

ECOSYSTEM RESEARCH INITIATIVE (ERI)
Pacific Region – “The Strait of Georgia in 2030”

Research Plan

The Strait of Georgia is the focus of many resource management and scientific issues within the Pacific Region of Fisheries & Oceans Canada. Public perception and on-going work in the Strait of Georgia shows that this marine ecosystem is facing significant stresses and possible threats. It is likely that these will bring major changes in the Strait of Georgia, and management will benefit from advice that warns and explains these changes and their causal mechanisms in an ecosystem context.

The Strait of Georgia is different now than it was 50, even 25, years ago. The Strait has warmed by 1°C over the past 100 years, from which 0.3°C occurred within the past 25 years. The seasonal pattern and magnitude of the freshwater discharge from the Fraser River may be changing. Pacific hake now dominates the resident fish biomass in the Strait, contributing to the increase in seals (a major predator on hake). The coho and Chinook fisheries are at very low levels and survival of hatchery-reared individuals is poor. Conversely, abundances of pink, chum and sockeye salmon in watersheds that flow into the Strait are relatively high. Herring are at high abundances, but may be declining. Groundfish species such as Pacific cod that have traditionally been fished in the Strait of Georgia are today nearly absent. In contrast, invertebrate fisheries have been steadily increasing in volume and value.

What has driven these changes in the Strait of Georgia, what is causing present changes, and what will the Strait be like in the future? Will there be commercial and recreational fisheries, and if so likely for what species? What might be the ecosystem consequences of salmon production totally supported by hatcheries, versus no hatcheries at all? How do regime shifts affect the carrying capacity of the Strait? Will the Strait be able to continue to support non-consumptive activities such as whale watching?

The *Central Theme* of this Ecosystem Research Initiative is “The Strait of Georgia in 2030”, i.e. what might the Strait of Georgia be like in 2030. Responding to this challenge of *imagining the future*, or *constructing scenarios*, involves: 1) understanding how this ecosystem works, 2) identifying the various drivers of change most likely to determine future conditions, and finally 3) analyzing the future responses of the system under the influences of these drivers of change. The research conducted within this Initiative is designed to align with the Departmental goals of ensuring a healthy and productive aquatic ecosystem in the Strait of Georgia, and to support sustainable fisheries and aquaculture in the Strait.

DFO context

The priority areas of the 5 year DFO research agenda addressed by the initiative include Habitat and Population Linkages, Ecosystem Assessment and Management, Fish population and community productivity, and Climate Change/Variability.

The Centre for Ocean Model Development & Application (COMDA) Centre of Expertise (COE) will be particularly relevant to the initiative, given its focus on ocean modeling of climate impacts. There is a potential linkage with the invasive species COE (Centre of Expertise for Aquatic Risk Assessment [CEARA]), and with the Centre of Expertise in Marine Mammalogy [CEMAM] in regards to scenarios involving marine mammals (e.g. pinnipeds).

The department is in the process of establishing a Climate Change Science Initiative (CCSI) starting in next FY. There will be close coordination between the national CCSI and the Climate Change theme of the Pacific ERI. It is anticipated that the CCSI will include the development of climate change predictions and scenarios affecting Canada, which could be used along with projections of atmospheric and hydrological changes as inputs to the regional scenarios for the Pacific region. It is expected that the models being developed in the framework of the Pacific ERI will be used in the development of the scenarios and projected regional oceanic changes.

In addition, linkages with other regional ERIs will be pursued. Already, good contacts have been established with the Maritime and Newfoundland region ERIs whose plans share strong similarities with the Pacific.

Discussions are underway to establish linkages with the ERIs from other regions and with the proposed national CCSI.

Drivers of Change

The Strait of Georgia is experiencing several significant factors which singly and in combination potentially cause changes in the marine ecosystem. Many of these 'drivers of change' are expected to intensify with time, and new ones are likely to emerge. Present factors include:

- changes in climate:
 - global and local warming of air and sea temperatures
 - increasing frequency of ENSO and ENSO-like events
 - changes in freshwater discharge timing and magnitudes
 - increasing sea level, leading to decreased wetlands
 - increasing short-term variability, e.g. of storms, rainfall patterns
 - increasing hypoxia in certain locations
- increasing urbanization:
 - increasing contaminants – of both 'legacy' and 'emerging' chemicals
 - increasing 'hard edges', i.e. built-up foreshores rather than beaches, estuaries, wetlands

- changing social uses and values for the marine environment
- habitat destruction
- changes in species composition:
 - from ‘natural’ responses of species to changes in physical conditions (e.g. warmer temperatures)
 - ‘invasions’ of non-indigenous species
 - disturbed and degraded ecosystems
 - fishing mortality
- management actions:
 - fishing regulations
 - establishment of marine protected areas – their size, design, purpose
 - hatchery operations
 - aquaculture operations
 - recreational activities
 - transport corridors
- catastrophic events:
 - major oil spills
 - major earthquake
 - major slope failure of the Fraser delta
 - crossing ecosystem threshold limits or ‘tipping points’

Imagining the Strait of Georgia in 2030 (“Scenarios”)

Building on these ‘drivers of change’ leads to the development of alternative scenarios of future conditions in the Strait. This is an approach that was used successfully by the Millennium Ecosystem Assessment (www.millenniumassessment.org) and the European Lifestyles and Marine Ecosystems project (www.elme-eu.org). Scenarios are essentially representations of potential future conditions that can be used to highlight differences in particular features, processes, or decisions about how the system might work. They should never be interpreted as forecasts, but as tools to allow comparisons of policy options and ecosystem function. They should be constructed to provide very different views of a future world, in order to successfully explore the system consequences (e.g. see http://www.elme-eu.org/public/Results/p7_Scenarios.pdf for a European application). For example, two alternative scenarios might relate to hatchery production of salmon: one in which salmon production in the Strait of Georgia is supported almost entirely by hatcheries, the other in which salmon production comes totally from wild populations. What are the ecosystem consequences of these alternative scenarios? Are either of these sustainable if present warming trends continue as predicted? Potential scenarios for the Strait of Georgia could include:

- implementation of major marine protected areas, such that significant areas of the Strait of Georgia would have no fishing (and possibly other restricted uses);
- change in species composition, especially of commercial species, for example reductions in salmon, increases in jellyfish;
- changes to the Fraser River estuary due, for example, to sea level rise;
- continued warming, and the consequences of that, e.g. increased hypoxia;

- increased hatchery production, e.g. major outputs of salmon from hatcheries;
- implementation of nuclear power plants and the effects on the Strait of Georgia ecosystem of injections of warm water, and related water cooling issues;
- decrease of pinnipeds, e.g. from disease;
- effect on the marine ecosystem of a major catastrophic event such as an earthquake, followed by a major slump of the Fraser delta and generation of a tsunami within the Strait.

Central Questions

Many detailed and research-intensive hypotheses, or scenarios, could be developed to study the Strait of Georgia within this Ecosystem Research Initiative. With limited resources, however, this Research Initiative must focus on a few key hypotheses that are central to the functioning of the system and its future changes. Thirteen hypotheses (framed as processes to be studied and not as definitive statements) are listed below and grouped under three main questions relating to: productivity, timing and resilience. Additional hypotheses and research by other groups are anticipated and could be appended to these DFO studies in a collaborative fashion in order to expand the questions and tools of this program.

Research Question 1.

Productivity: What controls the productivity of the Strait of Georgia?

What controls the productivity of the Strait of Georgia – at all trophic levels – and how this productivity is likely to be impacted by those factors which are driving changes in the Strait, are key questions for assessing the current and potential future states of the Strait. What controls the production of plankton, and how is this transferred up the food web to fish and higher trophic levels? Six hypotheses are proposed under this research question:

Hypotheses:

1. The advection of nutrient-rich deep water into the Strait ‘primes the production pump’ and is the key to the productivity of the Strait. This advection is affected by processes controlling the estuarine circulation of the Strait such as the characteristics of the deep source waters on the continental shelf west of Vancouver Island, the vertical stratification, and tidal and wind mixing.
2. Transfers of this production to higher trophic levels are mediated by the species composition of the phytoplankton – diatoms, flagellates, harmful algal blooms. Specific locations (“hot spots”) such as tidal mixing fronts and other features are significant to the productivity of the Strait and to food web transfers, in particular outside of the spring bloom period. The locations of these features may not shift over time (because they are topographically-fixed) but their use by different species and their related vulnerabilities may change, affecting the functioning of the entire system.
3. Growth and survival of higher trophic levels is determined by both the quality and availability of the lower trophic levels (“junk food hypothesis”). Food quality is

- determined by the chemical composition of prey species assemblages and their growing conditions.
4. The types of higher trophic level species that are supported by this production is determined by the cycling of plankton production within the pelagic or demersal food webs. For example, why are seals, Pacific hake, herring, and some salmon species doing well currently whereas groundfish species are not?
 5. Contaminants are major constraint on the productivity and abundance of higher trophic level species.
 6. Fishing has a significant overall negative effect on the productivity of the Strait of Georgia ecosystem.

Research Question 2.

Timing: How important are mismatches in the timing of physical and biological processes within the Strait of Georgia to ecosystem functioning?

Issues of timing are likely to be central to the changes that have taken place and which may take place within the Strait of Georgia marine ecosystem. This ecosystem may be keyed to timing matches in multiple processes; what happens when such timing is mismatched? Seasonality is a critical element for a number of physical and biological processes. Critical timing processes include:

- timing and amounts of freshwater runoff into the Strait
- timing of transitions between upwelling/downwelling seasons on the shelf west of Vancouver Island
- timing and intensity of wind mixing (storms)
- timing of phytoplankton blooms
- zooplankton life cycle timing
- timing of ocean entry of salmon and routes of fish migrations
- release timing of salmonids from hatcheries

Four hypotheses are proposed under this research question:

Hypotheses:

7. The amount and properties of the nutrient-rich shelf water entering the Strait as subsurface intrusions strongly depends on the strength of the estuarine circulation as well as the intensity of the upwelling/downwelling on the shelf. A change in the timing of the spring freshet in relation to the spring transition of the coastal winds and/or the establishment of the seasonal near surface stratification within the strait could have a potentially strong impact on the nutrient supply to the euphotic zone of the strait.
8. Warming and changes in winds and river flow patterns advance the spring plankton production cycle, leading to reduced production later in the spring at times when juvenile salmonids enter the Strait of Georgia (either from rivers or hatcheries), resulting in reduced growth and survival of these salmon.
9. Processes which improve the match and/or increase the duration of this production period favour improved salmon growth during their early ocean period. Salmon which grow rapidly earlier in the year have greater energy

- reserves to survive their first winter, leading to improved survival to the adult return stage.
10. Coho and Chinook enter the Strait of Georgia later in the year than other species of salmon, and therefore enter an ecosystem which is more variable in its productivity and with greater competition for food from herring, hake and other species of salmon. This has resulted in more variability and recent decreased abundances of coho and Chinook salmon in the Strait.

Research Question 3.

Ecosystem Resilience: What properties/characteristics of the Strait of Georgia ecosystem provide resilience against major disruptions and collapses of the system?

A theme running through international assessments, such as the Millennium Ecosystem Assessment (www.millenniumassessment.org), the Intergovernmental Panel on Climate Change (www.ipcc.ch), and the PICES report on marine ecosystems of the North Pacific (http://www.pices.int/publications/special_publications/NPESR/2005/npesr_2005.aspx) is that of ecosystem resilience (and vulnerability) to changes. Cumulative effects of multiple stressors, or one single catastrophic event, may alter the state or the resilience of the local ecosystem. For example, how much warming (or other stresses or their combinations) can the Strait absorb and still retain the same ecosystem structure and function? If the system changes to alternative states/regimes, how rapidly does this occur and what might be the warning signals? What system characteristics would lead to increased resilience to external stresses? Would a shift from wild harvest of salmon to aquaculture increase or decrease the resilience of the Strait of Georgia marine ecosystem? Three hypotheses are proposed under this research question:

Hypotheses:

11. Because of its current altered conditions, the Strait of Georgia has reduced resilience (increased vulnerability) to external stressors.
12. As a consequence of transport mechanisms associated with the estuarine circulation, the subsurface waters of the strait have been warming faster than the offshore ocean. This increased warming rate which is observed at depth in the Strait indicates an increasing vulnerability to global climatic changes.
13. One major catastrophic event, such as a major tsunami or a large slope failure of the Fraser delta could significantly affect the bottom and/or nearshore habitats and cause irreversible changes in the ecosystem of the Strait.

Key Products

The outcomes of this Initiative will include several key products:

1. Rapid assessment

An assessment of the current state of the marine ecosystem of the Strait of Georgia will be conducted. It will identify present conditions, how they differ from past conditions, and the drivers or stressors that have caused the Strait to change over the

past decades. A potential list of upper trophic level taxa for inclusion into this assessment is presented in Table 1. In addition to these fish stock assessments, the ecosystem assessment will include indicators of ecosystem status and trends based on the physical environment, lower trophic level productivity and composition, and non-harvest anthropogenic and socio-economic variables. A sample product is that for the Eastern Scotian Shelf by Frank and co-authors (DFO, 2003. State of the Eastern Scotian Shelf Ecosystem. DFO Can. Sci. Advis. Sec. Ecosystem Status Rep. 2003/004; http://www.dfo-mpo.gc.ca/csas/Csas/status/2003/ESR2003_004_e.pdf).

2. *Detailed assessment*

Detailed in-depth review of literature and current conditions, plus comparisons with similar systems elsewhere (e.g. possibly the Baltic Sea, Black Sea, Seto Inland Sea, and Chiloé Inland sea/archipelago). This will include background descriptions of the geological and socio-economic environments as well as speculations on potential future conditions.

3. *Models*

Statistical and mechanistic coupled bio-physical models describing how the Strait of Georgia is structured, how it functions, and how it responds to stresses and external forcing, will be a key output of this Initiative. These models can be used to examine hypotheses, to explore the consequences of management decisions and policy options, and to speculate on future scenarios for the Strait of Georgia marine ecosystem. They ultimately must include fish and other higher trophic levels, although it is recognized that initially separate models may be developed for the lower and upper trophic levels.

4. *Identification of critical areas and locations (“hotpots”)*

Not all locations within the Strait of Georgia are critical for the functioning of its marine ecosystem, although every location will be important in some way for at least one species or process. A smaller set of areas or locations is likely to have significant impacts on the structure and function of the ecosystem (“Ecologically and Biologically Significant Areas”). Critical areas and locations may also include sites of significant physical-biological interaction and/or sites which receive an inordinate amount of stress whose effects are felt beyond the site of the initial stress. These areas and locations need to be identified and highlighted for potential ‘special management concern’; they may also be significant locations which influence the resilience of the Strait of Georgia marine ecosystem to significant stressors. The design and evaluation of the effectiveness of marine protected areas in the Strait of Georgia is an important topic for research in this context.

5. *Development of ecosystem indicators for the Strait of Georgia*

Ecosystem indicators are key tools for the management of aquatic ecosystems. They can be used to assess the status of an ecosystem, its sub-components and the impacts of human activities. In addition, ecosystem indicators can be used to assess the social and economic benefits derived from ecosystem use. As outcomes from the rapid, and

detailed, assessments and the modeling activities, ecosystem indicators will be developed for the Strait of Georgia.

6. *Decision support tools*

The Strait of Georgia Ecosystem Research Initiative must provide a scientific basis for evaluating the potential outcomes of management decisions. The data, models, analyses and reports of the Initiative will assist with this, but a formal set of decision support tools will be useful. Such tools may also be useful to identify pathways and indicators leading to successful implementation of ecosystem objectives for management of the Strait of Georgia.

7. *Scenarios of potential alternative futures for the Strait of Georgia*

Exploring the various hypotheses listed above will provide the necessary knowledge to elaborate plausible scenarios for the future of the Strait of Georgia. These scenarios can be based on projections from models, or on narratives, or their combination. Such scenarios should include predictions of potential future climate conditions for the Strait of Georgia downscaled from IPCC climate models. They will provide a basis for exploring the ecosystem consequences of various policy options that may be proposed for the Strait of Georgia.

8. *Scientific legacy.*

There will be regular contributions of papers and reports to the scientific literature during the course of this Initiative, providing and synthesizing a substantial knowledge base on the Strait of Georgia marine ecosystem.

Initial Approach

The initial approach of the Strait of Georgia Ecosystem Research Initiative to reach these objectives and products will comprise the following elements:

- *Web site development.* A web site is essential for maintaining the integrity of the project and for smooth communication amongst project participants. It will be used to post announcements, findings, data, results, etc. At least parts of it should be open to the public to give visibility to the project and to facilitate interactions with non-DFO collaborators.
- *Bibliographic data base.* The project will need to be aware of previous research and interpretations of the Strait of Georgia. A bibliographic data base needs to be developed with references to as much information published about the Strait of Georgia as possible
- *Data recovery and database development.* The project critically needs to identify and assemble all relevant data for the Strait of Georgia marine ecosystem. There

- are considerable data, at least for some ecosystem components such as zooplankton, which are scattered among old records and different institutions and investigators about the Strait of Georgia. Relevant data sources need to be identified and a meta-database developed with pointers to what data exist where, including non-DFO data holders. Where possible, data sets need to be developed which assemble and integrate data into common databases, using the protocols of the National Science Directors Data Management Committee (NSDMC), so that these are readily accessible to the ecosystem models.
- *Model and decision support tool development.* Physical oceanographic, fisheries oceanographic, and coupled ecosystem model development needs to begin immediately. A promising model platform in use along the western coast of North America and elsewhere, for which considerable developmental work has been completed, is the ROMS approach (Regional Ocean Modeling System; www.myroms.org). Other modeling approaches would permit comparisons among model outputs and assessments of ‘uncertainties’ due to model structures. The integration of physical oceanographic and lower trophic level models with fish and upper trophic level models is an area of active scientific research worldwide. Initial modeling work may need to be done separately, but ultimately the intention is for these models to be fully coupled. Development of decision support tools, perhaps using Bayesian and/or fuzzy-logic type approaches, may also need to begin early in the project.
 - *Field programs.* The initial emphasis for funding is to be placed on data synthesis and development of integrating models for exploration of the central hypotheses. In order to continue key time series, rather limited support will be available for on-going monitoring programs in the Strait of Georgia. There is likely to be some consideration of new field sampling programs if they are focused on comparing results with sampling programs that were active several years to decades previously (for longer-term comparisons). Later in the program, targeted field studies to determine key unknowns deriving from the modeling and data synthesis activities will become important.
 - *Workshops for exploring scenarios.* Once reasonable skill has been achieved with modeling and understanding how the marine ecosystem of the Strait of Georgia is structured and how it functions, scenarios of potential future conditions and/or policy options for the Strait will be developed and explored, likely using a workshop approach. Although the concept of “The Strait of Georgia in 2030” is a central theme designed to capture the imagination, rigorous exploration of potential future conditions will become prominent in later years of the Initiative.
 - *Collaborations with outside partners.* The Strait of Georgia Ecosystem Research Initiative is expected to generate considerable interest from groups and agencies with expertise in the Strait of Georgia but who are outside of DFO. This will help to expand the Initiative into locations and issues which DFO is unable to address, using the DFO activities as an integrating “backbone” or framework. One such activity should include analyses of the socio-economic changes that the Georgia Basin system has undergone over the past several decades, with projections into the future (to 2030).

Spatial and Temporal Domain

Spatial domain:

- Johnstone Strait to mouth of Juan de Fuca Strait
- Puget Sound and the watersheds of the Strait of Georgia will not be a major focus of this Initiative, but could be included in some projects which take a comparative (or upstream, in the case of watersheds) approach.

Temporal domain:

- historical – extent of available data / information
- projections – to 2030, recognising different scales of seasonal, interannual and decadal variability

Timeline

2008	2009	2010	2011	2012
Project start-up; initial data 'rescue' & compilation; initial model development ; monitoring programs; interactions with non-DFO groups	Publication of rapid assessment; bio-physical model coupling; targeted field programs started; decision support tools	Completion of detailed assessment; testing of productivity, timing and resilience hypotheses; critical locations determined; scenarios developed	Continue testing of key hypotheses; field work and integration into models; decision support tools operational; scenarios explored	Project completion

2007/08 Funding allocation process

For internal DFO funding, a competitive process will be held involving a short (1-2 page) proposal (see attached template). These proposals will be assessed by the Project Management Team. The proposals must focus on the Key Products of this Initiative, taking into account the Central Questions and Initial Approach as outlined in this Research Plan. Group proposals are encouraged in which the work involves various individuals combining their expertise. Use of this funding will need to meet the usual DFO requirements for staffing, contracting, etc. Funding will be in one year packages (fiscal year), consistent with DFO policies. A short written report on progress will be expected every six months, with a Program workshop held once each year.

Participants are encouraged to collaborate (as appropriate) with non-DFO partners so as to combine funding and expertise regarding the Strait of Georgia ecosystem.

Table 1. Example of upper trophic level taxa that may be considered in the Rapid Assessment of status and trends of the Strait of Georgia marine ecosystem. Key data for each might include abundance, size-at-age, distributions (spatial and temporal), diets, and growth dynamics. Note that some species may cross several boundaries/ecosystems during their life cycles, and may migrate outside the Strait of Georgia on a seasonal time scale to feed, grow, or reproduce.

Estuary	Nearshore (<30 m)	Benthic	Small pelagics	Micronekton/small mesopelagics	Groundfish	Large pelagics	Predators
salmon (juveniles)	bivalves	shrimp & prawn	herring	<i>Leuroglossus</i> sp.	rockfish	Pacific hake	seals
cottids		crabs	sandlance	myctophids	lingcod	Pollock	sea lions
eulachon		octopus	capelin	planktonic shrimps and euphausiids	Pacific cod	dogfish	killer whales
			smelts		flatfishes	salmon adults	seabirds
			juvenile salmon		halibut		water and shore birds

Project proposal for 2007/2008

(two pages only- additional information will not be considered by the Committee)

Project Title:

Proponents names:

Affiliation:

E-mail address:

Phone:

Fax:

Amount requested: \$

Project Location:

1. Context:

2. Overview and approach:

3. Objectives:

4. Correspondence with SoG_ERI Hypotheses:

5. Deliverables (relate to *Key Products*):

6. Budget:

7. Possible extension of work past this fiscal year: