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A National Synthesis of the Fisheries and Oceans Canada Ecosystem Research Initiative

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

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ABSTRACT

Fisheries and Oceans Canada's 'Ecosystem Research Initiatives' (ERIs) were conducted from 2007-2012. The program was comprised of seven large-scale ecosystem research programs that focused on how Science could support the Department's implementation of an ecosystem-approach to management (EAM). Delivery of the ERIs varied between DFO Regions but all studies advanced understanding of how Canadian aquatic ecosystems are structured and how they function. In addition, the ERIs provided the opportunity to learn valuable lessons with respect to the design, coordination, and implementation of complex science programming at the ecosystem scale. Key conclusions and advice from the ERIs include: 1) the need for multi-sector cooperation at regional and national levels to identify priorities for Science support to management/policy; 2) the need for new tools to assess cumulative impacts; and 3) the improvement of comprehensive ecosystem-level monitoring, assessment, and predictive capabilities. A national science advisory process was convened on November 14-15, 2012 to discuss various aspects of the ERI program; this document provided the background information to that meeting.

Une syntèse nationale des initiatives de recherche écosystémique de Pêches et Océans Canada

RÉSUMÉ

Les initiatives de recherche écosystémique (IRE) de Pêches et Océans Canada ont été menées entre 2007 et 2012. Ce programme se composait de sept programmes de recherche sur l'écosystème à grande échelle, qui visaient à comprendre comment le secteur des sciences pouvait soutenir la mise en œuvre d'une approche écosystémique de la gestion (AEG) par le Ministère. L'exécution des IRE a varié entre les différentes régions du MPO, mais chaque étude a fait progresser nos connaissances de la structure et du fonctionnement des écosystèmes aquatiques du Canada. Les IRE ont également permis de tirer de précieuses leçons sur la conception, la coordination et la mise en œuvre de programmes scientifiques complexes à l'échelle des écosystèmes. Les conclusions et avis clés issus des programmes des IRE ont fait ressortir notamment ce qui suit : 1) la nécessité d'une collaboration multisectorielle aux échelons national et régional pour cerner les priorités du soutien scientifique à offrir aux décideurs et aux gestionnaires; 2) la nécessité de mettre au point de nouveaux outils pour évaluer les effets cumulatifs; 3) le renforcement des capacités globales de surveillance, d'évaluation et de prévision à l’échelle des écosystèmes. Un processus consultatif national en sciences a été convoqué les 14 et 15 novembre 2012 pour discuter des divers aspects du programme des IRE, et le présent document fournissait les renseignements de base à cette réunion.

1. BACKGROUND

1.1 DEPARTMENTAL COMMITMENT TO AN ECOSYSTEM APPROACH TO MANAGEMENT

Canada initiated a new approach to managing activities in the marine environment when the *Oceans Act* received Royal Assent in 1996. The *Oceans Act* formally introduced concepts such as sustainability, precautionary approach, ecosystem-based, integration, and adaptation and is a mechanism to harmonise Fisheries and Oceans Canada's (DFO) implementation of the *Fisheries Act*, *Species at Risk Act*, and the *Canadian Environmental Assessment Act* (Curran et al., 2012).

Since that time, many international agencies have widely endorsed an ecosystem approach to management (EAM) in a fisheries context and the primary literature includes many articles related to its interpretation and implementation (see references included in Rice, 2011 and Curran et al., 2012). Of particular interest to DFO are the initial EAM principles defined by the Convention on Biological Diversity (CBD, 2000), a technical paper produced by the Food and Agriculture Organisation (Garcia et al., 2003) as well as the ongoing work of the North Atlantic Fisheries Organisation and its Working Group on Ecosystem Approaches to Fisheries Management (e.g. NAFO, 2010a,b,c) and the European Union's Marine Strategy Directive[i].

DFO managers and scientists held initial discussions to determine a path forward with respect to implementing EAM in the Department's Large-Ocean Management Areas (LOMAs) at the 'Dunsmuir I' workshop (DFO, 2001). At 'Dunsmuir II' in 2007, progress in implementing EAM in the LOMAs was reviewed and it was determined that a new direction was needed given the challenges in applying the previous advice. DFO produced 'A New Ecosystem Science Framework in Support of Integrated Management' (DFO, 2007) followed by a 'Five Year Research Plan (2007-2012) (DFO, 2008) that was largely focused on the 'Ecosystem Research Initiatives' (ERI). The ERI program is discussed in detail in Section 1.2 below.

As the ERI program was coming to an end, at the June 2011 meeting of the DFO Sustainable Aquatic Ecosystems Strategic Outcomes Committee, senior management agreed that a Departmental approach to EAM was needed. A proposed framework that included five steps was provided for discussion (Figure 1). Despite this senior-level commitment, little progress has been made to date in terms of drafting a national strategy or framework for implementing EAM, although formal discussions at the Regional level to address this issue have taken place (Curran et al., 2012; DFO, 2013).

[i] Directive 2008/56/EC

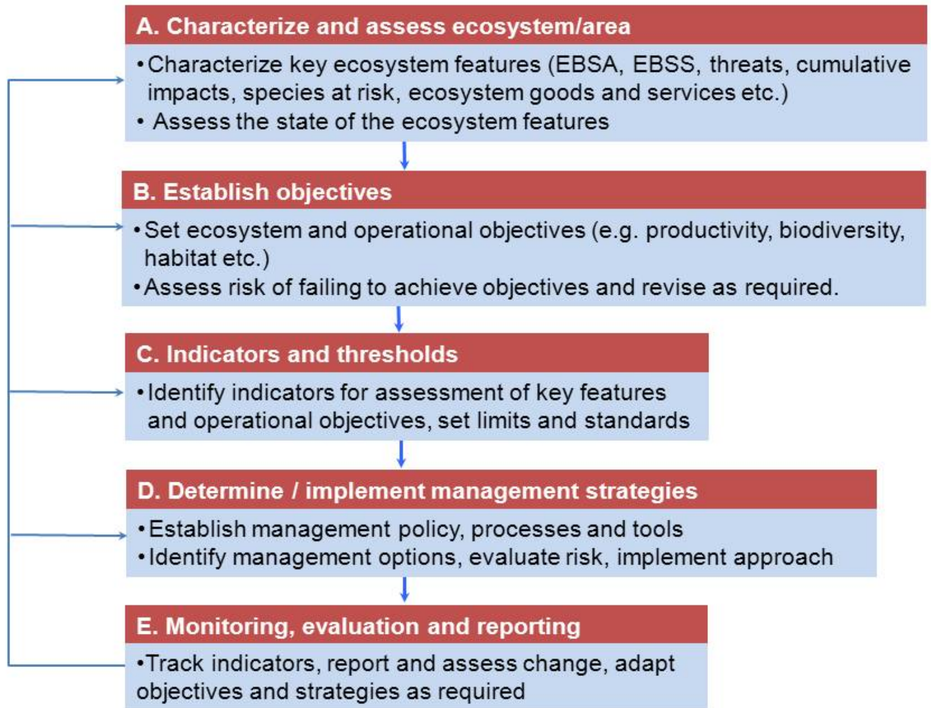

Figure 1. Proposed process for implementing an ecosystem-approach to management as discussed at the June 2011 meeting of the Fisheries and Oceans Canada Sustainable Aquatic Ecosystems Strategic Outcomes Committee.

1.2 OVERVIEW OF THE ECOSYSTEM RESEARCH INITIATIVES (ERI)

The ERIs explored opportunities where Science could support DFO's implementation of an EAM through Regionally-focused multidisciplinary research on ecosystems with pre-defined boundaries (DFO, 2008). A map indicating the general locations of each of the ERIs is shown in Figure 2.

The knowledge gained from these large-scale ecosystem studies was intended to inform the development and testing of tools required to assess the impacts of various human activities within Canadian aquatic ecosystems (see Section 2 for results of the ERIs). Each Regional ERI had specific objectives (Annex I); however, the over-arching themes of the ERI program were: i) understanding ecosystem processes; ii) understanding the impacts of environmental and climate variability; and iii) developing tools for science support of a Departmental EAM (DFO, 2008).

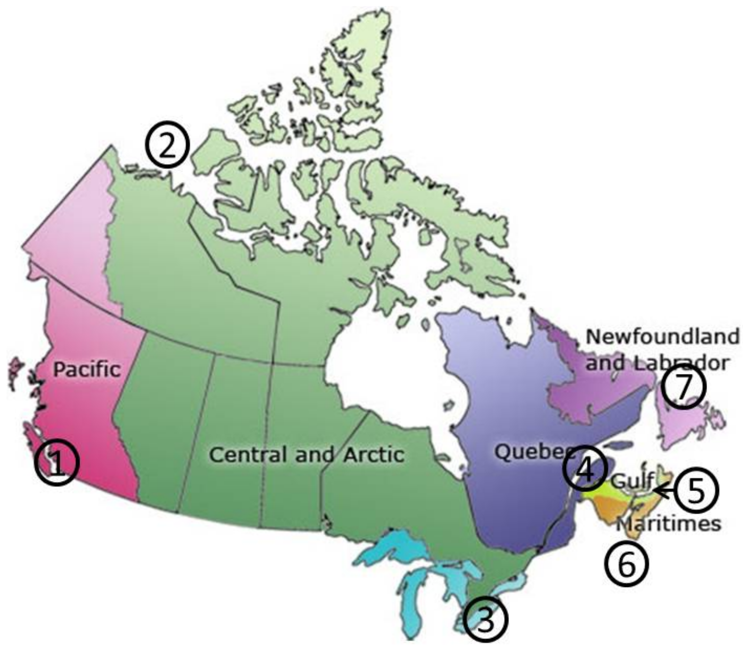

Figure 2. The Fisheries and Oceans Canada Ecosystem Research Initiatives focused on seven geographically-distinct areas with defined boundaries. These areas were: 1) the Strait of Georgia, 2) the Beaufort Sea Shelf, 3) Lake Ontario, 4) the Lower St. Lawrence Estuary, 5) the Northumberland Strait, 6) the Gulf of Maine, and 7) the Newfoundland Shelf.

1.3 THE STRATEGIC PROGRAM FOR ECOSYSTEM-BASED RESEARCH AND ADVICE (SPERA)

In 2012 DFO initiated its 'Strategic Program for Ecosystem-Based Research and Advice' (SPERA). Led by Science in close collaboration with other sectors, SPERA follows on from the ERIs and is intended to continue to provide a science-based foundation for management and decision-making related to the larger Departmental move toward EAM.

SPERA delivers targeted scientific research and advice that responds to specific policy and management priorities. Research needs are identified by an advisory committee comprised of Departmental representatives from Science, as well as Management and Policy sectors. Scientific research and advice under SPERA falls under three main themes: i) Quantifying ecosystem impacts of human activities; ii) Assessing and reporting on ecosystems; and iii) Tools for an EAM. Fiscal year 2012-13 was the inaugural year of SPERA with funding provided to 40 different projects addressing various aspects of the three research themes.

2. ERI HIGHLIGHTS: LINKING SCIENTIFIC RESEARCH TO POLICY AND MANAGEMENT

Overall, the seven ERIs have significantly advanced understanding of how Canadian large aquatic ecosystems are structured and how they function, which are prerequisites for effective EAM. While some of the ERI projects specifically addressed management and/or policy priorities, others were more focused on improving scientific understanding of ecosystem functioning and deriving specific recommendations for management/policy based on their findings. The scientific research conducted under the ERIs was valuable, and in some cases there were clear linkages between a particular project and an immediate, specific management/policy need related to EAM. A list of the scientific research projects funded by the ERIs is provided in Annex II and publications available to date are listed in Annex III.

2.1 STRAIT OF GEORGIA

Overall, this ERI identified six general processes to describe how the Strait of Georgia functions. These processes are:

i. Enrichment – how nutrients are provided to the system;
ii. Initiation – the physical processes controlling the development of plankton blooms in this system;
iii. Retention – how materials are retained within the Strait and made available to the food web;
iv. Concentration – physical processes by which materials are aggregated in certain locations at concentrations above the background average;
v. Trophic Dynamics – processes by which food and energy are transferred to higher trophic levels; and
vi. Habitat Dynamics – processes contributing to the functioning of this system, particularly as related to the nearshore and benthic processes.

Any stressor which interrupts or interferes with any of these aforementioned processes has the potential to disrupt the normal functioning of the Strait of Georgia ecosystem.

In addition, several studies identified potential ecosystem-level indicators, including an index to identify shifts in productivity regimes and several variables related to particular ecosystem relationships. The North Pacific Gyre Oscillation was identified as an important indicator of large scale processes affecting the Strait of Georgia. Sea temperature, winds, and various components of the zooplankton community were also identified as key local-scale indicators. Identification of these indicators is relevant to describing the early marine survival of Coho Salmon (*Oncorhynchus kisutch*) and the biomass of young-of-the-year Pacific Herring (*Clupea pallasi*). Three environmental variables (i.e. sea surface temperature, wind speed, the North Pacific Gyre Oscillation) and three human-related variables (i.e. the human population surrounding the Strait, recreational fishing effort, and the number of hatchery releases of Chinook Salmon (*Oncorhynchus tshawytscha*)) were sufficient to describe the regime-like behaviour of this system. However, it was noted that a more comprehensive process is needed to identify and prioritize potential indicators and link these to specific management objectives.

An analysis of the temporal variability of biomass in the Strait of Georgia food web since 1960 suggests that the Strait may currently be in a low productivity regime compared to the 1960s to

1980s, possibly in relation to changes in environmental conditions. Consequently, under the current conditions, fish stocks may not be able to rebuild as quickly as they may have in the past. Other studies suggest that management that balances exploitation across all (middle to higher) trophic levels produces higher overall yields, with fewer periods of fishery closures. The ecosystem models developed through the Strait of Georgia ERI can also be used to identify the fishing thresholds for individual species that could lead to ecosystem overfishing (i.e. thresholds beyond which the structure of the food web is seriously altered). In addition, recommendations were made regarding how management might release hatchery Coho Salmon in order to maximise their return rates, and on the locations for enhanced management of habitats important to forage species such as Sand Lance (*Ammodytes* spp.).

Several ecosystem-related science-based tools (i.e. assessments and models) were developed through this ERI and they are summarised in Table 3 of DFO, 2013. These tools can describe ecosystem processes and identify specific considerations for management, as well as provide information to inform management decisions. Some of those tools are sufficiently mature to be applied to all British Columbia marine areas, for other tools, however, their complexity and extensive data needs may limit their wide application without extensive Science support.

2.2 BEAUFORT SEA SHELF

The Beaufort Sea Shelf ERI focused on expanding our knowledge of the ecosystem by funding projects targeting specific trophic levels. These individual projects were then used to feed into an ecosystem model, linking all the projects together. The ecosystem model assesses the food web structure of the Beaufort Sea Shelf in order to account for the important species present in addition to the food web linkages that exist. Changes in the ecosystem over the last 30-40 years were re-created using environmental variables and harvest data in an attempt to understand important stressors within the ecosystem. Other Beaufort ERI projects (and in many cases the experts within partnering projects) filled information gaps concerning individual or multiple species, in order to advance our understanding of individual species' impacts on the food web and changes in the food web, and to assist with the development of indicators for future research and management.

Of the 10 projects funded under the Beaufort Sea Shelf ERI, eight were aimed at collecting baseline data for specific species or trophic levels, while two modelling projects (fish stable isotopes, and the ecosystem model) focused on utilizing the collected data to assess the functioning of the ecosystem. Various topics covered by the Beaufort ERI subsequently informed the ecosystem model, including: i) factors that influence primary production in the nearshore, how they change in response to stressors, and how these changes influence food web transfers and ecosystem services; ii) the selection of appropriate indicators for monitoring the coastal Beaufort ecosystem; iii) food web structure, in particular the lower trophic levels; iv) a suite of projects related to Beluga whales (*Delphinapterus leucas*), Killer whales (*Orcinus orca*), Bowhead whales (*Balaena mysticus*), and Ringed seals (*Pusa hispida*); and v) identification of emerging disease threats to marine mammals.

It is intended the data and models together will provide useful information to assist with integrated oceans management, particularly in the Tarium Niryutiat Marine Protected Area, as well as in more specific habitat management initiatives.

2.3 LAKE ONTARIO

Prior to the ERI, the majority of research in Lake Ontario had been conducted in the offshore (> 20 m) or in select coastal embayments (e.g. Bay of Quinte) assessed as ‘Areas of Concern’ under the *Great Lakes Water Quality Agreement*. However, rapid changes are occurring in nearshore coastal areas and the role of the nearshore in whole-lake dynamics is poorly understood. As such, areas of research for the Lake Ontario ERI focused on the nearshore environment in order to fill information gaps about the function of the nearshore, to determine its linkages to the offshore, and to explore its sensitivity and responses to multiple stressors. Results of this ERI research informed the DFO mandate directly (e.g. habitat, species at risk, and aquatic invasive species management) and indirectly through agreements (e.g. Great Lakes Fisheries Commission, Environment Canada, International Joint Commission, and Canada/U.S. Agreements).

Research in the Lake Ontario ERI was multifaceted and projects ranged widely in scale and complexity. Results from one ERI project showed that land use had a significant impact on fish communities in the nearshore zone of Lake Ontario and improved classification of these areas can inform EAM in order to better integrate land use planning with aquatic conservation efforts. Fish and environmental data mined from other studies for this project were from several sources and demonstrated the value of integrated (multi-agency) ecosystem science.

A Lake Ontario nearshore ecosystem model (LO-NEM) was developed and validated. The model assesses the sensitivity of different trophic groups to the cumulative impacts of multiple stressors in the nearshore. Scenario testing with future projections of land use and climate change can be used to inform EAM and to predict how the nearshore will respond to future conditions. Another ERI project, using fish hydro-acoustics, indicated that nearshore ecosystems are more sensitive to climatic events (e.g. storms, upwellings) than the offshore which will be an important consideration in the context of climate change.

An integrated project between Great Lakes science and the Canadian Hydrographic Service investigated the efficacy of using side-scan backscatter hydro-acoustic data to classify substrates in near shore areas. This work, although challenging, will continue to be advanced in future, possibly benefiting from experiences in marine areas (see for example, Northumberland Strait and Gulf of Maine).

Lake Ontario ERI research also showed that Bloody-Red Shrimp (*Hemimysis anomala*) densities decrease rapidly with distance from shore and that densities vary seasonally. Bloody-Red Shrimp has a potential role as a restored link between benthic and pelagic food webs, counteracting the decoupling effect of Zebra Mussels (*Dreissena polymorpha*) at certain sites. Improving our knowledge of this non-indigenous species will assist in management efforts to prevent its spread and to also better understand its potential food web impacts.

One study determined that criteria for identifying ecologically and biologically significant areas (EBSA) in the marine environment are suitable for identifying EBSAs in the Great Lakes, including coastal areas, and that these criteria can be extrapolated for use in other freshwater areas. This conclusion could support efforts to identify EBSA in freshwater areas across Canada as well as inform biogeographic classifications.

2.4 LOWER ST. LAWRENCE ESTUARY

Studies conducted under the Lower St. Lawrence Estuary ERI were focused on the specific impacts of human activities and pressures on the Lower St. Lawrence Estuary Beluga Whale (*Delphinapterus leucas*) and Blue whale (*Balaenoptera musculus*) populations. The designated critical habitat for Belugas in this region is defined as a continuous section of the St. Lawrence River Estuary. Therefore, identifying which features control the characteristics of this habitat and how it may be changing are important questions for science and management given the '*Threatened*' status of Belugas and the '*Endangered*' status of Blue whales under the federal *Species at Risk Act* and the related Departmental responsibilities for recovery. In addition to the Department's responsibilities under the *Species At Risk Act* (*SARA),* this research also informed the work of the Department's Oceans sector and the Centre of Expertise on Marine Mammals (CEMAM), as well as the Saguenay-St. Lawrence Marine Park.

ERI studies showed that the summer distribution of Belugas is characterised by three distinctive zones based on features such as the density of Sand Lance (*Ammodytes americanus*), the hardness of bottom sediment, and the speed and direction of surface current. In addition, these zones are in good agreement with the spatial distribution of the characteristics of the herd (e.g. females with calves). However, none of the available features (i.e. physical, chemical, and biological components of the habitat, recent diet and threats to Belugas or their habitat) could explain the summer distribution of Belugas in a finer spatial scale supporting the continuous aspect of the critical habitat designation. In addition, no links were found between marine traffic and Beluga distribution, and there were no signs of permanent 'avoidance' of the general shipping corridors by these whales. Areas with high concentrations of various chemicals were identified in St. Lawrence estuary sediments but no clear impact on the summer distributions of Belugas was found.

New results were also found on the dominant krill species in this region, their biomass, and spatial and depth distributions in relation to feeding by Belugas and Blue whales. These results suggest that the Arctic Krill (*Thysanoessa raschii*) is the dominant species compared with Northern Krill (*Meganyctiphanes norvegica*) as well as the preferred prey of baleen whales, possibly because it was found to be typically located higher than its counterpart in the water column. The connectivity between the northwest Gulf of St. Lawrence and the Estuary was shown to be very strong but seasonally variable using numerical modelling and current meter moorings, and possible indicators of krill transport potential were elaborated. Marine traffic noise was quantified as 'high' 75% of the time and consequently up to 40% of sounds emitted by Blue whales may be masked. While no increasing trends in persistent organic pollutants were found in krill, they may be a good indicator of environmental quality.

2.5 NORTHUMERLAND STRAIT

Communities surrounding the Northumberland Strait ERI have historically depended on its natural resources for their economic well-being. Significant impacts on the abundance and distribution of resources are of concern to local residents and have been linked to environmental degradation caused by a number of land-based and marine sources as well as climate change and sea level rise. Due to the nature of the sources, rate of environmental change, and the dynamic environmental interactions, determining the specific causes of these changes is challenging.

The compilation and analysis of the information amassed during this ERI is still ongoing. However, the data rescue and data mining component of this ERI can already be considered a success as the information has become accessible to a geo-coded database that has already been used by the Department's Centre of Expertise on Coastal Management. This research program is contributing to our understanding of the state of the aquatic ecosystem by continuing to develop indicators and by assessing how biodiversity and habitat quality have changed over time. This work has provided valuable information to develop new techniques that characterise habitat structure, especially in shallow coastal areas, and complements the work conducted by the Canadian Hydrographic Service. In particular, the water mass modelling research has provided new insight on invasive species dispersion (i.e. tunicates) and population productivity (e.g. lobster larvae).

2.6 GULF OF MAINE AREA

From an ecosystem perspective we know that physical and environmental drivers can affect fisheries productivity and the research from this ERI has contributed to greater understanding of these linkages. This ERI also provided the science to support MPA network planning within the Scotian Shelf bioregion. In particular, studies indicated how new benthic habitat mapping approaches can support the Oceans Sector through initial bioregion characterization and EBSA identification, through to MPA network design, and then monitoring and evaluation. A whole suite of research under this ERI focused on multispecies harvest rates and multispecies reference points which provide guidance for fisheries management under an EAM.

A major effort to recover and consolidate regional oceanographic and ecosystem data through this ERI has produced an unprecedented view of the historical baselines and decadal trends in key climate-relevant physical, chemical and biological properties of the Northwest Atlantic. Knowledge of these factors can help predict future fish recruitment and distribution, and therefore manage accordingly.

Substantial progress has been made in understanding the links between the growth dynamics and distribution of the plankton base of the marine food web, and their relationships with the oceanographic environment. This has shown that species assemblages and their distributions can be defined by local biological process (e.g. food abundance) and remotely by the water masses they inhabit. Additional studies have shown that smaller scale oceanographic processes can strongly influence the distribution and survival potential of early life (planktonic) stages of important commercial species (e.g. scallops) in the region. These findings are particularly important in the climate context since alternations in lower trophic level abundance and water mass properties will be early signals of climate change in the Northwest Atlantic.

Temporal trends in oceanographic properties and characteristics of fish populations along with meta-community analysis have shown that assessing the response of higher trophic levels to climate change is confounded by other pressures on the ecosystem (e.g. fishing). These studies have also shown that anthropogenic pressures such as fishing on harvest resource populations reduces the size and age structure of these populations which will increase their vulnerability to other pressures such as climate change.

A new integrated approach was developed and tested to classify benthic habitats using acoustic survey data, ground truth information, and species distribution modelling approaches. A key advance on prior approaches is the incorporation of fishing intensity measures and fishery survey data into benthic habitat modelling, leading to the identification of spatially-explicit, habitat-related fishery reference points, in the first instance for scallop fisheries. In addition, a new spatial statistical analysis ("gradient forest") approach was developed and published that explore the use of physical surrogates to characterize seabed diversity patterns, and their management applications.

This ERI also developed ecosystem models to quantify the impact of ecosystem interactions on harvest rates and species dynamics and to explore the structure and functioning of the Bay of Fundy-western Scotian Shelf ecosystem. This included the selection of multispecies reference points and harvest rates, key pieces of information for an EAM, and exploration of a triad of drivers (i.e. fisheries, environment, and trophic dynamics) on ecosystem dynamics.

2.7 NEWFOUNDLAND SHELF

To date, the main outcomes of the Newfoundland Shelf ERI include: i) a description of the status and trends of the main forage fish species, as well as the structure and changes in the fish community; ii) a characterization of main components of benthic communities; and iii) an analysis of trophic interactions among the key components of this marine community.

During the late 1980s and early 1990s most of the fish community in the Newfoundland and Labrador shelf marine ecosystems collapsed; the exceptions were small benthivore fish and especially shellfish, whose biomass increased significantly. Even though this collapse is often associated primarily with Atlantic Cod (*Gadus morhua*) in the early 1990s, declines in several functional groups started in the 1980s. The collapse was observed throughout the system and involved commercial and non-commercial species. Current levels of some fish functional groups are still well below pre-collapse levels.

New information on the spatial variation of biological characteristics and the feeding of forage species was collected and described. Trophic structure indicators clearly show a transition from a large fish community in the 1980s and early 1990s to currently one of shrimp and small fish. A study on the drivers of cod trajectory tested competing hypotheses for patterns in the variation of the cod stock biomass since 1985. Among the factors considered, patterns of variation in stock biomass of cod appear to be influenced by fisheries and the availability of Capelin (*Mallotus villosus*), but not by Harp Seal (*Pagophilus groenlandicus*) predation.

One general observation supported by the results of this ERI is that the productivity of the Newfoundland Shelf marine ecosystem seems to be driven by bottom-up processes. This should be of critical concern for management because it implies that strategies based on a narrowly-defined control of fishing mortality may not be sufficient to ensure long-term sustainability.

Fishing appears as a consistent and significant driver of the trajectories of five key fish species of the Newfoundland ERI marine community during the early-mid 1980s to the mid 1990s, and still remains as an important driver in more recent times (mid-1990s to 2008) when fisheries have been targeting mainly shrimp and crab species. Environmental variables also appear as significant drivers, but their effect is less consistent than that observed for fishing.

3. RESEARCH GAPS AND LINKAGES TO MANAGEMENT AND POLICY IMPLICATIONS

Although the ERIs significantly advanced understanding of how large Canadian aquatic ecosystems are structured and how they function, knowledge gaps still remain. Scientific research to address these gaps is necessary in order for Science to continue to inform and support Departmental management and policy applications, in particular with respect to implementing an EAM. Based on the findings of the ERIs, priority areas for ecosystem science pertaining to the specific objectives of the regional ERIs are discussed below (not in order of priority). It is worth noting that other research priorities that were not addressed by the ERIs also exist in all regions.

3.1 PRODUCTIVITY

A broader understanding of the productivity state of the ecosystem in relation to environmental conditions as well as key species interactions is needed. These factors may play a significant role in defining the extent of human use that is sustainable (e.g. exploitation levels, coastal and offshore development, resource extraction, and other human uses).

Studies of the linkages between environmental drivers and the trophic transfer through the food web are essential to better understand the mechanisms supporting ecosystem productivity. Detailed understanding of these mechanisms may not only generate a much needed context for the assessment of forage species and productivity at the base of the food web, it may also provide fundamental tools for developing realistic future scenarios (e.g. climate change, exploitation, cumulative impacts) for exploring medium to long-term management options.

Development of more robust atmospheric-oceanographic models, including the ability to downscale global climate models to specific locations, are needed to better project changes in distribution and productivity of regional ecosystems. This is important for forecasting the future effects of climate change on fisheries resources and for spatial planning.

3.2 ECOSYSTEM STRUCTURE

Characterization of the structure and trends of the aquatic community *beyond fisheries species* (e.g. size distribution and condition of species, composition of benthic communities, primary and secondary production) is a fundamental step to develop baselines that can be used to monitor changes at the ecosystem scale. Studies of forage species and lower trophic levels provide the underpinnings for the selection and interpretation of ecosystem indicators, and contribute to the detection of shifts in the productivity state of the system. Analyses of this kind provide contextual information for the interpretation of stock-specific trends and responses (e.g. “ecosystem consideration” sections in stock-assessment reports, evaluation of MPA effectiveness).

Enhanced understanding of the condition, spatial and temporal dynamics of forage species, particularly when exploited, is necessary to ensure their long-term viability and an adequate food supply for upper trophic levels. These types of studies can directly inform the application of the *Policy on New Fisheries on Forage Species*, as well as provide advice on the bounds for the productivity of higher trophic levels.

Comprehensive trophic structure and diet studies are needed to provide necessary information for the development of expanded single-species models (e.g. predation mortality terms), multispecies models (e.g. species interaction terms), and fisheries production models (e.g. trophic level estimates). These studies also provide the necessary information for early detection of changes in lower trophic levels, and hence, are indicators of potential changes in the productivity state of the system. They are relevant for considering specific management actions in terms of predation mortality and competition among species.

Studies of the spatial structure of the ecosystem (e.g. distributions of species assemblages, definition of eco-regions) are fundamental to establishing operational boundaries for spatially-defined ecosystem-level units. These units can serve as a basis for ecosystem management, inform identification of EBSAs and representative areas, and serve as the backdrop for the development of spatial-based modelling and management strategies for multiple human activities.

In general, the nearshore zone is poorly described and its role in ecosystem processes is not well understood. In particular, determination of biological productivity in these areas, as well as a comprehensive way to evaluate status and trends, are needed. The nearshore environment is where anthropogenic pressures are likely to be most apparent, and where management issues are increasingly complex, such as cumulative effects, multiple stressors, conflicting objectives, land-water interface, and multi-jurisdictional challenges. Spatial and temporal scales and acquiring adequate data are major challenges in nearshore environments.

Benthic-pelagic coupling and inshore-offshore linkages remain poorly understood but are critical factors that are needed to develop more comprehensive spatially-explicit ecosystem models. Improved understanding of these linkages would provide a more complete view of how changes in benthic and nearshore regions affect the function of entire ecosystems, and *vice versa*. In several DFO Regions, species which live on or in the bottom, in both offshore and nearshore areas, are among the most valuable of Canadian fisheries resources.

3.3 TOOL DEVELOPMENT

Research on multispecies/ecosystem modelling is central for the integration of ecosystem information. These types of studies provide an avenue to explore ecosystem-level dynamics (e.g. biomass-aggregate production models) and fisheries production potential that can be used to provide advice on sustainable fisheries exploitation levels and other uses. These studies can also explore trade-offs among human activities (e.g. between fisheries using multispecies models) that can serve as a basis for defining ecologically compatible management objectives, as well as to explore specific questions/hypotheses of management relevance (e.g. the impact of seals on cod, and cod on shrimp, etc.). They are crucial for the evaluation of alternative management strategies.

Prior investment in surveying and assessing the status and trends of benthic and nearshore systems has been rather limited, in part due to some technological challenges, and also due to the inherent spatial complexity of these systems. Newly-developed approaches by the ERI program to integrate optical survey technologies with acoustic-derived representations of seabed environments could be used to improve descriptions of these habitats, in particular at the small scales actually used by benthic fish and invertebrates.

Existing science program activities and mandates, particularly for seabed characterization using acoustic survey technologies, vary both regionally and nationally within DFO (Science, Canadian Hydrographic Survey), and across departments (DFO, Natural Resources Canada). An integrated national approach is required to ensure cost-effective use and application of existing technical approaches, and for development of comprehensive information products on seabed characteristics for use in EAM applications.

Evaluation and prioritisation of key ecosystem indicators, including their data requirements, is needed to ensure that management and conservation objectives are being met. This should include continued evaluation and recovery of existing data, as well as its integration into current data streams. Sufficient resources need to be provided for the analyses of such time series data and indicators so that a predictive capacity using these data can be developed.

The impact of multiple environmental and human pressures and their interactions on aquatic ecosystems are poorly known but are often at the centre of management issues and responses. Improved understanding of multiple stressors and their interactions are necessary for the development of appropriate tools to incorporate cumulative effects into risk assessments.

4. LESSONS LEARNED FROM THE ERI PROGRAM

In addition to advancing understanding of how Canadian aquatic ecosystems are structured and how they function, the ERI program provided the opportunity to learn valuable lessons with respect to the design, coordination, and implementation of Science programming within the Department.

4.1 COLLABORATIONS AND INTERACTIONS

There was a wide range of interaction between Science and other DFO sectors in developing the objectives and research areas for each of the ERIs; there was also variability in the applicability of results to Departmental management and/or policy. A key lesson learned from the ERI program is that there is substantial benefit in determining mandates and directions for research initiatives in collaboration with science, management, and policy colleagues. These interactions allow for clarification of perspectives between different groups, improve linkages between science and management priorities at the onset of the project, and facilitate integration of results into Departmental decision-making. A top-down approach can leave little scope for creativity so ample opportunity for brainstorming sessions among Science and other sectors to discuss how Science can best support Departmental needs is necessary.

Clear dialogue between sectors is particularly important when designing research projects to address short-term, immediate (1-2 years) management and policy needs, as the science requested is often required to inform a specific, urgent question or issue. However, these collaborations are also essential when designing longer-term (> 2 years) research programs that may be broader in scope and/or may not address an immediate management or policy need. CSAS processes were valuable for summarizing the ERI findings and for providing advice to management and policy sectors; in general, they were, and continue to be, the chosen method of delivery of Science advice to other sectors.

In many cases, the ERIs facilitated the development of regional, national, bilateral, and international linkages with similar programs and/or researchers working on EAM-related initiatives. This was highly beneficial to the researchers involved and ultimately had a positive influence on the ERI projects by allowing for multiple issues to be addressed under one unified effort. The ERIs brought together researchers who may not have previously collaborated with each other, thereby facilitating new combinations of knowledge, expertise, and data. In addition, a team approach to addressing research priorities often resulted in leveraging of other programs, leading to increased budgets to complete the work. Multiple years of guaranteed funding greatly increased the opportunities for leveraging with partners and this collaborative approach to research benefited the delivery of useful science support for management. However, with these benefits also came challenges (e.g. different schedules/timescales for deliverables, different objectives, unforeseen withdrawals of funding, failure to deliver expected results, and the ending of research partnerships once ERI funding ended).

4.2 DURATION AND FOCUS

The ERIs were a valuable first step in a Department-wide Science effort in support of EAM. Despite the completion of the ERIs, Departmental research to advance our understanding of Canadian ecosystems continues through other funding sources and initiatives across the country.

The research conducted under the ERIs was intended to inform the development and testing of tools necessary to assess the impact of human activities on ecosystems, however the strength of the linkage to this overarching objective varied between research projects and in some cases was difficult to recognise. That is not to say that research with broader scope is not useful, in fact it is necessary, as the findings of these studies can provide the basis for more targeted questions in the future. For example, research that aims to understand how those ecosystem features beyond direct management control can affect the ecosystem, or how ecosystems are structured and function, generally require longer timeframes to generate meaningful results.

Long-term observations and their analyses were essential for many of the ERIs. Regional ERIs with more extensive long-term datasets were able to undertake more comprehensive analyses and provide stronger recommendations to management. Continuation of these long-term observations and development of new data series are necessary for scientific outputs such as models and developing/monitoring indicators. In addition, they are crucial for the validation of management actions and policies.

While short term projects aimed at answering specific management questions are a useful EAM approach within DFO Science, some are of the opinion that the five-year timeframe allocated for the ERIs was too short to fully realise the benefit of this program. Ellis et al. (2011) conducted a comparative study of four recent regional biodiversity programs and concluded that a 10-year period is a more appropriate timescale for designing, implementing, and assessing the outcomes from large-scale research programs. A longer timeframe may also have eased the pressure on Departmental researchers who juggled competing priorities (e.g. additional regional, national, and international research and advisory responsibilities) while attempting to fulfill their ERI commitments. In some cases, a longer time period may have allowed for the completion of higher quality products.

4.3 RESOURCES

The availability of adequate resources (financial and human) is an essential component of complex research programs as considerable effort and expertise is required to implement individual projects and to effectively coordinate multiple projects under large-scale funding envelopes. In some cases, areas of priority science were not addressed under the ERIs owing to a lack of capacity to conduct targeted research, as a result of time and/or financial constraints and/or limited qualified personnel.

Throughout the ERI program, existing data and knowledge were not always readily accessible. Ecosystem data are often dispersed and in a variety of formats, making their collection and synthesis difficult – particularly across Regions and agencies. Common platforms for data collection, storage, and sharing are needed.

Realities and complexities of short-term staffing and finding/securing qualified talent (e.g. post-doctorates, biologists, technicians) were often a challenge and some ERI research projects were delayed as a result. Due to the short-term nature of funding for the ERIs, the personnel hired to conduct analyses were often not retained by the Department. The investment made to train these people, the additional capacity for ecosystem research that they represented, and their potential further contributions were ultimately lost. The departure of Departmental researchers, through retirement or other reasons, will increase the loss of expertise and knowledge that is essential to providing science support, in particular for implementing EAM.

5. CONCLUSIONS

The ERIs were a valuable first step in a Department-wide Science effort in support of EAM and they facilitated the development of regional, national, bilateral, and international linkages with similar programs and/or researchers working on EAM-related initiatives. Although the ERIs had their challenges, this was not unexpected as DFO Science continues to transition from conducting single-species stock assessments into complex, multi-disciplinary research projects. Nonetheless, the Department would benefit from an overarching and comprehensive framework to aid in implementing EAM and to guide the necessary Science support. This framework could also inform other EAM-related initiatives, including current and future funding directions. In addition, a multi-sector working group within each DFO Region to identify priorities that require Science support, to coordinate research efforts, and to implement EAM would ensure communication between Science and other sectors. These Regional working groups could feed into a similar national-level working group to share experiences and improve consistency across the Department.

A national ecosystem modelling and analysis working group is recommended to improve the Department’s ability to address ecosystem-scale issues and to continue to develop new tools and approaches to assess the cumulative effects of multiple stressors. Data and models which support quantifiable impact assessments, especially for cumulative effects scenarios, would better support Departmental decision making. Common platforms for data collection, storage, and sharing continue to be needed.

Comprehensive monitoring, analyses, and development of the Department’s predictive capability are fundamental to the successful implementation of EAM, but cost-benefit evaluation of collecting additional information needs to be considered. Adequate time for integration and synthesis of the results among complex and multiple projects is essential for the provision of meaningful science advice, particularly where extensive field programs are involved. A mechanism to acquire and maintain specialized Departmental personnel to conduct ecosystem science is essential.

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ANNEX I: OBJECTIVES OF THE REGIONAL ECOSYSTEM RESEARCH INITIATIVES

ERI	Primary Objectives
Strait of Georgia	To establish the basis for the management of ecosystem and human interactions in an integrative ecosystem framework.
Beaufort Sea Shelf	To address the cumulative impacts of multiple stressors on the Beaufort Sea Large Ocean Management Area through an integrated, ecosystem-based approach.
Lake Ontario	To complement and advance the common themes of the national ERI program within a Regional context by building on research and partnerships in Lake Ontario.
Lower St. Lawrence Estuary	To develop and apply an operational framework for the coordination of existing and new projects to address in an integrative manner several management and scientific issues related to impacts of human activities on biological and ecological processes in the Lower St. Lawrence Estuary.
Northumberland Strait	To produce new knowledge and improve existing knowledge that is needed for integrated management, to demonstrate a strong commitment to research to clients and partners, and to align with Departmental mandate.
Gulf of Maine Area	To augment current research efforts to provide the scientific basis for biodiversity, productivity, and habitat-related objectives, with a focus on southwest Nova Scotia and the Bay of Fundy areas.
Newfoundland Shelf	To fill knowledge gaps in the Regional Science program. The geographic extent of this work encompassed the Newfoundland and Labrador Shelves and Grand Banks (NAFO Divisions 2J3KLNO).

ANNEX II: TYPES OF SCIENTIFIC RESEARCH PROJECTS CONDUCTED UNDER THE REGIONAL ECOSYSTEM RESEARCH INITIATIVES

STRAIT OF GEORGIA

- Collection of high-resolution bathymetry data
- Physical, biological, and ecosystem modelling of the Strait of Georgia
- Habitat models of the Strait of Georgia
- High-frequency variability of physical-chemical-biological properties via moorings
- Identification of biological “hot spots”
- Research on novel contaminants
- Dynamics of the spring phytoplankton bloom
- Zooplankton long-term data recovery
- Stable isotopes as indicators of food web dynamics
- Ecosystem indicators and time series analyses
- Herring early life stage dynamics
- Seasonal field surveys of juvenile salmonids
- Acoustic tagging and tracking of salmon smolts
- Genetic analyses and identification of salmonid stocks
- Pink salmon production dynamics
- Coho salmon production dynamics from hatcheries
- Bayesian belief network analyses to predict early life dynamics of Coho salmon
- Small cetacean diet studies
- Pinniped diets, bioenergetics, and food web interactions
- Accumulation and removal of organic contaminants in pinnipeds
- Dynamics of transient killer whales

BEAUFORT SEA

- Ecosystem model of the Beaufort Sea Shelf
- Primary Production in the Beaufort Sea
- Arctic Coastal Ecosystems Studies (ACES) Program
- Genetic monitoring and Conservation of Beluga Whales (*Delphinapterus leucas*) in the western Canadian Arctic
- The Role of Fish in the Coastal Ecosystem
- Near-shore Food Web Structure of Lower Trophic Levels

- Identification of Emerging Infectious Disease Threats to Marine Mammals
- Beaufort Sea Killer Whale Observations
- Distribution, Movements and Behaviour of Bowhead Whales, Beluga Whales and Ringed Seals
- Beluga Health Program

LAKE ONTARIO

- Hydro-acoustic sensing of benthic substrate
- Hydro-acoustic fish biomass-depth relationship
- Coastal fishes
- *Hemimysis anomala* distribution and habitat in Lake Ontario
- Trophic position and potential impacts of *Hemimysis anomala* in Lake Ontario
- Near shore lower trophic levels (benthos, phytoplankton, zooplankton)
- Habitat classification in the near shore
- Ecological classification of the near shore of Lake Ontario
- Lake Ontario near shore ecosystem model
- Comparison of approaches for integrated management in Lake Ontario and marine coastal areas in Canada

LOWER ST. LAWRENCE ESTUARY

- Physical characteristics of the habitat
- Characteristics of the food web and composition of the diet of beluga whales of the St. Lawrence between 1998-2008 from fatty acid and stable isotope profiles
- Identification of important habitats of the St. Lawrence beluga
- Contaminants in the sediments of the Laurentian Channel and toxic algae
- Benthic description of important habitats of the St. Lawrence beluga
- Recent diet of the St. Lawrence beluga
- Characteristics of the pelagic habitat of the St. Lawrence beluga
- Transfer of phycotoxins
- Identification of ecosystem indicators and their trends in the Saint Lawrence Estuary
- Trophic links in the estuary; krill predators other than blue whales
- A study of the status of important pelagic species in the food web of the St. Lawrence: sand lance and capelin
- The role of forage species in structuring the distribution and migrations of top marine mammal predators in the Lower St. Lawrence estuary ecosystem and adjacent waters

- Navigation noise in the Lower St. Lawrence Estuary ecosystem and relation with the distribution of the rorquals
- The zooplankton “valve” over the control of the rorqual food basket
- Development of a 3D Ocean-NPZD-O-Krill model to understand and predict ecosystem changes in the St. Lawrence Estuary
- Spatial distribution and abundance of blue whales, their prey, and competitors in the Lower St. Lawrence Estuary: experimental modelling of trophic relationships.

GULF OF MAINE AREA

- Comprehensive, up to date databases for physics, chemistry and lower trophic levels for the Gulf of Maine and Western Scotian Shelf
- Update of the Wright et al. report: *Projecting Ocean Climate Change and Impacts in the NW Atlantic*
- Summary of physical response to climate variability and change in the Gulf of Maine region, based on Loder update and circulation model simulations and analyses
- Spatial variability in zooplankton seasonal cycles and environmental drivers of community changes in the Gulf of Maine
- Relationship between zooplankton communities and water masses
- Climatological spatial distributions of dominant zooplankton taxa in the Northwest Atlantic
- Influence of historical changes in larval production on sea scallop population connectivity on Georges Bank
- Influence of changes spring spawning on sea scallop population connectivity on Georges Bank
- Reproductive cycle of the sea scallop on Northeastern Georges Bank
- Influence of environmental variability on reproduction of sea scallop on Northeastern Georges Bank
- Impacts of Climate Change on Scotian Shelf ecosystem with implications for Gulf of Maine
- Common large-scale responses to climate and fishing across Northwest Atlantic ecosystems
- Development of geo-referenced database and data layers for physical environment factors and benthic biological survey data for the Gulf of Maine area
- New benthic optical survey programs on German Bank (DFO – Towcam) and in the Gulf of Maine Discovery Corridor (Joint with NSERC Canadian Healthy Oceans Network: DFO – Campod; NSERC – ROPOS)
- Predictive modelling of species-environment relationships - comprehensive spatial pattern of physical variables that influence benthic community composition at Gulf of Maine scale – Gradient Forest Approach
- Investigation of the impact of fishing gear on benthic communities - Assessment of relationships between fishing effort and spatial structure – Benthoscape analysis
- Development and evaluation of a multi-scale approach to predicting spatial patterns

- Development and evaluation of spatial impacts of fishing on productivity of scallops
- Review options for ecosystem modelling - Modelling tools workshop
- Development of Ecopath with Ecosim mass balance flow models for Canadian sub-regions of the Gulf of Maine Area (Bay of Fundy, western Scotian Shelf and NAFO Division 4X) for two contrasting periods (70s vs 95-00)
- Explore influence of triad of drivers (fisheries, environment and tropho-dynamics) on the ecosystem dynamics of 4X using Ecopath with Ecosim models
- Production of multispecies MSY estimates
- Multispecies production models and comparative analysis of role of triad of drivers at different levels of functional aggregation
- Development of Multispecies Virtual Population Analysis Model (MSVPA) for NAFO Division 4X, with a focus on SW Nova Herring. Consequences/implications for herring management based on modelling
- Exploration of patterns in fish diets across the Gulf of Maine Area using multivariate analysis

ANNEX III: ECOSYSTEM RESEARCH INITIATIVE PUBLICATIONS

This list of primary and grey literature publications only represents those published at the time this document was written; additional pending publications certainly exist that are not included below.

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