Habitat Mapping and National Seafloor Mapping Strategies in Canada

*R.A. Pickrill and V.E. Kostylev
Geological Survey of Canada (Atlantic), Natural Resources Canada, Bedford Institute of Oceanography,
P.O. Box 1006, Dartmouth, NS, B2Y 4A2, Canada
*Corresponding author, E-mail: dpickril@nrcan.gc.ca

Pickrill, R.A., and Kostylev, V.E., 2007, Habitat mapping and national seafloor mapping strategies in Canada, in *Todd, B.J., and Greene, H.G., eds., Mapping the Seafloor for Habitat Characterization: Geological Association of Canada, Special Paper 47, p. 483-495.*

Abstract

Recognizing the need for improved management of Canada's oceans, the Canadian government enacted Canada's Oceans Act (1996). This legislation lays the framework for precautionary, sustainable management of our offshore lands, encapsulating the principles of conservation and ecosystem-based management, and laying the foundation for systematic marine habitat mapping.

Demonstration projects from 1997 to 1999 in the Gulf of Maine proved the benefits of new seafloor mapping technology to ocean management, and led to the development of a national program to map Canada's offshore lands. Many of the underlining principles guiding seafloor mapping and research directions within Natural Resources Canada (NRCan) and the Department of Fisheries and Oceans (DFO) have been developed through the last decade. In 2002, research in NRCan was reorganized to improve alignment with government priorities; the resulting Geoscience for Oceans Management Program (GOM, http://www.gom.nrcan.gc.ca) acknowledged the role that seafloor mapping can contribute to habitat characterization and environmental stewardship. In the federal budget of 2005, funding was secured through the Canada's Oceans Action Plan to develop a national mapping strategy and extend mapping to priority areas across the country.

With one of the world's largest offshore territories, a relatively small population base, and a severe marine environment, Canada faces challenges in the implementation of integrated and sustainable management of our offshore lands. Through a series of stakeholder workshops, priority areas of national importance have been identified, and new standards for digital marine map products and a new marine map series have been approved. A habitat-mapping strategy has been developed to optimize program outputs that incorporate five different approaches to mapping. In response to each particular challenge, the actual approach applied to any particular area is being driven by the mapping scale, the ability to collect new data, the environmental constraints, and the time frame and stakeholder needs, yet always building toward a national framework.

Résumé

Conscient de la nécessité d'améliorer la gestion des océans au Canada, le gouvernement canadien a édicté la Loi sur les océans du Canada en 1996. Cette loi encadre la gestion préventive et durable de nos territoires en zone extracôtière, en intégrant elle comprend les principes de conservation et de gestion fondée sur les écosystèmes, et en jetant les bases pour la cartographie systématique des habitats marins.

Les projets de démonstration de 1997 à 1999 dans le golfe du Maine ont prouvé les avantages de la nouvelle technologie de cartographie des fonds marins en matière de gestion océanique, et ont mené à l'élaboration d'un programme national de cartographie des territoires en zone extracôtière du Canada. Plusieurs principes sous-jacents qui guident les directions de la cartographie du fond marin et de la recherche à Ressources naturelles Canada (RNCan) et au ministère des Pêches et des Océans (MPO) ont été élaborés au cours de la dernière décennie. En 2002, la recherche à RNCan a été réorganisée en vue d'améliorer l'alignement avec les priorités gouvernementales; le programme des géosciences à l'appui de la gestion des océans (GGO, http://sst.rncan.gc.ca/2002_2006/gom/index_f.php) qui en a résulté reconnaît le rôle de la cartographie du fond marin dans la caractérisation des habitats et dans la bonne intendance de l'environnement. Dans le budget fédéral de 2005, le financement a été assuré par l'entremise du Plan d'action du Canada pour les océans en vue d'élaborer une stratégie de cartographie nationale et d'étendre la cartographie aux zones prioritaires dans tout le pays.

Avec l'un des plus grands territoires en zone extracôtière au monde, une population relativement faible et un environnement marin difficile, le Canada fait face à des difficultés dans la mise en oeuvre d'une gestion intégrée et durable de ses territoires en zone extracôtière. Par l'entremise d'une série d'ateliers d'intervenants, les zones prioritaires d'importance nationale ont été définies et de nouvelles normes pour les produits numériques de cartes marines, ainsi qu'une nouvelle série de cartes marines ont été approuvées. Une stratégie de cartographie des habitats a été élaborée dans le but d'optimiser les résultats du programme qui incorpore cinq différentes méthodes de cartographie. Devant chaque défi particulier, la méthode appliquée à toute zone tient compte de l'échelle de cartographie, de la capacité de recueillir de nouvelles données, des contraintes environnementales et du cadre temporel ainsi que des besoins des intervenants, tout en travaillant toujours vers un cadre national.

INTRODUCTION

As the twentieth century drew to a close, Canadian ocean management policy and the supporting marine science within the federal government was entering an exciting new era. Competition for declining offshore resources, ecosystem collapse, and mounting public pressure for improved management of the public ocean asset, led the federal government to enact Canada’s Oceans Act (Parliament of Canada, 1996). This visionary legislation lays the framework for precautionary, sustainable management of our offshore lands while encapsulating the principles of conservation and ecosystem-based management.

Management of offshore lands has always been constrained by a lack of high-quality information on the marine ecosystem. However, converging surveying and navigation technologies enable precise positioning anywhere on the planet (using Global Positioning System, or GPS, technology), and the utilization of multibeam echo-sounder mapping to produce high-resolution imagery over wide areas of the seafloor. The precisely-positioned multibeam imagery has revolutionized hydrography, marine geoscience, benthic ecology, and habitat mapping – in essence enabling the collection of invaluable contextual information for habitat management – and thereby established the knowledge base for implementing integrated ocean management.

In the 1960 and 1970s, a systematic mapping program saw much of the surficial geology of the Canadian continental shelf mapped (*e.g.*, MacLean and King, 1971; Drapeau and King, 1972; MacLean *et al.*, 1977; Fader *et al.*, 1977). These maps, based on single-beam echo sounder, sidescan sonar, seismic surveys, and grain-size analysis, provided adequate coverage at a regional scale, laying the foundation for our understanding of the surficial geology of offshore Canada; these maps are still in use today. However, with the emergence of high-resolution swath mapping tools such as multibeam sonar it became clear that much of the complexity of the seafloor, now required for planning, was not captured by this map series (Loncarevic *et al.*, 1994). The 1980s and 1990s witnessed a hiatus in regional mapping, with the focus turning to local-scale projects, targeted at specific local issues and demonstrating the application of the new technology to marine geoscience. Toward the end of this period, geoscientists recognized the power of these new tools in mapping benthic habitats, but government research retrenched as budgets were cut and the opportunity to mount a new systematic mapping program, founded in the new technology, had passed.

PROGRAM RESPONSE

Industry was quick to recognize the power and utility of the new seafloor mapping tools. Regional mapping has been conducted by the oil industry as reconnaissance surveys for hazards, structural geology, and gas seeps. In engineering applications, multibeam sonar has been adopted as the industry standard for pipeline and cable corridor surveys (Pickrill *et al.*, 2001). In partnership with government, the fishing industry has invested heavily in surveys of scallop banks off southwest Nova Scotia. Maps of the bathymetry, surficial geology, and benthic habitat were exported to electronic charts and have been used very successfully to improve fishing efficiency, reduce environmental damage, and introduce new management practices to the fishery (Kostylev *et al.*, 2003; Pickrill and Todd, 2003). A direct result from this research partnership was the development of rapid, accurate methods to map seafloor habitat over large areas of the seafloor (Kostylev *et al.*, 2001).

As the utility of the seafloor-mapping technology was demonstrated to a widening group of stakeholders, new survey methods evolved and convergence occurred on a narrowing set of standard deliverables. Marine geoscience surveys are now two-phased operations. Regional multibeam surveys are conducted of the entire study area, or where complete coverage is impractical, over highest priority regions. This data undergoes preliminary interpretation, is exported as georeferenced imagery into electronic navigation systems, and is used to plan subsequent follow up ground-truth surveys, using conventional survey technologies. Depending on the type and frequency of the multibeam system, and methods of deployment, features resolved at the seabed typically range from 0.5 m in 10 m of water at the coast, to 5 m at the edge of the continental shelf to approximately 50 m on the mid-slope (1500 m water depth). Specific geomorphic features are then targeted to ground-truth the regional multibeam interpretation. A nested suite of tools, with increasing resolution and decreasing spatial coverage, are used to ground-truth the multibeam imagery; carefully planned sidescan sonar tows and mosaics, video transects and still photography are gaining more importance over conventional “blind” grab sampling. High-resolution seismic reflection surveys are conducted to determine sediment thickness and underlying shallow sedimentary structure. Carefully-planned and well-executed geophysical surveys are now relatively short in duration and enable high-resolution, regional-scale interpretations to be produced, embedded with site-specific habitat information including sediment texture, bedforms, and benthic species composition.

Demonstrable benefits of the seafloor mapping technology to a broad spectrum of users and managers of the ocean space, as well as convergence toward a standard suite of data, map products and interpreted reports, led to the development of a proposal for a national program to map Canada’s offshore lands. SeaMap, a joint initiative between Natural Resources Canada (NRCan) and the Department of Fisheries and Oceans Canada (DFO) is aiming to establish standards and set national priorities for mapping the shape of the seabed the bedrock and overlying sediments, and the associated benthic communities, thereby providing the knowledge base to deliver on Canada’s Oceans Act. Despite strong stakeholder support, the program is yet to be funded. However, the SeaMap proposal demonstrated a need, and many of the underlining principles are guiding seafloor mapping and research directions within NRCan and DFO over the ensuing years by:

! establishing habitat mapping as a priority research area for the Geological Survey of Canada, legitimizing the role of an Earth Sciences organization in mapping benthic habitat and providing a framework for integrated ocean management;

! providing a forum for establishing national seafloor mapping priorities; and

! demonstrating the ability and necessity to break down traditional boundaries between departmental mandates to deliver integrated priority research for the Canadian public.

In 2002, marine surficial geological research in NRCan was reorganized to maintain alignment with government priorities; the resulting Geoscience for Oceans Management Program (GOM, http://www.gom.nrcan.gc.ca) acknowledged the emerging need to deliver on new government policies in the oceans and recognizes the role that seafloor mapping can contribute to these.

The resulting project portfolio in GOM reflects national priorities in Canada’s offshore lands (Figure 1). Of the seven projects, six encompass a multidisciplinary approach to ocean management, and can be viewed as SeaMap demonstration projects, taking an integrated approach to mapping the bathymetry, surficial geology, and benthic habitat:

! the Strait of Georgia is subjected to the highest population pressure of any Canadian coast and presents a complexity of management issues including pipeline and cable crossings, slope stability, dredging and disposal, and sensitive habitats;

! the Queen Charlotte Basin has been the subject of a national debate to review lifting the moratorium on hydrocarbon exploration and the creation of Marine Protected Areas (MPAs);

! the Beaufort Sea/McKenzie Delta contains some of the largest hydrocarbon reserves in Canada and bringing these resources to market presents unique engineering challenges needing to be balanced with environmental concerns;

! on the Atlantic margin, the Eastern Scotian Shelf is one of the first Large Ocean Management Areas (LOMA) to be declared in Canada, incorporating The Gully Marine Protected Area and requiring the development of a management plan. The NRCan project supports the Eastern Scotian Shelf Integrated Management (ESSIM) initiative in DFO;

! the shallow southern banks off southwest Nova Scotia host a $100 million annual scallop fishery. Partnerships with industry have provided the opportunity to map large areas of these banks and develop innovative mapping and management plans for the fishery;

! the Placentia Bay project in Newfoundland is the highest priority area for research for the province of Newfoundland and Labrador reflecting the focus on shipping, industry, aquaculture, conservation, and fishing in the bay; and

! the Estuary of the Gulf of St. Lawrence is the “tailpipe” of the Great Lakes watershed, and as such, faces a number of management issues related to cumulative human impacts on the ecosystem. This, the newest project, is still under development.

There are many other high priority areas within Canada, but the project roster reflects the program resource base balanced with the ability to deliver nationally significant projects within a four-year time frame.

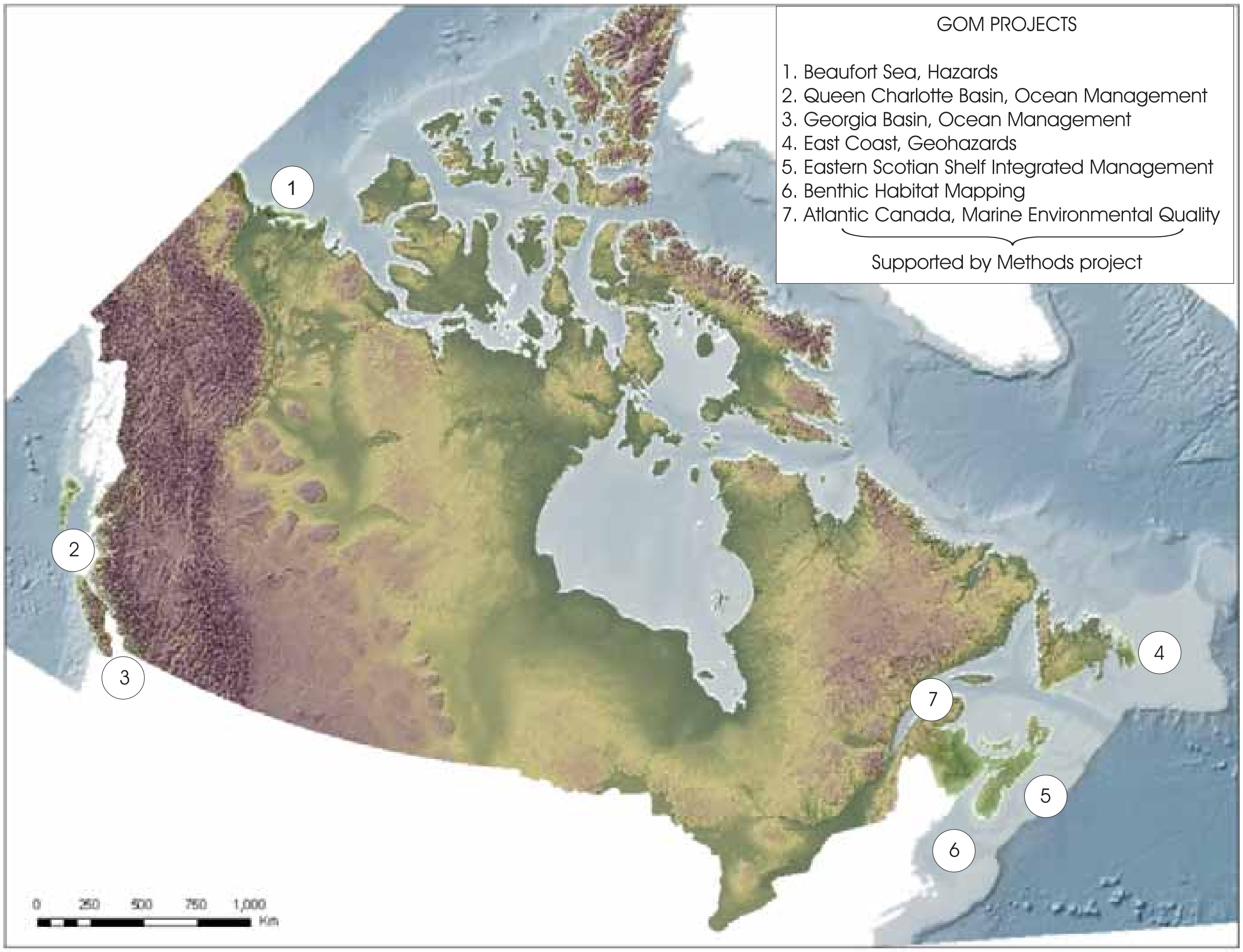

Figure 1. *Map of Canada showing the seven regional project locations in the Geoscience for Oceans Management Program and the primary issue.*

MAPPING APPROACHES

The basic mapping needs in each of the regional projects are the same: to map the bathymetry, geology, and benthic communities to the highest resolution possible. Practical limitations have led NRCan to develop five systematic approaches, targeted to project and stakeholder needs, and constrained by existing data and the ability to collect new data.

Geology and Community Analysis

Where 100% multibeam coverage exists for an area, and geological ground-truth has been completed to adequately characterize the regional geomorphology and seafloor sediment texture, targeted still photography and video imaging has been used to identify the megabenthos and to describe the geological setting of the sites. Frequency of occurrence and taxonomic diversity of benthic species is calculated for each photographic station, and selected grab samples are collected to verify identifications and preserve voucher specimens. Species are then grouped into major taxa for subsequent statistical analysis. In addition to grab sample analysis, the presence of burrows, trails, tracks, and pits is used to assess infaunal abundance and bioturbation.

The database compiled from the photographic sample analysis is statistically analyzed. A number of multivariate and non-parametric techniques are used to pinpoint important benthic habitat characteristics; the texture and shape of the seabed is the most commonly identified one. Based on similarity analysis, the method ranks the best correlations of combinations of the environmental factors to the structure of benthic community and defines the proportion of variance explained by the different environmental factors (*e.g.*, water depth, sediment texture, *etc.*), which consequently allows defining habitat boundaries on a map.

Applying these techniques to habitat mapping on Browns Bank off southwest Nova Scotia enabled Kostylev *et al.* (2001) to map seven habitats and corresponding associations of benthic animals (Figure 2); each habitat was distinguished by substrate, habitat complexity, relative current strength and water depth. A similar approach has been taken, in partnership with DFO, to defining the habitats within the proposed MPA of The Gully near Sable Island in

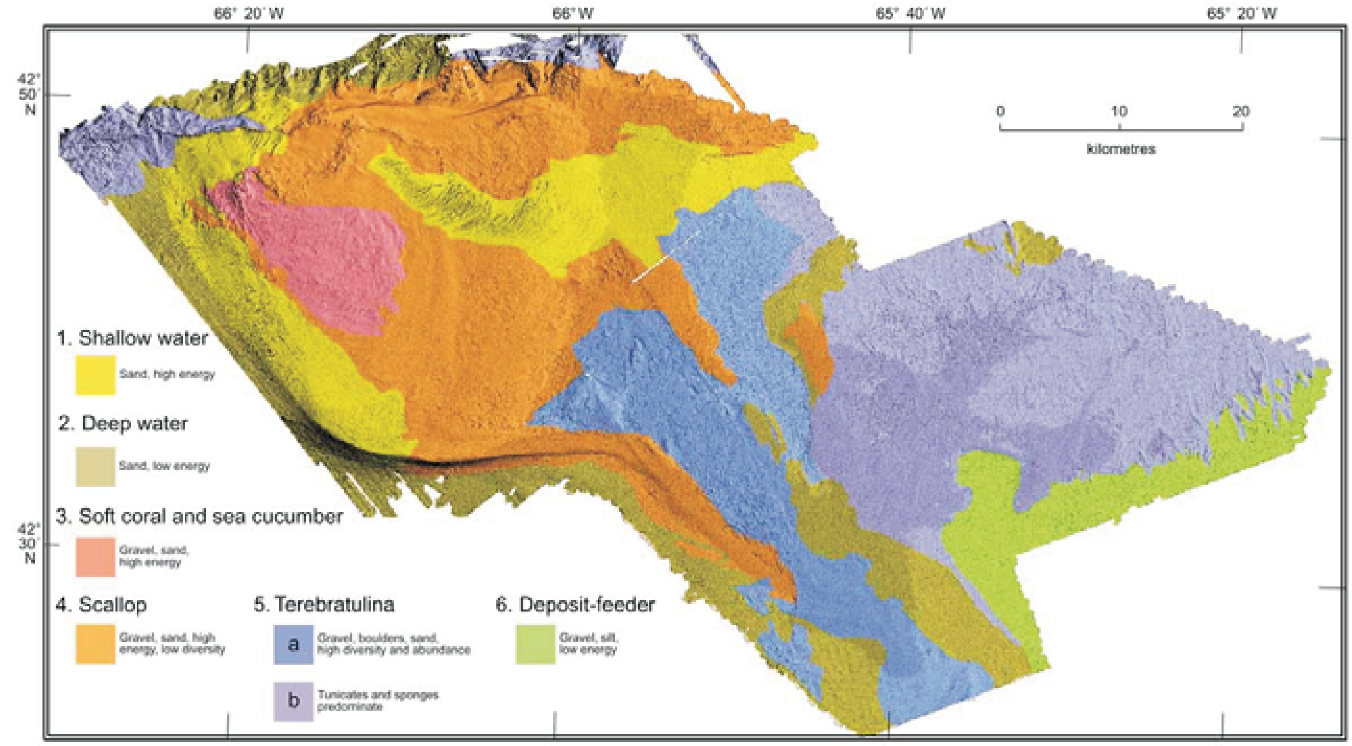

Figure 2. *Browns Bank habitat map from Kostylev* et al. *(2001).*

the ESSIM area (Kostylev, 2002; Hargrave *et al.*, 2004). Water mass properties, together with substrate type and bathymetry, were used to distinguish six types of benthic habitats. Geomorphology was shown as the driving force for distribution of deep-sea corals and for defining benthic community types.

Integrating multibeam mapping with geological surveys enables accurate, high-resolution maps of the geomorphology and sediment cover to be produced. As these are the principal controls of community structure, targeted but limited benthic sampling utilizing bottom photography can be used to ground-truth the main features. The geological interpretations can then be used to extrapolate each habitat type over relatively large areas of the seafloor. Although the benthic infauna is not well suited to this sampling approach, the disadvantages are outweighed by the speed of data analysis (Kostylev *et al.*, 2001). In the current cycle (3 years), the GOM Habitat Mapping project will produce an integrated suite of benthic habitat maps for Browns, German, and Georges banks, an area of approximately 20,000 km^2 off southwest Nova Scotia.

Acoustic Signature Mapping

Some ecologically important biogenic habitats, such as sponge reefs, have a distinct acoustic signature, clearly identifiable from sonar data. In the 1980s, sponge reefs were discovered in the deep waters of the continental shelf of the Canadian Pacific coast, north of Vancouver Island. Interest in these rare sponge communities grew, as it was realized that these sensitive habitats were being damaged by trawling and that pressure to lift the moratorium on hydrocarbon exploration off the British Columbia coast would add to the competition for use of the seafloor. Pressure mounted to better map the aerial extent of the reef complexes to determine appropriate conservation measures.

Initial studies demonstrated a clear link between the glacial history of the shelf and distribution of sponge reefs. During the last glacial lowstand, sea levels were lower and the continental shelf was subjected to extensive glaciation. During this time, icebergs calved from the ice front scoured the seabed leaving furrows and concentrating boulders on the furrow flanks. This relict landscape is now submerged in deep water on the mid-shelf and remains largely unaltered by modern marine processes. The large boulders are a stable site for attachment and growth of sponges and other filter-feeding organisms. These are the initial sites for colonization by sponge reefs where a hard substrate is available in a very stable area of low sedimentation and relatively strong currents. These currents ensure an adequate supply of nutrients is delivered to the reef sites and that sediment remains in suspension and does not blanket the reef surface. This direct link between the physical environment and sponge colonization enables predictive estimates of potential sponge habitat to be made.

Reef-building communities such as sponges and corals (Conway *et al.*, 1991; Fossa *et al.*, 2002) are some of the few benthic assemblages that can be physically identified by their acoustic signature (sidescan and multibeam sonar) and mapped directly rather than simply by association with the geological substrate (Figure 3). Data on the distribution of sponge reefs on the shelf of central British Columbia are sparse. However, recognition of the acoustic signature of the habitat, combined with an understanding of the physical constraints on suitable habitat type, balanced with local knowledge in the fishery, has enabled targeted multibeam sur-

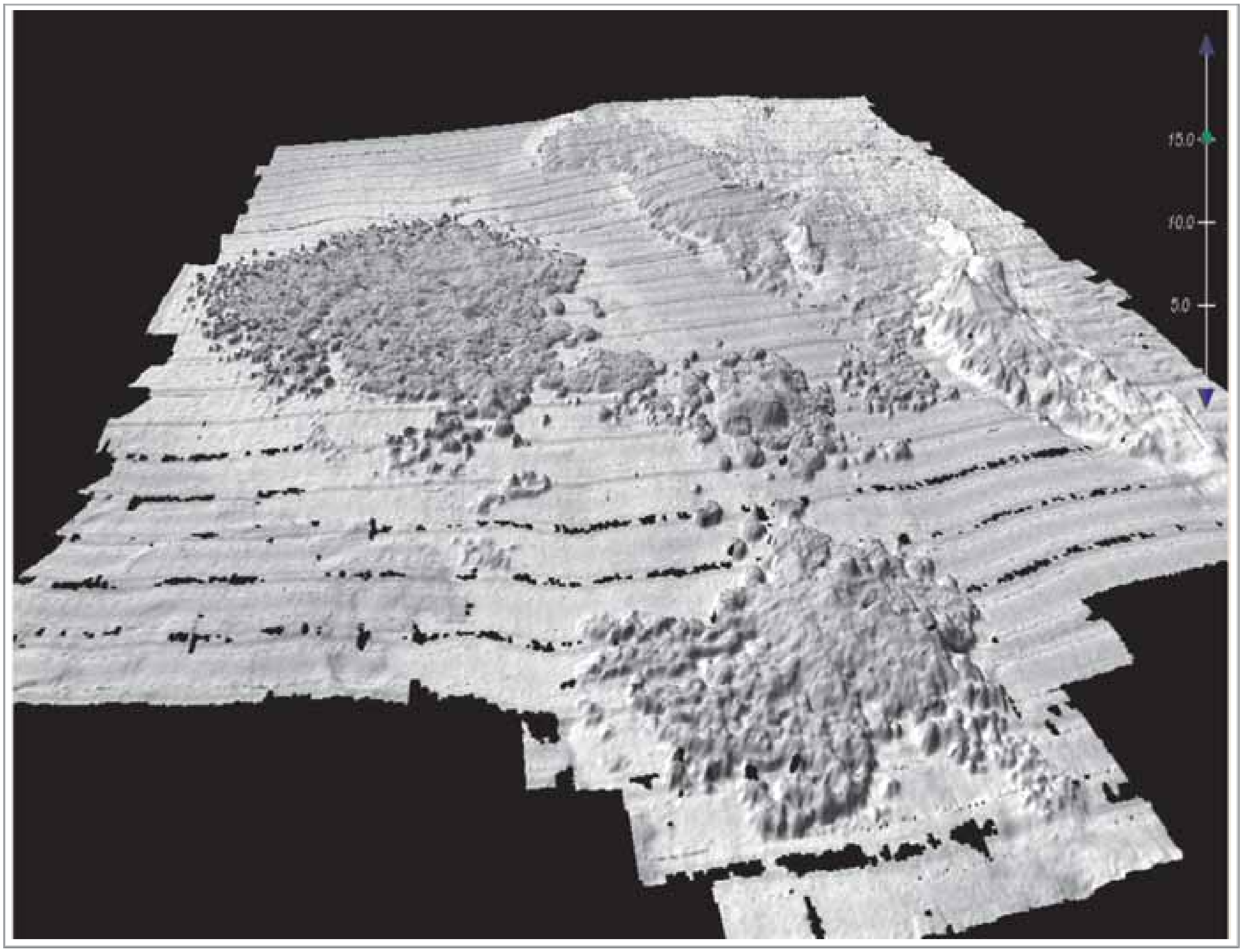

Figure 3. *Multibeam image of backscatter intensity draped over bathymetry of sponge reefs on Cook Bank, Queen Charlotte Basin, British Columbia. Water depth is approximately 200 m (Conway* et al.*, 2001).*

veys to be conducted on this coast. Four large reef complexes have been identified for consideration of exclusion of commercial fisheries and hydrocarbon exploration. This targeted survey approach represents a very cost-effective method to prioritize resources in a geographically vast area. The approach also quickly delivers a knowledge base upon which management and conservation plans can be founded.

Extrapolation of Local Habitat Models to Regional Applications

The Beaufort Sea shelf is shallow with most of the shelf less than 40 m water depth). This shallow depth, seasonal sea ice cover, and the high suspended sediment load from Mackenzie River outflow contribute to the harsh environmental conditions in the Beaufort Sea. The duration of the annual scientific field season is limited and the ability to accumulate sufficient data for regional coverage is reduced. A number of natural and anthropogenic processes affect seabed habitat and benthic community structure in the Beaufort Sea:

- seasonal ice scouring reworks the seafloor, disturbing the habitat, and creating unique geomorphology at the macro scale;
- local seafloor processes, such as expulsion of shallow gas at the surface, modify the seabed geomorphology, sediments and habitat; and
- oil and gas companies, exploring for hydrocarbons in the 1970s and 1980s dredged much of the available aggregate to create artificial ice islands for installation of oil rigs. At the time, this was one of the largest reclamation projects in North America. Dredging destroyed old habitats and created new habitats, many of which are now distinctly different from the natural environment.

The Beaufort Sea presented unique challenges in the characterization of benthic habitats. By recognizing the distinctly different physical environments at the seabed, and the gradation of processes across the shelf into deeper water, a number of distinct habitat types were recognized. Targeted seafloor mapping and sampling

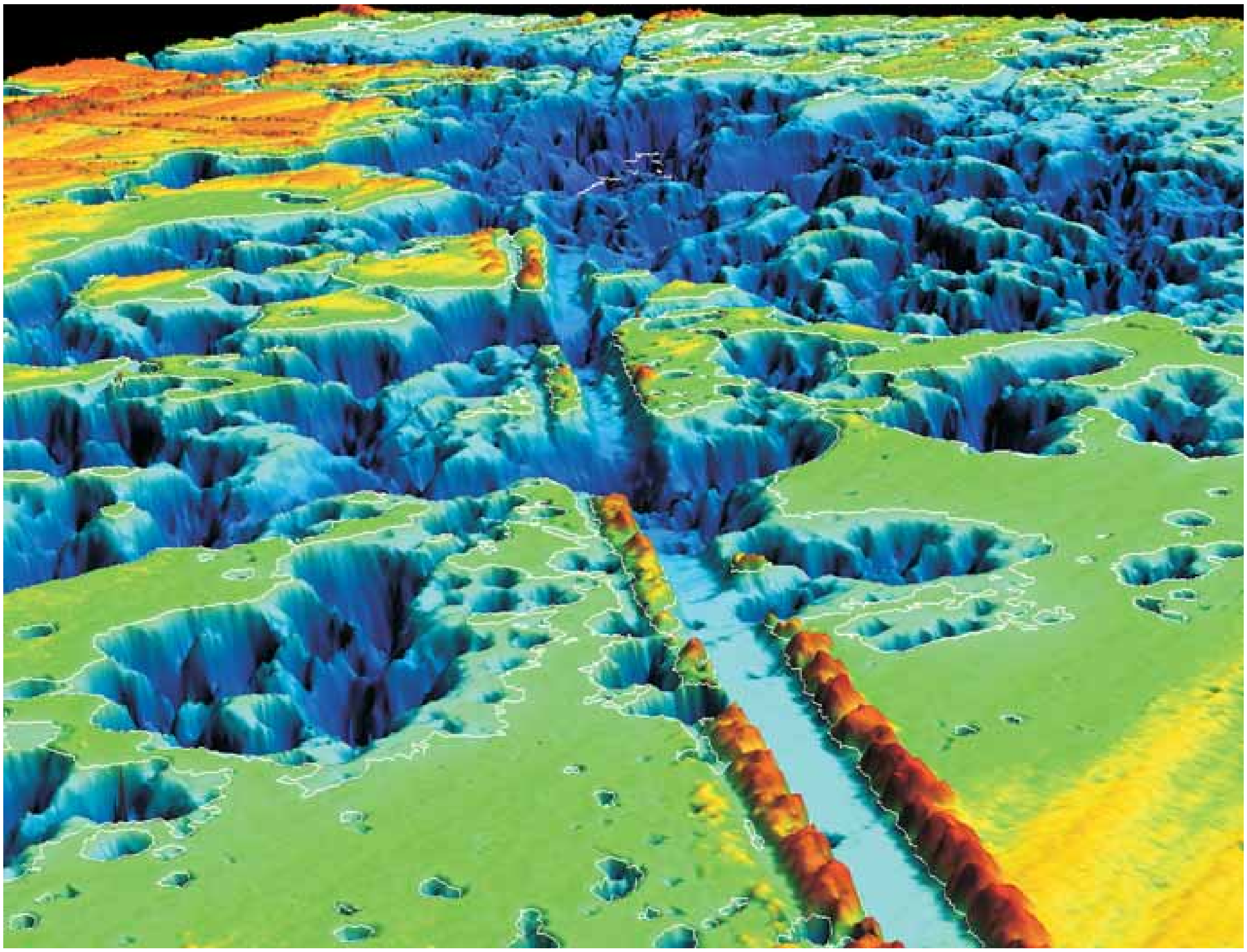

Figure 4. *Multibeam image of the shallow inner shelf of the Beaufort Sea. The flat seafloor has been cut by grounding ice, resulting in curvilinear furrows and flanking berms. The labelled furrow is 18 m wide. Expulsion of shallow gas from underlying sediments has left the surface pockmarked. These active seafloor processes have created unique seafloor habitats (Blasco* et al., *2005). Vertical exaggeration is 10 times.*

surveys were conducted at representative study sites including artificial islands, ice-scoured bottom, gas vents, distinct geology and water depths (Figure 4). The major physical forces structuring benthic habitats and defining benthic communities in the Beaufort Sea were found to be the disturbance regime (scouring), the presence of land-fast ice (which limits scouring and productivity in the nearshore zone), the overall low primary productivity in the sea controlled by seasonal ice, and the effect of the suspended sediment load from Mackenzie River runoff (Kostylev and Chapman, 2004). These major driving forces explain the increase of biodiversity and biomass of benthic communities with depth, the decrease in biodiversity in ice-scoured areas, and the scarcity of benthos on eroded surfaces of artificial islands. Ice scouring rates were assessed by Blasco *et al.* (1998) who, based on sidescan and multibeam sonar surveys, established the highest disturbance frequency in a 20 to 30 m water depth band along the coast. Outside of this band, any anthropogenic influence will have a drastic effect on the environment, because it takes more than 30 years for benthic communities in Arctic environments to recover from physical impacts (Conlan and Kvitek, 2005). On the basis of this knowledge, and by developing and testing models linking benthic community dynamics with seafloor processes, it is possible to extrapolate with confidence to the regional scale to provide a framework within which management plans (such as oil and gas installations) can be carried out. This approach has provided a pragmatic cost-effective solution to habitat mapping in extreme environments.

Deterministic Modelling

In the absence of continuous high-resolution information on seabed geology, and with aliased and patchy goundtruthing, it has been necessary to take other approaches to map benthic habitats on a regional and shelf-wide scale. Because habitat represents an integrated response to oceanographic, geological and biological conditions which jointly define the seabed environment, an interdisciplinary and interdepartmental (DFO-NRCan) approach was used to map the Scotian Shelf on the Canadian Atlantic margin. In this framework, two key questions were addressed: which areas of the seafloor are the most sensitive to human impacts and how can limited ecosystem knowledge be used to balance competing demands from resource exploration and conservation? The large area and limited time available to complete the study meant that these questions had to be answered through mapping and characterization of the seafloor environment based on our current understanding of biological, geological and oceanographic patterns and processes on the Scotian Shelf.

One of the modelling approaches is based on habitat template theory (Grime, 1977; Southwood, 1977, 1988), which was adapted to habitat mapping by Kostylev (2005) as a basis for predicting habitat properties and life history traits of benthic species. The model considers two principal selective forces, habitat disturbance and physiological adversity of the environment. These forces have shaped the existing communities of benthic species and defined life history traits of species found in different seabed habitats. The disturbance axis of the template, reflecting temporal persistence of habitat structure, was modelled based on the bathymetry, sediment characteristics, and current and wave energy available to disturb the seabed. It is expressed numerically as the ratio of the representative bottom stress to critical stress required for initiation of sediment movement. The adversity axis, which relates, in bioenergetics terms, to an organism's scope for growth, is modelled based on variability in oceanographic factors (chlorophyll concentration, water density gradients, bottom-water temperature and salinity). Indices, based on these factors, are combined in an additive fashion, which allows characterization of the environment on a continuous scale between 'benign' and 'adverse'. The resulting map (Kostylev, 2004) is a combination of the two axes, and highlights the most important characteristics of benthic habitats for management (Figure 5). In naturally disturbed environments (*e.g.*, shallow sandy banks), risk of Harmful Alteration, Disruption and Destruction (HADD) is lower than in naturally stable environments, which are more vulnerable to human impacts. Populations under fishing pressure in benign habitats are more likely to recover than populations in habitats with limited scope for growth (*e.g.*, deep-sea corals). The habitat template map (interaction of disturbance and productivity axes) acts as a guide for defining ecologically sensitive areas by providing a logical and quantitative framework.

The model has been subjected to intense scientific and public scrutiny through the ESSIM consultative planning process (DFO, 2005). It has been validated theoretically and accepted by fisher-

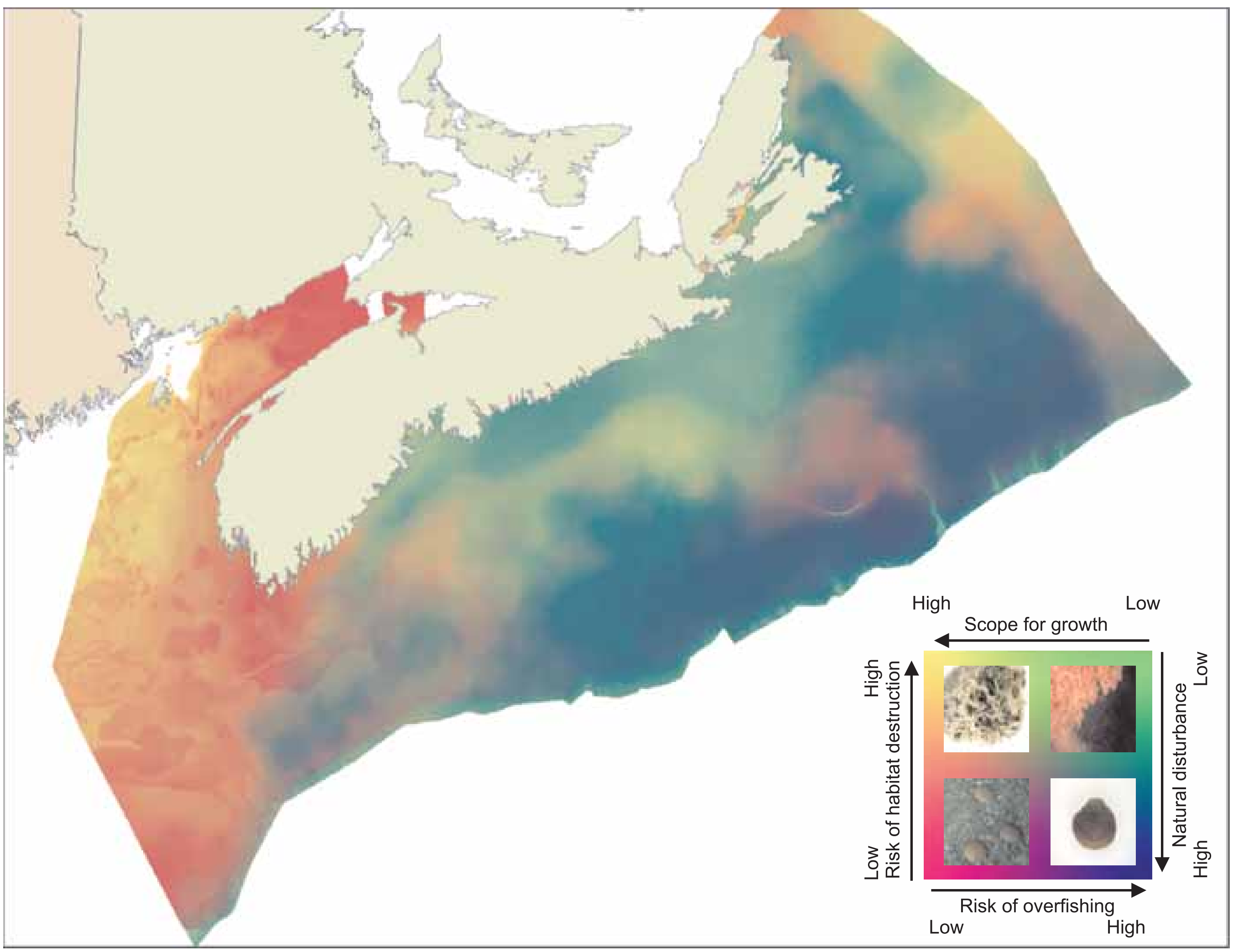

Figure 5. *Habitat template for the Scotian Shelf. The model integrates seafloor disturbance and habitat adversity to generate a single management template (Kostylev, 2004).*

men and other users as being environmentally and economically viable. The single-map approach alleviated difficulties inherent in simultaneous visual interpretation of a large number of environmental variables and helped to avoid the often arbitrary bounds and constraints of rigid classification schemes. As a management tool, the habitat template has other benefits. For example, knowing the life history traits of an organism, the template can be used to predict its distribution on the shelf. Conversely, knowing the physical conditions in a given area, predictions of likely inhabitants and biodiversity of the area can be made and incorporated in management decisions.

Human Impact and Ecosystem Change

A variety of anthropogenic activities modify the physical, chemical, and ecological conditions of the seabed and the structure of the associated benthic communities on an ongoing basis. Habitat alteration and destruction can be effectively monitored and mapped using remote-sensing technologies. Principal activities within Canadian waters include ocean dredging and dumping, and fishing. Historically, DFO has conducted extensive research into the impacts of trawling and hydraulic rake fishing for shellfish. NRCan has provided the geoscience input to these carefully designed controlled experiments (Schwinghamer *et al.*, 1998; Gilkinson *et al.*, 2003). When used as a part of integrated oceanographic and ecological studies, the habitat-mapping tools developed by NRCan provide users with invaluable information on structural changes of the affected habitats. For instance, impacts of dredging and dumping, including mine tailings discharge, have been the focus of multidisciplinary research within the current Geological Survey of Canada (GSC) program. Dredging and discharge leaves noticeable physical impacts on the seabed, and their effects can be monitored successfully using high-resolution acoustics and video monitoring techniques. These impact studies have only become possible with GPS and advanced, high-precision mapping techniques, enabling survey repeatability and allowing seabed changes to be quantified.

In Saint John Harbour in the Bay of Fundy (Canadian Atlantic coast), the considerable discharge of turbid waters from the Saint John River leads to rapid deposition of fine sediment, requiring annual maintenance dredging. The dredged sediment is disposed of at the Black Point dumpsite, where cumulative dumping has produced considerable sediment build-up (Tay *et al.*, 1997) and possible changes in the benthic community (Wildish and Thomas, 1985). In 1992, Environment Canada embarked on a three-year monitoring program to define the zone of influence of the disposal activities, assess the physical, chemical, and biological impacts caused by disposal, and to evaluate the long-term use of the site for future dredging projects. The study indicated that past disposal activities resulted in a significant build-up of dredged material within a one-kilometre radius of the disposal buoy. A joint research program between Environment Canada and the GSC was initiated in 1999 to determine recent changes in the disposal site and to study the fate and impact of dumped materials. Using high-resolution repetitive mapping, the GSC confirmed the build-up of dredged material and subsequent erosion of material during the winter. Numerical modelling has provided insight into sediment transport processes and associated changes in bottom communities. On this local scale, geology and anthropogenic alteration of habitat structures were the major drivers for environmental change.

Similarly, high-resolution mapping and seabed interpretation have proven to be important tools in high-resolution studies of habitat preferences of specific species. For example, joint NRCan-DFO studies of haddock habitat were based on sidescan sonar and multibeam sonar bathymetric surveys, towed video imagery and grab sampling (Anderson *et al.*, 2005). This project was aimed at improving the understanding of the relationships between benthic habitat, benthic communities, and demersal fish. Once the important types of habitats were defined and spatial and temporal dimensions of habitat utilization by fish understood, predictions of occurrence of critical fish habitat could be made through the mining of NRCan's acoustic databases. Through increasing scientific knowledge, this project will provide better advice for the management of fish habitat to ensure protection of its productive capacity and biodiversity.

In these two examples, high-resolution mapping and detailed analysis of acoustic/remotely-sensed information was critical to evaluate man's impact on the ecosystem and to improve fisheries-management practices.

BENEFITS OF HABITAT MAPPING

The acoustic seafloor mapping technologies that have evolved over the last fifteen years have been embraced quickly by the hydrographical and geological sciences. New survey techniques, data management, interpretation, and map products have evolved to optimize data utilization and provide new insights into our offshore geology. Application to habitat ecology has been a more recent development, in part, flowing from the geoscience applications. Over a short period of time the benefits to ecosystem research and management have been outstanding, and we have only begun to explore this application.This paper has demonstrated how acoustic mapping, when integrated with benthic sampling, can be utilized to characterize large areas of the seabed very rapidly. New standards have been established whereby maps of the seafloor shape, sediment cover, and associated benthic assemblages are now more than adequate to address many management issues in the offshore. The tools routinely used in land-management practice onshore are finally available to implement integrated management in offshore lands.

In Canada, the benefits of integrated, high-resolution seafloor mapping have been demonstrated to most sectors of the marine economy (Pickrill and Todd, 2003). For example, on Browns Bank, where one of the most important scallop (*Placopecten magellanicus*) fisheries in eastern Canada occurs, NRCan, together with a group of fishing companies, discovered that acoustic backscatter maps can be used to improve scallop catch rates (Kostylev *et al.*, 2003). Results of this research revolutionized the Canadian east coast scallop fishery by demonstrating and experimentally testing the relationship between multibeam backscatter and scallop catches and by showing the relationship between acoustic properties of the seafloor and scallop biomass. Multibeam backscatter maps installed in fishing fleet navigation systems led to manifold improvements in fishing efficiency (75% less time spent fishing, 36% less spent fuel) and better preservation of seabed habitat (74% less seabed trawled for the same tonnage of catch). Results from this research have been incorporated in management plans for this and other lucrative scallop banks off southern Nova Scotia.

From a conservation perspective, habitat mapping has defined major sponge reefs for consideration as MPAs on the Pacific coast; on the Atlantic margin, seabed maps from The Gully near Sable Island are incorporated in the management plans for this first MPA on Canada's east coast, while the ESSIM LOMA has adopted the habitat template as a scientific underpinning of management strategies. The hydrocarbon and engineering industries routinely include habitat mapping as part of environmental assessments of all significant developments in the offshore, either through legislated requirement, or simply through good stewardship. Marine ecozoning, which is zoning activities and defining policies based on the interaction of activity and the environment, is firmly dependant on scientifically sound habitat maps.

NATIONAL MARINE MAPPING STRATEGY

With one of the largest offshore territories, a relatively small population base, and a severe marine environment, Canada faces challenges to implement integrated management of our offshore territory. Bounded by resource constraints, and delivered through a national program structure, NRCan has been able to identify priority areas of national importance on which to focus habitat research. To optimize program outputs, a habitat mapping strategy has been developed.

Map Standards and Products

NRCan published the last systematic seafloor maps of surficial sediments in the 1980s. Following several successful demonstration projects, the GSC has established new standards for offshore maps based on multibeam sonar and other acoustic and bottom-sampling techniques (Shaw and Todd, 2002; Shaw and King, 2004). In partnership with the Canadian Hydrographic Service, systematic multibeam sonar mapping of high-priority areas has led to the development of a new NRCan Marine Map Series, with publication targeted at 1:50,000 scale, and regional maps being produced at 1;100,000, and specific issue-driven maps in the inshore being displayed at 1:10,000 or other appropriate scales (Figure 6). Four map sheets are scheduled within each map area: colour-shaded multibeam bathymetry, multibeam backscatter, interpreted geology, and benthic habitat. Where appropriate, sheets dedicated to specific issues, such as geohazards or land use, may be added. The first

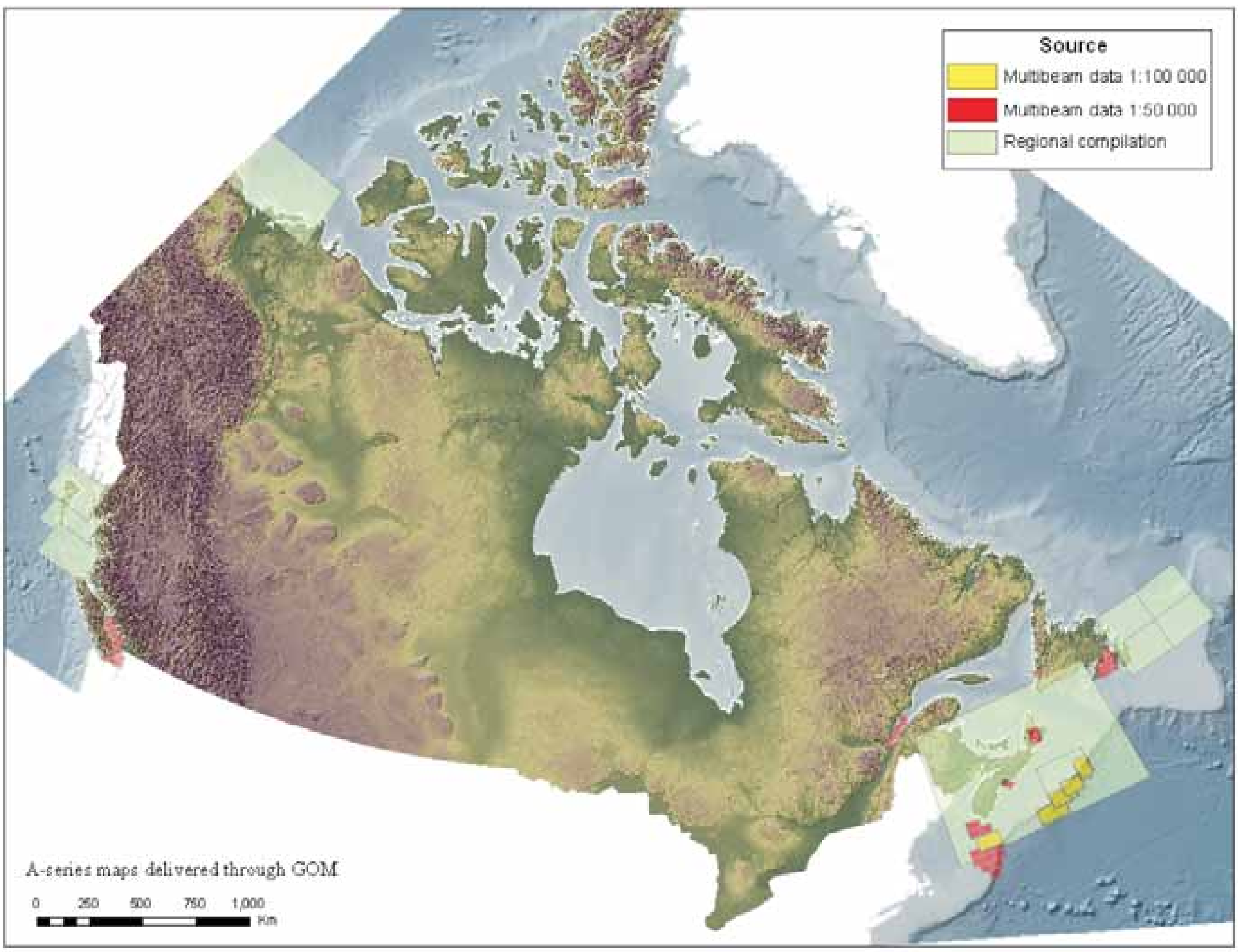

Figure 6. *New A-Series marine maps scheduled for production by NRCan over the next three years. On the continental shelf, maps based on multibeam sonar data will be published at a scale of 1:50,000; multibeam-based maps from the continental slope will be published at 1:100,000; regional-scale compilations from reprocessed, existing data will be produced at 1:250,000.*

maps in the series are in press (Shaw *et al.*, 2006, Todd *et al.*, 2006) and an additional 100 maps are planned for production over the next three years. All maps and supporting data will be available digitally and in hard copy. The long-term goal is to complete the mapping of Canada's offshore lands through a national prioritization process as resources become available.

Benthic habitat mapping presents a particularly acute challenge. In this paper, five different habitat mapping strategies currently being applied across Canada have been outlined. The mapping approaches differ for particular geographical areas or clients; any mapping undertaken simultaneously contributes to the framework of the national mapping strategy. The approach adopted in any one region, or with any issue-driven project, is dictated by a number of governing factors, summarized in Figure 7.

Challenges

In designing a mapping strategy for a particular region, four challenges that drive the survey design and program response need to be met. These are:

- scale – is the area geographically large or small, is it realistic to expect full multibeam coverage?
- new data requirements – is there adequate existing data or is new data collection required for the whole area?
- constraints – is the program operating in a severe environment constrained by weather, ice or shallow water? Are there financial or human-resource limitations? and
- what are the timelines for results?

Response

If the summation of the challenges is great and return on investment of resources and likelihood of success small, then priority within a national ranking system will be lowered and the project will not proceed. If the challenges are low, priority will be increased. The level of challenge will, in large part, determine the mapping approach and survey design. Where the challenge is greatest, dependence on empirical modelling will be highest. As challenges

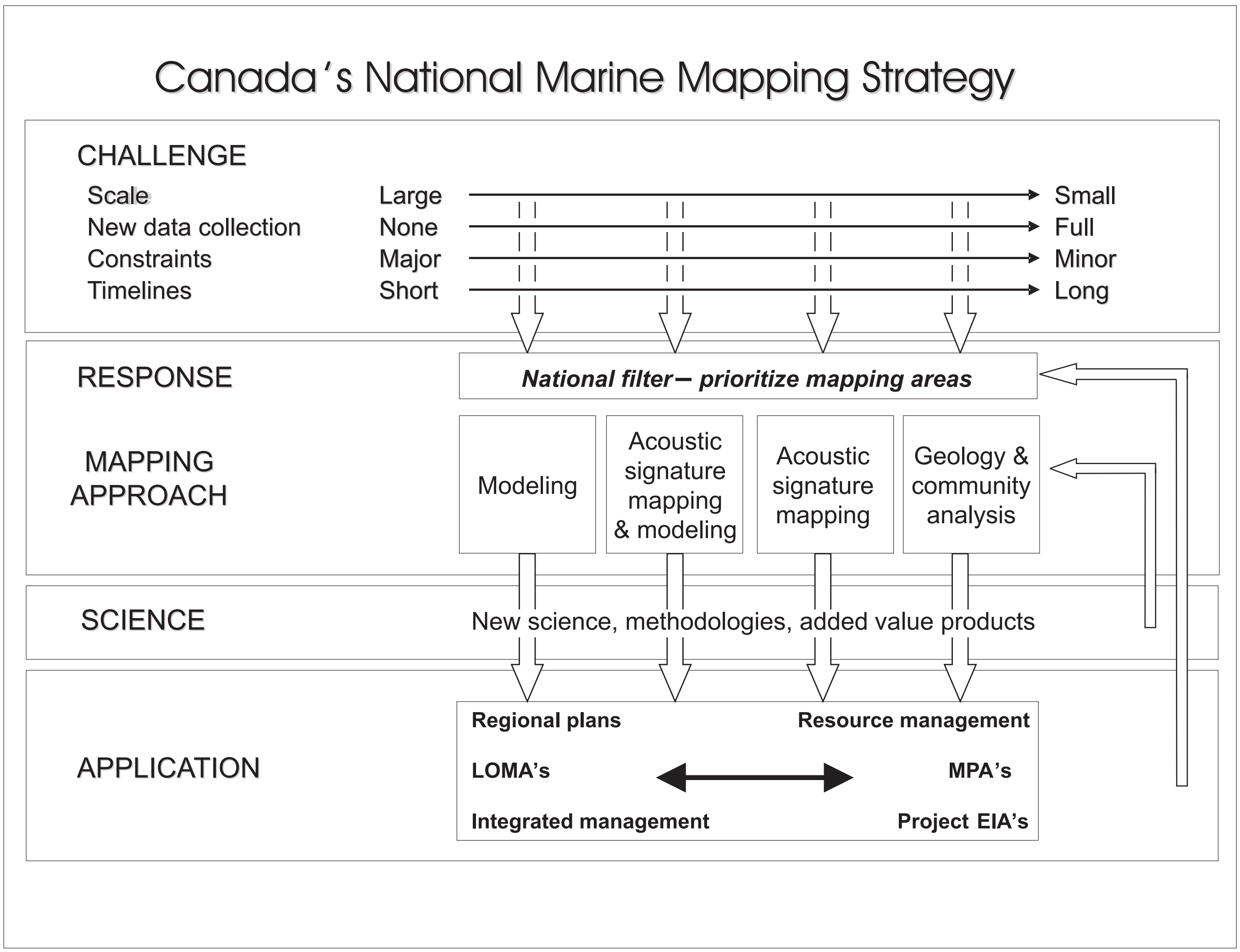

Figure 7. *NRCan's National Marine Mapping Strategy. Regional priorities are established, the challenges are identified and the appropriate response determined, leading to new scientific methods and products, and direct application to management issues.*

decease, acoustic signature mapping may be a viable option, or better still, full-scale mapping of the geology and associated community analysis. The latter is the preferred option and should be the national goal.

Science

Un-interpreted data is of little value to stakeholders. The key to all mapping approaches is adding scientific value to the raw data, through reports and new map products, thereby delivering to the user community added-value products and tools designed to address management issues.

Application

Products from the program must be broadly applicable to the widest user community. Standards must be established within which national comparisons can be made. Generally, the broad scale modelling applications are used by regional planning agencies at the federal level, whereas the detailed mapping and community analysis has greater appeal to industry and community users at the local level. The new nested map products (at the three scales of 1:50,000, 1:100,000 and 1:250,000) have been designed to meet the needs of users at both ends of the spectrum. Finally, feedback from the user community is critical to keeping products relevant and useable.

DISCUSSION

Delivering on integrated management of the ocean space is one of the major challenges facing the sustainable utilization of the planet in the 21st century. As the health of the global ocean ecosystems has deteriorated, many countries have begun to focus on this issue. Paralleling this awareness, emerging technologies have enabled scientists and managers with authoritative seafloor maps and data, upon which sound management decisions can be founded. In 1996, Canada's Oceans Act (Parliament of Canada, 1996) provided the legislative framework to manage the country's oceans. Federal departments realigned activities to meet these new challenges, and based on demonstrable successes, the federal SeaMap program was proposed to map Canada's offshore territories. Despite SeaMap not being funded, habitat mapping remained a priority for the federal government because mapping was needed to support delivery of the Oceans Act. The government responded to these needs in the federal budget of 2005 by funding the Ocean's Action Plan (Fisheries and Oceans Canada, 2005). This multi-departmental program is specifically designed to implement the Oceans Act. One of the pillars of the strategy is to deliver seafloor mapping as a foundation for implementing integrated management and establishing MPAs in five geographical priority areas: Queen Charlotte Basin, the western Arctic, the Gulf of St Lawrence, Placentia Bay, and the east Scotia Shelf. All five priorities are currently being mapped by the Geological Survey of Canada and Canadian Hydrographic Service. Funding from the Action Plan will accelerate this work and establish the foundation for ongoing national interdepartmental mapping strategies.

One-third of the Canadian land mass lies underwater, and while the subaerial land mass has been successfully mapped over the last two hundred years, the challenge for the next 20 years is to provide equivalent maps for the offshore, completing the mapping of Canada. The government recently provided funding to prepare the case to define Canada's outer limits under Article 76 in the United Nations Convention of the Law of the Sea (United Nations, 1982). Funding under the Geoscience for Oceans Management Program and the Oceans Action Plan will begin the process of systematically mapping lands within Canada's territory.

Delivering habitat mapping to support ocean management still represents a major challenge. Departments tend to operate within silos addressing their own mandates, rather than horizontally to address crosscutting issues. Historically, marine biology research in the Canadian government has targeted specific commercial species. A shift to ecosystem-driven science will be required to support ocean management, and this will take time to take place. Scientists and managers with new skills are required to implement new policy. Habitat mapping will remain one of the cornerstones of this research, and while great advances in habitat mapping have been made over the last decade, scope for ongoing research aimed at faster delivery of improved management tools remains an exciting challenge.

ACKNOWLEDGMENTS

We thank our colleagues at the Geological Survey of Canada for discussions that contributed to our ideas, in particular B.J. Todd, J. Shaw, R.C. Courtney, S.M. Blasco, K.W. Conway, J.V. Barrie, R. Parrott and E. King. Phil Weaver (National Oceanographic Centre) and Fiona Fitzpatrick (Marine Institute, Ireland) reviewed the manuscript.

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