An integrated analysis of the marine social-ecological system of the Strait of Georgia over the past four decades, and development of a regime shift index

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i) develop a Driver-Pressure-State-Impact-Response framework for the Strait of Georgia marine social-ecological system;

ii) use this framework in a structured approach to begin identifying a core set of indicators of ecosystem state and ecosystem responses to drivers and pressures in the Strait of Georgia;

iii) develop an approach to use these indicators to assess and integrate impacts and changes in the Strait
Variables included in analyses (with <4 missing years from 1970-2009):  

<table>
<thead>
<tr>
<th>Drivers &amp; Pressures</th>
<th>States &amp; Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOI (annual)</td>
<td>Bloom start date (modelled)</td>
</tr>
<tr>
<td>ONI (annual) – Nino Index</td>
<td>Sockeye marine survival (Chilko Lk)</td>
</tr>
<tr>
<td>PDO (annual)</td>
<td>Herring (number at age 3)</td>
</tr>
<tr>
<td>NPGO (annual)</td>
<td>Herring (spawning biomass)</td>
</tr>
<tr>
<td>Wind (YVR annual)</td>
<td>Sockeye (returns to Fraser R.)</td>
</tr>
<tr>
<td>YVR (air temp, annual mean)</td>
<td>Pink (escapement, excluding FR)</td>
</tr>
<tr>
<td>YVR (precip., annual sum)</td>
<td>Chum (returns to Fraser R.)</td>
</tr>
<tr>
<td>SST (Entrance Is., annual)</td>
<td>Seals (annual number)</td>
</tr>
<tr>
<td>SSS (Entrance Is., annual)</td>
<td>Killer whales (residents, annual #)</td>
</tr>
<tr>
<td>Fraser R. (flow vol, 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>Chinook (hatchery releases)</td>
<td>Herring (catch)</td>
</tr>
<tr>
<td>Coho (hatchery releases)</td>
<td>Flatfish (catch)</td>
</tr>
<tr>
<td>Recreational effort</td>
<td>Pacific cod (catch)</td>
</tr>
<tr>
<td>Human population (of Regional Districts around the SofG)</td>
<td>Lingcod (catch)</td>
</tr>
<tr>
<td></td>
<td>Pacific hake (catch)</td>
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<tr>
<td></td>
<td>Dogfish (catch)</td>
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<td></td>
<td>Total fish catch</td>
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<td></td>
<td>Total pelagic catch</td>
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<tr>
<td></td>
<td>Total demersal catch</td>
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<tr>
<td></td>
<td>Chinook catch (recreational)</td>
</tr>
<tr>
<td></td>
<td>Coho catch (recreational)</td>
</tr>
</tbody>
</table>

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Killer whale – Chinook workshop, 14 March 2012, Vancouver
## Drivers & Pressures:

**Natural:**
- NOI (annual)
- ONI (annual) – Nino Index
- PDO (annual)
- NPGO (annual)
- Wind (YVR annual)
- YVR (air temp, annual mean)
- YVR (precip., annual sum)
- SST (Entrance Is., annual)
- SSS (Entrance Is., annual)
- Fraser R. (flow vol, annual)
- pH (annual modal values)

**Human:**
- Chinook (hatchery releases)
- Coho (hatchery releases)
- Recreational effort
- Human population (Strait of Georgia)

## States & Impacts:

**Natural:**
- Bloom start date (modelled)
- Sockeye marine survival (Chilko Lk)
- Herring (number at age 3)
- Herring (spawning biomass)
- Sockeye (returns to Fraser R.)
- Pink (escapement, excluding FR)
- Chum (returns to Fraser R.)
- Seals (annual number)
- Killer whales (residents, annual #)
- Seabirds – demersal feeding
- Seabirds – pelagic feeding

**Human:**
- Herring (catch)
- Flatfish (catch)
- Pacific cod (catch)
- Lingcod (catch)
- Pacific hake (catch)
- Dogfish (catch)
- Total fish catch
- Total pelagic catch
- Total demersal catch
- Chinook catch (recreational)
- Coho catch (recreational)

## Redundancy Analysis

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Dependent variables</th>
<th>R² adj</th>
<th>Significance of model</th>
<th>Prop’n of total variance accounted by all RDA axes</th>
</tr>
</thead>
<tbody>
<tr>
<td>All drivers and pressures</td>
<td>States and Impacts</td>
<td>0.72</td>
<td>0.001</td>
<td>0.84</td>
</tr>
<tr>
<td>Natural and Human ‘parsimonious’ drivers and pressures:</td>
<td>States and Impacts</td>
<td>0.67</td>
<td>0.001</td>
<td>0.73</td>
</tr>
<tr>
<td>SST (Entrance Island),</td>
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<tr>
<td>Wind (YVR, annual mean),</td>
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<tr>
<td>NPGO (annual mean)</td>
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<tr>
<td>Population,</td>
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<tr>
<td>Recreational fishing effort (annual),</td>
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<tr>
<td>Hatchery releases of Chinook</td>
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</tbody>
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'Parsimonious' RDA (Scaling=0

RDA Axis 1, 66% of total variance

RDA Axis 2, 6% of total variance

1971-1984


Identification of significant change in time series

'Parsimonious' RDA 1

Year

RDA Axis 1 scores


'Parsimonious' RDA 2

Year

RDA Axis 2 scores


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Killer whales

Number of resident killer whales

Year


Regime shift years

Regime shift years
Harbour seals

![Graph showing Harbour seals with regime shift years highlighted between 1990 and 1995.](image)

**Year**

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Bayesian Network Model to predict regime shifts/changes in ecosystem structure based on the ‘parsimonious’ RDA analyses

Natural Drivers

SST
Wind (YVR)
NPGO

Human Drivers

Hatchery releases of Chinook
Recreational Effort
Popn

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Identification of significant changes in time series of:

RDA 1 and 2 of the States and Impacts (dependent variables)

‘Parsimonious’ natural and human explanatory variables (dependent variables)