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

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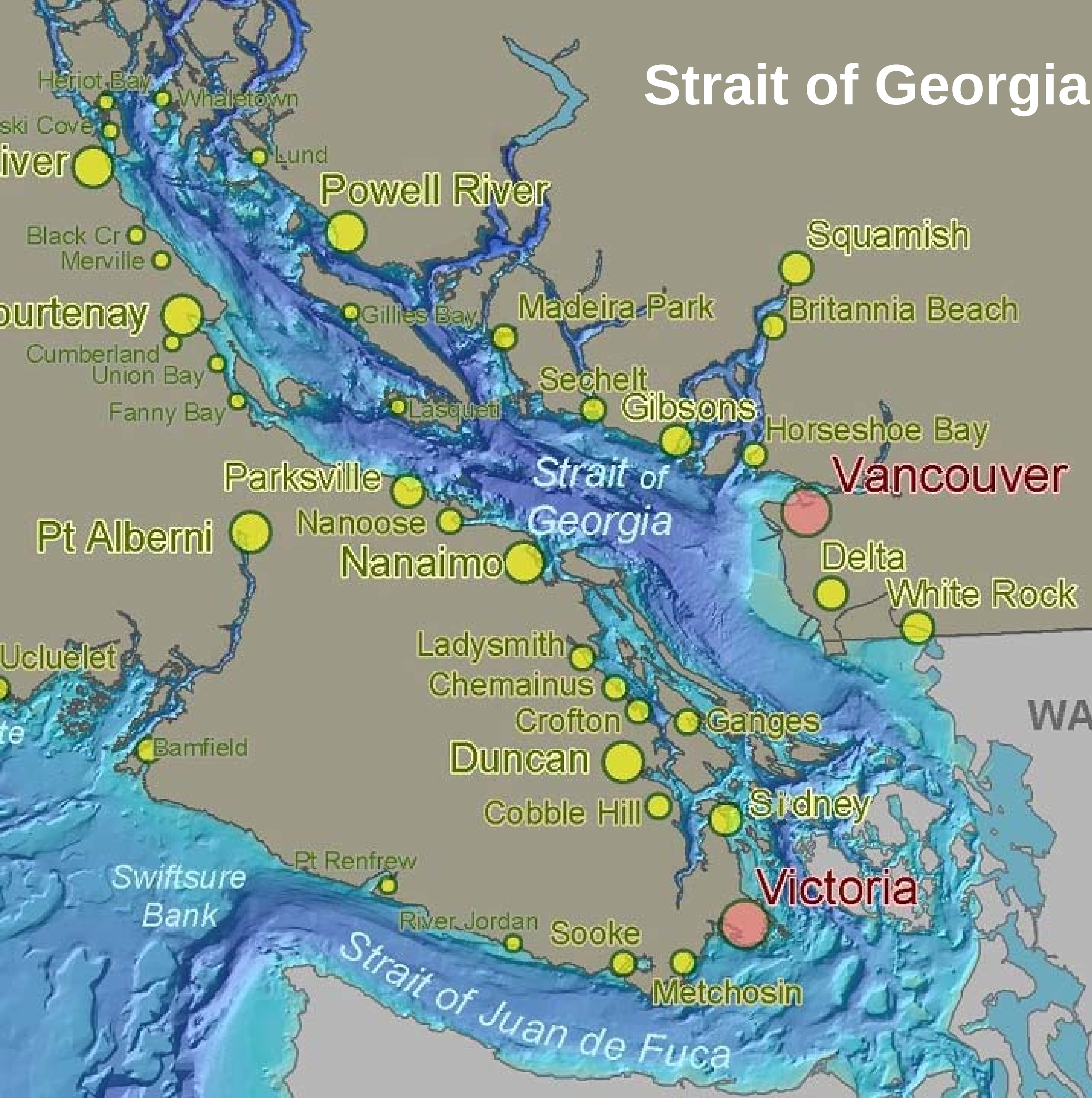
Strait of Georgia



A human-dominated system

Area = 6,800 km^2

Human population about 3 million

Killer whale population about 100

Strait 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

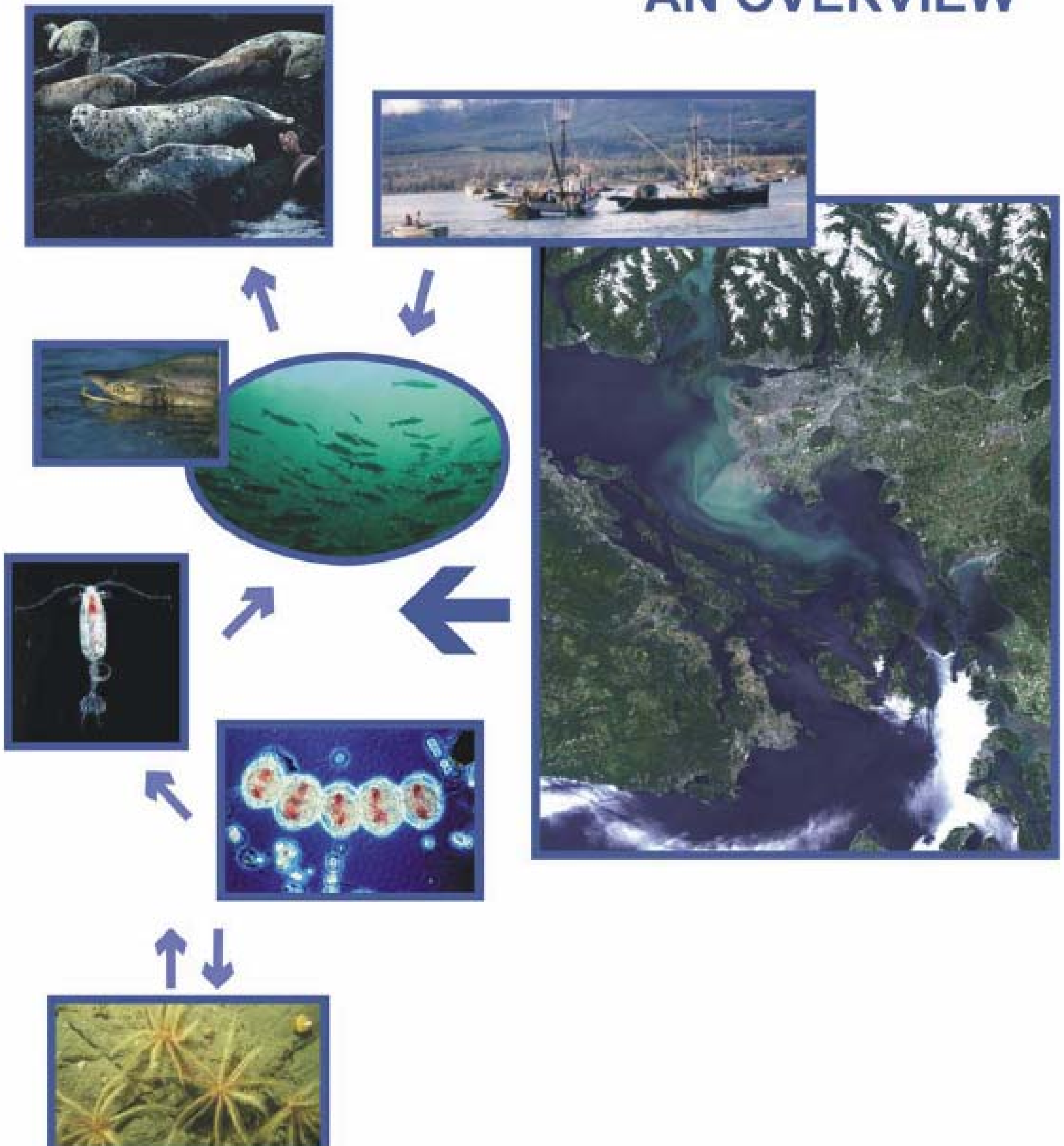
PICES FUTURE Program themes:

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+hake/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

Initiation (of plankton blooms)

Retention

Concentration

Trophic (food web) dynamics

Nearshore/benthic (habitat) dynamics

How the Strait of Georgia marine ecosystem 'works'

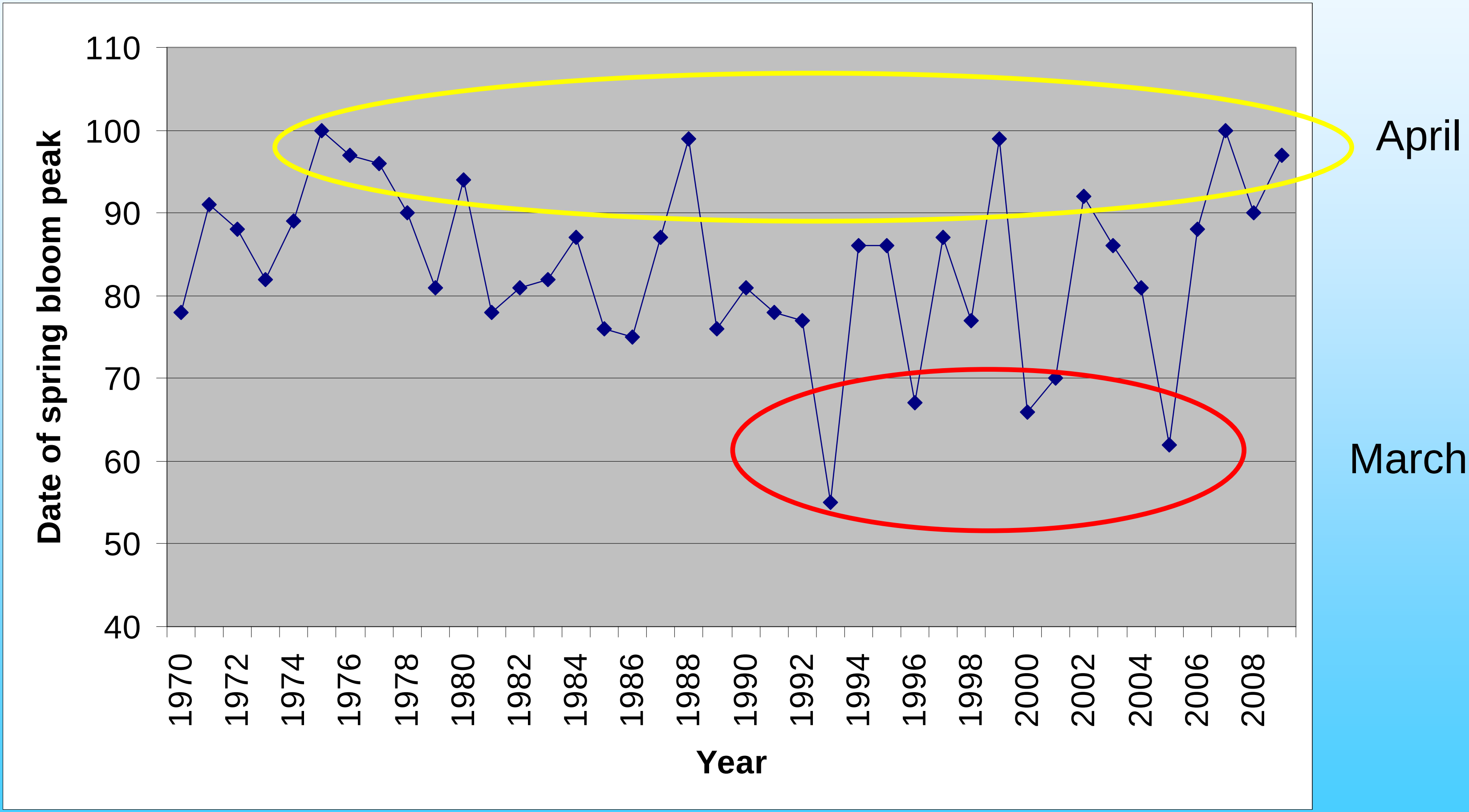
Initiation

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



Allen and Wolfe

How the Strait of Georgia marine ecosystem 'works'

Trophic (food web) dynamics

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)

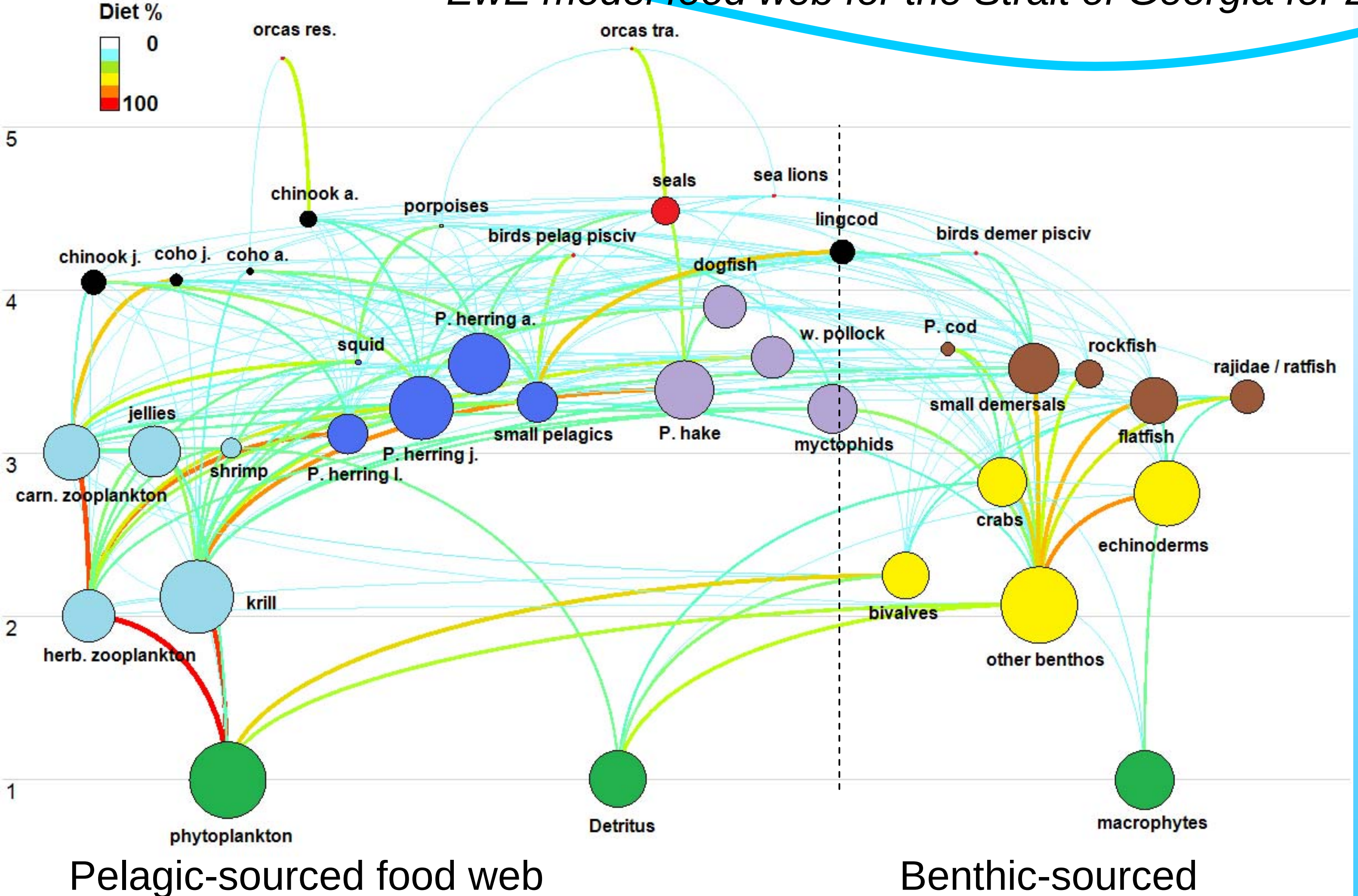
Zooplankton variations related positively (but weakly) with survival anomalies of salmon and herring in the Strait of Georgia

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

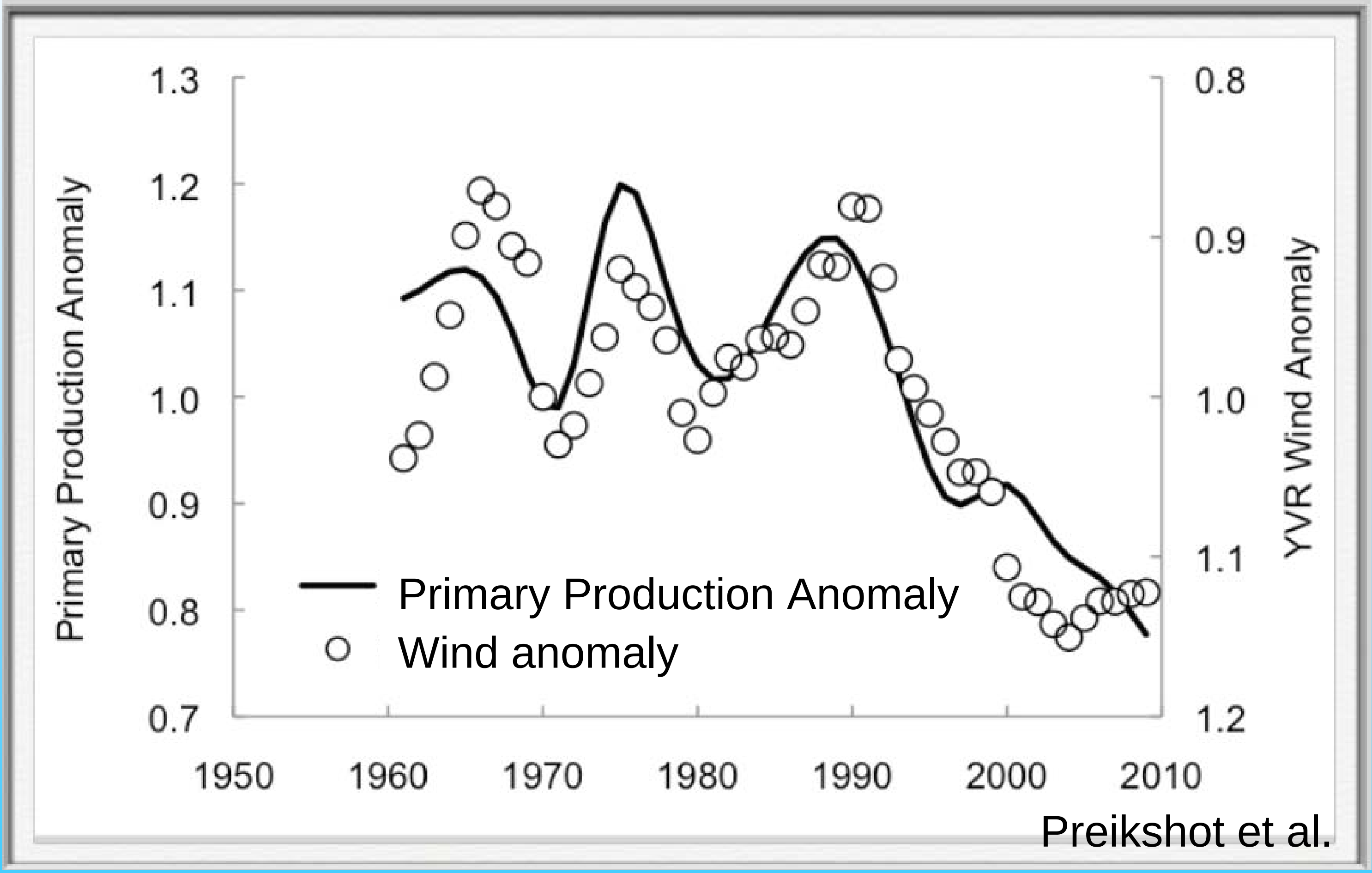


Preikshot et al.

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?



Preikshot et al.

Drivers of change acting on the Strait of Georgia

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

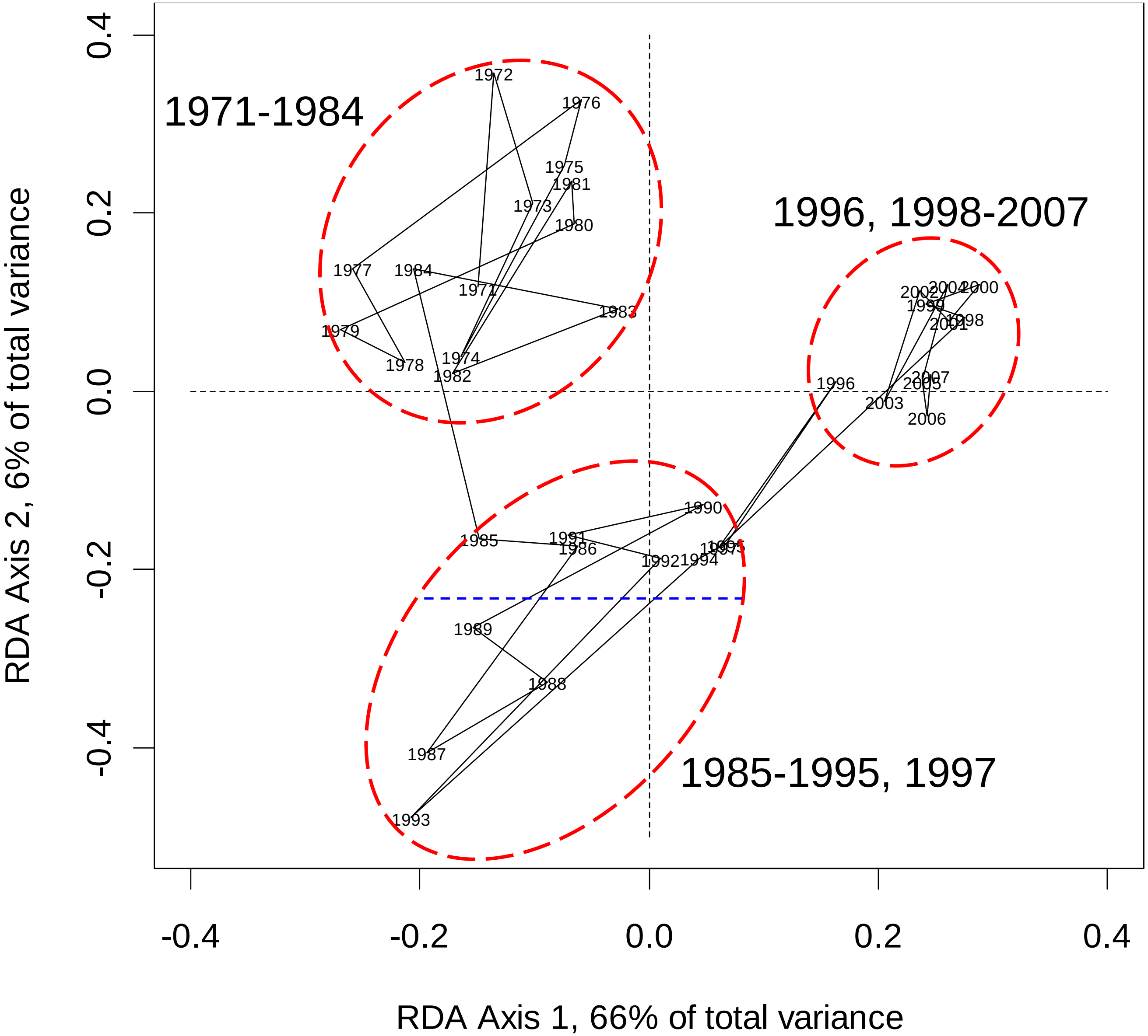
15 natural and human Driver & Pressure (explanatory) variables examined for statistical relationships with 22 State & Impact (response) variables for the Strait of Georgia, 1970-2010

Explanatory variables identified to be statistically significant (using redundancy analysis) were:

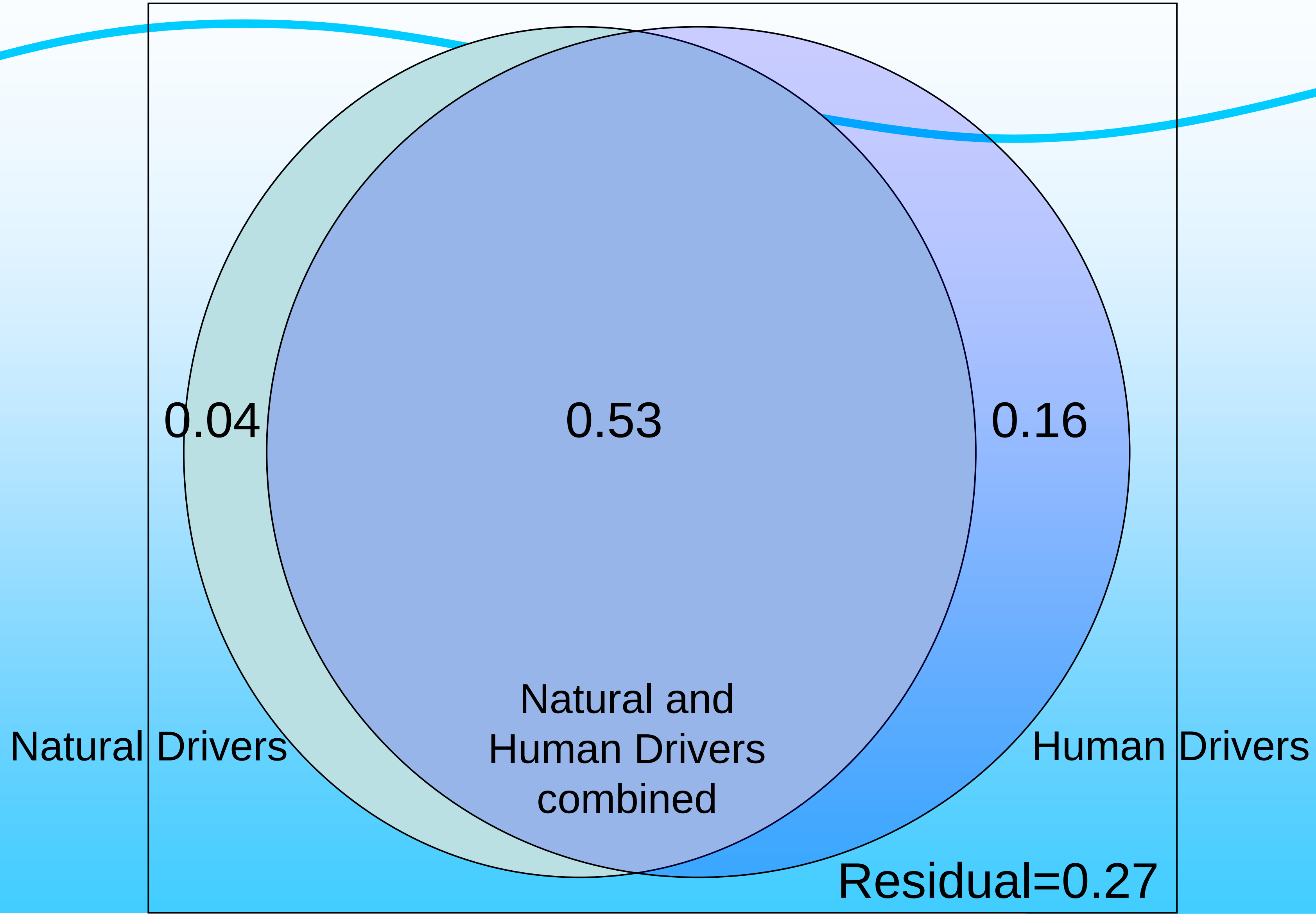
- sea surface temperature,
- wind speed,
- North Pacific Gyre Oscillation;
- human population,
- recreational fishing effort,
- number of Chinook salmon released from hatcheries

Perry

These six variables describe the regime-like behaviour of the Strait of Georgia since 1970



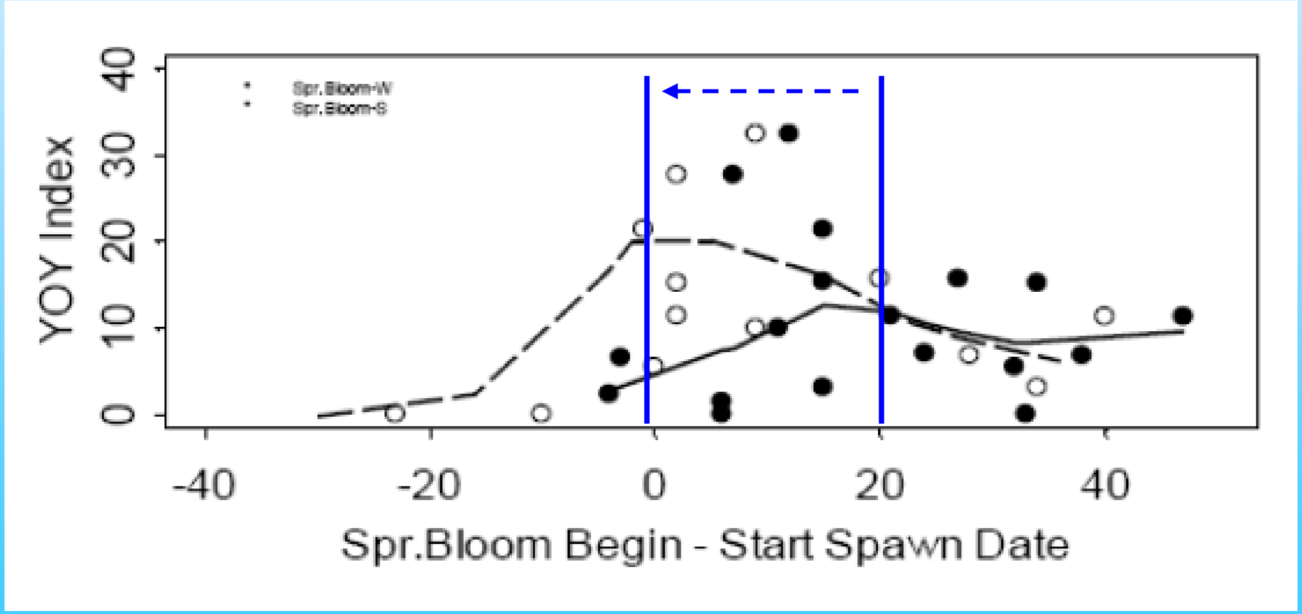
Variance of State & Impact variables partitioned among Natural and Human Drivers



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



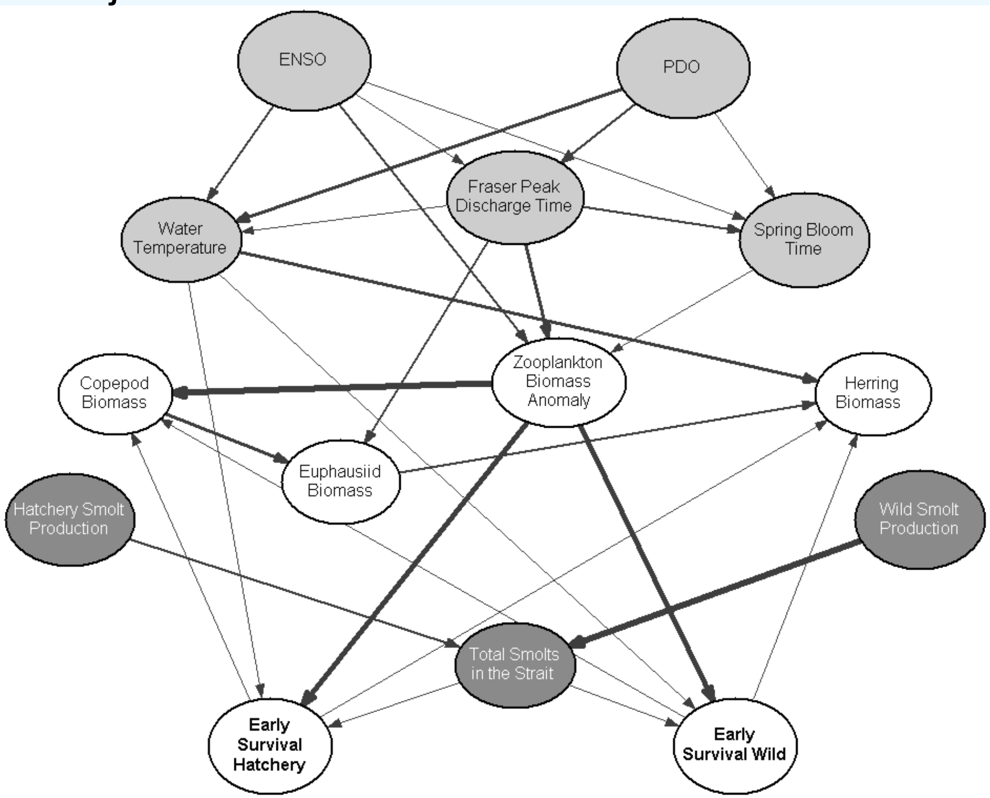
Symbols and lines represent two different models for the timing of the Spring bloom

Schweigert et al.

Considerations for management within an EAM

Indicators for early marine survival of coho salmon in SofG

Araujo et al.



Indicator	Diagnostic Value
Zooplankton biomass anomaly	0.212
Calanoid copepod biomass	0.083
Herring biomass (pre-fishery)	0.073
Water temperature	0.056
Fraser peak discharge time	0.043
Euphausiid biomass	0.032
ENSO	0.029
PDO	0.021
Log spring bloom time	0.006

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)

Considerations for management within an EAM

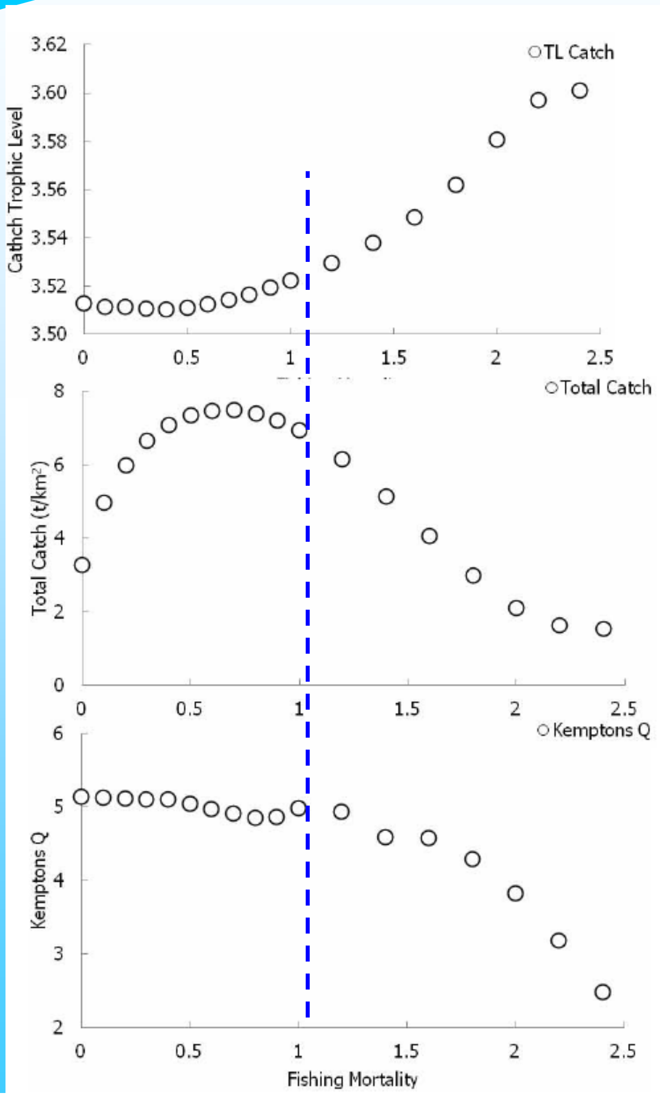
Identifying Ecosystem Overfishing thresholds

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



Trophic level of the catch

Total catch

Taxonomic diversity

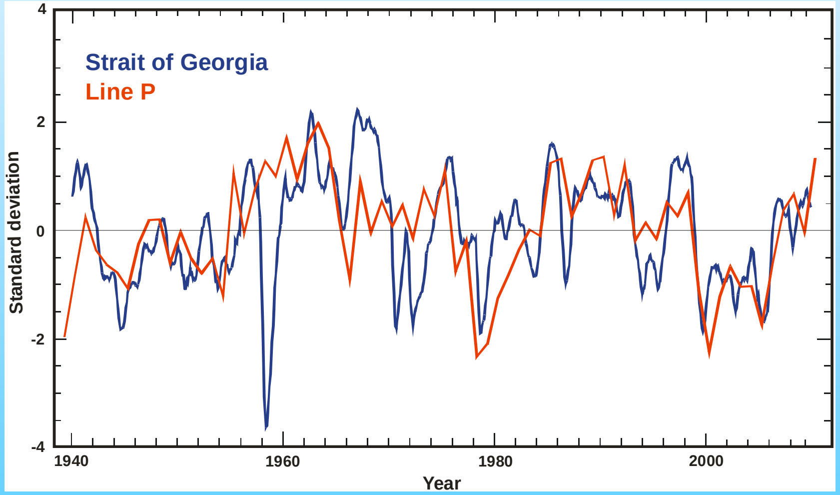
Marked changes in ecosystem characteristics occur when instantaneous fishing mortality on herring is about 1

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

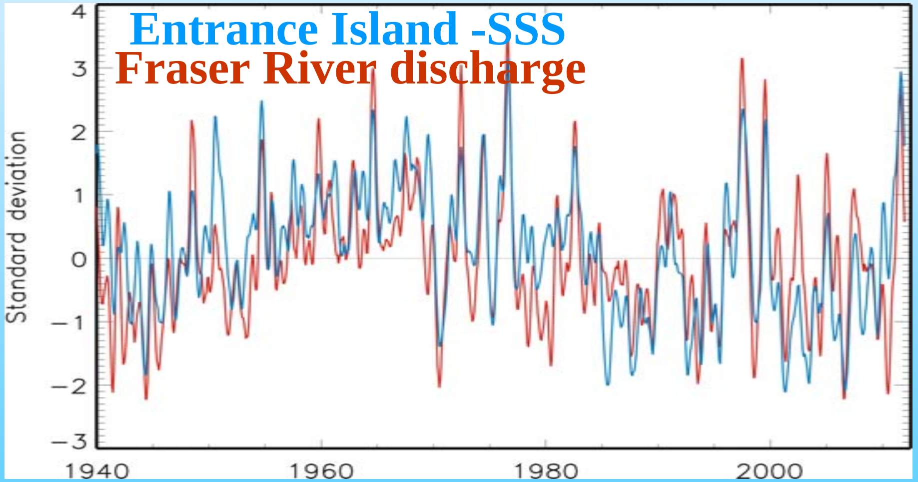
Into the future -
(some) predictability due to large-scale and local influences

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



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

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



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

P.Cummins, D. Masson

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)

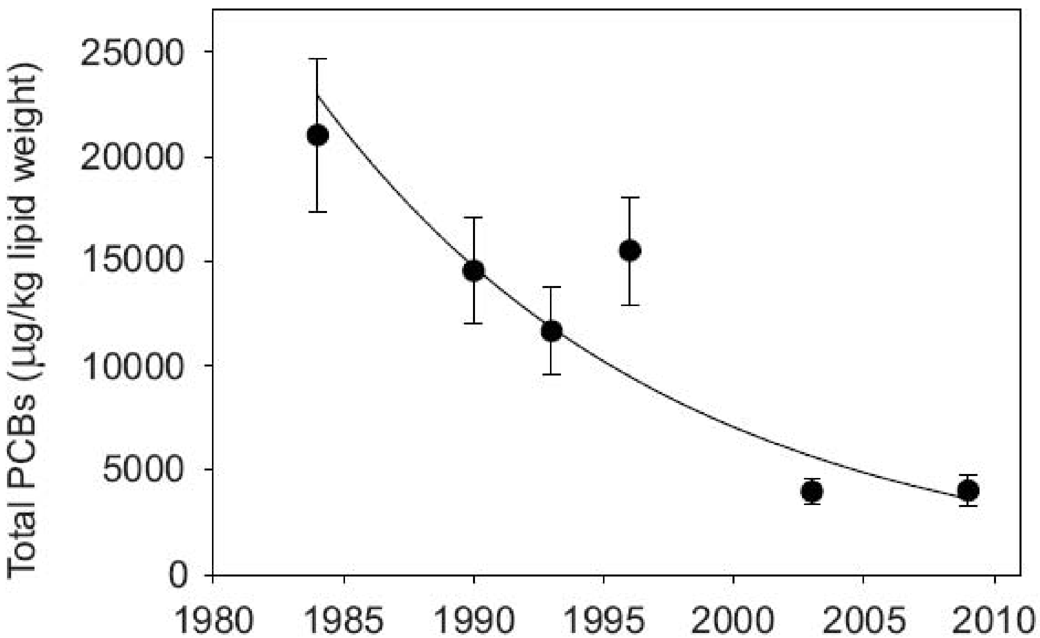
Potential to explore ecosystem impacts of biological scenarios:

- reappearance of humpback whales
- groundfish: recovery at last
- salmon: species specific responses to climate change

Akenhead et al.

Into the future

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

Ross et al.

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

B. de Lange Boom, J. Galloway, P. Wills, N. Sutherland, E. Gregr, G. Jamieson, J. Lessard, J. Schweigert, C. Fu, A. Pena, J. Holmes, T. Therriault, K. Cooke, L. Nichol, J. Ford, G. Ellis, P. Olesiuk, R. Sweeting, D. Mackas, R. Beamish, K. Lange, C. Neville, P. Ross, S. Johannessen, R. Macdonald, M. Galbraith, D. Faust, J. Gower, S. King, M. Foreman, M. Trudel, S.Tucker, J. Irvine, L. Godbout, D. Preikshot, T. Sutherland, P. Cummins, J. Curtis, C. Holt, A. Araujo, C. Robinson

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