units meet the goals specified for each of the conservation features, but also takes into account the area and boundary length of the various combinations. In so doing, the function calculates the score of particular combinations, or potential networks. The best solution to the task performed by MARXAN is a network for which the score is the lowest because a low score indicates that the area and boundary length are minimized and the goals are all met. We refer to the network with the lowest score as the *best network*. The remaining networks (i.e., 99 in our application) have higher scores but the differences in the scores of the top networks are often small.

MARXAN achieves varying degrees of success from run to run, due to the complexity of the task, the stochastic nature of the algorithm, and the practical constraint of limiting the number of iterations so that networks are found within workable periods of time. Thus MARXAN is not expected to produce a single, true, optimum network in any given run. We ran MARXAN through this iterative site-selection process 100 times for each of our analyses, and used the score from the objective function to evaluate the quality of each network generated.

Terms of the function

As MARXAN runs, the objective function is used to guide the iterative process in which various subsets of planning units are combined and assessed a score. This output value of the function is determined by three factors: the sum of the costs of the planning units (A, in the formula above); a term that increases with the collective perimeters of the clusters of selected planning units (B); and a term governed by the degree to which the goals have been attained in the proposed network (C).

Term A. This first part of the function guides MARXAN to use as few planning units as possible to meet the goals. In the analyses presented here, all planning units were assigned the same cost (cost = 1). The cost of adding a planning unit to the network is the same, regardless of which unit is added, as long as the other terms in the objective function remain constant. However, in more complex implementations of MARXAN, the cost variable can reflect actual costs; for example, the cost of natural resource revenues lost by protecting a particular planning unit.

Term B. Term B influences the aggregation of the selected planning units because it results in an increase in the score as the sum of boundary lengths goes up (i.e., around the clusters of planning units included in the network). For a variety of reasons, including management feasibility and ecological integrity, a network consisting of relatively few clusters of aggregated planning units may be more desirable than a fragmented network made up of widely dispersed planning units.

The effect of planning unit aggregation on network score, and thus network configuration, can be adjusted in term B by changing the boundary length multiplier (BLM). Increasing the boundary length multiplier to >1.0 amplifies the influence of boundary length and the network will tend to show a greater degree of aggregation. We employed several different boundary length multiplier values in our analyses, as specified in the following chapters.

Figure 4-4 illustrates hypothetical networks based on different configurations of planning units and the corresponding effects on boundary length. A site made up of a single isolated planning unit has four exposed sides, and networks constructed from such isolated planning units therefore result in the maximum boundary length per unit area (boundary length/area = 4.0), as shown in examples A and C. In the simplest case where just two planning units are aggregated (B), a relative decrease in boundary length is achieved while area is held constant. The combined boundary length is reduced from 8 to 6 and the boundary length-to-area ratio is decreased by 25% (i.e., boundary length to area ratio of 8:2 for isolated planning units, and 6:2 for aggregated planning units). When the number of planning units is greater (n = 100), this effect is much larger (C vs. D). The total boundary length of 100 isolated planning units is ten times greater than the boundary length of a single 10x10 cluster (i.e., 400:40): a 90% improvement in boundary length-to-area ratio occurs with aggregation. Degrees of aggregation between these extremes are usually desirable in most real-world applications and can usually be achieved by adjusting the boundary length multiplier.

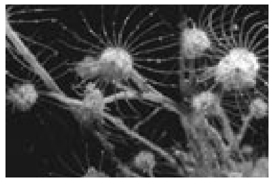
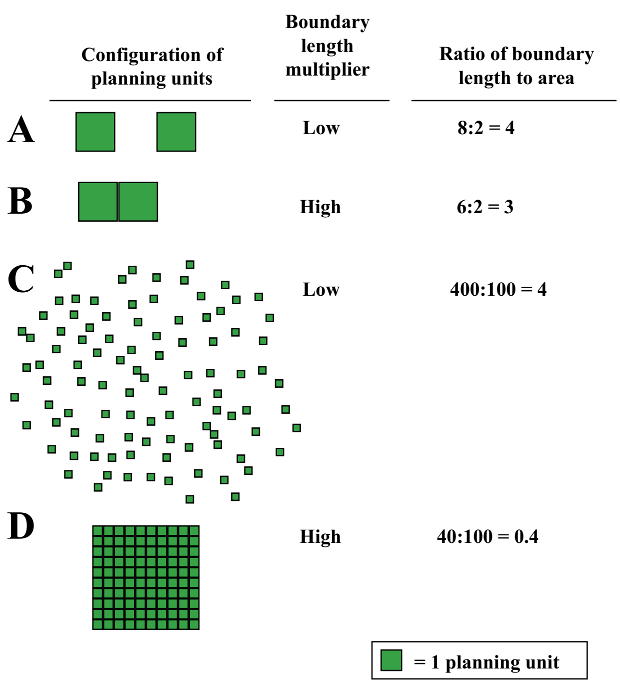


Figure 4-4. Examples of hypothetical networks based on different configurations of planning units, and the corresponding effects of the configurations on boundary length.



Term C. Term C concerns the attainment of the goals for each of the conservation features and includes a penalty for incomplete representation of any of them. This penalty is determined by the extra cost associated with the planning unit(s) and the boundary length needed to fully attain the goal (Ball and Possingham 2000). Each conservation feature is also assigned a factor – called the conservation feature penalty factor (CFPF) – that is used to weight the penalty. In our MARXAN analyses we initially set all of the conservation feature penalty factor values to be identical (1.0). The conservation feature penalty factor was increased only if a given conservation feature was represented at less than 90% of its goal. For the derivation of the network of priority areas for conservation (Chapter 9) only a small number of conservation feature penalty factors were adjusted upward to meet goals (n < 5%), and most of these were only increased from one to two (maximum = 3; Appendix C).

Finding the lowest score

MARXAN begins its iterative site-selection process by generating a random collection of planning units, i.e., an initial network or reserve system. This network is evaluated, and the algorithm continues by progressing through a series of changes, or iterations. In each iteration, a planning unit is selected at random and the algorithm evaluates the change in score that would occur if the planning unit were added or removed from the network. The randomly selected planning unit may be part of the present network, or one that is not yet included.

As MARXAN carries out its thousands of iterations it is evaluating many different networks by computing the score for each. The score varies as planning units are added and removed from potential networks. This variation in score with different network configurations can be described as something like a complex topography in which score corresponds to elevation. Such a topography includes a number of peaks and basins. The basins correspond to areas of relatively low score, and the deepest basin corresponds to the best network.

Finding the deepest basin – i.e., the lowest score – can be challenging because local basins can be inadvertently mistaken for the deepest. This occurs because no matter what direction one goes, the score will increase before it again decreases. In other words, one must climb to higher elevations before descending into even deeper basins.

MARXAN is good at solving this local minimum problem because it employs a sophisticated iterative improvement process that, under certain circumstances, allows for the acceptance of updated networks that actually correspond to a higher score. It is this feature that allows it to traverse the topography to find minima even when this involves several iterations in which the objective function may report poorer performance (i.e., increased score).

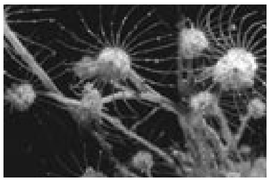
Temperature variable

Iterative improvement is achieved by introducing a variable called the temperature; it is high at the start of the site-selection process and decreases through successive iterative steps (i.e., cools). In this sense the method is similar to an annealing process in which the atoms of a heated material are joined to form a crystal through a slow cooling process. In this way, simulated annealing joins a system of planning units to form a near–optimal network, based on the Metropolis algorithm (Kirkpatrick et al. 1983). At each step the temperature is evaluated in relation to the change in the output of the objective function and a random number. When the temperature is high, reserve reconfigurations are accepted relatively frequently even when the objective function reports an increase in the score. With successive iterations the algorithm guides the process so that, gradually, the only changes accepted are ones that reduce the score. In this fashion simulated annealing is able to identify near-optimal networks within complex topographies. The number of iterations required is large; for the analyses presented here, we used runs of 1,000,000 iterations with one temperature step for each 100 iterations, or 10,000 steps. This was done according to an adaptive annealing schedule (Ball and Possingham 2000).

■ Summarizing multiple networks

The examination of multiple MARXAN networks allows one to identify planning units that are repeatedly included and others that may be selected for only a minority of the networks. This is most readily observed on a map where each planning unit is coded to show the number of times it was included in a set of 100 networks. Such maps are referred to as summed solution maps (Stewart and Possingham 2002) and are presented in the chapters that follow.

Typically, a core subgroup of planning units is included in nearly all the networks. These are planning units whose characteristics are such that one or more goals cannot be attained without them. Because they are essential to arriving at a network solution they are sometimes referred to as irreplaceable (Pressey 1994; Leslie et al. 2003; Stewart and Possingham 2003). The degree to which a given planning unit is irreplaceable can be quantified in various ways (Ball and Possingham 2000), and may be used as a guide to the utility of a given planning unit to conservation planning (Airamé et al. 2003; Ardron et al. 2003). Thus, planning units come with a wide range of irreplaceability.



Planning units with the highest irreplaceability are most likely to be needed as part of a network; conversely, the ability to achieve conservation goals will be most substantially decreased if these planning units are not available for protection. A planning unit may be irreplaceable because it contains a rare feature that is not found in other units. Planning units may also be relatively irreplaceable because they contain an unusually rich combination of features. If there are many highly irreplaceable planning units there will be less flexibility during site selection. The more replaceable planning units constitute a pool of units that offer flexibility in the development of networks. Some of the planning units in the network of priority areas for conservation discussed in Chapter 9 were required for each of the 100 networks examined and were thus irreplaceable. Many others were used in only some of the networks and these offered flexibility in network design.

Specification of goals for conservation features

The way in which we defined goals was specific to the individual conservation features and is detailed in the chapters that follow and summarized in Table 2-1.

For the seascapes (abiotic data, Chapter 8), goals were specified as a simple proportion of each class of seascape within each of the biogeographic areas. Because the entirety of each biogeographic area was classified by seascape, setting goals in this fashion in turn determined the minimum area required for a network. For example, with a goal of 20% for seascapes, the network will include at least 20% of the analysis region as a whole.

For the biological conservation features, goals were set as a proportion of some descriptive metric, such as relative abundance, and the selection of planning units was restricted to a subset of those determined to be of relatively high quality, as discussed further below. Thus, in contrast to those specified for seascapes, these goals were not explicitly tied to geographic dimensions.

As discussed in Chapter 9, the areal extent of a MARXAN network based on both seascapes and biotic data was very close to the area-based seascape goal of 20%. In a complex MARXAN analysis, the degree to which goals are met across the many conservation features varies, with some goals being exceeded (i.e., overshot) and others being attained just under the specified goal.

■ Attaining goals within all biogeographic areas

In Chapter 3 we presented our analysis region and biogeographic areas. To ensure that goals would be met for conservation features within each of the biogeographic areas, we assigned a unique code for each feature within each area and we set area-specific goals. Juvenile Atlantic cod, for example, were found throughout all biogeographic areas, but goals were specified and attained within Georges Bank, the Gulf of Maine, and the Scotian Shelf. Seascape types that were common to all three areas were represented within each area in all the networks identified with MARXAN. This approach ensured that examples of habitats that may be physically similar but contain different assemblages of species, situated in distinct biogeographic areas, would be included as part of the network of priority areas for conservation. Thus, for example, deep-water sandy-bottom habitat in the Gulf of Maine was treated as being distinct from deep-water sandy-bottom habitat on the Scotian Shelf or Georges Bank.

MARXAN output tables

For each individual network produced by a MARXAN run, two tables are written.

The first table is a simple two-column table describing the combination of planning units that make up the network for that run. This table is linked to a geographic information system to provide a map of the planning units included in the network. The second table describes how well the individual network performed with regard to meeting each conservation feature's goal. This is referred to as the table of missing values information (Ball and Possingham 2000).

MARXAN also provides information about the group of networks produced by the program (e.g., 100 networks). The first is a two-column table that contains a list of all the planning units in one column, and the number of networks in which that planning unit was chosen in the second column. This is referred to as the summed solution, and is linked to a geographic information system to produce a summed solution map. The second table, called the summary information table, contains information on the performance of each network.

The information included in the summary table, including the score for each network, allows one to compare the networks and yields a better understanding of the available conservation options. For example, one may evaluate how the scores of a range of networks compare with the best network, and also examine the cost, boundary length, number of planning units, and *overall* goal attainment. As a means of identifying alternatives, similarity matrices have been used in some instances to identify a selection of reasonably good networks that are maximally divergent in geography (Airamé et al. 2003), but this method has not been applied here.

Examples of MARXAN output tables and additional details are provided in the MARXAN manual (Ball and Possingham 2000).

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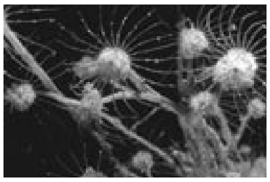

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Chapter 5

Areas of high primary production identified from chlorophyll concentration

Importance of primary production

Primary production, driven by sunlight, forms the base of the food chain in marine ecosystems. The areas of highest production support the highest overall biomass as well as a diversity of animal species. Relatively shallow areas associated with submarine banks and upwelling currents – Georges Bank for example – have high primary production and are widely recognized for their unusually abundant marine life (Ward 1995; Thurman and Trujillo 2002).

Globally, primary production is well known to be relatively high in the colder, oxygen-rich waters typical of the northwest Atlantic shelf, and this is critical to the impressive biomass production that has supported the region's historic whaling and fishing industries. The survival of larval fishes – cod for example – depends on the timing and seasonal abundance of phytoplankton (Beaugrand et al. 2003; Platt et al. 2003). Moreover, recent work suggests that there can be a direct, bottom-up control of fisheries production by phytoplankton (Ware and Thompson 2005). Baleen whales are also drawn to the region to feed on the abundant plankton. Incorporation of some of the areas of highest primary production is thus essential to the design of an effective network of priority areas for conservation.

Data sources and pre-processing

Production of biological material rests principally on photosynthesis by the unicellular dinoflagellates (algae; kingdom Protista) and other organisms making up phytoplankton (Levinton 2001). Production by phytoplankton depends upon the light-capturing molecule chlorophyll which can be detected by the color of the seawater with remote optical sensing (Platt et al. 1995). Thus, satellite imagery has been used to estimate the *potential* primary production in different regions of the ocean. (*Actual* production depends upon both the concentration of chlorophyll and the amount of light energy reaching the surface waters.) We identified areas that were consistently characterized by high chlorophyll concentrations.

The data we used were derived from satellite images of the sea surface obtained from the Sea-Viewing Wide Field-of-View Sensor Project (NASA 2006) and consisted of 2-week composite images (i.e., two per month) for a period of 5.5 years from September 1997 through March 2003 (133 images). Sea surface color has proven to be a reliable basis for estimating chlorophyll concentration (mg chlorophyll a/m^3) in seawater (Platt and Sathyendranath 1988; Sathyendranath et al. 2001; Ware and Thompson 2005), and was used to estimate chlorophyll concentration for each image pixel in our analysis region. Measurement resolution was approximately 1.1 km; it was determined by pixel size, which varied slightly with latitude (i.e., increasing to the north).

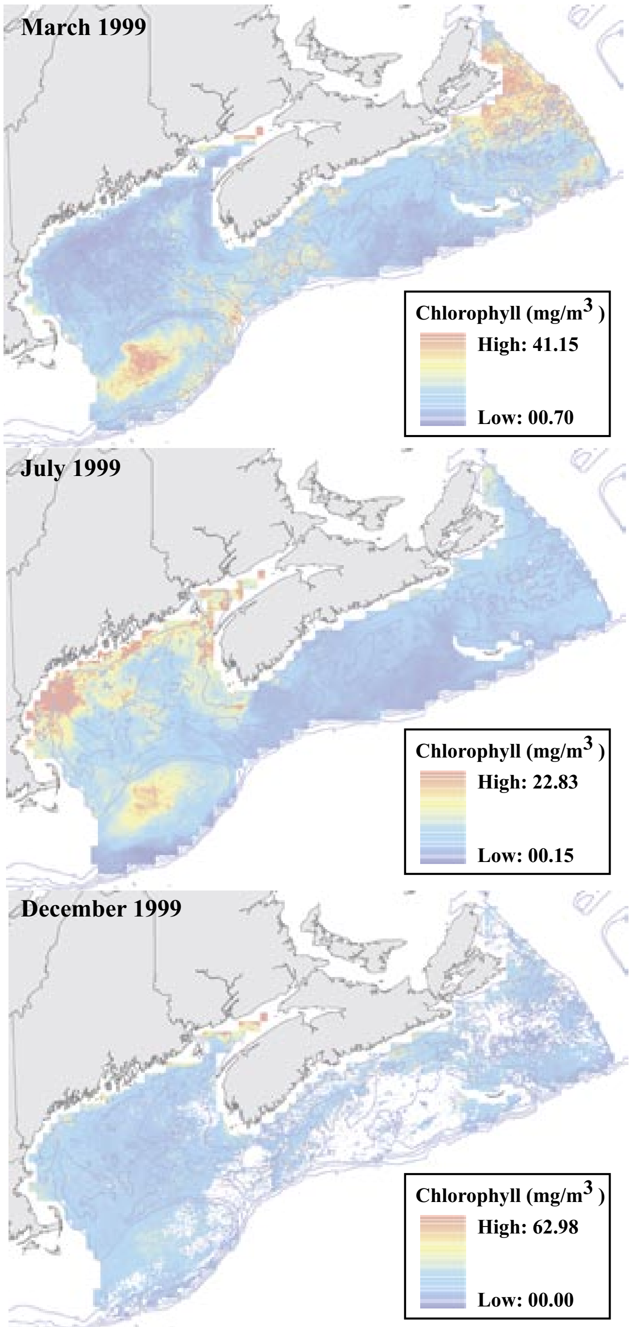
This method was influenced by cloud cover and by the turbidity that is common in shallow waters, particularly where rivers flow into the ocean (Ruddick et al. 2000). The near-shore and shallow water influences were reduced by restricting the analysis to a minimum depth of 30 m, and maintaining a 15-km buffer around land areas. Artifacts due to cloud cover were minimized by masking off clouded portions of the image during pre-processing.

■ How we identified areas of persistently high chlorophyll concentration

Our goal was to identify planning units that persistently exhibited unusually high chlorophyll concentrations (c), and we took these to be areas of anomalous production.

Identification involved three steps, beginning with an analysis of the pixels within each biogeographic area and during each 2-week period. All those pixels with chlorophyll concentrations in the top 10% were identified, i.e., for a given 2-week period and a given biogeographic area. Next, those pixels that ranked in the top 10% for three or more of the 5 years were flagged as corresponding to persistently high locations. Finally, any planning unit within which the combined area of the flagged pixels was at least 10 km^2 was taken as a planning unit with anomalously high production, i.e., compared to other planning units in the biogeographic area. This criterion corresponds to about 4% of the area of a planning unit, or about 10 pixels. The precise number of pixels per planning unit varied slightly with latitude.

Figure 5-1. Chlorophyll concentrations, three SeaWiFS 2-week composites.



Prior to this analysis, the chlorophyll concentrations were log transformed {ln (c + 1)} because the distributions of concentrations were not normally distributed. The mean and standard deviation (SD) for the transformed concentrations were computed for each biogeographic area and each 2-week period. Those pixels that were >1.28 SD above the mean were identified as being in the top 10%. Thus, the flagged locations were the pixels that appeared during one or more 2-week periods each year, and for 3 or more years (i.e., persistently high). This multi-year requirement was blind to the particular time frame within which pixels showed their annual high chlorophyll concentration, and the classification of planning units as anomalies was independent of differences in the duration of the periods of high concentration (i.e., number of 2-week periods for each year; see discussion below).

Figure 5-2. Annual cycles in chlorophyll concentrations as inferred from 1999 SeaWiFS satellite images of sea-surface color. Each point corresponds to the mean concentration for all pixels within the indicated biogeographic area and 2-week period (see Table 5-1). Values at the far right of the date scale (i.e., December) are closest in time to those at the far left (i.e., January).

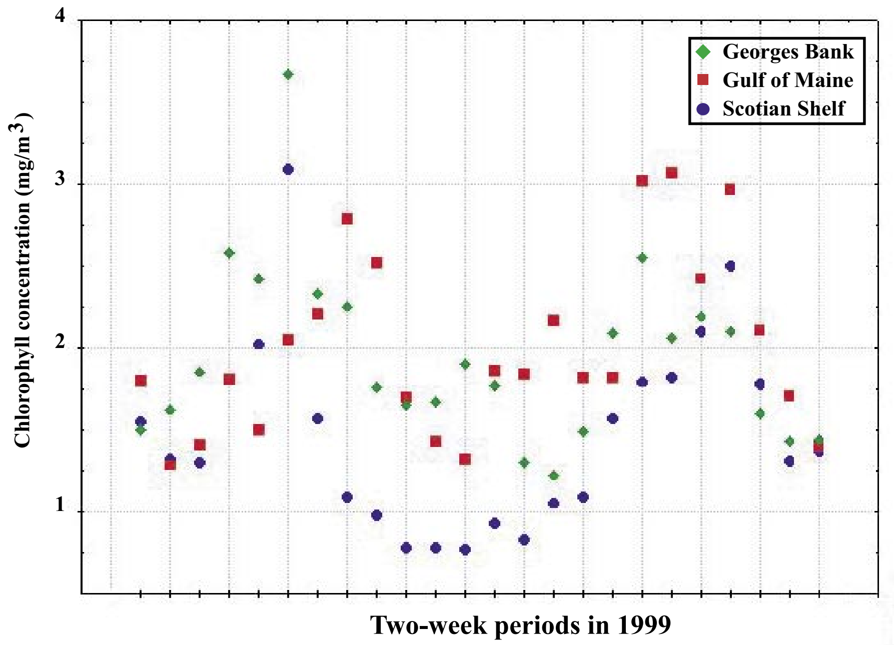
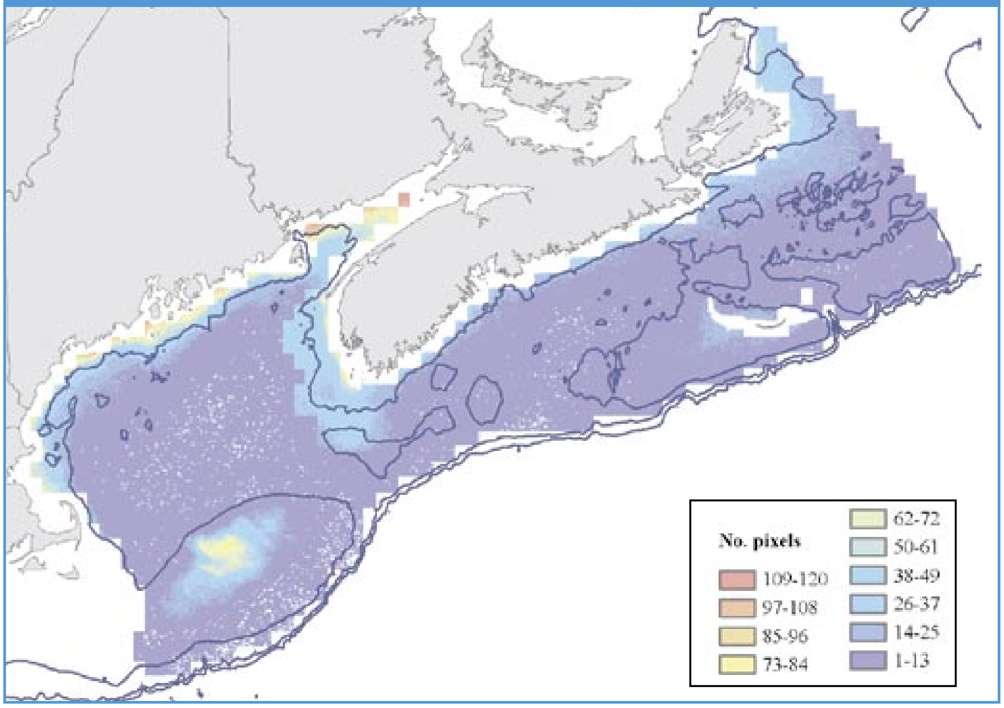


Figure 5-3. Distribution of pixels that exhibited persistently high chlorophyll concentrations: number of 2-week periods each pixel was in the top 10%. Includes only those pixels that were in the top 10% for at least 3 years (i.e., during at least one 2-week period for each of 3 years or more).



Chlorophyll concentration and distribution

Nearshore and other relatively shallow areas such as Georges, Browns, and St Anns Banks were commonly associated with high chlorophyll concentrations. This general pattern was clear in single example images (Figure 5-1) but spatial patterns in concentration were seasonally dynamic (Fisheries and Oceans Canada 2004). Chlorophyll concentrations were at a maximum during the spring and early fall periods, and reached their minima during the late fall-winter period and during mid-summer (Table 5-1; Figure 5-2). The maximum values observed during 1999 were between 55 and 63 mg/m^3, and occurred during the late fall period (November–December).

When we mapped the persistently high concentration pixels, a prominent nearshore concentration was similarly evident, with clear high spots at Georges, German, and St Anns Banks, and at Turcher Shoal off Yarmouth, Nova Scotia (Figure 5-3). Georges Bank was particularly prominent as an offshore area, with persistently high chlorophyll concentrations.

Figure 5-4. Frequency distribution for persistently high-chlorophyll pixels: number of 2-week periods for which each pixel was in the top 10% for chlorophyll concentration. Inset: expanded view of the right tail of the distribution, beginning at the 90th percentile point (i.e., 10% of the pixels were to the right of the arrow).

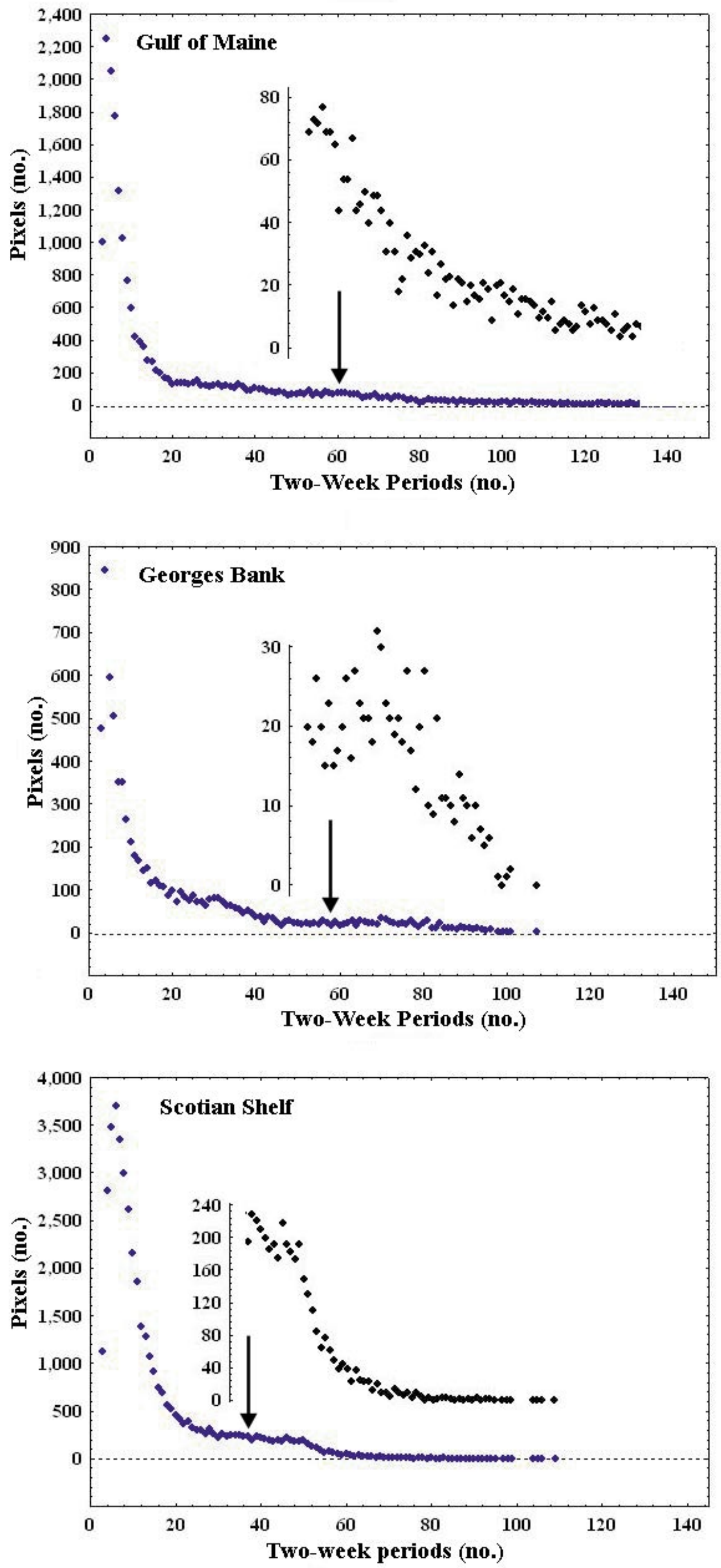
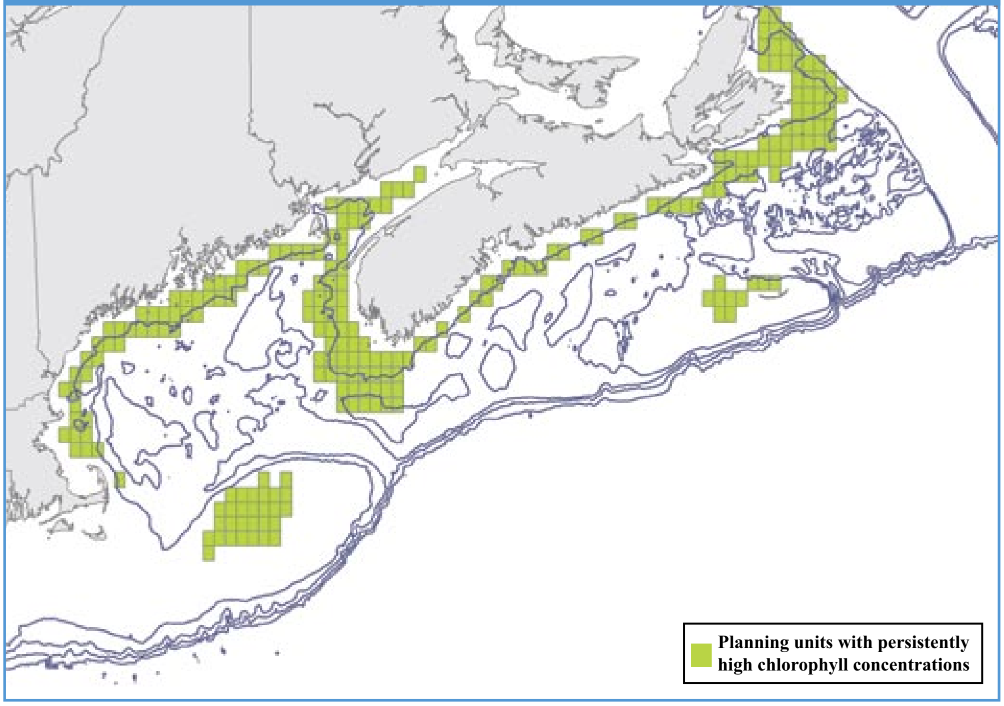


Figure 5-5. Areas of persistently high-chlorophyll concentrations.



Most of the persistently high pixels were in the top 10% for only 4 to 6 weeks, with the mode being 4 weeks over 5.5 years for the Gulf of Maine, 4 weeks for the Georges Bank, and 6 weeks for the Scotian Shelf – or roughly 1 week per year. However, these distributions were skewed because some of the pixels showed up much more often. Ten percent of these pixels were high for about 11 weeks per year for the Gulf of Maine (59 weeks in 5.5 years), 10 weeks for Georges Bank, and 6 weeks for the Scotian Shelf (Figure 5-4). Not surprisingly, the pixels that were highly productive for the longest tended to be included in the persistently high planning units as we have defined them here (Figure 5-5). About 20% of the planning units in the Gulf of Maine (67 units), 20% (29 units) on Georges Bank, and 23% (135 units) on the Scotian Shelf were classified as anomaly-containing and were used in the selection of priority areas for conservation (Chapter 9).

Table 5-1. Example of chlorophyll concentration in the study area: SeaWiFS data for 1999.									
	Mean[a]			Standard deviation			Maximum[a]		
Date in 1999	Georges Bank (mg/m³)	Gulf of Maine (mg/m³)	Scotian Shelf (mg/m³)	Georges Bank (mg/m³)	Gulf of Maine (mg/m³)	Scotian Shelf (mg/m³)	Georges Bank (mg/m³)	Gulf of Maine (mg/m³)	Scotian Shelf (mg/m³)
Jan 1–14	1.50	1.80	1.55	1.52	2.29	2.66	54.28	62.41	63.92
Jan 15–31	1.62	1.28	1.32	1.15	1.12	1.42	30.43	30.88	63.66
Feb 1–14	1.85	1.41	1.30	1.19	1.09	1.38	17.74	29.43	60.09
Feb 15–28	2.58	1.81	1.81	1.45	1.35	1.70	19.85	26.88	61.88
Mar 1–14	2.42	1.50	2.02	1.56	1.09	1.58	16.86	32.65	33.38
Mar 15–31	3.67	2.05	3.09	1.76	1.23	2.04	19.81	17.52	41.15
Apr 1–14	2.33	2.21	1.57	1.52	1.63	1.33	14.03	23.71	28.93
Apr 15–30	2.25	2.79	1.09	1.30	1.59	0.75	10.86	17.06	32.29
May 1–14	1.76	2.52	0.98	0.85	1.63	0.48	11.94	18.59	9.92
May 15–31	1.65	1.70	0.78	0.76	1.18	0.39	14.04	23.23	13.86
June 1–14	1.67	1.43	0.78	0.79	1.03	0.55	11.32	23.20	12.95
June 15–30	1.90	1.32	0.77	1.06	0.90	0.57	9.95	15.41	12.97
July 1–14	1.77	1.86	0.93	1.14	0.98	0.58	15.95	13.41	12.74
July 15–31	1.30	1.84	0.83	0.70	1.33	0.52	9.59	22.83	13.90
Aug 1–14	1.22	2.17	1.05	0.80	1.59	0.79	12.50	18.57	19.29
Aug 15–31	1.49	1.82	1.09	0.95	1.30	0.72	19.31	18.32	18.04
Sept 1–14	2.09	1.82	1.57	1.34	1.83	0.91	11.14	18.88	13.63
Sept 15–30	2.55	3.02	1.79	1.31	1.65	1.23	14.12	32.65	19.25
Oct 1–14	2.06	3.07	1.82	1.06	1.91	1.32	14.75	29.34	50.45
Oct 15–31	2.19	2.42	2.10	0.87	1.31	1.49	14.69	16.99	35.13
Nov 1–14	2.10	2.97	2.51	0.63	1.59	1.75	16.41	34.31	58.75
Nov 15–30	1.60	2.11	1.78	0.75	2.15	1.56	24.20	62.87	60.19
Dec 1–14	1.43	1.71	1.31	0.84	1.46	1.86	25.98	37.48	60.90
Dec 15–31	1.44	1.40	1.37	1.63	1.38	2.18	55.58	49.52	62.98

[a] *Mean is average of all estimates for the biogeographic area, one per pixel.*

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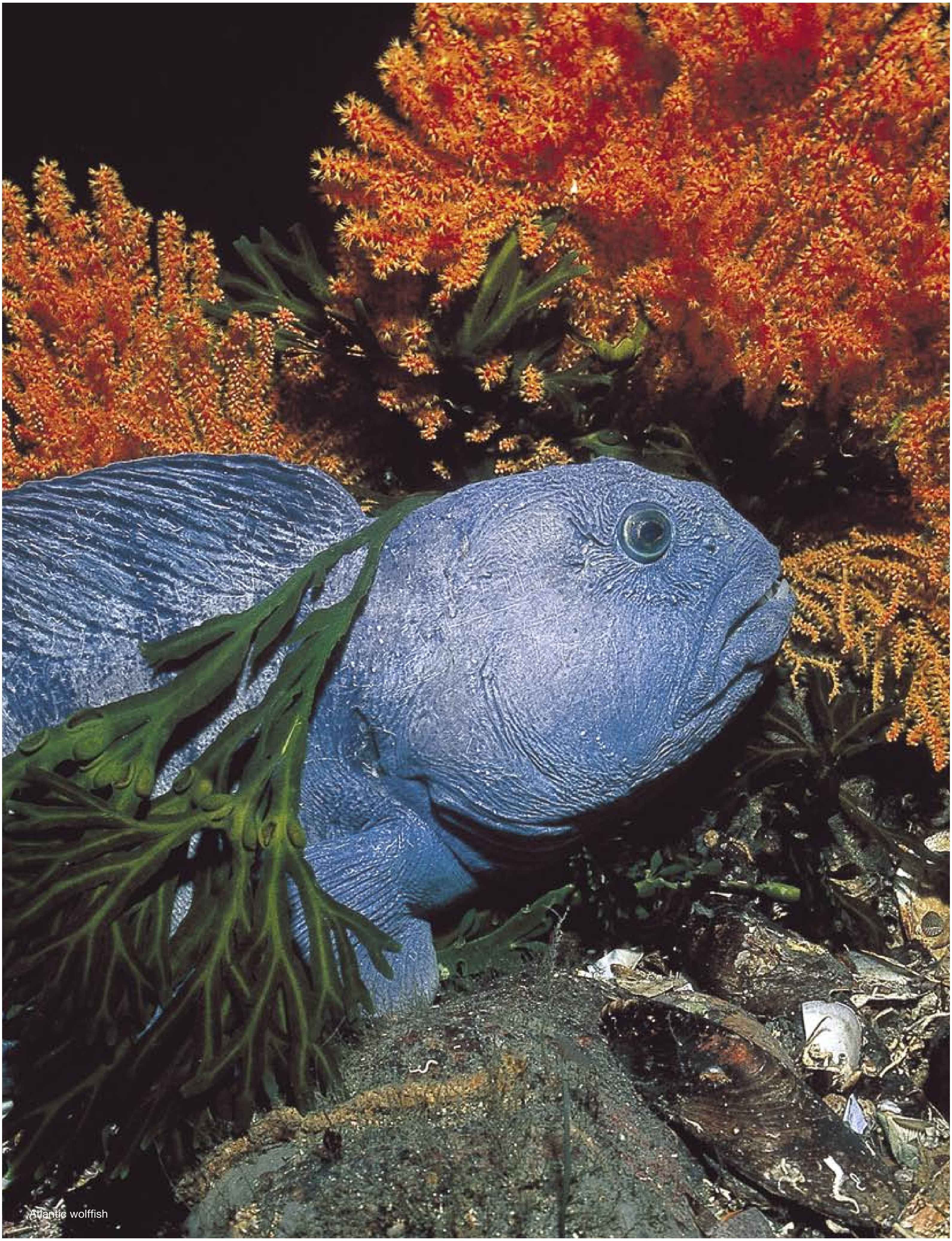


Atlantic wolffish

Chapter 6

Distinctive areas for demersal fishes

Importance of demersal fishes

The well-known groundfish, i.e., bottom-living fishes, or demersal fishes – including the gadoids (e.g., cod, pollock, hake) and flatfishes (e.g., pleuronectid flounders) – represent a major component of the marine ecosystems of the northwest Atlantic Shelf and have supported human populations along the region's coasts for thousands of years (Kurlansky 1997; Jackson et al. 2001). The demersal fishes are an important yet compromised component of regional biodiversity and are included in our derivation of priority areas for conservation (Chapter 9). This diverse group of species occupies a range of habitats and ecological niches, which makes them excellent indicators for biodiversity and benthic communities.

During the past two centuries a substantial industrial economy has developed around demersal and other fishes (Goode 1884). Unfortunately, several historically important fisheries have vanished altogether during this period. These include herring and mackerel in parts of coastal Maine, groundfish in Penobscot Bay, and fisheries based on migratory fishes (e.g., Atlantic salmon, and shad and other clupeids). Cod and a number of other groundfish species are classified as overfished (National Marine Fisheries Service 2005), and the Committee on the Status of Endangered Wildlife in Canada (2005) has classified several of its diminished cod populations as endangered, threatened or of special concern. The composition of present-day catches has changed markedly, which reflects substantial changes in the relative abundances of species, shifts in population size structure, and the trophic organization of ecosystems (Collette and Klein-MacPhee 2002; Link et al. 2002a; Link and Garrison 2002a; Link and Garrison 2002b; Link et al. 2002b; Rosenberg et al. 2005). The removal of cod and other top predators has produced ecosystem-altering trophic cascades, the consequences of which we are only beginning to understand (Frank et al. 2005).

Species richness, relative abundance, and distinctive areas

The high commercial value of these fishes motivated the Canadian and United States fisheries services to carry out systematic trawl surveys over much of the past century. These surveys have yielded strong quantitative data on the distributions of a large number of the region's fishes, including those that are commercially valuable and a great many others. We utilized these research trawl data to develop two types of biological conservation features for demersal fishes as means of identifying biologically distinctive areas: *species richness* (average number of species per trawl) and *relative abundance* (average number of individuals per trawl). Our site-selection process favored places that were both areas of high relative abundance and high species richness because they contributed to both goals.

Species richness and abundance

Species richness was mapped throughout the region so that locations of high richness could be identified and used as conservation features during site selection. Areas of high richness have conservation value because a relatively large number of species can be protected in a given location, and because these areas often have other important ecological attributes that allow them to support unusual species diversity for a number of taxa. Areas of high richness often fall at transitions between habitat types (i.e., ecotones). However, areas of high species richness are not expected to include all of the various demersal fish species and their associated communities. In general, species-rich areas include only a subset of the species found in a given region, and often are not the habitat areas that support individual species in the highest abundance.

In addition to richness, we mapped relative abundance for each species, and for juveniles and adults within a given species. For a given species, high abundance is a good indication of the location of important habitat areas (Auster et al. 2001; Cook and Auster 2005). Identifying high abundance areas for the different life stages of a species is important because fishes have well-known differences in habitat utilization between stages (Gotceitas and Brown 1993; Gotceitas et al. 1995; Gotceitas et al. 1997; Collette and Klein-MacPhee 2002; Cook and Auster 2005). For example, bottom features provided by gravel, rock, and biogenic structures such as sponges, corals, or plants define habitat areas that are particularly important for juveniles because they provide protection from predators and currents (Lindholm et al. 1999; Lindholm et al. 2001). Adults are influenced by other constraints such as food availability and availability of areas suited to spawning.

By incorporating abundance layers for the individual species we ensured that important areas for all species were included in site selection, including species that may not have been associated with areas of high richness. In our derivation of a network of priority areas for conservation we thus used a relatively large number of abundance conservation features, which corresponded to the number of species of fish included in the analysis. In contrast, the measurement of species richness is based on all the species found, but leads to just one conservation feature for each biogeographic area (see Chapter 9, Table 6-1).

Table 6-1. Fish species used for analyses of richness and abundance[a].

Species		
Family	Common name	Scientific name
Agonidae	Alligatorfish	*Aspidophoroides monopterygius*
	Atlantic sea poacher	*Leptagonus decagonus*
Ammodytidae	Northern sand lance	*Ammodytes dubius*
Anarhichadidae	Atlantic wolffish	*Anarhichas lupis*
	Spotted wolffish	*Anarhichas minor*
Argentinidae	Atlantic argentine	*Argentina silus*
Cottidae	Snowflake hookear sculpin	*Artediellus uncinatus*
	Hookear sculpin (Genus)	*Artediellus* spp
	Pallid Sculpin	*Cottunculus thompsoni*
	Twohorn sculpin	*Icelus bicornis*
	Spatulate sculpin	*Icelus spatula*
	Moustache sculpin	*Triglops murrayi*
	Atlantic hookear sculpin	*Artediellus atlanticus*
	Longhorn sculpin	*Myoxocephalus octodecemspina*
	Shorthorn sculpin	*Myoxocephalus scorpius*
Cryptacanthodidae	Wrymouth	*Cryptacanthodes maculatus*
Cyclopteridae	Lumpfish	*Cyclopterus lumpus*
Gadidae	Cusk	*Brosme brosme*
	Atlantic cod	*Gadus morhua*
	Haddock	*Melanogrammus aeglefinus*
	Red hake	*Urophycis chuss*
	White hake	*Urophycis tenuis*
	Greenland cod	*Gadus ogac*
	Pollock	*Pollachius virens*
Hemitripteridae	Sea raven	*Hemitripterus americanus*
Labridae	Cunner	*Tautogolabrus adspersus*
Liparidae	Atlantic spiny lumpsucker	*Eumicrotremus spinosus*
	Inquiline seasnail	*Liparis inquilinus*
Lophiidae	American Angler	*Lophius americanus*
Lotidae	Four beard rockling	*Enchelopus cimbrius*
Macrouridae	Longnose grenadier	*Coelorhynchus carminatus*
Merlucciidae	Silver hake	*Merluccius bilinearis*
	Spotted hake	*Urophycis regius*
Myxinidae	Atlantic hagfish	*Myxine glutinosa*
Ophidiidae	Fawn cusk eel	*Lepophidium cervinum*
Paralichthyidae	Gulfstream flounder	*Citharichthys arctifrons*
	Fourspot flounder	*Paralichthys oblongus*

Gulf of Maine			Georges Bank			Scotian Shelf			Length at maturity[b] (cm)
Richness analyses	Abundance analyses		Richness analyses	Abundance analyses		Richness analyses	Abundance analyses		
	Adult	Juvenile		Adult	Juvenile		Adult	Juvenile	
X	X		X		X	X	X	X	9
						X	X	X	16
X	X	X	X	X	X	X	X	X	18
X	X	X	X	X		X	X	X	35
						X			
X	X	X	X			X	X	X	29
						X	X	X	5
X	X		X						4
						X			
						X			
						X			
X	X	X	X	X	X	X	X		8
						X	X		3
X	X	X	X	X	X	X	X	X	21
X			X						
X	X		X			X			26
X			X			X	X		13
X	X	X	X			X	X		41
X	X	X	X	X	X	X	X	X	35
X	X	X	X	X	X	X	X	X	32
X	X	X	X	X	X	X	X	X	26
X	X	X	X	X	X	X	X	X	35
						X			
X	X	X	X	X	X	X	X	X	45
X	X	X	X	X	X	X	X	X	33
X	X		X	X					8
						X	X		3
						X			
X	X	X	X	X	X	X	X	X	34
X	X		X			X	X		11
						X			
X	X	X	X	X	X	X	X	X	23
X			X	X	X				26
X	X	X	X			X	X	X	40
X			X	X	X				25
X			X	X	X	X	X		6
X	X		X	X	X				27

Table 6-1. (Continued)

Species		
Family	Common name	Scientific name
Petromyzontidae	Sea lamprey	*Petromyzon marinus*
Pleuronectidae	Witch flounder	*Glyptocephalus cynoglossus*
	Atlantic halibut	*Hippoglossus hippoglossus*
	American plaice	*Hippoglossus platessoides*
	Yellowtail flounder	*Limanda ferruginea*
	Winter flounder	*Pseudopleuronectes americanus*
	Greenland halibut	*Reinhardtius hippoglossoides*
Rajidae	Thorny skate	*Amblyraja radiata*
	Little skate	*Leucoraja erinacea*
	Winter skate	*Leucoraja ocellata*
	Smooth skate	*Malacoraja senta*
	Barndoor skate	*Raja laevis*
Scophthalmidae	Windowpane flounder	*Scopthalmus aquosus*
Scorpaenidae	Northern searobin	*Prionotus carolinus*
Sebastidae	Acadian redfish	*Sebastes faciatus*
	Redfish (Genus)	*Sebastes spp*
Squalidae	Spiny dogfish	*Squalus acanthias*
Stichaeidae	Snake blenny	*Lumpenus lumpretaeformis*
	Daubed shanney	*Lumpenus maculatus*
Zoarcidae	Fish doctor	*Gymnelis viridis*
	Ocean pout	*Macrozoarces americanus*
	Wolf eelpout	*Lycenchelys verrilli*
Count = 27	59	59

[a] *X indicates species was included in the analysis.*

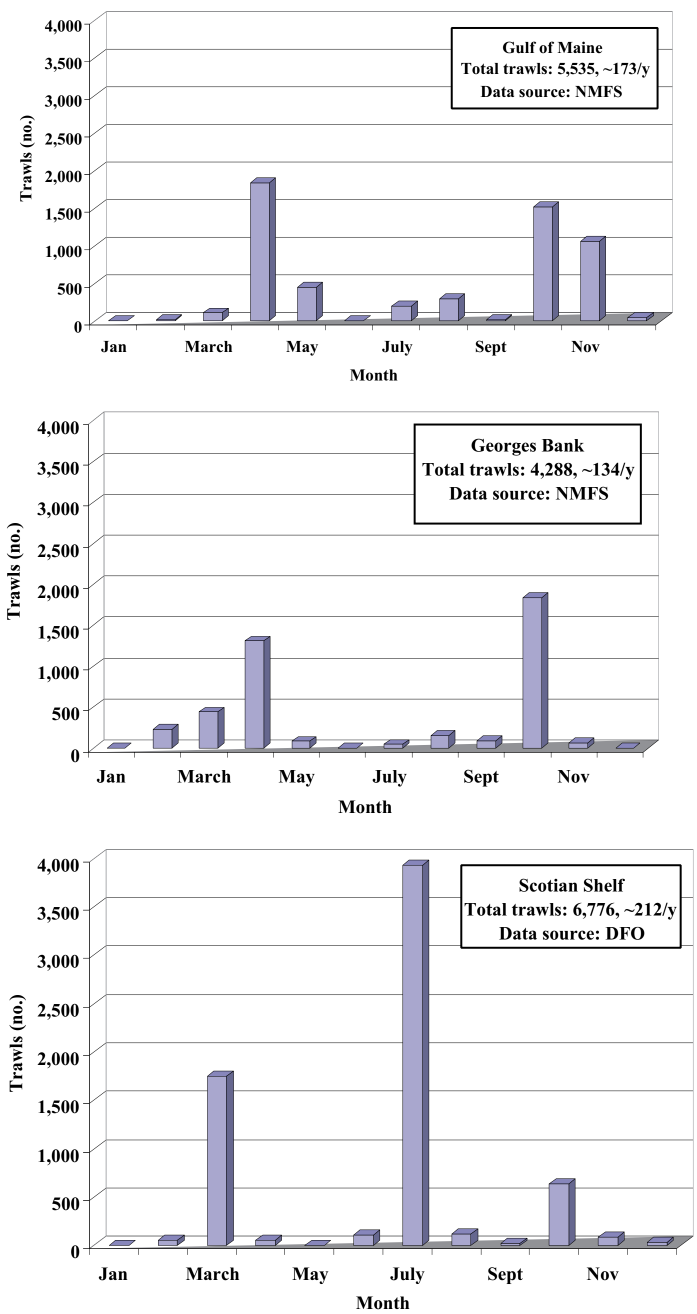
[b] *Numbers in bold are from the literature; the others were computed.*

Gulf of Maine			Georges Bank			Scotian Shelf			Length at maturity[b] (cm)
Richness analyses	Abundance analyses		Richness analyses	Abundance analyses		Richness analyses	Abundance analyses		
	Adult	Juvenile		Adult	Juvenile		Adult	Juvenile	
X			X						
X	X	X	X	X		X	X	X	30
X			X			X		X	92
X	X	X	X	X	X	X	X	X	27
X	X	X	X	X	X	X	X	X	26
X	X	X	X	X	X	X	X	X	27
						X		X	72
X	X	X	X	X	X	X	X	X	50
X	X	X	X	X	X	X	X	X	43
X	X	X	X	X	X	X	X	X	85
X	X	X	X			X		X	56
X			X	X	X	X			65
X	X		X	X	X				22
X			X	X	X				14
X	X	X	X	X	X				22
						X	X	X	21
X	X	X	X	X	X				72
X			X			X	X	X	20
X	X	X	X			X	X	X	9
						X			
X	X	X	X	X	X	X	X	X	29
X			X			X			
45	34	27	45	30	28	48	34	30	

Data sources and sampling

We used data collected during surveys conducted by the Canadian and United States governments between 1970 and 2002; Scotian Shelf data were collected by the Department of Fisheries and Oceans Canada (DFO), and the Gulf of Maine and Georges Bank data were collected by the U.S. National Marine Fisheries Service (NMFS).

Figure 6-1. Temporal distribution of research survey trawls (i.e., effort) for each biogeographic area.

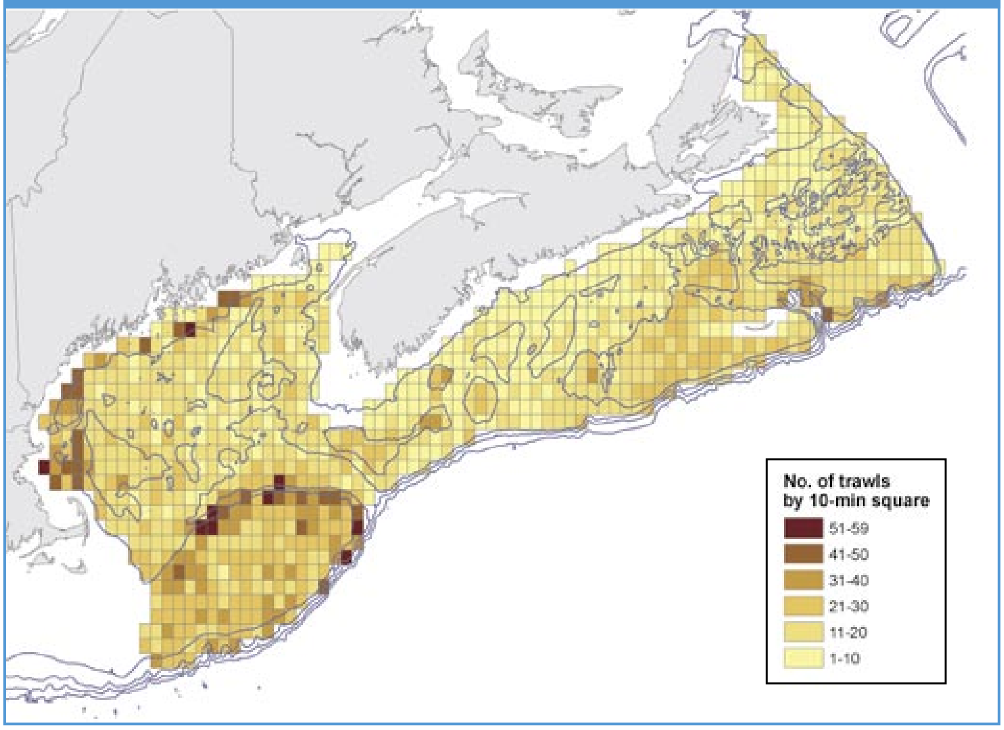


Marine Ecosystem Conservation for New England and Maritime Canada

The survey methods of the Department of Fisheries and Oceans Canada and the National Marine Fisheries Service – which have been discussed in a number of publications (Grosslein 1969; Clark and Brown 1977; Mahon and Smith 1989; Mahon et al. 1998; Shackell and Frank 2002) – were similar and were integrated for the East Coast of North America Strategic Assessment Project during 1994–1996 (Brown et al. 1996). Both employed a random sampling design with stratification by depth and location. Standard, bottom-trawl gear was towed at 10.5 km/h for a 30-minute trawl of 5.25 km (1.8 nmi). The National Marine Fisheries Service sampling was conducted throughout the year, but was heaviest during the spring and fall, with fewer trawls undertaken during the mid-summer and winter. The Department of Fisheries and Oceans Canada trawled primarily during July, March, and October (Table 1 in Brown et al. 1996; Figure 6-1).

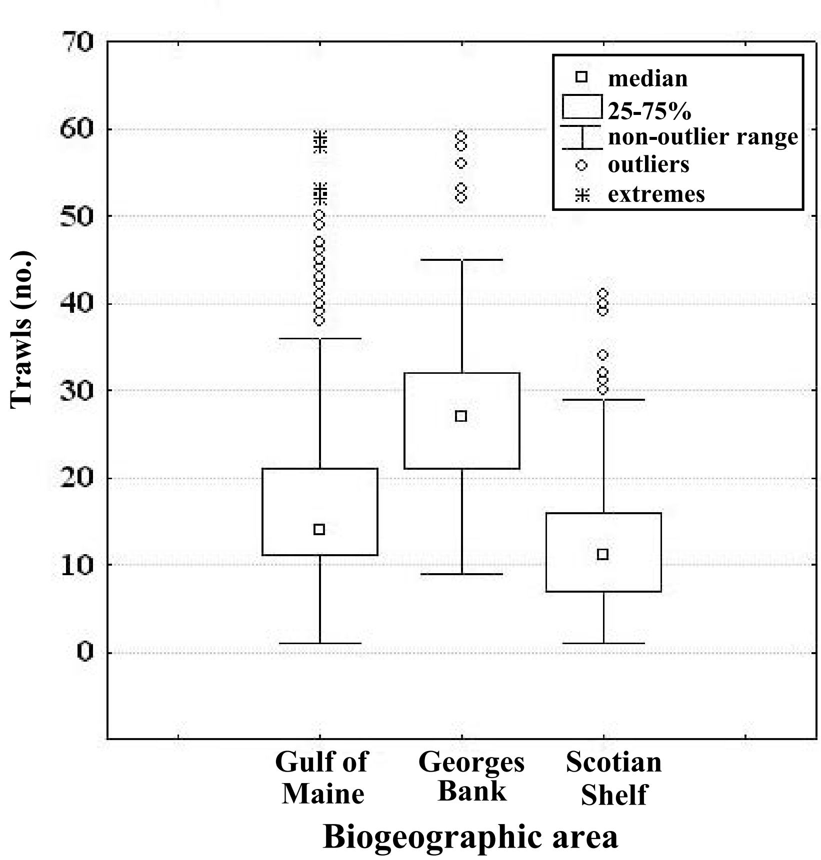
The analyses presented here were handled following the methodology used for the East Coast of North America Strategic Assessment Project. This included standardizing trawls to a 5.25-km distance based on reported trawl distances and eliminating trawls flagged as invalid.

Figure 6-2. Spatial distribution of research survey trawls across analysis region.



Spatial coverage of survey effort across the biogeographic areas was reasonably complete, but distribution of effort was not uniform, with certain areas being sampled more intensively than others (Figure 6-2). For example on Georges Bank, many of the planning units with the highest sampling were clustered along the edges of this biogeographic area. Overall, Georges Bank had the highest number of samples with a median of 29 trawls per planning unit, while the median was 14 for both the Gulf of Maine and the Scotian Shelf (Figure 6-3). On an annual basis, the effort was about 0.51 trawls/planning unit in the Gulf of Maine, 0.84 trawls/planning unit on Georges Bank, and 0.36 trawls/planning unit on the Scotian Shelf. The number of trawls per planning unit was used to correct abundance estimates in order to reduce the influence of these local sampling differences, as detailed below.[2]

Figure 6-3. Median number of trawls for each biogeographic area with quartiles and ranges.



[2] Note that in Figures 6-2 and 6-3, planning units that were not sampled were not included: i.e., 10, or 3%, of 329 planning units for Gulf of Maine, and 30, or 5%, of 575 for the Scotian Shelf. All 154 planning units on Georges Bank were sampled.

Selection of species

Although the Department of Fisheries and Oceans Canada and the National Marine Fisheries Service trawls were designed for assessing stocks of demersal fishes, they yielded rich samples including a host of invertebrates, several hundred fish species (demersal, bathydemersal, pelagic, mesopelagic, and coastal), and fishes that were typical of other regions, including the Arctic, southern Atlantic Shelf, Caribbean, and Sea of Japan. However, for each biogeographic area, we included only demersal fishes that were classified as residents according to published accounts (Scott and Scott 1988; Brown et al. 1996; Auster 2000; Collette and Klein-MacPhee 2002; FishBase 2000). We excluded species whose principal ecology was centered in the inshore coastal zone or the deeper waters beyond the shelf edge (depth <200 m), as well as species likely to be distant strays and occasional migrants.

By using the abundance and richness of resident species, we directed site selection to ecologically important areas for them. We avoided directing selection to areas that might be marginal for non-resident species, for example species whose principal ecology is the continental slope or beyond. Areas exploited on the shelf by slope species are likely the best places for them on the shelf, but perhaps suboptimal when viewed in the context of the species' entire range.

Analysis of fish distributions

■ Species richness analyses

For each planning unit, we determined the number of trawls (n_t) and the number of species recorded for each (n_{spp}), and computed effort-normalized species richness (SR) as the mean number of species counted per trawl $\{SR = (\Sigma\ n_{spp}) \div (n_t)\}$. We used this average richness metric to map the distribution of richness and we used it as one of the data layers for identifying priority areas for conservation (Chapter 9). Other studies have estimated local species richness by using cumulative species richness curves derived from repeated samples (Shackell and Frank 2002). In areas where sufficient sampling is done over a reasonably short period of time, these cumulative richness measures probably give better estimates of true species richness at a given time. However, because our primary goal was to compare the relative richness among many planning units with variable sampling effort across units, average richness (n_{spp}/trawl) was judged to be more appropriate for our analyses.

■ Species abundance analyses

The minimum sample size for analyzing abundance distributions for individual species was 200 individuals per biogeographic area and maturity class (Table 6-1). In a few cases, one class or the other met this criterion, but not both. This meant that a few species were dropped from the abundance analyses, which generally decreased the number of species to about 80% of the starting number for each biogeographic area. I.e., in Table 6-1, the count in the species richness column may be higher than the count in the abundance columns. Because two separate data layers for each species – adult and juvenile – were used for site selection, the number of conservation features for fishes was high (see also Chapter 9).

The relative abundance of a species within each planning unit was computed from the numbers of individual fish from the available trawls. These counts (c) were normalized with a log transformation because the distributions were skewed: ln (c + 1.0). Relative abundance was then computed using the number of trawls per planning unit (n_t) in order to correct for differences in sampling effort: relative abundance = (Σ ln (c +1)) ÷ (n_t). We refer to this metric as relative abundance because it is thought to be proportional to the true abundance for a species, and indicative of a species' abundance distribution across the area. Thus, one can examine a map of relative abundance and identify places where that species has been most abundant *relative* to other places. However, quantitative comparisons between species may be problematic because the efficiency of the sampling method is not expected to be uniform across all species. In our analysis we use this measure only for within-species determinations of relative abundance. We recognize that some within-species biases may result from dependence of sampling efficiency on habitat type, but we assume that this effect is not substantial enough to obscure the patterns we seek to discover. The relative abundance values presented below can be converted back to number of individuals/trawl by subtracting 1.0 from e^{RA}.

■ Assessing maturity

For each species, the distribution of juvenile fishes was examined by selecting those individuals that were at or below the estimated length at maturity (Table 6-1). Wherever possible, maturity estimates were derived from studies that used logistic regression to identify the length at which half of the individuals of a given species were expected to have attained sexual maturity (e.g., Wigley and Gabriel 1991; O'Brien et al. 1993). In a number of cases we had to rely on less rigorous maturity size estimates (Collette and Klein-MacPhee 2002; FishBase 2000).

Estimates of length at maturity often differ by sex; but, for most of the species we examined, these differences were on the order of 10% or less. Our analyses required the use of a single maturity length per species in order to utilize data that did not allow partitioning of the samples by sex. When separate maturity lengths were provided in the literature, we used the midpoint between the male and female length.

For about one-third of the species we analyzed (n = 16), published maturity estimates were not available. In these cases we used an approximation of length at maturity based on population size structure and known maturity lengths. Our examination of the relationship between known lengths at maturity and the mean size of individuals in samples from the Scotian Shelf, Georges Bank, and portions of the Gulf of Maine (Department of Fisheries and Oceans Canada research trawls) revealed a significant correlation ($r = 0.70$, $P < 0.00001$) between these variables. When better estimates were lacking, we used the best-fit regression equation from this relationship to compute proxy maturity lengths from mean size for a species: LM cm = (1.03 x mean length) – 2.34.

Maturity has been defined in a variety of different ways (Burnett et al. 1989), which adds some variability to the published estimates of length at maturity. Estimating length at maturity is further complicated by regional differences in maturity within a species, year-to-year changes in size at maturity, effects of harvesting on population structure, and variation in apparent size at maturity that reflects when samples were taken relative to spawning periods (Halliday 1987). Thus we acknowledge that the length at maturity criteria utilized here are only rough estimates. Nevertheless, they allow us to make a first pass through large datasets that span large temporal and spatial extent, and to examine the distributions of fishes at different life history stages.

Analyses: results and discussion

Species richness patterns

The analyses of the patterns of richness within resident demersal species were based on a total of 59 species (including two genus-level designations), representing 27 families (Table 6-1). The most speciose families were sculpins (Cottidae, 9 species), cods (Gadidae, 7 species), flatfishes (Pleuronectidae, 6 species), and rays (Rajida, 5 species) (Figure 6-4[3]). The species lists for Georges Bank and the Gulf of Maine were the same, and just over half (58%) of the species were common to all three biogeographic areas. A substantial number of the species listed as resident demersals for the Scotian Shelf were not listed within either of the other biogeographic areas (i.e., 24% were unique; Table 6-1).

Figure 6-4. Number of species within each family for whole region-three biogeographic areas combined.

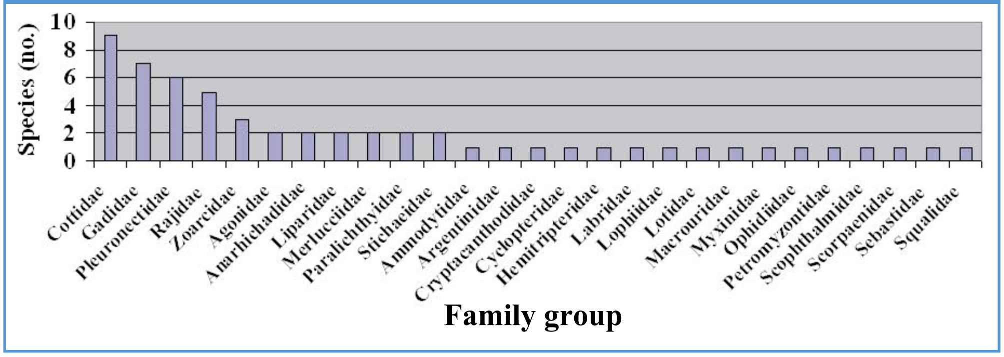
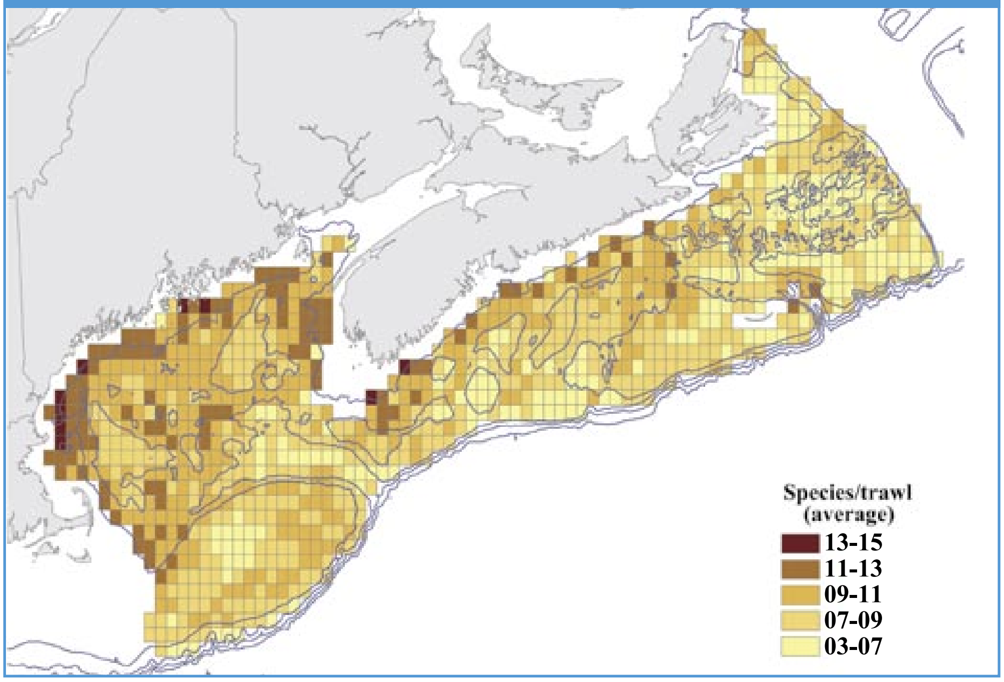


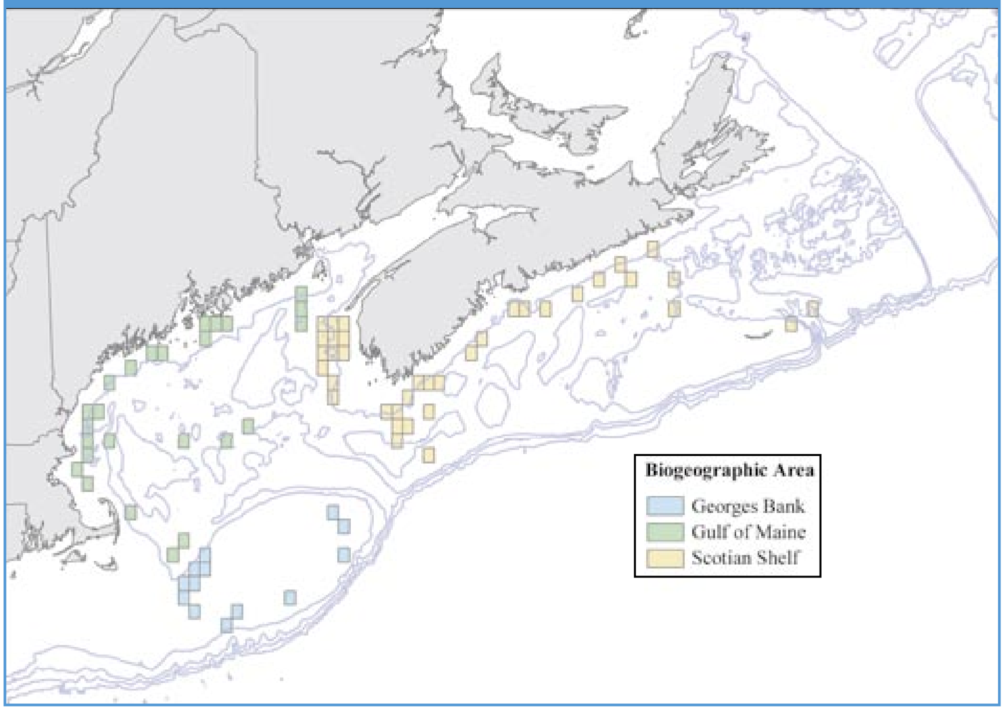
Figure 6-5. Species richness of demersal fishes, as average number of species per trawl.



[3] Note that in Figure 6-4 only one species is indicated for the Sebastidae. This is likely an underestimate because several species occur within the Scotian Shelf but the data were classified only to genus (Sebastes spp). Only Sebastes fasciatus was identified in the other areas.

Areas with the highest average species richness formed a crescent-shaped band starting near the Great South Channel (125 km southeast of Chatham, Maine), roughly following the 100-m isobath within the Gulf of Maine, and ending near the Bay of Fundy, off southeastern Nova Scotia (Figure 6-5). This band of richness continued in a less-pronounced fashion along the nearshore boundary of the Scotian Shelf biogeographic area. A second prominent peak in richness occurred in the center of the Gulf of Maine near certain features, including Cashes Ledge, Ammen Rock, Platts Bank, and Three Dory Ridge. The deeper basins within the Gulf of Maine tended to display lower average species richness. Much of Georges Bank had moderate richness, with a distinct richness peak at the northeastern tip. Smaller areas with high richness – i.e., areas made up of two to three planning units – were also found near the Gully, and off Cape North (Cape Breton Island), on the Scotian Shelf. The areas of highest average species richness appeared to be concentrated near ecological transition zones (i.e., ecotones); for example, transitions between coastal and shelf regions or shelf and slope regions, or around distinctive features such as Stellwagen Bank and Cashes Ledge. It is also interesting to note that some of the most highly productive areas, Georges Bank for example, exhibited moderate to low-average demersal fish richness (Figure 6-5).

Figure 6-6. Planning units that were in the top 10% for species richness, by biogeographic region.



Average richness of the planning units was ranked, and we examined the species composition of the planning units with the highest average richness. We identified a group of units such that the sum of their average richness values was equal to 10% of the total for the biogeographic area (Figure 6-6). These highest richness planning units numbered 25 of 329 planning units (8%) for the Gulf of Maine, 13 of 153 (8%) for Georges Bank, and 37 of 575 (6%) for the Scotian Shelf.

In all biogeographic areas, some species failed to appear in any of these highest average richness areas: one species (2%) in the Gulf of Maine, seven (16%) in Georges Bank, and ten (21%) on the Scotian Shelf. In the Gulf of Maine, about one-third of the species appeared in fewer than half of the highest richness planning units, and only 9 of 45 species (20%) appeared in all of these planning units. Similarly, in Georges Bank, about one-third (29%) of the species appeared in fewer than half of the highest richness units, and only one-third of the species (31%) appeared within all of these planning units. On the Scotian Shelf, 17 of the species (35%) occurred in fewer than half the highest richness planning units, and only 6% (n = 3) appeared in all of these planning units (Figure 6-7).

Figure 6-7. Presence of resident demersal fishes in highest richness planning units (as %) in the three biogeographic areas (see Table 6-2).

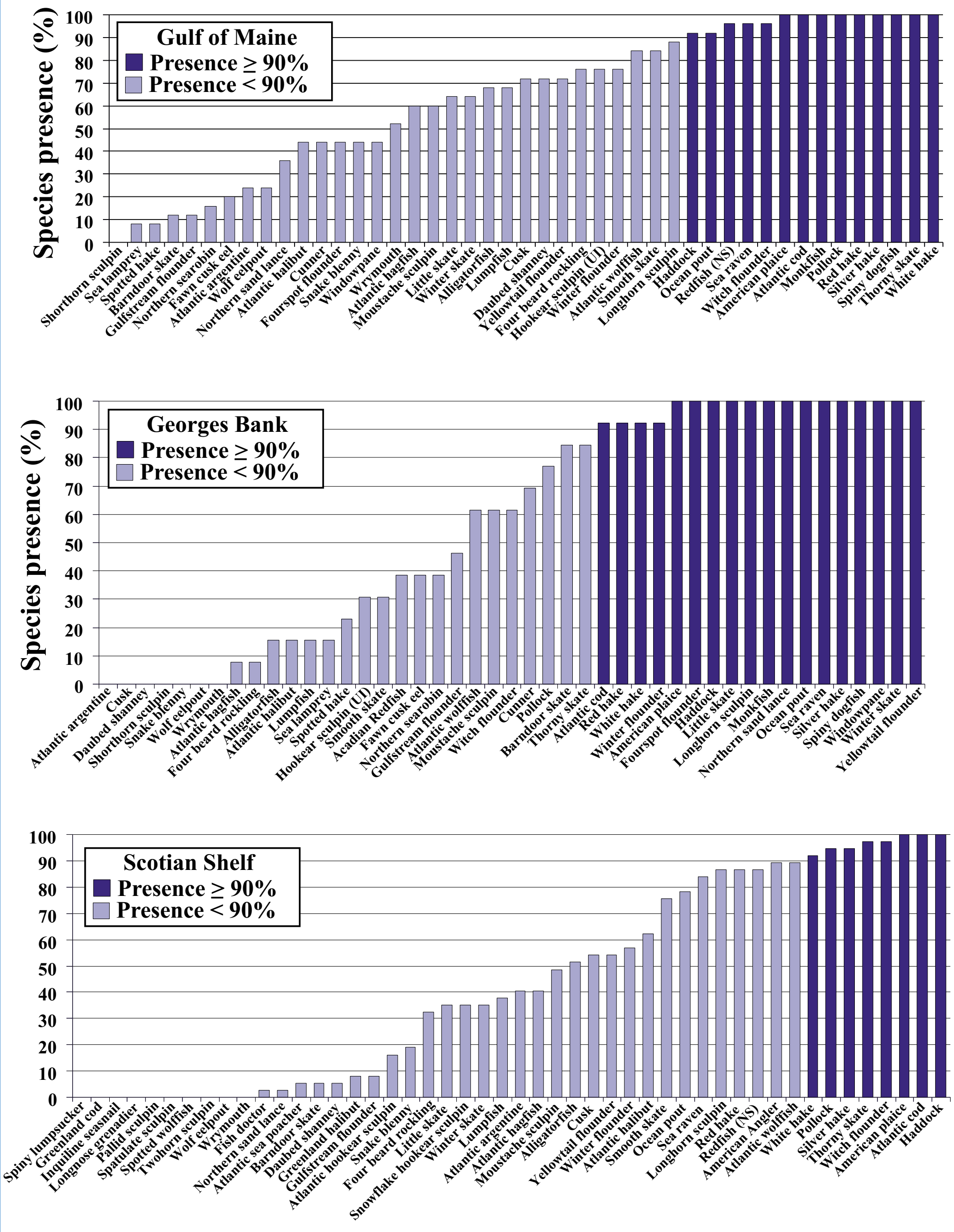


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Table 6-2. Species that occurred in 90% or more of the highest richness planning units (top 10% of planning units, Figure 6-6), by biogeographic area.[a]

Presence of species, by no. of biogeographic areas	Gulf of Maine	Georges Bank	Scotian Shelf
Three biogeographic areas			
American plaice	X	X	X
Atlantic cod	X	X	X
Haddock	X	X	X
Silver hake	X	X	X
White hake	X	X	X
Two biogeographic areas			
Monkfish	X	X	
Ocean pout	X	X	
Red hake	X	X	
Sea raven	X	X	
Spiny dogfish	X	X	
Pollock	X		X
Thorny skate	X		X
Witch flounder	X		X
One biogeographic area			
Redfish (NS)	X		
Fourspot flounder		X	
Little skate		X	
Longhorn sculpin		X	
Windowpane		X	
Winter flounder		X	
Winter skate		X	
Yellowtail flounder		X	
Count	14	17	8

[a] *X indicates species was present.*

Within all three biogeographic areas, cod, haddock, American plaice, and silver and white hake constituted a small group of species that consistently appeared in the highest average richness planning units; i.e., over the entire sampling period, they occurred in 90% or more of these planning units (Table 6-2). Although richness was generally lower in the Georges Bank than in the other areas (Figure 6-5), it had 17 species that occurred within 90% or more of its highest richness planning units, compared with 14 species in the Gulf of Maine and only 8 on the Scotian Shelf. In the Georges Bank area the highest average richness values were 11 species/trawl compared to 14 in the other two areas. This may well have resulted from a more uniform distribution of species within Georges Bank (note lower SD below), but could also have stemmed from seasonal or longer-term shifts in species composition, such that richness remained low, while these species counts remained high. The mean richness across each biogeographic area (i.e., using one average richness value per planning unit) was: Gulf of Maine 9.7 species/trawl ± 1.7 SD, Georges Bank 8.4 species/trawl ± 1.3 SD, and Scotian Shelf area 8.05 species/trawl ± 1.8 SD.

The total number of resident demersal species encountered in each of the biogeographic areas was 45 to 48 (Table 6-1), yet in those areas with the highest average species richness the average richness ranged from only about 11 to 14 species per trawl. Thus, even in the areas with the highest richness, the number of species per trawl was, on average, only a small portion of the total. In each biogeographic area we also examined the cumulative species richness (i.e., the species count based on all trawls combined) for planning units with high average richness. As expected, the highest cumulative richness values, based on over 30 samples per planning unit collected over 3 decades, were closer to the species totals, with 38 species in the Gulf of Maine, 34 on Georges Bank, and 28 on the Scotian Shelf. Cumulative richness was not used as the basis of our spatial analyses because it depended strongly upon the number of samples per planning unit and this was variable across the study area.

Figure 6-8. Examples of abundance patterns for selected species of resident demersal fishes.

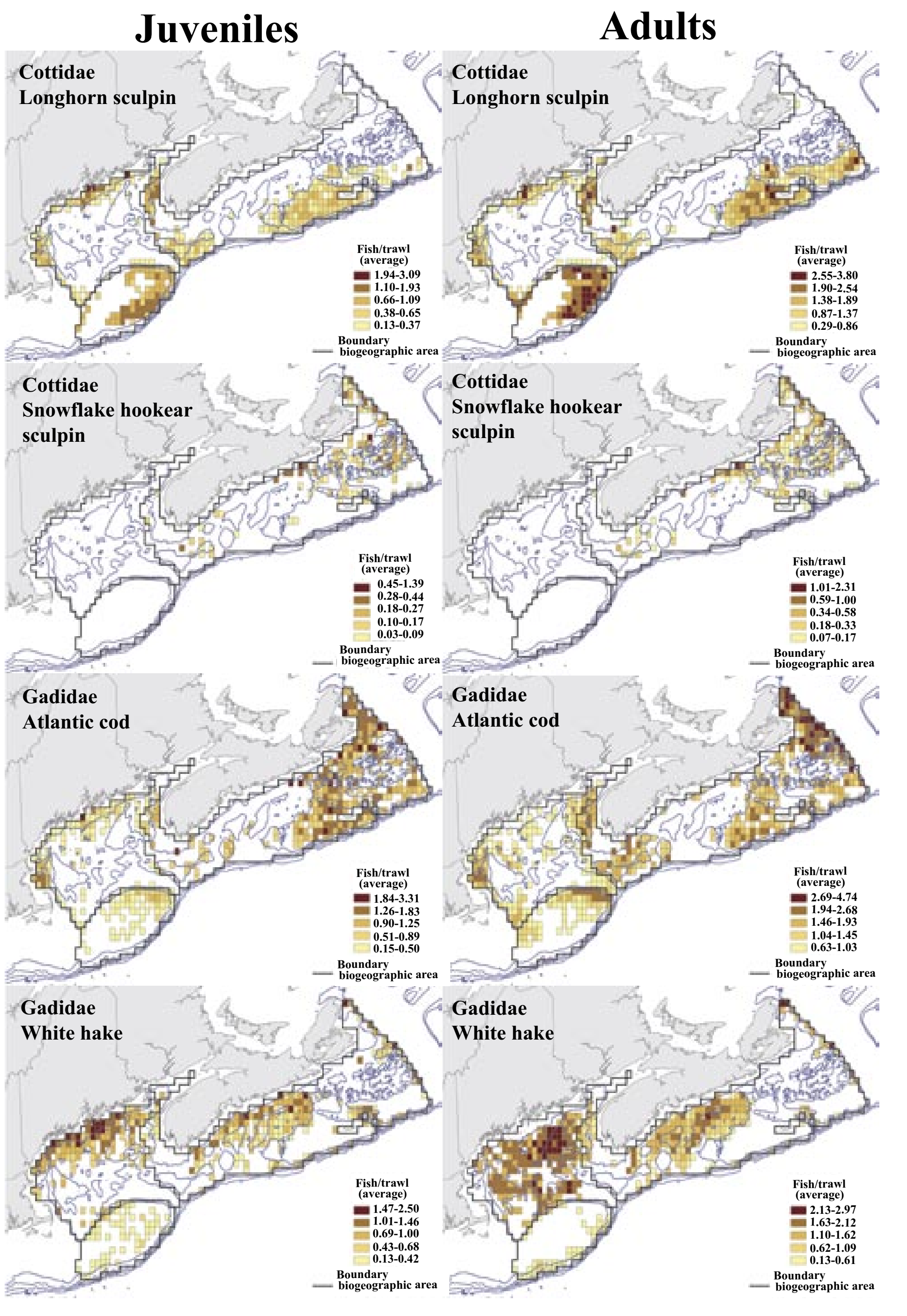


Figure 6-8 continued

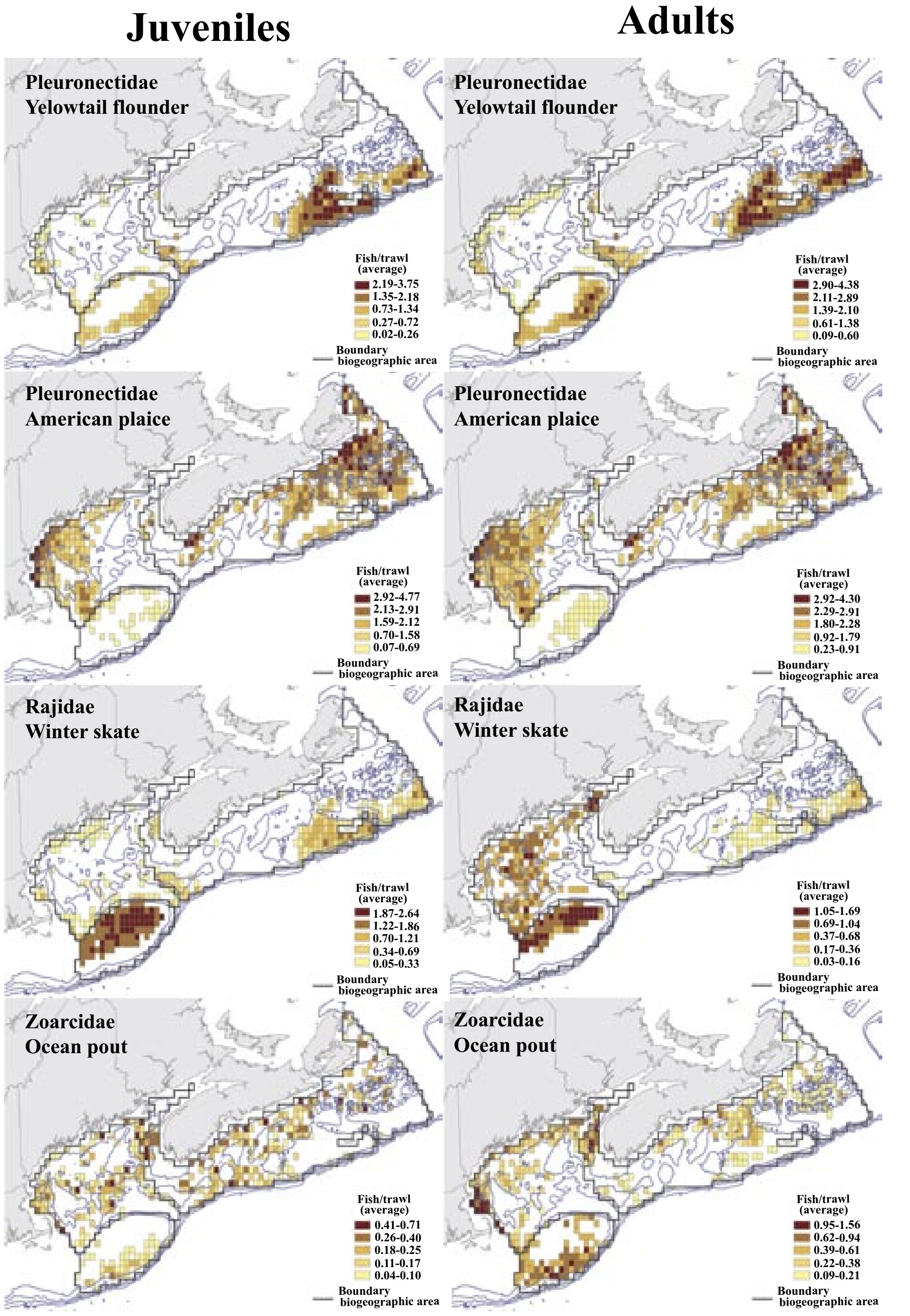
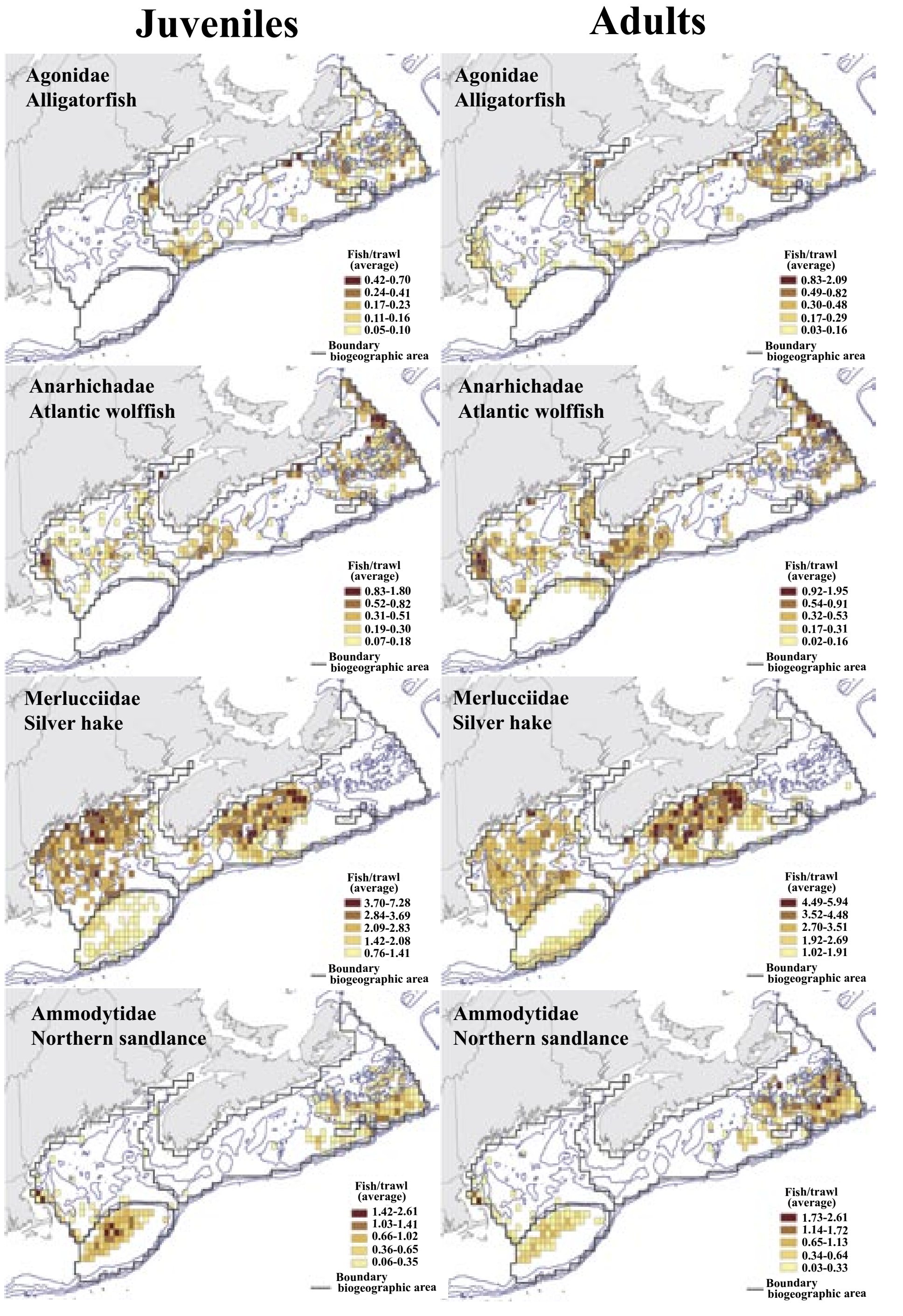


Figure 6-8 continued



As discussed above, including some high richness areas is an important conservation planning objective. However, including the highest richness areas does not ensure that all species are represented nor does it ensure that those areas that support high abundances are included. Thus, the use of abundance distributions for individual species is also important for achieving conservation objectives.

Abundance distributions

With 59 species of demersal fishes, from 27 families, a diversity of abundance patterns was revealed. Figure 6-8 shows examples for twelve species, with the selection biased toward those families with the most species. In general, the deep basins of the Gulf of Maine were more sparsely populated by this group than some of the shallower banks and nearshore areas, as is reflected in the analysis of richness. Juvenile distributions were similar to those of adults in many cases (Figure 6-8). There were, however, some important juvenile-adult contrasts in abundance patterns. For example, on Georges Bank the shallow shoal areas often had higher relative density for juveniles than adults. Clear examples of this were provided by juvenile white hake, silver hake, and winter skate (Figure 6-8). In the evaluation of juvenile and adult distributions it should be noted that our analysis does not extend entirely into the nearshore zone where some species, cod for example, are known to have nursery areas. Additionally, the use of length at maturity to separate populations into juveniles and adults may have influenced the contrasts between these life history stages. For example, the distributions of young fish ≤1 year old are often different from older yet still immature fish. We did not attempt to evaluate these more fine-scale ontogenetic patterns. Additional abundance distribution maps are available in a number of other published sources (Brown et al. 1996; Mahon et al. 1998; Collette and Klein-MacPhee 2002).

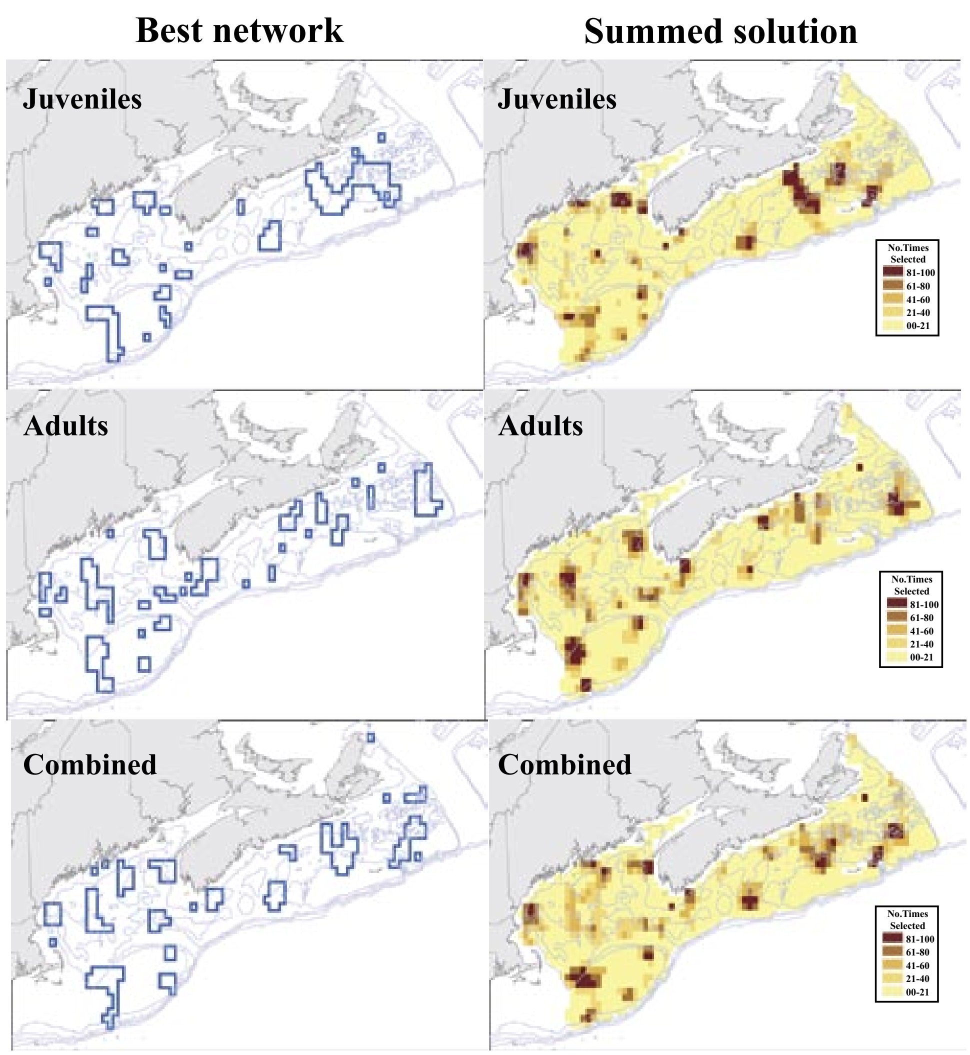
The juvenile and adult abundance data presented here were used in concert with species richness as components for the selection of priority areas for conservation (Chapter 9). Although the overlap between the abundance distributions for juveniles and adults was substantial, as was the overlap between areas of high abundance and high overall species richness, the use of these separate layers in the derivation of priority areas for conservation ensures that areas that are distinguished in some, but not all, of these attributes will be captured in site selection.

MARXAN analysis for fishes

We used computer-based site-selection (MARXAN) to identify combinations of areas that efficiently met the goals for abundance for all of the resident dermersal fish, both juveniles and adults. We did not include species richness in this exploratory analysis. The results allow the distribution of areas that were selected on the basis of this one category of conservation features to be compared with the networks of priority areas for conservation that were identified on the basis of all conservation features simultaneously (see Chapter 9). It is important to note that this MARXAN analysis was not used to identify the network of priority areas for conservation presented in Chapter 9.

The examples provided here were produced with moderate constraints placed on the boundary length (boundary length multiplier = 2), and with goals set to 20% of the abundance represented within the pool of planning units that met a minimum abundance threshold (i.e., those planning units with relative abundance at or above the mean for each species). Site selection was limited to this pool of planning units to ensure that goals were met by using areas containing relatively good habitat as judged by abundance. Note that this set of goals results in selecting just over 10% of the total (logged) abundance for fishes.

Figure 6-9. Networks of areas selected by MARXAN based on fishes alone. Left column: the best network. Right column: all 100 MARXAN runs presented as summed solutions (see Chapter 4).



The best networks for juveniles and adults consisted of similar combinations of single and multi-unit areas, and had a number of areas in common (Figure 6-9, left). The areas for juveniles represented 19% of the total area of Georges Bank (8,027 km^2, 29 planning units), 14% of the Gulf of Maine (12,426 km^2, 47 planning units), and 15% of the Scotian Shelf (22,079 km^2, 86 planning units). For the adults, the areas were 18% of Georges Bank (7,769 km^2, 28 planning units), 16% of the Gulf of Maine (13,883 km^2, 52 planning units), and 14% of the Scotian Shelf (21,082 km^2, 82 planning units). The areas comprising the best network overlapped with those areas that were most frequently selected by MARXAN (Figure 6-9, right). Note that those areas that were selected in only some of the MARXAN runs allow flexibility in site selection.

A network that met goals for juveniles and adults simultaneously was identified by using both data layers (Figure 6-9, bottom). The best network was dominated by areas of moderate size (i.e., each consisting of 4–8 planning units) and contained fewer single-unit areas and fewer very large areas (see Sable Island area for juveniles, Figure 6-9, left). This network consisted of three areas representing 20% of Georges Bank (8,579 km^2, 31 planning units), 9 areas representing 18% of the Gulf of Maine (15,400 km^2, 58 planning units), and 11 areas representing 16% of the Scotian Shelf (23,102 km^2, 90 planning units). Two of the areas straddled biogeographic boundaries.[4]

Acknowledgments

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[4] Note, in Figure 6-9, for the juvenile MARXAN run just one conservation feature penalty factor value (1%) had to be increased from 1.0 to 2.0, whereas none of the conservation feature penalty factor values for adults was changed. For the combined analysis only one conservation feature penalty factor was increased to 2 (Appendix C).

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Humpback tail

Chapter 7

Distinctive areas for whales and dolphins

Background

■ Importance of whales and dolphins

Like the demersal fishes, whales drew European explorers to North America and supported a major industry for several centuries, beginning in the 1500s (Dow 1925; Leatherwood et al. 1976). Eventually the whaling industry collapsed as certain key species became increasingly rare, and as alternatives to whale products became more widely available (e.g., paraffin and kerosene).

As a group, whales and dolphins, or cetaceans, have played a prominent role in the ecology of the northwest Atlantic. The total cetacean biomass for the Gulf of Maine and Georges Bank was estimated to be on the order of 200,000 tons during the period 1979 to 1982 (Kenney et al. 1997). These predators consume over one million tons of prey annually – as much as one-fifth of the total net primary production in the Gulf of Maine region – feeding on zooplankton, larger invertebrates such as squid, and a number of fishes. They have few predators and hold an apical position within our marine ecosystems (Kenney et al. 1997).

Whales are an important part of regional biodiversity. Their spatial distribution in the oceans correlates with components of the marine ecosystems for which we currently lack good data, including invertebrates and some of the smaller fishes. As such, whales are valuable as habitat and biodiversity indicators, or umbrella species, and are clearly worthy targets of conservation efforts in their own right. We have included them here as one of our classes of biological conservation features.

■ Current status and populations

The North Atlantic gray whale *(Eschrichtius robustus)* was hunted to extinction by the start of the eighteenth century (Mitchell and Mead 1977). Current populations of some species in the analysis region are dangerously small (Kraus et al. 2005), including the North Atlantic right whale *(Eubalaena glacialis glacialis)* and blue whale *(Balaenoptera musculus)*.

A number of species are considered to be at risk by United States (United States Fish and Wildlife Service 2006) and Canadian agencies (Committee on the Status of Endangered Wildlife 2006) (Tables 7-1). In the United States, fin *(Balaenoptera physalus),* humpback *(Megaptera novaeangliae),* sei *(Balaenoptera borealis),* and North Atlantic right whales are listed as endangered under The Endangered Species Act *(United States House of Representatives 1973).* Under the Canadian Species at Risk Act (2003), the Committee on the Status of Endangered Wildlife in Canada (2006) has identified the North Atlantic right whale as endangered, and the fin whale and harbor porpoise *(Phocoena phocoena)* as species of special concern.

Data sources and sampling

As a part of our effort to identify priority areas for marine conservation, we mapped important habitats for whale populations by analyzing spatial data for six species of toothed whales *(odontocetes)* and five species of baleen whales *(mysticetes).*

Our analysis was based on the North Atlantic Right Whale Consortium (NARWC) database, which is maintained at the University of Rhode Island (Brown et al. 2001; Kenney 2001; Kenney et al. 2001). The core of the North Atlantic Right Whale Consortium database

Table 7-1. Cetacean species included in the analyses for Gulf of Maine and Georges Bank areas.

		Risk category	
Common name	Scientific name	United States	Canada
Whales and dolphins	Order Cetacea		
Toothed whales (n = 6)	Suborder Odontoceti		
Atlantic white-sided dolphin	*Lagenorhynchus acutus*	Not listed	Not listed
Bottlenose dolphin	*Tursiops truncatus*	Not listed	Not listed
Gray grampus (or Risso's dolphin)	*Grampus griseus*	Not listed	Not listed
Harbor porpoise	*Phocoena phocoena*	Not listed	Special concern[b]
Pilot whale	*Globicephala* sp.	Not listed	Not listed
Saddleback (or common) dolphin	*Delphinus delphis*	Not listed	Not listed
Baleen whales (n = 5)	Suborder Mysticeti		
Fin whale	*Balaenoptera physalus*	Endangered[a]	Special concern[b]
Humpback whale	*Megaptera novaeangliae*	Endangered[a]	Not listed
Minke whale	*Balaenoptera acutorostrata*	Not listed	Not listed
North Atlantic right whale	*Eubalaena glacialis*	Endangered[a]	Endangered[b]
Sei whale	*Balaenoptera borealis*	Endangered[a]	Data deficient

[a] *http://www.nmfs.noaa.gov/pr/species/esa.htm.*
[b] *http://www.cosewic.gc.ca/eng/sct5/index_e.cfm.*

is derived from the Cetacean and Turtle Assessment Program (CETAP), which collected data during aerial and shipboard surveys between 1978 and 1982. The Cetacean and Turtle Assessment Program (1982) dataset includes more than 10,000 sightings distributed throughout the shelf waters from Cape Hatteras to Nova Scotia. This program was designed to characterize marine mammal and sea turtle distributions as part of an environmental impact assessment for proposed offshore petroleum exploration. North Atlantic Right Whale Consortium has integrated the Cetacean and Turtle Assessment Program data with data from numerous smaller scale, intensive surveys, most of which focus on the North Atlantic right whale. We considered several other more opportunistic and variable cetacean datasets but did not include any of them due to the limited spatial and temporal coverage of their survey methodologies (Table 7-2).

The survey effort for the North Atlantic Right Whale Consortium dataset was relatively thorough on Georges Bank and in the Gulf of Maine, but coverage of the Scotian Shelf biogeographic area was restricted to the southwest portion and was less thorough (Figure 7-1). We therefore used North Atlantic Right Whale Consortium data for Georges Bank and the Gulf of Maine only, and excluded the data for the Scotian Shelf.

Figure 7-1. Distribution of cetacean survey effort for NARWC data: total survey distance (km) for each planning unit. Units with less than 10 km of survey were excluded.

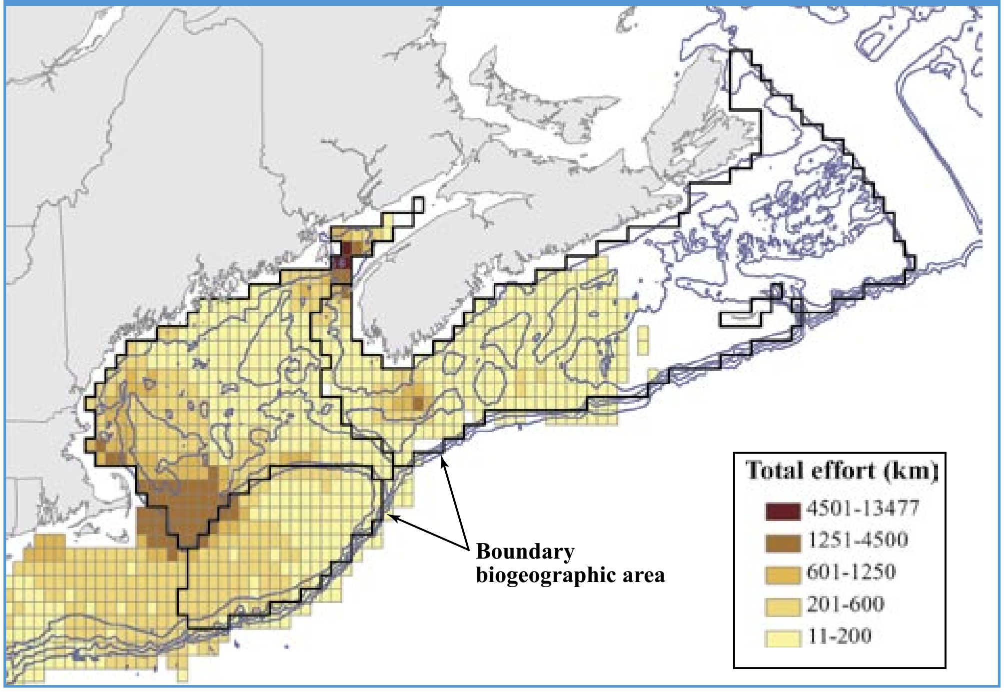
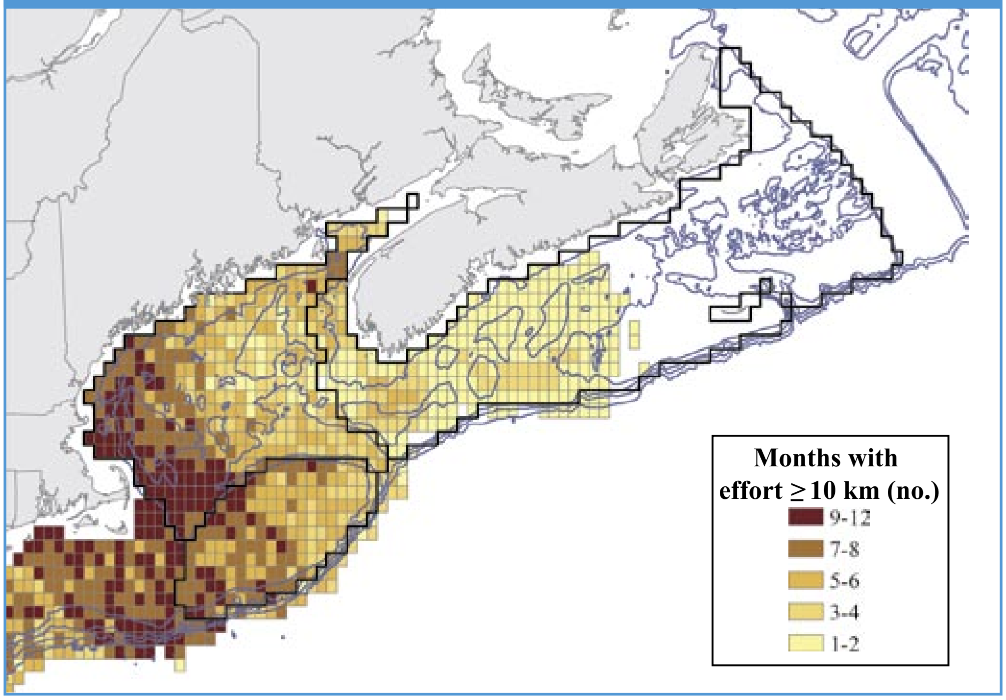
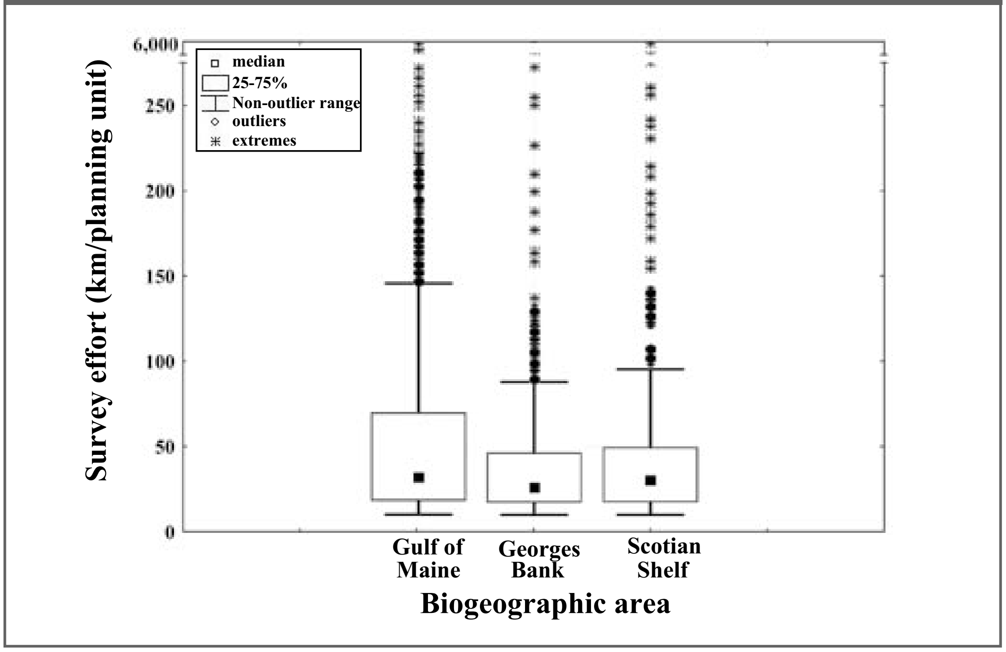


Figure 7-2. Distribution of cetacean survey effort for NARWC data: number of months with more than 10 km of survey effort for each planning unit.



It should be noted that the spatial pattern of effort was uneven (Figures 7-1 and 7-2), with more sampling having occurred in areas known to be important for right whales (e.g., Great South Channel, Cape Cod Bay, Jeffreys Ledge, outer Bay of Fundy). The survey effort for a

Figure 7-3. Distribution of cetacean survey effort for NARWC data: total effort within each biogeographic area for those planning units with $\geq$10 km of effort. (Vertical scale is broken after 275 km/planning unit because only a few planning units had very high survey effort values)



few planning units in the Gulf of Maine was over 5,000 km. The maximum effort values for Georges Bank and Scotian Shelf were 708 and 746 km/planning unit (Figure 7-3). Methods for correcting these sampling biases have been described elsewhere (Kenney and Winn 1986; Shoop and Kenney 1992) and were employed here.

Figure 7-1 summarizes the total survey effort. Total effort reflects the sum of survey distance (km) for all months and all years surveyed, and provides a summary view of how effort was allocated throughout the analysis region. Figure 7-2 summarizes effort in terms of the number of months (0-12) for which planning units had a minimum amount of survey effort (i.e., effort > 10 km).

Analysis of sightings

The number of sightings per unit of effort was used to estimate the relative abundance of each whale species throughout the study region. The estimates were computed for each month of the year, for each 10-minute square. The sightings were judged to be the best-available data for estimating relative abundance and have been the basis for a number of important published studies (Kenney et al. 1997; Kenney and Winn 1986).

We assumed that sightings correlated with actual abundance, but the correlation is not expected to be perfect. For example, we were not able to correct for differences in behavior of a given species, such as feeding and migration, that may have influenced sighting rates independent of abundance. Note also that the relationship between sightings and actual abundance almost certainly varied to some degree between species due to behavioral differences that influenced the ease with which animals were sighted. Thus, this estimate of *relative* abundance is reasonably good for evaluating the abundance of a

Table 7-2. Data sources of potential value for analysis of cetacean distributions.[a]

Dataset	Description	Biogeographic coverage: Southern New England	Georges Bank	Gulf of Maine	Scotian Shelf	Shelf edge
NARWC[b]	Corrected abundances	Good	Good	Good	Partial	Partial
PIROP[c]	Opportunistic sightings	Patchy	Patchy	Patchy	Patchy	Patchy
Blandford[d]	Whaling station kill records and sightings	No coverage	Very patchy	Very patchy	Patchy	Very patchy
DFO[e]	Opportunistic sightings and interactions with fishing gear (e.g., bycatch)	No coverage	Very patchy	Patchy	Patchy	Very patchy
Whitehead Lab[f]	Sightings	No coverage	No coverage	No coverage	Focused around the Gully	Focused around the Gully

[a] *See Appendix D for a list of abbreviations.*
[b] *Brown et al. 2001; Kenney 2001; Kenney et al. 2001*
[c] *http://www.seamap.env.duke.edu/datasets/detail/280.*
[d] *Sutcliffe and Brodie 1977*
[e] *Division of Fisheries and Oceans, Fisheries Observer Program. Unpublished data*
[f] *Hal Whitehead, Professor, Dalhousie University, Halifax, Nova Scotia, personal communication, 2002*

single species in a given location relative to other locations for that species, but probably not as valuable for estimating differences in actual abundance of species. In the analyses presented in this report, we used the sightings data to assess the relative abundance of each species considered throughout the analysis region, but did not use these data for quantitative comparisons across species.

Sightings per unit of effort (SPUE) were derived from the complete set of aerial and shipboard surveys available from the North Atlantic Right Whale Consortium database. Unreliable data, such as unsure or possible sightings, or those that were collected during unfavorable environmental conditions (e.g., poor visibility, high sea states) were excluded. The amount of survey effort (e in km) in a given planning unit (10 minutes square) was determined and the SPUE was computed as sightings (s in number of individual animals) per 1,000 km of effort (SPUE = 1000 x s/e). One thousand kilometers is the standard unit of effort employed by North Atlantic Right Whale Consortium. Planning units with <10 km of survey effort for a given month were judged to be under-sampled for the month

Table 7-3. Sightings of whales and dolphins, by biogeographic area.[a]

Species name	Biogeographic area	Count
Atlantic white-sided dolphin	Georges Bank	3688
	Gulf of Maine	40183
	Scotian Shelf	2165
Blue whale	**Scotian Shelf**	**3**
Bottlenose dolphin	Georges Bank	571
	Gulf of Maine	117
	Scotian Shelf	**8**
Fin whale	Georges Bank	295
	Gulf of Maine	3793
	Scotian Shelf	210
Harbour porpoise	Georges Bank	277
	Gulf of Maine	17474
	Scotian Shelf	822
Humpback whale	Scotian Shelf	269
	Gulf of Maine	2323
	Georges Bank	223
Killer whale	**Gulf of Maine**	**8**
Minke whale	Georges Bank	78
	Gulf of Maine	651
	Scotian Shelf	123
Pilot whale	Georges Bank	1719
	Gulf of Maine	2902
	Scotian Shelf	744
Right whale	Georges Bank	49
	Gulf of Maine	13219
	Scotian Shelf	1054
Risso’s dolphin	Georges Bank	179
	Gulf of Maine	37
	Scotian Shelf	30
Saddleback dolphin	Georges Bank	1795
	Gulf of Maine	154
	Scotian Shelf	755
Sei whale	Georges Bank	31
	Gulf of Maine	447
	Scotian Shelf	375
Sperm whale	**Scotian Shelf**	**19**
	Gulf of Maine	**13**
	Georges Bank	**13**
White-beaked dolphin	**Gulf of Maine**	**27**

[a] *Entries in bold were excluded from the analysis because the number of sightings was <30.*

and we excluded them from our analysis. The median values for effort (km/planning unit) were quite similar within Georges Bank (26), Gulf of Maine (31), and the Scotian Shelf (30), but some areas of the Gulf of Maine were sampled more intensively than either Georges Bank or the Scotian Shelf (Figure 7-3). The raw SPUE data were normalized with a transformation {ln (SPUE + 1)} before being used in our analyses. We collapsed the transformed SPUE data across the year by computing the average of the twelve monthly sampling bins available in the North Atlantic Right Whale Consortium dataset to get an average SPUE/planning unit, and used this as our estimate of relative abundance. We then used this relative abundance metric to identify a network of priority areas for conservation, as described in Chapter 9.

Also, SPUE distributions for each species were examined for the spring-summer season (April to September) and the fall-winter season (October to March) to detect seasonal shifts in distributions. Most species were sighted more often during the spring-summer season. In some cases, seasonal differences in distributions were also observed. However, the areas used were clear, even in distribution maps combining data across all seasons of the year.

We applied a minimum criterion of thirty sightings per biogeographic area in order for a species to be included in our analyses. Of the fifteen cetacean species included in the original SPUE data provided by North Atlantic Right Whale Consortium, six toothed whales *(odontoceti)* and five baleen whales *(mysticeti)* met our sightings criterion (Table 7-1). Three toothed whales – the white-beaked dolphin *(Lagenorhynchus albirostris),* the sperm whale *(Physeter macrocephalus)*, and killer whale *(Orcinus orca)* – were insufficiently sighted for a meaningful spatial analysis, as was case for the rare blue whale *(Balaenoptera musculus, mysticeti)* (Table 7-3).

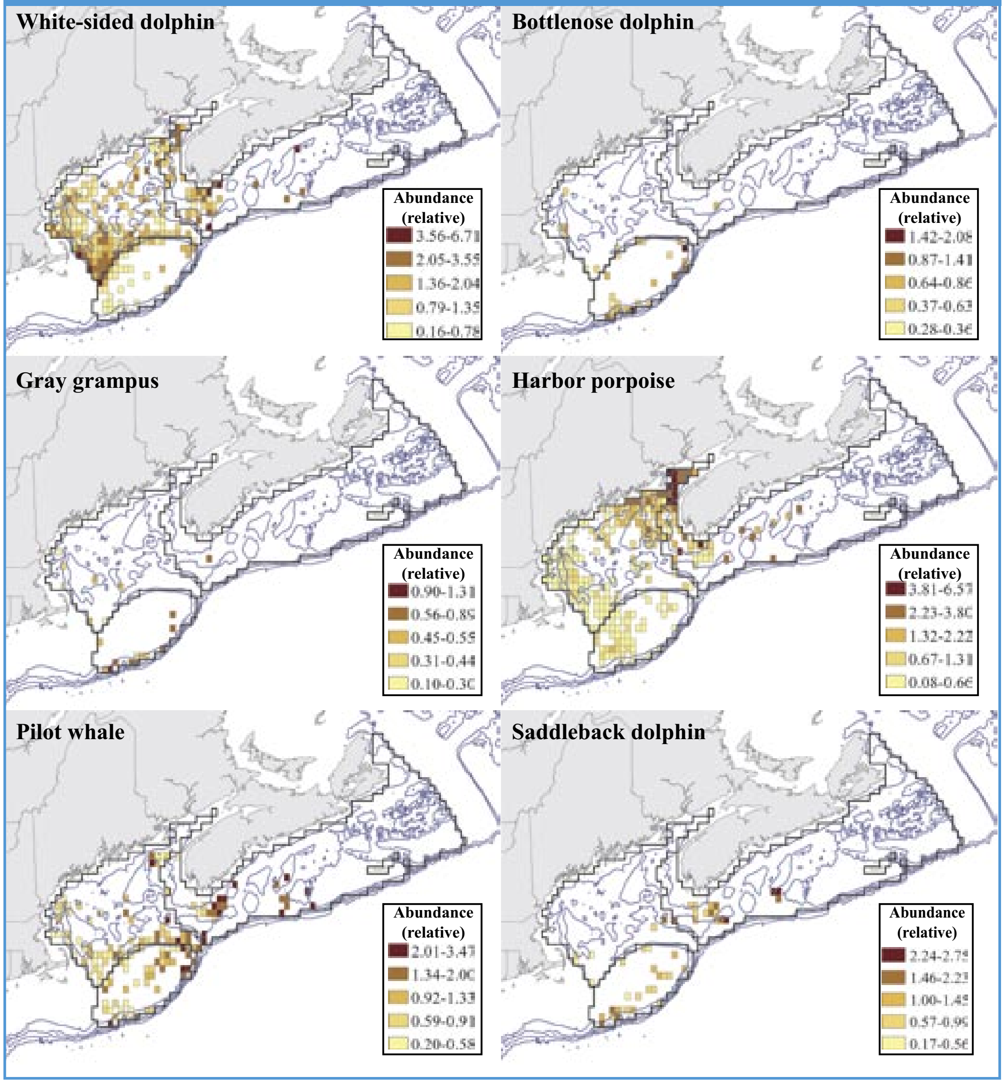
Results of analyses

■ Patterns of relative abundance and richness

The relative abundance patterns for both odontocetes (Figure 7-4) and mysticetes (Figure 7-5) revealed clear concentrations along the margins of Georges Bank and in the Great South Channel, extending into the area of Stellwagen Bank and Jeffreys Ledge, the outer Bay of Fundy, and Roseway Basin at the northern edge of Browns Bank. Among odontocetes, the white-sided dolphin, harbor porpoise, and pilot whale showed high relative abundance in all of these areas. Harbor porpoises showed a distinct concentration in the outer Bay of Fundy area, and the distribution of pilot whales *(Globicephala sp.)* was biased toward the northeastern tip of Georges Bank and Roseway Basin. The bottlenose dolphin *(Tursiops truncatus)* and the common (or saddleback) dolphin *(Delphinus delphis)*, and the gray grampus *(Grampus griseus)*, were sighted less frequently, and sightings were concentrated along the southeastern margin of Georges Bank. All three also had areas of relative abundance on the Scotian Shelf, near Roseway and Emerald Basins. The common dolphin was sighted most frequently at these same Scotian Shelf locations.

Of the five mysticete species examined, all were sighted relatively frequently in the outer Bay of Fundy, and in the vicinity of Roseway Basin on the Scotian Shelf (Figure 7-5). The humpback whale *(Megaptera novaeangliae)*, fin whale *(Balaenoptera physalus)*, and minke whale *(Balaenoptera acutorostrata)* also had high relative abundance in Massachusetts Bay, near Stellwagen Bank. Sightings of the sei whale *(Balaenoptera borealis)* were most frequent off-shore, with areas of highest relative abundance in Roseway Basin and on the

Figure 7-4. Distribution of sightings of dolphins and porpoises (odontocetes) in the Gulf of Maine and Georges Bank biogeographic areas: average annual SPUE values.



northwestern edge of Georges Bank.

The white-beaked dolphin *(Lagenorhynchus albirostris)*, sperm whale *(Physeter macrocephalus)*, and blue whale *(Balaenoptera musculus)* were sighted infrequently (<30 sightings per biogeographic area) and were excluded from our spatial analysis (Table 7-3). The sperm whale was, however, sighted in all three biogeographic areas (total of 52 sightings), and the white-beaked dolphin was occasionally sighted, but only in the Gulf of Maine area (27 sightings). The blue whale was sighted only three times, exclusively on the Scotian Shelf.

An overall picture of the usage patterns was gained through maps of species richness (Figure 7-6) and a relative abundance summary for all the cetaceans combined (Figure 7-7). For the abundance summary, the relative abundance values for each species were first divided by the maximum value for a species (i.e., corrected), thereby setting the maximum to unity. Next, the sum of these corrected values was determined for each planning unit

Figure 7-5. Distribution of sightings of baleen whales (mysticetes) **in the Gulf of Maine and Georges Bank biogeographic areas: average annual SPUE values.**

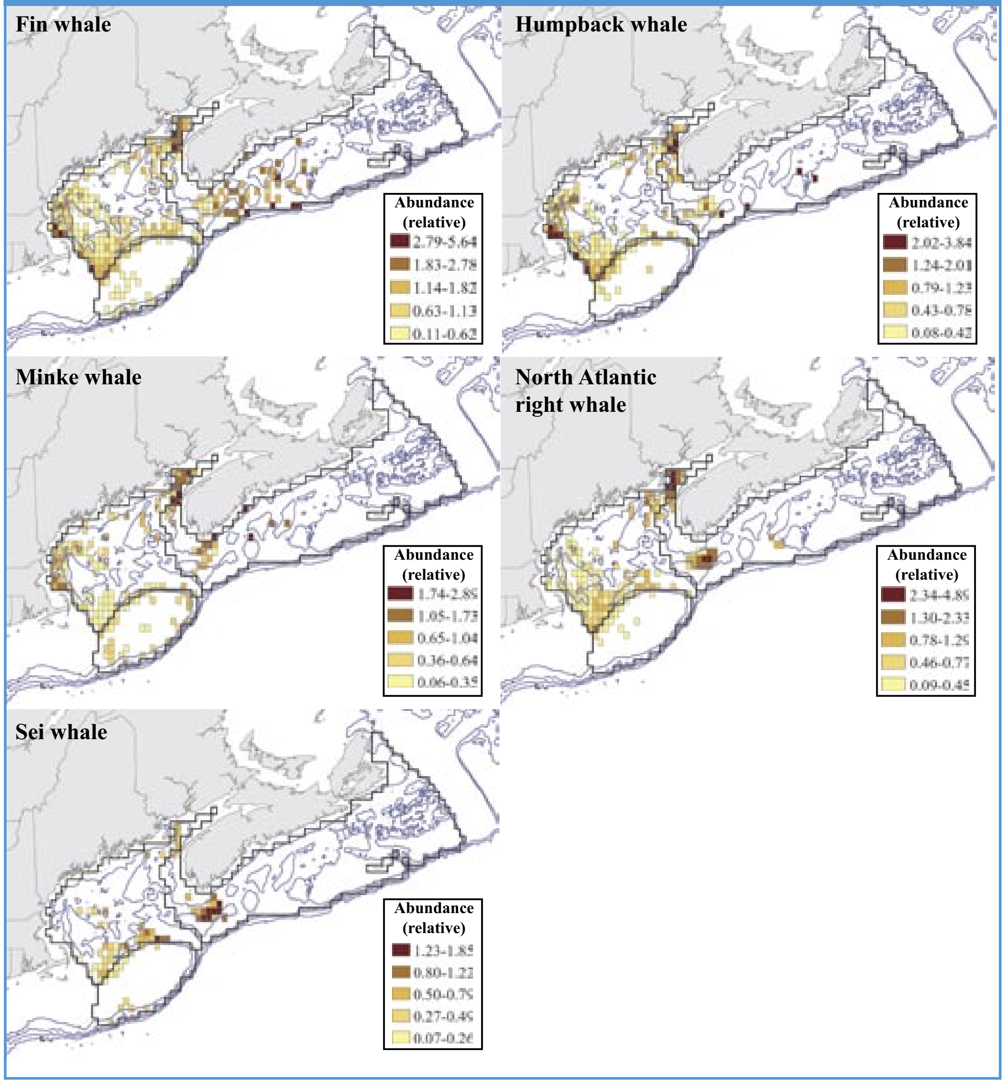
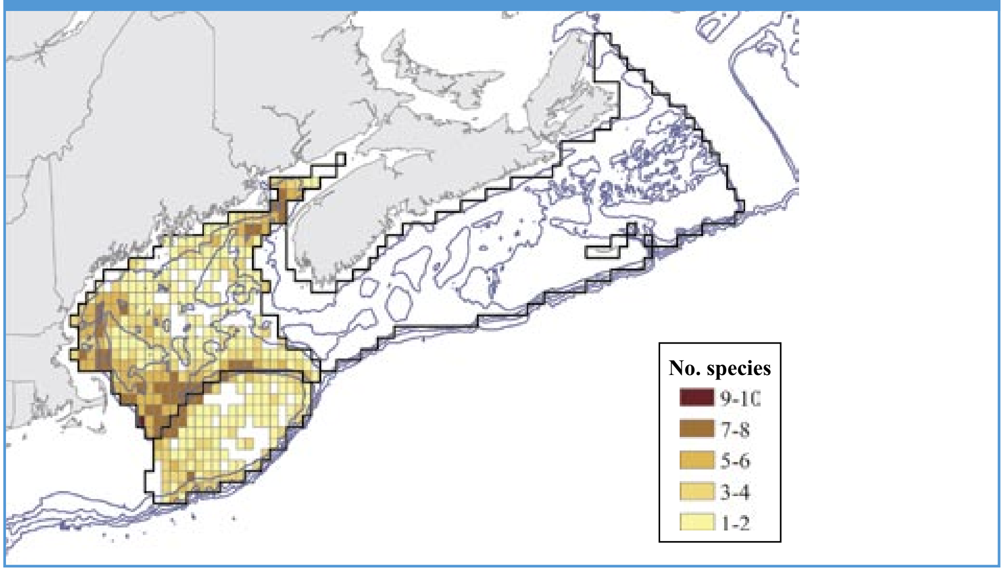


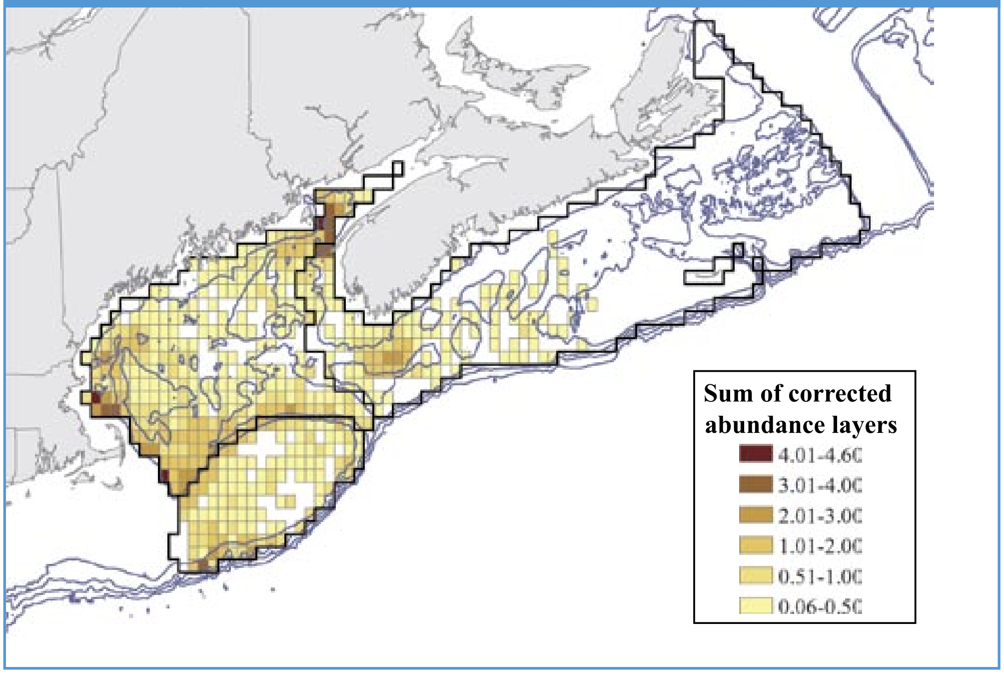
Figure 7-6. Species richness for cetaceans, by counts within planning units.



across all species and mapped, which provided a summary view of relative abundance. This view was quite similar to that provided by cetaceans species richness. Both of these views revealed distinctive areas around the Great South Channel, Georges and Stellwagen Banks, Jeffreys Ledge, the outer Bay of Fundy, and Roseway Basin.

The patterns of habitat use of these and other species have been analyzed previously in terms of cetacean biomass, including a seasonal analysis, separate treatments for endangered species, and species separated by feeding strategy (Kenney and Winn 1986). The patterns revealed by Kenney and Winn were quite similar to those shown here, with the critical importance of the Great South Channel, Stellwagen Bank, Jeffreys Ledge, Bay of Fundy, and the shelf break areas around Georges Bank similarly indicated.

Figure 7-7. Summary of relative abundance for all cetacean species. Summary based on sum of corrected relative abundance layers.



MARXAN analysis for whales and dolphins

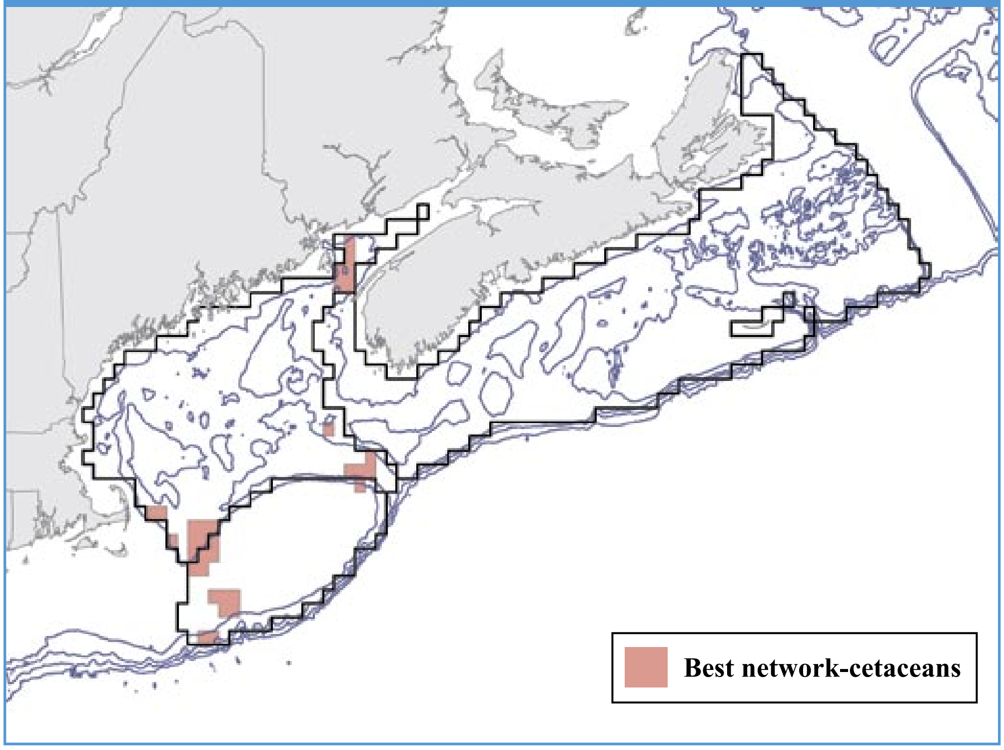
We used MARXAN to identify networks of areas that efficiently met goals based on the abundance distributions for all of the cetacean species. The results of this analysis allow the distribution of areas that were selected on the basis of this one class of conservation features to be compared with the network of priority areas that was identified on the basis of all features (see Chapter 9). However, this exploratory analysis was not used to identify the latter.

For each species, those planning units for which the SPUE was equal to or greater than the mean for the biogeographic area were identified as important habitat areas, and MARXAN selected from among these planning units. Goals for each species were set as a proportion (20%) of the sum of the relative abundance values among those planning units that were at or above the mean for each biogeographic area.

The areas identified with MARXAN met the relative abundance goals for each of the eleven species. All conservation feature penalty factor values were held at 1.0 and the boundary length multiplier was 0.5 (see Chapter 4).

The best network based on conservation features for the cetacea (Figure 7-8) included areas in the Great South and Fundian Channels, outer Bay of Fundy, southwestern Georges Bank, and a small area in Crowell Basin at the eastern edge of the Gulf of Maine area, due west of Browns Bank. The Great South Channel and Outer Bay of Fundy areas correspond directly to areas with high species counts and corrected abundance (Figures 7-6 and 7-7) and areas of high cetacean biomass (Kenney and Winn 1986). The selection of a single planning unit in Crowell Basin was apparently driven by just two species, the pilot whale and common dolphin. The areas selected in Georges Bank corresponded to about 9% of the bank (13 planning units; 3,626 km^2) and those in the Gulf of Maine corresponded to 6% of that area (20 planning units; 5,344 km^2).

Figure 7-8. Best network of areas selected for cetaceans with MARXAN.



The waters of Stellwagen Bank and Jeffreys Ledge, off Massachusetts, were areas of high relative abundance for a number of species, including the humpback whale, the fin whale, and the minke whale, and the white-sided dolphin (Figures 7-4 and 7-5), yet were not included in the featured MARXAN network for cetaceans (Figures 7-8, 7-9, and 7-10). Each of these species had high relative abundance in other areas as well (e.g., Bay of Fundy, Great South Channel), which allowed MARXAN to attain abundance goals in these areas. During the process of identifying a network of priority areas for conservation, when the cetacean data were analyzed with the other data layers, a substantial area encompassing Stellwagen Bank and a portion of Jeffreys Ledge was selected (Chapter 9). Stellwagen Bank is known as a feeding area for humpbacks and other whales during the spring and summer (Wiley et al. 2003b), and Jeffreys Ledge is thought to be used by female right whales with calves (Weinrich et al. 2000). This important information was not available

Figure 7-9. Locations of planning units most often included in networks for cetaceans: summary of all 100 MARXAN runs.

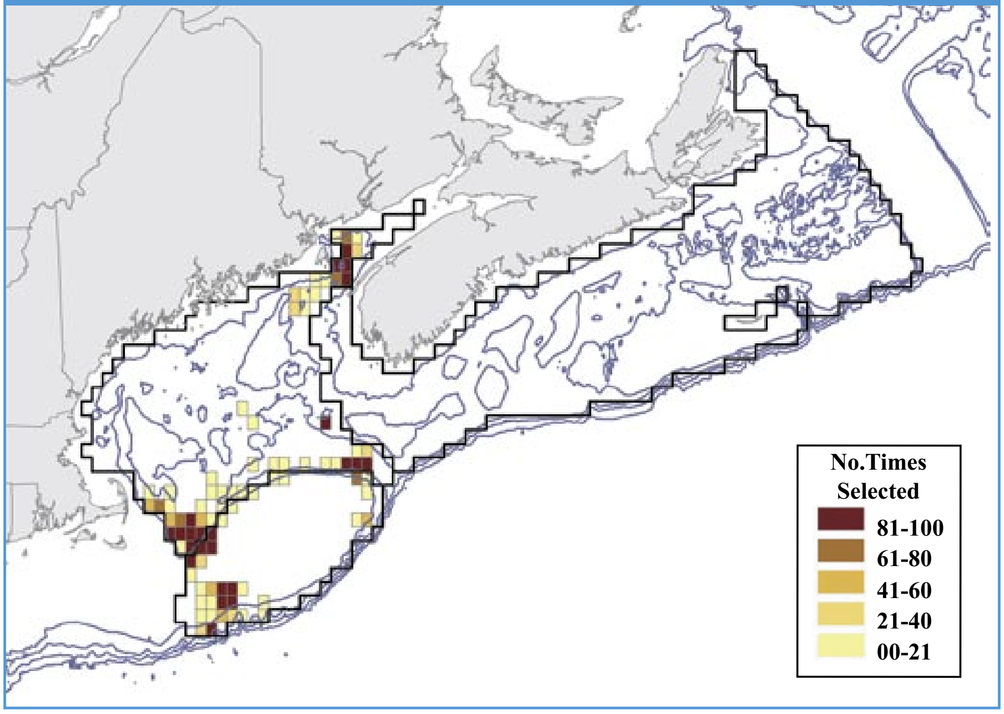
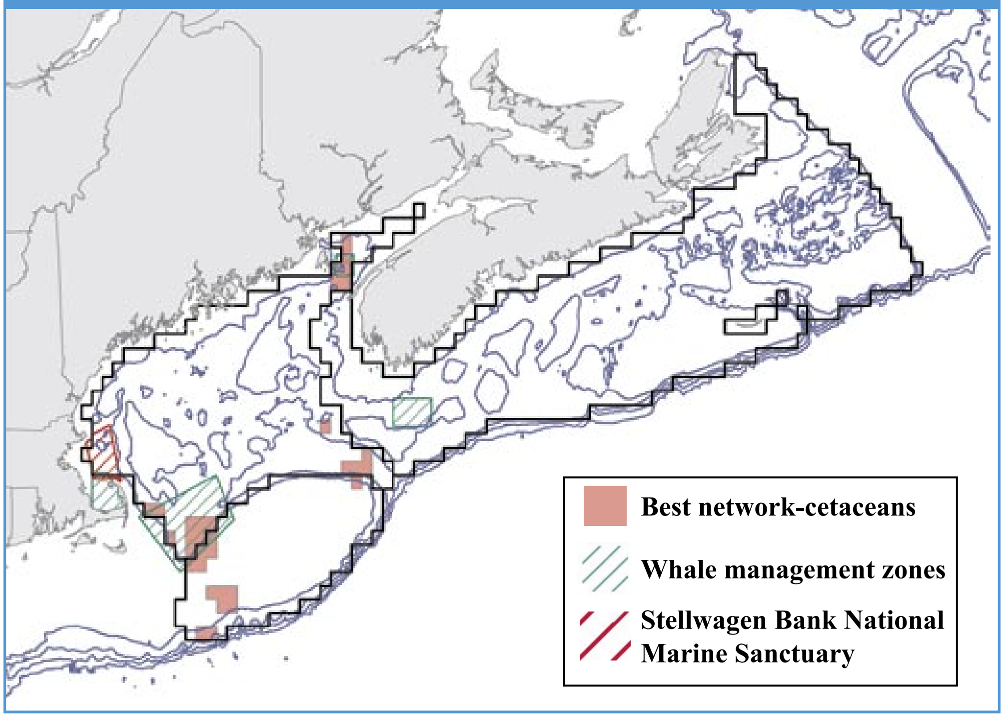


Figure 7-10. Network of areas selected for cetaceans shown with the location of four whale management zones and the Stellwagen Bank National Marine Sanctuary.



within the abundance data we employed here. As discussed in Chapter 2, we have chosen not to include specific localities of known biological significance identified outside of systematic surveys. However, important whale feeding and calving areas would be good candidates for explicit inclusion in future applications of this site-selection method.

Discussion of whale and dolphin distributions and conservation

We have not attempted to capture the well-known seasonal (Kenney et al. 1997) and longer-term cycles in the habitat-use patterns of cetaceans. Habitat-use patterns by whales follow long-term cycles that correlate with the abundance of prey species, as does habitat use by some of the fishes. Humpback whales, for example, shifted from feeding grounds in the northern Gulf of Maine to the southern Gulf during the late 1970s and 1980s, which coincided with declining herring populations and an increasing sand lance abundance in Massachusetts Bay (Kenney et al. 1996). Nevertheless, the analysis presented here is one component of a larger effort to identify priority areas for long-term conservation that will meet a wide spectrum of biodiversity and ecosystem conservation objectives. In this context, inclusion of areas that are used only part of the year, or as part of a longer-term cycle, is desirable and can be best achieved by taking the longest term view that available data will allow.

The MARXAN network illustrated here overlaps with the Great South Channel Critical Habitat Area and the Right Whale Conservation Area at Grand Manan Basin (Canada's Outer Bay of Fundy) (Figure 7-10). Although the Scotian Shelf was not included in the site selection, Canada's Right Whale Conservation Area at Roseway Basin overlaps extensively with the areas of highest species density in this region (Figures 7-6 and 7-7). MARXAN did not select the Stellwagen Bank National Marine Sanctuary (7-10), but this sanctuary was clearly indicated as an important area, as noted above (Figures 7-6 and 7-7), and it is identified as a priority area for conservation (Chapter 9). That these high-use areas have been recognized and put under the management of government agencies is positive. Nevertheless, the current extent of protection is probably insufficient for many species, particularly the larger mysticete whales. Ship strikes (Knowlton and Kraus 2001; Jensen and Silber 2003) and gear entanglements (Hamilton et al. 1998; Robbins and Matilla 2000) continue to be major mortality factors for large whales, and both can occur within these designated areas as currently regulated (Wiley et al. 2003a).

Acknowledgments

We are indebted to Robert D. Kenney, University of Rhode Island, for providing the SPUE data derived from the North Atlantic Right Whale Consortium database, and for his advice on the interpretation of these data. We are grateful to Hal Whitehead, Dalhousie University, for his guidance, and to Robert Kenney and David Wiley, Stellwagen Bank National Marine Sanctuary, for their valuable comments on a draft of this chapter.

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Northern red soft coral

Chapter 8

Classifying seascapes based on abiotic characteristics of the water and seafloor

Introduction to our approach

As described in Chapters 1 and 2, our goal was to identify a network that can protect the full range of marine biodiversity in the analysis region by incorporating representation of habitat as a design criterion. This chapter describes the method we used for classifying marine habitat, and the maps we used for incorporating representation into the design of our network of priority areas for conservation.

Our classification system and maps grew out of an approach advanced by Day and Roff (2000) that is based on the observation that physical habitat types can be used to partially predict distributions of marine life. In the approach presented here, physical habitat types were characterized based on a suite of relatively enduring and recurrent characteristics that are themselves known to influence the distribution of species and biological communities. These included characteristics of the seawater, composition of the seafloor, and depth.

Using an approach based on physical habitat types defined by enduring and recurrent abiotic characteristics is advantageous in our region for two reasons. First, the use of these characteristics makes the classification relatively stable (or naturally adaptable) through time. Second, the approach can be implemented using physical datasets for which we have relatively good coverage throughout the region.

Like any classification system, the seascapes described in this chapter reflect one level in a hierarchy of scales. The biogeographic areas presented in Chapter 3 represent a level of classification that encompasses the seascapes; site-level planning will require a finer classification to distinguish physical habitat differences subsumed by the seascapes described in this chapter.

To the best of our knowledge, the maps presented here represent the first effort to provide region-wide habitat maps for the shelf waters of the greater Gulf of Maine and Scotian Shelf. This classification and mapping work is offered as a “proof of concept” that sufficient data exist to proceed with representative marine conservation in the region.

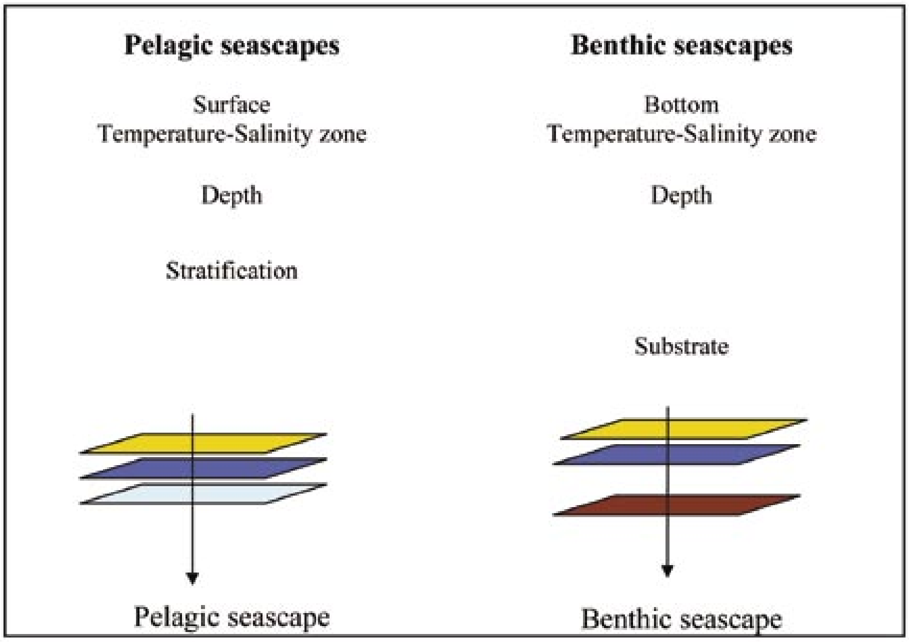
Seascapes classification system

Our seascapes classification system characterizes physical habitats at each geographic location within our analysis region, and it distinguishes the pelagic (water column from the nearshore boundary to the open ocean offshore) and benthic (seafloor) realms. The distributions of demersal and benthic communities are most strongly shaped by the characteristics of the seafloor, while the distribution of pelagic communities is more heavily influenced by the physical parameters of the water column (Cox and Moore 2000). Nevertheless, the interactions between these realms are important (Ward 1995; Collette and Klein-MacPhee 2002; Wahle et al. 2006).

Characteristics used to define benthic and pelagic seascapes

In this classification system, each pelagic and benthic seascape is defined by a unique combination of characteristics: surface water temperature-salinity zone, depth class and degree of stratification within the pelagic realm, and bottom temperature-salinity zone, depth class, and substrate type in the benthic realm (Table 8-1; Figure 8-1).

Figure 8-1. Defining pelagic and benthic seascapes from multiple data layers.



Zones of similar water temperature and salinity

Zones of similar water temperature and salinity, or temperature-salinity zones, in some respects are analogues of major climatic regions in terrestrial environments, and at broad scales they correlate well with the differences in biological community types (McGowan 1985; Elphick and Hunt 1993; Drinkwater et al. 1999; Day and Roff 2000; Breeze et al. 2002). Pronounced differences in the temperature and salinity of ocean water can occur at a single geographic location where the water is vertically stratified. To capture these differences we have divided the temperature-salinity zones into two parts, benthic and pelagic.

A number of studies have explored the influence of seawater temperature and salinity characteristics, or water masses, on biogeography (Chapter 3). However, it was challenging to produce the static classification scheme we required for seascape mapping and site selection because water masses are dynamic in space and time. Water masses gain and lose heat, change density, and move with ocean currents over annual and other cycles. Such movement may result in collisions of water masses that can lead to mixing and/or forcing of denser water below less dense water. As a result of this dynamism, over the span of a year, any one place in the ocean may come into contact with a range of water masses (see Appendix D). In classifying seascapes, we defined zones that experienced similar ranges of temperature and salinity conditions over the course of the full year.

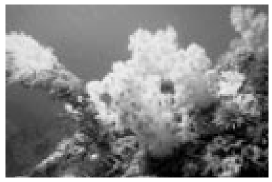


Table 8-1. Component layers for deriving seascapes.

Layer	Biogeographic area	Data sources
Water mass (temperature and salinity)	All	*Hydrographic Atlas for the Eastern Continental Shelf of North America* (NOAA 2005).
Depth	All	A compilation of depth-sounding data from ship tracks and sampling stations generated by David Greenberg, Bedford Institute of Oceanography.[a]
Stratification	All	Density anomaly (1,500 x $\Delta\sigma_t$) derived from the Oceanographic databases, Bedford Institute of Oceanography (2006).
Substrate	Scotian Shelf and Bay of Fundy[b]	Geological survey of Canada maps (King 1970, MacLean and King 1971, Drapeau and King 1972, Fader et al. 1977, and MacLean et al. 1977).
	Deep Sea	Geological Survey of Canada's *Surficial Geology of the Scotian Slope* (Piper and Campbell 2002).
	Gulf of Maine & Georges Bank	U.S.Geological Survey's *East Coast Sediment Analysis* (Poppe and Polloni 2000).
	Gulf of Maine near shore	Data collections of Joe Kelly, University of Maine.[c]

[a] *David A. Greenberg, Scientist, Coastal Ocean Science, Bedford Institute of Oceanography, personal communication, 2002*
[b] *Bay of Fundy is part of the Gulf of Maine.*
[c] *Joseph T. Kelly, Professor, Department of Geological Sciences, University of Maine, personal communication, 2002*

Stratification of the seawater

The water column in the ocean varies from well mixed to highly stratified, as detected by differences in water density. Density is strongly influenced by temperature and salinity (Thurman and Trujillo 2002). The degree of stratification and the spatial patterns of waters that become stratified are important determinants of the distributions of organisms living in the water column, including the pelagic species of the offshore. In much of the Gulf of Maine and Scotian Shelf, the vertical stratification pattern changes with the season. In winter and spring, stratification breaks down and the water column is well mixed throughout, while in summer the sunlight warms the top water layers, leading to the formation of distinct temperature strata within the water column that may last into the fall. Other parts of the region do not exhibit strong stratification, and remain relatively well mixed throughout the year. Mixing, whether seasonal or continuous, is important to ecological processes because mixing of the water column replenishes nutrients in the upper layers where photosynthesis occurs (Smith 1996).

The boundary between adjacent water masses, often detected by sharp changes in temperature and salinity, is called a front. The high concentration in frontal areas of phytoplankton and the small organisms that feed on phytoplankton attracts an abundance of other marine life including larger predatory fishes and marine mammals (Beer 1997; Etnoyer et al. 2004). Unique transitional communities of zooplankton are also often found in frontal zones (Perry et al. 1993).

Thus, our classification scheme differentiates areas that typically become stratified at some point in the year, areas that tend to be well mixed throughout the year, and the frontal areas that occur between these two. Stratification was one of several characteristics we used to classify the pelagic seascapes.

Depth

Water depth is another fundamental influence on the distribution of marine organisms. Depth directly influences light penetration, hydrostatic pressure, and degree of physical disturbance on the seafloor, all of which affect the composition and distribution of biological communities.

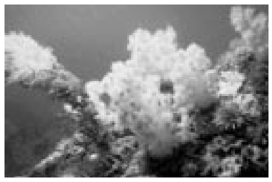
For example, shallow areas are inhabited by communities that depend on high light availability and which are well adapted to dynamic conditions related to wave action (Cox and Moore 2000). Shallower environments tend to be well mixed without vertical stratification, and do not display the extremes of salinity, pressure, and darkness found in deep-water environments. Seafloor communities in deep waters (<60 m) are relatively sheltered from natural disturbances caused by storms and wave action. In deep water, the water column consists of a range of habitats exploited by pelagic animals, from warm surface waters with low salinity and high light levels, to mid- and deep-water zones with increasing salinity, lower temperatures, and less light penetration. Because of the range of mechanisms by which depth influences the distribution of biological communities, we used depth to characterize both the benthic and pelagic seascapes.

Substrate

Substrate plays a key role in influencing the composition and distribution of benthic and demersal communities. Marine benthic communities are typically distinguished on the basis of whether they occur on hard or soft substrates and on the basis of particle sizes that range from large boulders to the fine particles of mud. Grain size dictates the size of animals that live amongst the grains and the types of animals that attach to, and forage and spawn on, the surface of the substrate (Etter and Grassle 1992). Grain size is influenced by such factors as origin, currents, and depth. These differences in turn influence the types of sessile organisms that can make a living in or on the substrate. As a determinant of the distribution of biological communities, substrate is most influential in the benthic realm. Our classification used substrate to classify benthic seascapes only.

Defining and mapping the seascapes

The range of values of each characteristic was split into ecologically meaningful classes appropriate for the analysis region, as defined through a review of the literature and an analysis of the data. These values were mapped, which created a separate layer for each characteristic. Finally, these layers were combined to create seascape maps for the benthic and pelagic realms. Below we describe how we carried out each of these steps.



■ Analysis region for seascape mapping

The seascapes were developed in 2002–2003, prior to the majority of the analyses described in this document, and were designed to cover a study area that was larger than that used to identify our network of priority areas for conservation (Chapter 9). As a result, the seascapes begin their coverage 5–10 geographic minutes (approximately 7–16 km) offshore and extend into the Shelf Break and southern New England biogeographic areas. This full extent is presented here, and could be utilized in future MARXAN analyses that cover a larger area.

■ Analysis resolution for seascapes

The seascapes were created on a grid of 5-minute squares. This corresponds to approximately 6–9 km on a side, or an area of about 66 km^2 (19 nmi^2; 26 mi^2) depending on the location within the analysis region.

Note that this 5-minute square grid is finer than the 10-minute square planning unit grid used for mapping the biological conservation features and for identifying the network of priority areas for conservation (Chapter 9). Thus, there were four 5-minute squares for each planning unit. Consequently, the seascapes we developed could support a finer level of analysis than that used to identify priority areas for conservation.

■ Zones of similar temperature and salinity

Zones of similar temperature and salinity were defined based on data provided in the *Hydrographic Atlas for the Eastern Continental Shelf of North America* (National Oceanic & Atmospheric Administration 2005). This atlas spans more than 30 years and is comprised of data from several Canadian and United States sources. The atlas consists of monthly average values in 10-minute squares for the surface and bottom, and for various intermediate depths. As a consequence of this data structure, these input layers were compiled at a lower resolution than our final seascapes map. The four 5-minute squares within each 10-minute square were all assumed to have the same temperature and salinity values.

Figure 8-2. Three examples of benthic temperature-salinity zones as identified with cluster analysis (k = 30) and plotted according to mean temperature and salinity for each month of the year. Note that variation occurs across the months, but each zone is recognizable as a distinct cluster. Salinity expressed as parts per thousand (ppt).

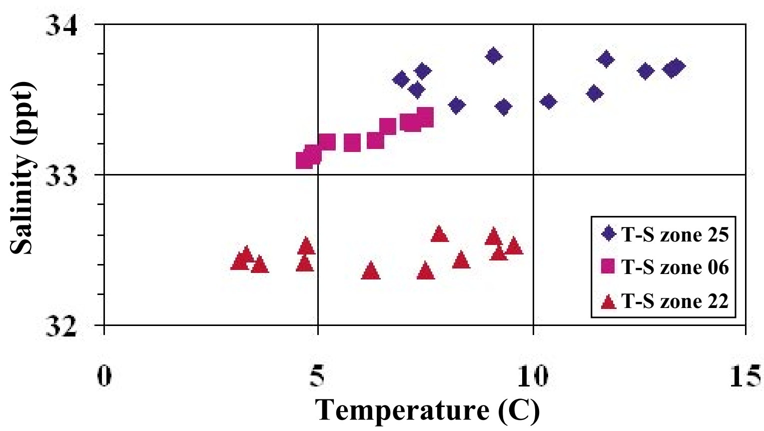
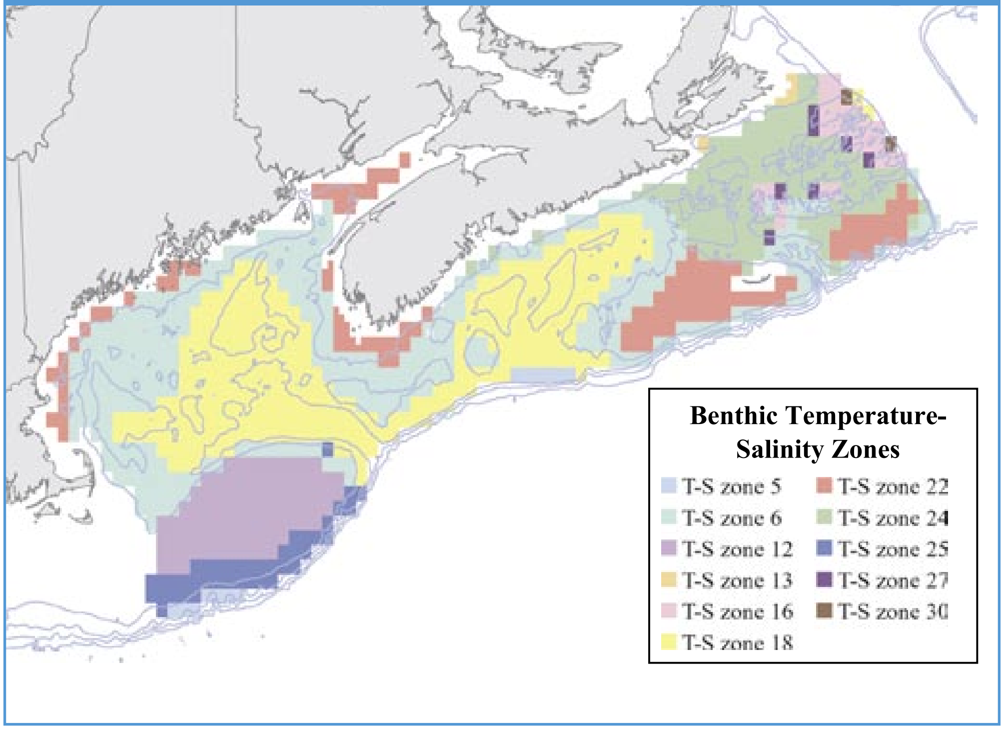
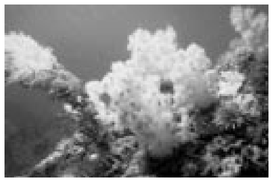


Figure 8-3. Benthic temperature-salinity zones. Each color corresponds to one cluster, or a zone of similar temperature and salinity as identified through cluster analysis.



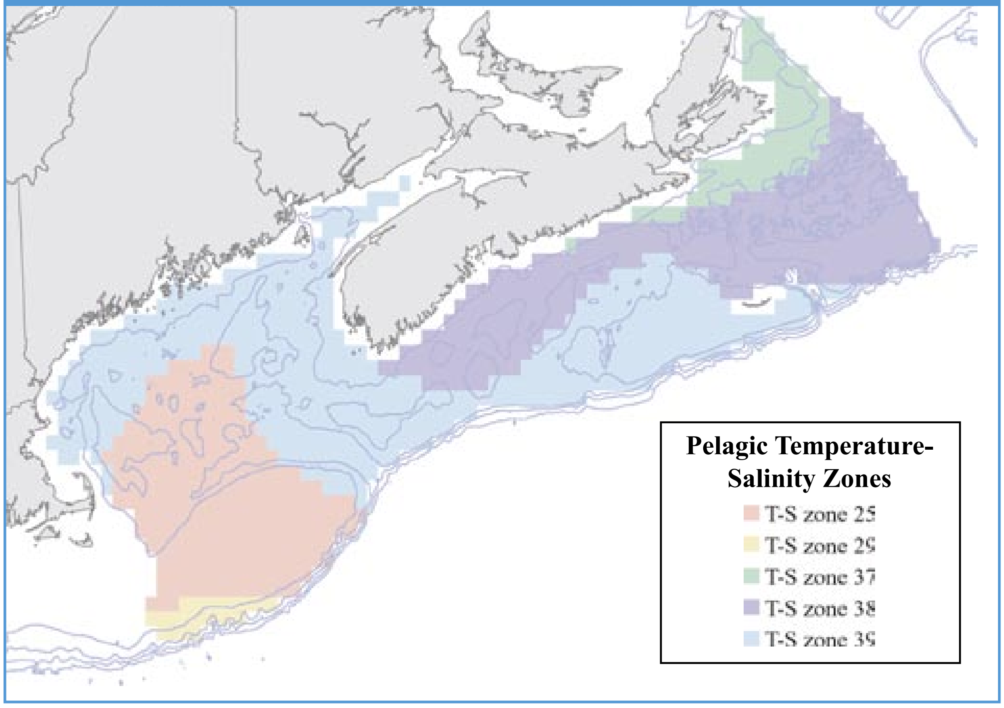


A multi-variate cluster analysis was employed to identify zones of similar temperature and salinity regimes in both the benthic and pelagic realms (temperature-salinity zones). Cluster analysis is a powerful tool for identifying natural groupings within complex data spaces (Hargrove and Hoffman 2004). The geographic locations of water masses, and the associated values of temperature and salinity, vary seasonally. The cluster analysis performed using the full set of temperature and salinity data, which covered twelve months of the year (one pair of data per month), allowed us to define geographic zones that followed similar temperature-salinity regimes (Figures 8-2, 8-3, and 8-4).

The clustering technique we employed has been detailed elsewhere (MacQueen 1967; Hargrove and Luxmoore 1997) and was based on Principal Components Analysis and a k-means clustering algorithm. In this application of cluster analysis, the number of clusters (k) was specified in advance. In an exploratory analysis, the results of a number of different cluster analyses were examined (k from 10 through 100, in steps of 10). After examining the results in relation to a variety of sources of information on water masses, and consulting with experts, we adopted k values of 30 clusters for the benthic zones and 50 clusters for the pelagic zones. This analysis was based on the entire dataset for the east coast of North America so as to avoid biases in the clustering that may have occurred if the data had been limited to our analysis region. Five of the pelagic and eleven of the benthic temperature-salinity zones identified extended into, or were contained within, the three biogeographic areas of our analysis region.

Additional details regarding the temperature and salinity data are provided in Appendix D.

Figure 8-4. Pelagic temperature-salinity zones. Each color corresponds to one cluster, or a zone of similar temperature and salinity characteristics as identified through cluster analysis.



Marine Ecosystem Conservation for New England and Maritime Canada

■ Stratification

The stratification parameter – calculated based on depth, tidal current velocity, and drag coefficient – has been valuable for predicting the locations of fronts and for delineating spawning areas of fish (Iles and Sinclair 1982) and pelagic communities (Pingree 1978; Day and Roff 2000). Due to the limited data available for our analysis region, and to the challenge of incorporating tidal current velocity information for the Bay of Fundy, we chose to evaluate stratification based on the difference between seawater density at the surface and seawater density at a depth of 100 m, and used this as a proxy for the stratification parameter (Roff et al. 2003).

Density of sea surface waters is typically 1027 kg/m^3. Variation in this value for different water masses and strata is small, making the last two digits of greatest interest. It is thus customary to report the density (σ_t) as (Stewart 2005):

$$\sigma_t = \text{density} - 1000 \text{ kg/m}^3$$

Thus, σ_t is generally in the neighborhood of 27 kg/m^3 and referred to as the Knudsen parameter, or density excess (Beer 1997). We used σ_t to compute the difference between density at the surface and at 100 m as follows:

$$\Delta\sigma_t = \sigma_{t\ 100m} - \sigma_{t\ surface}$$

For the purposes of defining seascapes we then computed a density anomaly following methods of Roff et al. (2003), where 1500 is simply a constant used to magnify the density gradient:

$$\text{density anomaly} = 1500 \times \Delta\sigma_t$$

Table 8-2. Stratification classes based on density anomaly.

Range of density anomaly	Description
0 to 100	Well mixed
100 to 1,000	Frontal
>1,000	Stratified

Values of σ_t for 1980 through 2000 were obtained from the oceanographic databases, Bedford Institute of Oceanography (2006). For each series of observations at a point (i.e., each profile), $\Delta\sigma_t$ was calculated as the difference between the surface observation (the first observation taken within 20 m of the surface) and the 100-m observation (or the bottom observation when depth was <100 m). These point values were grouped by 5-minute-square grid cell for each month. An average $\Delta\sigma_t$ value was computed for each month, and the maximum of these monthly averages was identified for each 5-minute square. For those 5-minute squares that lacked σ_t samples, we spatially interpolated $\Delta\sigma_t$ values from neighboring 5-minute squares using an Inverse Distance Interpolator. The resulting layer of $\Delta\sigma_t$ values, representing the month with the highest average value for that 5-minute square, was transformed into the density anomaly (i.e., multiplied by 1500) to create the layer we used as a proxy for stratification in our classification of pelagic seascapes. Classification categories were developed for the surface water based on the density anomaly (Table 8-2; Figure 8-5).

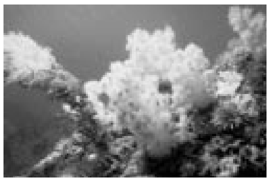


Figure 8-5. Distribution of stratification classes (density anomaly) used for defining pelagic seascapes.

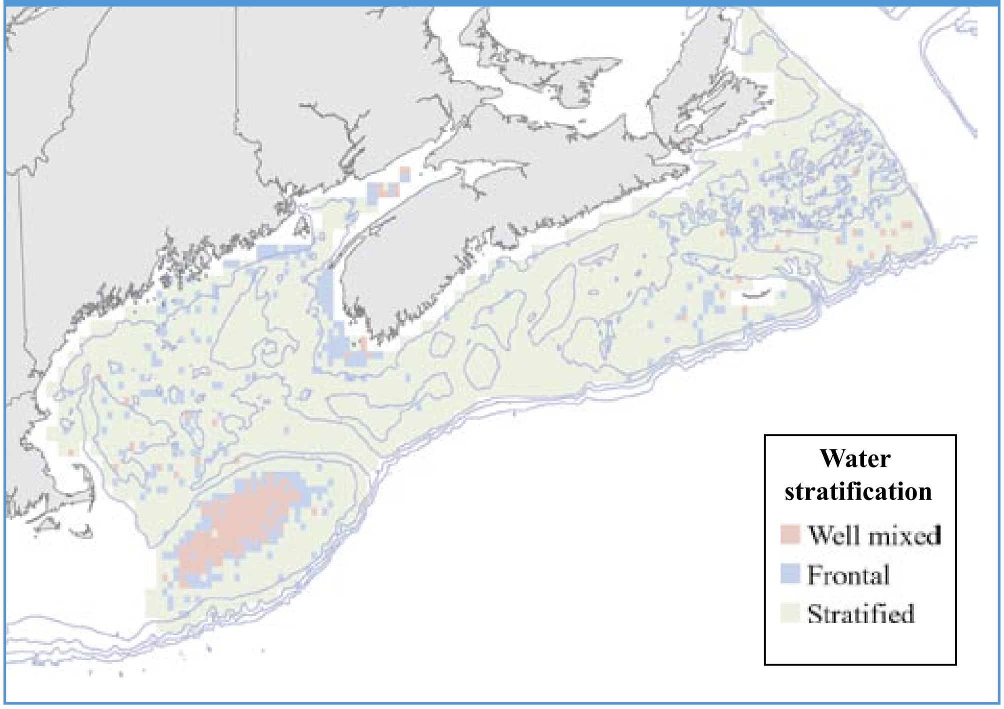


Table 8-3. Depth classes used for defining seascapes.

Depth zones	Characteristics
0 to 60 m	Includes the near shore euphotic zone; typical depth of the thermocline in the analysis region.
60 to 200 m	Constitutes epipelagic zone.
200 to 500 m	Delineates deep basins and channels. The deepest basin in the Gulf of Maine is 498 m.
500 to 1000 m	Delineates shelf break/continental slope and lower limits of the mesopelagic zone.
>1000 m	Delineates the light deprived, aphotic/abyssal, or bathypelagic zone.

■ Depth

A bathymetric dataset, compiled from a number of sources by David Greenberg[5] of the Bedford Institute of Oceanography, was used to characterize depth. These data, which consisted of depth soundings from ships and fixed sampling stations, were relatively dense (5 to 15 samples per 5-minute square) in the shelf areas that made up our final analysis region. The point data were interpolated using an inverse distance weighting algorithm with six nearest neighbors to create a grid with a resolution of 5 geographic minutes.

We attempted to supplement these data with contour data from the Geological Survey of Canada's East Coast Basin Atlas series (Atlantic Geoscience Centre 1989, 1991) with the aim of increasing the precision in our depth classification, but we saw no substantial improvement in the definition of topography in the Scotian Shelf area. Our depth layer is thus based only on the Greenberg compilation.

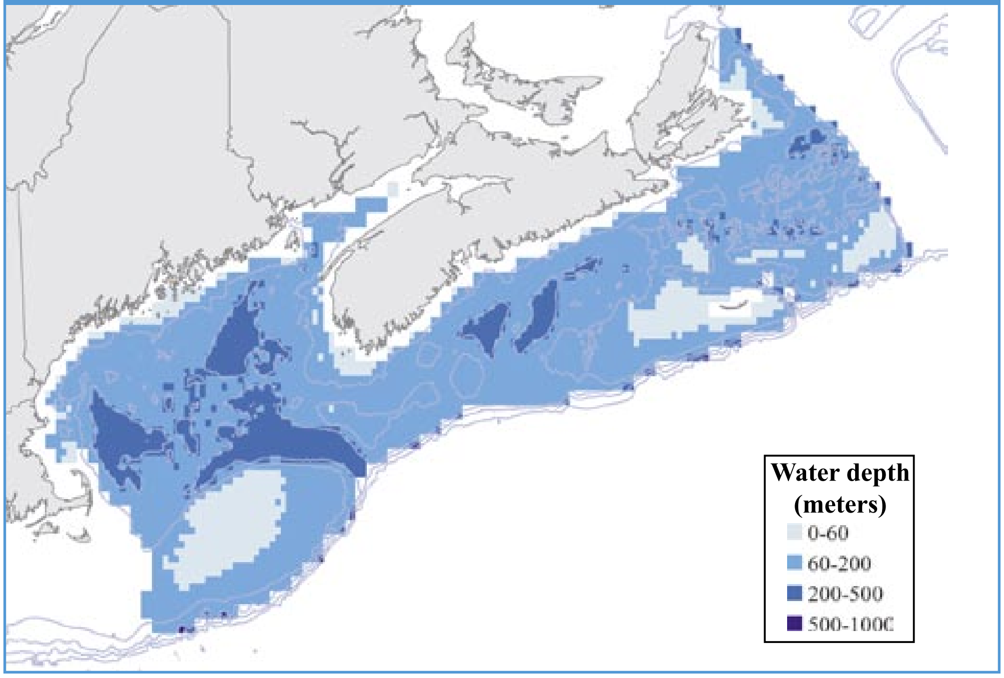
Light penetration, pressure, salinity, and temperature are important covariates of depth that influence the distribution of marine life and ecological communities, and depth is thus fundamental in the delineation of marine habitats (Waller 1996; Levinton 2001). With reference to the abundant literature that examines these relationships, as well as expert consultations, we have adopted a system of depth classifications for use in characterizing the seascapes (Table 8-3). The first four categories pertain to the analysis region for this report, ranging from a shallow euphotic zone through a deeper epipelagic zone corresponding to the deepest waters of the basins and channels (Figure 8-6).

■ Substrate

The characteristics of the seafloor are important determinants of the distributions of benthic and demersal species and communities. Nevertheless, developing a uniform substrate data layer for seascape classification in our large analysis region was challenging. Several different data sources were combined to achieve complete coverage (leaving only a small area east of Cape Breton without data), and considerable effort was devoted to unifying these datasets (Table 8-4; Figure 8-7).

[5] David A. Greenberg, Scientist, Coastal Ocean Science, Bedford Institute of Oceanography, Dartmouth, Nova Scotia; personal communication, 2002.

Figure 8-6. Depth zones used for defining seascape types.



Two issues contributed to these challenges. First, the classifications used to characterize sediments varied from one dataset to the next and the correspondence between these classifications had not been developed. Second, the quality of the datasets available for United States and Canadian waters varied substantially in terms of the sophistication of the classification procedures and spatial sampling resolution.

Substrates are typically described in terms of grain size and/or texture. The best interpolation methods for geophysical maps, however, include information about the geologic origin of the substrate based upon knowledge of surficial geology, transport, topography, and other factors. Substrate classification based on interpolations of grain size samples supplemented with knowledge of these other factors was available for the Scotian Shelf and Bay of Fundy (Fader et al. 1977), but not for the remainder of the analysis region. For the United States waters of the Gulf of Maine and Georges Bank, the best-available maps were based only on simple interpolation of grain-size characterizations (Poppe and Polloni 2000; Poppe et al. 2003). The number of substrate classes used was small compared to those developed for Canadian waters, and they lacked simple correspondences (Table 8-4).

The correspondence problem was mitigated by the development – in consultation with expert marine geologists – of a generalized classification scheme that allowed us to combine datasets. The scheme involved an amalgamation of different substrate classes into five broad categories: (1) clays and silt, (2) muddy sands, (3) sand, (4) gravel and till, and (5) bedrock. While this scheme resulted in a loss of precision for the Scotian Shelf and the Bay of Fundy where better classification had been done, it was necessary in order to make the best use of the data available overall.

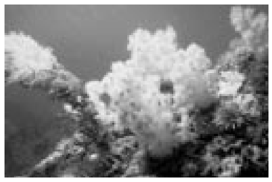
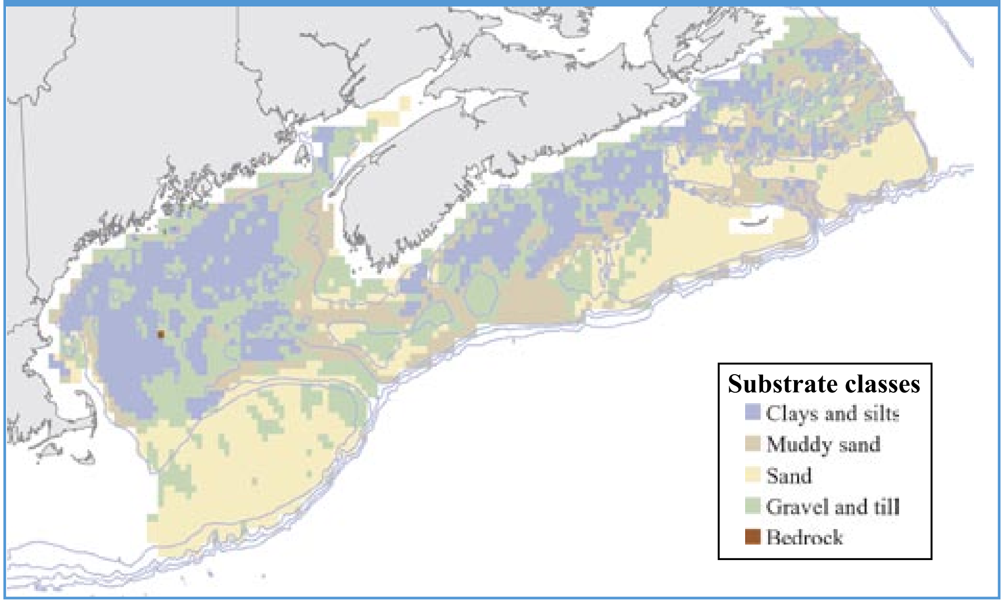


Figure 8-7. Substrate classifications used for defining seascapes, illustrated in a grid of 5-minute squares.



The substrate data for the United States waters was also based on sampling that was, in some areas, at a lower resolution than the 5-minute square grid of the source maps and the grid used in our analysis (Poppe and Polloni 2000; Poppe et al. 2003). The substrate classifications for this part of our analysis region involved spatial interpolation from more widely spaced samples; the certainty of the classification of 5-minute squares was consequently lower than for the Canadian portion of the region. Future work of the type undertaken here would clearly benefit from higher-resolution maps based on better interpolation supplemented by expert input. Due to these aspects of this important data layer, our analyses, which are presented below, provided insight on how the substrate layer influenced the identification of representative networks. We also examined the influence of seascapes on the derivation of priority areas for conservation, which is discussed in Chapter 9.

We applied the generalized classification to the individual polygon (vector) files before amalgamating them to create a single vector file. We then converted this file to a 5-minute raster (grid) file and used it to assemble the seascapes.

■ Compiling seascapes

With each of the components of the seascape defined – i.e., parsed into categories and mapped into a grid of 5-minute squares – seascape classes were defined by overlaying these maps (Day and Roff 2000). As mentioned previously, benthic seascapes were derived from seafloor type, depth, and benthic water characteristics, and pelagic seascapes were derived from stratification, depth, and surface water characteristics.

Each class within a data layer (e.g., each of five classes within the substrate data layer) was assigned a unique code, each with a different order of magnitude (Tables 8-5 and 8-6). For example, a 5-minute square had a pelagic seascape code of –25110 if the pelagic temperature-salinity zone was #25, the depth class corresponded to the 0–60 m euphotic zone, and the water column was well-mixed (density anomaly in the range of 0–100 kg/1,500•m^3) (–25110 = –25000 + –100 + –10). After deriving the pelagic and benthic seascapes in this fashion, the 5-minute square grid was converted to vector format.

Table 8-4. Classes of sediments used for defining seascapes: correspondence among classification schemes.

Classes of sediments	Data sources: GSC Shelf	GSC Deep Sea	USGS	Kelly Data
A: Clays and silts	LaHave clay Emerald silt	Mud Muddy fine sand	Sand-silt/clay	Near-shore basin (mud) Shelf valley (generally mud)
B: Muddy sand	Sambro sand Sable Island sand and gravel (variable sand, silt and clay, 2d)	Muddy sand and gravel Locally muddy fine sand and bedrock	Clay-silt/sand	Outer basin
C: Sand	Sable Island sand (<50% gravel) Sambro sand (BoF/mainly sandy gravel)	Fine sand	Sand	Near shore ramp (Sand)
D: Gravel and till	Sable Island sand (<50% sand with LaHave clay and undifferentiated sand and gravel, 2b and 2c) Scotian Shelf drift	Coarse sand and gravel Glacial till	Gravel Gravel-sand sand/silt/clay unconsolidated with till	Rocky zone (rock)
E: Bedrock		Bedrock	Bedrock	

Table 8-5. Benthic seascapes classification.

Benthic Temperature-Salinity zones	Cluster code	Depth class	Depth code	Generalized substrate class	Substrate code
5	5000	0 to 60 m	100	A: Clays and silts	10
6	6000	60 to 200 m	200	B: Muddy sand	20
12	12000	200 to 500 m	300	C: Sand	30
18	18000	500 to 1,000 m	400	D: Gravel and till	40
22	22000	>1,000 m	500	E: Bedrock	50
24	24000				
25	25000				

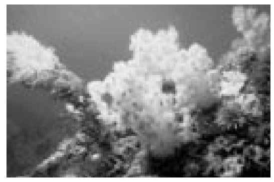


Table 8-6. Pelagic seascapes classification.

Pelagic Temperature-Salinity zones	Cluster code	Depth class	Depth code	Stratification class	Stratification code
25	–25000	0 to 60 m	–100	Well mixed	–10
29	–29000	60 to 200 m	–200	Frontal	–20
37	–37000	200 to 500 m	–300	Stratified	–30
38	–38000	500 to 1,000 m	–400		
39	–39000	>1,000 m	–500		
44	–44000				

Table 8-7. Number of benthic and pelagic seascapes classified.

Seascape	Unique (no.)	Gulf of Maine (no.)	Georges Bank (no.)	Scotian Shelf (no.)	Total (no.)
Benthic	77	29	22	57	108
Pelagic	36	14	14	19	47

Seascape mapping: results and discussion

To the best of our knowledge, the maps presented here showing benthic and pelagic seascapes represent the first systematic effort to provide ecoregional-scale habitat maps for the shelf waters of the greater Gulf of Maine and Scotian Shelf (Figures 8-8 and 8-9). We identified 36 unique pelagic and 77 unique benthic seascape classes within the three biogeographic areas of our analysis region (Table 8-7). Approximately one-third of the seascape classes occurred in two or more of our three areas.

For the benthic seascapes, the frequency distributions for occurrence of classes (i.e., number of 5-minute squares, or observations, for a given class per biogeographic area) were skewed, with many of the seascapes occurring in a relatively small number of 5-minute squares, and a few occupying more substantial areas. For the benthic seascapes, 25% (i.e., the lower quartile) appeared in five or fewer 5-minute squares. The number of 5-minute squares corresponding to the cut-off for the lower quartile represented <1% of the 5-minute squares making up each biogeographic area, i.e., five 5-minute squares in the Gulf of Maine, two 5-minute squares on Georges Bank, and three 5-minute squares on the Scotian Shelf. Thus many of the benthic seascapes were quite restricted in their geographic extent. Those benthic seascapes that were most extensive (top 10%) occupied at least 12% of the Gulf of Maine (158–189 five-minute squares), 20% of Georges Bank (122–174 five-minute squares), and 6% of the Scotian Shelf (131–208 five-minute squares). In each area, the most extensive benthic seascape occupied 28% of the Georges Bank area, 14% of the Gulf of Maine area, and 9% of the Scotian Shelf area.

Figure 8-8. Distribution of benthic seascapes defined by depth, substrate, and benthic temperature-salinity zones.

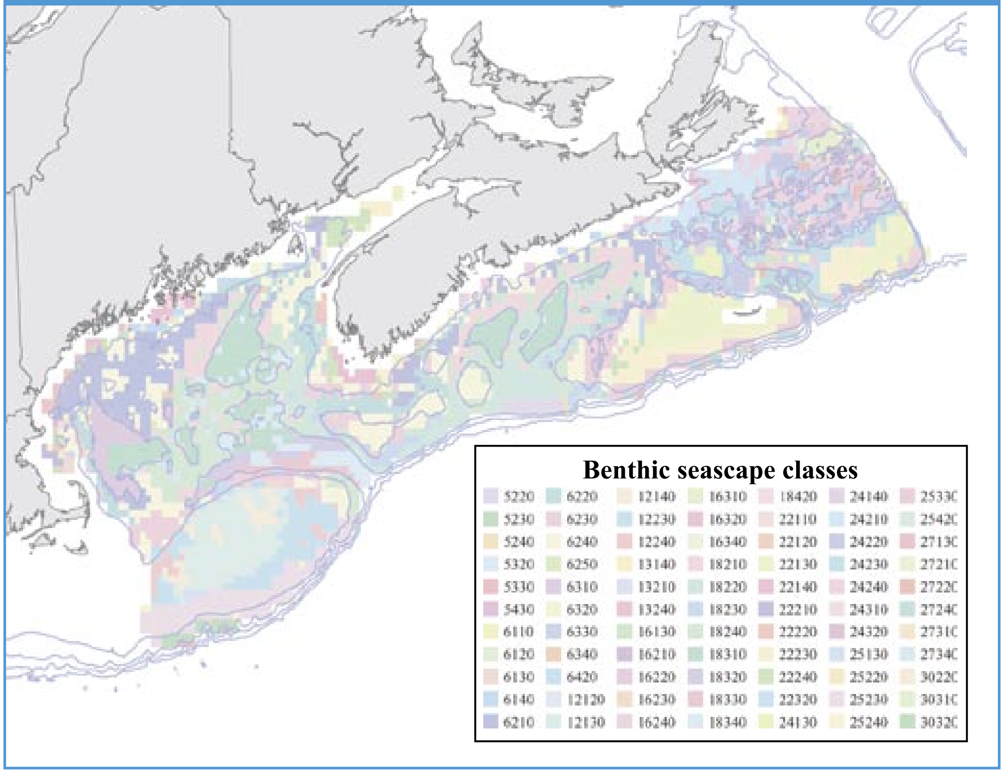
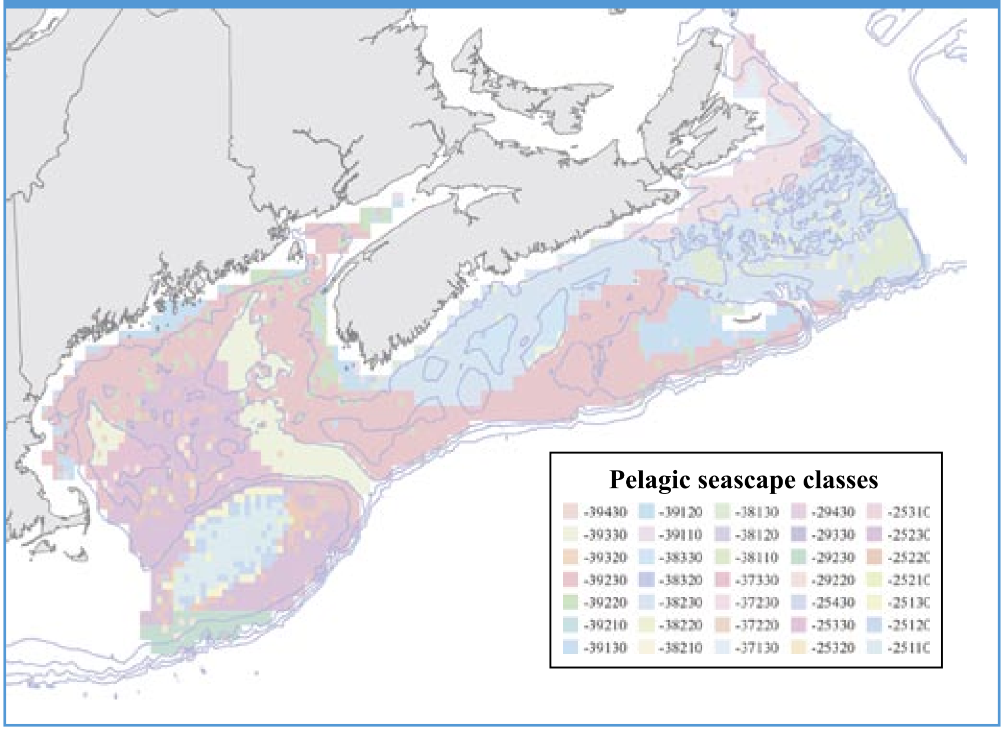
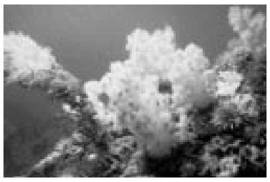


Figure 8-9. Distribution of pelagic seascapes defined by stratification, depth, and pelagic temperature-salinity zones.





Chapter **8**

Classifying seascapes based on abiotic characteristics of the water and seafloor

The area-frequency distributions for pelagic seascapes were similar to the benthic, with most of the seascapes amounting to <10% of the 5-minute squares of a given biogeographic area, while a few were dominant within the region. The lower quartile points were five 5-minute squares for the Gulf of Maine (five 5-minute squares <1% of total), two 5-minute squares for Georges Bank (<1% of total), and seven 5-minute squares for the Scotian Shelf (<1% of total). The pelagic seascapes that were most extensive (top 10%) occupied at least 20% of the Gulf of Maine 5-minute squares (259–462 five-minute squares), 21% of Georges Bank (131–208 five-minute squares) and 10% of the Scotian Shelf (228–800 five-minute squares). The most extensive single pelagic seascape occupied approximately one-third of each biogeographic area.

Infrequent seascape classes occurred in a few 5-minute squares (n 5-minute squares ≤12), and could have resulted due to an unusual combination of otherwise commonly occurring characteristics (e.g., sandy bottom in deep water), a single rare characteristic (e.g., exposed bedrock on the seafloor), or a combination of these factors. Within our analysis region, the infrequent benthic seascape classes usually resulted from unusual combinations of characteristics that were individually prevalent in the region. However, some of the infrequent seascapes also resulted from the inclusion of a single uncommon characteristic. For example, in the Gulf of Maine, only one 5-minute square was assigned bedrock as a substrate class, and the seascape based on this was necessarily restricted to one location. Another infrequent seascape class was based on common depth and substrate attributes, but had an uncommon benthic temperature-salinity zone that was warmer than the two dominant masses within the Gulf of Maine. Deep waters (d > 500 m) were unusual within the Scotian Shelf area, and these also corresponded to infrequent benthic seascapes. Overall, depth and substrate were the most important determinants of rarity among benthic seascapes. The situation was similar for the pelagic seascapes, with a deep-water classification being the most common single explanation of infrequent classes. All of the stratification and water-mass classes were relatively common among pelagic seascapes.

The degree to which seascapes can be used to predict the distributions of marine life, or the distributions of the distinctive areas examined in this report, has not been analyzed experimentally or in any other quantitative sense here. Clearly, further study of the predictive power of these seascapes or other marine habitat classifications for this region would be valuable. As discussed in Chapter 9, we have used the seascapes in combination with a suite of biological conservation features to identify a network of priority areas for conservation.

MARXAN analysis based on seascapes

We used MARXAN to identify networks of areas that were representative of each of the seascape classes. However, these particular MARXAN analyses were exploratory and were not used to identify the network of priority areas for conservation (Chapter 9). The methodological details were provided in Chapter 4 and were essentially the same as those described in the preceding chapters on biological conservation features. As discussed in Chapters 2 and 3, our conservation planning was done at the level of these biogeographic areas. Thus a seascape class that occurred in Georges Bank was treated as distinct from identical classes that occurred in one of the other areas. The number of seascape conservation features specified in site selection increased as a result of finding the same seascape in more than one biogeographic area. For example, the 77 unique benthic seascapes translated into 108 conservation features during site selection. The goal for each seascape class was set to 20%.

First we present a representative network for the benthic seascapes alone, then one for the pelagic, and finally a network that is representative of all of the classes for both benthic and pelagic. As before, we focus here on the best of 100 networks as an example.

The best representative network for benthic seascapes consisted of 29 areas distributed throughout the analysis region (Figure 8-10, top). The selected areas covered a total extent of approximately 56,091 km^2 (16,356 nmi^2; 21,657 mi^2), or about 20% of each of the biogeographic areas. The areas ranged from single 10-minute square planning units (n = 14; 48%) to large areas composed of many planning units.

The number of benthic seascape conservation features was large (n = 108), and many of these occurred in relatively limited areas (i.e., one or a few 5-minute squares, discussed above). This contributed to the need for comparatively numerous small areas in this network (i.e., fragmentation). The limited extent of many of the benthic seascapes also necessitated over-representation (see Chapter 4 regarding overshoot). As an example, consider a seascape class that occurred in only one 5-minute square. With a goal of 20%, only one-fifth of a 5-minute square was needed, but the minimum possible area that could be selected was a full 5-minute square or five times the goal. Over-representation also occurred because site selection was carried out at a resolution of 10-minute square planning units, which made it necessary to build the network in increments of four 5-minute squares. Thus, with infrequent seascape classes that occurred in small clusters, some over-representation was unavoidable.

Among the 78 seascape conservation features that were over-represented, representation was, on average, 2.5 times larger than the goal (see additional discussion in Chapter 9). The limited distribution of a number of the benthic seascapes was also reflected in the summed solution, revealing a variety of locations that were required for most or all of the networks (i.e., irreplaceable planning units; Figure 8-10, middle). Attaining acceptable representation of each of the seascape conservation features (i.e., ≥90% of the goal) proved to be challenging for the benthic seascapes. Multiple blocks of 100 runs were required with adjustments to the conservation feature penalty factor for several seascapes, in order to shift the balance between meeting individual seascape goals and the other constraints included in the objective function (e.g., degree of clustering – boundary length multiplier; see Chapter 4).

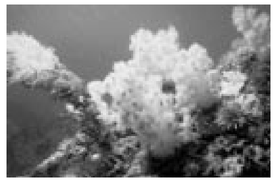


Figure 8-10. Networks based on benthic seascapes. Top: a representative network for benthic seascapes shown with summed solution. Middle: several irreplaceable planning units (arrows) are shown within the same summed solution illustrated in the top map. Bottom: a representative network for benthic seascapes based on water masses and depth, but not substrate, shown with summed solution. Summed solutions summarize 100 MARXAN runs and colored perimeters show best networks.

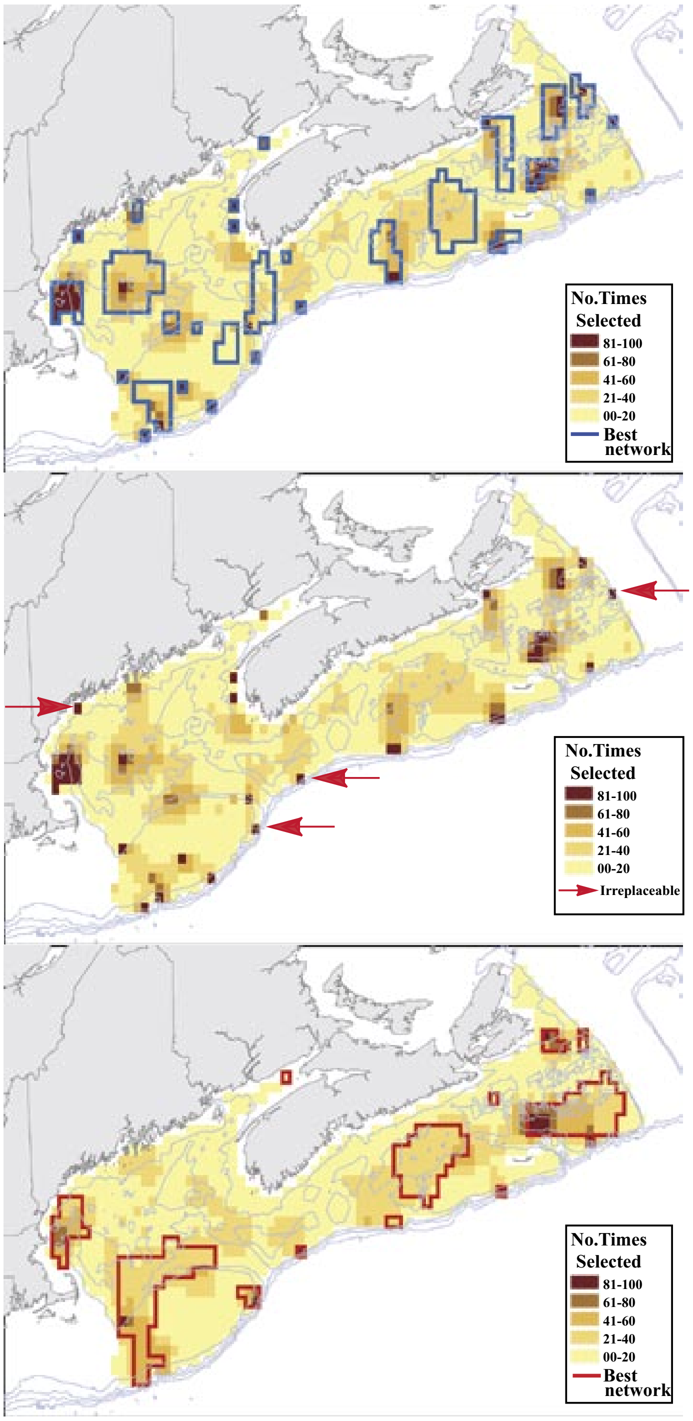


Figure 8-11. Representative network for pelagic seascapes with summed solution.

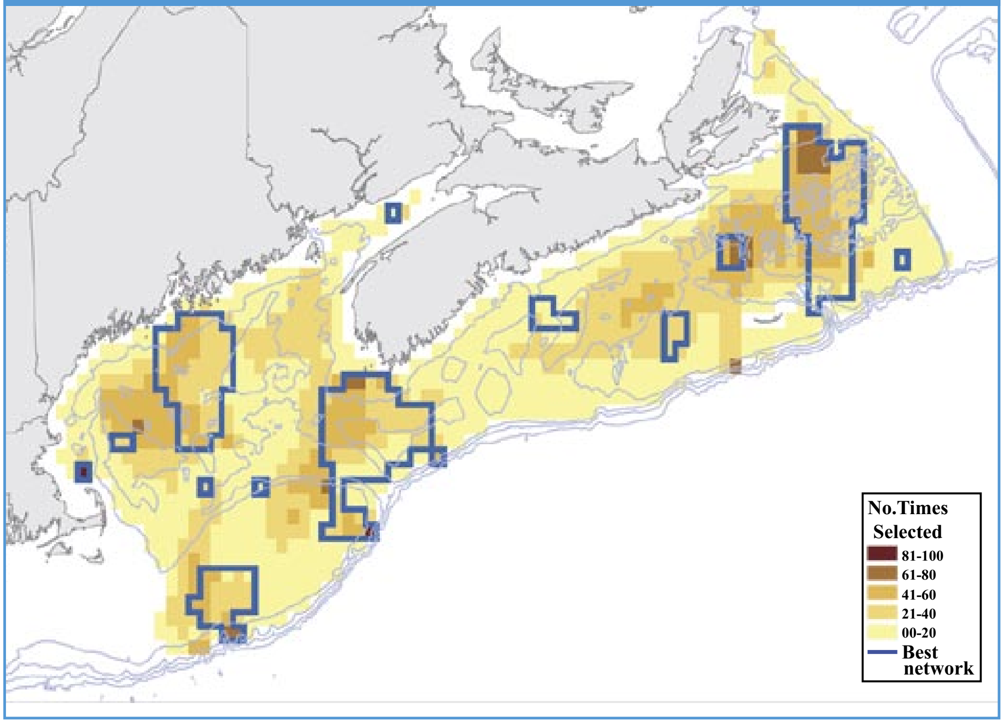
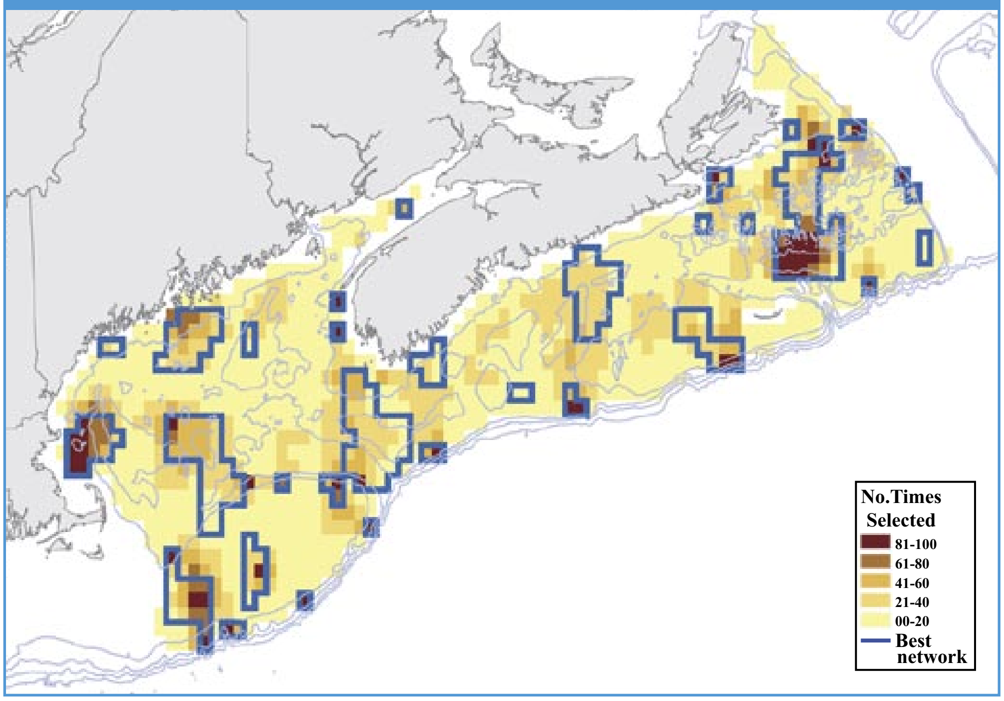
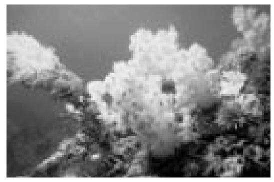


Figure 8-12. Representative network for benthic and pelagic seascapes combined; best network with summed solution.





In order to further explore the distribution of benthic seascapes and the specific influence of substrate classification on them, an additional analysis was performed in which the benthic seascapes were defined without the substrate. Without substrate data, the number of seascape conservation features decreased from 108 to only 32. MARXAN site selection based upon these substrate-free seascapes resulted in a network with 78% fewer single-unit areas (3 instead of 14; Figure 8-10, bottom), and a network based on less than half as many areas overall (12 instead of 29). Additionally, the summed solution revealed increased flexibility – with most units being employed in half or fewer of the runs – and many fewer units that were essential to all networks. Thus, the substrates appeared to have a particularly important influence on the nature of the benthic seascape layer and on the form of the networks selected by MARXAN.

In contrast, the representative network for pelagic seascapes consisted of only 13 areas, spanning a combined area of 53,744 km^2 (15,672 nmi^2; 20,751 mi^2), or about 20% of each of the biogeographic areas (Figure 8-11). Fewer of the areas were small, with only five consisting of single planning units. There were fewer exceptionally infrequent pelagic seascape conservation features (i.e., single 5-minute squares) compared to the benthic seascapes, and goal attainment was generally more flexible. This was illustrated by the summed solution (Figure 8-11), which showed that only a few units were consistently needed in the various MARXAN runs (i.e., few irreplaceable planning units). Goals for most pelagic seascapes could be met in a variety of locations. As was the case for benthic seascapes, multiple sets of 100 MARXAN runs were required to achieve a best network in which all seascapes came within 90% of the full goal.

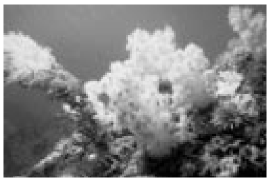
An analysis based on both benthic and pelagic seascapes was performed to obtain a network that was fully representative of marine habitats as we have defined them. The network consisted of 31 areas, covering an area of 57,414 km^2 (16,742 nmi^2; 22,167 mi^2), or about 20% of each of the biogeographic areas (Figure 8-12). As expected, the network included a number of small areas (32% of the selected areas were made up of a single planning unit). As discussed in Chapter 9, this representative network developed from seascapes alone was similar in some respects to the best network of priority areas for conservation. These two networks shared over half of their planning units.

Acknowledgements

The preparation of the seascape maps depended upon a diverse set of data, and the advice and cooperation of a large number of academic and government scientists to whom we owe a great debt. Some of the expert input came through formal peer review meetings and workshops (1998–2003) (Appendix A), but a great deal also came from the willingness of individuals to contribute their time to consultation and to helping with data analysis. The following is a summary of some of these contributions.

We thank David Greenberg, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, for his help with the bathymetric data used for our depth classifications. Doug Gregory, Bedford Institute of Oceanography, kindly facilitated our use of the oceanographic databases for computing the density anomaly, and John W. Loder, Bedford Institute of Oceanography, assisted with defining ranges for classifying the pelagic seascapes based on density anomaly.

We are indebted to Stephen Brown and Ken Buja, Biogeography Office, National Marine Fisheries Services / National Oceanic & Atmospheric Administration, for providing the data from the temperature and salinity atlas (National Oceanic & Atmospheric Administration 2005), and to William Hargrove and Forest Hoffman, Oak Ridge National Laboratory, Tennessee, for carrying out the temperature-salinity cluster analysis. Brian Petrie, Bedford Institute of Oceanography, provided a critical review of our application of cluster analysis for defining temperature-salinity zones, offered important feedback on preliminary analyses, and offered guidance on the cluster analysis approach. Gordon Fader and David Piper, Geological Survey of Canada, and Joseph Kelly, University of Maine, provided extensive help with our development of a uniform substrate classification scheme for our analysis region.



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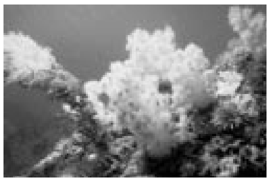


Northern bottlenose whale

Chapter 9

A network of priority areas for conservation

This chapter describes how we drew together the biological conservation features (Chapters 4 to 7) and seascapes (Chapter 8) to identify a network of priority areas for conservation (Figure 9-1). The site-selection methods are the same as those employed in the exploratory MARXAN analyses for each class of conservation features described in the preceding chapters. However, the analysis presented here achieves goals for all conservation features simultaneously. Thus, the network of priority areas for conservation developed here includes distinctive areas for marine life and is representative of the range of physical habitat types. This is an example of a network that is suited to achieving broad objectives for conserving biological diversity and supporting marine ecosystems. Several alternative networks are also presented for comparison.

The priority areas for conservation that constituted the best network for our region are described in detail in Appendix E, including histograms and pie charts that summarize all the areas in terms of their contributions to the goals for the different classes of conservation features; a table listing the geographic coordinates for each priority area is also provided.

Figure 9-1. Network of priority areas for conservation in the greater Gulf of Maine and Scotian Shelf. The 30 priority areas are described in detail, by number, in Appendix B.

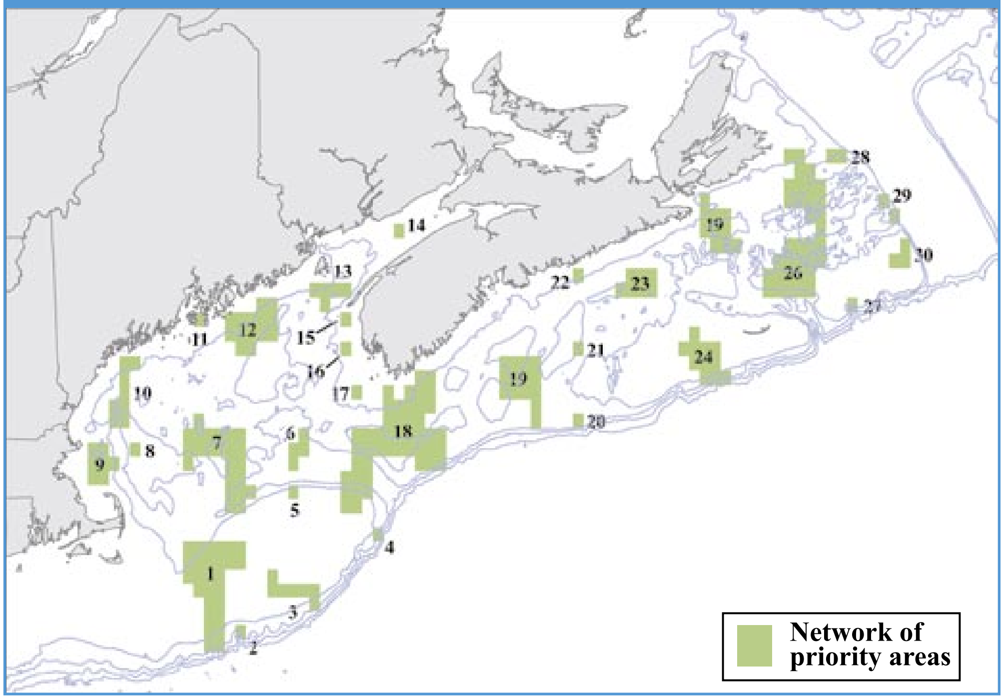
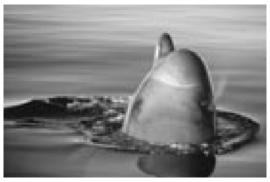


Table 9-1. Goals used for identifying priority areas for conservation with MARXAN.

Conservation feature	Goal used for identifying priority areas for conservation
Areas of persistently high chlorophyll concentration	Goal = 20%. Percentage of the area exhibiting persistently high chlorophyll concentrations; area measured in planning units, or 10-minute squares Chapter 5
Species richness	
Demersal fishes	Goal = 20%. Percentage of the richness values contained in those planning units with richness values at or above the biogeographic area mean. Chapter 6
Abundance	
Juvenile demersal fishes	Goal = 20%. Percentage of the abundance values contained in those planning units with abundance values at or above the biogeographic area mean. Chapter 6
Adult demersal fishes	Goal = 20%. Percentage of the abundance values contained in those planning units with abundance values at or above the biogeographic area mean. Chapter 6
Cetacean	Goal = 20%. Percentage of the abundance values contained in those planning units with values at or above the mean for the biogeographic area. Chapter 7
Pelagic seascapes	Goal = 20%. Percentage of each seascape type, in units of 5-minute squares. Chapter 8
Benthic seascapes	Goal = 20%. Percentage of each seascape type, in units of 5-minute squares. Chapter 8



Identifying priority areas for conservation: our method

The MARXAN site-selection method is described in Chapter 4, and the data and the details of specifying goals for the conservation features are in Chapters 5 to 8. The goals used in the MARXAN analysis for deriving the network of priority areas for conservation are summarized in Table 9-1. The network presented here was based on 100 MARXAN runs with a boundary length multiplier of 2. Initially, all the conservation feature penalty factors were set to 1. However, in order to attain the minimum criterion of 90% of each goal, a few of the conservation penalty factors (<5%) had to be increased (see Chapter 4): the factor was increased to 2.0 for ten benthic seascapes, four pelagic seascapes, and one species of juvenile fish. The conservation feature penalty factor was increased to 3 for just two of the benthic seascapes.

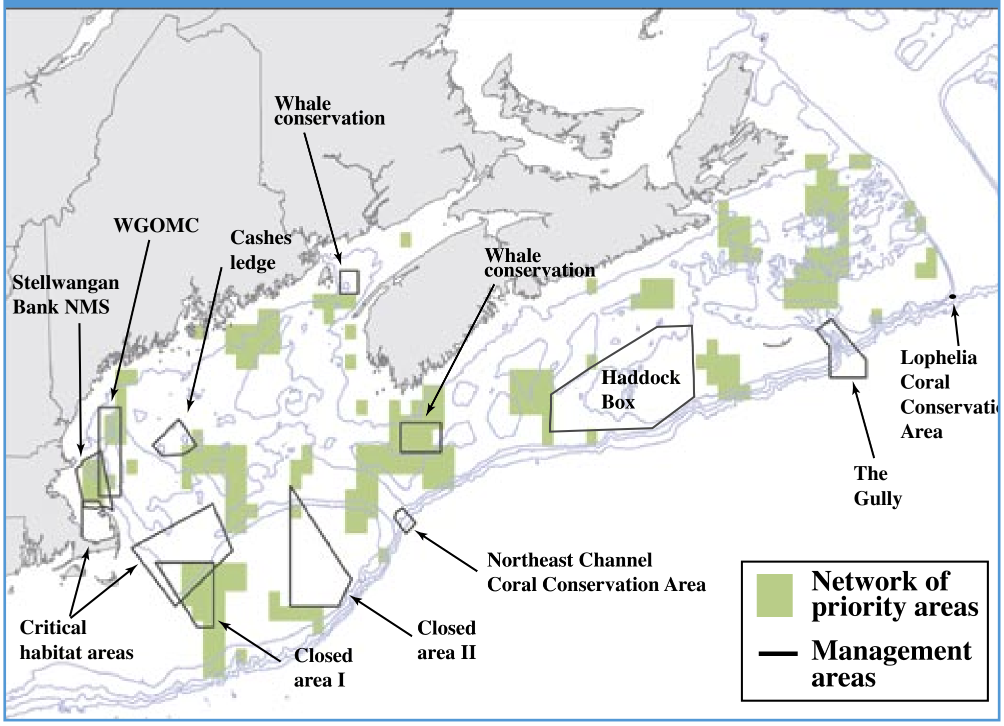
Characteristics of the network of priority areas for conservation

The network of priority areas for conservation achieved goals for a diverse set of conservation features within three biogeographic areas (Figure 9-1). The network encompassed the full range of seafloor types, depths (Appendix E), water conditions, and biological attributes. The priority areas for conservation differed substantially in the nature of their contributions to the network, but each area complemented the contributions of the other areas.

The network consisted of 30 priority areas based on 237 of the 1,057 planning units, representing approximately 22% of the whole area, or 62,449 km^2 (18,210 nmi^2; 24,112 mi^2). The constituent priority areas ranged from small areas of one or two planning units to larger multi-unit areas – with the largest consisting of 46 planning units – extending over 12,279 km^2 (3,581 nmi^2; 4,741 mi^2) and straddling all three biogeographic areas.

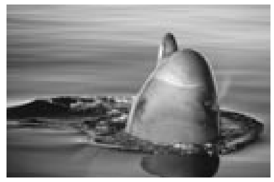
Our analysis region included a wealth of ecologically productive banks. The locations of these and other areas of interest (e.g., critical habitat areas, fisheries closed areas, etc.) relative to the priority areas for conservation are shown in Figure 9-2.

Figure 9-2. Locations of some existing management areas relative to the network of priority areas for conservation. NMS: National Marine Sanctuary; WGOMC: Western Gulf of Maine Closed Area. See Figures 3-1 and 9-1 for additional geographic details.



Georges Bank is pre-eminent among the banks, with unusual primary production (Chapter 5), a history of vast fisheries resources (Chapter 6), and a diversity of whales (Chapter 7) and other marine life. Seven of the priority areas for conservation included portions of Georges Bank; these areas comprised 10,827 km^2 (3,157 nmi^2; 1,180 mi^2) or 26% of this biogeographic area. The largest priority area within Georges Bank was area no. 1, at 7,517 km^2 (2,192 nmi^2; 2,902 mi^2). It was located at the Great South Channel and overlapped both a United States Critical Habitat Area and a fisheries Closed Area (Figure 9-2).

Eleven priority areas for conservation were located in the Gulf of Maine biogeographic area, including several large priority areas that extended into adjacent regions. The priority areas in the Gulf of Maine spanned 19,081 km^2 (5,564 nmi^2; 7,367 mi^2) or 22% of this region. Priority area no. 7 was the largest area (6,174 km^2) and extended from the northern edge of Georges Bank to the Cashes Ledge area. Priority area no. 9 overlapped substantially with the Stellwagen Bank National Marine Sanctuary and no. 1 overlapped the western Gulf of Maine fisheries Closed Area.



A network of priority areas for conservation

On the Scotian Shelf, a total of 16 priority areas for conservation were identified, encompassing 32,541 km^2 (9,489 nmi^2; 12,564 mi^2) or 22% of this biogeographic area. The largest priority area in the network, no. 18, was the only one on the Scotian Shelf that overlapped with other biogeographic areas, i.e., at the Fundian Channel. This priority area also overlapped with the whale habitat area at Roseway Basin. Several of the priority areas were adjacent to the Haddock Box fisheries management area, and the second-largest priority area on the Scotian Shelf (no. 26) extended northward from the Sable Gully, which is a submarine canyon where a marine protected area was established in 2005 by the Canadian government.

In general, larger priority areas for conservation contributed proportionately more to meeting goals than did smaller ones (Appendix E), resulting in a clear linear correlation between the size of a priority area and the number of individual conservation features to which a priority area contributed. This was true for both the seascapes and for the cetaceans and demersal fishes. Additionally, large priority areas tended to contribute more toward the goals for particular conservation features than did smaller priority areas. For example, a linear increase in contribution to the goal for primary production occurred with an increase in the size of a priority area. Thus, the largest priority areas (i.e., nos. 1, 18, and 26) tended to make relatively substantial contributions to individual goals, and contributed to a more diverse suite of conservation features. The three largest priority areas each contributed to all of the classes of conservation features (Appendix E).

The smallest priority areas for conservation generally contributed to meeting goals for only a few conservation features (see Appendix E). For example, areas nos. 14, 20, and 27 consisted of single planning units and each made substantial contributions to the goals for just one or two seascapes. Each of these provided the entire representation for a single benthic seascape. The benthic seascape represented within priority area no. 14[6] – i.e., sand bottom in deep water within the Bay of Fundy – was detected in only about 1% of the Gulf of Maine biogeographic area (fifteen 5-minute squares). Those represented within priority areas nos. 20 and 27 were even less common, being detected in one and two 5-minute squares respectively, or in <1% of the Scotian Shelf biogeographic area. The single planning units constituting each of these priority areas were thus selected in virtually all of the MARXAN runs (100 of 100 runs for priority area no. 20, and 99 of 100 runs for no. 27). The rarity of these seascapes made these planning units essential to meeting seascape goals, i.e., they were considered irreplaceable (see Chapters 4 and 8).

[6] BSS no. 22230

Descriptions of three priority areas for conservation

Although the network as a whole met all the goals, each individual priority area contributed to only some of the conservation features. In most cases, an area contributed to only part of the goal for a given conservation feature (e.g., 5% of the goal for fish species richness), with the complement being contributed by other areas. To illustrate how areas differed in their contributions, brief descriptions of three priority areas for conservation in the Gulf of Maine are provided below.

Figure 9-3. Summary of three priority areas in terms of their contributions to the goals for the different classes of conservation features (histograms) and their seafloor characteristics (pie charts).

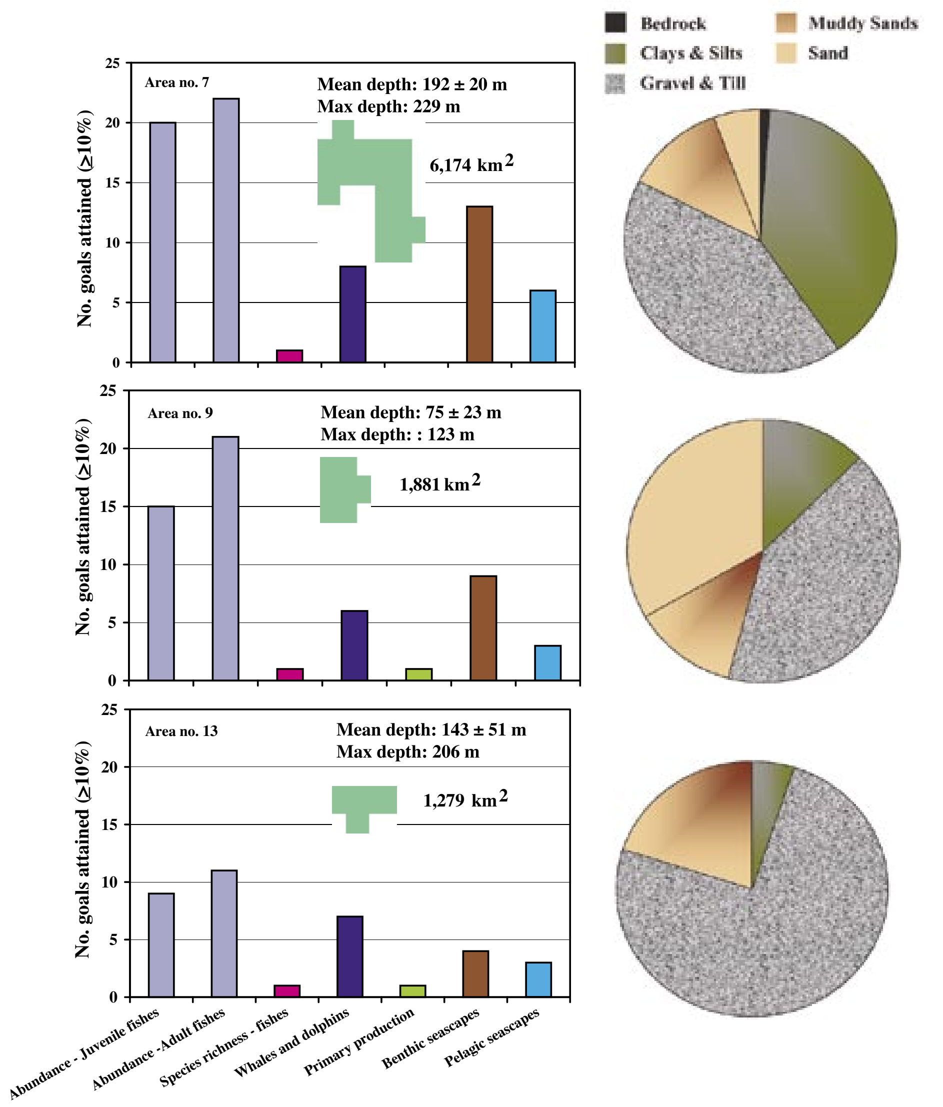
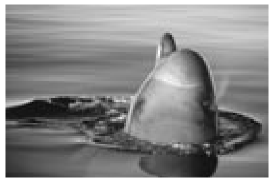


Figure 9-3 shows the number of conservation features to which each of the three priority areas contributed; a criterion of 10% or more of the goal was applied for the purposes of counting these contributions so as to avoid counting very small contributions. The total number of conservation features was highest for those areas that fell in more than one biogeographic area, and there were many more conservation features for fishes and seascapes than for the other classes. There was just one conservation feature for primary production per biogeographic area, as was the case for fish species richness; consequently the histograms in Figure 9-3 show either zero or one for these features.

Priority area for conservation no. 7 (23 planning units; Gulf of Maine), which was the largest priority area for conservation confined to the Gulf of Maine, spanned 6,174 km^2 (1,800 nmi^2; 383 mi^2) and extended east and south from the region of Cashes Ledge to the northern edge of Georges Bank. This priority area was important to a range of biological goals including many of the demersal fishes, demersal fish species richness, and marine mammals. It was particularly important for adult hookear sculpin and cusk of both life stages, as well as Risso's dolphin – it contributed to achieving 80% or more of these goals. Priority area for conservation no. 7 also met 50% or more of the goals for adults of redfish, silver hake, white hake, adult and juvenile red hake, juvenile daubed shanny, and sei whales. Priority area no. 7 was essential to meeting goals for 5 of the 29 benthic seascapes and 6 of the 14 pelagic seascapes in the Gulf of Maine. Largely comprised of clays, silts, gravel and till, with small sections of sand, muddy sands, and bedrock, this priority area had a mean depth of 192 m ± 20 (630 ft ± 65).



A network of priority areas for conservation

Priority area for conservation no. 9 (7 planning units; Gulf of Maine) was situated in Massachusetts Bay. It spanned 1,881 km^2 (1,800 nmi^2; 383 mi^2), and included Stellwagen and Tillies Banks. This priority area overlapped extensively with the Stellwagen Bank National Marine Sanctuary, the southern portion of the United States Western Gulf of Maine Fisheries Closed Area and the northern portion of the United States Cape Cod Bay Critical Habitat Area.

This priority area was particularly important for meeting a range of biological goals, including making contributions to most of the demersal fish goals (89%, juveniles and adults combined), a number of cetacean goals, and the Gulf of Maine goal for primary production. This priority area played a major role in meeting goals for juvenile fishes, including several that have been depleted by overfishing. These included juveniles of Gulf of Maine Atlantic cod, yellowtail flounder, winter skate, northern sandlance, and longhorn sculpin. Priority area no. 9 was also important for cunner, Atlantic wolffish, and ocean pout, and it contributed to the goal for demersal fish species richness. In terms of marine mammals, this priority area was most important for the bottlenose dolphin and humpback whales, but it contributed to meeting goals for most (73%) of the eleven species included in the analysis, including the highly endangered North Atlantic right whale. Priority area no. 9 contributed 80% or more of the representation for four of the benthic and two of the pelagic seascapes; and, to a smaller extent, it contributed to several other seascape goals. Comprised of one-third gravel and till and one-third sand, with the remaining portion made up of clays, silts, and muddy sands, this priority area for conservation had a mean depth of 75 m ± 23 (247 ft ± 76).

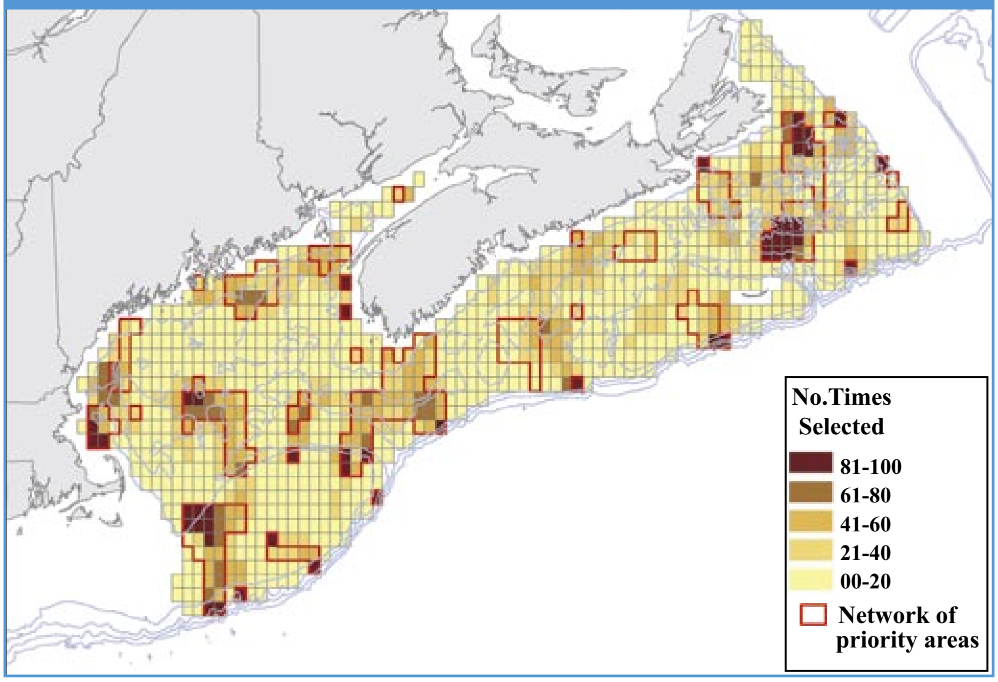
Priority area for conservation no. 13 (5 planning units; Gulf of Maine and Scotian Shelf) was located just south of Grand Manan in Canada, overlapping the southern portion of one of the two Canadian North Atlantic Right Whale Conservation Areas. This priority area was 1,279 km^2 (373 nmi^2; 494 mi^2) and, like priority area no. 12, it contributed to a great many of the biological goals, including making modest contributions to fish species richness and primary production. The area contributed to 7 of 11 cetacean goals, including about one-third of each of the goals for North Atlantic right, humpback, fin, and minke whales, and almost half the goal for harbor porpoise. It also contributed moderately to over half of the demersal fish goals, including juveniles of a number of commercially exploited species such as Atlantic cod, white hake, ocean pout, and haddock. The area provided representation for five benthic seascapes, with over 80% of the goal being met for two of them. It also provided representation for four pelagic seascapes, providing most of the representation for one of them. The bottom of priority area no. 13 was mostly gravel and till with some muddy sands and a small amount of clays and silts. Mean depth was 143 m ± 51 (468 ft ± 168).

Goal attainment within the network

Our network of priority areas for conservation performed well in the sense that the inclusion of the various conservation features was generally close to the goal, i.e., it was most commonly between the actual goal and 1.5 times the desired goal (i.e., actual representation/goal = 1.5). The medians for all classes of conservation features, for representation relative to goals, ranged from 1.17 to 1.45. Of the very few under-represented biological features, all were within 10% of the goal. For juvenile and adult fish relative abundance, only 1% of the conservation features were slightly under the goal in terms of representation; and for all fish species, richness, cetacean, and primary production goals were met or exceeded.

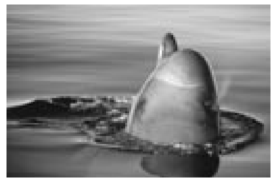
As discussed in Chapter 4, conservation features were sometimes over-represented (i.e., overshot) as a consequence of the need to attain goals for other features. Over-representation also occurred in cases where a large proportion of a goal fell in a restricted area (e.g., within one or a few planning units; discussed in Chapter 8). For the majority of

Figure 9-4. Frequency with which individual planning units were selected over 100 MARXAN runs (i.e., summed solution).



biological features (i.e., 75th percentile point) representation was at or below 1.8 times the goal. More over-representation occurred for the seascapes than for the biological goals, with 6% of the pelagic seascapes and 27% of the benthic seascapes represented in the range of three to five times the goal. All of the seascape conservation features in this range had goals that were smaller than the individual planning units making up our analysis grid because they were uncommon combinations of abiotic characteristics that occurred only within limited areas. As discussed in Chapter 8, seascapes were defined using a grid of 5 geographic minutes (four 5-minute squares per planning unit). The uncommon seascapes were typically found in only five of these 5-minute squares (median = five 5-minute squares; range = one to eight 5-minute squares). For a benthic seascape that occurred in a cluster of only five 5-minute squares, the goal was one 5-minute square (i.e., five 5-minute squares × 0.2 = one 5-minute square). Because our site-selection analysis used 10-minute-square planning units, such a seascape could be represented at only four times the goal under the best of circumstances.

This tendency to over-represent uncommon conservation features was an unintended consequence of the method. To the extent that these correspond to ecologically distinct but uncommon areas, this over-representation may be beneficial to the performance of the network. Verification of these rare conservation features through additional research would be valuable in order to further refine network design.



A network of priority areas for conservation

Analysis of multiple MARXAN network solutions

As detailed in Chapter 4, MARXAN can produce multiple solutions to the same problem, and the network of priority areas for conservation discussed here was the best of 100 MARXAN solutions. To gain an appreciation for the variability among networks, Figure 9-4 shows, on a single map, the frequency with which individual planning units were selected over 100 MARXAN runs, i.e., this is the summed solution (see Chapter 4). Those planning units that were most often selected are shaded the darkest: these planning units were most essential to MARXAN as it sought to minimize the objective function.

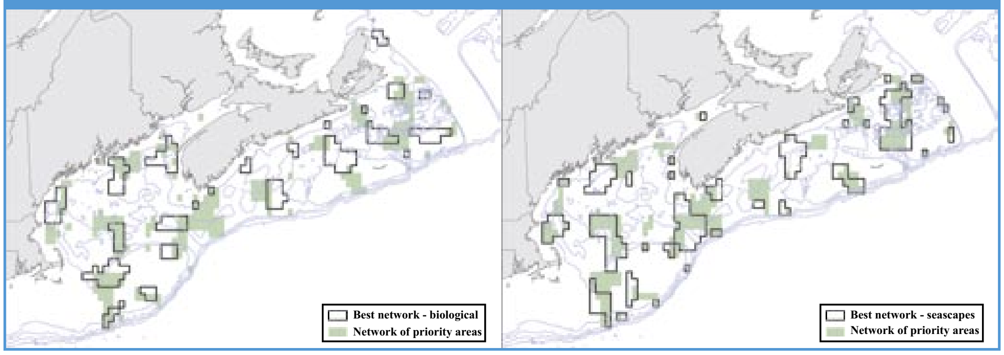
The importance of the most frequently selected planning units was largely determined by the distribution of the various conservation features. As discussed above with respect to benthic seascapes, when a conservation feature had a limited distribution, the few planning units that held the feature tended to be more essential to attaining goals. Conversely, conservation features that were broadly distributed offered flexibility, which allowed goals for these features to be met by a variety of planning units. Thus, the planning units that were selected relatively infrequently (lightly shaded in Figure 9-4) constituted a pool of planning units that allowed flexibility in site selection.

The variability illustrated in the summed solution is valuable because it allows one to consider alternative networks during conservation planning (see discussion below). This aspect of our MARXAN analyses can be considered quantitatively. The distribution of scores was rather narrow, with a coefficient of variation (i.e., the standard deviation divided by the mean score) of only 1.13%. The score associated with the best network was 2.6 SD below the mean, but only about 3% less than the average for the 100 runs. Thus, a number of other networks performed nearly as well as the best network and they could be considered viable alternatives.

■ Distinctive vs. representative conservation features: influence on site selection

We generated a MARXAN network based solely upon distinctive conservation features (i.e., primary production, cetaceans, fish), and upon representative features alone (i.e., benthic and pelagic seascapes) (Figure 9-5). There was some overlap of these networks and the network of priority areas (Figure 9-1). The areal extent of the network based on marine life was a bit smaller (179 planning units) than the network of priority areas for conservation (237 planning units). About 35% (63) of the planning units in the network based on marine life were in common with those constituting the priority areas for conservation. The areal extent of the network based on seascapes (229 planning units) was nearly identical to that of the network of priority areas for conservation. For seascapes alone, 52% of the planning units making up the best network were the same as those incorporated in the network of priority areas for conservation. This qualitative comparison of networks provides some insight into the influence of these two types of conservation features on the network of priority areas for conservation. Quantitative analyses that consider network variation within these different MARXAN analyses might also be valuable but they were not undertaken.

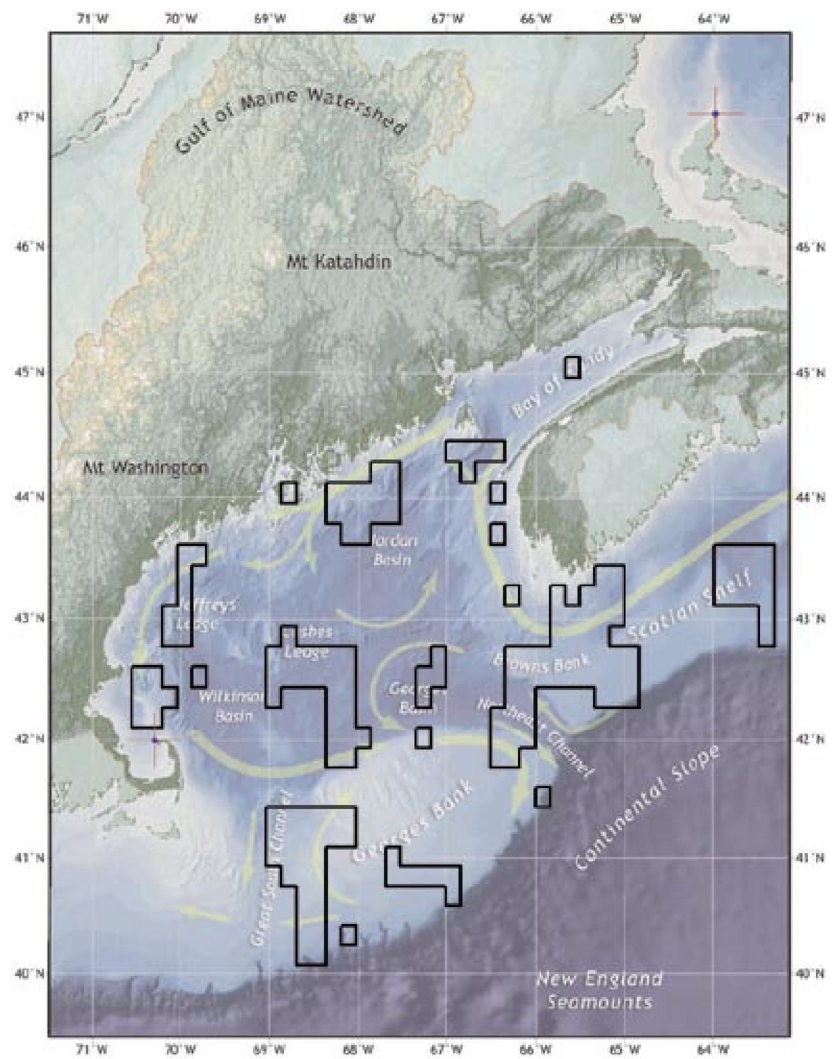
Figure 9-5. Left: Network of areas based only on biological conservation features. Right: Network of areas based only on seascapes (see Figure 8-12). The network of priority areas for conservation is reproduced for comparison (see Figure 9-1).

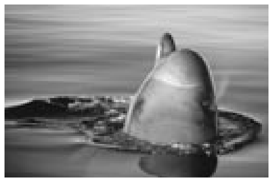


■ Comparison of network of priority areas with known significant areas

The network of priority areas for conservation includes areas that are well known for reasons ranging from historical importance for fisheries to their current importance for whale watching and broad ecological significance. For example, the priority areas for conservation captured historic spawning areas for cod and haddock in coastal Maine (Ames 2004) and many historic fishing grounds for a variety of demersal fishes (Rich 1929). Our analysis of Department of Fisheries and Oceans Canada data on the distributions of spawning females of three demersal species (haddock, yellowtail flounder, silver hake) also indicates that at least 11 of the 30 priority areas for conservation include spawning areas for one or more of these species (Bryan 2005); areas no. 18 and 24 included spawning areas for all three of these species. The network includes areas overlapping with, or adjacent to, some existing marine management areas (Figure 9-2). Examples include United States fisheries management areas on Georges Bank (Closed Areas I and II), the United States Western Gulf of Maine Closure in the Gulf of Maine, and the Canadian Haddock Box on the Scotian Shelf. The boundaries of the United States Stellwagen Bank National Marine Sanctuary off Massachusetts are nearly identical to priority area for conservation no. 9, and no. 26 is adjacent to Canada's Gully Marine Protected Area

Figure 9-6. Network of priority areas for conservation shown with the major surface water circulation patterns from the southwestern Scotian Shelf through the Gulf of Maine and Georges Bank. Circulation map courtesy of Gulf of Maine Area Program of the Census of Marine Life (Island Institute 2003).





A network of priority areas for conservation

on the Scotian Shelf. This network also includes areas in and around designated Whale Conservation Areas at Grand Manan and Roseway Basin, and Critical Habitat Areas at Cape Cod and the Great South Channel (overlapping priority area for conservation no. 1).

The congruence of some of the priority areas for conservation with areas of previously recognized biological significance provides some added confidence in our approach to selection. The methods we used were quite different from those that produce local historical knowledge or those used by resource managers in our region to date. Nevertheless, some of the same places were identified.

As discussed in Chapter 1, the stewardship of most of the existing managed areas is inadequate for achieving long-term ecosystem conservation objectives (Recchia et al. 2001). The Gully Marine Protected Area on the Scotian Shelf is an important exception and provides a valuable model for future efforts in marine stewardship. The Gully is designated for long-term protection of biodiversity; this area is largely outside the boundaries of the Scotian Shelf biogeographic area and thus could not have been among the areas selected with MARXAN.

■ Potential connectivity among priority areas for conservation

The movement of organisms among suitable habitat areas is a critical consideration in the design of conservation networks in both terrestrial (Rosenberg et al. 1997; Levey et al. 2005; Stokstad 2005) and marine settings (Roberts et al. 2003). For example, on land, habitat corridors may be used to connect distant conservation areas.

Although we did not explicitly include information about connectivity in the design of our network of priority areas, the network is expected to benefit from connectivity due to the ocean currents of this region (Figure 9-6). During early life stages, many invertebrates and fishes are planktonic and are passively transported from the source areas where they were spawned to destinations determined by water circulation.

The circulation of waters in the region is complex, in part because of differences between deep and surface waters, and because of seasonal variation (Conkling 1995; Beardley et al. 1996). However, general circulation patterns provide some valuable insight into the way in which portions of our network may be connected through transport of plankton. During at least part of each year, there is a prominent flow of surface water southwest along the Scotian Shelf and into the Gulf of Maine. This flow could provide connectivity between priority areas for conservation within the Scotian Shelf and those within the Gulf of Maine, at least for some species. At the southwestern end of the Scotian Shelf, flow turns to the north which is the beginning of a prominent counter-clockwise circulation within the Gulf. The priority areas along the perimeter of the Gulf could be connected through this counter-clockwise circulation. The priority areas within the Georges Bank area could be connected to each other and the remainder of the network by the prominent gyre that is driven by flow out of the Gulf of Maine (Backus and Bourne 1987).

Nevertheless, the degree to which elements of this network may be connected for particular taxa and life history stages remains to be investigated (see Palumbi 2004; Sotka and Palumbi 2006). For many species the required data are simply not available. Roberts et al. (2003) have discussed the complexity of evaluating connectivity within marine networks and have proposed a number of design features that increase the likelihood that a network will capitalize on the natural movement patterns of organisms and nutrients. Our network of priority areas for conservation includes a number of these features, including areas of varied size and separation and network designs that recognize biogeographic areas. The addition of data on dispersal patterns and expert knowledge about connectivity in our region should be used in future analyses.

■ Flexibility of the method

In addition to the best-performing network detailed above (Figure 9-1), there were others that were nearly as good and we have provided two examples here (Figure 9-7). Both of these alternatives were based on nearly the same number of planning units (238 vs. 237) and roughly half of the planning units were the same as those in the network of priority areas for conservation. The availability of alternative networks is useful in a conservation planning process involving a diversity of stakeholders.

Figure 9-7. Two networks identified with the same goals as the network of priority areas but which had slightly poorer (higher) scores . The left one scored 0.01% higher than the best network, and the right one scored 1.2% higher.

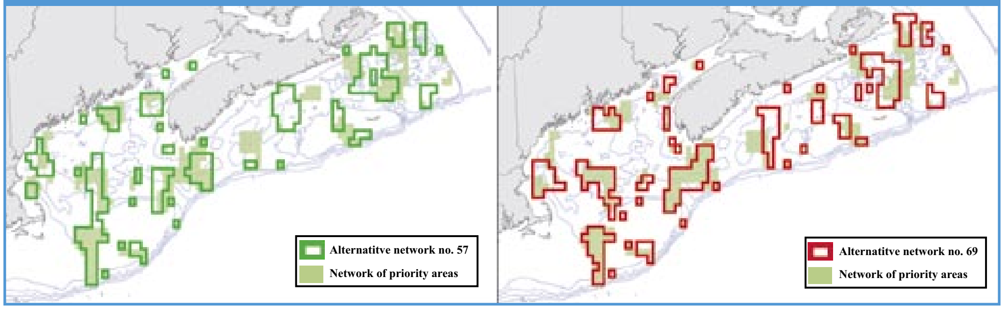
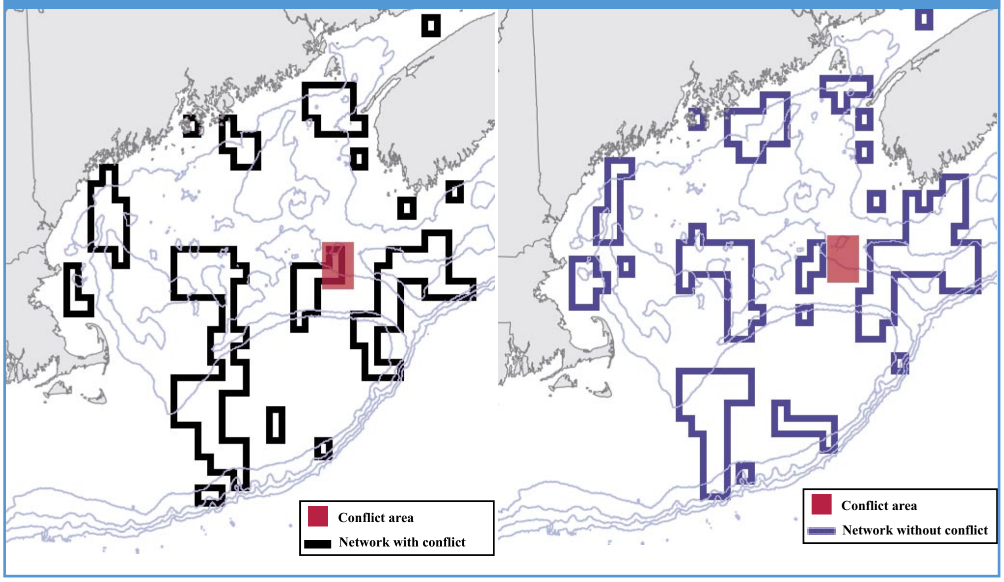
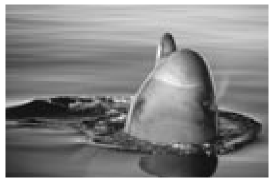


Figure 9-8. Example of how MARXAN can be used to resolve a conflict. Left: Conflict with a user group in portion of an area near Georges Bank. Right: An alternative network that was generated using the same conservation features and goals, but does not require the disputed area.



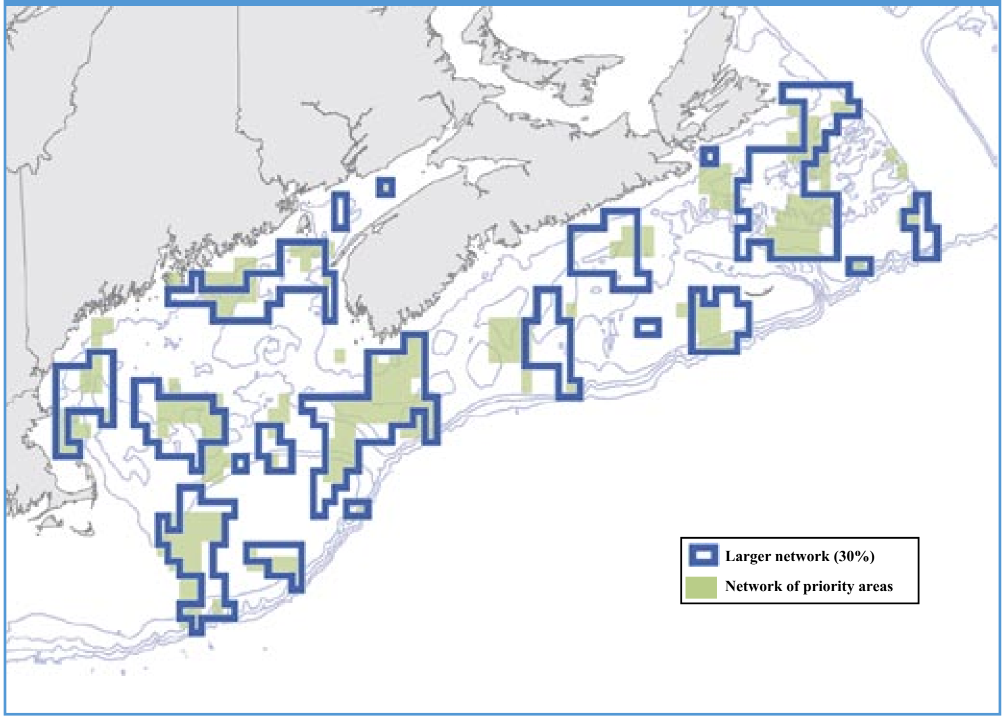


A network of priority areas for conservation

As an example, consider a hypothetical situation in which a proposed network includes a particular area where there is a conflict such that the social cost of putting the area into protected status would be unacceptably high (Figure 9-8). One might maintain all the same conservation goals but use an alternative network that eliminates the conflict, albeit at the expense of the chosen network being slightly poorer in terms of spatial efficiency and/or the degree to which goals are attained.

A broader and more efficient (but also more data intensive) approach is to use one or more data layers on social and/or economic cost to explicitly adjust the costs of the individual planning units before executing site selection with MARXAN. Recall that the analyses we carried out for deriving our network of priority areas for conservation assumed a uniform cost (cost = 1.0) for all planning units. By adjusting planning unit costs based on economic data, for example, one can direct site selection toward those areas where the costs are low, within the limits of conservation feature goals. We did not attempt this here, but this could be an important addition for future work and it fits naturally within the basic approach we have outlined. Indeed, MARXAN was designed with this kind of analysis in mind.

Figure 9-9. A network identified by MARXAN based on the same conservation features as those used for the network of priority areas for conservation (Figure 9-1), but with the goals increased from 20% to 30%.



Marine Ecosystem Conservation for New England and Maritime Canada

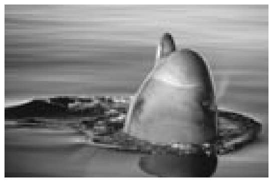
Network design is also influenced by the way in which goals for conservation features are set. Ideally, goals should be tailored to the particular feature, species, or community of concern (Poiani et al. 2000; Tear et al. 2005). Factors that should be considered include information on spatial requirements of various biological components of the ecosystem; local population structure, dispersion and its relationship to connectivity among areas; and the way in which future conservation areas might be managed. Future analyses could refine the goals we have set based on factors such as these.

Areal extent is a fundamental variable in network design (see Chapter 2). Our methods allow one to vary the conservation goals and produce networks that include various areas. We used 20% for our network of priority areas but it may be appropriate to design networks based on a different areal extent (National Research Council 2001). As an illustration we produced an alternative network with goals set at 30% (Figure 9-9). As with the other alternatives, the 30% network has much in common with the network of priority areas for conservation (Figure 9-1).

From networks of priority areas for conservation to improved area-based stewardship of marine ecosystems

The network of priority areas for conservation identified here, and the method of identification, illustrate a powerful use of scientific information for marine conservation planning. It is an approach that requires planning objectives to be carefully defined in advance, and then utilizes a systematic site-selection methodology to choose a system of areas that satisfies those objectives. It is also suited to incorporating a wide range of information, including information about human uses and socioeconomic impacts.

We acknowledge that the data for large-scale marine conservation planning are not perfect – much is unknown about the greater Gulf of Maine and Scotian Shelf ecosystems, but this will always be the case. Nevertheless, the data have proven sufficient, and we know this because the resulting network identified a number of priority areas that coincided with places that are already well known for their ecological significance, in some cases dating back to the earliest historical accounts of the region. Our site-selection process was strengthened through the integration of a relatively large number of data layers.



A network of priority areas for conservation

What is certain is the seriousness of the effects humans have had on our marine ecosystems, as is the urgency of implementing new approaches to marine conservation. Embracing the challenge of guiding marine activities by using the best-available science in a public process for implementing a well-planned system of marine protected areas, including fully protected zones, has been recommended by a diverse cross-section of the community including marine scientists and the public. Two major commissions in the United States – the Pew Oceans Commission (2003) and the United States Commission on Ocean Policy (2004) – have included marine protected areas in their recommendations, and Canada has a mandate for marine protected areas under the Oceans Act (Canada, Parliament 1996), Oceans Action Plan (Fisheries and Oceans Canada 2005), and international commitments.

The marine conservation problems in the northwest Atlantic Shelf region are serious. Solutions are urgently needed, and action should not be delayed. We are confident that our method of identifying a network of priority areas for conservation is a sound, science-based foundation for conserving the biodiversity and ecosystems of the northwest Atlantic Shelf region. As such, it should be integral to a public process for developing an improved program of marine stewardship for the ecological regions shared by New England and maritime Canada. We cannot afford to wait.

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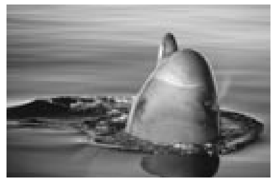

A network of priority areas for conservation

Young codfish and benthic invertebrates within the Stellwagen Bank National Marine Sanctuary

Appendices

Appendix A. Peer reviewers

Peer review workshops

This project benefited from the expert consultation, advice, and review provided by a substantial number of individuals who participated in peer-review workshops held over the course of the project. We wish to express our sincere appreciation to the people listed here for their thorough and constructive input.

Phase I: Scotian Shelf Case Study – Toronto 2000

Prior to 2001 a number of consultations were held on the work that served as the precursor to this project, i.e., the "Case Study of the Application of WWF-Canada's National Classification for Marine Conservation to the Scotian Shelf" contained in Day and Roff (2000). One of these consultations involved a meeting of several experts in Toronto in 2001. The following people provided advice and/or reviews during or after that meeting:

Peter Auster	University of Connecticut
Derek Fenton	Fisheries and Oceans Canada, Bedford Institute of Oceanography
Gordon Fader	Geological Survey of Canada, Bedford Institute of Oceanography
Doug Gregory	Fisheries and Oceans Canada
Jennifer Hackett	Geological Survey of Canada, Bedford Institute of Oceanography
Chris Hawkins	Fisheries and Oceans Canada, Bedford Institute of Oceanography
Tony Iacobelli	WWF-Canada
Kevin Kavanagh	WWF-Canada
John Loder	Fisheries and Oceans Canada, Bedford Institute of Oceanography
Donald McAllister	Ocean Voice International
Inka Milewski	WWF-Canada
Phil Moir	Geological Survey of Canada
Neil Munro	Parks Canada
Ingrid Peterson	Fisheries and Oceans Canada
Bob Rutherford	Fisheries and Oceans Canada, Bedford Institute of Oceanography
Mark Taylor	Geomatics International Inc., Burlington, Ontario
Mark Williamson	Geological Survey of Canada

Phase II: Expanded Seascapes – Boston 2001

On May 15, 2001 at the New England Aquarium Exploration Center in Boston, the following group was assembled to review an approach to mapping physical habitat types that built upon and expanded the above-mentioned case study. Participants were presented with a report entitled *The Application of an Ecological Classification System to Map Physical Habitat Types (Seascapes) in the Gulf of Maine.*

Ken Buja	National Ocean Service–NOAA
Brad Butman	U.S. Geological Survey
Jeremy Collie	University of Rhode Island
Michael Connor	New England Aquarium
Mark Costello	Huntsman Marine Science Centre
Gordon Fader	Natural Resources Canada
Dan Farrow	National Ocean Service–NOAA
Roger Griffis	National Ocean Service–NOAA

Robert Groman	Woods Hole Oceanographic Institution
Les Kaufman	Boston University
Joseph Kelley	University of Maine
Vladimir Kostylev	Geological Survey of Canada, Bedford Institute of Oceanography
James Manning	New England Fishery Management Council
David Mountain	National Marine Fisheries Service–NOAA
Steve Murawski	National Marine Fisheries Service–NOAA
Andy Rosenberg	University of New Hampshire
Bob Rutherford	Fisheries and Oceans Canada, Bedford Institute of Oceanography
Marilyn ten Brink	U.S. Geological Survey
Page Valentine	U.S. Geological Survey
Anthony Wilbur	Massachusetts Office of Coastal Zone Management
Martin Willison	Dalhousie University
Jon Witman	Brown University

Phase III: Comprehensive Conservation Framework – Halifax 2003

A large group was convened for the WWF/CLF MPA Planning Framework Peer Review Workshop, which was held in Halifax, January 14–15, 2003. Reviewers at this workshop were presented with an earlier form of the seascapes and distinctive areas mapping, and with initial MARXAN outputs and methodology. The workshop was chaired by Graham Daborn of Acadia University.

Peter Auster	University of Connecticut
Michael Beck	The Nature Conservancy
Gordon Fader	Geological Survey of Canada, Bedford Institute of Oceanography
Ken Frank	Fisheries and Oceans Canada, Bedford Institute of Oceanography
Dick Haedrich	Memorial University
Jeffrey Hutchings	Dalhousie University
Lewis Inzce	University of Southern Maine
Glen Jamieson	Fisheries and Oceans Canada–Pacific Region
Trevor Kenchington	Gadus Associates
Bob Kenney	University of Rhode Island
Vladimir Kostylev	Geological Survey of Canada, Bedford Institute of Oceanography
Anthony Lock	Environment Canada
Paul McNab	Fisheries and Oceans Canada, Bedford Institute of Oceanography
Ransom Myers	Dalhousie University
Robert O'Boyle	Fisheries and Oceans Canada, Bedford Institute of Oceanography
Mike Sinclair	Fisheries and Oceans Canada, Bedford Institute of Oceanography
David Wildish	Fisheries and Oceans Canada, St. Andrews Biological Station
Martin Willison	Dalhousie University
Boris Worm	Dalhousie University
Kees Zwanenburg	Fisheries and Oceans Canada, Bedford Institute of Oceanography

The following people provided reviews during 2003, but were not able to attend the Halifax workshop:

Satie Airamé	Channel Islands National Marine Sanctuary
Rikk Kivitek	California State University, Monterey Bay
Joseph Kelley	University of Maine
Les Watling	University of Maine

Appendix B. Glossary of terms

This glossary contains standard definitions as well as aspects of usage specific to the report. In some cases examples of sources that discuss or define these terms are provided. Thurman and Trujillo (2002) and Ricklefs and Miller (2000) provide excellent glossaries, and Walker (1989) is a biological dictionary.

5-minute square (FMS). A 5-minute square is 5 geographic minutes on a side, and corresponds to an area of approximately 58 km^2 in our analysis region. We used a grid of 5-minute squares to classify the seascape (see Chapter 8), but the priority areas for conservation were derived with a lower-resolution grid of 10-minute squares. Each 10-minute square contains four 5-minute squares.

10-minute square (TMS). A 10-minute square is 10 geographic minutes on a side, and corresponds to an area of approximately 234 km^2 in our analysis region. Our analysis grid was based on a grid of 10-minute squares.

Abiotic. Non-living. The substrate type (e.g., sand, gravel) and depth of the water are abiotic features of the seascape as defined in this report.

Analysis region. The analysis region is the part of the northwest Atlantic continental shelf for which conservation planning was undertaken and within which the networks of priority areas for conservation were derived. This region begins off Cape Cod, a major faunal divide separating warmer water communities from those to the north and east, and extends through Georges Bank, the Gulf of Maine and Bay of Fundy, and the Scotian Shelf, covering a total area of approximately 277,388 km^2 (80,886 nmi^2; 107,100 mi^2). The northern boundary demarcates a transition to colder water species and communities, and the seaward edge is defined by the 200-m isobath, beyond which bathydemersal and pelagic communities predominate along the shelf slope and in the bathyal zone. Three biogeographic areas were recognized within this analysis region and were integral to the selection of priority areas for conservation.

Biotic. Living or pertaining to living organisms. Fish, whales, and primary production are examples of biotic conservation features used in this report.

Biogeographic area. An area of the world containing recognizably distinct and characteristic fauna or flora (Walker 1990). We recognize three biogeographic areas within our analysis region.

Benthic. Of or pertaining to the benthos, or aquatic life that lives on the bottom. The benthic habitats discussed in this report are those found in, on, or near the seabed.

Best network. The term best network is applied here to the MARXAN solution for which the objective function produces the smallest overall score. The best networks identified in this report were those that had the lowest score among 100 MARXAN runs based on the same conditions (e.g., goals for conservation features, boundary length modifier, conservation penalty factor etc.).

Best solution. See Best network.

Biological conservation feature. Biological conservation features were used in combination with an abiotic characterization of the seascape for conservation planning. The biological conservation features included distributions of individual species of whales and fishes, distributions of species richness for fishes, and distributions of areas of persistently high primary production.

Complementary areas. An ensemble of sites that functions in combination to meet regional conservation goals is said to consist of complementary areas. Within a set of complementary areas, the individual sites typically make different contributions to the regional goals by protecting conservation features that are not conserved elsewhere (Groves et al. 2002).

Community. Communities (or ecological communities) are populations of organisms associated by the places they inhabit and the interactions among individuals (Ricklefs and Miller 2000). Communities are composed of recurring and interacting assemblages of organisms characterized by consistent composition, structure, and habitat. Communities may be defined at a range of spatial scales and trophic or taxonomic divisions.

Connectivity. Connectivity is a term used in conservation biology to describe the degree to which separated habitat areas are *connected* from the perspective of the life forms that inhabit the areas. Networks of reserve areas are said to exhibit connectivity if they allow dispersal of organisms among reserves and thus gene flow; protected habitat corridors are used in some situations to ensure connectivity.

Conservation feature. A physical trait of the environment, a process, or a biological distribution (or proxy for one of these), any of which, if present, may be used as a criterion for site selection. Our analysis included conservation features based on biological elements such as the distributions of individual species of whales and fishes and the presence of recurring high primary production, as well as abiotic features in the form of physical habitat types ("seascapes") that served as proxies for biological communities. Chapter 2 contains a table describing the conservation features included in our analysis.

Conservation feature penalty factor (CFPF). In MARXAN the objective function includes a penalty term that increases when the goal for a conservation feature is not met. This penalty can be scaled by the conservation feature penalty factor. Increasing this factor for a given conservation feature drives MARXAN toward solutions that fully attain the goal for the feature.

Data layer. A spatially referenced dataset containing a common feature type or theme. For example, the data that describe the geographic distribution of juvenile Atlantic cod comprise one of the many data layers used in our analysis. Spatially referenced data can be displayed as a map using geographic information system software.

Demersal. Found in deep water, just above or on the sea bottom (Walker 1990; Waller 1996). In this report, a number of the biological conservation features were demersal fishes, or fishes that live near the bottom. These fishes are sometimes called bottom-living fishes, or groundfish.

Density anomaly. The density anomaly describes the degree to which seawater is stratified by contrasting density (σ_t) at the surface with density at a depth of 100m. The density anomaly is computed by multiplying the difference in density ($\Delta\sigma_t$) by a constant (1,500). Large values occur when there are substantial differences between surface water conditions and those at depth.

Distinctive area. An area distinguished from its surroundings by one or several unique biological or physical attributes. Examples include a known spawning area for a fish, or a rare habitat area such as a seamount (Day and Roff 2000; Roff and Evans 2002). The analysis in this report includes distinctive areas based on biological conservation features.

Ecological community. See *community*. Populations associated by the places they inhabit and the interactions among individuals (Ricklefs and Miller 2000).

Front. A major discontinuity between ocean currents and water masses in any combination (Levinton 2001). For example, the area of sharp temperature change between tidally mixed near-shore and stratified, deeper off-shore waters is a front.

Fully protected marine protected area. An area where

(a) any removal of marine species and modification or extraction of marine resources (through fishing, dredging, mining, drilling, etc.) is prohibited, and
(b) other forms of human disturbance are restricted.

Fully protected marine protected areas are "areas that are fully protected against all preventable threats" (Day and Roff 2000). The terms "marine reserve" and "no-take marine protected area" are sometimes used to refer to fully protected marine protected areas or full-protection zones within a multiple-use marine protected area. See also multiple-use marine protected area.

Greater Gulf of Maine region. In this report the *Greater Gulf of Maine* refers to an area made up of the Gulf of Maine itself, the Bay of Fundy, and Georges Bank. However, in our analyses, we treat the Gulf of Maine and the Bay of Fundy as a single biogeographic area and Georges Bank as a separate biogeographic area (see Chapter 3).

Goals (for the protection of conservation features). For each conservation feature used to identify priority areas for conservation, a quantitative goal was specified. This was the quantity of each conservation feature to be included in an acceptable network design. For example, we applied a goal of 20% for the areas of persistently high primary production within each of the biogeographic areas. Note that the documentation for the site-selection tool applied here, MARXAN, refers to such goals as targets (Ball and Possingham 2000).

Habitat. The place where an organism (e.g., plant or animal) normally lives, often characterized by the place's conspicuous features such as the dominant plant type, soil or seafloor type, temperature zone, elevation, or depth (Ricklefs and Miller 2000). In this report we have classified the habitat of our analysis region to produce a map of physical habitat types, called seascapes, and to achieve representation when deriving networks of priority areas for conservation.

Indicator species. See umbrella species below.

Marine protected area (MPA). The most widely accepted definition of a marine protected area is that developed by the World Conservation Union, International Union for the Conservation of Nature and Natural Resources (1994):

> *. . . an 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.*

This definition includes a broad spectrum of objectives and management regimes. The IUCN protected area categories provide a useful framework for characterizing the different types of marine protected areas that exist along this spectrum. Marine reserves and multiple-use marine protected areas represent different ends of this spectrum (Day and Roff 2000).

Marine reserve. See *fully protected marine protected area*

MARXAN. **MA**rine **R**eserve Design by Spatially E**X**plicit **AN**nealing is a site-selection program used to design conservation networks. The program is based upon simulated annealing. MARXAN evaluates thousands of combinations of areas in a process that yields networks of areas that meet conservation goals efficiently. The networks produced by MARXAN are also called *solutions*.

Network (reserve, marine protected area, or priority area for conservation network). Networks of protected areas consist of a distributed system of sites designed to meet multiple conservation objectives that cannot be achieved by any single site alone (Day and Roff 2000; Roberts and Hawkins 2000). Networks of such complementary areas also have beneficial properties that may emerge from distributing conservation among multiple sites and from biological interactions among sites (Roberts et al. 2003). The solutions produced by MARXAN are networks of areas.

Pelagic. Of, relating to, or living in the water column of the open ocean, pertaining to the surface or middle depths (Walker 1990; Longhurst 1998; Day and Roff 2000). Open-water animals such as tuna or herring, and the larval stages of many fishes and invertebrates, are said to be pelagic. In this report, pelagic seascapes pertain to habitats of the water column defined from the near-shore boundary to the open ocean waters offshore.

Planning unit. The basic spatial unit available for selection in systematic conservation planning software such as MARXAN (Ball and Possingham 2000). Our analysis was based upon a grid composed of approximately 1,000 planning units, each being 10 geographic minutes square, or about 234 km^2. Note that the actual size of the 10-minute squares varies slightly with latitude over the analysis region.

Primary production. The rate at which organisms convert solar or chemical energy into living material (biomass).

Priority area for conservation. Areas that make up a network that meets a specified set of conservation goals. In this report, goals were specified for a suite of biological conservation features (e.g., fishes, whales) and for the habitat types we refer to as the seascapes. Each individual priority area for conservation within a network generally makes a unique contribution to meeting the assortment of goals, and contributes a great deal to some, and little or nothing to others. As an ensemble, the priority areas for conservation meet all the goals and are thus said to be complementary. Networks such as those developed here, which include a sample of each habitat type, are called representative networks.

Relative abundance. In this report, relative abundance for fishes and cetaceans is a measure based on the number of individuals sighted or caught in a trawl in a particular planning unit, corrected for differences in sampling effort. We refer to this metric as relative abundance because it is thought to be proportional to the true abundance for a species (i.e., the actual number of fish per area), and indicative of the species' abundance distribution across the area. Thus, one can examine a map of relative abundance and identify places where that species has been most abundant relative to other places.

Representation. In conservation planning representation refers to including examples of the range of biological diversity (from genes to ecosystems) and the associated physiochemical environments of an analysis region within a network of protected areas. The quality of a network may be evaluated based upon the degree to which it achieves representation (Day and Roff 2000; The World Conservation Union 2004). In this report we have aimed to generate representative networks of areas by setting goals for including a proportion of every physical habitat type, a proxy for the diversity of biological communities within the analysis region, as captured by our classification.

Seascape. A physical habitat type defined on the basis of a combination of characteristics. Here we have defined the seascapes of our region, both benthic and pelagic, based on enduring abiotic features of the marine environment including water conditions, depth, and substrate composition. Seascapes are described here as units of a mosaic of coarse-scale marine habitat types that are much like landscapes or landscape units in terrestrial ecology and gap assessment (Primack 2002).

Species richness. One of a number of different measures of the diversity of species in an area. For this report we have defined species richness as the average number of species per unit area. Where an area (e.g., planning unit) was sampled repeatedly, species richness was taken as the average number of species per sample; we did not employ cumulative or other measures of richness. Species richness is one aspect of biodiversity, and is defined in a number of different ways in the literature.

Spill-over effect. Describes the emigration, or export, of marine life from protected areas to surrounding areas. For example, successful protected areas may produce an abundance of eggs, juveniles, and/or adults of some species of fish, which move to adjacent waters and thus provide benefits outside the boundaries of the protected areas (Partnership for Interdisciplinary Studies of Coastal Oceans 2002).

Stratification. The formation, as a function of salinity and/or temperature, of layers of different densities within the water column.

Thermocline. A region beneath the well-mixed surface waters where sharp temperature changes occur with increasing depth (Walker 1990; Longhurst 1998).

Temperature-salinity zone. Seawater temperature and salinity were subjected to a cluster analysis to define temperature-salinity zones, or areas of similar temperature and salinity (see Chapter 8). The analysis was based on data collected over all 12 months of the year. Consequently each temperature-salinity zone displays an annual cycle in temperature and salinity, similar to the climate zones based on annual rainfall and temperature that are used in terrestrial ecology.

Umbrella species. Species whose protection automatically extends to other species and the associated communities. Umbrella species can be used as indicators of a broader swath of biological diversity, sometimes called indicator species or flagship species (Primack 2002). Both the cetaceans and demersal fishes included in this report as biological conservation features served as umbrellas during site selection.

Water mass. A volume of water that has defined salinity and temperature characteristics; water masses might be considered analogues of the major climatic regions of terrestrial environments.

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Appendix C. MARXAN run details

Table C-1. Details of MARXAN analyses depicted in figures. [a, b]

Figure no. [c]	Analysis name	Runs shown [d]	Boundary length multiplier	Adjustment to conservation feature penalty factor	Network score [e]	Cost [e]	Total boundary Length for network [e]	Penalty for failing to attain goals [e]	Shortfall [f]	Missing values (No.) [g]
1-2	pac41	best (44)	2	2 increased to 3, 15 to 2	362.0	237	61	3.01	3.24	0
6-9 Juveniles-Best	juveniles9	best (54)	2	1 increased to 2	246.7	162	41.67	1.33	0.27	0
6-9 Juveniles-Summed	juveniles9	all 100 summed	2	1 increased to 2	255.1	159.75	46.6	2.1	1.13	0.32
6-9 Adults-Best	adults3	best (55)	2	0	255.2	162	45.67	1.9	1.35	0
6-9 Adults-Summed	adults3	all 100 summed	2	0	261.0	167.2	45.83	2.13	1.28	0.21
6-9 Combined-Best	fish7	best (91)	2	1 increased to 2	274.5	179	46	3.51	2.44	0
6-9 Combined-Summed	fish7	all 100 summed	2	1 increased to 2	283.4	179.5	50.84	2.16	1.14	0.32
7-8 Cetaceans-Best	cetaceans6	best (57)	2	0	56.3	33	11.33	0.58	0.61	0
7-9 Cetaceans-Summed	cetaceans6	all 100 summed	2	0	57.1	33.91	11.5	1.15	1.01	0.02
7-10 Cetaceans-Best	cetaceans6	best (57)	2	0	56.3	33	11.33	0.58	0.61	0
8-10 Top	benthicSS25	best (12)	2	20 increased to 2, 2 to 3	329.6	224	50.33	4.93	7	0
	benthicSS25	all 100 summed	2	20 increased to 2, 2 to 3	340.3	224.7	54.55	6.57	8.34	1.53
8-10 Middle	benthicSS25	all 100 summed	2	20 increased to 2, 2 to 3	340.3	224.7	54.55	6.57	8.34	1.53
8-10 Bottom	benthicSSNS4	best (43)	2	3 increased to 2, 1 to 3	285.1	214	34.67	1.76	2.8	0
	benthicSSNS4	all 100 summed	2	3 increased to 2, 1 to 3	294.7	213.6	39.12	2.86	3.98	0.89
8-11	pelagicSS12	best (31)	2	6 increased to 2	287.0	215	34.33	3.37	4.8	0
	pelagicSS12	all 100 summed	2	7 increased to 2	297.6	215.3	39.18	3.99	5.21	0.48
8-12	seascapes13	best (19)	2	18 increased to 2, 1 to 3	349.2	229	57	6.23	7.8	0
	seascapes13	all 100 summed	2	19 increased to 2, 1 to 3	358.3	230.9	60.94	5.47	6.01	1.72
9-1	pac41	best (44)	2	2 increased to 3, 15 to 2	362.0	237	61	3.01	3.24	0
9-2	pac41	best (44)	2	2 increased to 3, 15 to 2	362.0	237	61	3.01	3.24	0
9-4	pac41	best (44)	2	2 increased to 3, 15 to 2	362.0	237	61	3.01	3.24	0
	pac41	all 100 summed	2	2 increased to 3, 15 to 2	372.8	235.74	66.25	4.54	4.32	1.19
9-5 Left	distinctive1	best (63)	2	0	278.7	179	48.67	2.32	1.51	0
	pac41	best (44)	2	2 increased to 3, 15 to 2	362.0	237	61	3.01	3.24	0
9-5 Right	seascapes13	best (19)	2	18 increased to 2, 1 to 3	349.2	229	57	6.23	7.8	0
	pac41	best (44)	2	2 increased to 3, 15 to 2	362.0	237	61	3.01	3.24	0
9-6	pac41	best (44)	2	2 increased to 3, 15 to 2	362.0	237	61	3.01	3.24	0
9-7 Left	pac41	57	2	2 increased to 3, 15 to 2	362.1	238	59.67	4.71	4.86	2
	pac41	best (44)	2	2 increased to 3, 15 to 2	362.0	237	61	3.01	3.24	0
9-7 Right	pac41	69	2	2 increased to 3, 15 increased to 2	366.4	238	63	2.42	3.65	0
	pac41	best (44)	2	2 increased to 3, 15 to 2	362.0	237	61	3.01	3.24	0
9-8 Left	pac41	22	2	2 increased to 3, 15 to 2	367.0	235	62	7.97	5.69	2
9-8 Right	pac41	best (44)	2	2 increased to 3, 15 to 2	362.0	237	61	3.01	3.24	0
9-9	example only									
	pac41	best (44)	2	2 increased to 3, 15 to 2	362.0	237	61	3.01	3.24	0

[a] Values in italics are averages based on 100 runs that correspond to summed solutions.
[b] See Chapter 4.
[c] Like colors correspond to a single panel within a figure.
[d] Network solutions depicted in figure (numeric identifier between 1 and 100).
[e] Number of planning units, from objective function.
[f] Sum of the amounts by which conservation features failed to meet their goals.
[g] Number of conservation features for which network failed to reach 90% of the goal.

Appendix D: Seasonal water mass movements

In developing a data layer for input into the seascapes classification, we were interested in identifying zones that display similar regimes of variation in temperature and salinity throughout the year (as described in Chapter 8). Our solution to this was to perform a cluster analysis that combined the full set of temperature and salinity data, i.e., utilising one “pair” of 30-year averages for each month of the year to yield a single set of clusters,one for the benthic realm (Figure D-1) and one for the pelagic realm (Figure D-2).

Prior to implementing this approach, however, the same data were used to create a separate cluster map for each month. These maps reveal temperature and salinity conditions at a finer temporal resolution and, taken together, provide a picture of the seasonal movement of these clusters. At this temporal resolution, the clusters were judged to be a useful proxy for the water masses characteristic of the analysis region.

Included in this appendix are month-by-month cluster maps based on 50 pelagic and 30 benthic clusters, as for the annual cluster maps used in the seascapes. These maps were also used to create animations of cluster movements throughout the year.

Figure D-1. Pelagic temperature and salinity clusters (50 clusters), January to December.

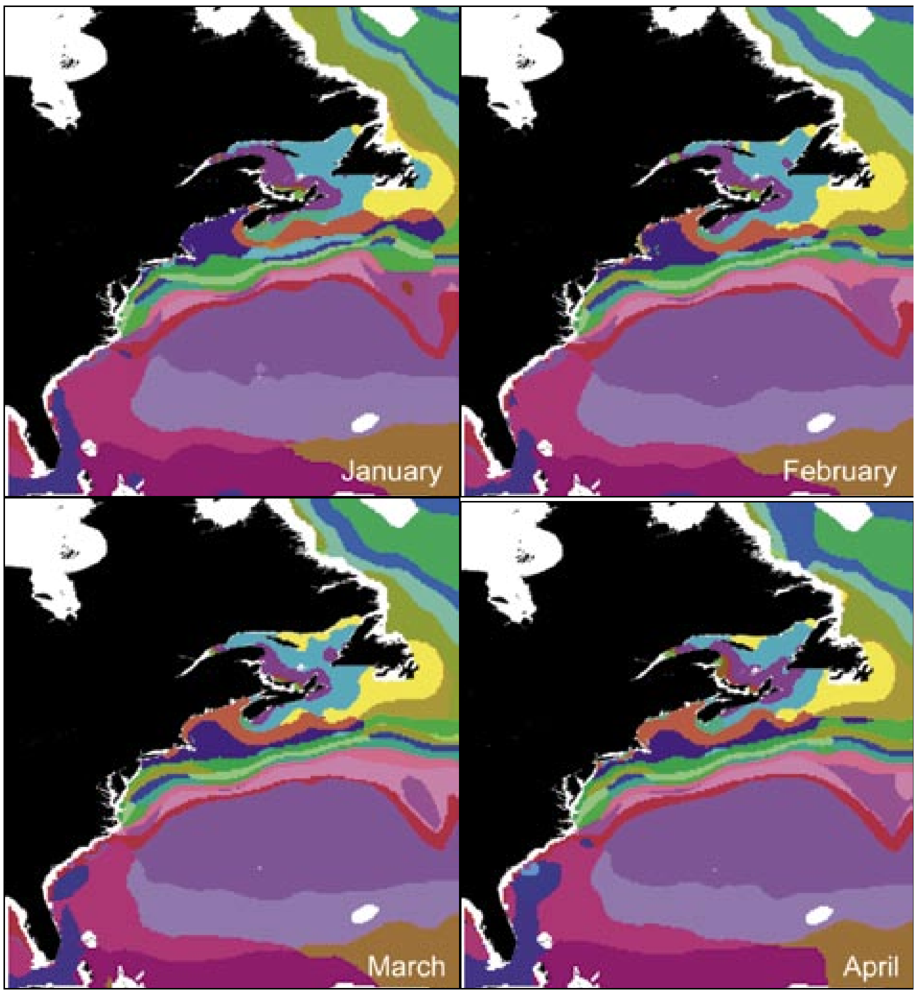


Figure D-1. Pelagic temperature and salinity clusters (50 clusters), January to December. (Continued)

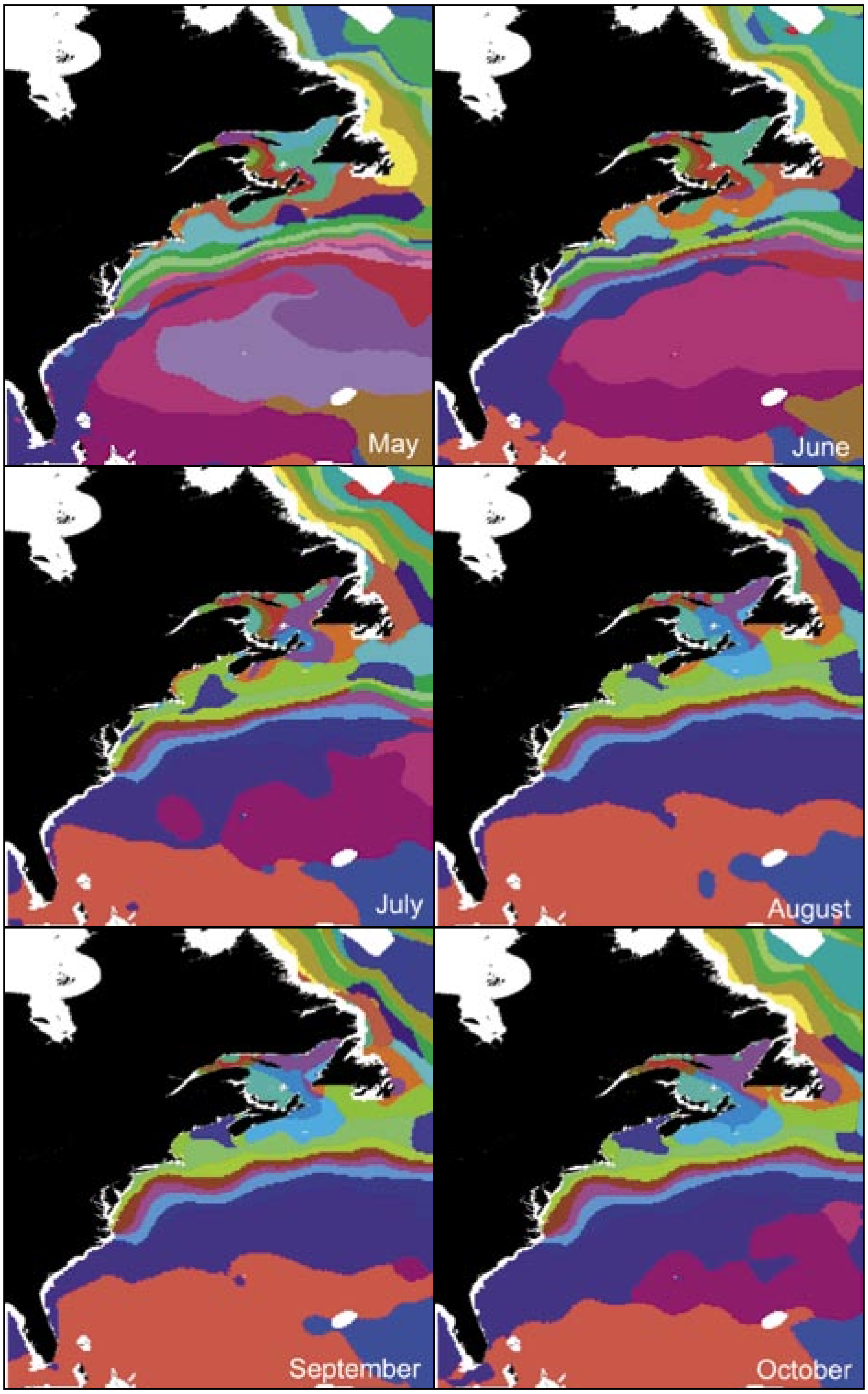


Figure D-1. Pelagic temperature and salinity clusters (50 clusters), January to December. (Continued)

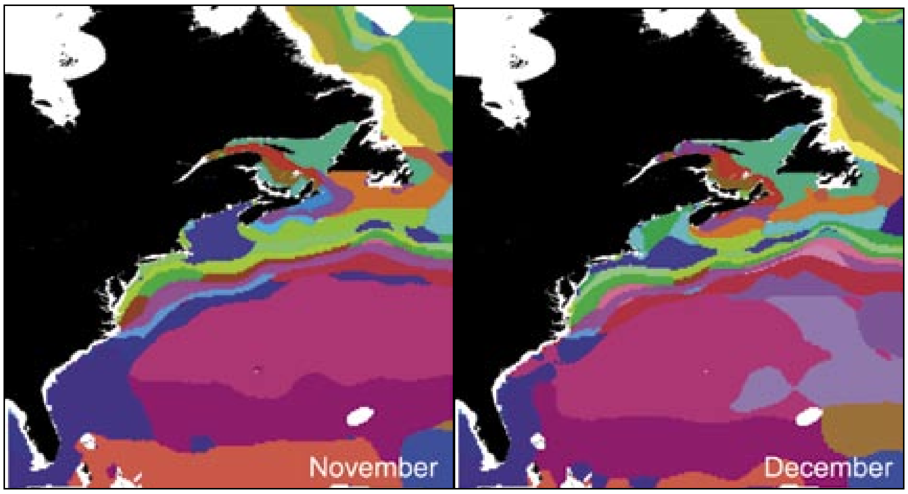


Figure D-2. Benthic temperature and salinity clusters (30 clusters), January to December.

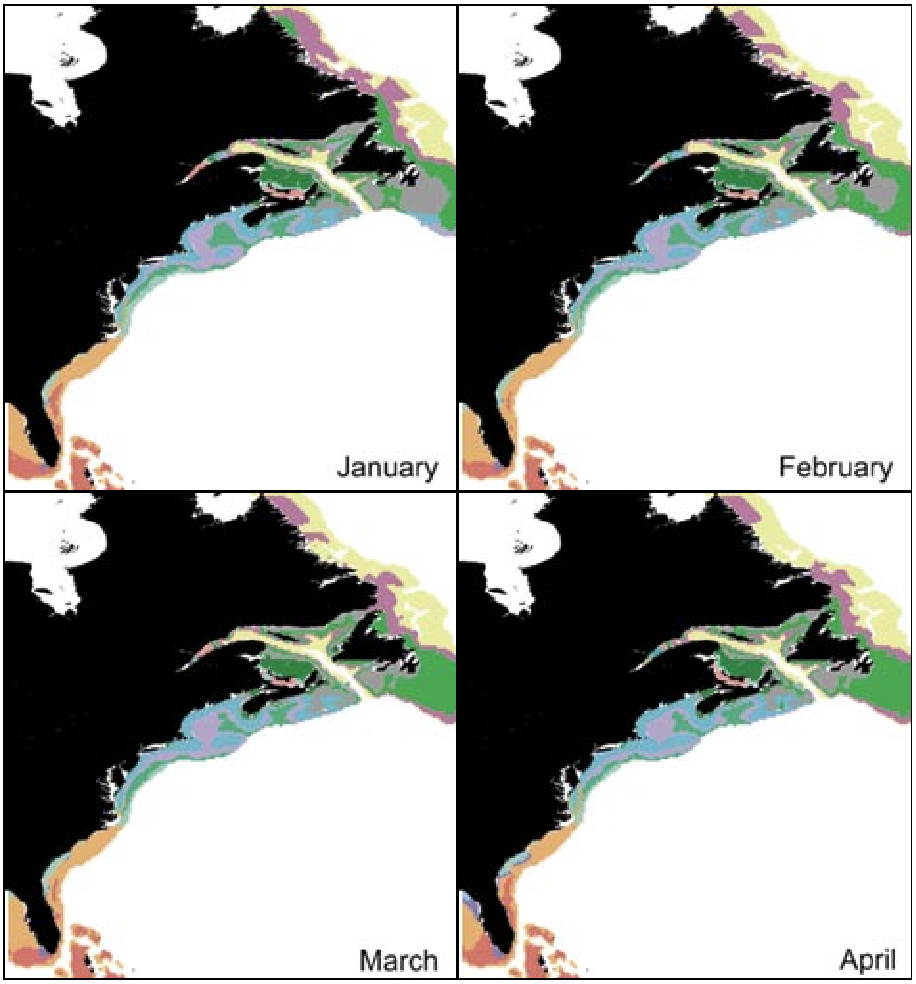


Figure D-2. Benthic temperature and salinity clusters (30 clusters), January to December. (Continued)

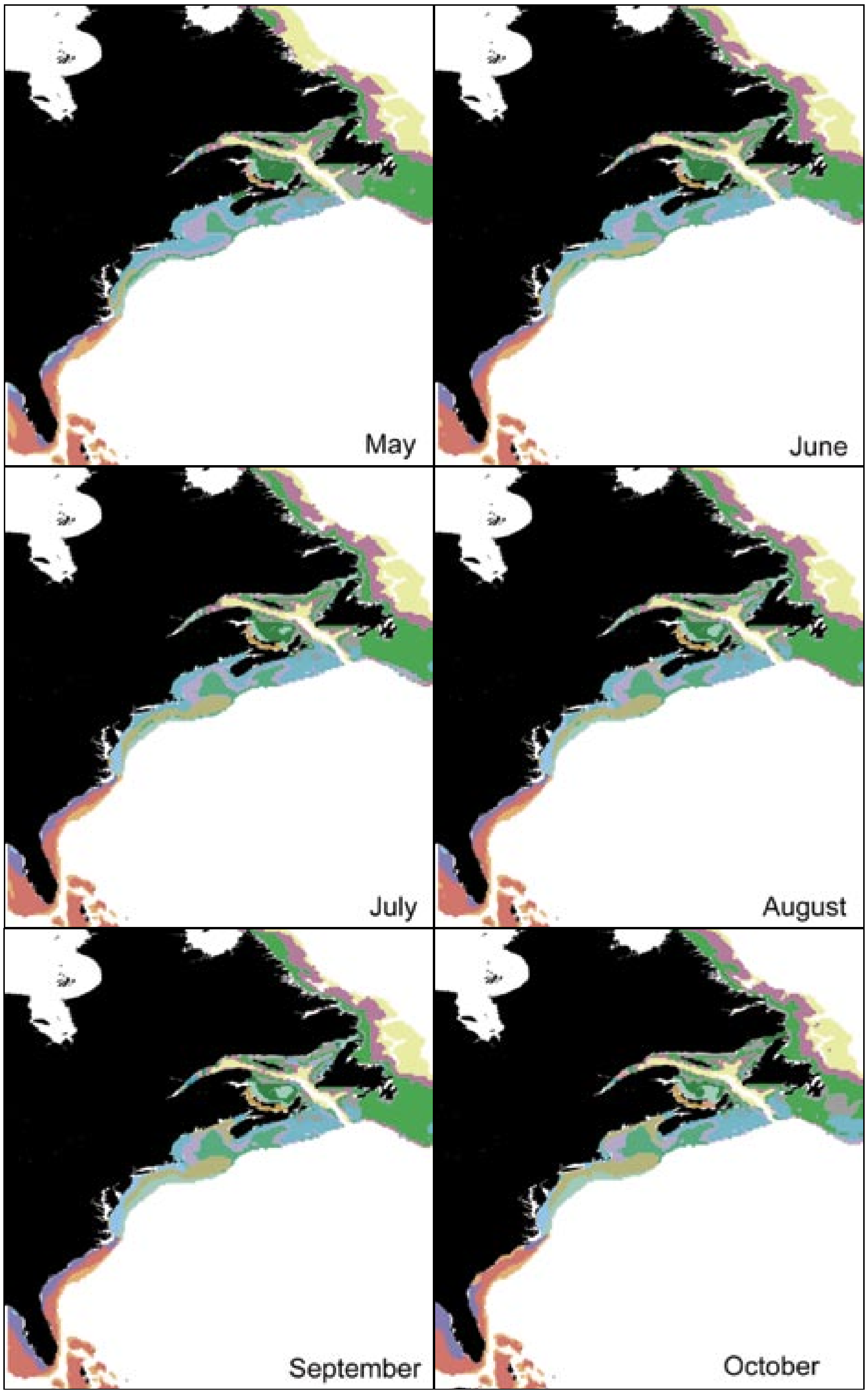
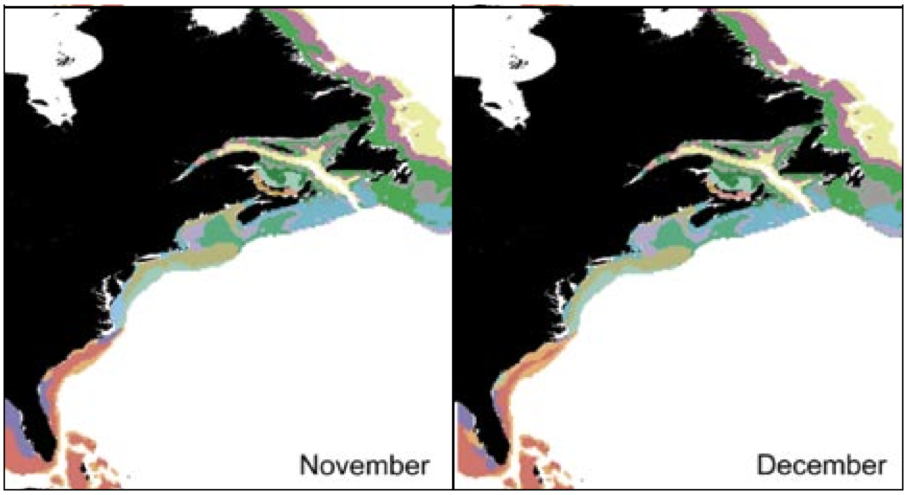


Figure D-2. Benthic temperature and salinity clusters (30 clusters), January to December. (Continued)



Appendix E. Detailed descriptions of the priority areas for conservation

All 30 of the priority areas for conservation that comprised the network of priority areas for conservation are described below. These descriptions are followed by a set of histograms and pie charts that summarize the contributions of all the priority areas in terms of their contributions to the goals for the different classes of conservation features and their seafloor characteristics. Table E-1 provides the geographic coordinates for each priority area for conservation and Table E-2 provides the depths.

Below, the term *modest* is used to characterize contributions that generally comprised <50% of the whole goal, and *large* describes contributions that comprised 80% or more of the total. In addition to providing information about the percentage of a given goal fulfilled by a priority area for conservation, we also report on the number of goals to which a given priority area for conservation contributed. For example, there were 27 goals specified for juvenile demersal fishes in the Gulf of Maine (i.e., goals for 27 species). If a given priority area for conservation (e.g., no. 11) contributed some amount to 7 of these, it contributed to the goals for 41% of the conservation features.

Priority area for conservation no. 1 (27 planning units; Georges Bank & Gulf of Maine) was a large area (7,517 km^2; 2,192 nmi^2; 2,902 mi^2) at the Great South Channel. It was primarily located within Georges Bank (89%), with 11% of it situated in the Gulf of Maine biogeographic area. Priority area no. 1 played a prominent role in meeting goals for whales and dolphins, including three species classified as endangered, and it overlapped with a large portion of the United States Great South Channel Critical Habitat Area and United States fisheries Closed Area II. It also made a major contribution to meeting goals for the demersal fishes by contributing over 50% to the abundance goals for seven species of flounder and a number of other species. For example, this priority area was important for meeting goals for monkfish, ocean pout, northern sand lance, and barndoor skate, and it made a major contribution to the species richness goal for Georges Bank. This area had a high relative abundance for juvenile fishes including white hake and haddock, which are two demersal species that have been recognized as overfished. Over 80% of the goal for Georges Bank primary production was attained at priority area no. 1. This PAC was primarily sandy bottom, with some gravel and till, and had a mean depth of 80 m ± 54 (262 ft ± 176). Our analysis of distributions of spawning female fish indicate that this priority area for conservation may include a spawning area for haddock (Bryan 2005).

Priority area for conservation no. 2 (1 planning unit; Georges Bank) was a single planning unit (282 km^2; 82 nmi^2; 109 mi^2) just west of priority area for conservation no. 1, at the shelf edge. This priority area made a pattern of contributions to the goals for fishes that was similar to priority area no. 1, and it contributed modestly to Georges Bank goals for dolphins. This priority area also contributed to the representation of three of the 22 Georges Bank benthic seascapes, including exclusive representation of two of them. One of these benthic seascapes was entirely contained within priority area no. 2, and for the other seascape, one of two 5-minute squares was included. About 50% of priority area for conservation no. 2 was sandy bottom, but it included gravel and till as well as muddy sands. Mean depth was 231 m ± 140 (759 ft ± 459).

Priority area for conservation no. 3 (7 planning units; Georges Bank) was a larger site with an area of 1,952 km^2 (569 nmi^2; 109 mi^2) extending from the shelf break westward into the central part of the bank. The contribution of this priority area for conservation to goals for demersal fishes was similar to the previous two, but it made relatively large contributions for longhorn sculpin, sea raven, and barndoor skate, and a modest contribution to Georges Bank species richness. Priority area no. 3 contributed to meeting goals for 4 of 14 Georges Bank pelagic seascapes and 5 of 22 benthic seascapes, including exclusive representation of two. The area had predominantly sandy bottom with a mean depth of 85 m ± 28 (277 ft ± 92), and it overlapped with the southern portion of United States fisheries Closed Area II. Our analysis of distributions of spawning female fish indicate that this priority area for conservation may include a spawning area for yellowtail flounder.

Priority area for conservation no. 4 (1 planning unit; Georges Bank) was another single planning unit located at the shelf edge on the northern tip of Georges Bank. This priority area for conservation contributed moderately to meeting goals for a diversity of species. It was particularly important for Acadian redfish, contributing more than half of the goal for adults and a quarter for juveniles. Priority area for conservation no. 4 also contributed moderately to goals for barndoor and thorny skate, pollock, and fin whales. It contributed to meeting goals for several of the seascapes, including exclusive representation of two benthic and two pelagic seascapes. This area had a predominantly sandy bottom but included some muddy sands. Mean depth was 239 m ± 155 (784 ft ± 509).

Priority area for conservation no. 5 (1 planning unit; Georges Bank) was a single planning unit at the northern edge of Georges Bank that contributed moderately to a large number of biological goals including two of the cetaceans and many of the goals for demersal fish abundance and species richness. It also provided all of the representation for two of the benthic seascapes and contributed modestly toward meeting goals for two of the pelagic seascapes. Three-quarters of this priority area had a sandy bottom with the remainder being gravel and till. Mean depth was 72 m ± 22 (236 ft ± 73). Our analysis of distributions of spawning female fish indicate that priority area no. 5 may include spawning areas for haddock (Bryan 2005).

Priority area for conservation no. 6 (4 planning units; Gulf of Maine), at 1,071 km^2 (312 nmi^2; 413 mi^2), was a modestly sized priority area for conservation located in the deep water of the Fundian Channel, off the northern edge of Georges Bank. This was another priority area whose principal contribution to meeting biological goals was modest but diverse, including contributing to goals for a number of fishes and cetaceans. However, priority area no. 6 was essential for meeting the Gulf of Maine goal for saddleback dolphins, and it was also relatively important for Atlantic argentine. This area contributed moderately to goals for several benthic and pelagic seascapes. The bottom was approximately two-thirds clays and silts, and one-third gravel and till with a small amount of muddy sands. Mean depth was 282 m ± 47 (926 ft ± 155).

Priority area for conservation no. 7 (23 planning units; Gulf of Maine), which was the largest priority area for conservation confined to the Gulf of Maine, spanned 6,174 km^2 (1,800 nmi^2; 383 mi^2) and extended east and south from the region of Cashes Ledge to the northern edge of Georges Bank. This priority area was important to a range of biological goals including many of the demersal fishes, demersal fish species richness, and marine mammals. It was particularly important for adult hookear sculpin and cusk of both life stages, as well as Risso's dolphin – it contributed to achieving 80% or more of these goals. Priority area for conservation no. 7 also met 50% or more of the goals for adults of redfish, silver hake, white hake, adult and juvenile red hake, juvenile daubed shanny, and sei whales. Priority area no. 7 was also essential to meeting goals for 5 of the 29 benthic seascapes and 6 of the 14 pelagic seascapes in the Gulf of Maine. This priority area for conservation was largely comprised of clays, silts, gravel and till, with small sections of sand, muddy sands, and bedrock. The mean depth was 192 m ± 20 (630 ft ± 65).

Priority area for conservation no. 8 (1 planning unit; Gulf of Maine) was a small site due east of Cape Ann, between Stellwagen Bank and the Western Gulf of Maine Fisheries Closure. This priority area was in the bottom quartile in terms of contributions to goals, and made only modest contributions to the fish goals and the bottlenose dolphin goal. This small priority area for conservation did provide complete representation for one of the pelagic seascapes, and made a modest contribution to meeting one of the benthic seascape types. Mean depth was 249 m ± 6 (818 ft ± 19) and the bottom was entirely made up of clays and silts.

Priority area for conservation no. 9 (7 planning units; Gulf of Maine), was situated in Massachusetts Bay. It spanned 1,881 km^2 (1,800 nmi^2; 383 mi^2) and included Stellwagen and Tillies Banks. This priority area overlapped extensively with the Stellwagen Bank National Marine Sanctuary, the southern portion of the United States Western Gulf of Maine Fisheries Closure, and the northern portion of the United States Cape Cod Bay Critical Habitat Area.

This priority area was particularly important for meeting a diversity of biological goals, including making contributions to most of the demersal fish goals (89%, juveniles and adults combined), a number of cetacean goals, and the Gulf of Maine goal for primary production.

This priority area played a major role in meeting goals for juvenile fishes, including several that have been depleted by over fishing. These included juveniles of Gulf of Maine Atlantic cod, yellowtail flounder, winter skate, northern sandlance, and longhorn sculpin. Priority area no. 9 was also important for cunner, Altlantic wolffish, and ocean pout, and it contributed to the goal for demersal fish species richness. In terms of marine mammals, this priority area was most important for the bottlenose dolphin and humpback whales, but it did contribute to meeting goals for most (73%) of the eleven species included in the analysis, including the highly endangered North Atlantic right whale. This priority area for conservation contributed 80% or more of the representation for four of the benthic and two of the pelagic seascapes; and, to a smaller extent, it contributed to several other seascape goals. Comprised of one-third gravel and till and one-third sand, with the remaining portion made up of clays, silts, and muddy sands, this priority area for conservation had a mean depth of 75 m ± 23 (247 ft ± 76).

Priority area for conservation no. 10 (8 planning units; Gulf of Maine) was an elongate area extending from Jeffreys Ledge north toward Casco Bay on the coast of Maine, and covered an area of 2,107 km^2 (614 nmi^2; 813 mi^2). This area was similar to priority area no. 9 in its contribution to abundance goals for a large number of fish species (90%) and to demersal fish species richness. It also contributed moderately to meeting goals for 7 of 11 cetaceans as well as primary production. This area encompassed a diversity of seascape types, including eight benthic and four pelagic seascapes. Similar to priority area for conservation no. 6, the bottom of this one was approximately two-thirds clays and silts and one-third gravel and till with a small amount of muddy sands. Mean depth was 127 m ± 54 (416 ft ± 176). This is an area where cod and haddock are known to have spawned historically (Ames 2004).

Priority area for conservation no. 11 (1 planning unit; Gulf of Maine) was a small shallow site situated in Penobscot Bay, near the islands of North Haven and Vinalhaven in Maine. This area made only moderate contributions to biological goals, including contributions to many of the fish goals (41% for juveniles, 15% for adults) and a small contribution to the goal for harbour porpoise. This priority area was more important for meeting seascape goals, including exclusive representation of one of the 29 Gulf of Maine benthic seascapes and a moderate contribution to two of the 14 Gulf of Maine pelagic seascapes. This priority area for conservation had a mean depth of 32 m ± 11 (105 ft ± 37) and contained equal amounts of clays and silts and gravel and till. This is another coastal area that includes an historically important cod spawning area (Ames 2004).

Priority area for conservation no. 12 (14 planning units; Gulf of Maine) was a relatively large priority area for conservation of 3,617 km^2 (1,055 nmi^2; 1,396 mi^2), in the region of Schoodic Ridge and Jordan Basin, that contributed to most of the fish goals (85%) and Gulf of Maine goals for demersal fish species richness, and contributed substantially to primary production. The area contributed to juvenile fish goals for a relatively large number of species (89%), and half or more of the goal was met for a number of these including Atlantic cod, white hake, longhorn sculpin, and witch and winter flounder. Goals were fully achieved for winter flounder (adults and juveniles) and adult windowpane flounder at priority area no. 12. Modest contributions were made for 5 of 11 cetaceans including humpback, fin, minke, and right whales. A substantial contribution for harbour porpoise was also achieved in this area. Goals for ten different benthic seascapes were met, with one benthic seascape entirely represented. The area contributed to goals for four different pelagic seascapes. Predominantly comprised of clays and silts, the bottom of this priority area for conservation also contained small amounts of gravel and till and muddy sands. Mean depth was 145 m ± 50 (476 ft ± 164).

Priority area for conservation no. 13 (5 planning units; Gulf of Maine and Scotian Shelf) was located just south of Grand Manan in Canada, overlapping the southern portion of one of the two Canadian North Atlantic Right Whale Conservation Areas (DFO). This priority area for conservation was 1,279 km^2 (373 nmi^2; 494 mi^2) and, like priority area no. 12, it contributed to a great many of the biological goals, including making modest contributions to fish species richness and primary production. The area contributed to 7 of 11 cetacean goals including about one-third of each of the goals for North Atlantic right, humpback, fin, and minke whales, and almost half the goal for harbour porpoise. It also contributed moderately to over half of the demersal fish goals, including juveniles of a number of commercially exploited species such as Atlantic cod, white hake, ocean pout, and haddock. The area provided representation for five benthic seascapes, with over 80% of the goal being met for two of them. It also provided representation for four pelagic seascapes, with most of the goal being met for one of them. The bottom of priority area no. 13 was mostly gravel and till with some muddy sands and a small amount of clays and silts. Mean depth was 143 m ± 51 (468 ft ± 168). Our analysis of the distributions of female fish indicate that this priority area includes a spawning area for silver hake (Bryan 2005).

Priority area for conservation no. 14 (1 planning unit; Gulf of Maine) was a single planning unit inside the Bay of Fundy that contributed little to the biological goals except it made a small contribution to the goal for primary production. However, this priority area did provide complete representation for one of the benthic seascapes. It also contributed to four pelagic seascapes including a substantial part of the representation of one of these (68; -39210). Mean depth was 81 m ± 4 (267 ft ± 14) and the seafloor type was entirely sand.

Priority area for conservation no. 15 (1 planning unit; Scotian Shelf), just outside St. Mary's Bay, Nova Scotia, was a single planning unit that contributed primarily to meeting goals for seascapes. It contributed substantially to two of the benthic seascapes, providing exclusive representation for one (432; 22120) and holding the full complement of the goal for another that was over-represented in combination with priority areas no. 18 and no. 26 (436; 22220). This area also made modest contributions to two of the pelagic seascapes. With a mean depth of 64 m ± 11 (211 ft ± 38), the seafloor type was entirely muddy sands.

Priority area for conservation no. 16 (1 planning unit; Scotian Shelf) was another single planning unit off western Nova Scotia, near Yarmouth. This priority area was in the bottom quartile in terms of its overall contribution. It provided exclusive representation for one of the benthic seascapes and made small contributions to one additional benthic and three pelagic seascapes. It contributed little to meeting biological goals with the exception that about one-fifth of the goal for adult winter flounder was attained at this priority area. Mean depth was 69 m ± 8 (225 ft ± 28) and the bottom was made up entirely of muddy sands.

Priority area for conservation no. 17 (1 planning unit; Scotian Shelf) was a single planning unit due south of priority area for conservation no. 16, in the region of German Bank, that contributed to two benthic seascapes, one modest and the other substantial (71%), and made modest contributions to two of the pelagic seascapes. It made no notable contribution to any of the biological goals, and contributed only a single planning unit toward the goal for primary production. This priority area was in the bottom quartile in terms of its overall contribution. Mean depth was 81 m ± 5 (267 ft ± 17). The seafloor type was three-quarters gravel and till and one-quarter sand.

Priority area for conservation no. 18 (46 planning units; Georges Bank, Gulf of Maine, Scotian Shelf), at 12,279 km^2 (3,581nmi^2; 4,741 mi^2), was the largest priority area for conservation. It extended north from the northeastern tip of Georges Bank through the Fundian Channel in the Gulf of Maine region, and into the southernmost portion of the Scotian Shelf. A small portion at the northern edge of Georges Bank (11%) was in an area of gravel and till of well-known importance to juvenile cod and other demersal fishes. An additional 11% fell in the Gulf of Maine region in the deeper waters of the Fundian

Channel, again with gravel and till substrate. The larger part on the Scotian Shelf (78%) encompassed two ecologically important features, Browns Bank and Roseway Basin, including one of the Canadian North Atlantic Right Whale Conservation Areas (DFO). The data available for cetaceans in the southeastern portion of the Scotian Shelf clearly indicated that the portion of this priority area for conservation co-extensive with Roseway Basin was a high-use area for most of the cetacean species, including right whales (see Figure 7-7). As expected, this priority area for conservation contributed to the goals for an unusually large number of biological and abiotic goals. It contributed to varying degrees to the attainment of 12 pelagic seascapes, including two for which the representation was exclusive, and three for which this priority area provided at least 60% of the goal. Twenty-six benthic seascapes were represented to some extent within priority area no. 18; 10 of these were entirely represented, and 19 were represented at over 50% of the goal. Priority area no. 18 was very important to the attainment of abundance goals for a host of juvenile fishes including haddock, Acadian redfish, pollock, moustached sculpin, alligatorfish, and little skate. Eighty percent or more of the goals for adult haddock, winter flounder, pollock, moustached sculpin, Atlantic hookear sculpin, Atlantic wolffish, little skate, and thorny skate were also attained at this priority area. This area contributed substantially to goals for both juvenile and adult Georges Bank cod, and to a lesser degree to Scotian Shelf cod goals. The bottom of this priority area for conservation was a little over one-third gravel and till, with the remainder consisting of muddy sands and sand and a small amount of clays and silts. Mean depth was 125 m ± 58 (411 ft ± 189). Our analysis of distributions of spawning female fish indicate that this priority area may include spawning areas for haddock, silver hake, and yellowtail flounder (Bryan 2005).

Priority area for conservation no. 19 (14 planning units; Scotian Shelf) was mid-sized, at 3,675 km^2 (1,072 nmi^2; 1,419 mi^2), on the Scotian Shelf, including a portion of LaHave Bank, and LaHave and Emerald Basins. This priority area for conservation was particularly important to meeting benthic seascape goals, but it made modest contributions to a number of biological goals including species richness and abundance for 20 juvenile and 21 adult fish goals. Most of these contributions (85% juveniles and 57% adult) were less than one quarter of the goal. This priority area for conservation provided representation for six benthic seascapes; for five of these it contributed over half of the Scotian Shelf goal. The contribution to pelagic seascapes was modest with small contributions to each of three types. Mean depth was 167 m ± 38 (546 ft ± 124) and the bottom consisted of nearly equal portions of clays and silts, gravel and till, and muddy sands. Our analysis of distributions of spawning female fish indicate that priority area no. 19 may include spawning areas for haddock and silver hake (Bryan 2005).

Priority area for conservation no. 20 (1 planning unit; Scotian Shelf) was a small site on the edge of the Scotian Shelf just south of Emerald Bank. This priority area was most important for its contribution to the representation of just two benthic seascapes, with one of these being exclusively represented in this single planning unit (401, 5240). Priority area for conservation no. 20 made only a minor contribution to a single pelagic seascape. It made only minor contributions (<5% of goal) for a few of the fish species. This was another priority area for conservation that fell in the bottom quartile in terms of overall contribution to goals. The seafloor type was half gravel and till, and half muddy sands. Mean depth was 115 m ± 3 (376 ft ± 11). Our analysis of distributions of spawning female fish indicate that this priority area may include spawning areas for silver hake (Bryan 2005).

*Priority area for conservation no. 2*1 (1 planning unit; Scotian Shelf), a single planning unit located in Emerald Basin, made minor contributions to a small number of seascapes and biological goals and was among the priority areas in the lower quartile. None of the contributions to fish goals reached 25%. Goals for only three juvenile and four adult fish were at 5% or more. The contribution to fish species richness was <2% of the goal and there was no contribution to primary production. The area did contribute about 10% of the goal for juvenile red hake, and 17% of the goal for adult gulf stream flounder. This priority area for conservation also made modest contributions to two pelagic seascapes, providing about one-third of the representation for one of these. Modest contributions were made for three benthic seascapes. Mean depth was 197 m ± 18 (647 ft ± 57), The bottom consisted of three-quarters clays and silts and one-quarter muddy sands.

Priority area for conservation no. 22 (1 planning unit; Scotian Shelf) was an isolated planning unit near the coast, just east of Dartmouth, Nova Scotia. It played a key role in meeting the goal for a single benthic seascape, and played a minor role for a second seascape. It also played a minor role for two of the pelagic seascapes. Priority area no. 22 also made a minor contribution to the various biological goals, with no contribution exceeding 25% (max. = 12% for adult red fish). This priority area made small contributions to goals for two of the juvenile fishes and six adult fishes, as well as to fish species richness, but it contributed nothing to primary production. This priority area for conservation was in the bottom quartile overall. With a mean depth of 73 m ± 27 (241 ft ± 88), priority area for conservation no. 22 consisted entirely of gravel & till. Our analysis of distributions of spawning female fish indicate that this priority area may include spawning areas for silver hake (Bryan 2005).

Priority area for conservation no. 23 (7 planning units; Scotian Shelf) was a moderately sized area of 1,786 km^2 (521 nmi^2; 690 mi^2) on the Scotian Shelf, north of Western Bank in the area of The Bull Pen. This priority area for conservation contributed modestly to 16 juvenile and 18 adult fish goals, but the contributions exceeded a quarter of the goal for only five of each. There was also a small contribution (11%) to the goal for demersal fish species richness. This priority area made no contribution to the goal for primary production. Priority area no. 23 contributed to goals for 5 of the 57 Scotian Shelf benthic seascapes, and provided 85% of the goal for one of these. The contribution to 4 of 19 pelagic seascape goals was small, with a maximum of 16%. Mean depth was 168 m ± 24 (550 ft ± 80). The seafloor type was predominantly clays and silts with a small amount of gravel and till. Our analysis of distributions of female fish indicate that this priority area may include spawning areas for silver hake (Bryan 2005).

Priority area for conservation no. 24 (11 planning units; Scotian Shelf) extended from the shelf edge in the region of Dawson Canyon, north onto Sable Island Bank. This was one of the moderately large priority areas for conservation, at 2,868 km^2 (836 nmi^2; 1,107 mi^2), and it contributed to a wide diversity of biological and seascape goals. This area made substantial contributions to the benthic seascapes by contributing to a total of seven different types, at 50% or more for four of these, and by providing exclusive representation for two (411, 6340; 412, 6420). Similarly, priority area no. 24 contributed to seven pelagic seascapes and provided over half of the representation for four of these. It also contributed to the goal for Scotian Shelf primary production and for demersal fish species richness. This area contributed to 77% of juvenile fish goals, including half or more of the goal for six species, and it contributed to 62% of goals for adults, with five species at half or more of the goal. The bottom was predominantly sand with small amounts of gravel and till and muddy sands. Mean depth was 98 m ± 119 (323 ft ± 391). Our analysis of distributions of spawning female fish indicate that this priority area may include spawning areas for haddock, yellowtail flounder and silver hake (Bryan 2005).

Priority area for conservation no. 25 (10 planning units; Scotian Shelf) was another moderately large area . It covered an area of 2,512 km^2 (732 nmi^2; 970 mi^2) in the area of Canso Bank at the eastern portion of the Scotian Shelf. This priority area made diverse contributions to biological and abiotic goals. It contributed to over half of the juvenile and adult goals for demersal fishes, with levels over 50% for several, including juvenile Atlantic sea poacher, snake blenny, and adult daubed shanny. This was one of only three areas that contributed to the goals for Greenland halibut (juveniles). It also contributed to the goal for species richness (10%) and to primary production (18%). Four of seven benthic seascapes represented at this priority area had over half of their goals met here, including exclusive representation of three. Of seven pelagic seascapes represented, at least half of the goals for three were met here. The bottom was half clays and silts, with smaller amounts of gravel and till and sand, and a trace amount of muddy sands. Mean depth was 129 m ± 51 (424 ft ± 166).

Priority area for conservation no. 26 (34 planning units; Scotian Shelf) was the second largest priority area in the network, at 8,556 km^2 (2,495 nmi^2; 3,304 mi^2). It extended north from the Gully to Scatarie Bank at the easternmost part of the Scotian Shelf region. This large area contributed to over one-fifth of the demersal fish species richness goal for the Scotian Shelf and to a similarly large part of the goal for areas of high primary production. The priority area contributed to over 80% of the goals for juvenile and adult fishes, making major contributions (≥50%) to juvenile and adult daubed shanny, snake blenny, northern sand lance, Atlantic sea poacher, thorny skate, and American plaice. The area also made a major contribution to juvenile snowflake hookear sculpin, smooth skate, and witch flounder, and it was the most important of three priority areas for conservation where juvenile Greenland halibut were represented. The priority area contributed to adult goals for Atlantic spiny lumpsucker, moustached sculpin, and four beard rockling, all at half or more of the abundance goal. It also contributed to 53% of the Scotian Shelf benthic seascapes (n = 57 total), and most of these were represented at 50% or more of the goal. Fourteen benthic seascapes were captured only within this priority area for conservation. Twelve of nineteen Scotian Shelf pelagic seascapes (63%) were represented here, with five (26%) represented at ≥50% of the goal. Three of these were represented only in this area. The bottom had approximately equal portions of clays and silts, gravel and till, muddy sands, and sand. Mean depth was 124 m ± 50 (408 ft ± 164). Our analysis of distributions of spawning female fish indicates that this priority area may include spawning areas for yellowtail flounder and silver hake (Bryan 2005).

Priority area for conservation no. 27 (1 planning unit; Scotian Shelf) was an isolated planning unit located at the head of Shortland Canyon. It made only minor contributions to biological goals (max. <5%), i.e., to five juvenile fish and nine adult fish. Priority area no. 27 played an important role in meeting benthic seascape goals by contributing to three types and providing exclusive representation for one of these. The area also contributed to two pelagic seascapes, but these contributions were minor (<5%). Mean depth was 141 m ± 82 (462 ft ± 271). The bottom was half muddy sands and half sand. An analysis of distributions of spawning female fish indicated that this priority area for conservation may include spawning areas for yellowtail flounder (Bryan 2005). This was one of the eight single-planning-unit areas that was in the bottom quartile for its overall contributions.

Priority area for conservation no. 28 (2 planning units; Scotian Shelf), like priority area no. 29, was small and located at the shelf edge along the Laurentian Channel just south of Scaterie Bank. The extent of this priority area for conservation was 492 km^2 (144 nmi^2; 190 mi2). It made substantial contributions to goals for four of the benthic seascapes – exceeding goals for two – and providing exclusive representation for one of these (455, 30310). Minor representation was provided for three pelagic seascapes. It made a small contribution to species richness for demersal fishes, and contributed to varying degrees to the goals of 12 (40%) juveniles and 16 (47%) adults. Priority area for conservation no. 30 was one of three priority areas that contributed to the goal for juvenile Greenland halibut (15%). The area also contributed notably (10% of goal or more) to both stages of Atlantic wolffish, adult Atlantic hagfish, lumpfish, snowflake hookear sculpin, and Atlantic hookear sculpin. One-quarter of the bottom consisted of clays and silts, and the remainder was largely muddy sands, with about a quarter clays and silts. Mean depth was 188 m ± 38 (616 ft ± 126).

Priority area for conservation no. 29 (2 planning units; Scotian Shelf) was a small area of 500 km^2 (146 nmi^2; 193 mi^2) located where the eastern edge of the Scotian Shelf meets the Laurentian Channel, near Artimon and Misaine Banks. The most significant contributions of this priority area were to the benthic seascapes; it contributed to five (9%) and the contributions to three of these were at or above the goal. The network representation of two of these benthic seascapes was exclusive to this area. Modest contributions were made to three (16%) of the pelagic seascape goals. This area made a modest contribution to species richness for demersal fishes, and contributed small amounts toward meeting abundance goals for 43% of the juvenile and 53% of the adult abundance goals. This priority area for conservation was one of a few that contributed to the goals for North Atlantic hagfish – 15% for adults and 7% for juveniles. The bottom of this priority area for conservation was two-thirds muddy sands and one-third gravel and till, and it had a mean depth of 164 m ± 46 (537 ft ± 151).

Priority area for conservation no. 30 (3 planning units; Scotian Shelf) was a modest-sized priority area for conservation, with an extent of 759 km^2 (221 nmi^2; 293 mi^2), located on the Eastern Shoal of Banquereau near the easternmost part of the Scotian Shelf. The area contributed substantially to both pelagic and benthic seascape goals, and made moderate contributions for some of the demersal fishes. The area contributed to two pelagic seascapes, representing one of these at a level that slightly exceeded the goal and thus adding to the representation of this seascape that was also provided at one other priority area for conservation, i.e., no. 26. Contributions were also made for two benthic seascapes, including more than half the goal for one of them. Overall, this priority area no. 30 contributed to some extent to 23% of the juvenile demersal fishes goals and to 29% of adult goals. Particularly important contributions were provided for adult and juvenile winter skate, yellowtail flounder, and longhorn sculpin. Mean depth was 40 m ±6 (132 ft ± 19) and the bottom was entirely sand. An analysis of distributions of spawning female fish indicated that this priority area for conservation may include spawning areas for yellowtail flounder and silver hake (Bryan 2005).

Figure E-1, below: Summaries of all 30 priority areas for conservation in terms of their contributions to the goals for the different classes of conservation features (histograms) and their seafloor characteristics (pie charts). Histogram bars show the total number of conservation features to which each priority area for conservation contributed ≥10% of the goal, within each of the classes of conservation features. Note that total number of conservation features was highest for those priority areas for conservation that spanned more than one biogeographic area because goals were set for each. There were many more conservation features for fishes and seascapes than for the other classes. There was just one conservation feature for primary production per biogeographic area, as was the case for fish species richness. Note, there were no cetacean conservation features for the Scotian Shelf biogeographic area due to incomplete data (*).

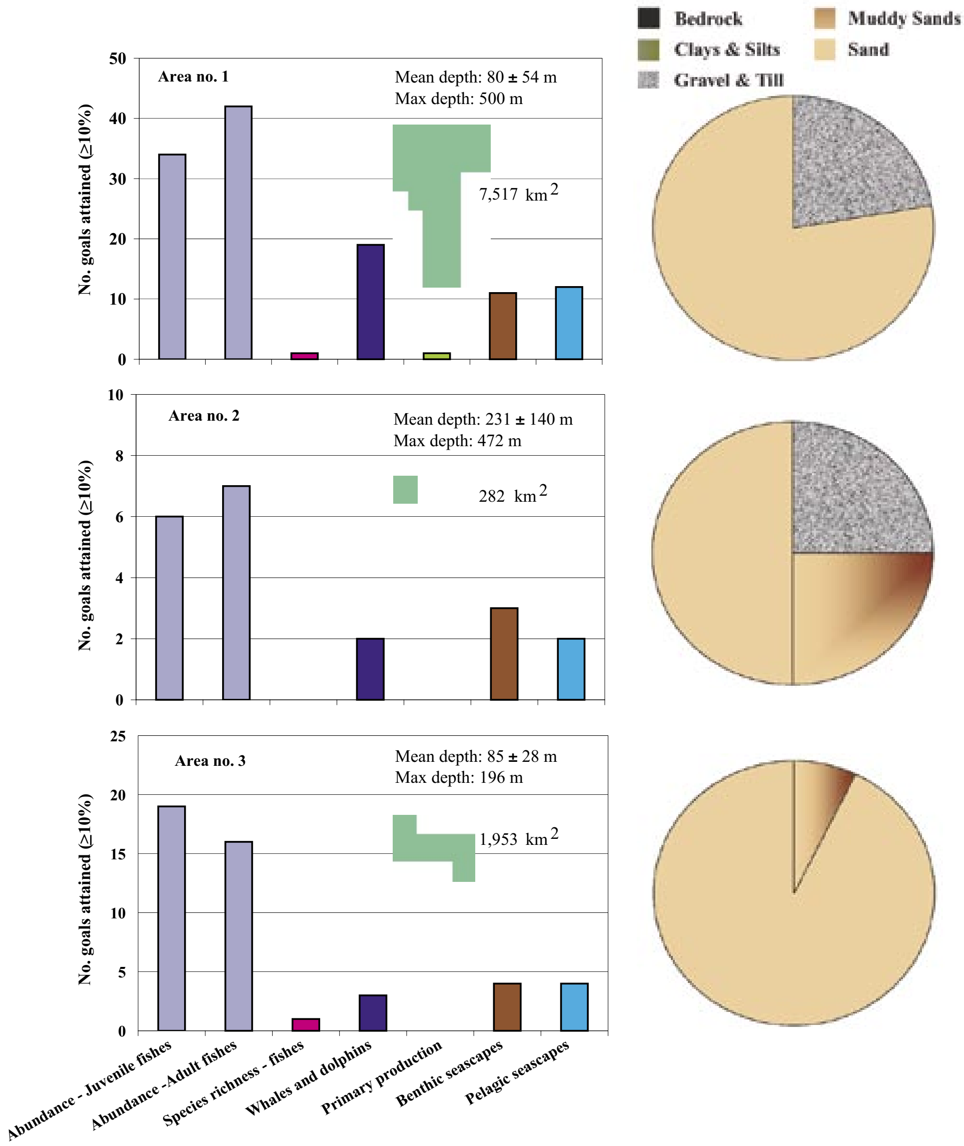


Figure E-1: (Continued)

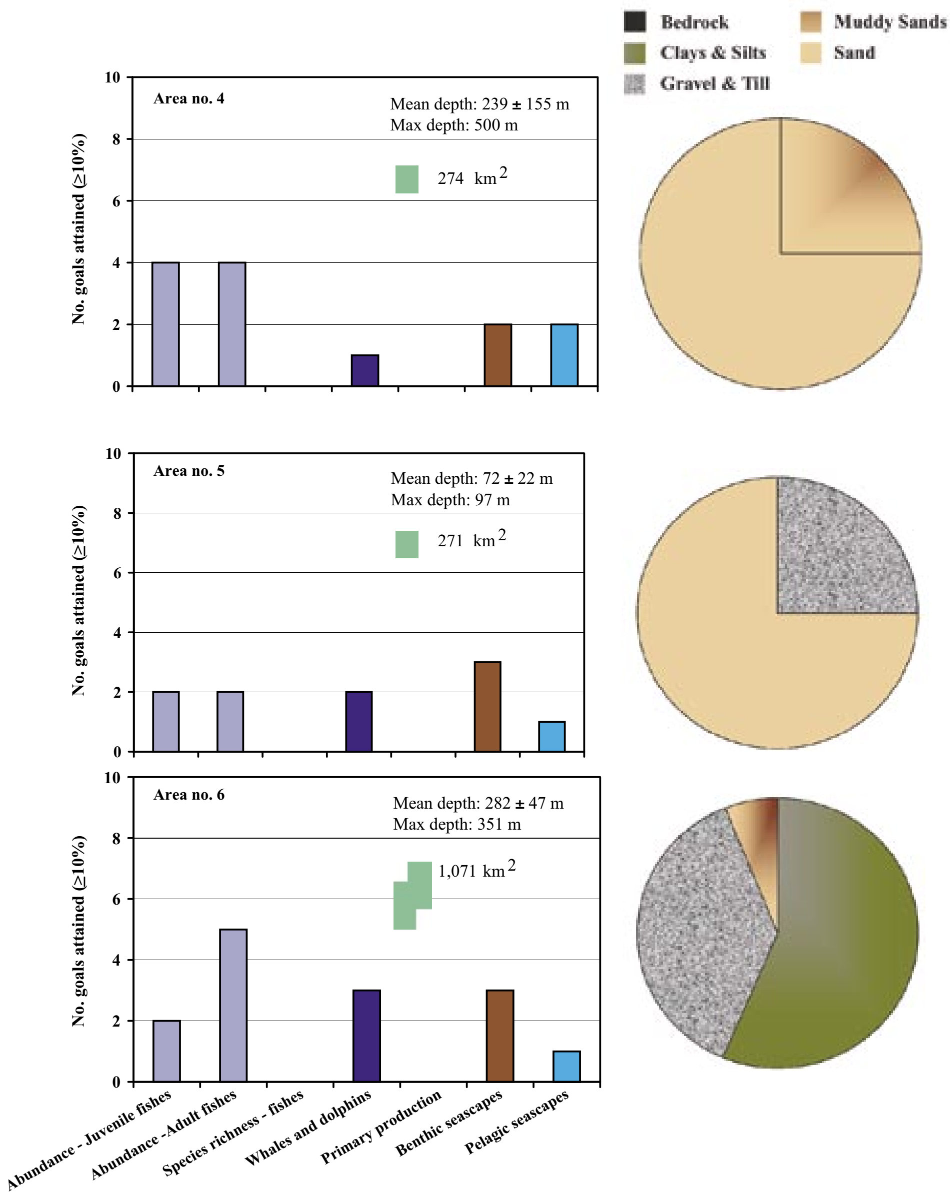
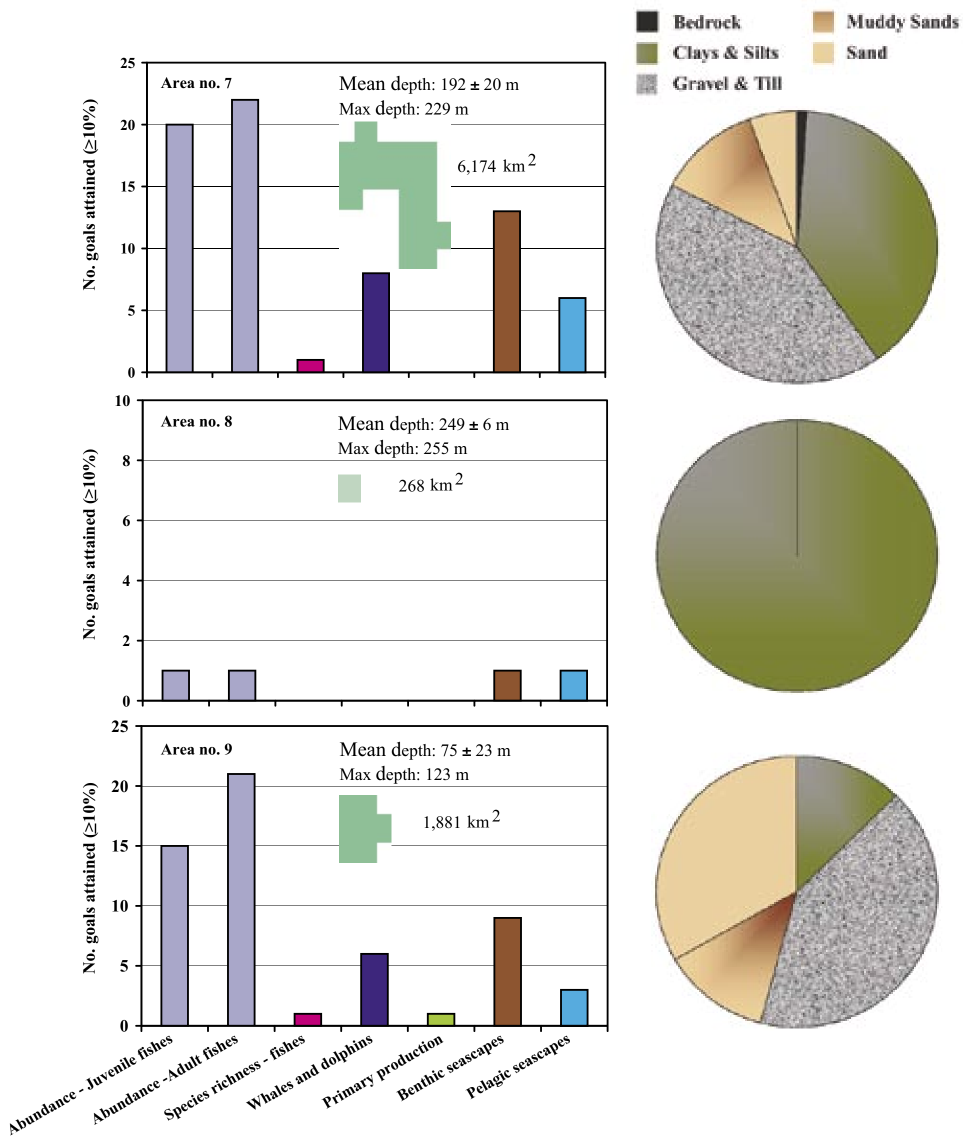


Figure E-1: (Continued)



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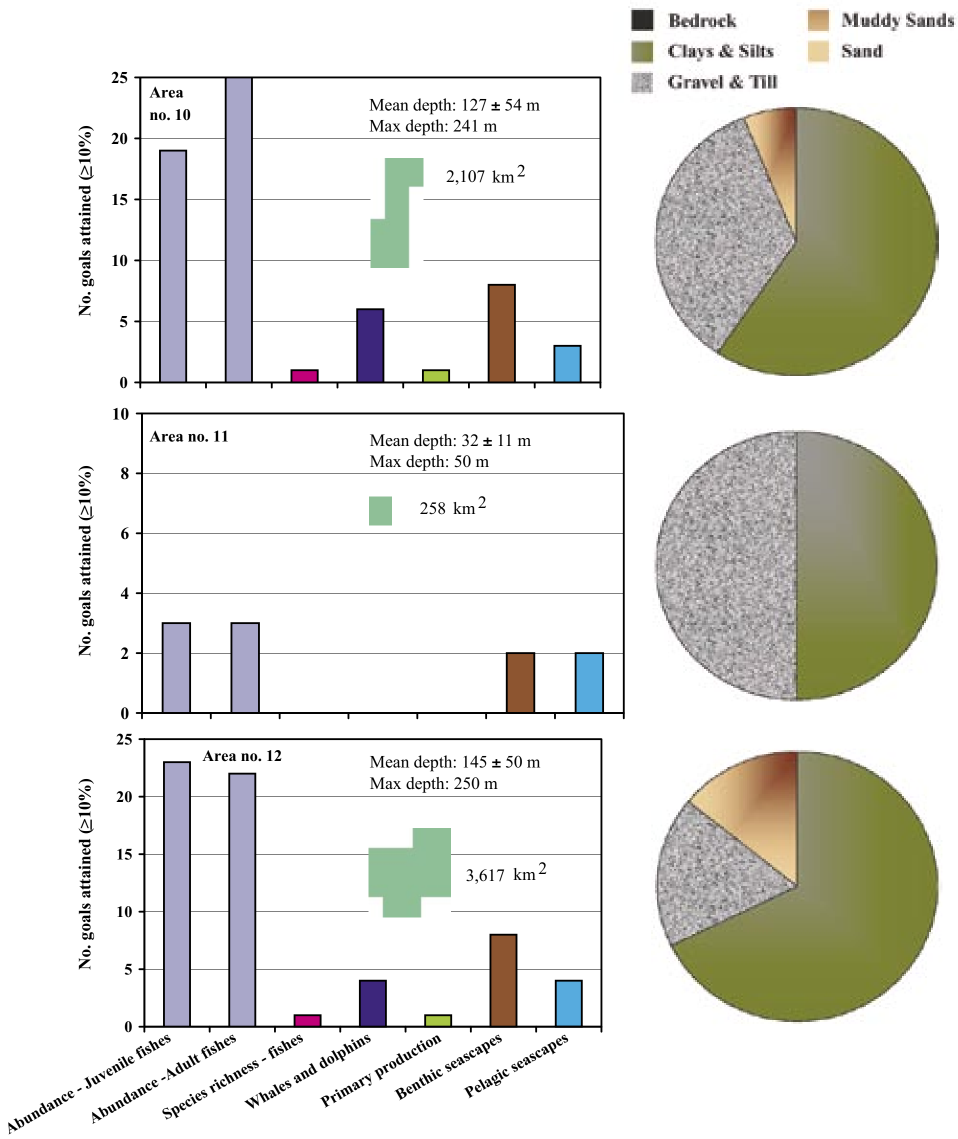


Appendices

Figure E-1: (Continued)

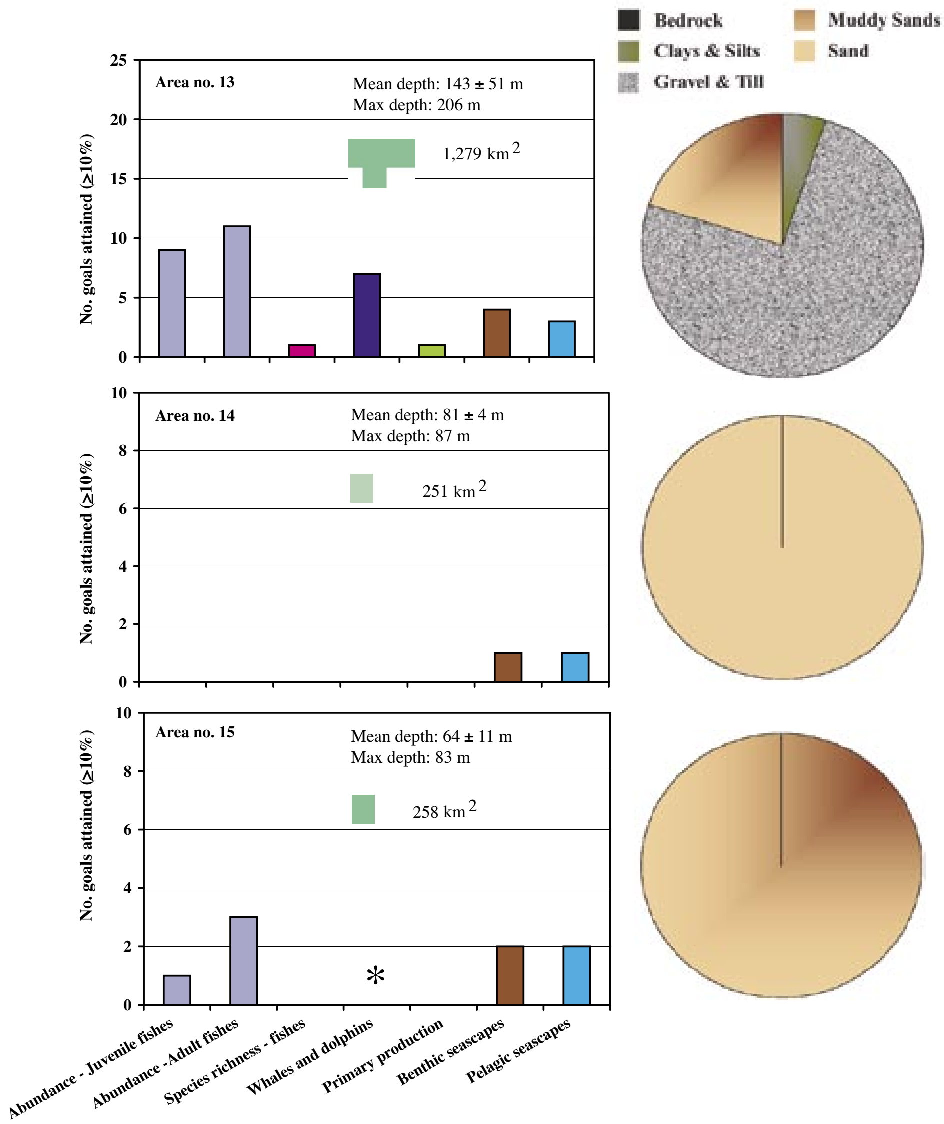
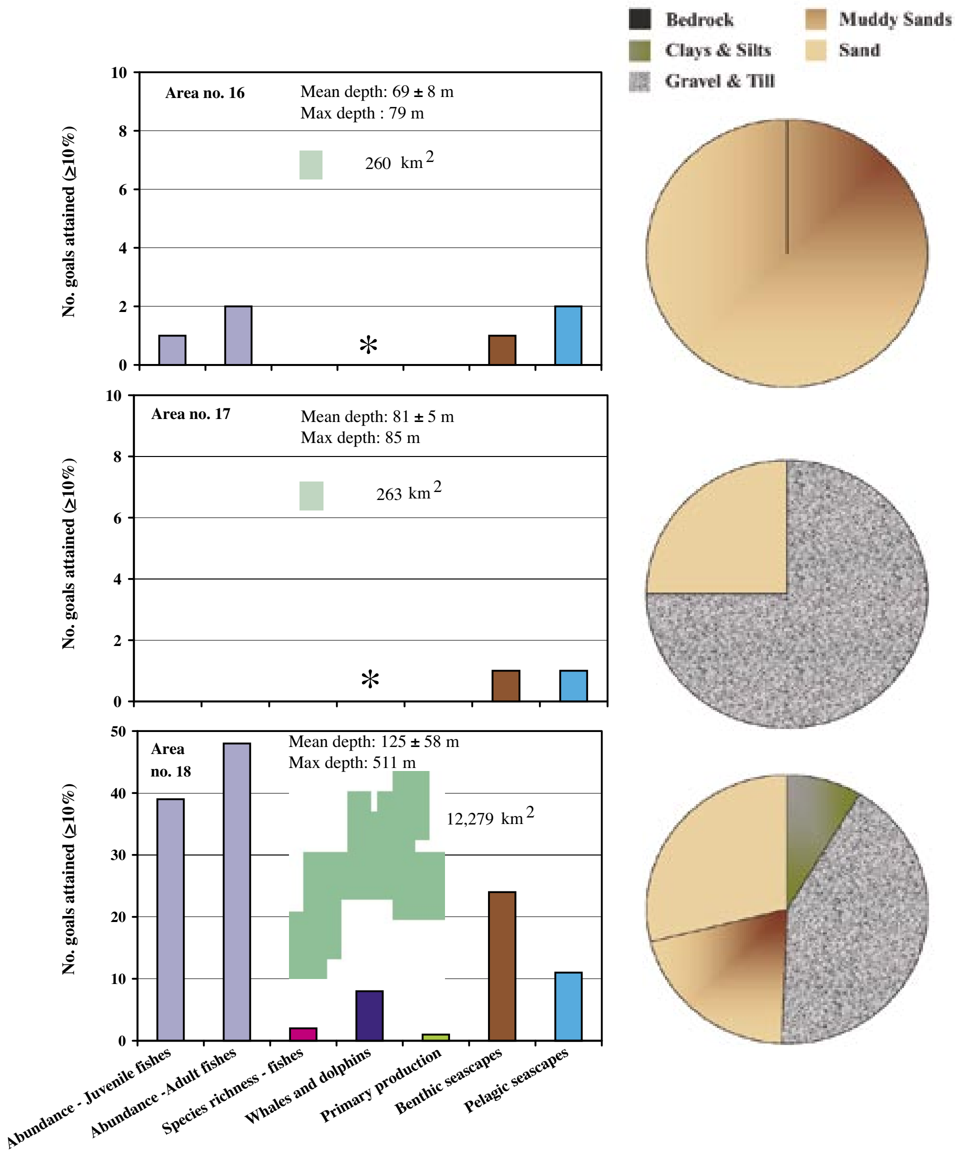
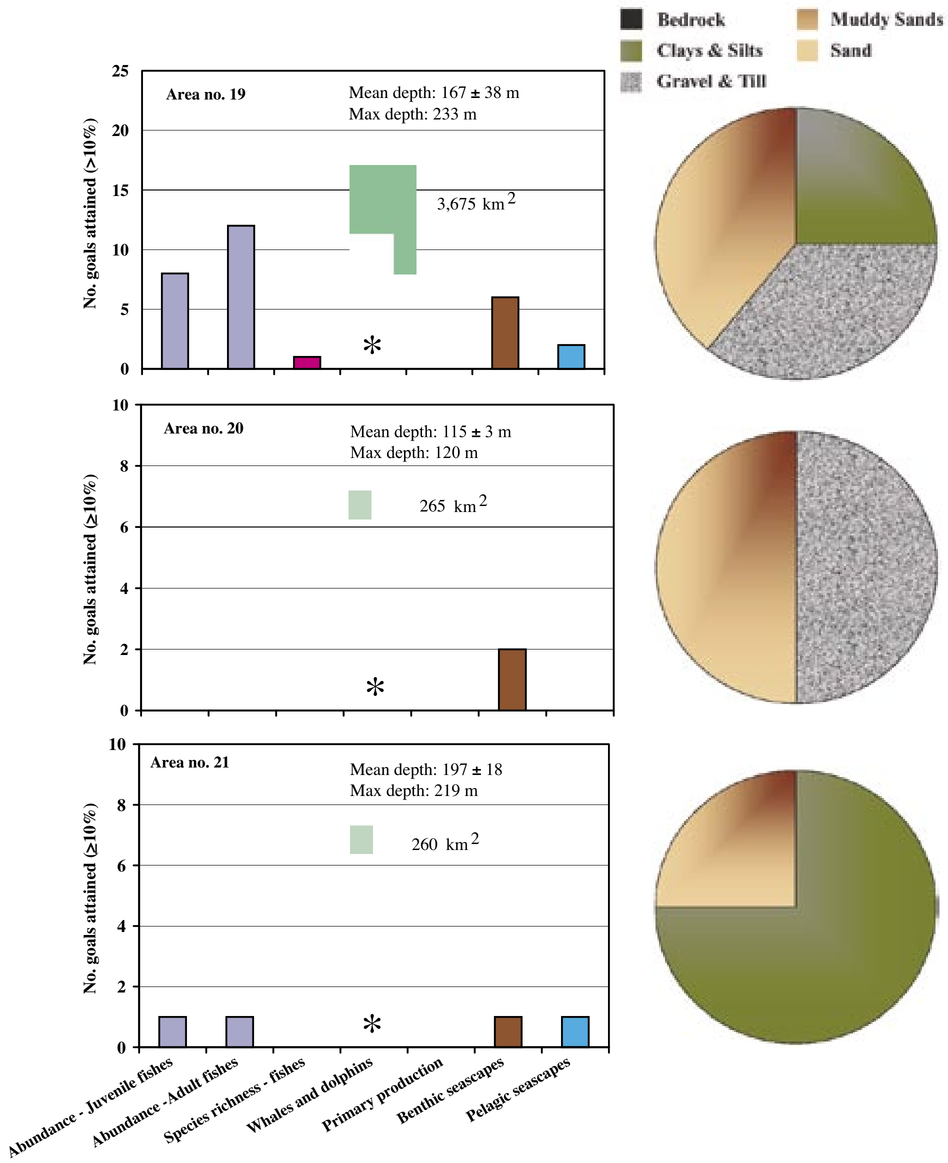


Figure E-1: (Continued)



Appendices

Figure E-1: (Continued)



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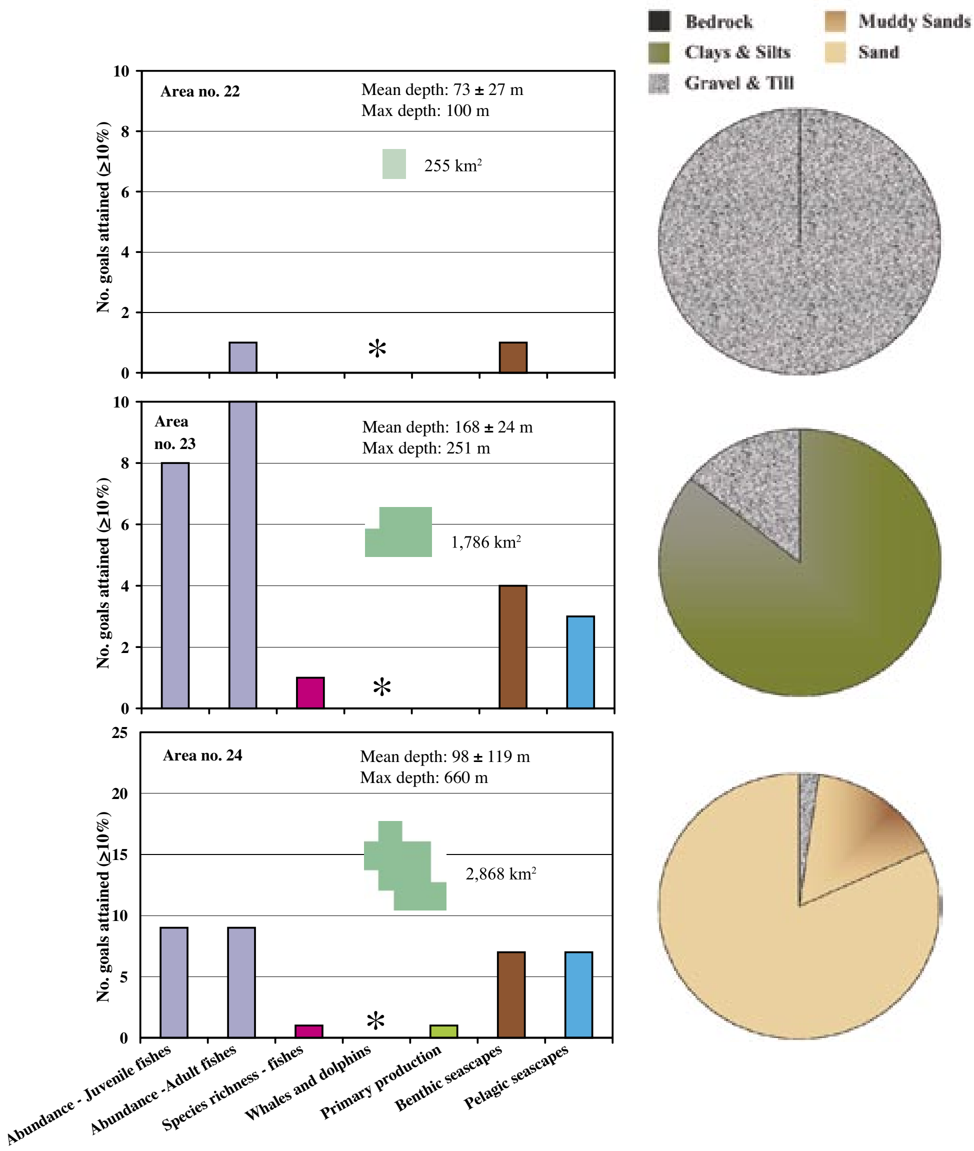

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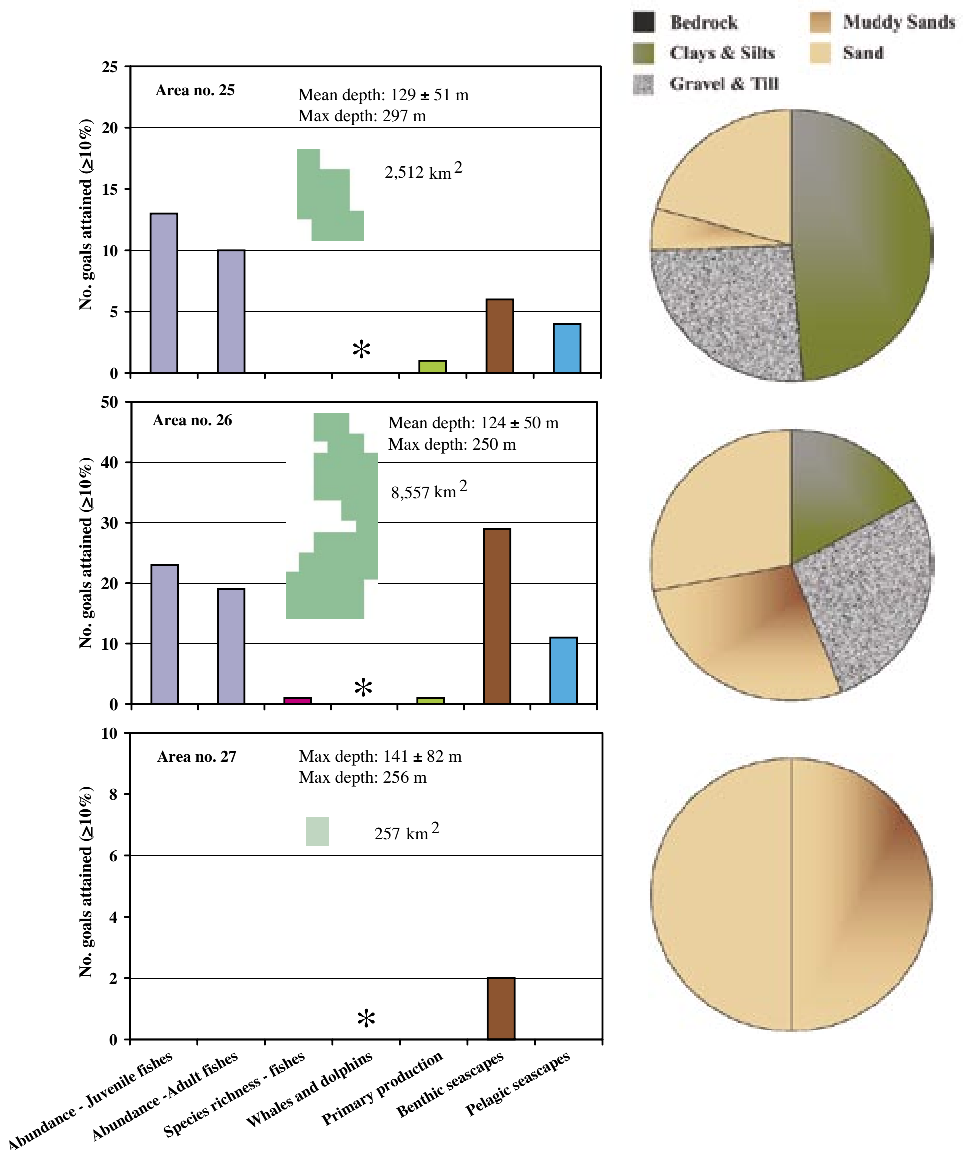

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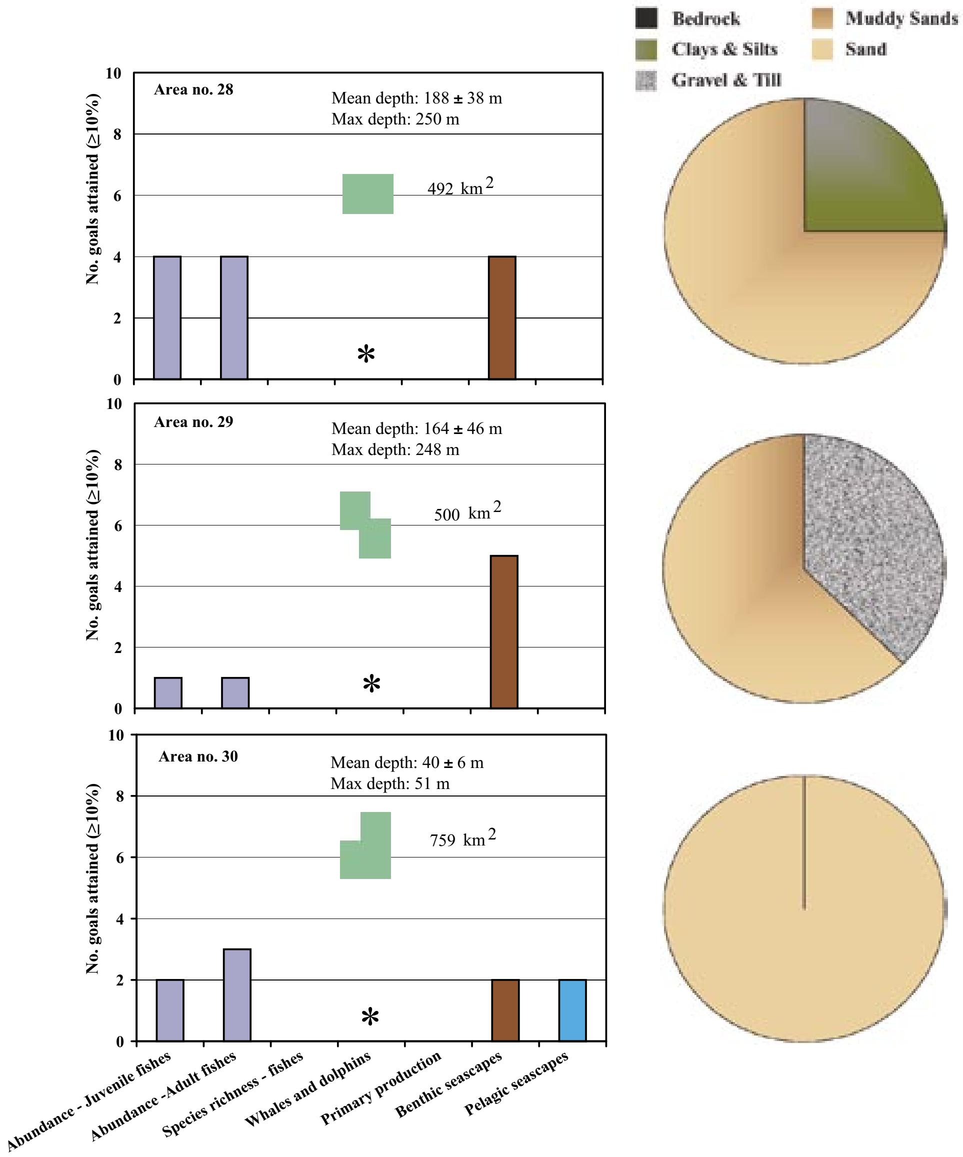

Marine Ecosystem Conservation for New England and Maritime Canada

Table E-1. Geographic coordinates of priority areas for conservation. Each planning unit is listed as the latitude and longitude of its center point.

Priority area for conservation no.	Planning units (no.)	Area (km2)	Biogeographic area	Longitude	Latitude
1	27	7517	Georges Bank	-68.42	40.92
				-68.75	41.25
				-68.58	41.25
				-68.58	40.92
				-68.75	40.92
				-68.42	41.08
				-68.58	41.08
				-68.08	41.25
				-68.92	41.08
				-68.25	41.42
				-68.42	41.25
				-68.25	41.25
				-68.75	41.08
				-68.58	40.25
				-68.42	40.25
				-68.42	40.42
				-68.58	40.42
				-68.42	40.58
				-68.58	40.75
				-68.08	41.42
				-68.58	41.42
				-68.42	41.42
				-68.58	40.58
				-68.42	40.75
			Gulf of Maine	-68.92	41.25
				-68.75	41.42
				-68.92	41.42
2	1	282	Georges Bank	-68.08	40.42
3	7	1953	Georges Bank	-67.58	40.92
				-66.92	40.75
				-67.58	41.08
				-67.42	40.92
				-67.25	40.92
				-67.08	40.92
				-66.92	40.92
4	1	274	Georges Bank	-65.92	41.58
5	1	271	Georges Bank	-67.25	42.08
6	4	1071	Gulf of Maine	-67.08	42.58
				-67.25	42.42
				-67.25	42.58
				-67.08	42.75
7	23	6174	Gulf of Maine	-68.42	42.75

Table E-1. (Continued)

Priority area for conservation no.	Planning units (no.)	Area (km^2)	Biogeographic area	Longitude	Latitude
				-68.42	42.58
				-68.25	42.75
				-68.08	42.75
				-68.75	42.75
				-68.92	42.75
				-68.75	42.92
				-68.58	42.75
				-67.92	42.08
				-68.25	42.25
				-68.08	42.25
				-68.08	42.42
				-68.25	42.42
				-68.92	42.42
				-68.75	42.58
				-68.08	42.08
				-68.25	41.92
				-68.08	41.92
				-68.08	42.58
				-68.25	42.58
				-68.58	42.58
				-68.92	42.58
				-68.25	42.08
8	1	268	Gulf of Maine	-69.75	42.58
9	7	1881	Gulf of Maine	-70.25	42.25
				-70.42	42.58
				-70.25	42.58
				-70.42	42.42
				-70.25	42.42
				-70.08	42.42
				-70.42	42.25
10	8	2107	Gulf of Maine	-69.92	43.25
				-70.08	43.08
				-69.92	42.92
				-70.08	42.92
				-69.92	43.08
				-69.92	43.42
				-69.75	43.58
				-69.92	43.58
11	1	258	Gulf of Maine	-68.75	44.08
12	14	3617	Gulf of Maine	-67.92	43.92
				-67.92	43.75
				-68.08	43.75
				-67.75	43.92
				-68.08	43.92
				-68.25	43.92

Table E-1. (Continued)

Priority area for conservation no.	Planning units (no.)	Area (km^2)	Biogeographic area	Longitude	Latitude
				-67.58	44.25
				-67.58	43.92
				-67.58	44.08
				-67.75	44.25
				-68.25	44.08
				-68.08	44.08
				-67.92	44.08
				-67.75	44.08
13	5	1279	Gulf of Maine	-66.92	44.42
				-66.75	44.42
				-66.58	44.42
				-66.42	44.42
				-66.75	44.25
14	1	251	Gulf of Maine	-65.58	45.08
15	1	258	Scotian Shelf	-66.42	44.08
16	1	260	Scotian Shelf	-66.42	43.75
17	1	263	Scotian Shelf	-66.25	43.25
18	46	12279	Scotian Shelf	-65.75	42.58
				-65.58	42.58
				-65.25	42.42
				-65.42	42.58
				-65.25	42.58
				-65.08	42.58
				-64.92	42.58
				-65.08	43.08
				-65.25	43.08
				-65.42	43.08
				-65.08	42.42
				-65.92	42.58
				-65.75	42.92
				-66.08	42.58
				-66.25	42.58
				-64.92	42.75
				-65.08	42.75
				-65.25	42.75
				-65.42	42.75
				-65.58	42.75
				-65.75	42.75
				-65.92	42.75
				-65.58	42.92
				-66.25	42.75
				-65.75	43.08
				-65.25	42.92
				-65.42	42.92
				-66.08	42.75

Table E-1. (Continued)

Priority area for conservation no.	Planning units (no.)	Area (km²)	Biogeographic area	Longitude	Latitude
				-65.25	43.42
				-64.92	42.42
				-65.08	43.25
				-65.58	43.08
				-65.25	43.25
				-65.42	43.25
				-65.75	43.25
				-65.08	43.42
			Gulf of Maine	-66.08	42.42
				-66.25	42.42
				-66.42	42.25
				-66.08	42.25
				-66.25	42.25
			Georges Bank	-66.42	41.92
				-66.08	42.08
				-66.25	42.08
				-66.25	41.92
				-66.42	42.08
19	14	3675	Scotian Shelf	-63.58	43.25
				-63.42	42.92
				-63.92	43.25
				-63.42	43.25
				-63.42	43.42
				-63.58	43.42
				-63.75	43.42
				-63.75	43.25
				-63.92	43.42
				-63.42	43.58
				-63.58	43.58
				-63.42	43.08
				-63.75	43.58
				-63.92	43.58
20	1	265	Scotian Shelf	-62.75	42.92
21	1	260	Scotian Shelf	-62.75	43.75
22	1	255	Scotian Shelf	-62.75	44.58
23	7	1786	Scotian Shelf	-61.58	44.58
				-61.92	44.42
				-61.75	44.42
				-61.58	44.42
				-61.75	44.58
				-62.08	44.42
				-61.92	44.58
24	11	2868	Scotian Shelf	-60.58	43.75
				-60.92	43.75
				-61.08	43.75

Table E-1. (Continued)

Priority area for conservation no.	Planning units (no.)	Area (km^2)	Biogeographic area	Longitude	Latitude
				-60.75	43.75
				-60.92	43.92
				-60.92	43.58
				-60.75	43.58
				-60.75	43.42
				-60.58	43.42
				-60.42	43.42
				-60.58	43.58
25	10	2512	Scotian Shelf	-60.42	45.08
				-60.58	45.25
				-60.75	45.08
				-60.58	44.92
				-60.42	45.25
				-60.58	45.08
				-60.75	45.25
				-60.75	45.42
				-60.25	44.92
				-60.42	44.92
26	34	8557	Scotian Shelf	-59.25	45.92
				-59.25	45.75
				-58.92	45.25
				-58.92	45.08
				-59.08	45.25
				-59.25	45.42
				-59.08	45.42
				-59.08	45.75
				-59.42	45.58
				-59.08	44.92
				-59.42	45.42
				-58.92	45.58
				-59.08	45.58
				-59.25	45.58
				-58.92	45.42
				-59.08	44.42
				-59.25	44.42
				-59.42	44.42
				-59.58	44.42
				-59.75	44.42
				-59.42	45.92
				-59.08	44.58
				-59.25	44.58
				-59.42	44.58
				-59.58	44.58
				-59.42	44.92
				-59.75	44.58

Table E-1. (Continued)

Priority area for conservation no.	Planning units (no.)	Area (km^2)	Biogeographic area	Longitude	Latitude
				-59.25	44.92
				-58.92	44.75
				-59.08	44.75
				-59.25	44.75
				-59.42	44.75
				-59.58	44.75
				-58.92	44.92
27	1	257	Scotian Shelf	-58.42	44.25
28	2	492	Scotian Shelf	-58.58	45.92
				-58.75	45.92
29	2	500	Scotian Shelf	-57.92	45.42
				-57.75	45.25
30	3	759.4	Scotian Shelf	-57.75	44.7502
				-57.583	44.9168
				-57.583	44.7502

Table E-2. Water depths in the network, by priority area for conservation number.

Priority area for conservation number [a]	Mean (m)	SD (m)	Min. (m)	Max. (m)	Mean (ft)	SD (ft)	Min. (ft)	Max. (ft)	Measurements (no.)
1	80	54	30	500	262	176	100	1640	108
2	231	140	135	472	759	459	444	1550	4
3	85	28	50	196	277	92	165	644	28
4	239	155	100	500	784	509	328	1640	4
5	72	22	50	97	236	73	163	317	4
6	282	47	201	351	926	155	658	1150	16
7	192	20	101	229	630	65	330	750	92
8	249	6	240	255	818	19	789	836	4
9	75	23	35	123	247	76	115	403	28
10	127	54	35	241	416	176	115	792	32
11	32	11	19	50	105	37	63	164	4
12	145	50	50	250	476	164	163	820	56
13	143	51	50	206	468	168	164	675	20
14	81	4	75	87	267	14	247	285	4
15	64	11	54	83	211	38	179	271	4
16	69	8	58	79	225	28	192	260	4
17	81	5	73	85	267	17	238	280	4
18	125	58	23	511	411	189	77	1677	184
19	167	38	91	233	546	124	298	765	56
20	115	3	110	120	376	11	362	392	4
21	197	18	170	219	647	57	559	717	4
22	73	27	42	100	241	88	138	328	4
23	168	24	145	251	550	80	475	822	28
24	98	119	38	660	323	391	125	2165	44
25	129	51	51	297	424	166	168	974	40
26	124	50	47	250	408	164	153	819	136
27	141	82	61	256	462	271	199	840	4
28	40	6	32	51	132	19	106	169	12
29	164	46	107	248	537	151	352	815	8
30	188	38	147	250	616	126	483	820	8

[a] See Figure 9-1 for locations of priority areas, by number.

References

Ames, E. P. (2004). Atlantic cod stock structure in the Gulf of Maine. *Fisheries* **29**, 10–28.

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Appendix F. Abbreviations

BIO	Bedford Institute of Oceanography
CETAP	Cetacean and Turtle Assessment Program
DFO	Department of Fisheries and Oceans-Canada
NARWC	North Atlantic Right Whale Consortium
NMFS	National Marine Fisheries Service
NOAA	National Oceanic & Atmospheric Administration
PIROP	Programme Intégré de recherches sur les oiseaux pélagiques
SPUE	Sightings Per Unit of Effort
USGS	United States Geological Survey