Understanding ecosystem structure, function, and change in the Strait of Georgia, Canada: A human-dominated marine ecosystem

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Strait of Georgia

A human-dominated system

Area = 6,800 km²

Human population about 3 million

Killer whale population about 100
Straits of Georgia Ecosystem Research Initiative (2008-2012)

Main themes: Understanding the ecosystem and the management of human interactions in an *integrative framework*:

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

3) Developing science-based management and decision-making tools to support healthy and sustainable marine resources

PICES FUTURE Program themes:

1. What determines an ecosystem’s intrinsic resilience and vulnerability to natural and anthropogenic forcing?

2. How do ecosystems respond to natural and anthropogenic forcing, and how might they change in the future?

3. How do human activities affect coastal ecosystems and how are societies affected by changes in these ecosystems?
STRAIT OF GEORGIA ECOSYSTEM RESEARCH INITIATIVE: AN OVERVIEW

DATA ANALYSIS
- Bottom type
- Zooplankton data
- Satellite imagery
- Bibliography
- Cetacean diets
- Forage species distribution
- Radar winds
- Contaminants in seals
- Salmon: abundance, distribution, timing

NUMERICAL MODELS & ECOSYSTEM INDICATORS
- ROMS/physical
- ROMS/NPZD
- OSMOSE
- ECOPATH
- Ecosystem indicators

FIELD WORK
- Seal tagging/survey
- Salmon/acoustic tags
- Salmon prey quality
- Herring+halibut/acoustic survey
- Moorings/short-term events
- Sediment/water exchanges
The Strait of Georgia is changing

- Strait has warmed by 1°C in past 100 years
- Seasonal pattern and magnitude of Fraser River discharge changing
- Pink and Chum salmon are at high abundances; Coho and Chinook are low; Sockeye is declining but variable
- Herring at high abundances, but recent declines
- Some semi-demersal species at high abundances (e.g. Pacific hake)
- Other demersal species at low abundances (e.g. Pacific cod, rockfish)
- Seals are at high abundances
How the Strait of Georgia marine ecosystem ‘works’

6 general processes:

- Enrichment
- \textbf{Initiation} (of plankton blooms)
- Retention
- Concentration
- Trophic (food web) dynamics
- Nearshore/benthic (habitat) dynamics
How the Strait of Georgia marine ecosystem ‘works’

Initiation

Processes that initiate phytoplankton blooms in the Strait of Georgia

- interactions of wind and tidal mixing with surface heating and freshwater and the amount of light received by phytoplankton cells
  - model suggest timing of Spring bloom controlled mostly by local winds, secondarily by cloud cover (Collins et al., 2009)
  - long term mean date of Spring bloom = 25 March (about yearday 85), but can vary by up to 6 weeks (Collins et al., 2009)

- peak bloom date is estimated to have varied with about decadal periodicity: later in 1970s and 2000s, earlier in 1990s (Allen and Wolfe)

- interannual variability of bloom date has increased
How the Strait of Georgia marine ecosystem ‘works’

Modeled Spring bloom timing

Date of spring bloom peak

Year


March

April

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Zooplankton

Variability since 1990 related to large- and local-scale processes:

• Large-scale: North Pacific Gyre Oscillation (NPGO) (positive correlation)
• Local-scale: temperature anomalies through water column (negative)

Processes appear related to exchange with outer coast zooplankton populations, and changes in timing of life history events in the Strait (phenology)

Zooplankton variations related positively (but weakly) with survival anomalies of salmon and herring in the Strait of Georgia

Mackas et al.
How the Strait of Georgia marine ecosystem ‘works’
Trophic (food web) dynamics

EwE model food web for the Strait of Georgia for 2009

Pelagic-sourced food web

Benthic-sourced

Preikshot et al.

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How the Strait of Georgia marine ecosystem ‘works’

Primary production ‘anomaly’ back-calculated from the EwE model, and spring-summer winds at Vancouver airport

Declining productivity of the SofG since 1990?

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Drivers of change acting on the Strait of Georgia

<table>
<thead>
<tr>
<th>Drivers &amp; Pressures</th>
<th>States &amp; Impacts</th>
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</thead>
<tbody>
<tr>
<td><strong>Natural</strong></td>
<td></td>
</tr>
<tr>
<td>Northern Oscillation Index (NOI; annual)</td>
<td>Spring phytoplankton bloom start date (modelled)</td>
</tr>
<tr>
<td>Oceanic Niño Index (ONI; annual)</td>
<td>Sockeye salmon marine survival (Chilko Lake)</td>
</tr>
<tr>
<td>Pacific Decadal Oscillation (PDO; annual)</td>
<td>Herring (number at age 3)</td>
</tr>
<tr>
<td>North Pacific Gyre Oscillation (NPGO; annual)</td>
<td>Herring (spawning biomass)</td>
</tr>
<tr>
<td>Wind speed (Vancouver airport; annual)</td>
<td>Sockeye salmon (returns to Fraser River)</td>
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<tr>
<td>Air temperature (Vancouver airport; annual mean)</td>
<td>Pink salmon (escapement, excluding Fraser River)</td>
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<tr>
<td>Precipitation (Vancouver airport; annual sum)</td>
<td>Chum salmon (returns to Fraser River)</td>
</tr>
<tr>
<td>Sea surface temperature (SST: Entrance Is., annual)</td>
<td>Harbour seals (annual number)</td>
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<tr>
<td>Sea surface salinity (SSS; Entrance Is., annual)</td>
<td>Killer whales (residents, annual number)</td>
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<tr>
<td>Fraser River flow (volume, annual)</td>
<td>Seabirds – demersal feeding (Christmas Bird Count)</td>
</tr>
<tr>
<td>pH (annual modal values)</td>
<td>Seabirds – pelagic feeding (Christmas Bird Count)</td>
</tr>
<tr>
<td><strong>Human</strong></td>
<td></td>
</tr>
<tr>
<td>Chinook (number of hatchery releases)</td>
<td>Herring (commercial catch)</td>
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<tr>
<td>Coho (number of hatchery releases)</td>
<td>Flatfish (commercial catch)</td>
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<tr>
<td>Recreational fishing effort</td>
<td>Pacific cod (commercial catch)</td>
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<tr>
<td>Human population (of Regional Districts around the Strait)</td>
<td>Lingcod (commercial catch)</td>
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<tr>
<td></td>
<td>Pacific hake (commercial catch)</td>
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<td>Dogfish (commercial catch)</td>
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<td>Total commercial fish catch</td>
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<td></td>
<td>Total pelagic fish catch</td>
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<td></td>
<td>Total demersal fish catch</td>
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<tr>
<td></td>
<td>Chinook salmon recreational catch</td>
</tr>
<tr>
<td></td>
<td>Coho salmon recreational catch</td>
</tr>
</tbody>
</table>

15 natural and human Driver & Pressure (explanatory) variables examined for statistical relationships with 22 State & Impact (response) variables for the Strait of Georgia, 1970-2010

Explanatory variables identified to be statistically significant (using redundancy analysis) were:
- sea surface temperature,
- wind speed,
- North Pacific Gyre Oscillation;
- human population,
- recreational fishing effort,
- number of Chinook salmon released from hatcheries

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These six variables describe the regime-like behaviour of the Strait of Georgia since 1970.
Variance of State & Impact variables partitioned among Natural and Human Drivers

Natural and Human Drivers combined

Residual=0.27

Natural Drivers

Human Drivers

0.04

0.53

0.16
Considerations for management within an Ecosystem Approach - Indicator for early survival of herring in Strait of Georgia

Relationships between herring and spring phytoplankton bloom:
• highest abundances of young of the year herring in September occur when herring spawning begins about three weeks prior to the start of the spring bloom and ends about the beginning of the bloom

Symbols and lines represent two different models for the timing of the Spring bloom

Schweigert et al.

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Considerations for management within an EAM
Indicators for early marine survival of coho salmon in SofG

Araujo et al.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Diagnostic Value</th>
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</thead>
<tbody>
<tr>
<td>Zooplankton biomass anomaly</td>
<td>0.212</td>
</tr>
<tr>
<td>Calanoid copepod biomass</td>
<td>0.083</td>
</tr>
<tr>
<td>Herring biomass (pre-fishery)</td>
<td>0.073</td>
</tr>
<tr>
<td>Water temperature</td>
<td>0.056</td>
</tr>
<tr>
<td>Fraser peak discharge time</td>
<td>0.043</td>
</tr>
<tr>
<td>Euphausiid biomass</td>
<td>0.032</td>
</tr>
<tr>
<td>ENSO</td>
<td>0.029</td>
</tr>
<tr>
<td>PDO</td>
<td>0.021</td>
</tr>
<tr>
<td>Log spring bloom time</td>
<td>0.006</td>
</tr>
</tbody>
</table>

Bayesian network model

The 3 best indicators of coho early marine survival:
- zooplankton biomass anomaly,
- calanoid copepod biomass,
- biomass of herring

To maximise survival of hatchery coho and minimise negative impacts on wild coho, release hatchery coho during favourable ocean conditions (negative PDO and ENSO)

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Considerations for management within an EAM
Identifying Ecosystem Overfishing thresholds

Fishing

- use of the SofG Ecopath with Ecosim (EwE) model to explore thresholds for ‘ecosystem overfishing’
  - ecosystems considered overfished when cumulative catches cause, e.g.:
    - biomasses declines of one or more important species;
    - changes in species composition or population demographics;
    - harvests of prey species impair the long-term viability of ecologically important, non-resource species (e.g., marine mammals, seabirds)
  - run EwE model with successively greater fishing mortalities and determine the fishing mortality which causes marked changes in key ecosystem properties
    - e.g. run model 1960 to 2010 with increased fishing pressure applied to herring
Considerations for management within an EAM
Ecosystem responses to increased fishing on herring

Marked changes in ecosystem characteristics occur when instantaneous fishing mortality on herring is about 1. This is the level of fishing that occurred in the late 1960s, just prior to the collapse of the stock. Current fishing on herring is well below this threshold.

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Into the future - (some) predictability due to large-scale and local influences

NE Pacific variability drives low frequency variability in Strait of Georgia temperature (large scale effect)

Fraser River flow drives Sea Surface Salinity anomalies in the Strait of Georgia (local scale effect)

Depth averaged temperature anomaly in SofG (blue); 10-50m temperature anomaly on Line P (red)

Strait of Georgia salinity and Fraser runoff (Morrison et al. 2011)

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Into the future

Climatic factors

• expect continuation of observed 1970-2005 depth-averaged warming of 0.024 °C/yr

• start of upwelling off the west coast of Vancouver Island has been occurring later over the past 5 decades and the duration of the upwelling season has become shorter (Foreman et al., 2011)

• expect modifications of the freshwater discharge seasonal cycle, such as an earlier freshet, due to a warming climate (Morrison et al., 2002)

Potential to explore ecosystem impacts of biological scenarios:

• reappearance of humpback whales

• groundfish: recovery at last

• salmon: species specific responses to climate change

Akenhead et al.
Harbor seals reveal an improving trend in the quality of the Salish Sea food web, as depicted by declining levels of PCBs and other persistent contaminants.

But flame retardants (PBDEs) have been increasing.
Governance

With the pressures on the Strait of Georgia, it has become:

- increasingly dominated by human impacts, although environmental (climate-related) changes remain important
  - climate likely dominates inter-annual variability
  - climate and human impacts force decadal and longer variability

- increasingly dominated by pelagic species, although benthic invertebrates appear to be within historic ranges

- different now than 30-50 years ago

- low abundances of some salmon:
  - salmon are culturally important/symbolic; they are perceived by many people to reflect the “health” of the ecosystem
    ➢ Cohen Commission
Conclusions

Strait of Georgia is changing and will continue to change

Whether these changes are “bad” depends on how they compare to desired outcomes for the Strait

Goal should be to retain the natural ability of the Strait to adjust to, and recover from, changes – i.e. to retain the resilience of the Strait

Elements of an ecosystem approach to managing human interactions with the Strait of Georgia as studied by this Ecosystem Research program:

• identifying anthropogenic stressors, and how the Strait “works”
• comprehensive monitoring
• developing indicators (of ecosystem ‘health’, and for management)
• identifying thresholds
• tools for ecosystem assessments (e.g. different ecosystem models)
• spatial management (pelagic, benthic, nearshore habitats)
• data management
• identifying and resolving (some) knowledge gaps

(DFO CSAS SAR 2011/75)
Participants


www-sci.pac.dfo-mpo.gc.ca/sogeri/default_e.htm

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