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Maritimes Region / **Région des Maritimes**

Significance of the Maritimes Region Ecosystem Research Initiative to Marine Protected Area network planning within Fisheries and Oceans Canada

Importance de l'initiative de recherche écosystémique dans la région des Maritimes dans le cadre de la planification du réseau de zones de protection marine au sein de Pêches et Océans Canada

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ABSTRACT

This research document outlines the relevance to Marine Protected Area (MPA) network planning of scientific work recently completed under Fisheries and Oceans Canada's Maritimes Region Ecosystem Research Initiative (ERI). Domestic legislation and international commitments that underpin MPA network planning within Canada, as well as recent policy developments that influence Canadian fisheries management are reviewed to help clarify definitions surrounding the use of the term MPA. Five component elements that the Department is required to consider in overseeing the process for implementing a network of MPAs are then described. For each network planning element, the anticipated science support needs are identified. Emerging ERI research results are described, including new methodological approaches that can contribute to this planning requirement. Similarly, anticipated requirements for ongoing science support for MPA network management, monitoring, review and evaluation, as well as implementation of the Department's Sensitive Benthic Areas policy, are briefly reviewed. Broader issues related to science support for MPA network planning, and linkage points between the Maritimes ERI and other regional, national, and international science programs are identified.

RÉSUMÉ

Le présent document de recherche décrit l'utilité de la planification du réseau de zones de protection marine de la recherche scientifique récemment réalisée dans le cadre de l'initiative de recherche écosystémique de la région des Maritimes de Pêches et Océans Canada. La législation nationale et les engagements internationaux qui soutiennent la planification du réseau de zones de protection marine au Canada, de même que les récentes élaborations de politiques qui influencent la gestion des pêches au Canada font l'objet d'un examen, de sorte à clarifier les définitions liées à l'utilisation du terme « zone de protection marine ». Cinq composantes du Ministère qui sont requises pour considérer la supervision du processus de mise en œuvre d'un réseau de zones de protection marine sont alors décrites. Les besoins prévus en matière de soutien scientifique sont décrits pour chaque composante de la planification du réseau. Les résultats de la recherche de l'initiative de recherche écosystémique font l'objet d'une description, y compris les nouvelles approches méthodologiques qui peuvent contribuer à la présente exigence de planification. De plus, les exigences attendues pour le soutien scientifique continu dans le cadre de la gestion, de la surveillance, de l'examen et de l'évaluation du réseau des zones de protection marine, de même que la mise en œuvre de la politique du Ministère liée aux zones benthiques vulnérables, sont brièvement examinées. Des enjeux plus vastes liés au soutien scientifique de la planification du réseau de zones de protection marine et aux liens entre l'initiative de recherche écosystémique dans la région des Maritimes et les autres programmes scientifiques internationaux, nationaux et régionaux sont déterminés.

INTRODUCTION

While a diverse range of specific fisheries and habitat management options are available to manage human use of Canada's ocean resources, such as spatial and temporal closures and restrictions in intensity of human interventions in particular marine locations, the designation of a network of marine protected areas (MPAs) is generally considered the cornerstone for a comprehensive approach to sustainable oceans use that respects Canada's various international commitments, and national ocean policy instruments. The overall rationale, key drivers, and projected timelines for implementation for a national network of MPAs have been well established. However, the actual process and specific considerations through which a network of MPAs will be developed, within the context of bioregional planning, remain developmental in scope. Fisheries and Ocean's (DFO's) Maritimes Region Ecosystem Research Initiative (ERI), while not designed primarily around science support for the development of MPA network planning, has undertaken a significant range of research activities that can contribute towards this exercise.

First, the structure of the Maritimes Region's ERI is outlined (see also Curran et al. 2012, and Brickman et al. 2012 for additional details on the overall scope of the scientific work). Next, the domestic legislation and international commitments that underpin MPA network planning within Canada is summarized, as well as recent policies under which fisheries management is evolving. Also, some of the definitions surrounding the use of the term MPA are clarified, based on both national and international formulations. Then, five planning elements that the Department is required to consider in overseeing the process for implementing an MPA network are reviewed. For each network element, anticipated science support needs and how ERI research results, including new methodological approaches, contribute to this planning requirement are identified. Similarly, anticipated requirements for ongoing science support for MPA network management, monitoring, review and evaluation are discussed, along with similar considerations for science support to the Department's Sensitive Benthic Areas (SBAs) policy (a component of the Department's Fisheries Renewal program: http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/benthi-back-fiche-eng.htm). Finally, some broader issues related to science support for species and habitat considerations of marine conservation planning are discussed, identifying linkage points between the Maritimes Region ERI and other regional, national, and international science programs.

THE MARITIMES REGION ECOSYSTEM RESEARCH INITIATIVE (ERI)

The overall structure and objectives of DFO Maritimes Region's ERI, along with distinctions between it and the historical structure of scientific research conducted within this DFO region are more fully covered by Curran et al. (2012). The ERI was viewed as an opportunity to augment regional research programs that provide the scientific basis for achievement of biodiversity, productivity and habitat-related objectives for an ecosystem approach to management in the Gulf of Maine. There were three research themes, worked on by teams of DFO scientists from the region's two science establishments (note that regional science reporting structures were revised, effective April 1, 2012, such that some of the Division and Section names that follow are no longer in use):

- Theme 1: Assess impact of climate variability and climate change on the ecosystems of the Gulf of Maine – led by researchers from the Ocean Sciences Division, and the Ecosystem Research Division at the Bedford Institute of Oceanography (BIO).
- Theme 2: Predict spatial patterns in benthic communities to assist management of human impacts – led by researchers from the Population Ecology Division (PED) at BIO,

and from the Coastal Oceanography and Ecosystem Research Section at the Saint Andrews Biological Station (SABS).

- Theme 3: Quantify the impact of ecosystem interactions on harvest rates and dynamics of commercially targeted (and non-targeted) species – led by researchers from PED and the Population Ecology Section at SABS.

Based on an environmental scan of emerging regional priorities, there was a decision to focus the Maritimes ERI predominantly on offshore portions of the Gulf of Maine region. Additionally, selection of research program areas was undertaken with consideration towards likelihood for developing partnership-based approaches, both internally within the Department (e.g. Theme 1 linking with the Department's Climate Change Initiative); nationally with academic researchers (e.g. Theme 2 linking with the Canadian Healthy Oceans Network, CHONe); bi-laterally with US federal research within the Gulf of Maine (e.g. Theme 3, ecosystem modeling); and internationally (e.g. Theme 2 linking with the International Census of Marine Life, CoML).

DOMESTIC LEGISLATION AND POLICY DRIVING PROTECTED AREA PLANNING

The key legislation driving the establishment of marine protected areas is the *Oceans Act* (1997), which states that, "for the purposes of integrated management plans...the Minister will lead and coordinate the development and implementation of a national system of marine protected areas on behalf of the government of Canada." An *Oceans Act* MPA may be designated for special protection for the conservation and protection of: a) commercial and non-commercial fishery resources, including marine mammals and their habitats; b) endangered or threatened marine species and their habitats; c) unique habitats; d) marine areas of high biodiversity or biological productivity; and e) any other marine resource or habitat as is necessary to fulfill the mandate of the Minister.

In September 2011, Canada's federal, provincial and territorial members of the Canadian Council of Fisheries and Aquaculture Ministers (all except Nunavut) approved the policy document *National Framework for Canada's Network of MPAs*. This now provides strategic direction for the design of a national network of MPAs, formed from component bioregional networks, the level at which planning will be undertaken. The Scotian Shelf Bioregion, which is inclusive of the Bay of Fundy, forms one of 13 Canadian bioregions (Figure 1).

Within the Scotian Shelf Bioregion (DFO Maritimes Region), the Oceans and Coastal Management Division (OCMD) of the Ecosystem Management Branch is leading MPA network planning, which requires both internal and external cooperation. Federal partners in this exercise include Environment Canada who can designate National Wildlife Areas and Migratory Bird Sanctuaries, and Parks Canada who can designate National Marine Conservation Areas. Provincial partners are Nova Scotia and New Brunswick who claim jurisdiction and manage a range of marine activities such as rockweed harvesting, aquaculture leasing and monitoring, and renewable energy siting. However, provincial authority to designate protected areas in the marine realm varies across the country and additionally; provinces do not have authority to restrict activities such as fishing.

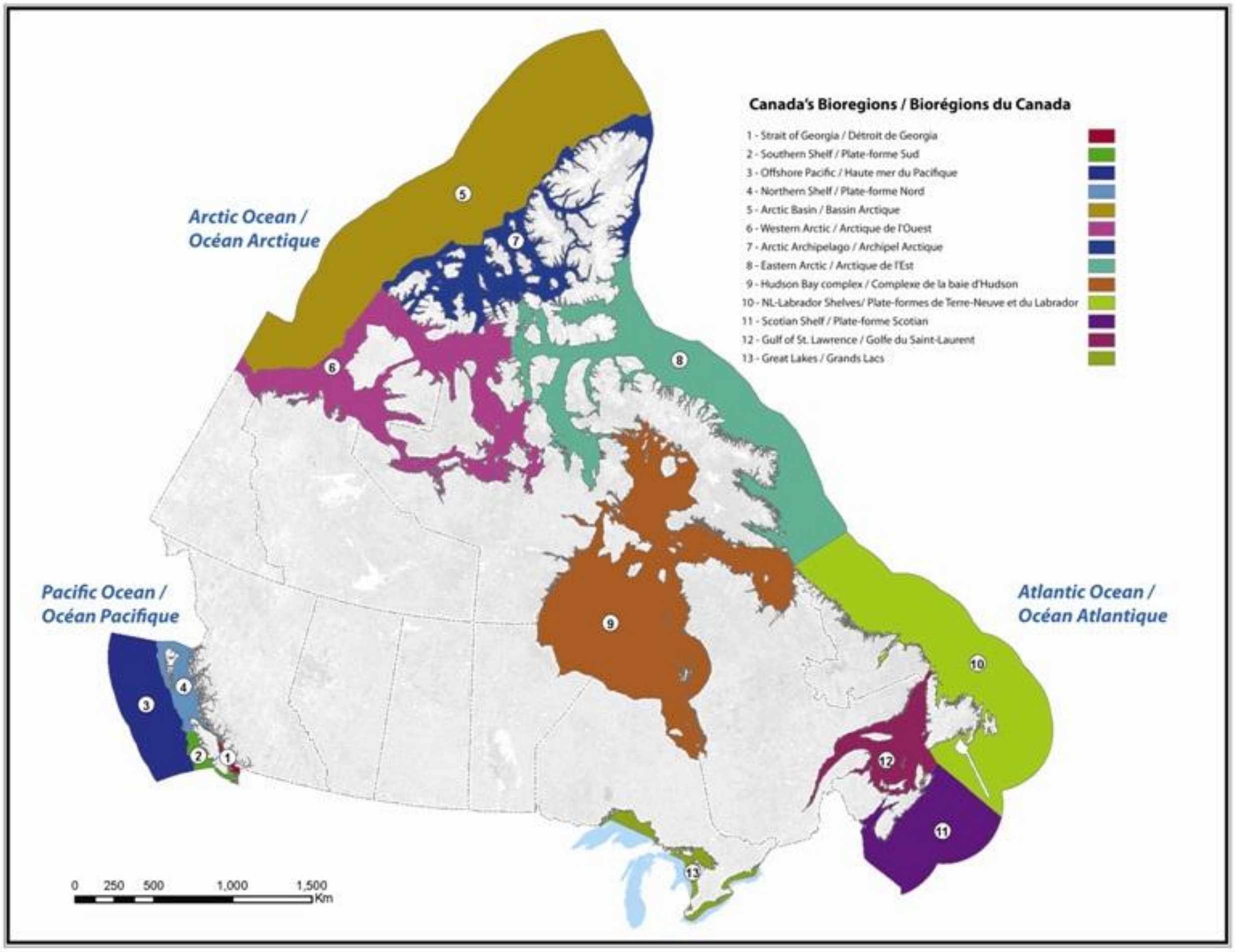

Figure 1. The bioregions of Canada's oceans, recommended by DFO Science as the appropriate scale for MPA network planning (DFO, 2009).

Internally, OCMD is working closely with the Maritime Region's Resource Management Branch, given an overlapping mandate of the two branches to protect marine habitat. Resource Management Branch's planning is guided by the *Policy for Managing the Impacts of Fishing on Sensitive Benthic Areas* (SBA Policy), which the Department published in 2009. The purpose of the SBA Policy is to help the Department manage fisheries to mitigate impacts of fishing on sensitive benthic areas or avoid impacts of fishing that are likely to cause serious or irreversible harm to sensitive marine habitat, communities and species.

INTERNATIONAL COMMITMENTS DRIVING PROTECTED AREA PLANNING

The United Nations 1992 Convention on Biological Diversity (CBD) set the primary international commitment for Canada to follow with respect to biodiversity conservation (Convention on Biological Diversity Secretariat, 2009). Article 8a of the CBD states, "Each Contracting Party shall, as far as possible and as appropriate, establish a system of protected areas or areas where special measures need to be taken to conserve biological diversity." Canada's response to the CBD was the 1995 *Canadian Biodiversity Strategy* that stated Canada would, "...make every effort to complete Canada's networks of protected areas representative of land-based natural regions by the year 2000, and accelerate the protection of areas that are representative of marine natural regions."

Subsequent international summits and follow-on processes to the original CBD have successively iterated the required commitments that parties should follow to ensure forward progress towards effective marine conservation within national jurisdictions, as well as on the high seas. These processes include the 2002 World Summit on Sustainable Development that led to the commitment to establish representative networks of MPAs by 2012, and the CBD 2004 Program of Work on Protected Areas commitment to establish a comprehensive MPA network within an overall ecosystem approach by 2012.

Most recently, in decision X/2 from the tenth meeting of the Conference of the Parties to the CBD, held in Nagoya, Aichi Prefecture, Japan, in October 2010, a newly revised and updated *Strategic Plan for Biodiversity for the 2011-2020 period* was adopted. This includes 20 Aichi Biodiversity Targets. Target 11, which falls under Strategic Goal C (to improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity) expects that by 2020, "…at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes."

In a similar manner to MPA network planning, the SBA Policy, and it's implementation activities, respond to international commitments undertaken by the Government of Canada, in this context largely with respect to Resolutions 59/25 (2005) and 61/105 (2007) of the General Assembly of the United Nations. These resolutions call upon regional fisheries management organizations to address the impact of destructive fishing practices on what are referred to as *vulnerable marine ecosystems* (akin to sensitive benthic areas).

WHAT IS A MARINE PROTECTED AREA (MPA)?

For the purposes of this research document, an MPA is defined as, "A clearly defined geographical space recognized, dedicated, and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values." This definition comes from international reviews sponsored by the International Union for the Conservation of Nature (IUCN) and the World Commission on Protected Areas (WCPA) (Dudley, 2008). The Department is currently drafting new criteria for defining MPAs, but these have not been finalized (as of October 2012). The definition above implies a wide range of possibilities. In looking at existing DFO designations, for example, an *Oceans Act* MPA would clearly fit the definition. Another example of an MPA would be the Coral Conservation Areas which Maritimes Region has designated through the *Fisheries Act.* Areas which may provide some protection for specific species, yet continue to allow fishing for other species, are generally <u>not</u> considered MPAs in a formal sense (e.g. the Haddock Box which is closed to groundfish fisheries, yet remains open for scallops; Lobster Fishing Area 40 which is closed for lobster but not for other fisheries). While there were valid conservation arguments for the original designation of these closures, and their continued maintenance under spatial management, such areas will have to be examined on a case by case basis for their inclusion within a network of MPAs.

Although self-imposed measures by industry (e.g. the recent Groundfish Enterprise Allocation Council closure in Emerald Basin) can offer a certain degree of protection, the IUCN definition of an MPA requires protection through legal or other effective means, to achieve the long-term conservation of nature. Self-imposed closures, by themselves, do not offer the requisite legal or enforceable protection by DFO, and may only be temporary. The Department has the option of further consultation with industry to make such measures regulatory if it appears that they are not being fully-respected, or if industry itself wishes to further pursue legal designation as a protected area. Permanency, meeting the IUCN definition, may thus be achieved through a multi-step process involving consideration of this type of conservation measure on a case by case basis with the industries that have come forward with them.

The IUCN has developed a six category system for describing different levels of protection and/or management objectives associated with protected areas (Table 1; from Hastings, 2011). Protected areas often have more than one category, or zone, of activity allowed. For example, the Gully and Musquash MPAs within DFO's Maritimes Region have three zones, and each allows different levels of human use activity. Multiple use MPAs are very common, and classifying them as per the IUCN categories is often a difficult exercise.

Table 1. IUCN category system for protected areas.

Category	Category Name	Management Approach
Ia	Strict nature reserve	Highly restricted human access
Ib	Wilderness area	Limited use by indigenous and local communities
II	National park	Focus is on recreation or education
III	Natural monument or feature	Focus is on a specific feature
IV	Habitat/species management area	Focus is on a specific habitat or species
V	Protected landscape or seascape	Focus is on human-nature interaction
VI	Protected area with sustainable use of natural resources	Allows for “low-level non-industrial use of natural resources”

REPORTING ON PROGRESS

Canada is signatory to, and involved in, international conventions and programs such as the IUCN and its World Commission on Protected Areas, as well as the CBD and its Program of Work on Protected Areas which is facilitated by the Canadian Parks Council. The work includes both terrestrial and marine ecosystems of Canada, although significantly more attention has been paid to the terrestrial ecosystems to date. The Department has recently begun collaborating with Environment Canada and the Canadian Council on Ecological Areas to develop and maintain an up to date inventory of MPAs under the Conservation Areas Reporting and Tracking System (CARTS). Information from CARTS is used to generate one of the four Canadian Environmental Sustainability Indicators, and also to provide regular updates to the World Database on Protected Areas, feeding national and international reporting requirements.

WHAT CONSTITUTES A NETWORK OF MARINE PROTECTED AREAS (MPAs)?

Canada has recently released the *National Framework for Canada's Network of MPAs* that provides the common ground for developing networks of MPAs in all of Canada's ocean space (Government of Canada, 2011). In developing the framework, Canada adopted the IUCN 2007 definition of a network of MPAs as, "A collection of individual marine protected areas that operates cooperatively and synergistically, at various spatial scales, and with a range of protection levels, in order to fulfill ecological aims more effectively and comprehensively than individual sites could alone." This means that sites selected for protection are not randomly selected or *ad hoc* in their distribution. Rather, the network is designed (and sites are selected from that design) with synergy and connectivity in mind. This obviously brings with it a higher degree of reliance on an effective scientific decision support process in the original scoping and assessment of various options for network design, as well as a greater degree of consultation (for the network's overall aims) on achieving consensus on the network design as a whole, beyond specific negotiations with respect to individual MPAs.

Table 1. MPA network design elements, defining features, and ecological considerations.

Network element	**Features defining the network element**	**Considerations**
Ecologically and Biologically Significant Areas (EBSAs)	EBSAs are areas that provide important service to one or more species/populations within an ecosystem, or to the ecosystem as a whole, as compared to other surrounding areas.	Various criteria used in designating EBSAs are reviewed in the text of the document, below.
Representativity (also known as representation)	Representativity is achieved by capturing a range of habitat diversity that reflects the full range of ecosystem types.	Range of habitat examples, habitat classification systems, intactness of habitats, naturalness.
Connectivity	Connectivity allows linkages between sites (larval dispersal, adult migration, or species exchanges) and individual sites benefit from one another.	Currents, gyres, migration routes, species dispersal.
Replication	Replication of ecological features means that more than one site will contain examples of any given feature (species, habitats, or ecological processes).	Accounts for uncertainty, natural variation, and the possibility of catastrophic events.
Adequate and viable sites	All sites within a network should be large enough, and have enough protection, to ensure the ecological viability and integrity of the feature(s) for which they were selected.	Size, shape, buffers, threats, surrounding environment, scale of features.

From both DFO (DFO, 2010a) and CBD guidance (Convention on Biological Diversity Secretariat, 2009) on developing networks of MPAs, there are five elements to be considered in designing a network: Ecologically and Biologically Significant Areas (EBSAs); Representativity; Connectivity; Replication; Adequate and Viable Sites (Table 2). The foundation of the MPA network is the protection of EBSAs and the other four elements are 'design features'. For each of these network elements, scientific information, analysis, and guidance is required during the initial network design phase, as well as for the anticipated engagement with stakeholders on component MPA selection. Science advice is subsequently needed to assist in the designation of specific MPAs (including assessment of consequences of different boundary selections), as well as for ongoing monitoring. Although the Maritimes ERI was not specifically designed to support MPA network planning *per se*, the following discussion of pertinent ERI research results is structured under the five required MPA network elements.

ECOLOGICALLY AND BIOLOGICALLY SIGNIFICANT AREA (EBSA) IDENTIFICATION

Both DFO (DFO, 2004) and the CBD have provided guidelines and criteria for identifying EBSAs. For the purposes of EBSA identification, in the context of MPA network planning, DFO national guidance has been to use the CBD criteria in the Scotian Shelf bioregion. Therefore, in order to identify EBSAs, the following CBD criteria will be used (Convention on Biological Diversity Secretariat, 2009): uniqueness or rarity; special importance for life-history stages of species; importance for threatened, endangered or declining species and/or habitats; vulnerability, fragility, sensitivity or slow recovery; biological productivity; biological diversity; and naturalness.

The identification of EBSAs, as well as the identification of representative areas described below, will also support the implementation of the SBA Policy (see Figure 2). The first step in applying the SBA Policy is the assembly and review of data that will help determine the type and location of benthic features where fishing activities occur, or are being proposed. The next step involves determining the ecological and biological significance of the benthic area, and determining the sensitivity of the area to fishing. Areas deemed both significant, and at risk of serious or irreversible harm from fishing, qualify as a sensitive benthic area under the SBA Policy. The SBA Policy also requires measures to be developed, in both historically fished areas as well as frontier areas, for collecting additional data on significance and sensitivity where current data is insufficient (including through the use of encounter protocols), and for managing risks. Clearly, given the overlapping nature of the definitions, criteria, and implementation timelines for MPA network planning and application of the SBA Policy, there is a need for continued dialog between Ecosystem Management, Resource Management and Science sectors in order to streamline the scientific work required for decision support.

The ERI program presently has only fairly limited contributions that it can make towards the identification of specific EBSAs at the full bioregional scale, as it was not designed as a comprehensive ecosystem assessment directed across a full range of species groups, habitats, or ecosystem structure considerations. In Theme 3, ecosystem modeling approaches subdivided the Gulf of Maine system into just a few large spatial domains. The relevance of that work to EBSA identification is thus more contextual, perhaps helping to identify some of the complex linkages across different components of the ecosystem that support biological productivity. Theme 2, in contrast, was largely organized to address research questions related to the spatial structure of benthic communities, and as such, its component projects were undertaken at a range of specific spatial scales, and can perhaps more easily be integrated into EBSA identification. Some of the ERI work undertaken in Theme 2 (on reference points to maintain spatial distribution of target benthic species, such as sea scallops, and on preferred habitat for certain other benthic species) can also directly support the SBA Policy (Brown et al., 2012; brief descriptions of this research may also be found in Brickman et al., 2012).

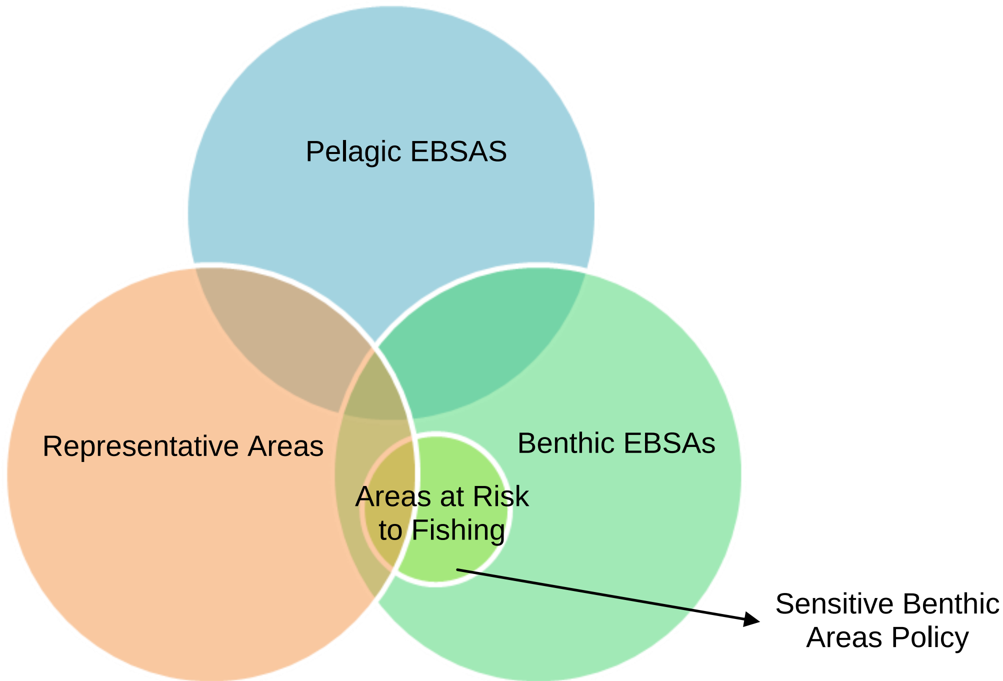

Figure 2: Overlap between the Sensitive Benthic Areas Policy and key elements of Marine Protected Area network planning (representative areas; pelagic, and benthic EBSAs).

Most projects in Theme 1 were directed at broad ecosystem properties such as the potential sensitivity of the system as a whole to climate change. Some Theme 1 projects did focus on specific life history considerations, such as research on connectivity between sea scallop populations, which may assist with general considerations of the spatial scale, directionality, and magnitude of connectivity within the bioregion. Modeling techniques developed for the work on sea scallop metapopulations could also be adapted more broadly to assist with understanding some productivity aspects of EBSA identification.

One of the activities undertaken in Theme 2 was to review the literature on the various strategies used to produce benthic habitat maps using acoustic remote sensing techniques, coupled with *in situ* sampling. The acoustic systems considered by Brown et al. (2011) were single-beam acoustic ground discrimination systems, sidescan sonar systems, and multi-beam echo sounders. Their review highlights rapid evolution in sophistication in the ability to image and thus map seafloor habitats. Along with development in acoustic survey capabilities, new methods have been tested to segment, classify and combine these data with biological ground truth sample data. Such studies can generally be categorized into one of three over-arching strategies (Figure 3): 1) Abiotic surrogate mapping; 2) Assemble first, predict later (unsupervised classification); and 3) Predict first, assemble later (supervised classification). All three strategies provide valuable mapping resources to support management objectives related to EBSA identification specifically, and MPA network analysis generally.

There remains much scientific work to be done on outstanding technological, methodological, ecological and theoretical questions related to evaluation of the distribution and status of marine benthic communities before ocean managers can access a turnkey system for MPA planning. Nonetheless, recent advances derived from spatial ecological studies founded on high-resolution environmental data sets will help us to examine patterns in community and species distributions, a vital first step in unveiling ecologically important areas, and thus providing improved spatial information for management of marine systems.

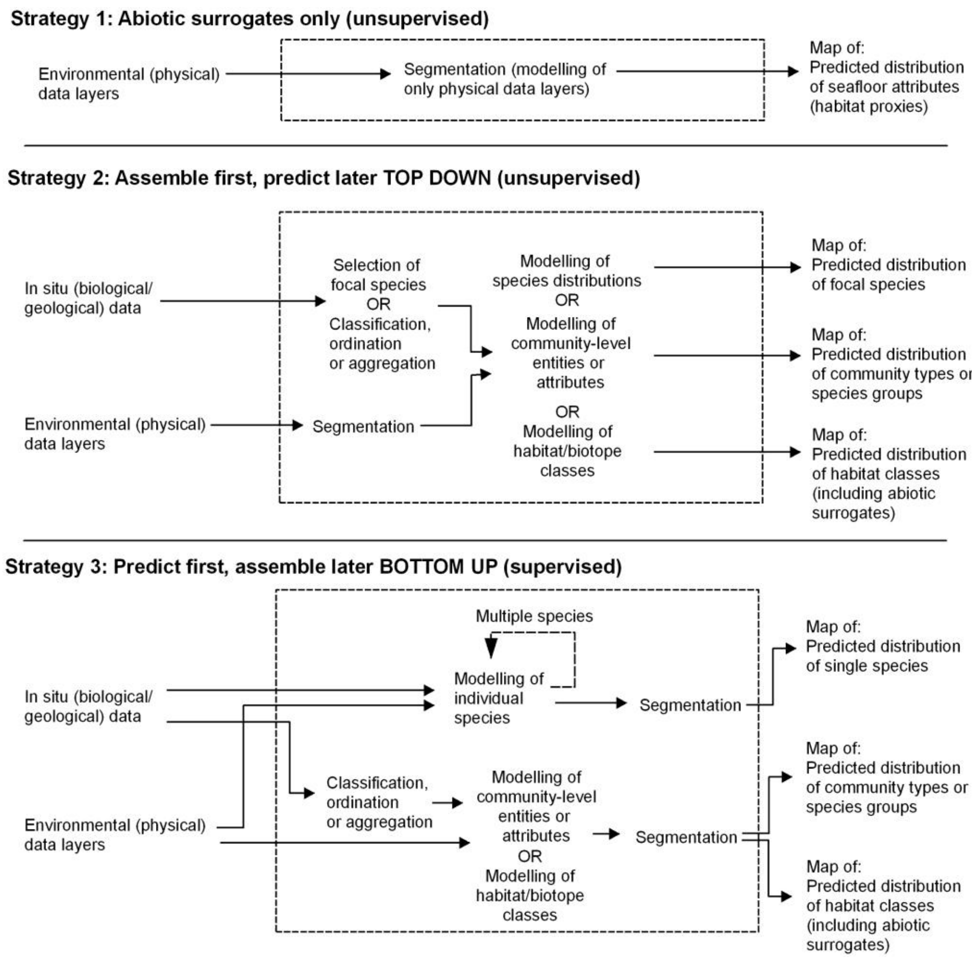

Figure 3. Three basic strategies for the production of benthic habitat maps (Brown et al., 2011; based on a prior schema, referenced in the article).

Collaborative projects with groups external to the department, partly facilitated through the ERI program under Theme 2, provide additional results that can contribute towards EBSA identifications. Through the CoML, several links were made with the Gulf of Maine Area (GoMA) Program of the Census between 2008 and 2010 and with other Census programs during CoML's international synthesis activities in 2010. Within a Canadian context, joint research activities were also conducted through CHONe (www.chone.ca) during research explorations of the Gulf of Maine Discovery Corridor in 2009 and 2010.

Under CoML's GoMA Program, several expert groups have completed syntheses of known biodiversity for specific ecosystem compartments within the Gulf of Maine, such as slope and seamount environments (Kelly et al., 2010), zooplankton and pelagic nekton (Johnson et al., 2011), and planktonic microbes (Li et al., 2011). These reviews included DFO scientists working within the ERI program and provide current synopses of the literature. Additional summaries for coastal margin and benthic systems are in preparation. With collaborators from Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO), a new statistical analysis technique, "gradient forest" (Ellis et al., 2012), was developed to explore the use of abiotic surrogates to predict the diversity of seabed assemblages (discussed more fully below). The process of development of synopses of a broad range of regional abiotic variables (Greenlaw et al., 2010), and the statistical analysis of benthic grab and demersal trawl databases in relation to them suggests the presence of transition areas that may be unique (and require consideration as EBSAs) due to specific combinations of environmental variables.

When CoML's GoMA Program was under development in the mid-2000's, then readily available species lists for the Gulf of Maine suggested a regional species pool of approximately 2,000 named species. Through collaborative research with the Atlantic Reference Centre of the Huntsman Marine Science Centre, the GoMA Program supported development of the Gulf of Maine Register of Marine Species (GoMRMS; Incze et al., 2010), and also facilitated the transfer of over 830,000 species distribution records to the Ocean Biogeographic System (OBIS). In 2010, GoMRMS was formally transferred to DFO, and now forms part of a new national system, The Canadian Register of Marine Species (http://www.marinespecies.org/carms/; Kennedy et al., 2010; Van Guelpen and Kennedy, 2011).

Formal species registers will lag behind provisional species lists in terms of the overall number of species they contain, as the former requires that species recorded from the region are verified by taxonomic editors before formal inclusion within the register, whereas provisional species lists may be derived from a range of regional species lists maintained by a number of different research agencies and individuals. The availability of species distribution records through OBIS, an internationally-organized, open-access biogeographic information system is extremely important with respect to facilitating the process of discovery of biodiversity information for a range of research and ocean management questions, including EBSA identification (e.g. see Archambault et al. (2010) on known biodiversity within Canada's three oceans).

Representation of biodiversity knowledge within ecosystem based management and MPA development is important with respect to conveying the overall knowledge of how the natural system is structured, and how it functions. Although the gaps to knowledge are well known among the science community, the same is not true for stakeholders and the general public. Through the GoMA Program, a three-part model for the representation of biodiversity knowledge was developed (Incze et al., 2010; Ellis et al., 2011; Lawton et al., 2012). One aspect, the size spectrum of biodiversity within a system, and the extent of the known versus the unknown species, is particularly pertinent to the designation of MPAs, and in whether or not designation can be shown explicitly to meet EBSA criteria. Whereas the most recent update of provisional named species in the GoMA area has recently reached 5,569 (Lewis Incze, University of Maine, pers. comm.), this represents only a fraction of the overall regional species pool. Knowledge of small-sized organisms (e.g. meiofauna) is extremely limited (Figure 4), and the actual numbers of species within the system for which there is any form of routine monitoring and management represents just a small number of larger-sized organisms (with the exception perhaps of harmful algal bloom monitoring, and fecal coliform bacteria monitoring).

In the absence of improved monitoring of the spatial distribution of the named species within the system, designation of marine protected areas using EBSA criteria will need to rely upon very selective biodiversity inventories. For example, as of November 2009, of 2,472 named invertebrate species in the Gulf of Maine provisional species list, it is estimated that at least 1,001 species from 17 phyla inhabit the coastal margins of the Gulf of Maine (coastal margin defined as water depths <20m; Lawton et al., unpublished data). Based on reviews of existing literature, 75 species of marine fishes also frequent the coastal margin (13% of the known regional fish fauna consisting of 578 species, as of November 2009; Lawton et al., unpublished data). Many of these records are derived from localized biological sampling, and/or represent the accumulation of species records from various historical investigations conducted within the Gulf of Maine area since the late 19th century. There are presently no systematic coastal biodiversity inventories underway within the Canadian jurisdiction of the Scotian Shelf bioregion. Thus, characterization of a set of regional EBSAs will be based on a fairly limited portion of the biological size spectrum (Figure 4), and will need to rely on spatially-biased sampling information. Nonetheless, through the process of reviewing available species distribution information within the Scotian Shelf bioregion, against evolving sets of EBSA criteria, specific geographic areas do tend to be routinely identified by the process, suggesting that at least a first-order characterization of a set of EBSAs may be reasonably robust.

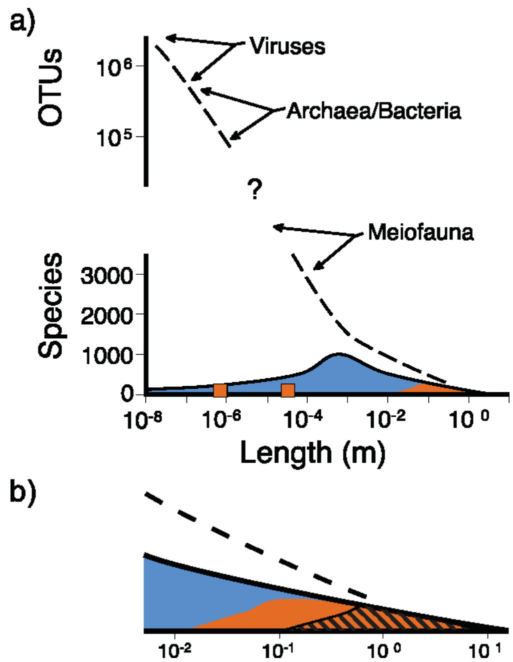

Figure 4. Biodiversity size spectrum within the Gulf of Maine ecosystem (Incze et al., 2010; Lawton et al., 2012). a) Length-based schematic showing the approximate size distribution of adult stages of named species (solid line, blue fill), and a suggestion of the possible extent of the unknown biodiversity (broken line). The line for known (named) taxa approximates species numbers for groups of organisms contained within size groupings of $10^x \pm 10^{0.5x}$ m, where x is a whole number from −8 to 1. For the prokarya and viruses, diversity is expressed as "types" or operational taxonomic units (OTUs), since there is no agreement on what makes a species in these groups. The shape of the curve of unknown biodiversity from meiofauna to viruses, and the maximum number of types cannot be projected with any certainty. b) Enlarged lower right portion of the size-diversity curve illustrating where most "monitored" and "managed" species occur. Examples of "monitored" species (line with orange fill) are unmanaged species caught in fisheries assessment surveys, and seabird abundances at long-term study sites; "managed" species (line with diagonal line fill) are those with management plans such as commercial fish, crustaceans and mollusks, cetaceans, and threatened or endangered species. Solid squares on the x-axis in the main portion of the figure represent harmful algal species and coliform bacteria for which there are also monitoring programs within the Gulf of Maine.

Within CHONe, academic researchers from Dalhousie and Memorial universities, along with DFO partners, conducted an expanded program of marine biodiversity research in the northern Gulf of Maine in 2009 and 2010 (Figure 5). This new work was concurrent with ERI-based field studies in the German Bank area under ERI's Theme 2, and both research programs had a principal focus on benthic diversity in relation to seabed habitat.

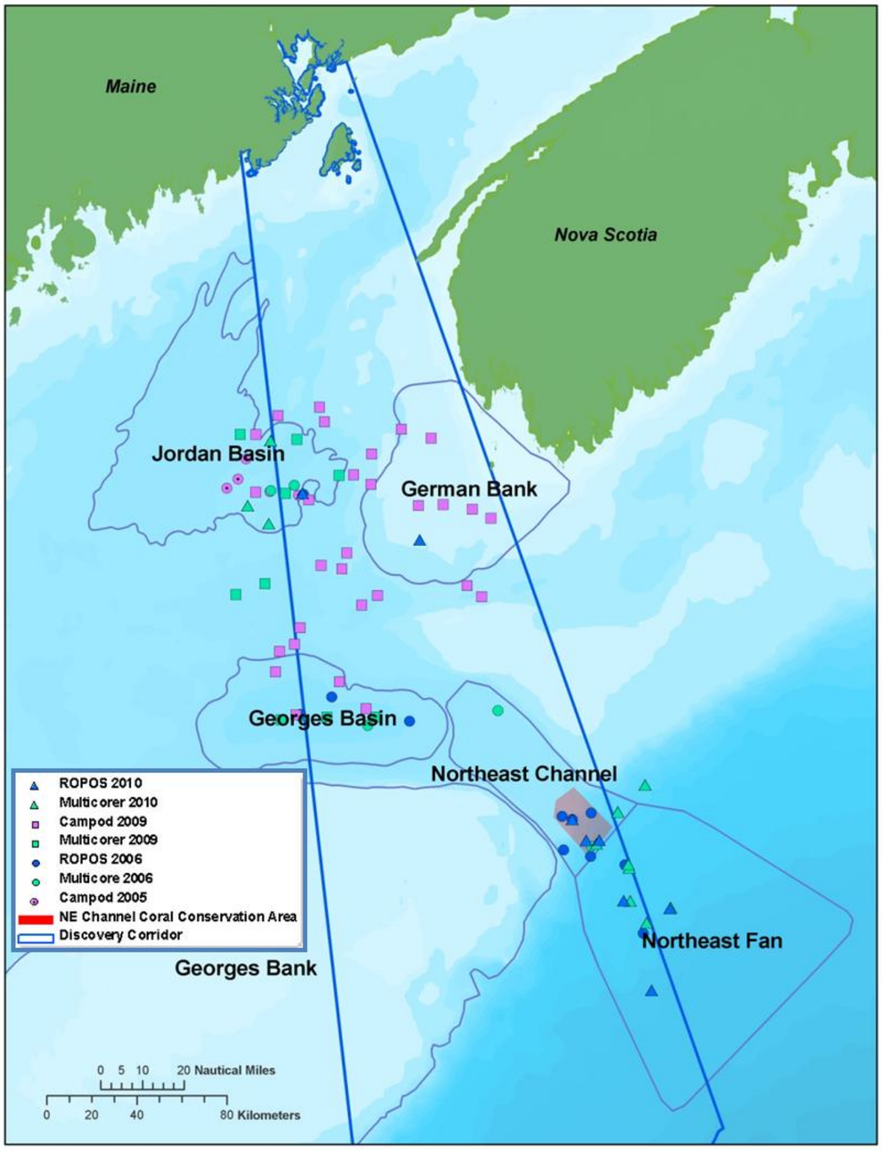

Figure 5. Composite representation of the seabed biodiversity surveys conducted within the Gulf of Maine Discovery Corridor under CHONe in 2009 and 2010, along with prior collaborative research surveys in 2005 and 2006.

The linkage with the CHONe research effort enabled additional high-resolution digital still and video images of benthic habitats from the German Bank area to be provided in support of ERI research on benthic species distribution modeling (Brown et al., 2012). The CHONe research program benefited from this linkage by gaining access to OLEX-based seabed bathymetry acquired under the ERI program (Figure 6). That imagery has helped with the design of several seabed research projects within the Discovery Corridor, as significant areas in offshore northern Gulf of Maine remain to be surveyed using multi-beam sonar. The OLEX-based imagery has proved sufficient to resolve major bathymetric features within Jordan Basin, such as the presence of linear ridge features (Figure 6C) that were found to contain dense aggregations of anemones and other filter feeding species, as well as corals (Metaxas and Lawton, unpublished data). The CHONe-based research now underway on the spatial pattern of benthic communities within the Discovery Corridor, matched with recent research approaches developed under ERI Theme 2, will help to define integrated approaches for benthic diversity assessments in deep offshore environments, contributing to the identification of EBSAs within the bioregion.

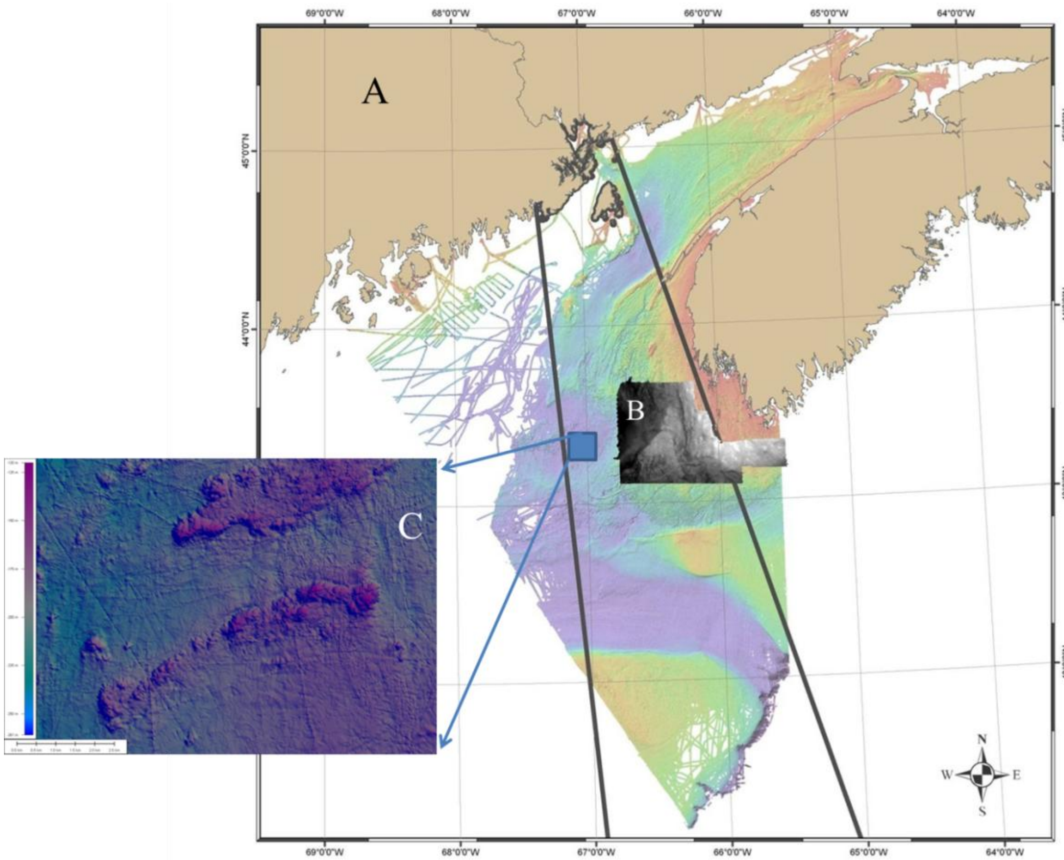

Figure 6. OLEX-based seabed bathymetry for the northern Gulf of Maine (color-scaled coverage in map A), along with an indication of existing high-resolution multi-beam survey in the German Bank area (gray-scaled coverage in map B). Preliminary assessment of bathymetric features revealed by the OLEX data, compared to multi-beam bathymetry, and prior geological interpretations of German Bank by B. Todd (Natural Resources Canada) suggests that OLEX imagery may prove useful for defining bathymetric complexity in areas lacking multibeam survey coverage. An example is provided in map C from a portion of Jordan Basin. Seabed biodiversity surveys within the Discovery Corridor have been organized and led by a group of DFO (P. Lawton, SABS; E. Kenchington, BIO) and academic researchers (A. Metaxas, Dalhousie University; P. Snelgrove, and S. Bentley, Memorial University of Newfoundland).

REPRESENTATIVITY

DFO guidance (DFO, 2010a) is that, "...representative MPAs should capture examples of different biogeographic subdivisions that reasonably reflect the full range of ecosystems which are present at the scale of network development, including the biotic and habitat diversity of those ecosystems." Planning for representation in MPA networks is preferably accomplished based on detailed knowledge of each species' distribution, abundance, life history and their interactions with other species and the biophysical environment in which they exist (Banks and Skilleter, 2007). However, as noted above, there are major gaps in knowledge of the distribution and abundance of many species, especially in the marine environment. As a result, there is a need to use different approaches for mapping expected species diversity and distribution patterns. Surrogate approaches can include the use of physical habitats, species assemblages or higher taxonomic levels, environmental diversity or focal species (e.g. Greene et al.,1999; Greenlaw et al., 2011; Roff and Zacharias, 2011). Regional conservation planning has generally met these requirements with broad-scale representative maps.

There are different forms of representative mapping, depending of the availability of data. The best case scenario includes actual, or predicted single species or assemblage distributions based on measured statistical relationships between biota and physical habitat layers. This is sometimes possible, given more comprehensive data collected on some species (e.g. marine fishes obtained from the ecosystem trawl surveys of the Maritimes Region; some marine mammals). However, often only physical variables are available at the extent of the required classification. These have been used as surrogates to biological species diversity and distribution given the extensive literature on species-environment relationships showing correlations of biological patterns with environmental variables (Riccardi and Bourget, 1999; McArthur et al., 2010).

Despite the correlations shown from the literature, there have been few studies globally, and none regionally, to suggest how well the combination of physical factors available explains species diversity and distribution patterns. Taking advantage of a research opportunity provided through CoML, one project conducted in Theme 2 of the ERI sought to determine how well physical habitat variables function as surrogates to predict benthic species diversity and distribution. CoML funding enabled researchers from Canada, the US, and Australia to conduct a comparative analysis to determine and contrast the important physical variables influencing seabed species diversity and distribution patterns within three different marine regions: the Gulf of Maine, the Great Barrier Reef, and the Gulf of Mexico[1]. By conducting a comparative analysis to explore such relationships it was hoped that consistent patterns might emerge that could form the basis for predictive mapping using environmental surrogates in new areas where there may only be limited available biological information.

In preliminary project meetings, it became evident that although there were a number of existing statistical methods available for ecological analyses of species and community distributions in relation to their responses to environmental gradients, these were somewhat limited for application to the objectives set for the comparative analysis. Based on the utility of the ensemble classification/regression tree method Random Forest (Breiman, 2001), and its prior use to assess predictor importance for individual species, the team explored approaches to extend this analytical approach to whole assemblages.

The new capabilities sought included being able to establish where along the range of any specific environmental gradient important compositional changes occur, to identify any important thresholds or change points, and to explore the relative importance of different predictors. Additionally, due to the diversity of biological sampling approaches used in different regions (gear types, survey designs, etc.) there was a need for the new analysis approach to be able to integrate abundance information for multiple species derived from multiple sampling devices, and of different types (counts or weight).

The new statistical approach developed through the project collaboration, “gradient forest”, is formally described by Ellis et al. (2012). To implement gradient forest, team members Ellis, Smith and Pitcher developed two new statistical packages in the R computing environment (R

[1] *During its final phase, the Census of Marine Life funded a series of synthesis projects. C. Roland Pitcher (CSIRO, Australia) and P. Lawton (DFO, Canada) received funding to convene an international team from several Census programs to investigate the influence of environmental variables on seabed diversity.*

Development Core Team, 2011) that are now available to the scientific community (http://gradientforest.r-forge.r-project.org). The refined information generated using gradient forest allows for more accurate capturing of biodiversity and distribution patterns for bioregionalization, delineation of protected areas, or designing of biodiversity surveys.

For the comparative analysis of species–environment relationships, the project team used contemporary and historical groundfish and benthic macrofauna data, as available from each region, and developed a standardised set of physical, geological, and environmental data sets at a mesoscale for each region (between 20 and 29 environmental predictors were used in analyses, depending on the specific region and biological data analyzed). Detailed information on the biological and physical datasets compiled for the Gulf of Maine can be found in Greenlaw et al. (2010).

The scientific synthesis, on commonalities and contrasts in results from gradient forest analyses across the Gulf of Maine, Gulf of Mexico, and Great Barrier Reef benthic species datasets is provided by Pitcher et al. (2012). Gradient forest provides numerous analytical and graphical outputs, including a list of the relative importance of each physical variable in explaining beta diversity patterns. Some patterns matched expectation, such as the most influential variables across datasets in the Gulf of Maine: temperature, depth, salinity, chlorophyll and substrate. It was not expected that remotely sensed sea surface temperature (SST) would be the most important variable identified for more than one dataset. The SST included in the analysis was a higher resolution than most other variables included, and therefore was likely functioning as a surrogate for a combination of environmental variables (circulation patterns, water column mixing, depth, and food supply to the benthos) that were either lower resolution in the analysis, or currently unavailable. This finding shows that SST can be a predictor of even benthos in the absence of other high resolution environmental variables, and it should be included in future regional analyses such as these. The gradient forest statistical analysis outputs can be used to develop a map of expected patterns of biodiversity composition across the region (Figure 7). This represents a biologically informed prediction of species diversity and distribution patterns, which advances on purely physically-based bio-regional planning.

Topographic variables such as complexity, aspect, slope and benthic position index were continually chosen as the least important predictors across each of the datasets. Hard, topographically complex habitats are known from optical sampling to have biotic compositions that differ from sedimentary habitats (Kostylev et al., 2001; Brown et al., 2011; Brown et al., 2012). However, at the large regional extent explored in the present analyses, contrasting spatial resolutions (or ecological “grain” size) among the mapped physical predictors, and inherent sampling characteristics of the biological data sets used, are likely involved in this result.

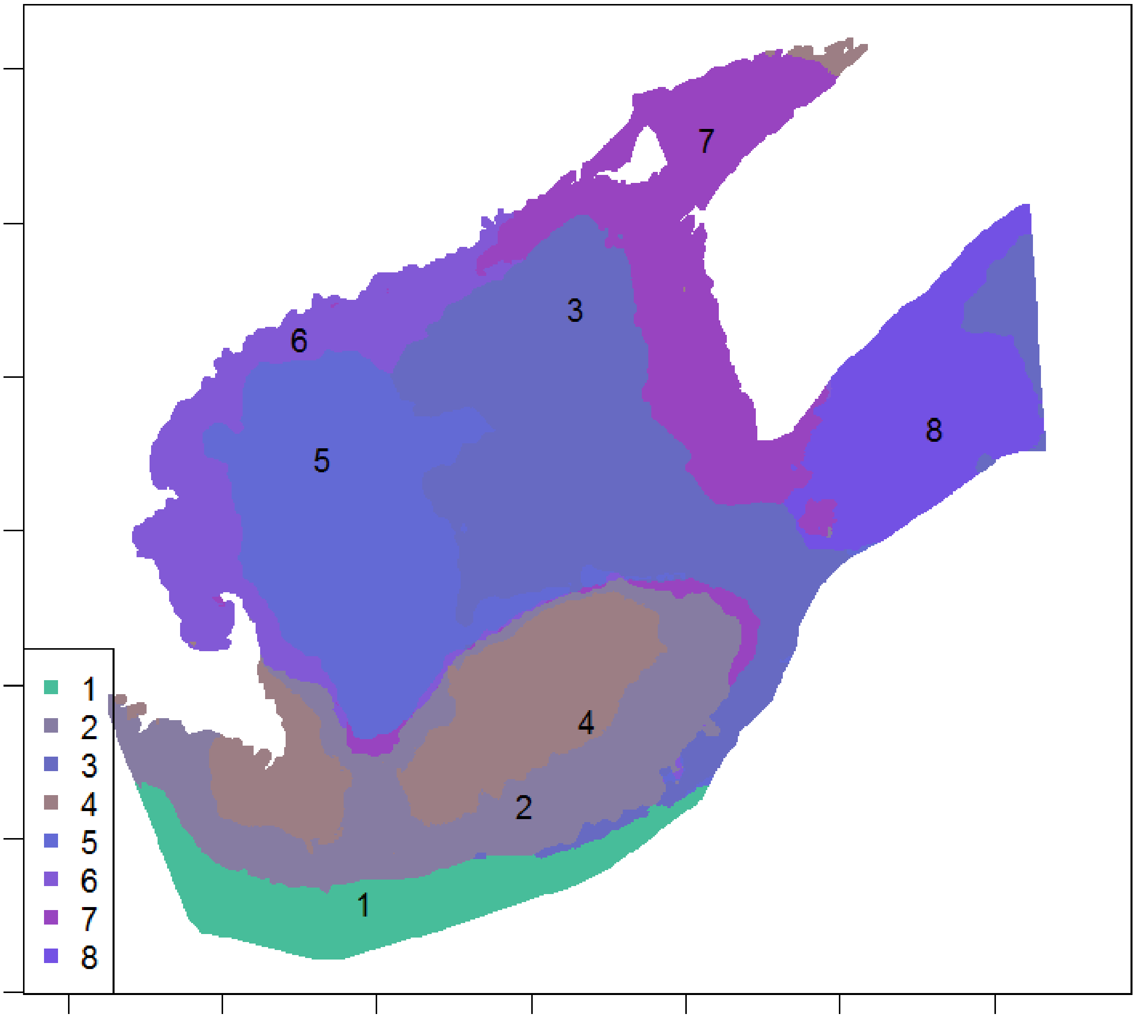

Figure 7. Geographical representation of clustered species assemblage classes based on National Marine Fisheries Service spring trawl survey dataset. Projection is based on the Universal Transverse Mercator (UTM) geographic coordinate system.

Overall, the amount of variation explained by physical factors in all regions ranged from 13-35%, but ranged up to >50-80% for some individual species (Pitcher et al., 2012). This result was not unexpected, given that physical variables were mapped at a certain scale and anthropogenic and biological influences were not included in the analysis. However, this suggests that although physically based surrogates are often the only option for representative planning in many regions, they should be used with caution, and achieving better biological sampling data should be considered a primary goal when attempting representative planning.

Even though the importance of the physical variables has only been measured for the Gulf of Maine, their importance is expected to be similar in regions of close geographic proximity (e.g. the Scotian Shelf). Hence, the method provides a list of the physical surrogates most important to acquire when attempting to create physically-based biogeographic subdivisions in regions with limited biological data, where an intensive analysis such as this could not be applied.

Prior work in the region emphasised the use of a selected set of predictors of species diversity and distribution, largely based on arguments derived from life history theory. Kostylev and Hannah (2007) developed a predictive benthic habitat classification based on Southwood's template of life history strategies, which was used in the previous iteration of MARXAN for the Scotian Shelf. Their work predicts spatial distribution of benthic organisms with specific life history strategies (r and K) using only physical variables. In the habitat template model, different community compositions were predicted using two axes: *Disturbance* - the ratio of Frictional Velocity to the critical current, and *Scope for Growth* – using spring chlorophyll minus the summer stratification, annual bottom temperature, oxygen and salinity.

The results using gradient forest identified similarities to the physical factors identified as important by Kostylev and Hannah, and the factors used in their model. The model identified benthic temperature, frictional velocity and chlorophyll average or seasonal range to be important. However, in contrast to Kostylev and Hannah's predictions, distributions of benthic macrofauna and groundfish, as modeled using gradient forest, were related to depth and average SST in many cases, and these variables were ranked above those factors Kostylev and Hannah used for their model. This has important implications for future representative planning, given that the same factors were not consistently chosen between datasets and between regions. If possible an analysis using gradient forests should be applied, to determine which physical factors are most appropriate for determining species diversity and distribution patterns across the Scotian Shelf bioregion.

Representative mapping is a complicated task, given that representative mapping can be applied at various scales in the spatial hierarchy (Roff and Zacharias, 2011) and include various forms of data. Within the Maritimes Region, MPA network planning occurs at the scale of the Scotian Shelf/Bay of Fundy bioregion, a first-order subdivision of Canadian marine regions (Figure 1; DFO, 2009). Although the concept of representation can be applied across the entire spatial hierarchy from global (over thousands of kilometres) to micro-community (millimetres to centimetres) as described in Roff and Zacharias (2011), at the bioregion level a single MPA could not be considered to capture the range of species and habitats of the region.

In addition to undertaking coarse-grained subdivisions of the bioregion (typically based primarily on physical environment factors), when feasible, further mapping at the habitat level would directly ensure that an MPA network planning scheme captures the range of habitats and species within a bioregion. Two main analytical methods to explore species-environment relationships were developed within Theme 2 of the ERI project (for initial applications, see Brown et al., 2012; Pitcher et al., 2012). Both methods are useful for representative mapping at any scale, where there is adequate biological data distributed across the domain of interest for specific biological community types. For domains of interest where biological data is lacking, prior application of the methods in other areas may help inform on important physical factors that may be used as surrogates for the distribution and abundance of specific community types.

CONNECTIVITY

Once EBSAs are identified and representativity has been considered, an analysis of connectivity should be conducted. During the ERI program, an updated overview of circulation features in the Maritime Canada Region was developed (reviewed by Brickman and Loder in Brickman et al., 2012). Major circulation features in the region, and how they are interrelated, were explored, based on data and circulation model simulations. Interrelationships included the seasonality of circulation features, simulations of the inflows into the Gulf of Maine from the Scotian Shelf, as well as retention and connectivity analyses between various offshore banks (Georges Bank, GB; Browns Bank, BB; Emerald Bank, EB; Western Bank, WB; Sable Island

Bank, SIB, BQ; and Banquereau Bank). The results on retention/connectivity should be of significant interest to ocean managers.

With respect to connectivity between banks it was found that, in general, banks are connected to one neighbour only. On average, BQ retains fewer particles than it exports to WB/SIB; WB/SIB retains about five times more particles than it exports to EB; BB exports about two times more particles to GB than it retains; and GB is not significantly connected to any upstream banks. ERI modeling results on regional circulation could be examined as an overlay of the EBSAs in a geographic information system (GIS) work space. EBSAs that have been identified can then be evaluated based on the network concept of connectivity, also taking into account whether or not EBSAs may conform to larval retention areas.

Another example of retention/connectivity calculations, based on Theme 1 research, comes from work on developing spatial reference points for data poor fisheries, specifically the northern sea cucumber, *Cucumaria frondosa*. Reported by Shackell, Brickman, and Frank (in Brickman et al., 2012), this show how spatial reference points might be developed for fisheries management; however, some of the sequential modeling considerations for dealing with management questions where there is only limited biological data, could be transferred to MPA planning considerations. Within a cluster in a lightly fished region, high density areas represent superior habitat simply because they support more individuals per unit area than low density habitat. These high density areas are also important to the reproductive cycle of broadcast spawners. Extending these modeling considerations to defined EBSA locations, and proposed representative areas, could prove useful.

REPLICATION

Network design includes replication of features to ensure ecological resilience and integrity, unless they are unique and only found in one area. ‘Features’ can include species, habitats and ecological processes that naturally occur in any given biogeographic area. In some way it provides a degree of insurance against loss of any feature as a result of natural or human disturbance, and also helps to ensure that natural variation in any feature is captured.

The ERI program was largely focused in the northern Gulf of Maine, and specifically in the offshore portion of the region, and not within coastal areas, nor the Bay of Fundy (except for research conducted under Theme 1, and ecosystem modeling under Theme 3). As such, it was generally more spatially constrained than prior regional habitat modeling work and species distribution modeling undertaken at the scale of the bioregion (Kostylev and Hannah, 2007; Shackell et al., 2012). The new gradient forest-based analyses of groundfish assemblage structure in relation to abiotic surrogates, combined with these prior habitat modeling approaches should offer some contributions towards defining replication at the bioregional level. At a more spatially-restricted scale, dealing with the spatial design of specific MPAs, the benthic habitat modeling work conducted under ERI Theme 2 (e.g. Brown et al., 2012) will provide useful techniques for determining the actual set of features that are contained within particular area designations, and perhaps more importantly, how replication of features might be constrained under selection of different boundary conditions. This, of course, is also predicated on further expansion of seabed mapping within the region at the spatial resolution that will permit habitat modeling to be undertaken, and retention of technical and scientific capacities within the region to undertake required analyses for prospective MPAs. Replication also depends on defining another important criterion for specific habitat types, which is adequacy. Without knowing the appropriate amount of habitat it is necessary to protect for specific habitats available for the region, it is hard to determine how well these habitats are replicated within an MPA planning scheme.

ADEQUATE AND VIABLE SITES

The boundaries and protection measures for each EBSA selected for protection should be sufficient to ensure the ecological viability and integrity of the feature(s) for which it was selected. This network component considers both size/shape and protection level. For instance, features should not be bisected (e.g. protecting one canyon wall and not the other) and the optimal size will be dependent on the scale and extent of the feature to be protected. For example, if the aim is to protect a sponge community that is sensitive to smothering by sediment, would it be adequate to have a closed area boundary that tightly encircles the sponges? Any bottom trawling that occurred close to the boundary and up-current of the sponge community would lead to a high risk of smothering by disturbed sediments. In this case, one would need to examine persistent and seasonal currents, gyres, and general circulation patterns in order to ensure adequate protection by way of a buffer which would restrict bottom gear to operating further away from the community.

As discussed under the previous section, ERI research and recent collaborative research under the CoML and CHONe research networks (among other habitat modeling initiatives) can provide scientific guidance on this type of question, based on recent experience with bank-scale habitat modeling and biological survey approaches. However, for the short term this will inevitably be based on existing research experience derived for only a subset of habitat types and locations. To determine adequacy, it would be necessary to map finer scale habitat features than are currently available at the extent of the bioregion. If resources became available to acquire this data, then development of species-area curves by habitat type could be accomplished based on detailed biological survey coverages. Expectation for network design to be comprehensive with respect to adequacy and viability criteria, along with management expectation to subsequently undertake performance monitoring, will need to be matched against science capacities, both internal and external to the department, to deliver. As with most criteria, in the face of limited resources to objectively and substantively document MPA criteria, the designation approach should be conservative, which in this context would imply larger areas, rather than constrained area designations around particular features that are to be included within the network design.

IMPLEMENTATION OF THE NETWORK (SITE DESIGNATIONS)

Implementation of the network, or site designations, will be a collaborative effort between the relevant federal and provincial departments. It is also thought that implementation will happen over time and as resources allow. As EBSAs are identified, it will be necessary to examine each one independently to determine the appropriate management measure in order to achieve “effective management measures for the long term conservation of nature” (as per the IUCN definition of a protected area, described above). For some areas, a *Fisheries Act* closure may be appropriate, others may require an *Oceans Act* MPA designation, and others may be more appropriate for another government department (e.g. Canadian Wildlife Service or Parks Canada). The determination of levels and types of protection will be dependent on many factors such as ecosystem sensitivity to impacts, target species and habitats requiring protection, and the urgency of protection measures required (i.e. degree of threat to the area). It is important to note that not all EBSAs will require protection through MPA designation. Most protected areas will include EBSAs, either because the whole of an MPA represents an EBSA, or because an MPA selected as a representative area of a particular habitat feature within the bioregion encompasses a sub-area that was identified as an EBSA (see also Figure 2). Protected areas are spatial in nature; however, there are other non-spatial management measures (such as gear modifications or seasonal avoidance) that can also contribute to conservation.

National priorities under the SBA Policy are coldwater corals, sponge-dominated communities, hydrothermal vents and seamounts. In March 2010, DFO held a national science advisory process on the occurrence, sensitivity to fishing, and ecological function of corals and sponges in the Canadian Exclusive Economic Zone. The results of this process (DFO, 2010b) are expected to help establish a nationally consistent approach to identifying significant areas under the policy. Future priorities under the SBA Policy may reflect other examples of potentially vulnerable marine ecosystems identified in *International Guidelines for the Management of Deep-Sea Fisheries in the High Seas (Annex 1),* which were issued by the Food and Agriculture Organization of the United Nations in 2008. Species groups, communities and habitat forming species that are documented or considered sensitive and potentially vulnerable to deep-sea fisheries in the high-seas, and which may contribute to forming vulnerable marine ecosystems include:

- certain coldwater corals and hydroids, e.g. reef builders and coral forest including: stony corals (Scleractinia), alcyonaceans and gorgonians (Octocorallia), black corals (Antipatharia) and hydrocorals (Stylasteridae);
- some types of sponge dominated communities;
- communities composed of dense emergent fauna where large sessile protozoans (xenophyophores) and invertebrates (e.g. hydroids and bryozoans) form an important structural habitat; and
- seep and vent communities comprised of invertebrate and microbial species found nowhere else (i.e. endemic).

Topographical, hydro-physical, or geological features (including fragile geological structures), that potentially support the species groups or communities referred to above include:

- submerged edges and slopes (e.g. corals and sponges);
- summits and flanks of seamounts, guyots, banks, knolls, and hills (e.g. corals, sponges, xenophyphores);
- canyons and trenches (e.g. burrowed clay outcrops, corals);
- hydrothermal vents (e.g. microbial communities and endemic invertebrates); and
- cold seeps (e.g. mud volcanoes for microbes, hard substrates for sessile invertebrates).

In the initial planning stages of the ERI program, the need to develop approaches to assess vulnerability, sensitivity and degree of risk to benthic habitats and communities was recognized, and some proposals for work specifically to address this need were articulated, but eventually not conducted due to shifts in research staff complements. As the ERI program developed it became obvious that simply advancing the capacity to document and model the spatial pattern of benthic communities was a large undertaking in itself that would contribute directly into marine spatial planning for both fisheries and marine conservation considerations. Accepting this caveat, through research under the Maritimes ERI there are now several locations and spatial domains within the Scotian Shelf bioregion with comprehensive mapping of habitat types, as well as preliminary characterization of benthic community structure. Along with similar locations investigated under other scientific programs for which detailed spatial habitat mapping has been undertaken, additional research could be undertaken to assess vulnerability and risk criteria in support of MPA network planning, and application of the SBA Policy.

ONGOING PROTECTED AREA MANAGEMENT

The direct application of recent ERI-sponsored habitat classification work for informing boundaries and zones when designing new MPAs or fisheries closures has been described above. There is also direct relevance of this work to ongoing protected area site management. For instance, in an *Oceans Act* MPA, any activities that are not listed in the regulations as 'exceptions' require an applicant to apply to DFO for approval of said activity. If protected area program staff have detailed benthic habitat maps in hand, it will be far easier to assess any high impact activity applications (e.g. trawling). Comparison of the proposed location(s) of the activity against detailed, GIS-based, mapped knowledge of the site and the conservation objectives for the protected area would allow staff to make an informed decision and approve or deny the activity approval accordingly.

There has certainly been a major advance in the capacity to acquire and manipulate geospatial information through undertaking the ERI program, as well as the development of some new technical approaches, and increased familiarity with various habitat modeling approaches. However, what has not been secured to date is the capacity to retain these skills, and software systems, and to formalize and secure these new capacities to support enhanced decision support demands implied within ongoing protected areas management. Perhaps one of the key benefits of the ERI program has been the gauging of overall institutional capacities and resourcing needed to undertake this type of habitat modeling work. This should facilitate frank discussion on sustainable capacities to support protected areas management, and more than likely, appropriate systems to deal with uncertainty.

REVIEW AND EVALUATION OF THE MPA NETWORK

Along with the development and implementation of a network of MPAs there is an expectation that a set of management objectives will be articulated to inform scientific monitoring programs and periodic review of the effectiveness of individual MPAs and the network as a whole in meeting those objectives. Monitoring program design will be sensitive to the actual performance measures established, which may vary between MPAs. For example, monitoring objectives in some MPAs may be related to the change in overall distribution, density, and population characteristics of certain specific species for which the MPA was designated, while in others, monitoring may be directed to obtaining a more comprehensive inventory of the species within the MPA, or to determine if changes in community composition following MPA designation proceed according to predictions. Continual evaluation of any fully designated or planned MPA network will also be necessary, to ensure the network is properly representing ecologically significant species and habitats along with their representative counterparts, as more comprehensive and finer scale biological and physical variables will become available over time. Many of the field investigation approaches, data assimilation techniques, and statistical modeling approaches developed in the ERI research program could be adapted towards MPA performance monitoring. Based on preliminary acoustic seabed surveys and initial biological groundtruthing, baseline maps of the habitat mosaics within MPAs could be produced. Species distribution modeling approaches, such as those used on German Bank (Brown et al., 2012), could be used to analyze existing species and community characteristics.

Subsequent biological surveys could be designed to examine whether or not habitat occupation of particular species, or community characteristics change over time. Given an expectation of only limited resources available for monitoring, it is logical that only a subset of MPAs would be selected for detailed assessment, with observations from those studies applied to other MPAs, using appropriate experimental designs and controls. Even with just a few key objectives to be assessed, the level of research investment may be quite significant, and perhaps best applied to particular MPAs that have a pre-existing body of information.

EXISTING GAPS AND FUTURE WORK

There was significant discussion during the planning stages of the ERI program on developing scientific approaches to assess vulnerability and sensitivity of benthic communities; however, the major emphasis in the final projects undertaken was to advance techniques for mapping their spatial structure. One approach that was considered (but not finally analysed) was to address vulnerability and sensitivity by applying biological traits analysis to benthic faunal assemblage information for several areas that were under study, and to use functional groups of organisms, rather than species identity, in analysis of distribution in relation to abiotic factors. This remains a clear research opportunity with respect to developing decision support for MPA planning, and for operational considerations in managing by-catch, and habitat interactions with commercial fishing activities under the SBA Policy. Kostylev and Hannah's habitat template approach addresses this question from the evolutionary perspective of life history traits using integrated parameters for disturbance and scope for growth. It is not as amenable as species distribution modeling approaches, such as Maxent and the gradient forest approach, for application against different sets of highly spatially-resolved habitat variables. A follow-on project from the current ERI could include more comprehensive benthic community sampling in one or more of the regions where there are now very detailed spatial representations of habitat structure, along with information on the distribution of commercial fishing activity. In addressing these questions (vulnerability, sensitivity, risk) it should be noted that the intensity of the field evaluation work required may mean that only a few particular habitats, or species complexes may be able to be investigated.

Even given the emphasis on the benthic ecosystem of the northern Gulf of Maine, the ERI work was largely restricted to two different spatial scales of enquiry: shelf-scale, with respect to the investigation of abiotic surrogates to explain beta diversity patterns in fish and invertebrates using historical benthic grab and contemporary demersal trawl survey data (e.g. Pitcher et al., 2012); and bank-scale, with respect to habitat and species distribution modeling (e.g. Brown et al., 2012). There remain opportunities to bridge across these scales in the future, as the analytical techniques that have been developed or adapted by the ERI program are not restricted to application at any one scale.

The ERI program overall was oriented to the offshore portion of the Gulf of Maine, and did not have a coastal research component; nor a significant deep-water or slope component. Also, in terms of scientific support for development of a network of MPAs, the ERI program did not encompass detailed work on pelagic species, in terms of transitory and migratory species distributions that includes different areas that are important for different life stages, such as spawning, over wintering, etc. Given some major challenges in undertaking biological sampling in an intensive manner across a bioregion, work conducted within the ERI program to develop predictive modeling tools is one of the areas that should receive greater attention moving forward.

In particular, there is a need for more frequent discussion between the region's physical and biological oceanographers, using in part the program experience of the Maritimes ERI, to define the types of physical variables that may be routinely required for future predictive modeling scenarios. Ideally, this would include refinements to temperature, salinity, dissolved oxygen, nutrients, primary and secondary productivity measurements, and spatial representation of water movements, particularly as it relates to achieving the connectivity design element within

MPA network planning. In some cases, the abiotic variables required for decision support for MPA planning may not currently be routine outputs from ongoing oceanographic modeling, thus requiring some customization of present scientific workflows.

Based on the experience from the Maritimes ERI program with determining the significance of abiotic surrogates in predicting biodiversity patterns, while predictive modeling offers a potential means to integrate biological and environmental data, it is also a data-intensive process not necessarily possible across the entire region. The assumption is that abiotic surrogates can predict, or at least correlate with, patterns of biological distributions reasonably well. Thus, testing this prediction with sampling is important. Data-rich areas, such as the ERI study area, could be used to verify and assess performance of predictive models, and in turn provide cost-efficient protocols for ground-truthing predictions when abiotic surrogates are used for prediction in data-poor regions. Disturbance history, and in particular the effects of cumulative fishery activity on benthic community characteristics, is obviously a potentially significant modifier of organism-habitat relationships. In the Maritimes ERI, a focused study was undertaken to model the effects of scallop fishing intensity on scallop productivity in relation to different habitat suitability on German Bank (reviewed in Brickman et al., 2012; see also Smith et al. (2009) for an earlier investigation). Since most areas of the Scotian Shelf bioregion are open to fishing, but all areas are not fished at the same level of intensity, benthic disturbance from fishing could influence present biological patterns and distribution. Thus predictive modeling using present-day biological information may lead to designation of representativity criteria for network MPA planning that will be quite different from the community characteristics and trajectories that will emerge once MPAs are designated. Broadening current modeling capabilities to incorporate fishing intensity variables from a range of fishing fleets may help to resolve this issue.

The ERI program was undertaken from 2009 to 2011. For a research program addressing ecosystem-level questions for a large coastal shelf system, both the period of time for the program development and execution, as well as the overall resources applied, represent modest investments, based on international experience. As part of the synthesis phase of the CoML, the GoMA program sponsored a review of the drivers, design, program experiences, current outputs, and projected longer-term outcomes for four regional-scale biodiversity programs (Ellis et al., 2011) covering four CoML-affiliated programs: GoMA, the Gulf of Mexico, the Great Barrier Reef, and the Baltic History of Marine Animal Populations. In terms of scientific program evolution (Figure 8), a decade represents an appropriate time-scale to gauge impact.

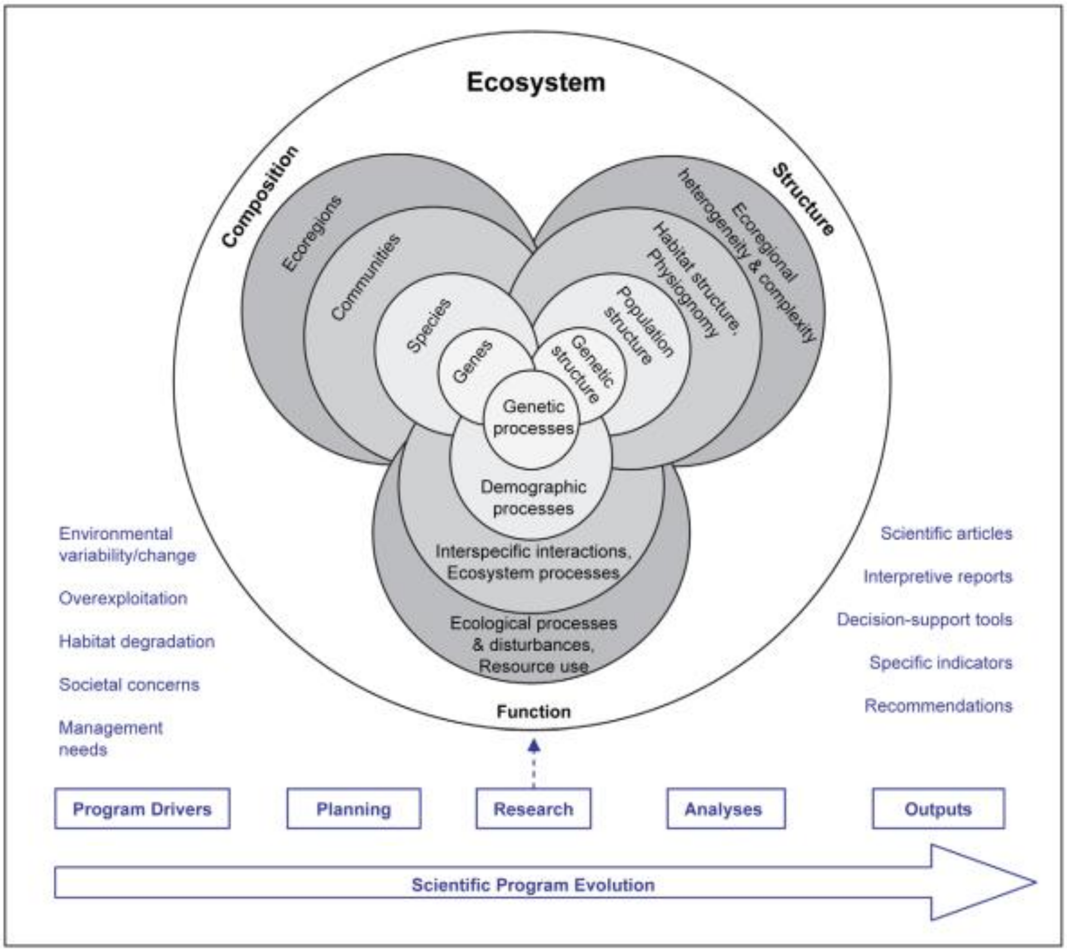

Figure 8. Elements of biodiversity research needed to support ecosystem-based management. Decreasing scales of biodiversity, from ecoregions to genes, are depicted from the outer to inner core of each element. Scientific program evolution is depicted by steps above the horizontal arrow. Feedback loops for iterative programs are not included. Examples of program drivers are listed at left. Ecosystem-based management uses insights provided by detailed research rather than the myriad research results themselves. These insights are summarized or integrated as outputs, such as the examples listed at right (Ellis et al., 2011); adapted from several prior schema; references within article).

In terms of the ERI program, the creation of an identity as a large collaborative program infrastructure (beyond component regional DFO science programs) provided the capability to link with similar collaborative programs, both nationally and internationally (as described above). Moving forward in meeting the imperative and demands for scientific advice for establishing a network of MPAs within the Maritimes Region, and implementing the SBA Policy, attention should be paid to these recent science program experiences, nationally and internationally. Creation of a cohesive internal science program architecture that can address both short-term and longer-term implications for protected areas designation, monitoring, and evaluation, would position the department well to entrain outside scientific expertise, and experience.

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