A SYNTHESIS OF THE OUTCOMES FROM THE STRAIT OF GEORGIA ECOSYSTEM RESEARCH INITIATIVE, AND DEVELOPMENT OF AN ECOSYSTEM APPROACH TO MANAGEMENT

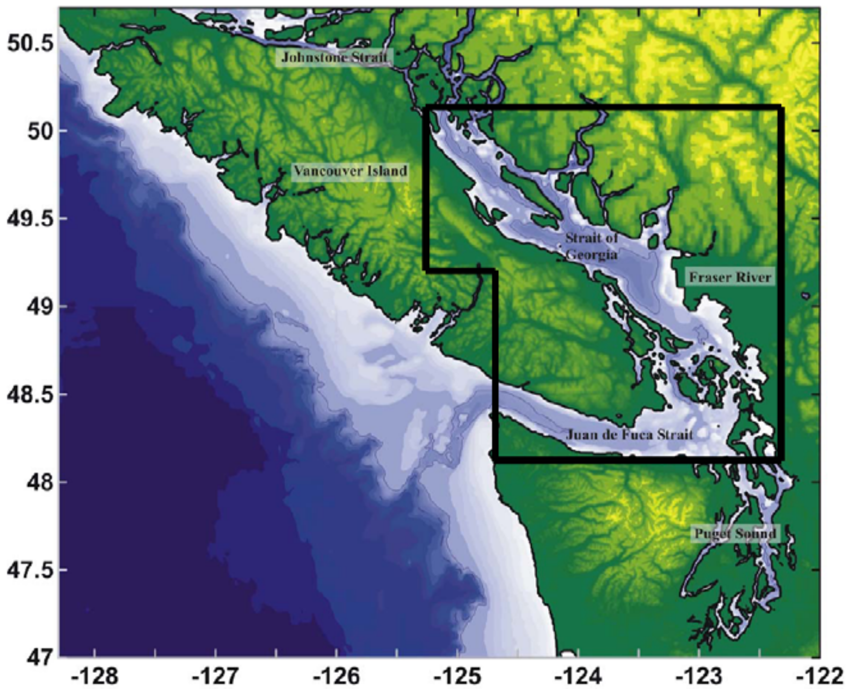

Figure 1. The marine ecosystem comprised of the Strait of Georgia, Juan de Fuca Strait and Puget Sound. The geographic region which is the primary focus of the Strait of Georgia Ecosystem Research Initiative is identified within the box.

Context :

Fisheries & Oceans Canada (DFO) has committed to a sustainable, precautionary and integrated ecosystem approach to oceans management. To support the development and implementation of such an approach, seven Ecosystem Research Initiatives (ERIs) were established by DFO Science to facilitate integrated research on a particular ecosystem with predefined geographical boundaries. The overall purpose of the ERIs was to serve as pilots for DFO's ecosystem approaches to management and to enhance the capacity to provide scientific advice in support of these approaches. In Pacific Region, the Strait of Georgia was selected as the pilot study ecosystem. The Strait of Georgia Ecosystem Research Initiative began in January 2008, and concluded its directly-funded phase on 31 March 2012. The synthesis described in this report, arising largely from projects funded by this initiative, provides a conceptual understanding of how the Strait of Georgia marine ecosystem works, some aspects of its relationships with the human social system of this region, and some important considerations for its management using an ecosystem approach. In addition, it provides guidance as to tools useful for providing science advice in an ecosystem context. Recommendations for a process to deliver Science advice for an ecosystem approach to management in Pacific Region are also provided.

This Science Advisory Report is from the 11-13 September 2012 Regional Peer Review meeting reviewing: "A synthesis of the outcomes from the Strait of Georgia Ecosystem Research Initiative, and their ecosystem approaches to management and policy implications". Additional publications from this process will be posted as they become available on the Fisheries and Oceans Canadian Science Advisory Secretariat website at www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

SUMMARY

- Selected results are synthesized from the Strait of Georgia Ecosystem Research Initiative (ERI), as a contribution to developing an ecosystem approach to the management of this marine system;
- The synthesis provides an overview of some of the key findings regarding the current understanding of how the Strait of Georgia marine ecosystem ‘works’, the drivers of change acting on the Strait and how some of these may influence the Strait in the mid-future;
- Several ecosystem-related science-based tools (assessments and models) were developed to describe ecosystem processes. These also identified some specific considerations for management and can provide information to assist with management decisions. Some tools can readily be applied to all B.C. marine areas, whereas others are complex with extensive data needs;
- For the Strait of Georgia and other areas, potential indicators need to be identified and prioritized, including their data requirements, to meet objectives relating to an ecosystem approach to management. A comprehensive review and evaluation of all potential ecosystem indicators was not conducted. However, several studies did identify potential ecosystem-level indicators for specific management objectives;
- To implement an ecosystem approach to management (EAM), a process for the collaboration and coordination among Sectors is necessary. A cross-sector working group is recommended. This working group could also serve to interact with other Regions and other external initiatives;
- Consideration of productivity regimes and food web dynamics (predation and prey requirements) should be integrated into stock assessments, and used to inform other Departmental planning processes;
- The near-shore zone in the Strait of Georgia, and elsewhere in the Pacific Region, is poorly described and its role in ecosystem processes is not well understood. To provide science advice with respect to the value of this zone to ecosystem dynamics, including fish productivity, further study is necessary;
- Ecosystem data are dispersed and in a variety of formats, making their collection and synthesis difficult; common platforms and formats for storage and access of these data are needed;
- Tools developed through this process have broader applicability than just the Strait of Georgia and should be considered for other areas of the Pacific coast.

INTRODUCTION

Background

DFO is committed to implementing an ecosystem approach to the management of Canada’s aquatic environments. Although a departmental framework has not yet been approved, appropriate components of an ecosystem approach to management (EAM) may include:

a) characterise and assess the ecosystem (i.e. assess the state of the ecosystem);

b) establish ecosystem objectives (for example set operational objectives regarding productivity, biomass, diversity) and assess the risk of failing to achieve these objectives;

c) identify indicators and thresholds for assessment and management;

d) determine and implement management strategies; and

e) monitor, evaluate, and report, including tracking indicators, assessing and reporting on changes, and adapting objectives and strategies as required.

To explore different ways in which DFO Science might support the development of an ecosystem approach to management in waters under Federal jurisdiction, pilot Ecosystem Research Initiatives (ERIs) were initiated across Canada with funding provided from 2008-2012 as part of the five year science plan. The Strait of Georgia ecoregion was selected as the location for the Pacific ERI because of its accessibility, the extent of existing data and knowledge, and the importance of its resources to Canadians. The program focused on the Strait of Georgia and Juan de Fuca Strait, although some individual studies included the mainland inlets on the eastern side of the Strait of Georgia and/or Puget Sound (Fig. 1). The overall objective of the Strait of Georgia ERI program was to establish the basis for the management of ecosystem and human interactions in an integrative ecosystem framework. Specifically, it examined the following departmental priorities:

1) Understanding how this system works (what controls the productivity?);
2) Identifying the drivers of change acting on the Strait and how these drivers might change in the future; and,
3) Developing ecosystem-related science-based management and decision-making tools to support healthy and sustainable marine resources.

A previous report (DFO, 2012) proposed the science elements for an ecosystem approach to the Strait of Georgia. These elements include the identification of anthropogenic stressors; the necessity of indicators and monitoring; the selection of baselines, reference levels, and thresholds; spatial management approaches; modeling; and data management. The present report builds on a selection of these elements.

Rationale for Assessment

This Science Advisory Report describes examples of key outcomes from the Strait of Georgia ERI that are available to date and considerations for further development and implementation of an ecosystem approach to management in this Region, based on the results and lessons learned from this pilot ERI. Specifically, the objectives of this assessment were to:

1. Provide a synthesis (based largely on the Strait of Georgia ERI) of how the Strait of Georgia ecosystem works (what controls the productivity), what drivers of change are acting on the Strait, and how these drivers might change in the future;
2. Identify potential issues and specific recommendations for management attention within an ecosystem approach to management that result from (1), including examples of specific applications of existing DFO ecosystem-related policies (e.g. forage fish policy);
3. Provide guidance on tools developed and used during the Strait of Georgia ERI for generating science advice within an ecosystem context;
4. Identify critical knowledge gaps and future research needs to advance the development of integrated ecosystem assessments and management approaches in Pacific Region;
5. Provide lessons learned and recommendations on how to deliver Science advice for an ecosystem approach to management in Pacific Region.

ASSESSMENT

How the Strait of Georgia marine ecosystem 'works'

Results from the Strait of Georgia ERI projects and other relevant studies suggest that the overall productivity of the Strait of Georgia can be attributed to six key processes: enrichment, initiation, retention, concentration, trophic (food web) dynamics, and nearshore/benthic dynamics (Table 1).

Table 1. Six key processes influencing how the Strait of Georgia marine ecosystem functions.

Process	Examples
Enrichment	• input of nutrients via intermediate and deep water inflows • organic carbon from terrestrial sources • replenishment of surface nutrients by mixing and advection
Initiation (of plankton blooms)	• changes in vertical stability of the water column • seeding of early spring phytoplankton blooms from mainland inlets into the Strait of Georgia
Retention	• topographic containment of the Strait of Georgia system • limited connections with adjacent open ocean (2% of perimeter) • strong vertical mixing at openings with open ocean which re-circulates organisms back into the strait • relatively deep median depth (150 m) • mean water replacement time of 20 months
Concentration	• river plume and tidal mixing fronts • feeding and spawning aggregations of fish
Trophic (food web) dynamics	• strong seasonal plankton production cycles • dominant contributions to zooplankton biomass of crustacean and gelatinous predatory species, often with large daily or seasonal vertical migrations • large biomass of relatively few mid-trophic level forage species, in particular Pacific herring • large biomass of small sized seasonal migrants out of the Strait (salmon) • timing match-mismatch processes • dominance of pelagic over demersal fish fishery production
Nearshore/benthic dynamics	• provides fixed structural features (in contrast to the pelagic features) • 98% of perimeter is nearshore habitat • nearshore plants contribute to productivity of Strait of Georgia system • strong benthic-pelagic coupling in these shallow areas • important location–specific features for species survival, especially invertebrates

Based on ERI research studies, there are six important general concepts to note regarding the functioning of the Strait of Georgia ecosystem:

- <u>exchanges with outside water bodies</u>: The productivity of the Strait of Georgia ecosystem appears to depend on exchanges with adjacent water bodies outside of the Strait, despite only 2% of the perimeter being connected to open ocean waters. The sub-surface intrusions from the west coast of Vancouver Island are needed to replenish nutrients and oxygen in the Strait of Georgia system. Pacific herring and Pacific salmon are important seasonal migrants in the Strait of Georgia, exchanging nutrients and energy between the Strait and oceanic regions. Adult herring are in the Strait in autumn and winter, but largely depend on summer plankton production along the west coast of Vancouver Island to support the productivity of their population. Juvenile salmon of several species are in the Strait in spring and summer, with most overwintering in oceanic waters;

- pelagic versus demersal fishery production: The Strait of Georgia fishery is currently more productive of pelagic fish species than it is of demersal fish species. The production of pelagic species may be favoured by the deep median depth (about 150 m) of the Strait of Georgia and the shorter residence times of the near-surface water masses, which reduces the settling of organic matter to the bottom and promotes its recycling, or replenishment, in pelagic waters;
- strong seasonality of pelagic productivity: The most productive period in the Strait of Georgia is from late winter to early summer, when resident fish populations such as Pacific hake and migratory populations such as Pacific herring are spawning, and juvenile salmon enter the Strait. This enhanced productivity at this time may be related to the peak in spring zooplankton biomass in the upper waters, in particular of the nutritious large calanoid copepods. This suggests that survival of herring and salmon survival over their early life stages is likely related to spring and early summer zooplankton dynamics;
- match-mismatch: The potential for mismatches among the spatial and temporal overlaps of predators and prey is high, particularly in spring when the productive season begins (e.g. a relationship has been found between herring productivity and the timing of the spring phytoplankton bloom);
- species matter: In contrast to mid-trophic level vertebrate predators, which are assumed (and appear to be) non-selective of their prey, higher trophic level species can be highly selective of their prey (e.g. southern resident Killer whale predation on Chinook salmon);
- nearshore habitat: many species of fish and invertebrates of commercial and cultural importance to the Strait of Georgia use the nearshore region for some or all of their life cycle. At present, the cumulative effects of processes and disturbances occurring at these local spatial scales to the functioning of the Strait of Georgia ecosystem are generally poorly understood.

Ecosystem Drivers

Several processes and stressors drive changes in semi-enclosed marine systems like the Strait of Georgia, and many manifest themselves at different spatial scales (Table 2).

Table 2. Examples of drivers of change acting on semi-enclosed marine systems generally and specifically on the Strait of Georgia, distinguished by their primary spatial scales.

Spatial scale	General drivers of change	Specific drivers of change in the Strait of Georgia
Large (global, ocean basin)	• climatic variability • climate change	• sea level • temperature • acidification • hypoxia
Medium (regional)	• exploitation of living resources • food web alterations • habitat modifications • nutrient loading • non-native species introductions	• fishing • basin scale habitat changes • contaminants • tourism and recreation • agricultural runoff • sewage • shipping
Local (bays and coastlines)	• changes to sediment inputs • changes to freshwater inputs • shoreline development • marine structures	• changes in bank morphology, e.g. Fraser River delta • beach erosion • shoreline development and hardening • changes in hydrography and circulation • local intertidal habitat modifications, e.g. tidal flats, eel grass • aquaculture (development and operations) • industrial activities

Among the anthropogenic stressors that were examined, two were investigated in greater detail: fishing is an important pressure throughout the Strait, and coastal habitat modifications have altered nearshore biological communities. In addition, contaminants, particularly the concentrations of polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) in plankton and their transfer up the food web to accumulate in marine mammals, can have a long residence time in the Strait, although recent observations indicate they are presently stable or declining, largely as a result of regulatory actions.

Both large-scale processes, such as those related to the Southern Oscillation Index and the North Pacific Gyre Oscillation Index, and local processes related to winds and river discharge, were shown to be related to changes in the marine ecosystem of the Strait of Georgia.

Projections are available for how some of these stressors may change in the future. Among the anthropogenic stressors, it is foreseeable that the human, largely urban, population surrounding the Strait of Georgia will increase, and those pressures that are proportional to population growth are likely to increase. Rates of population growth to 2036 in the districts surrounding the Strait are projected to range from +20% to +30% on Vancouver Island and to over +40% in the lower mainland. Projections for change in some environmental processes can also be made, largely downscaled to the Strait of Georgia from coupled global climate models. These include continuation of the depth-averaged warming trend of 0.024 °C/yr that has been observed over the period 1970 to 2005, continuation of the offshore trend towards a later and shorter upwelling period, and modifications in the seasonal cycle of freshwater discharge (such as an earlier freshet), due to a warming climate. In addition, it is expected that the number of non-native species in the Strait of Georgia will rise due to increases in international shipping and successful establishment of potential seed populations in the Pacific U.S.

Tools for providing science advice in an ecosystem approach

Several tools and approaches to providing scientific advice on management issues within an ecosystem context were developed or expanded within this ERI. These include ecosystem assessments, statistical analyses of ecosystem data, probabilistic (Bayesian) networks, simulation models, and habitat models. A comparison of these tools, and guidance as to their ease of application, data needs, and limitations, is provided in Table 3.

Table 3. Selected tools for providing science advice in an ecosystem approach to the management of Pacific Region marine systems.

Tools	Ease of application	Data and resource needs	Limitations	Potential applications
Ecosystem assessments and overviews	Variable • straightforward application of available scientific information; becomes more complex depending on the availability of data	Variable • depends on what data are available, and where they are distributed	• limited by what data are available and where they reside (e.g. centralised, dispersed, community-based knowledge)	• State of the Ocean reports • Ecosystem Status and Trends reports • ecosystem risk assessments
Principal Components and Redundancy Analyses (statistical techniques)	Easy to moderate • depends on level of analysis and quality of data • many software packages are readily available	Simple to complex • depends on the analyses chosen and the quality of the data	• most require data with few missing values • longer series are preferred	• integrated ecosystem analyses • pathways of effects models • ecological risk assessments
Probabilistic (Bayesian) networks	Easy to apply once constructed • moderate to difficult to build depending on available data • key step is developing the model structure (compartments and linkages)	Flexible: simple to complex • can work with opinion of one expert, or many, up to detailed empirical data and model outputs	• generally not highly detailed • cannot include loops • poorly suited to modeling temporal dynamics • limited integration of variables with different time and space scales	• identification of key indicator variables, e.g. for stock or habitat assessments • exploration of alternative management scenarios • Integrated Fisheries Management Plans
Simulation models (e.g. ROMS; Nutrient-Phytoplankton-Zooplankton models; Ecopath with Ecosim and OSMOSE upper trophic level models)	Difficult • community platforms exist for some types of models, but much work is needed to adapt to specific applications	Large • significant needs for data to initialize and validate models • for upper trophic level models, data are often used for similar species but from other ecosystems	• computer power can be a limitation, • depending on the complexity and resolution • coupling models, e.g. from circulation to upper trophic levels, is usually complex	• simulations of alternative fishery management scenarios • habitat impact assessments (e.g. aquaculture siting) • assessment of forage fish policy applications
Habitat models (e.g. benthic and nearshore habitat classifications; identification of important benthic habitats for particular species)	Simple to complex • for habitat suitability models, simple if habitat preferences are known, appropriate data are available, and used in ArcGIS or similar platforms • complex if multiple data are required with different spatial detail and held by multiple agencies	Simple to complex, depending on objective • usually requires integrating data of different quality obtained from multiple sources	• limited by available data • spatial resolution often a problem (most models interpolate over large areas and miss fine spatial details) • incorporating temporal changes into spatial analyses is not easy • usually species specific; not easily applicable to multiple species	• habitat risk assessments • Integrated Fishery Management Plans • habitat suitability analyses

Considerations for an ecosystem approach to management in the Strait of Georgia

An essential step in the development of an ecosystem approach to management is identification of the objectives and goals. This determines what is to be achieved and what needs to be done to reach these goals. Setting ecosystem objectives should involve broad sectors of society; in the absence of clear objectives, goals relating to conservation of ecosystem structure (e.g. species), function, and production of ecosystem services are usually assumed. The interacting space and time scales also need to be considered when formulating objectives and providing advice to management within an ecosystem approach. For example, nearshore tidal flats may be affected by local coastal development but also by regional temperature trends. The findings contained in this Science Advisory Report therefore serve as examples of what could be considered when developing an ecosystem approach to management for the Strait of Georgia, in particular related to anthropogenic stressors, spatial management of nearshore and benthic habitats, and indicators and thresholds. Detailed findings of individual projects are being published in a dedicated issue of *Progress in Oceanography*; additional analyses which are currently ongoing will be published later.

How the Strait of Georgia marine ecosystem works, and the potential drivers of changes in this ecosystem, are described above (e.g. Table 1). Any stressor which interferes with the six characteristic processes has the potential to disrupt the functioning of the Strait of Georgia ecosystem, and therefore represents a potential concern for an ecosystem approach to management. Several specific examples of results related to particular stressors, which were found to have an influence on this ecosystem, are highlighted here.

<u>Anthropogenic stressors</u>

Fishing is an important stressor on the Strait of Georgia. Lower and upper trophic level ecosystem models were developed (Table 3), and used to assess potential ecosystem consequences of management actions involving fishing and stock rebuilding strategies. While further tuning of the models is necessary, results from one model suggest that a critical threshold for ecosystem overfishing, defined as abrupt changes to the structure and function of this system, caused by increased fishing on herring, could occur at fishing intensities which have been experienced in the past. The current fishing mortality for herring in the Strait of Georgia, however, appears to be well below this critical threshold. This model also suggests that the current productivity of the Strait may be lower than it was in the 1970s and 1980s, with the consequence that the recoveries of depleted populations may take longer than expected.

Other modeling studies suggest that, in general, a fisheries management strategy which is adjusted for the current productivity regime [e.g. heavier (lighter) fishing pressure during periods when there is higher (lower) productivity at the lower trophic levels] is likely to produce higher yields and have fewer years with fishery closures than when fishing is conducted at a constant but moderate intensity, without adjustments to match current system-wide productivity changes.

Non-native species are a concern for the Strait of Georgia. About three times the number of non-native species have been identified in the Strait than in other regions of the B.C. coast (Johannessen and McCarter, 2010). Reasons for this include the estuarine nature of this system which provides a variety of habitats and variable conditions, aquaculture activities which may introduce non-native species during the import of aquaculture seed stocks, and ocean shipping. Examining one potential vector for the introduction of non-native species, an ERI study concluded that transport vessels that are not required to exchange ballast waters *en route*, i.e. those originating north of Cape Blanco, Oregon, have the potential to introduce non-native species.

Nearshore/benthic habitats

Some nearshore and benthic areas with particular value to the ecosystem structure and function of the Strait of Georgia were identified. They provide examples of where, and why, spatial management approaches may be necessary to support a healthy ecosystem. The Roberts Bank area of the Fraser River delta is representative of many parts of the proposed Fraser River and Boundary Bay ecologically and biologically significant area (EBSA), and has been identified as an important feeding location for juvenile salmon and migrating shorebirds such as the western sandpiper (*Calidris mauri*). An ERI study of Roberts Bank identified the need to consider both local (e.g. port development) and regional (e.g. warming and sea level rise) scale stresses on this system when future human activities are considered.

The habitat suitability model developed by another ERI project identified potential habitats for Pacific sand lance in the Strait, an important small forage fish about which little is known. Suitable burying habitats for sand lance are patchy, and limited to about 6% of the area of the Strait of Georgia, with the largest patches located in the southern Strait adjacent to Roberts Bank and in the Haro Strait area. These areas may require enhanced management attention, in particular because sand lance are difficult to survey directly and thus few warnings may be apparent should population declines occur.

Indicators:

Indicators are essential to estimate how well the ecosystem objectives are being met. There are two general classes of indicators: environmental indicators of the present state of the ecosystem (e.g. temperature), and management indicators to assess the activities and conditions over which humans have some direct control (e.g. fishing effort). These latter are linked to management instruments and strategies. In addition, good indicators need to be easily measured, cost effective, and easily interpreted. The Strait of Georgia ERI did not conduct a comprehensive review and evaluation of all potential ecosystem indicators that might be proposed for this region. Such a review and evaluation is needed.

Several ERI studies did identify potential ecosystem-level indicators for specific management objectives. For shifts in productivity regimes, potential indicators include abiotic variables such as sea surface temperature, wind speed, the North Pacific Gyre Oscillation, and variables related to the human population surrounding the Strait of Georgia. Potential indicators of the early marine survival of coho salmon in the Strait of Georgia include calanoid copepod biomass, the anomaly of the zooplankton biomass, and the biomass of herring. For herring recruitment projections, the highest abundances of young of the year herring at the end of summer appear to occur when herring spawning begins about three weeks prior to the start of the spring bloom and ends approximately at the beginning of the bloom.

Sources of uncertainty

Although much has been learned about how the Strait of Georgia marine ecosystem functions and potential issues for management attention, many data and knowledge gaps persist. Many of these gaps can be broadly characterized into abiotic and biotic factors. Examples of abiotic factors include:

- interactions among the several processes by which water masses are replaced within the Strait, and the influences of changes in the characteristics of the source waters on these interactions and on the conditions in the Strait;
- influence of winds and freshwater on low-frequency changes in the productivity of the marine food web;
- relative impacts of average versus short term but intense events, such as long-term mean versus storm winds.

- foreshore development and the potential cumulative effects on shoreline and intertidal habitat.

Key uncertainties among biotic factors include:

- causes of high interannual variability among salmon stocks migrating through the Strait of Georgia, and whether the Strait is an important region in which this variability is generated;
- updating of the diets of pinnipeds feeding in the Strait
- clarification of recent trends in Pacific hake and walleye Pollock abundances and distributions, including possible changes in their diets as the body size of hake has decreased;
- confirmation of possible changes in the abundances of large lipid-rich and cold-water preferring copepods that have been key to the high spring productivity of the Strait, including assessment of the nutritional quality of these and other zooplankton that may be becoming more abundant.
- distribution of the different nearshore habitat types and species utilization and timing e.g. shoreline spawning distributions of forage fish.

The Strait of Georgia ERI supported the development of several types of modeling tools, including two alternative upper trophic level models. Although not sufficiently developed by the conclusion of the program to conduct a comparison of these models, such 'competing' models and formal comparisons of their outputs would advance understanding of such models, their sources of uncertainty, and the credibility of their results. In addition, probabilistic (Bayesian) network models are useful at identifying critical gaps in understanding of the mechanisms affecting species responses to multiple stressors. Spatially-explicit models for the Strait do not exist at present, but are urgently needed for a number of management concerns, e.g. relating to marine protected areas, aquaculture, and local habitat issues. In general, nearshore and benthic habitats, and their coupling to the overall functioning of this ecosystem, are poorly known, in particular at local scales.

Science support for an ecosystem approach to management requires a broad and extensive knowledge base, spread over many disciplines. As DFO scientists with experience of the Strait of Georgia ecosystem retire, there is a risk of increasing loss of knowledge of this system. In particular, important data on local habitats and on previous states of this ecosystem may still reside in the offices of individual researchers or be scattered among several institutions. There is a need for these data to be assembled and archived in forms available to promote an ecosystem approach to the Strait of Georgia.

CONCLUSIONS AND ADVICE

To explore different ways in which DFO Science might support the development of an ecosystem approach to management in waters under Federal jurisdiction, pilot Ecosystem Research Initiatives were initiated across Canada with funding provided from 2008-2012 as part of the five year science plan. This synthesis of the Strait of Georgia ERI presents an overview of what has been learned about the Strait of Georgia through these studies, which is considerable, while simultaneously highlighting how much is still not understood. It provides an overview of some of the key findings regarding the current understanding of how the Strait of Georgia marine ecosystem works, the drivers of change acting on the Strait and how some of these may influence the Strait in the next few decades. Important processes that govern how the Strait of Georgia marine ecosystem works, and what controls its productivity, are: enrichment, initiation (of plankton blooms), retention, concentration, trophic (food web) dynamics and nearshore/benthic dynamics, along with the linkages between the nearshore, pelagic and benthic zones. These key processes provide a context within which to evaluate the potential impacts of natural and anthropogenic changes and stressors on this system.

Several ecosystem-related science-based tools (including ecosystem assessments and several types of models) were developed to describe ecosystem processes and to assist with management decisions, and specific management considerations. Examples are given of management questions for which ERI tools and results can be used to provide greater understanding, and to identify issues that may warrant further attention. Several tools are sufficiently mature that they can be applied to all B.C. marine areas; for other tools, their complexity and extensive data needs may limit their application without extensive Science support.

Accessing sufficient and relevant data to conduct analyses within an ecosystem approach was a problem for the Strait of Georgia ERI, in particular for modeling and statistical analysis projects. As a consequence, many of these projects conducted their own “data archaeology” activities, and several projects were funded explicitly to assemble and make available dispersed historical data. Developing an ecosystem approach requires obtaining diverse data often from multiple institutions, for which at present there is no formal infrastructure or support.

The Strait of Georgia ERI did not conduct a comprehensive review and evaluation of potential ecosystem indicators for this region. However, several studies did identify potential ecosystem-level indicators for specific management objectives. To identify shifts in productivity regimes, potential indicators include abiotic variables such as sea surface temperature, wind speed, the North Pacific Gyre Oscillation, and variables related to the human population surrounding the Strait of Georgia. Additional variables were identified as indicators for particular ecosystem relationships (e.g. calanoid copepod biomass, anomaly of zooplankton biomass and herring biomass were found to be significant indicators of the early marine survival of coho salmon in the Strait of Georgia). However, it was noted that a more comprehensive process to identify and prioritize potential indicators and link these to specific management objectives is needed.

Some specific findings are highlighted in this synthesis. For example, a model analysis of the variability of biomass in the Strait of Georgia food web since 1960 suggests that the Strait may be currently in a low productivity regime compared with the 1960s to 1980s, possibly related to changes in environmental conditions. Consequently, depleted fish stocks may not be able to rebuild as quickly as they may have in the past. Studies also suggest a management policy that balances exploitation across middle to higher trophic levels produces higher overall yields with fewer periods of fishery closures. The ecosystem models developed can also be used to identify thresholds for individual species that could lead to ecosystem overfishing, i.e. beyond which the structure of the food web is seriously altered.

Another finding suggests that there is the potential for the introduction of non-native species into the Strait of Georgia from residual ballast waters, particularly from vessels operating exclusively between Cape Blanco and the Strait of Georgia, currently exempt from ballast water exchange.

Understanding the role of nearshore habitats both on local and strait-wide productivity was highlighted as relatively poorly understood and as requiring further investigation. A habitat-based spatial model was developed for the Strait to identify Pacific sand lance burrowing habitat, an important mid-trophic level species about which little is known. This finding highlights the potential to use this type of model to identify important habitat for other species (and their life history stages) and its relevance to spatial ecosystem management decisions.

The overall conclusion of this review is that results of the Strait of Georgia ERI can serve as the basis for exploring scenarios related to the management of both anthropogenic and non-anthropogenic stressors in the Strait of Georgia, and potentially be applied to other ecoregions in the Pacific Region. These findings and this review highlight that, to be of value to ecosystem managers and decision makers, identifying ecosystem objectives, and the relevant questions for Science advice, are critically important. This requires collaboration and communication between

Science and the various management sectors (fisheries, habitat, oceans, salmon enhancement, Species at Risk and aquaculture), iteratively throughout the process.

While not an exhaustive list, key recommendations from the review of the Synthesis of the Strait of Georgia ERI include:

Recommendations

1. To implement EAM, a process for collaboration and coordination among Sectors is necessary. A cross sector working group is recommended. This working group could also serve to interact with other Regions and other external initiatives.
2. For the Strait of Georgia and other areas, identify and prioritize potential indicators, including their data requirements, to meet the objectives of an ecosystem approach to management.
3. Consideration of productivity regimes and food web dynamics (predation and prey requirements) should be integrated into stock assessments, and inform other Departmental planning processes.
4. The nearshore zone in the Strait of Georgia, and elsewhere in the Pacific Region, is poorly described and its role in ecosystem processes is not well understood. To provide science advice with respect to value of this zone to ecosystem dynamics, including fish productivity, further study is necessary.
5. Ecosystem data are dispersed and in a variety of formats, making their collection and synthesis difficult; common platforms and formats for storage of these data are needed.
6. Tools developed through this process have broader applicability than just for the Strait of Georgia and could be considered for other areas in Pacific Region.

OTHER CONSIDERATIONS

Developing ecosystem approaches to managing marine systems is an active and current subject of research internationally. DFO can benefit from, and contribute to, these activities by facilitating discussions and collaborations with other agencies working in the Georgia Basin region. These include local university projects such as the Victoria Experimental Network Under the Sea (VENUS) run by the University of Victoria, and proposals from the Pacific Salmon Foundation for enhanced ecosystem studies of Pacific salmon in the Strait of Georgia. The Puget Sound Partnership is developing similar concepts to those described here; both activities would benefit from enhanced collaborations.

SOURCES OF INFORMATION

This Science Advisory Report is from the September 11-13, 2012 meeting on a synthesis of the outcomes from the Strait of Georgia Ecosystem Research Initative, and their ecosystem-based management and policy implications. Additional publications from this process will be posted as they become available on the Fisheries and Oceans Canada Science Advisory Schedule at www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

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