



A New Ecosystem Science Framework

in Support of Integrated Management



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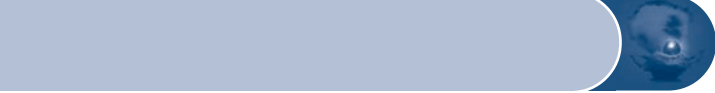
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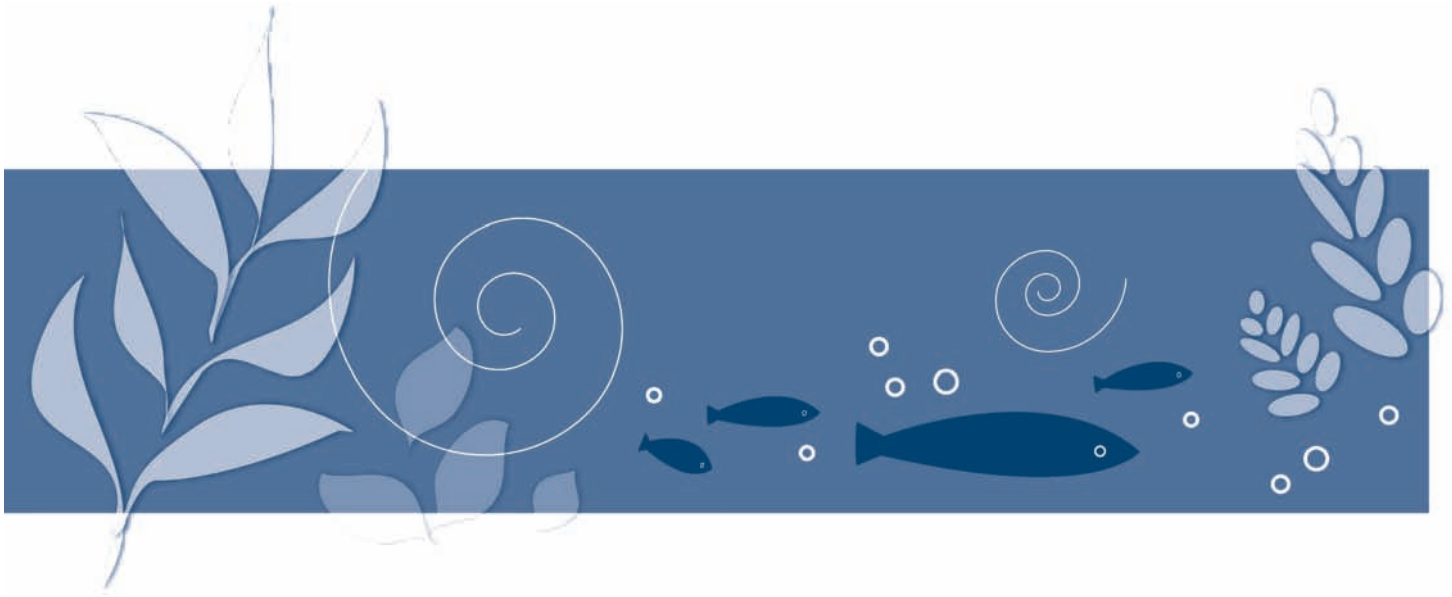
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Table of Contents

Introduction	1
What is an aquatic ecosystem?	1
What is ecosystem science?	1
Why an ecosystem science approach?	2
Benefits and challenges of moving to an ecosystem science approach	3
<i>Benefits</i>	3
<i>Challenges</i>	3
Why an Ecosystem Science Framework?	4
The Ecosystem Science Framework	4
1 <i>Risk assessment tools</i>	4
2 <i>Performance evaluation of ecosystem indicators</i>	4
3 <i>Tools for evaluating decision-support rules</i>	5
4 <i>Operationalize “regime shifts”</i>	5
5 <i>Apply knowledge of productivity changes</i>	5
6 <i>Recovery potential of depleted species</i>	5
7 <i>Key features of ecosystem structure and function</i>	5
8 <i>Knowledge access and spatial management methodologies</i>	5
9 <i>Best practices for ecosystem assessments</i>	6
Conclusion	6
Annex – Examples of ecosystem science in support of integrated management	7
A. <i>Ecosystem management in the Great Lakes</i>	7
B. <i>The Strait of Georgia and ecosystem-based management</i>	9
C. <i>Ecosystem-based approach for the Northumberland Strait</i>	10
D. <i>The Whole Lake Aquaculture Experiment: An example of ecosystem-based science</i>	11
E. <i>Lower St. Lawrence Estuary</i>	11
F. <i>The Fundy Isles (SW New Brunswick Bay of Fundy) case study</i>	12
G. <i>Examples of DFO activities placed in an ecosystem context</i>	13





Introduction

DFO Science is working to ensure a vibrant and sustainable aquatic science program that is based on excellence, continues to support DFO and Government of Canada priorities, and better serves Canadians. Scientific capacity and resources are being challenged to meet the increasingly complex and growing requirement for science advice, projects and services to support the department's strategic outcomes, federal policies, programs, decisions and regulations. Therefore, aligning DFO Science activities with existing and emerging priorities, both within the department and across the federal government, presents an additional challenge.

The Science Management Board (SMB) was established in 2005 to provide strategic direction to the Science program, identify issues that affect DFO's ability to meet mandated objectives, and select priorities in need of Science support. At its first meeting, which was held in October 2005, the SMB confirmed that the highest priority for DFO Science is providing scientific support for ecosystem-based management. To provide this support, DFO Science needs a framework for realigning its focus to ensure the long-term stability of the monitoring and data management programs, and to maximize flexibility in the area of research and the provision of products, services, and, particularly, scientific advice to respond to changing needs.

This document provides the rationale for an ecosystem science approach and describes the proposed framework for realigning the DFO Science program to support an ecosystem approach to management and better reflect an ecosystem science program.

What is an aquatic ecosystem?

An ecosystem is a system with a specific geographic location that includes all living organisms (humans, plants, animals, micro-organisms), the physical, chemical, and climatic environment, and the processes that control the dynamics of the system. The interaction of organisms in an ecosystem is dynamic and subject to internal and external disturbances. Therefore, the relationships of organisms in an ecosystem may change over time.

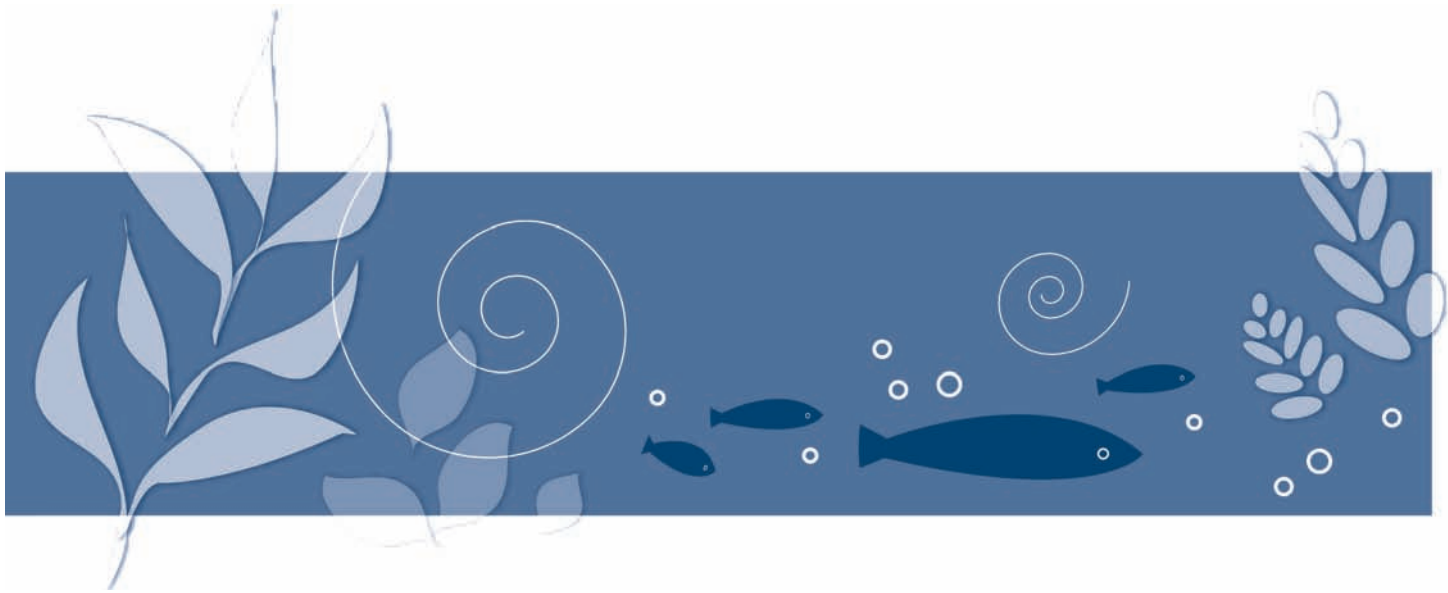
While aquatic ecosystems may be separated by geographical barriers, as in the case of lakes, watersheds, or enclosed bays, aquatic ecosystems often blend into one another because of porous boundaries set by currents, features of the seafloor, or water masses. Aquatic ecosystems can also be nested inside larger ecosystems.

The scope of an ecosystem depends on what is being examined. Depending on the issue, a pond may be examined as a separate ecosystem or as part of a watershed ecosystem. Similarly, a coastal bay may be studied for its own dynamics, as part of a coastal shelf, or as part of a large marine ecosystem where migratory whales live.

What is ecosystem science?

Ecosystem science takes a broad approach to studying relationships and interactions in the ecosystem, and integrates science outputs to provide a sound scientific foundation for policies and programs.

Since it is impossible to study and understand all the processes and relationships in an ecosystem, ecosystem science focuses its efforts on identifying and understanding the key relationships in nature, and their links to human needs and actions.



Why an ecosystem science approach?

Aquatic ecosystems are increasingly affected by human activities. Limiting possible damage and making human activities more sustainable is the complex task of policy-makers and managers who, in turn, rely on scientists for advice on which to base their decisions.

Ecosystem science is the foundation for the science needed to support the integrated management of diverse human activities — such as fishing, aquaculture, transportation, and oil and gas exploration — that are regularly undertaken in the same area. Ecosystem science provides essential advice to decision-makers, who manage fisheries, aquaculture, habitat, ocean resources, and the recovery of species-at-risk, on how these activities interact with one another and affect aquatic ecosystems. Ecosystem science is needed to inform the department's policies and management practices, and to determine the necessary features of our Science activities.

- **Research** should improve our knowledge of key ecosystem relationships and linkages to human activities and be broadly applicable to all departmental responsibilities.
- **Monitoring** and **data and information management** should produce ecosystem-focused **products and services** of value to all parts of the department.
- **Science advice** should be provided in an ecosystem perspective and be integrated across client sectors.

An ecosystem science approach means changing the way DFO provides science support, not just redistributing resources. Traditionally, DFO Science has supported the management of human activities on an activity-by-activity basis and focused its effort primarily on the intended targets of each of these activities (e.g., the target species of a fishery). Major events, such as the collapse and non-recovery of the east coast ground fisheries and dramatic fluctuations in returns of west coast salmon stocks, have demonstrated that this approach is inadequate.

DFO Science cannot continue to focus primarily on information collection and analyses of those ecosystem components closely linked to individual activities. Scientists must provide decision-makers with comprehensive ecosystem advice about how human activities may interact with other activities being undertaken in the same aquatic ecosystem, or take adequate account of major environmental drivers in the ecosystem.

At the same time, improving the knowledge base for managing one activity will likely improve the information available to manage other activities in that ecosystem. Effective fisheries management, for example, requires much more knowledge about an aquatic ecosystem than simply the fish stock abundance and population dynamics. A good ecosystem science framework will benefit both activity-specific management and management of all activities considered together.

The following eight priority areas, identified by the SMB under “Science in Support of Ecosystem-based Management,” provide a sound basis for the development of an ecosystem science framework.

- 1 Setting clear **objectives** for monitoring and protection
- 2 Developing **ecosystem indicators** and reporting systems
- 3 Developing **risk-based frameworks**
- 4 Generating **integrated information for fisheries management**
- 5 Identifying **habitats of special importance** and sensitivity
- 6 Considering impacts on aquatic **biodiversity** (*Species at Risk Act* and *invasive species*)
- 7 Understanding **pathways of effects** driving changes
- 8 Understanding **climate variability** and impacts on resources



As illustrated in *Table 1*, these priority areas are common to the DFO program areas requiring science support (Fisheries, Aquaculture, Oceans, Habitat Management, and Species at Risk) and are important for the integrated management of human activities in aquatic ecosystems.

An ecosystem approach is consistent with global trends, both in terms of other countries and research organizations. The European Commission is consulting on a comprehensive European Marine Strategy, which features an ecosystem approach to integrated management of human activities in the seas. The International Council for the Exploration of the Sea (ICES) is reorganizing its expert groups to focus on integrated ecosystem assessments and its advisory committees to provide integrated advice to fisheries, environmental agencies, and commissions. The National Oceanographic and Atmospheric Administration (NOAA) Ecosystem Review Team of the United States is recommending that NOAA marine science refocus on integrated regional assessments as the starting point for support and advice to all management clients (fisheries councils, sanctuary managers, and coastal zone planners).

Benefits and challenges of moving to an ecosystem science approach

Benefits

An ecosystem science approach will enable DFO Science to identify, monitor, and interpret trends in the features that are most important to an ecosystem’s sustainability, and integrate existing knowledge about the effects of fisheries, aquaculture, habitat, and oceans activities on these important ecosystem features. It will also help identify knowledge gaps

and bring specialists together so that DFO Science can build its advice around increased understanding of these features (which vary naturally and in response to human activities) and provide integrated and consistent science advice for decision-makers in all sectors.

Instead of duplicating existing capacity internally, DFO Science advice and support will make better use of existing science capacity in a wide range of areas, be built around a dynamic and flexible workforce, and reflect evolving international approaches to marine and freshwater science. This will improve confidence and credibility with clients, industry, and stakeholders, and make the new Science program more efficient, effective, consistent, and streamlined.

Challenges


Effective implementation of ecosystem science changes the way DFO has traditionally been organized. It requires a move away from scientists focused on single management issues to a team approach that brings together a wide range of skills. As a result, ecosystem science will change the make-up of the Science program workforce and require improved and interactive knowledge bases that support fisheries, aquaculture, habitat, and oceans management.

Stakeholders and clients requiring science advice and support adapted to their needs have come to rely on the traditional single-activity approach, and they are demanding increasingly specialized products and services. They will require help to understand the ecosystem approach, including how it can provide them with better inputs for their decision-making. Engaging DFO scientists and clients of the Science program (including DFO sectors, other federal departments, industry, and stakeholders) in the shift to ecosystem science will be a key element of DFO strategy.

Table 1 - Illustration of the common support each priority area of Ecosystem Science provides to the major clients of DFO Science.

Area of Ecosystem Science	Fisheries	Aquaculture	Oceans	Habitat	Species-at-risk
1 Ecosystem Objectives	1	1	1	1	1
2 Ecosystem Indicators	1	1	1	1	1
3 Risk-based Framework	1	1	1	1	1
4 Integrated ecosystem information for Fish Management	1	2	2	3	1
5 Habitats of special importance	2	2	1	1	1
6 Biodiversity	1	1	1	1	1
7 Pathways-of-effects	2	2	2	1	2
8 Climate variability and effects	1	2	1	2	1

(1 = direct and immediate supporting relationship; 2 = indirect but immediate benefits to clients from Science advances; 3 = indirect longer term benefits)



Limited human and financial resources are a continuing concern for the Science program, as indeed they are for aquatic science programs all over the world. Demands for science advice and support will continue to exceed the capacity of the program, even when the support is more integrated.

Why an Ecosystem Science Framework?

Although DFO Science is trying to co-ordinate the delivery of its functions, the demands of each DFO program area have been developed independently within the department and, as a result, DFO Science has been providing tailor-made products to each of its five main client programs. Science can no longer be a different program for each client.

DFO Science is developing an ecosystem science framework that integrates advice and support so it can provide decision-makers with effective support and address the limitations of single-activity management. The framework integrates existing knowledge about ecosystem dynamics and the effects of human activities on them, assesses the aspects that are most important to that ecosystem, and interprets the trends and patterns in ways that can be applied to risk assessment and management of human activities in aquatic ecosystems.

While client sectors may initially perceive fewer “custom-made” science products as a reduction in science support, they will, in fact, be getting improved science support. The Ecosystem Science Framework will help DFO Science make linkages between program areas, modernize program delivery, and support integrated policy-making and management. Such advice will help policies and management activities to become more general, flexible, and applicable to a range of conditions. The ecosystem approach provides the department with a common path to the future. As such, a solid ecosystem science framework is essential to enable us to travel that path together.

The Ecosystem Science Framework is guided by the commonality of client sector needs and provides multi-functional products. Of course, important activities of DFO Science that support maritime safety, sovereignty, and security cannot be reflected in the ecosystem science framework, but they will continue to respond to departmental priorities.

The Ecosystem Science Framework

DFO Science has identified a number of key components that will form the basis of the Ecosystem Science Framework. They reflect the highest priority management and policy challenges of both the department and the Government of Canada, as well as the multi-functional nature of an ecosystem science approach.

1 Risk assessment tools

- **Develop flexible risk assessment tools to provide risk-based science advice for policy and management.**

All policy and management activities need risk management, risk quantification, and risk-based decision-support tools that are practical and easily applied. Flexible risk assessment tools can be developed and implemented in the short term and all program areas will benefit from the more effective use of whatever ecosystem knowledge exists for a particular area and activity.

2 Performance evaluation of ecosystem indicators

- **Develop tools for evaluating performance of ecosystem indicators to help choose among competing suites of ecosystem indicators.**

Policy and management decisions must be based on reliable, rule-based indicators to ensure fair and stable advice. The advice must be available in a timely manner and be appropriate as to scale – whether that means advice pinpointed to a particular species in a particular area, or advice supporting a broad framework solution. Consideration must also be given as to whether such advice needs to be reviewed on a regular basis, as conditions change, or can be considered as appropriate for a long period of time. Consistent with this objectives-based management approach, DFO Science has put significant effort into developing and applying ecosystem indicators as the basis for making the ecosystem approach operational. Many suites of ecosystem indicators are being discussed within Science and among science, management, and policy experts. However, efficient and broadly applicable tools to evaluate the performance of ecosystem indicators in applied contexts have not been developed yet so the selection of indicators lacks an adequate science foundation. The knowledge exists to quickly develop and implement indicators that are known to be reliable in operational situations.





3 Tools for evaluating decision-support rules

- **Systematize the production of rule-based management systems to make support for robust fisheries management rules faster.**

Teams of science, policy, and management staff are gaining experience in developing strategic and operational decision-support rules. But progress is slow because each rule is developed for a case-specific application. The challenge is to evaluate the robustness of decision-support rules in achieving stated objectives in the face of uncertainties. Knowledge exists to develop general and flexible methods to test the robustness of proposals for rule-based management. Substantial progress on testing the proposals is feasible in the short-term. Some longer-term research is necessary to explore effective management rules for variable environments.

4 Operationalize regime shifts

- **Operationalize the concept of ecological regime shifts to deal with large-scale shifts, such as climate change.**

World-class research, much of it in Canada, has established that ecosystems may exist in more than one natural regime, and that changes in ecosystem regimes may be abrupt. When such changes occur, strategies for managing human activities may also have to change to ensure continued progress towards ecological, social, and economic objectives. Large-scale regime shifts may be driven by atmospheric climate processes or major changes to predator and prey abundances. However, there has been insufficient progress in exploring the management implications of climate variability and ecosystem effects of over-fishing. An ecosystem science framework must include the concept of operationalizing ecosystem regime shifts.

5 Apply knowledge of productivity changes

- **Consolidate knowledge of stock and ecosystem productivity to apply existing and new understandings to management advice.**

Recent research has greatly increased our awareness that the productivity of commercially exploited and farmed fish and invertebrates can vary greatly, and that a change in productivity has important implications for management. Although we are accumulating substantial knowledge on the causes of the variations, little of this knowledge makes its way into scientific advice on policy and management actions. An ecosystem science framework must consolidate existing knowledge of changes in stock and ecosystem productivity, and develop approaches to ensure that knowledge is reflected in science advice. Operationalizing ecosystem regime shifts and stock productivity work are complementary. If both are approached rigorously, significant progress is expected in the medium term. The transfer of knowledge to practice may also open up new science questions for future exploration.

6 Recovery potential of depleted species

- **Identify factors affecting recovery of depleted populations to support long-term and short-term stock-rebuilding efforts.**

Integrating knowledge of changes in stock productivity with policies and management practices will contribute to the recovery of depleted populations, whether listed under the Species at Risk Act (SARA) or assessed by DFO as in need of rebuilding. Currently, the reasons for the department's success in recovering some stocks, but not others, are poorly understood. Ecosystem science — to clarify the factors affecting the recovery potential of depleted populations — is essential for all departmental activities, particularly those activities provided for by SARA. This work will take time, but regular incremental benefits to all client sectors are expected.

7 Key features of ecosystem structure and function

- **Identify key structural and functional components of ecosystems to identify the ecosystem objectives and indicators that matter.**

The objective-setting process must focus on the properties that are most important to preserve ecosystem structure and function, and that are most directly affected by human activities. Correspondingly, the extensive scientific literature on ecosystem structure and function needs to be moulded into practical and consistent approaches to identify the key structural and functional components of aquatic ecosystems (such as predators or prey, habitat features, and even integrative functional properties reflecting community resilience and energy transfers). Determining the measurable properties that matter most to ecosystem structure and function will ensure workable indicators that guide decision-makers to the properties that will ensure human use of aquatic ecosystems that is sustainable.

8 Knowledge access and spatial management methodologies

- **Tap into existing information on aquatic habitats and use spatial information in science advice to take full advantage of databases and to focus on localized issues.**

Currently, the department's ability to implement an ecosystem science approach is limited. Data do not exist for many aquatic habitat features and populations of importance, and in some cases, information may exist but not be organized in ways that allow DFO Science to access it efficiently and systematically. Likewise the international scientific community is only beginning to develop the necessary knowledge and methods to address advisory questions in spatial contexts, and DFO Science needs to be more fully engaged in these initiatives. These components are essential to providing credible science in support of ecosystem-based management.

DFO Science needs to tap into any relevant databases they do not already hold. If the information exists but has not been made available, usable databases must be created.

Where essential habitat information does not exist, appropriate methodologies for collecting and using the information must be developed and implemented. These tasks are challenging, but crucial to the ecosystem science approach.

9 Best practices for ecosystem assessments

- **Identify best practices for ecosystem assessments to support a multi-functional approach to DFO science.**

The department has already conducted integrated ecosystem assessments for large, select ocean management areas. The capacity to conduct ecosystem assessments needs to be enhanced. It is equally important that the usefulness of these assessments as the starting point for science advice in the area being assessed must be evaluated. The goal is to identify the best practices for ecosystem assessments, and an essential component of “best” is that the assessments embody the multi-functionality necessary for an ecosystem science approach.

Table 2 illustrates the strong linkages between the key components of the Ecosystem Science Framework and the SMB priority management and policy challenges, and demonstrates the multi-functional nature of an ecosystem science approach.

All future DFO Science initiatives will support the eight priority areas identified by the Science Management Board and be developed in the context of key components of the Ecosystem Science Framework:

Short-term initiatives (one to three years) will consolidate the current state of knowledge and science progress, and produce specific science products for immediate use;

Medium-term initiatives (three to five years) will involve multi-functional science products where the consolidation of existing knowledge will, over time and as additional knowledge gaps are filled, likely result in a greater payoff; and

Long-term (beyond five years) initiatives are expected to provide benefits to client sectors throughout their lifetime.

Table 2 - Illustration of the multi-functionality of the key components in relation to SMB priority areas for Ecosystem Science

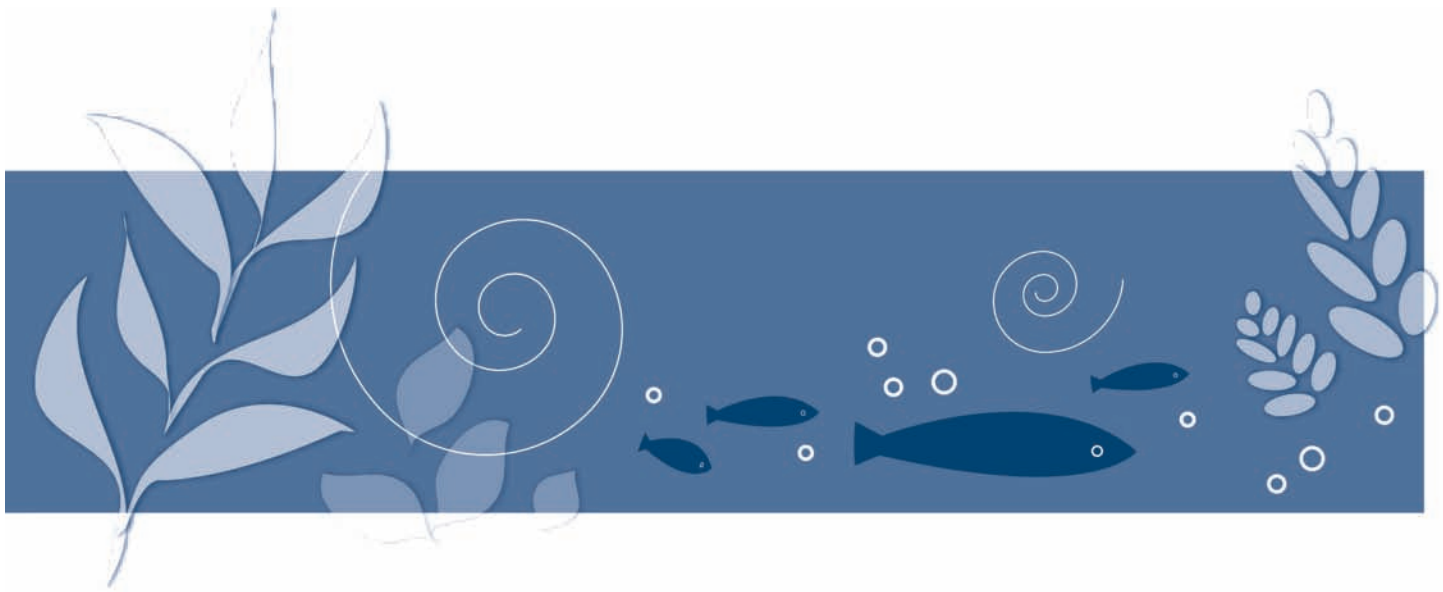
Priority Areas Components of Framework	Ecosystem objectives	Ecosystem indicators	Risk-based frameworks	Information for fish management	Special habitat	Biodiversity	Pathways of effects	Climate impacts
1 Risk assessment tools	2	1	1	1	2	2	1	1
2 Performance evaluation of ecosystem indicators	2	1	1	1	2	1	1	1
3 Tools for evaluating decision-support rules	1	1	1	1	2	2	1	1
4 Operationalize “regime shifts”	1	2	3	1	2	2	2	1
5 Apply knowledge of productivity changes	2	2	2	1	2	2	2	1
6 Recovery potential of depleted species	2	2	2	1	1	1	2	2
7 Key features of ecosystem structure and function	1	2	2	2	1	1	2	2
8 Knowledge access and spatial management methodologies	2	2	2	2	1	1	1	2
9 Best practices for ecosystem assessments	1	2	2	1	1	1	2	2

(1 = direct and immediate supporting relationship; 2 = indirect but immediate benefits to clients from Science advances; 3 = indirect longer-term benefits)

Conclusion

In summary, this document provides the rationale for an ecosystem science approach and describes the proposed framework for realigning the DFO Science program to support an ecosystem approach to management and better reflect an ecosystem science program.





Annex

This annex addresses ecosystem-based management from two perspectives: the challenges and benefits of an ecosystem-based management approach, and how science can support an ecosystem-based management approach.

The first three examples provide an overview of how ecosystem-based management can be approached in the Great Lakes, the Strait of Georgia, and the Northumberland Strait.

Examples D, E, and F demonstrate how the DFO Science program supports an ecosystem science approach with respect to aquaculture in the Experimental Lakes Area, tracking ecosystem stressors in the Lower St. Lawrence Estuary, and integrated coastal zone management in the Fundy Isles.

Example G highlights how an ecosystem-based management approach can be used to address high-profile and priority issues in the department.

A. Ecosystem management in the Great Lakes

The ecosystem approach to management is relatively new. It was pioneered in the Canada/U.S. International Great Lakes Water Quality Agreements (GLWQA) of the 1970s. Since 1989, Canada has spent nearly \$300 million in federal resources on actions designed to restore and protect the Great Lakes. As a result, the lakes are cleaner and healthier today than they have been in the past 50 years.

The Great Lakes are globally significant ecosystems. Together, lakes Erie, Huron, Michigan, Ontario, and Superior hold 20 percent of the world's surface freshwater. Forty million people live in the region and depend on the lakes for drinking water, including 30 percent of Canada's population and 10 percent of the U.S. population. Human health and economic success rely on the long-term health of this ecosystem. Shipping, industry, agriculture, tourism, and recreational and commercial fishing depend on the lakes. The Great Lakes fisheries are among the world's most valuable freshwater fisheries, with an estimated combined Canada/U.S. annual value of \$7 billion. The fisheries contribute \$450 million a year to Canada's economy. Recreational angling contributes \$350 million and commercial fishing, with an average annual landed value of about \$45 million, contributes approximately \$100 million.

Ecosystem management of the Great Lakes is a necessary and costly multi-partner undertaking. Implementation includes departmental programs, Great Lakes Action Plans, Great Lakes Fishery Commission programs, the Canada-Ontario "Respecting the Great Lakes Basin" Agreement and bi-national institutions with U.S. agencies. Smaller-scale and narrowly focused management actions, such as the Strategic Great Lakes Fisheries Plan promoted by the Great Lakes Fishery Commission (GLFC), had limited success but lake-wide ecosystem management plans now include many of its objectives.



Challenges in the Great Lakes Basin ecosystem

A long history of agricultural, industrial, and municipal development put the Great Lakes ecosystem under tremendous stress. More than half of Canada's 444 species at risk reside in the Great Lakes Basin. By the 1960s, human and industrial waste created serious eutrophication problems, and increased the loadings of persistent toxic chemicals, particularly in the lower lakes. Other concurrent stresses, such as climate change, invasive species, and loss and alteration of habitats due to human development, have added to the problems requiring management.

The concept of beneficial use

A framework for the ecosystem management approach emerged from the concept of "beneficial use," which was promoted to define and prioritize GLWQA management actions. The concept embodies ecological values of the ecosystem, such as food web health, fish populations, and fish and wildlife habitat, along with human values. Beneficial use was applied on a broad scale and governments were urged to develop lake-wide management plans to restore all impaired beneficial uses throughout the lakes. The management approach was further refined in GLWQA revisions, with plans to restore 14 beneficial uses in particularly degraded areas, referred to as Areas of Concern (AOCs). Restoration goals, often referred to as "delisting criteria," were developed.

Definition of the ecosystem management approach

Ecosystem management is holistic. It recognizes the connections between air, land, water, and all living beings. Ecosystems transcend geopolitical boundaries, and natural boundaries, such as lakes and their watersheds, are the management units of the approach. The research and understanding, monitoring, regulation, and implementation of actions require the involvement of international, federal, provincial, and municipal governments.

The following principles must be followed in ecosystem management:

- Encompass a holistic view, including the whole system, not just parts.
- Focus on interrelationships among the components of the environment, and between living and non-living things.
- Ensure balanced consideration of the natural environment, society, and economy.
- Use natural geographic units such as watersheds.
- Incorporate the concepts of ecological sustainability.
- Respect for species other than humans and for generations other than the present.

Great Lakes ecosystem management: The DFO Science role

Since the early 1980s, DFO has held the Canadian mandate for fish, fisheries, fish habitat, and productive capacity in the bi-national and multi-party organizations that continue to facilitate and support the recovery of AOCs across the Great Lakes, and that have led the development of lake-wide ecosystem management plans. DFO has contributed through scientific research, organization, leadership, identification of monitoring requirements, and continued advocacy for conservation, protection, and restoration of fish and fish habitat resources. DFO is a signatory of the Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem (COA). DFO assessments of the Great Lakes' productive capacity for the GLFC, and its Canada/U.S. partner agencies, helped determine sustainable guidelines for stocking top predators, the economic mainstay of Great Lakes fisheries.

The DFO Great Lakes Laboratory in Burlington, Ontario, is a pivotal player in the implementation of programs on food web, and habitat research and monitoring. Improved ecosystem management depends on understanding the impacts of management actions (fisheries, habitat, nutrient/contaminant management) in concert with other drivers of change such as climate, water levels, and species invasions. Recently, emphasis has been placed on the development of dynamic predictive nutrient, ecosystem, and habitat models to understand the relative importance of these influences. Ecosystem models are being used to assess the compatibility of multiple objectives and identify critical knowledge gaps. There is recognition that goals set separately and not as part of an ecosystem framework are unlikely to be compatible and likely to be counterproductive when implemented in the real world. As a result, there is greater understanding that fisheries management and habitat plans, traditionally developed separately, should be reconciled.

DFO Science has made major contributions to Great Lakes ecosystem science. Some examples include the creation of an energy flow model of the Bay of Quinte ecosystem that uses 30-plus years of multi-trophic monitoring data to examine the impact of nutrient management, successive species invasions, and exploitation on fisheries production. Science sector has developed research and monitoring tools, such as Indices of Biotic Integrity, to evaluate recovery of fish populations, zooplankton size/productivity indices, and phytoplankton productivity and composition indicators, which together provide metrics of ecosystem health. Monitoring of contaminants in Great Lakes food webs and modelling of pathways of bioaccumulation accomplished two goals: these activities clarified concerns about bioaccumulation risks and enabled forecasting of ecosystem recovery rates when use and loadings of specific chemicals were controlled. For a study sponsored by the International Joint Commission, DFO contributed a dynamic assessment model for all nearshore fish populations and habitats in Lake Ontario. The model was based on habitat classification and assessment tools



developed for use by Fish Habitat Management and the Great Lakes Action Plan partners in area habitat management and restoration plans.

Planned contributions of DFO Science to Great Lakes ecosystem management

- **Habitat:** 1) Scientific evaluation of the success of habitat restoration activities in AOCs, such as Toronto Harbour and the Lake St. Clair-Detroit R. corridor; 2) A key partner in merging of habitat and fisheries management plans in several AOCs; 3) Developing predictive habitat-based population models for key sport fish in AOCs.
- **Invasive species:** 1) Monitoring plans for invasive species, particularly in AOCs, key pathways for introductions; 2) Risk assessment of key pathways for introduction of invasive species to the Great Lakes; 3) Research to understand the impact of invasive species on the health of food webs and fish populations.
- **Ecosystems:** 1) Multi-trophic monitoring of ecosystem health in AOCs and whole lakes; 2) Developing and reporting on metrics of beneficial use; 3) An ecosystem model for the Hamilton Harbour AOC; 4) Development of ecosystem recovery strategies for species at risk and understanding the role of critical habitat; 5) Evaluating restoration goals with ecosystem models.

B. The Strait of Georgia and ecosystem-based management

More than two-thirds of the population of British Columbia is concentrated on the lower mainland and on southern Vancouver Island, on either side of the Strait of Georgia. In the next 20 years, this population of just over 2.7 million people (2001 Census) is forecast to grow 30 percent or more. Already a heavily used waterway, the Strait of Georgia is “the most at-risk natural environment in Canada,” according to Parks Canada.

Benefits of the ecosystem approach

The ecosystem approach to management focuses on the causes and the consequences of change to the species in the strait. In the Strait of Georgia, this approach must account for the natural ecosystem changes to plants and animals, some of which may occur rapidly, as well as impacts caused by fishing, increased population, industry, pollution, and greater recreational use.

Advice with greater ecosystem content might include using trends in temperature, salinity, winds, and freshwater flows into the strait to identify how the strait is changing and what the changes mean for harvests. Simple measures of the timing of plankton production may be key indicators of future trends in abundance of herring, Pacific hake, coho, Chinook, sockeye, chum, and pink salmon. Increasing bottom

temperatures, particularly in the winter, may influence advice on Pacific cod and perhaps other species through its effects on spawning. Ecosystem science provides managers with more information about the factors that affect the abundances of particular species. This information should help managers and clients understand better the need for conservation during unfavourable environments, as well as the opportunities for fishing during favourable conditions.

A successful ecosystem management approach means that stewardship will improve, even as the strait continues to change. Canadians will gauge the success of the approach by the overall health of the species in the ecosystem.


Ecosystem challenges in the Strait of Georgia

The strait is a major rearing area for juvenile Pacific salmon that traditionally contribute about 35 to 40 percent of the total Pacific salmon catch. Pacific herring in the strait are currently at historic high levels, amounting to 60 to 70 percent of the total annual B.C. herring catch over the past five years. There are major commercial fisheries for Dungeness crab, spot prawns, geoducks, and sea urchins, representing about 35 percent of the total billion-dollar B.C. shellfish industry in 2005.

Pacific hake, the largest biomass of fish, have become so numerous in recent years that their growth has been stunted. Spiny dogfish, a long-lived and slow-growing species, are widespread and abundant. Even though they are not highly esteemed by humans, they may play an important role in the balance of nature in the strait. Historically, lingcod was a major predator, but severe over-fishing has reduced their abundance and the impact of their predation. Pacific cod was also an important species in earlier decades, but they have almost disappeared in recent years, probably because of the increased temperatures in their spawning areas. Seal and sea lion populations have significantly increased in the past 20 years. These changes in fish and marine mammal populations mean that predation relationships have changed greatly in the strait’s ecosystem over the past two decades.

Less favourable conditions in the strait for coho salmon are reflected in the marine survival of the species, which has been nearly an order of magnitude lower in the 1990s than it was in the 1960s and 1970s. The natural changes have implications for sustainable exploitation rates, rebuilding strategies and targets, and hatchery operations. During periods of low productivity such as the present, exploitation rates must be low to be sustainable, recovery of depleted populations will be difficult, and there may be greater competition between hatchery-reared coho and wild chum. Science advice attuned to ecosystem status is crucial for all of those management and policy activities.

The Strait of Georgia traditionally supported one of the major recreational fisheries in Canada. There are still sport fisheries for salmon, rockfish, and some other species, but the large fishery for coho salmon collapsed when coho changed their behaviour in the mid-1990s and no longer were found in the strait in the spring and summer prior to spawning.



The strait has warmed about 1°C in the past 100 years and 0.3°C in the past 25 years, and could increase another 2°C in the next 50 years. There is also an indication that salinity in the deeper water is declining. Flows from the Fraser River are expected to continue to change, with increased flows in the late winter and decreased flows in the summer. In six of the last 15 years, river temperatures have sometimes exceeded the lethal levels for salmon migrating to their spawning grounds. The pattern and amount of Fraser River flows also indirectly provide most of the nutrients to the Strait of Georgia by drawing nutrient-rich, deeper, open ocean water into the strait. Winds, sunlight, and nutrients combine to produce the plankton that feeds the juvenile fish and shellfish. Winds in the spring may be weakening, which would reduce plankton production after the initial bloom. In recent years, it appears that fish that begin feeding earlier survive better than fish that begin feeding later, as evidenced by the high abundances of pink and chum salmon and the low abundances of coho salmon.

The ecosystem approach also takes into account the impact on migratory species that reside temporarily in the area. Besides the large resident populations of seabirds, ducks, and geese, the Strait of Georgia is a vital stopover point in the Pacific Flyway, a major bird migration route. The Fraser River estuary and Boundary Bay form the largest winter waterfowl resting area in North America.

C. Ecosystem-based approach for the Northumberland Strait

During the last century, human activities have likely caused important modifications to the unique environment of Northumberland Strait. In order to implement an ecosystem-based approach for the management of this water body, DFO initiated an Environmental Overview Assessment Report and has begun the process of integrating information from various sources (fisheries, scientific surveys, socio-economic studies) and making it available to stakeholders.


Northumberland Strait, separating Prince Edward Island from New Brunswick and Nova Scotia, is 225 km long and ranges from 14 to 48 km wide. It features Canada's warmest ocean water temperatures. Surface water temperatures reach about 10°C by early June, and 20°C to 23°C by late July. Estuarine temperatures are higher and rise more rapidly in the spring. Shallow depth causes strong tidal currents, mixing of the water column from surface to bottom, turbulence, and a high concentration of suspended red silt and clay. Between December and April, sea ice generally covers the strait to thicknesses up to 120 cm, and water temperatures fall to about -1°C. The strait is less than 20 m deep over a large central area and about 70 m deep at its ends. About 140,000 inhabitants (2001 Census) in 55 communities reside along the strait.

Northumberland Strait is a dynamic, productive ecosystem. Lobster is the most valuable fishery in this rich fishing ground, which is one of Canada's most densely fished areas, with more than 2,000 fishing enterprises. Important species in the strait include lobster, scallop, herring, rock crab, American plaice, mackerel, tuna, cod, winter flounder, white hake, alewife, silversides, smelt, oyster, mussel, quahog, soft shell clam, and Irish moss. Grey and harbour seals are found year-round in nearshore areas. Whales and porpoises enter the area in spring, feed through the summer, and leave in winter. Pipefish, a member of the seahorse family, are common in the warm estuaries. Some non-native species were likely introduced by the earliest European explorers, but new arrivals, such as green crab, several species of algae, and four species of tunicate have the potential for serious environmental and economic consequences. Aquaculture of mussels and oysters is practised in estuaries on both sides of the strait. Because of the warm summer water temperatures and sandy beaches, waterfront real estate is very valuable. There are several parks along the strait and recreational boating and fishing are popular.

Stakeholders express concern for the future of Northumberland Strait

Stakeholders have expressed themselves on a variety of ecosystem issues. Fishers have stated that there have been steep declines in several key commercial species that have worsened in recent years and can be attributed in part to changes in the environment, the construction of Confederation Bridge, and fishing practices, such as dragging. They are concerned about the loss of fishing enterprises, unemployment, out-migration of young people, falling living standards, and loss of socio-economic viability for many coastal communities.

Other stakeholders express similar concerns about the future of commercial, cultural, and recreational activities occurring in and along the strait. They report that water quality is deteriorating at an accelerating rate. They note dramatic increases in the build-up of sediment and the presence of suspended solids, and feel that these changes are impacting fish populations and habitat in the strait, its many estuaries, and its drainage basins. They also refer to increased nutrients and contaminants from land-based activities, like intensive agriculture; to effluents from industries, fish plants, and municipalities that contribute to the problem of eutrophication; and to infilling and construction of cottages that contribute to shoreline erosion and destruction of wetlands.



D. The Whole Lake Aquaculture Experiment: An example of ecosystem-based science

Most of Canada's aquaculture is marine-based, but there is increasing interest in the potential for commercial freshwater aquaculture, or fish farming, to provide protein for human consumption. At the Experimental Lakes Area (ELA) in northwestern Ontario, DFO researchers are conducting a whole-ecosystem study, collecting data before and after the installation of a fish farm, which will yield an unparalleled data set to assess the impacts of freshwater cage aquaculture using current industry practices.

The detailed study of processes and mechanisms will provide the basis for modelling and extrapolations to different systems. These data will be used to provide advice on site location and operation of current and future fish farms. Detailed understanding of the effects of freshwater aquaculture will help DFO to balance the potentially conflicting demands of fish farmers, cottagers, commercial, and recreational fishermen, all of whom impact fish habitat.

The study is quantifying the effects of aquaculture on water quality, primary production, sediments, and the composition and behaviour of native invertebrate and fish communities. A mass-balance approach along with measurement of stable sulphur, nitrogen, and carbon isotopes is being used to trace the movement of aquaculture-related waste materials through the ecosystem. The study lake, Lake 375, was studied for two years prior to the establishment of a small fish farm in 2003. DFO researchers are now following changes in key ecosystem variables in Lake 375 and a nearby reference lake, Lake 373, for which there is long-term reference data. In conjunction with these studies, a parallel set of observational data are being collected from active fish farms in Georgian Bay, Lake Huron, and in Lake Diefenbaker, Saskatchewan. These data will be used to develop models scaling the results from Lake 375 to larger systems currently used for aquaculture operations.

Since 2003, approximately 10,000 rainbow trout have been introduced every May and raised in the farm cage located in Lake 375. Changes in the size of cultured trout in relation to water temperature, nutrient retention by the farmed fish, and digestibility are carefully monitored to model waste production. Waste production and delivery to the sediments is also being determined directly, using a network of sediment traps located below the cage and throughout the lake. A mass balance model is being constructed to quantify the fate of phosphorus, carbon, and nitrogen added to the ecosystem by the fish farm.

In both Lakes 375 and 373, changes in water quality are being followed by bi-weekly sampling of water chemistry (including all major nutrients), carbon 14 (C14) primary production, and phytoplankton and bacterial biomass, algal physiological nutrient status, and community composition. An array of

periphyton trays located around the lake is being used to assess the spatial distribution of nutrient-related effects on algal growth. Similar measurements on algal species composition, productivity, and physiological status are being taken in the littoral zone. Changes in the abundance and spatial distribution of zooplankton and larger planktonic invertebrates, including *Mysis* and *Chaoborus*, are being undertaken bi-weekly.

The impacts of the fish farm on sediments and their associated biota are being assessed by regularly collecting samples along a transect extending out from the cage every spring and fall and, on a larger spatial scale, through bi-weekly sampling of sediments throughout both the experimental and reference lakes.


Little is known about whether aquaculture waste can be used as a novel energy source by native biota such as fish and invertebrates. Waste generated from the aquaculture operation has a unique stable isotopic signature, and changes in these signatures in Lake 375 biota indicate the degree to which the lake ecosystem incorporates aquaculture waste.

Changes in the abundance and growth of native fish populations in Lakes 375 and 373 are being monitored by sampling twice a year. Almost all fish are returned live to the lakes. DFO researchers are placing small radio-linked acoustic transmitters in native fish to track fish movements and behaviour before and after the cage installation. Transmitters are also placed in 5–10 rainbow trout each year that are subsequently released into Lake 375 to mimic and better understand the behaviour of "escapees." Changes in the distribution of minnows are also being followed by intensive sampling at different locations around Lake 375.

E. Lower St. Lawrence Estuary

There is a definitive requirement for the development of an ecosystem science framework to better understand and monitor the interactions between the ecosystem components and changes resulting from increased human pressures in the Lower St. Lawrence Estuary (LSLE). The following overview provides context for this requirement.

The LSLE extends from the mouth of the Saguenay Fjord downstream to Pointe-des-Monts, Quebec. It is a critical area within the estuary and Gulf of St. Lawrence ecosystem. The most important mechanisms occurring in the LSLE are the intense tidally induced mixing between fresh water and salt water, and upwelling at the head of Laurentian Channel, which is also known as the nutrient pump. Relatively nutrient-rich water of the intermediate layer is also mixed into the surface layer by entrainment with the St. Lawrence River water, and both form the Gaspé Current that transports nutrients along the Magdalen Shallows toward Cabot Strait. These hydrographic processes are responsible for the high biological production as far as the southern Gulf. In addition, the high production in the LSLE supports an abundant zooplankton community, although a large proportion of the bio-



mass found locally results from advective transport in deep waters. The resulting accumulation of zooplankton biomass and associated occurrence of pelagic fish at the head of the Laurentian Channel represents a highly important food source for marine mammals summering in the LSLE, including several species at risk, such as the beluga population of the St. Lawrence Estuary and the blue whale.

Tracking the impact of ecosystem stressors to the Lower St. Lawrence Estuary

The LSLE is also subjected to a wide variety of human uses and related stressors that pose a significant threat to the integrity of physico-chemical and biological processes occurring in this area, with potential implications for their downstream influence on productivity in the southern Gulf of the St. Lawrence. These include:

- the accumulation of contaminants originating from the Great Lakes and St. Lawrence River in sediments of the Laurentian Channel;
- hypoxia conditions in deep waters of the Laurentian Channel, which have been increasing since the 1930s as a result of climate change and eutrophication in the St. Lawrence Estuary;
- marine mammal disturbance resulting from intense commercial navigation, increasing marine mammal observation activities, and a growing interest in oil and gas exploration (seismic surveys) in the LSLE; and
- freshwater input modulations related to water level management in the St. Lawrence Seaway, hydroelectric development, and climate change (precipitation).

The specific and combined impacts of these various activities and pressures are not well understood, and innovative approaches are required to address these issues given the complexity of physico-chemical and biological processes occurring in the area, and potential interactions between the various stressors in influencing these processes.

F. The Fundy Isles (SW New Brunswick Bay of Fundy) case study

The Fundy Isles region of the mouth of the Bay of Fundy is exceptional in its productivity, spectrum of marine habitats, and biodiversity. The region has been historically significant in its fisheries for herring, lobster, scallop, and groundfish, and in recent decades it has become the centre of the substantial Atlantic marine finfish aquaculture industry. More recently there has been renewed interest in energy-related developments in the area, including in-stream tidal power generation and proposals for liquefied natural gas (LNG) terminals. It is an area inhabited by several species with designation under the *Species at Risk Act* (including right whale, inner Bay of Fundy salmon, and harbour porpoise),

and includes one of the first marine protected areas (Musquash).

The mouth of the Bay of Fundy, particularly the Fundy Isles region, is an obvious case study for implementation of an ecosystem-based management approach. The Fundy Isles region is an area of intense overlap in ocean uses. There are a number of significant interactions among uses and examples of multiple uses impacting valued ecosystem components. The area is the subject of an experiment in integrated management through the southwestern New Brunswick Marine Resource planning initiative. Further, the Fundy Isles are adjacent to the border with the United States, providing an opportunity for consideration of transboundary/international governance issues.

The St. Andrews Biological Station (SABS) was built in the Fundy Isles a century ago in large part because of the diverse marine habitats and proximity to important fisheries, and it has accumulated a substantial understanding of the area. SABS has recently realigned its activities to focus on the science required for integrated coastal zone management and approaches to the application of ecosystem-based management. SABS has reorganized to explicitly integrate fisheries (Population Ecology), Environmental Science, Oceanography, and Aquaculture sections under the working theme “Integrated science for integrated management” to anticipate and to provide the science required for evolving management of the Bay of Fundy/Gulf of Maine.

SABS research on the science required for an operational ecosystem-based approach involves developing and demonstrating concepts, comparing approaches, and providing advice. The scope of the research includes:

- research and advice on indicators and reference points for the broader suite of operational objectives (tactics) required of management plans under an ecosystem-based approach;
- methods to estimate the cumulative impact of various activities in relation to conservation objectives (sum across management plans);
- research on the relevance of contextual indicators and impact of changing conditions on reference points;
- decision-support approaches and methods of integrating science information in support of decisions that are broader than individual management plans;
- scientific basis for advice in relation to depleted and sensitive species and for degraded and significant areas;
- approaches to monitoring in the coastal zone in relation to the evolving needs of an ecosystem-based approach; and
- research and advice on interactions among ocean uses, and between ocean uses and the biological elements of the ecosystem.

Recognizing the holistic nature of an ecosystem-based approach, SABS has increased collaboration with Oceans and Habitat, with Fisheries and Aquaculture Management, and with academic colleagues (specifically through a memorandum of understanding with University of New Brunswick and the Huntsman Marine Science Centre) to increase the scientific capacity in this study area.


G. Examples of DFO activities placed in an ecosystem context

The following examples demonstrate how key DFO initiatives can be reoriented to more broad-based and widely applicable Science support.

- **Cod recovery** — Although rebuilding many Atlantic cod stocks has been a priority over the past 15 years, progress has been slow. DFO has only partial knowledge of why depleted populations have failed to respond to rebuilding initiatives, which is hampering both rebuilding efforts and the department's credibility. We have learned that the productivity of cod stocks has changed and know some of the causes of the changes in productivity, but have not yet built a working knowledge of how the conditions of ocean climate (often referred to as "regimes") are related to the capacity to rebuild. We also know that the spatial distribution of cod has changed with the declines, but do not have the necessary understanding to accommodate the changes in recovery planning or relate them to changes in marine habitats. Natural mortality has increased in several stocks. Although evidence indicates seal predation may be a factor, we have insufficient knowledge of the factors causing changes in natural mortality to include those factors in our recovery planning. Cod Recovery Plans will be rule-based, formally or informally, in risk-structured programs. For these to succeed, the rule indicators and their corresponding objectives will have to be cost-effective for monitoring, and a reliable basis for management decision-making. While some of this knowledge may be consolidated into the integrated large ocean management area assessments, additional application-specific interpretation by DFO Science will be required to translate the assessments into fisheries recovery planning.
- **Wild Salmon Policy** — After several years of planning, the Wild Salmon Policy has been accepted as the starting point for conservation and management of Canadian west coast salmon stocks. Even more than with Atlantic cod, the role of the ocean environment has been shown to be important to the productivity and sustainable harvest levels of wild salmon and highly variable over longer time frames. This must be addressed in science advice in an ecosystem context.

The complex life histories of Pacific wild salmon require greater information on habitat needs and habitat status, as well as knowledge of how spatial processes affect past and future population trajectories. Our knowledge of these factors is incomplete and what is known is not yet fully integrated into science advice in a way that provides for an ecosystem approach to wild salmon management. As with Atlantic cod, past recovery efforts of depleted population units have met with mixed results, for reasons that are only partly understood. To use the existing (but incomplete) knowledge again, good risk management tools with reliable "triggers" and control rules will be needed.

- **Aquaculture and environmental impacts** — Only recently has DFO Science begun to provide advice on the effects of cage aquaculture on marine ecosystems. Even at this early stage, there is a clear need for good risk management tools and informative indicators and decision-support rules. We are learning which parts of the marine ecosystem are most directly affected by aquaculture facilities and the major indirect effects. However, we need a better understanding of the implications of making alterations in different parts of those systems. Aquaculture advice needs to focus on places, rather than fish populations, so it can address things minimizing the undesired consequences of siting facilities. Aquaculture production, like productivity of wild populations, is occurring in an ever-changing environment. Effective science support needs to know how to interpret and apply monitoring information in the context of expected productivity and possible ecosystem effects.
- **Pathways of habitat effects** — Pathways of effects have been developed for a number of "in-water" activities, but DFO Science has not reviewed the basis for many of these pathways. Risk-based tools, applied spatially rather than on target populations, will be the cornerstones for science support. The tools will require good decision-support rules and informative indicators that take realistic account of the changes already inherent in aquatic habitats. Developing and validating decision-support rules, and their subsequent application, will also require access to types of data not traditionally used to provide advice on populations. DFO Habitat Management has used the pathways-of-effects approach to focus attention on the highest risks and the greatest potential impacts. Realizing these goals, however, requires greatly improving our knowledge of which parts of aquatic ecosystems are most crucial for health and productivity.
- **Oil and gas exploration, and development in the North** — Hydrocarbon exploration and development in the North characterize the challenges the department faces when balancing the potential benefits of commercial activities against the potential costs of "worst-case" scenario ecosystem effects. These challenges can only



be met if we have clear objectives, good risk evaluation, and management tools that are based on reliable indicators, and effective rule-based management strategies. Advice will have to be robust both spatially and in terms of populations. With limited site-specific information for most of the Arctic, it will be essential to know what parts of the ecosystem are most crucial for monitoring impacts and for ensuring that impacts of these activities are managed in a precautionary (but not prohibitive) framework.

- **Stock assessment** — The ecosystem approach changes science support in traditional areas such as stock assessment for fisheries management, just as the ecosystem approach is changing fisheries management itself. Changes include the need for rule-based and risk-based management strategies using reliable indicators, broadening the basis for science advice to include the regime status of the environment, and applying knowledge of how stock productivity is expected to change with population demographics and environmental conditions. It will also be necessary to assess status and trends of some non-commercial species such as species taken as by-catch in fisheries and benthic ecosystem components important for roles in providing habitat or food for other species. Both objectives and management strategies will have to be rethought to place fisheries management in the same spatial context as the other human activities simultaneously affecting the ecosystem.

