

# Overview of climate change effects in British Columbia marine ecosystems

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Sabine Jessen, Hussein Alidina



*In association with:*  
**David Suzuki Foundation, Sierra Club of BC  
Living Oceans Society**



GLOBEC (<http://www.cop.noaa.gov/stressors/climatechange/current/fact-globecpne.html>)

# Marine Ecosystems of British Columbia



Ministry of Sustainable  
Resource Management  
Decision Support Services

Prepared for:  
Decision Support Services

### Legend

Protected Areas



0 50 100

Kilometer

Projection: Albers Equal Area Conic Datum: NAD83

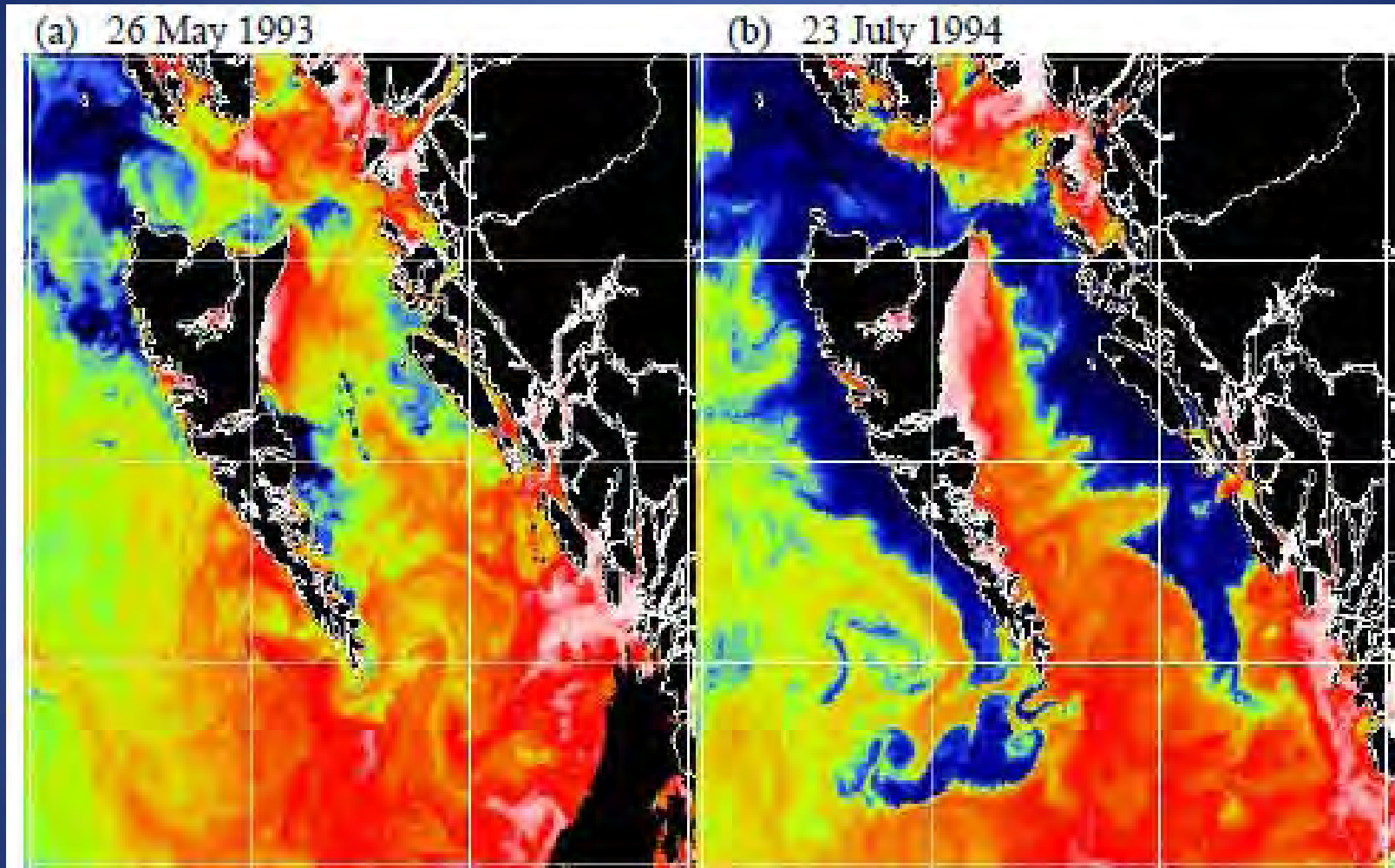
Data Source(s):  
1:250,000 MSRM Base Information  
British Columbia Marine Ecological Classification 1995



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# Sea Surface Temperature

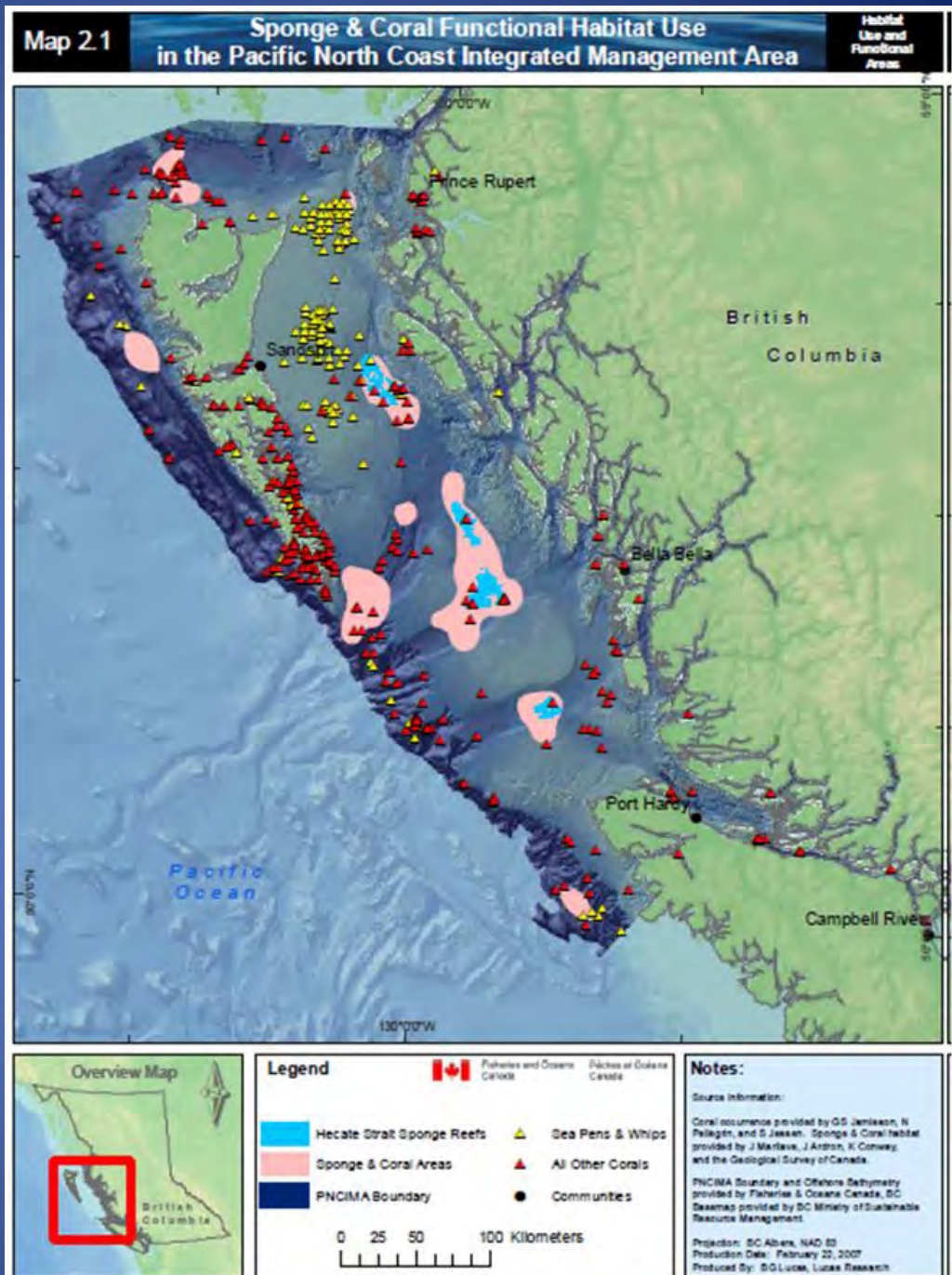


Sea surface temperature (SST) images of observations by AVHRR sensor on NOAA satellites

Perry, R. I., B. Crawford, and A. Sinclair. 2007. Chapter 1: Ecosystem Description. Pages 3-45 in B. G. Lucas, S. Verrin, and R. Brown, editors. Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA). Can. Tech. Rep. Fish. Aquat. Sci. 2667: xiii + 104 p.

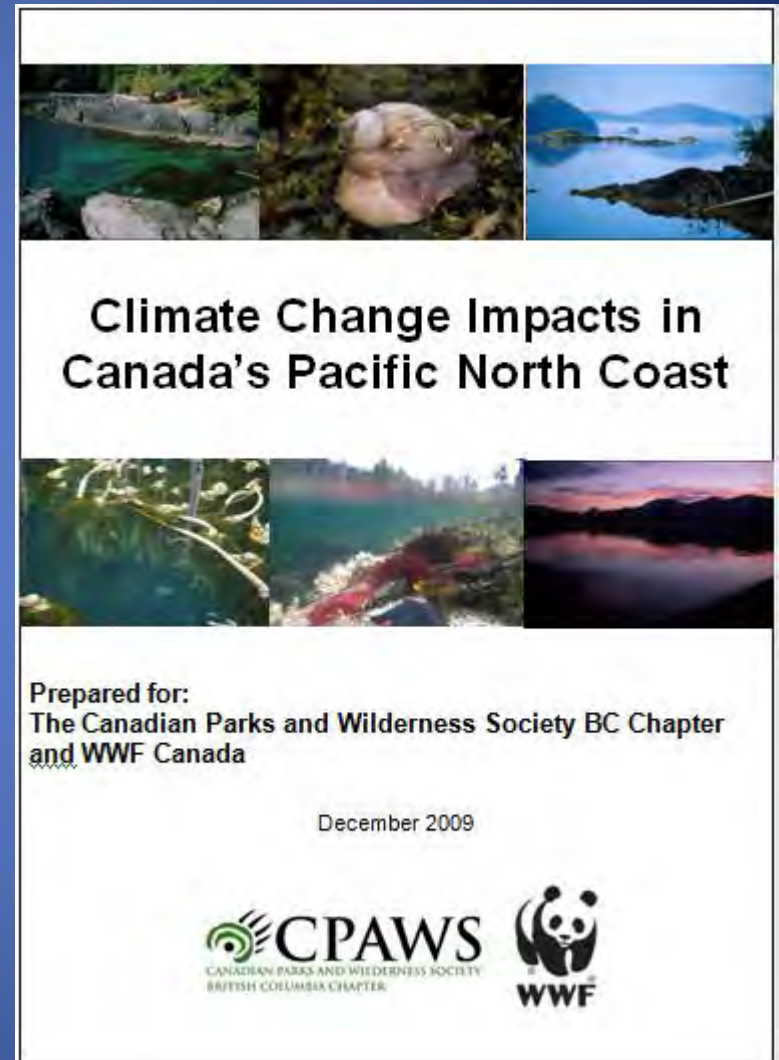
# Functional Habitat Use

Lucas, B. G. and G. S. Jamieson. 2007. Chapter 2: Habitat use and functional areas in the Pacific North Coast Integrated Management Area in B. G. Lucas, S. Verrin, and R. Brown, editors. Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA). Can. Tech. Rep. Fish. Aquat. Sci. 2667: xiii + 104 p.



# CC impacts review for the PNCIMA

1. Physical changes:
  - Model projections
  - Literature review
2. Biological impacts:
  - Literature review – observations
3. Expert review
4. Identify information gaps
5. Make recommendations



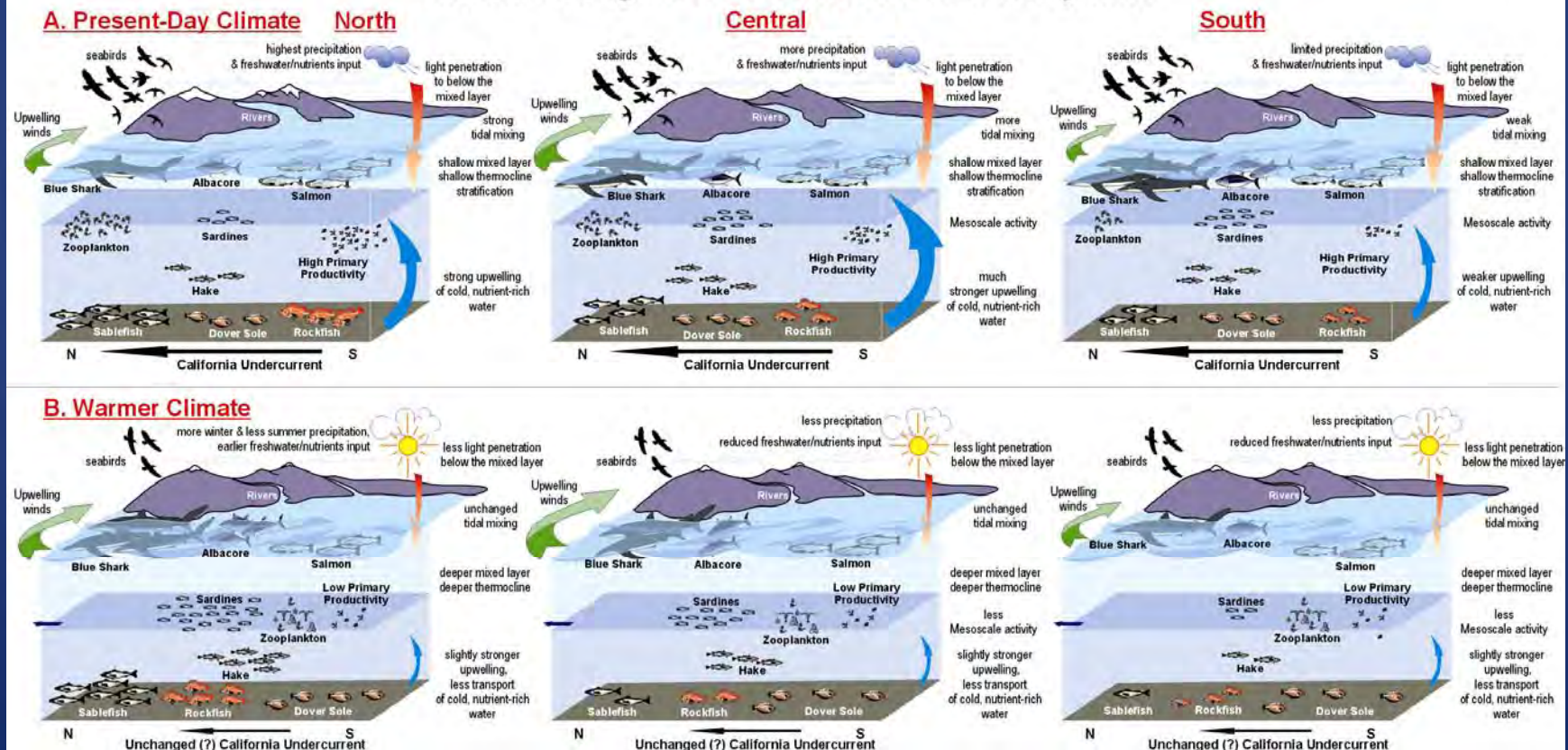
# Other projects and approaches

<b>Acronym</b>	<b>Name / description</b>	<b>Example host</b>
Strait of Georgia 2030	Projecting the state of the Strait of Georgia in 2030	Fisheries & Oceans Canada
CanESM	Canadian Earth System Model over global domain with NPZD ocean ecosystem/carbon cycle and terrestrial carbon system embedded in coupled atmosphere-ocean climate model	CCCMA
ECOPATH with ECOSIM	Trophodynamic fisheries ecosystem model with temporal and spatially explicit dynamics, non-trophic mediation, physical and production forcing, economics, value chain, policy analysis, etc.	UBC FC; CEFAS, CSIRO, NMFS, OGS, SAMS
OSMOSE	Object-oriented Simulator of Marine Ecosystems Exploitation / Individual-based model; now linked with an NPZD and more sophisticated fleet dynamics models are likely to emerge as it transitions to a dynamic whole of system representation.	IRD, DFO
ROMS-NPZD	Regional Ocean Model System-Nutrient Phytoplankton Zooplankton Detritus / 3D pelagic ecosystem model coupled to a 3D ROMS split-explicit free surface oceanic model	AZTI, IRD, IOS, DFO
Sea Around Us	Dynamic bioclimate envelope model for projecting distributions of marine fish and invertebrates	UBC FC
Sea Around Us	Application of macroecological theory to predict effects of climate change on global fisheries potential	UBC FC

# Climate Forcing and Marine Ecosystems of the North Pacific

Jacquelynne R. King, Vera N. Agostini, Gordon McFarlane, Christopher Harvey, Michael Foreman, James Overland and Kerim Aydin

## Climate Change and the California Current System





# Expected physical changes

- Temperature (+)
- Dissolved oxygen (-)
- pH (-)
- Precipitation (+)
- Salinity (-)
- Snowpack (-)
- Stratification (+)
- Sea level (+)
- Storminess (+)
- North Pacific current (+)
- Upwelling (+)
- ENSO (increased frequency?)
- PDO (?)

# Measurements

<i>Climate variable</i>	<i>Magnitude of change (qualitative or quantitative)</i>
<i>SST</i>	Increase of 0.5°C over 50 years
<i>Bottom Temperature</i>	+0.6°C over 50 years at 100 - 400 m depth +0.9°C over 48 years at 10 - 50 m depth
<i>Salinity</i>	-0.18 ppt over 50 years at Line P
<i>pH</i>	declining 0.0017/yr in upper surface of Pacific Declining at 0.045/yr at Tatoosh intertidal
<i>Dissolved Oxygen</i>	22% decline over 50 years at OSP 100 - 400 m Shoaling hypoxia
<i>Currents or wind patterns</i>	Increased upwelling brings “corrosive” water
<i>Frequency of extreme events</i>	No predicted increase in storms on the BC coastline ENSO may change with increases in atmospheric CO <sub>2</sub>

# The PNCIMA setting



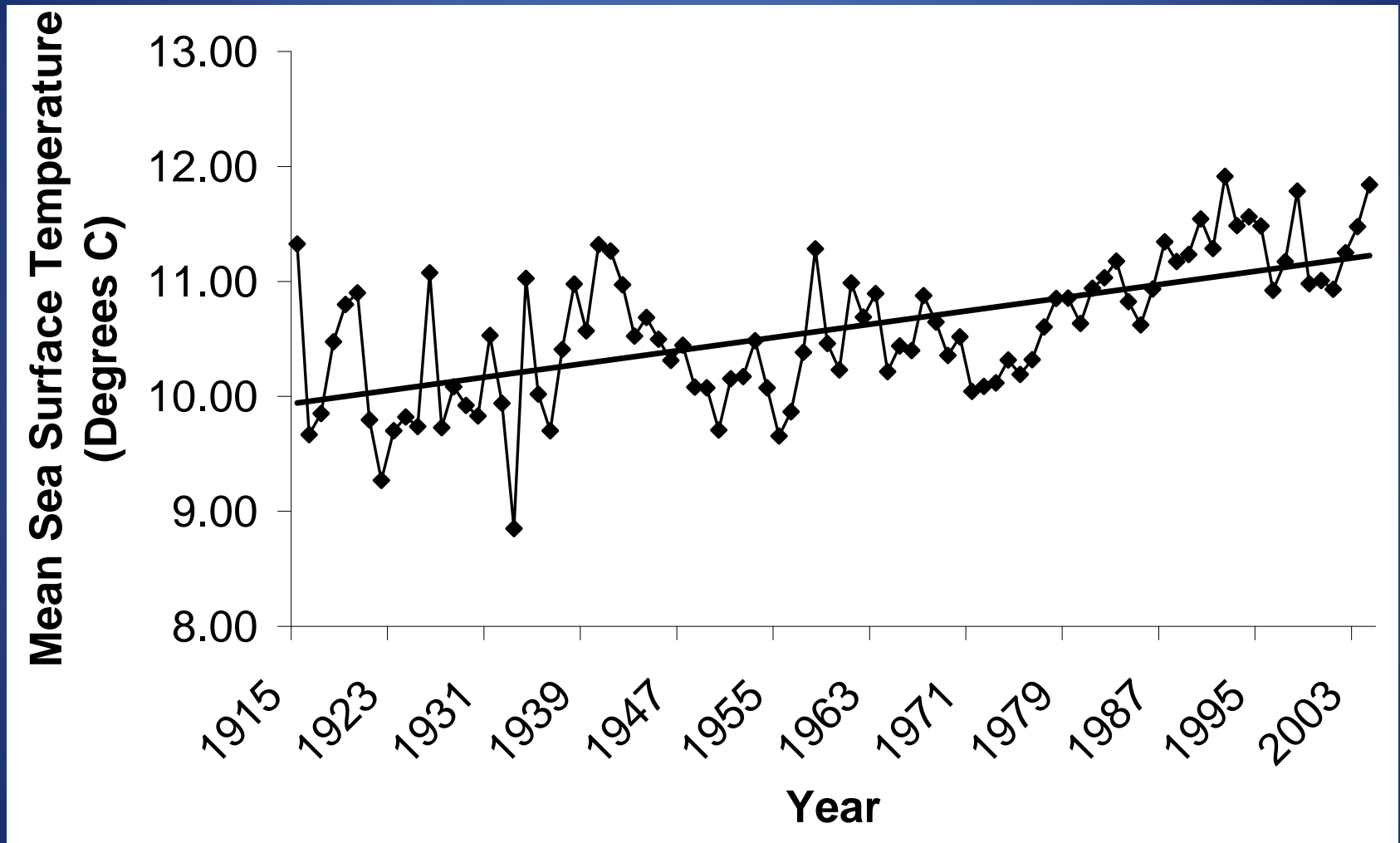
- One of 5 LOMAs
- 88,000 km<sup>2</sup>
- Rocky coastline
- Fjords
- Broad soft bottoms
- Complex Oceanography
- Diverse habitats



# Existing work

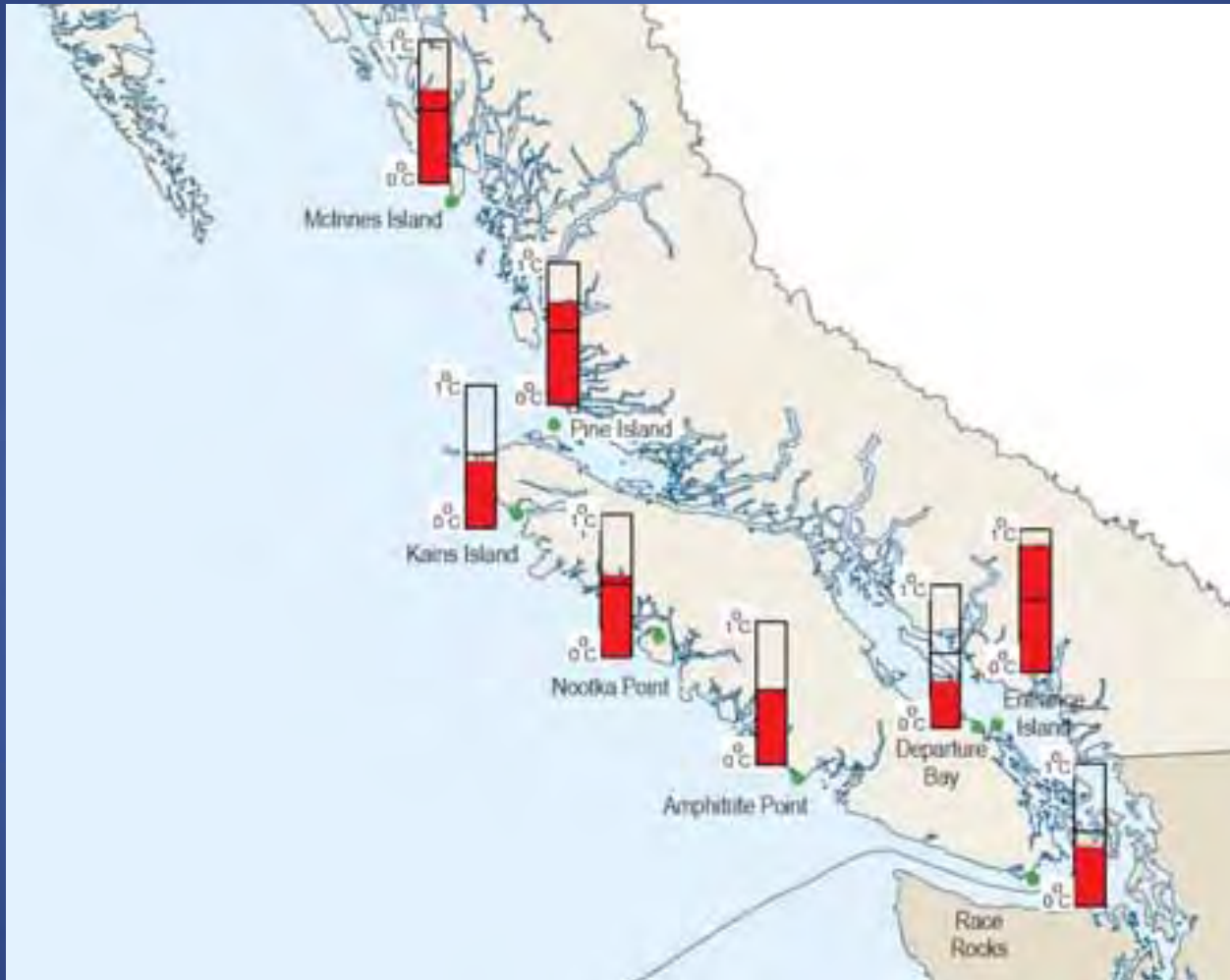
- Beamish, R. J., J. R. King, and G. A. McFarlane. 2009. Canada. Pages 14-55 in R. J. Beamish, editor. **Impacts of climate and climate change on the key species in the fisheries in the North Pacific**. PICES Scientific Report No. 35. PICES Working Group on Climate Change, Shifts in Fish Populations, and Fisheries Management. North Pacific Marine Science Organization (PICES), Secretariat, Sidney BC.
- DFO. 2008. **State of the Pacific Ocean 2007**. DFO Can. Sci. Advis. Rep. 2008/028. [www.dfo-mpo.gc.ca/csas](http://www.dfo-mpo.gc.ca/csas).
- Harley, C.D.G. A. R. Hughes, K. M. Hultgren, B. G. Miner, C. J. B. Sorte, C. S. Thornber, L. F. Rodriguez, L. Tomanek, and S. L. Williams. 2006. **The impacts of climate change in coastal marine systems**. Ecology Letters, 9, 228-241.
- Kimmel, E. 2009. Background Report: **Climate Change Adaptation and Biodiversity**. Adaptation to Climate Change Team, Simon Fraser University, Vancouver
- Lucas, B. G. and G. S. Jamieson. 2007. Chapter 2: **Habitat use and functional areas in the Pacific North Coast Integrated Management Area** in B. G. Lucas, S. Verrin, and R. Brown, editors. Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA). Can. Tech. Rep. Fish. Aquat. Sci. 2667: xiii + 104 p.
- Lucas, B. G., S. Verrin, and R. Brown, editors. 2007. **Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA)**. Can. Tech. Rep. Fish. Aquat. Sci. 2667: xiii + 104 p.
- Perry, R. I., B. Crawford, and A. Sinclair. 2007. Chapter 1: **Ecosystem Description**. Pages 3-45 in B. G. Lucas, S. Verrin, and R. Brown, editors. Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA). Can. Tech. Rep. Fish. Aquat. Sci. 2667: xiii + 104 p.

# SST – Strait of Georgia



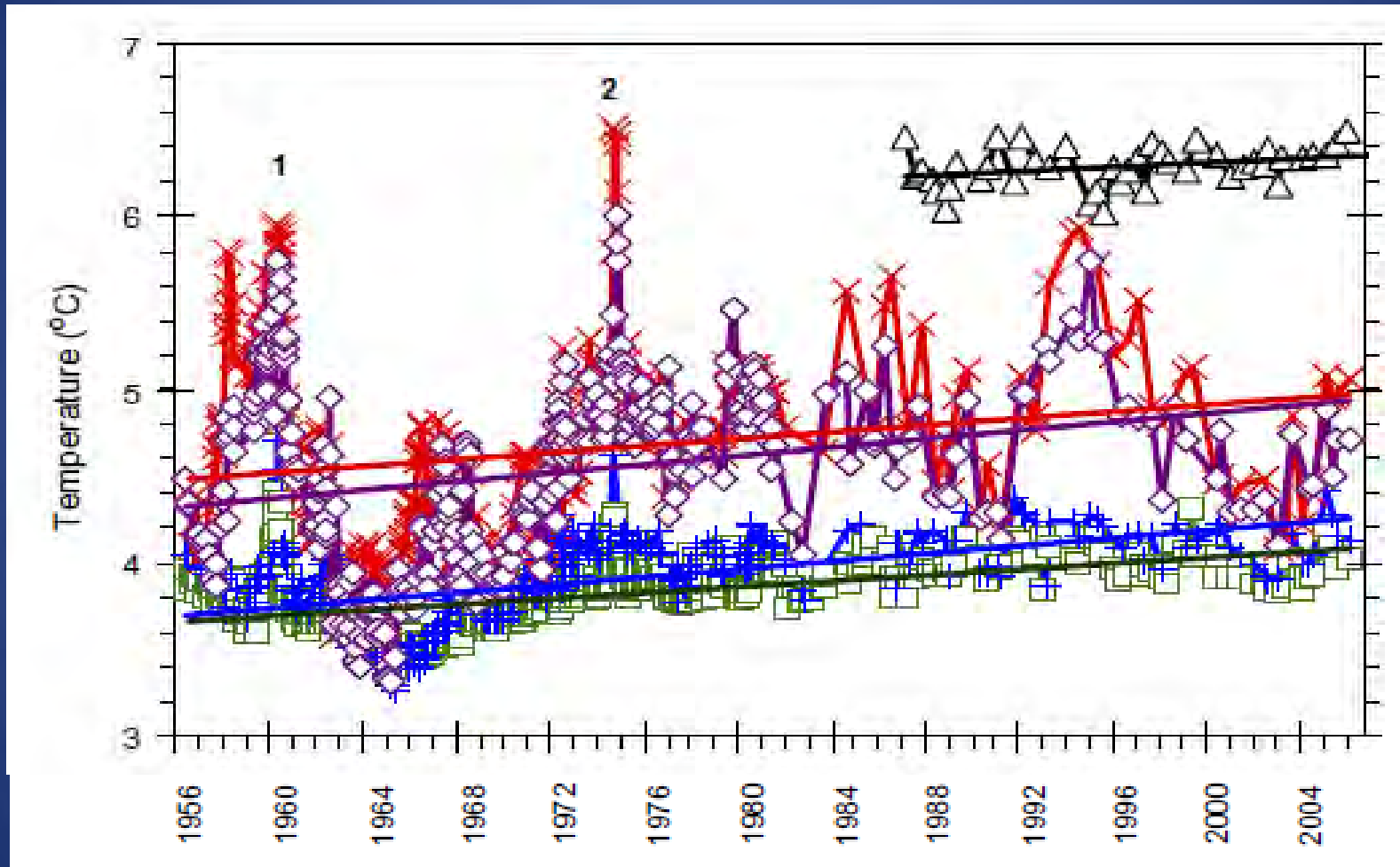
Beamish, R. J., J. R. King, and G. A. McFarlane. 2009. Canada. Pages 14-55 in R. J. Beamish, editor. Impacts of climate and climate change on the key species in the fisheries in the North Pacific. PICES Scientific Report No. 35. PICES Working Group on Climate Change, Shifts in Fish Populations, and Fisheries Management. North Pacific Marine Science Organization (PICES), Secretariat, Sidney BC

# SST over 50 years



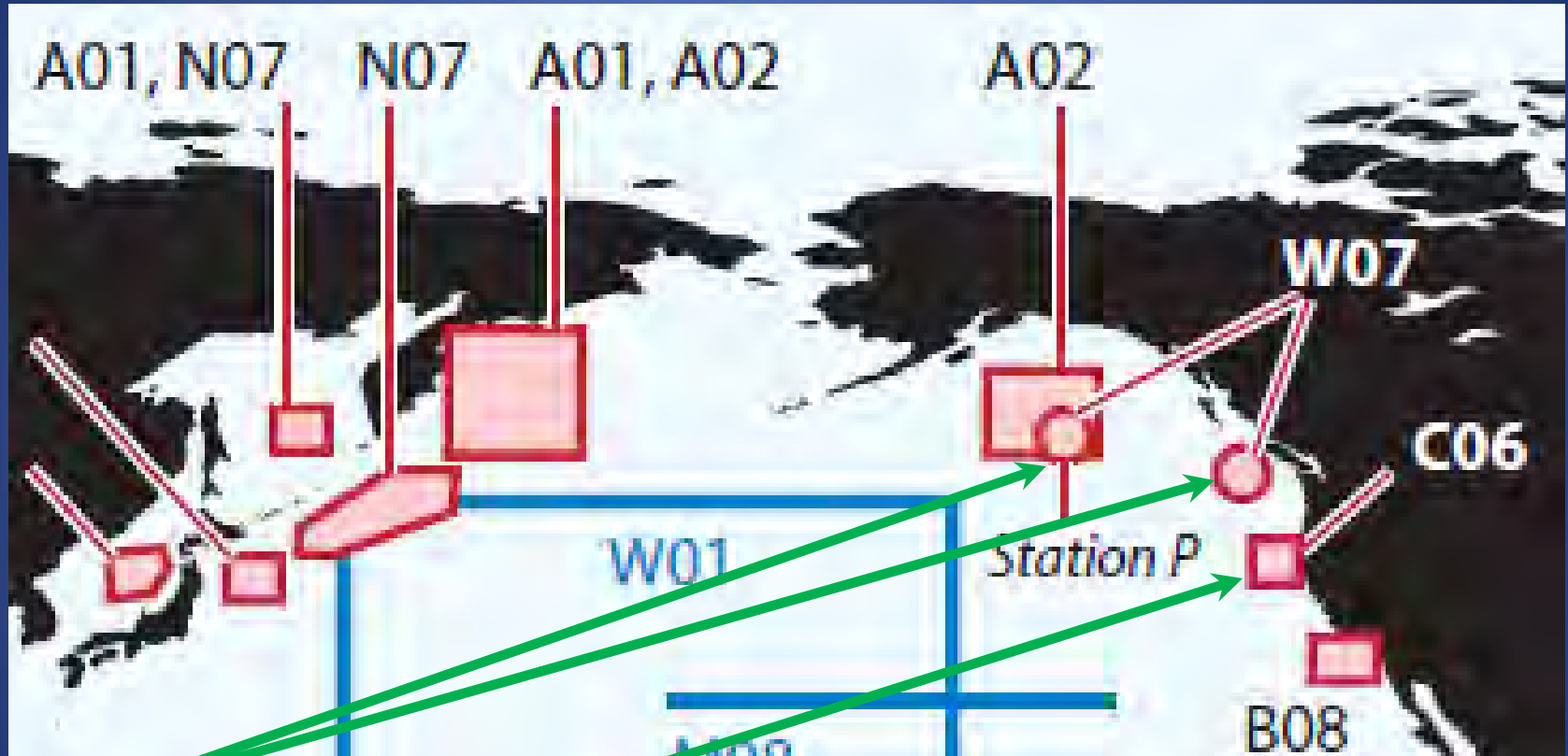
B.C. Ministry of Environment. 2007. Environmental Trends in British Columbia: 2007. State of Environment Reporting. Victoria, B.C. [www.env.gov.bc.ca/soe/et07/](http://www.env.gov.bc.ca/soe/et07/)

# Line P Temp (125 m – 400 m)



Whitney, F. A., Freeland, H. J. and Robert, M. 2007. Persistently declining oxygen levels in the interior waters of the eastern subarctic Pacific. *Progress in Oceanography*, 75: 179-199

# Deoxygenation studies

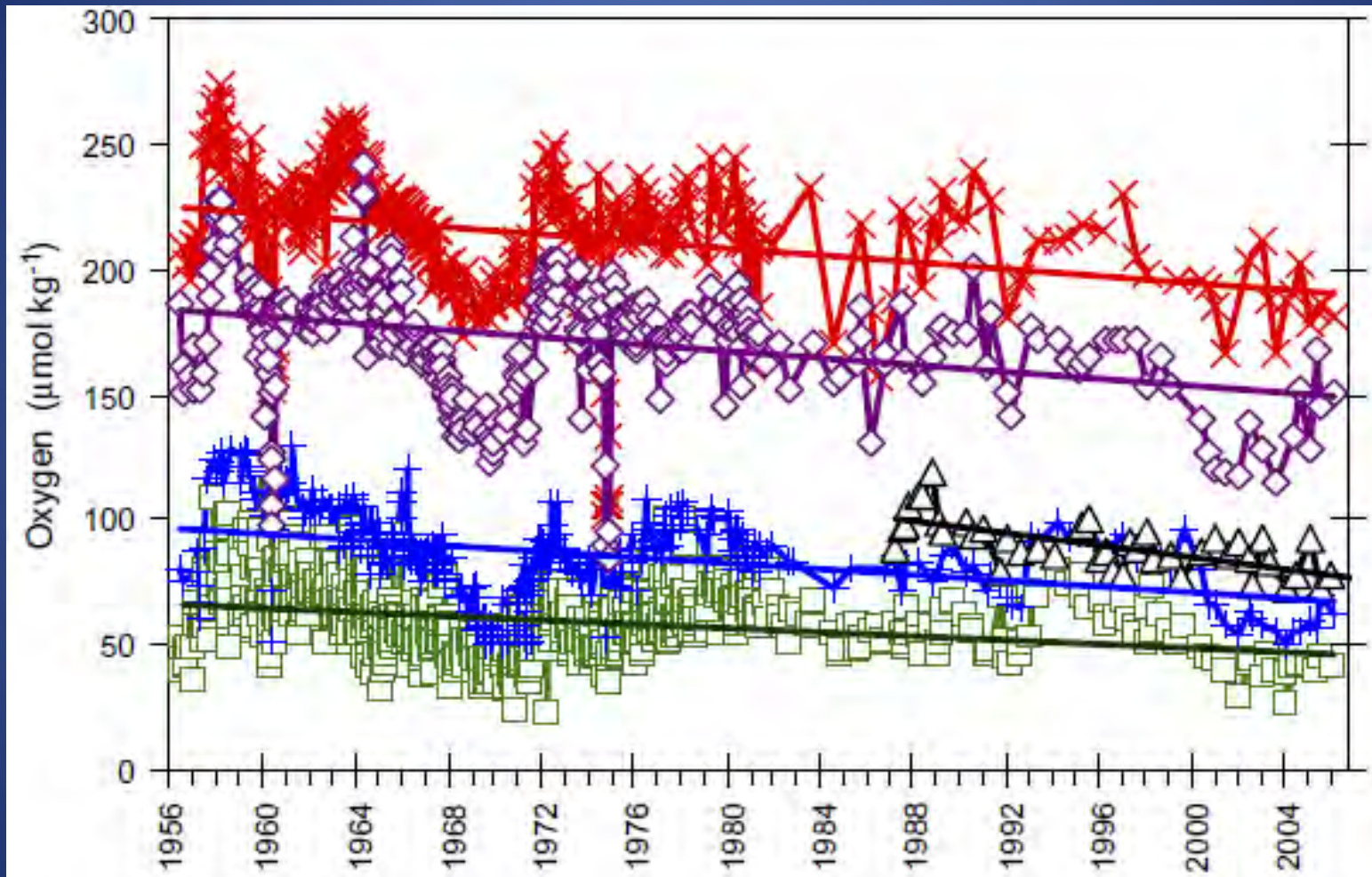


Whitney, F. A., Freeland, H. J. and Robert, M. 2007. Persistently declining oxygen levels in the interior waters of the eastern subarctic Pacific. *Progress in Oceanography*, 75: 179-199.

Chan, F., Barth, J. A., Lubchenco, J., Kirincich, A., Weeks, H., Peterson, W. T. and Menge, B. A. 2008. Emergence of anoxia in the California current large marine ecosystem. *Science*, 319: 920-920.

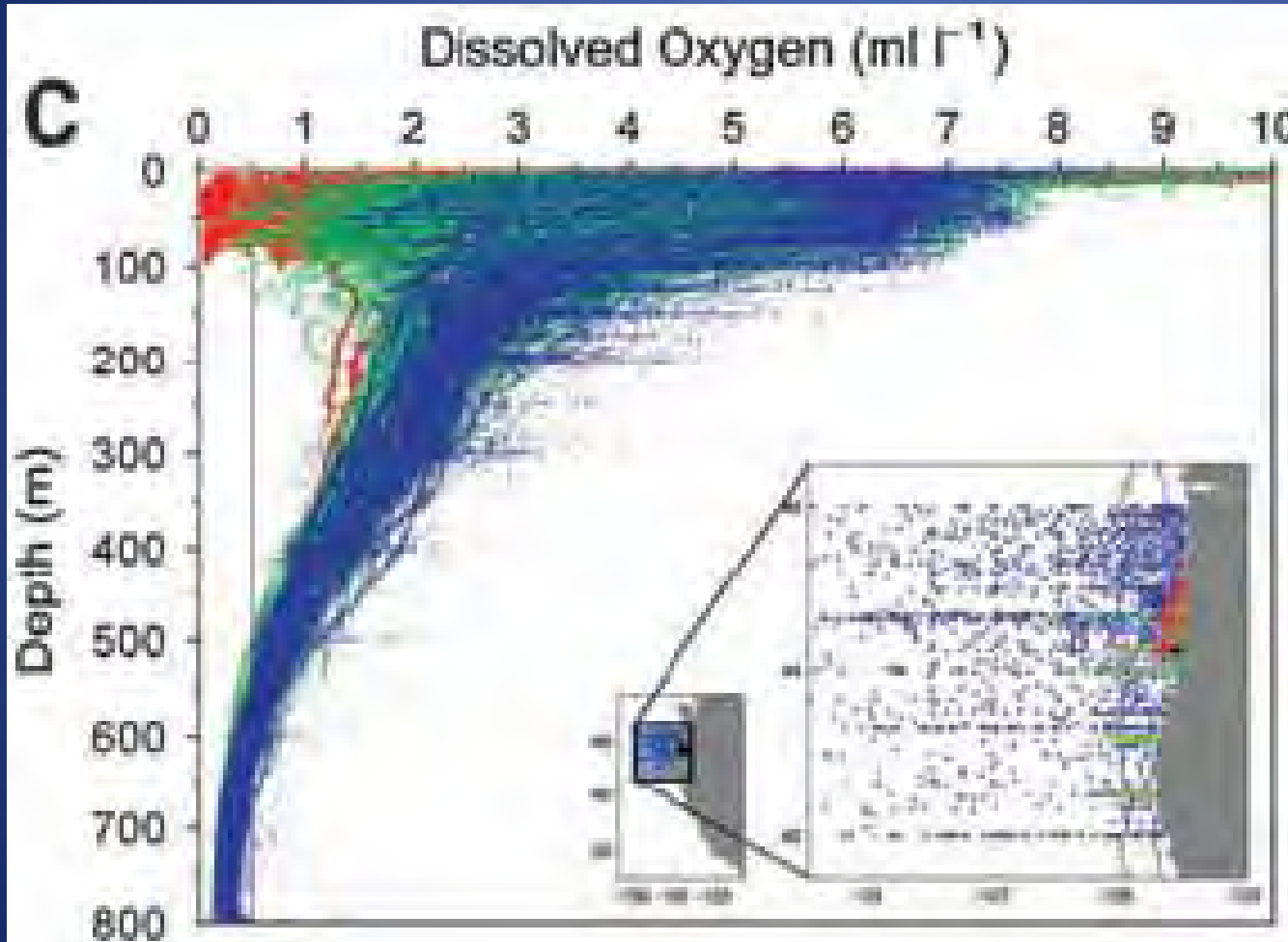


# NE Pacific Deoxygenation



Whitney, F. A., Freeland, H. J. and Robert, M. 2007. Persistently declining oxygen levels in the interior waters of the eastern subarctic Pacific. *Progress in Oceanography*, 75: 179-199

# Emergence of hypoxia in NCC



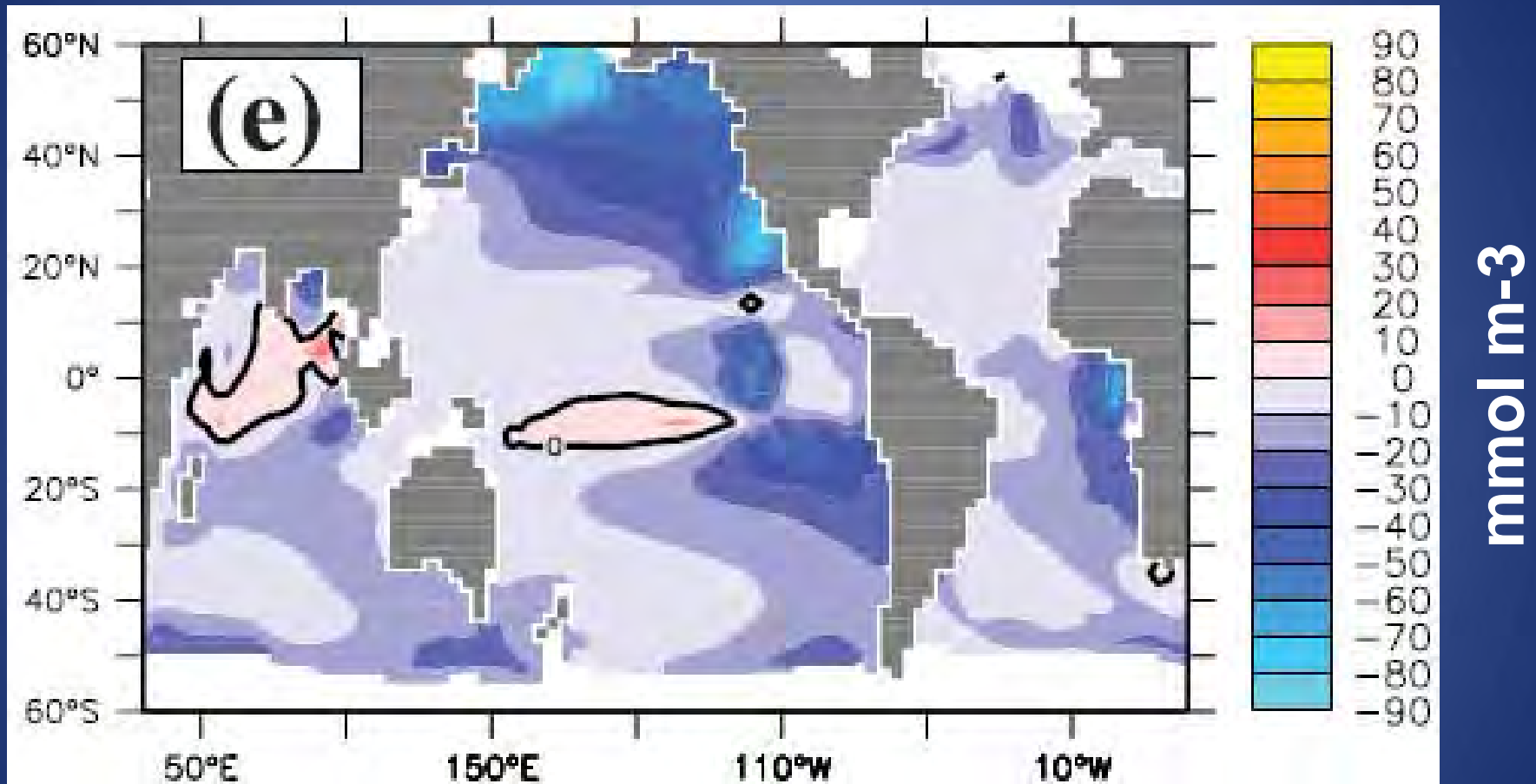
**1950-1999**

**2000-2005**

**2006**

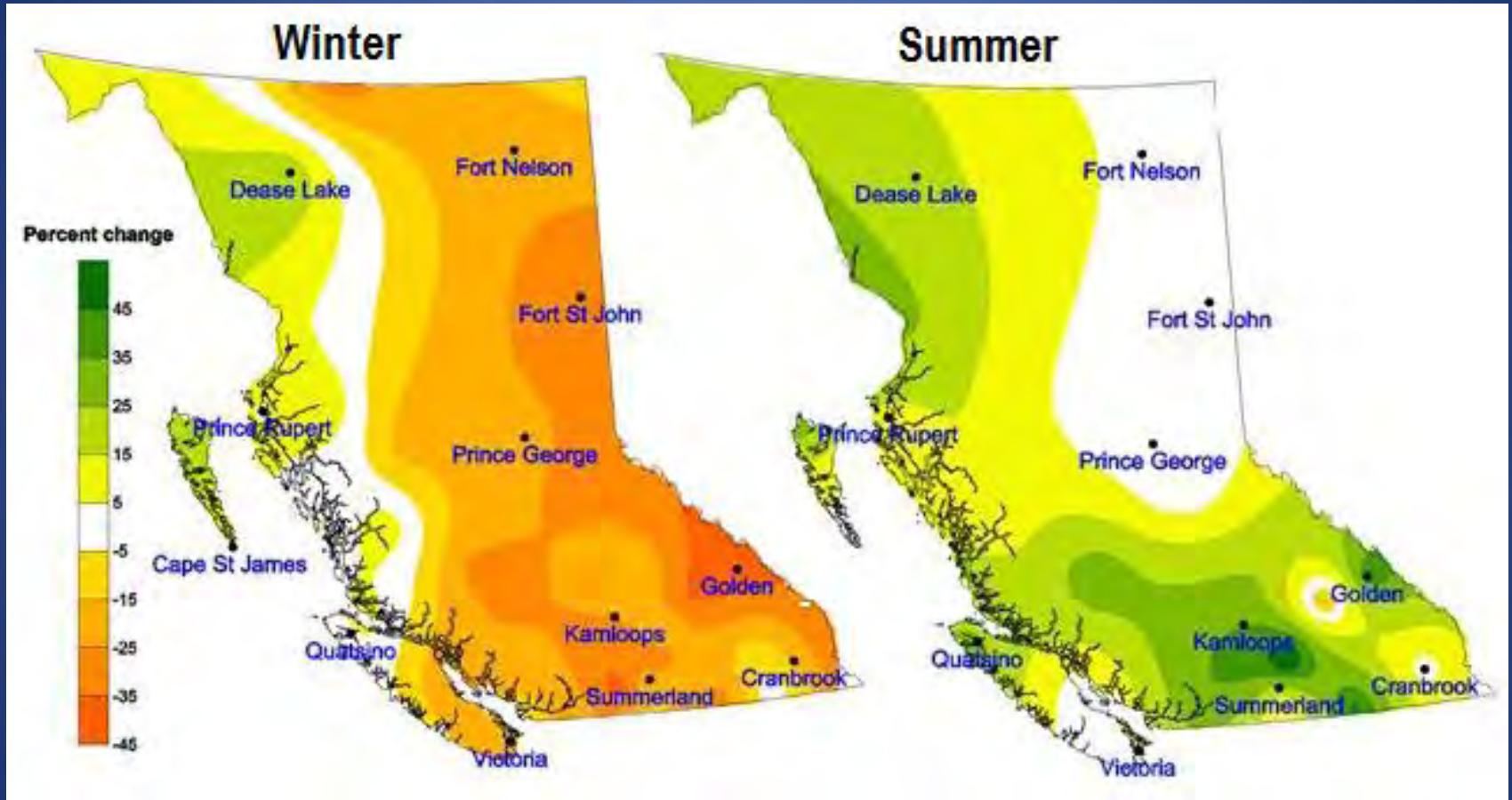
Chan, F., Barth, J. A., Lubchenco, J., Kirincich, A., Weeks, H., Peterson, W. T. and Menge, B. A. 2008. Emergence of anoxia in the California current large marine ecosystem. *Science*, 319: 920-920.

# North Pacific Deoxygenation by 2100



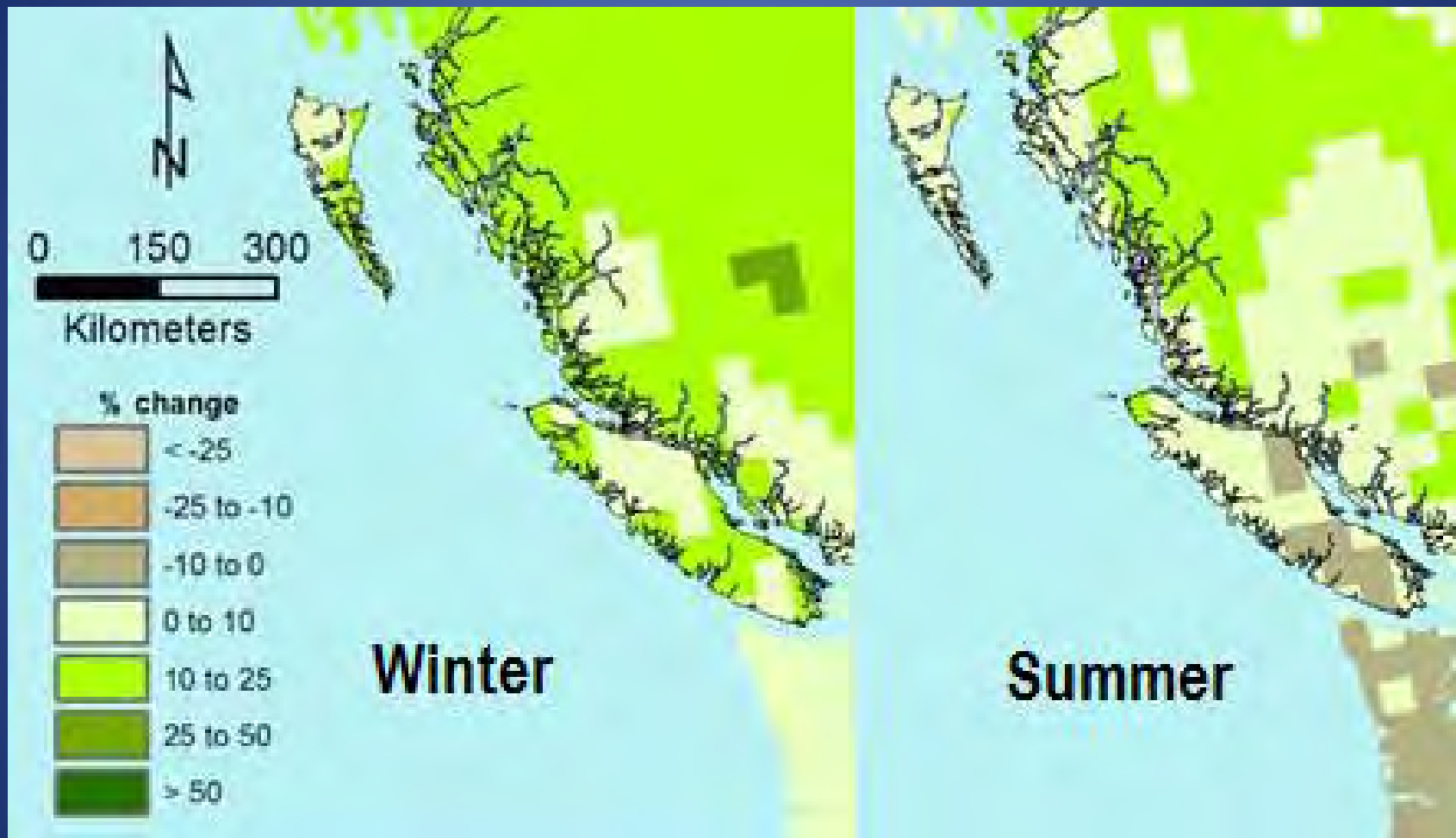
Oschlies, A., Schulz, K. G., Riebesell, U. and Schmittner, A. 2008. Simulated 21st century's increase in oceanic suboxia by CO<sub>2</sub>-enhanced biotic carbon export. *Global Biogeochemical Cycles*, 22

# Past precipitation changes

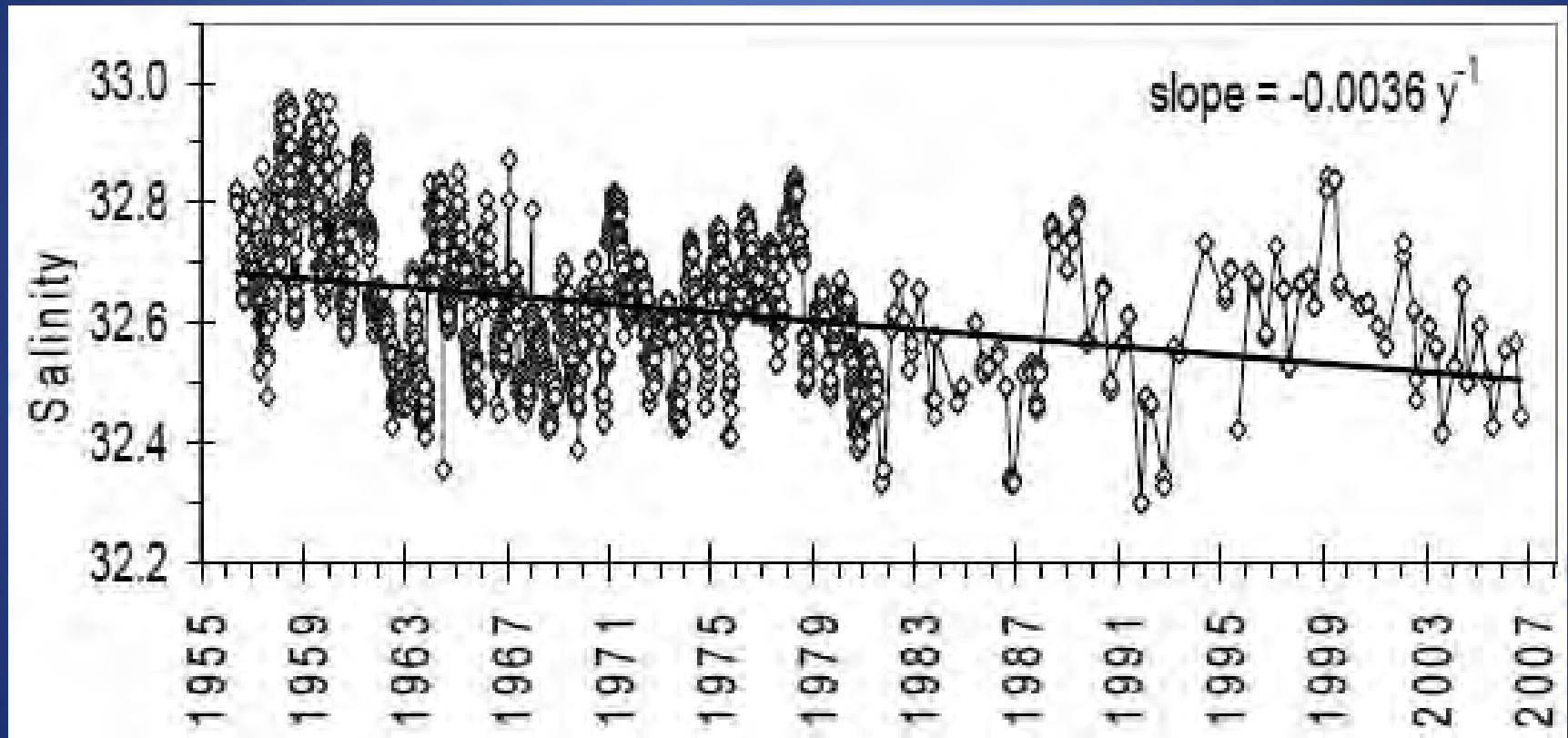


B.C. Ministry of Environment. 2007. Environmental Trends in British Columbia: 2007. State of Environment Reporting. Victoria, B.C. [www.env.gov.bc.ca/soe/et07/](http://www.env.gov.bc.ca/soe/et07/)

# Precipitation in 2050



# Surface Salinity, Line P



Whitney, F. and M. Robert. 2007. Ocean observations from Line P and Skaugran surveys. Pages 29-30 in *State of the Pacific Ocean 2006*. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2007/019

# Acidification: Aragonite Saturation Horizon

Aragonite Saturation Horizon

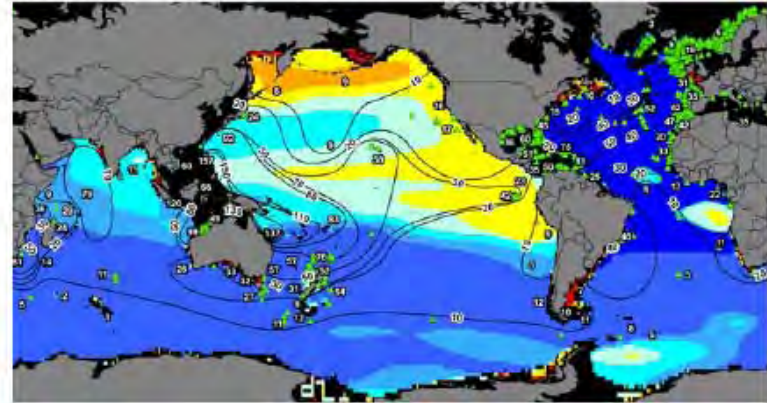


2040

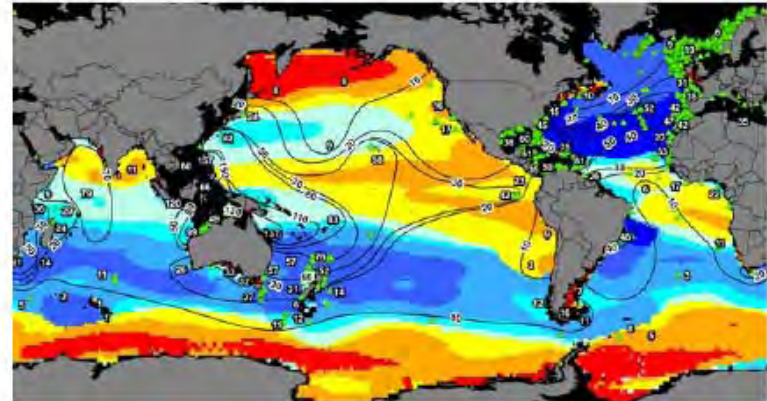
2099

Guinotte, J.M. and V. J. Fabry. 2008. Ocean Acidification and Its Potential Effects on Marine Ecosystems. *Ann. N.Y. Acad. Sci.* 1134: 320–342

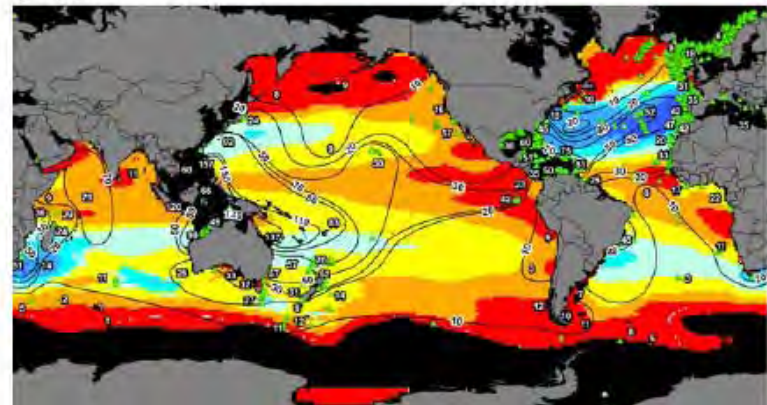
A-Preind



B-2040



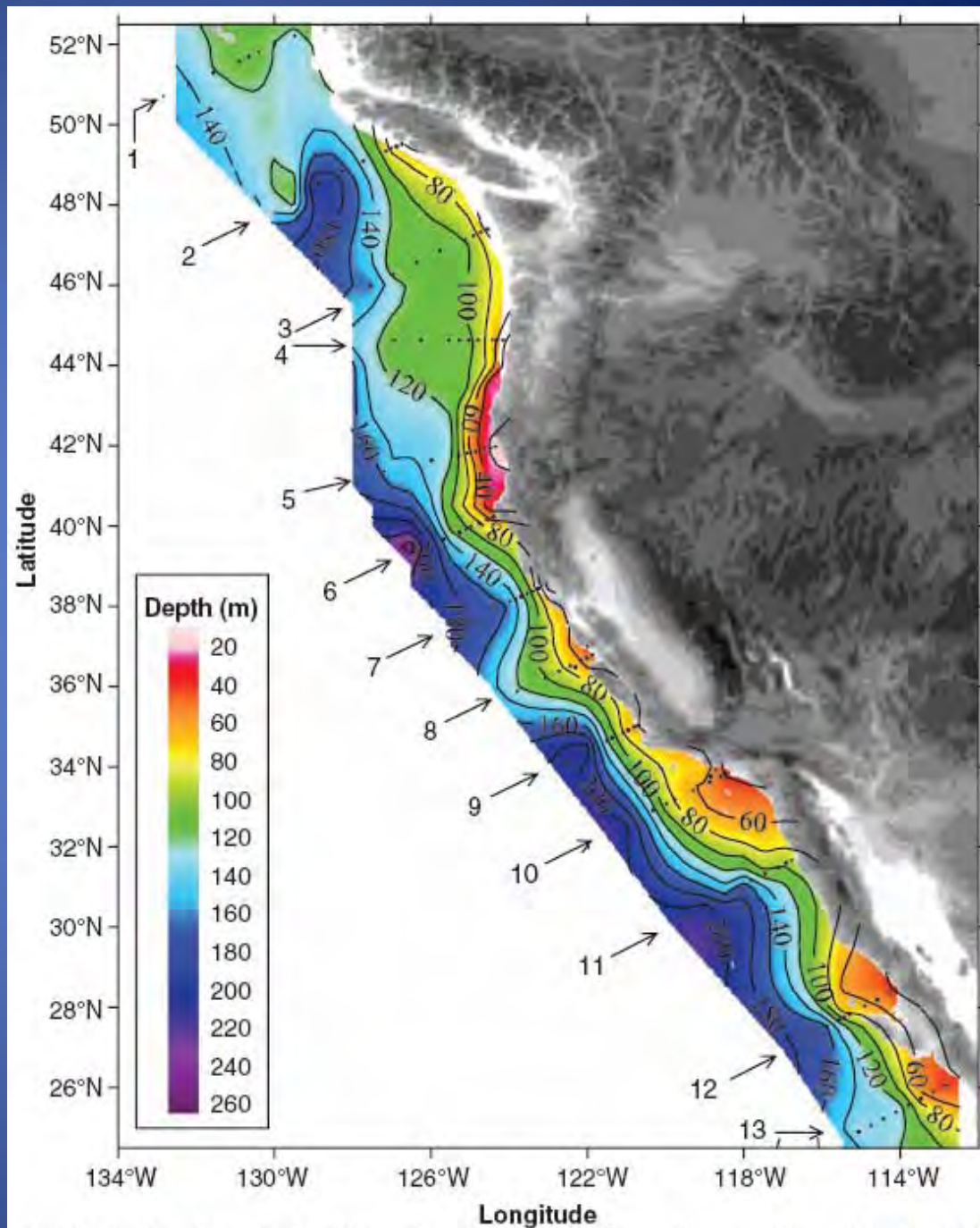
C-2099



# Acidification: Aragonite Saturation Horizon

Aragonite Saturation Horizon

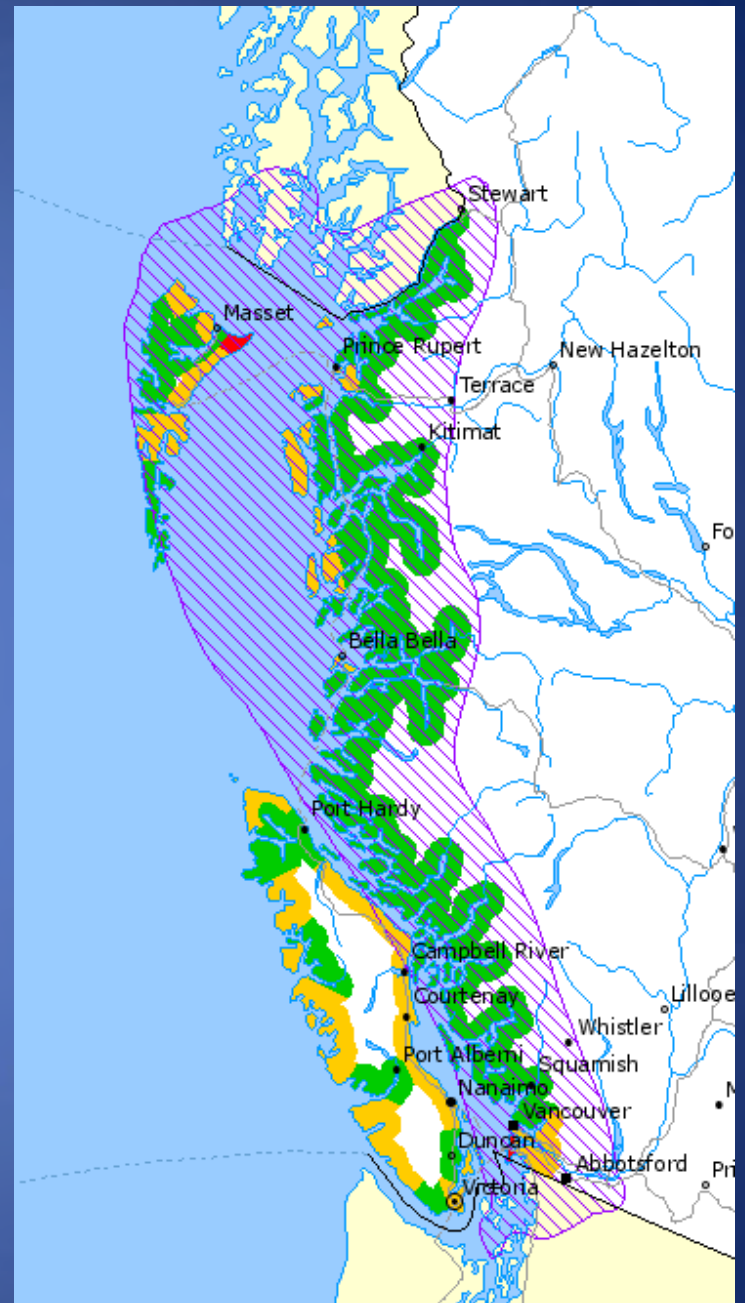
Feely, R. A., Sabine, C. L.,  
Hernandez-Ayon, J. M., Ianson, D.  
and Hales, B. 2008. Evidence for  
upwelling of corrosive "acidified"  
water onto the continental shelf.  
*Science*, 320: 1490-1492





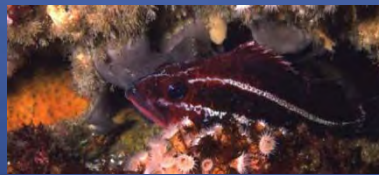
# Sea Level Rise Sensitivity

Shaw, J, R.B. Taylor, D.L. Forbes, M.-H. Ruz, and S. Solomon. 1998. Sensitivity of the Coasts of Canada to Sea-level Rise. Geological Survey of Canada Bulletin 505. Ottawa.



# Types of biological effects

- Poleward shift of species ranges
- Changes in phenology
- Mis-matches and re-assembly of communities
- Increased extinction risk
- Physiological stress
- Invasive species and disease
- Effects of exposure to toxins
- Nutrient enrichment and algal blooms
- Increased vulnerability to other anthropogenic stressors



# General trends in BC

**Primary producers** – Reduction in warmer, more stratified conditions (except seagrasses), but enhanced with upwelling

**Invertebrates** – Potentially strong effects from productivity changes, temperature, acidification, salinity, deoxygenation, nutrients and pollution.

**Fishes** – Some major shifts in distributions and assemblages.  
Major impacts on valuable and iconic species

**Birds, mammals, turtles** – Sensitive indicators

**Select habitat types and 'Ecoregions'** – Unique impacts

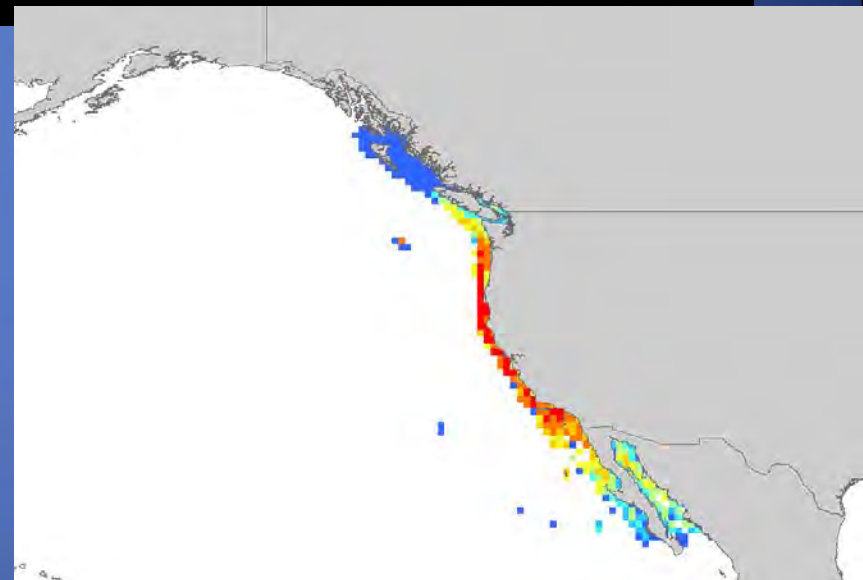
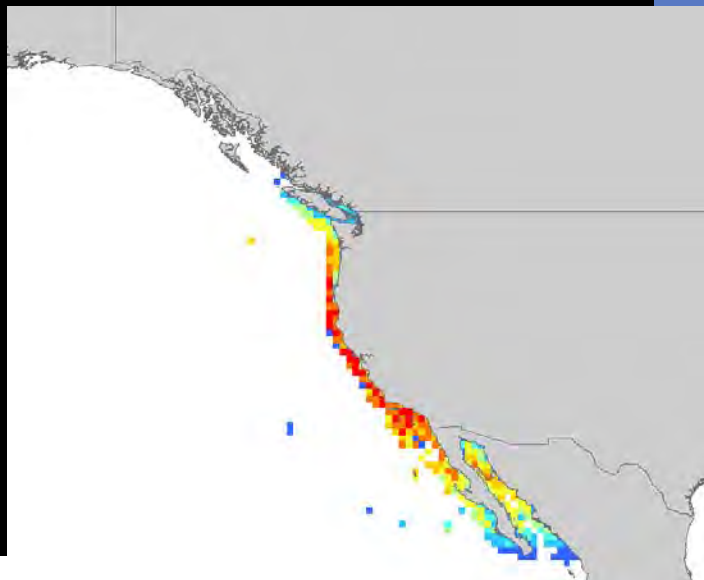
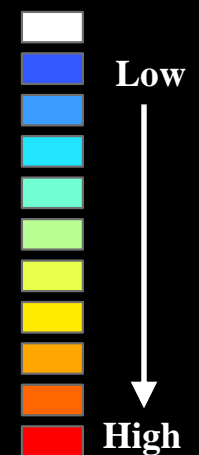
# Range shifts

## Example: Pacific hake

2001

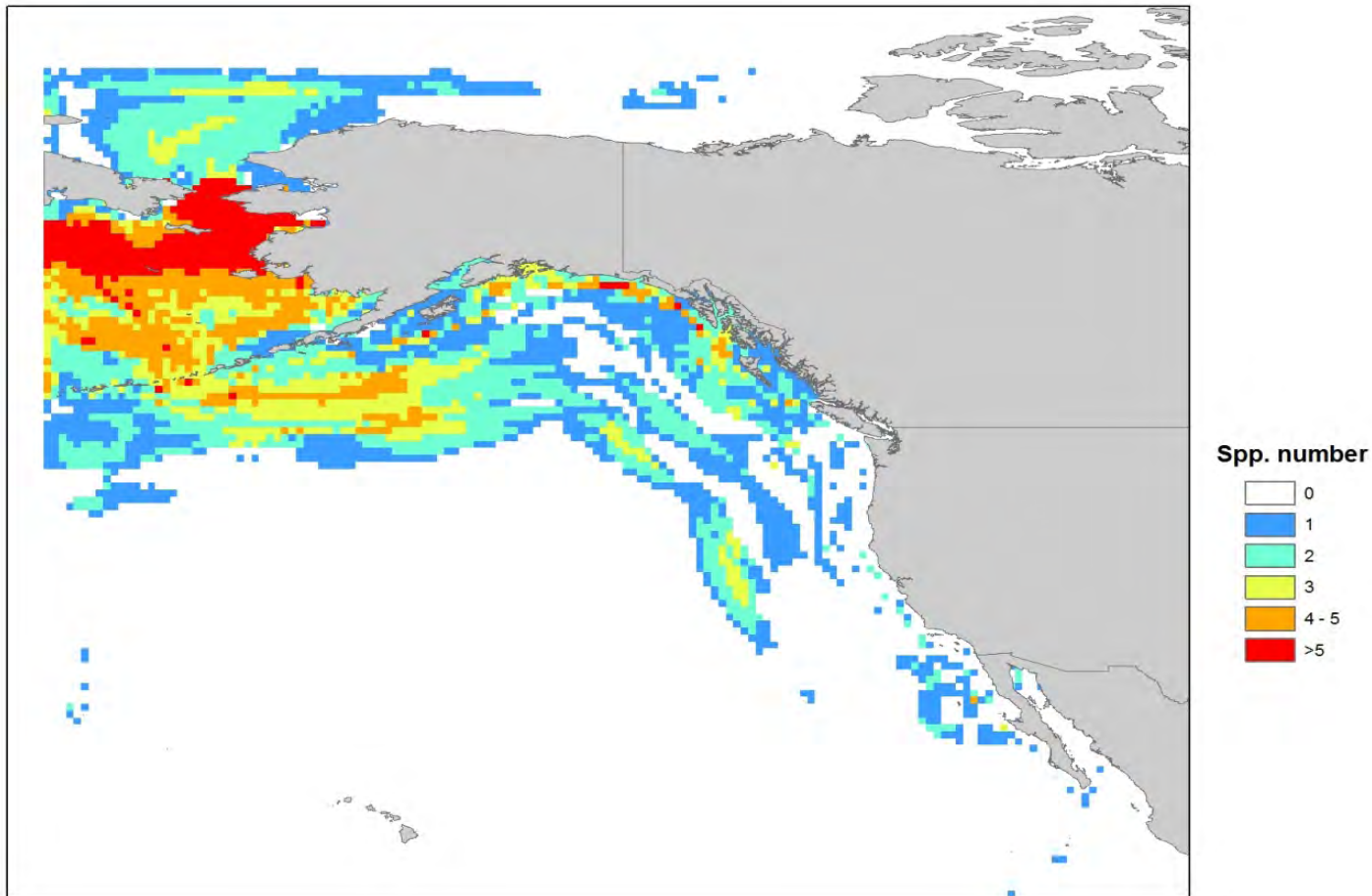
2050

Relative  
abundance



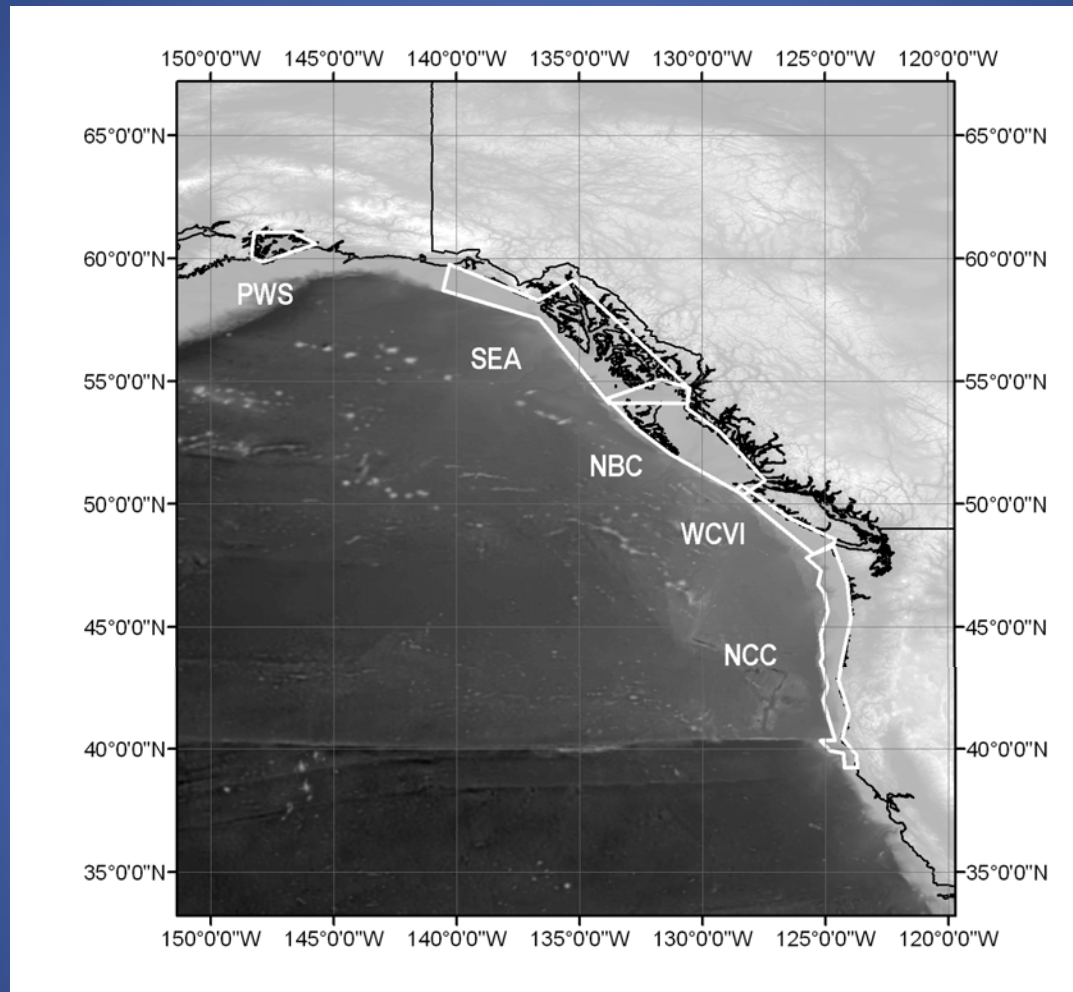
William L. Cheung, Thomas A. Okey and Richard D. Brodeur (In prep) Projecting future change in pelagic nekton communities along the west coast of North America. Session B1, Effects of Climate Change on Fish and Fisheries, Sendai, Japan, April 2010.

# Species invasion (number) by 2055



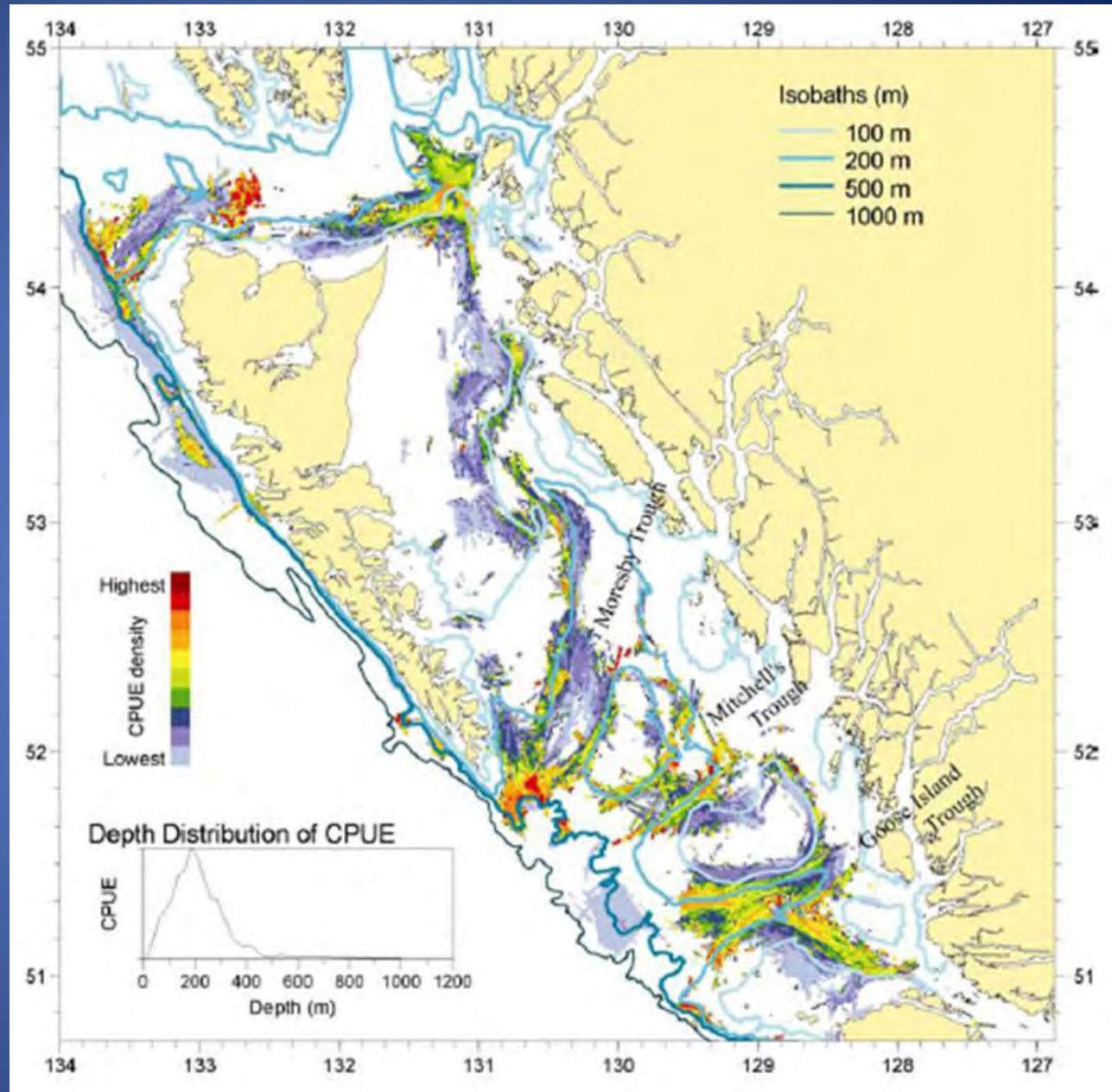
William L. Cheung, Thomas A. Okey and Richard D. Brodeur (In prep) Projecting future change in pelagic nekton communities along the west coast of North America. Session B1, Effects of Climate Change on Fish and Fisheries, Sendai, Japan, April 2010.

# Trophodynamic envelope modelling



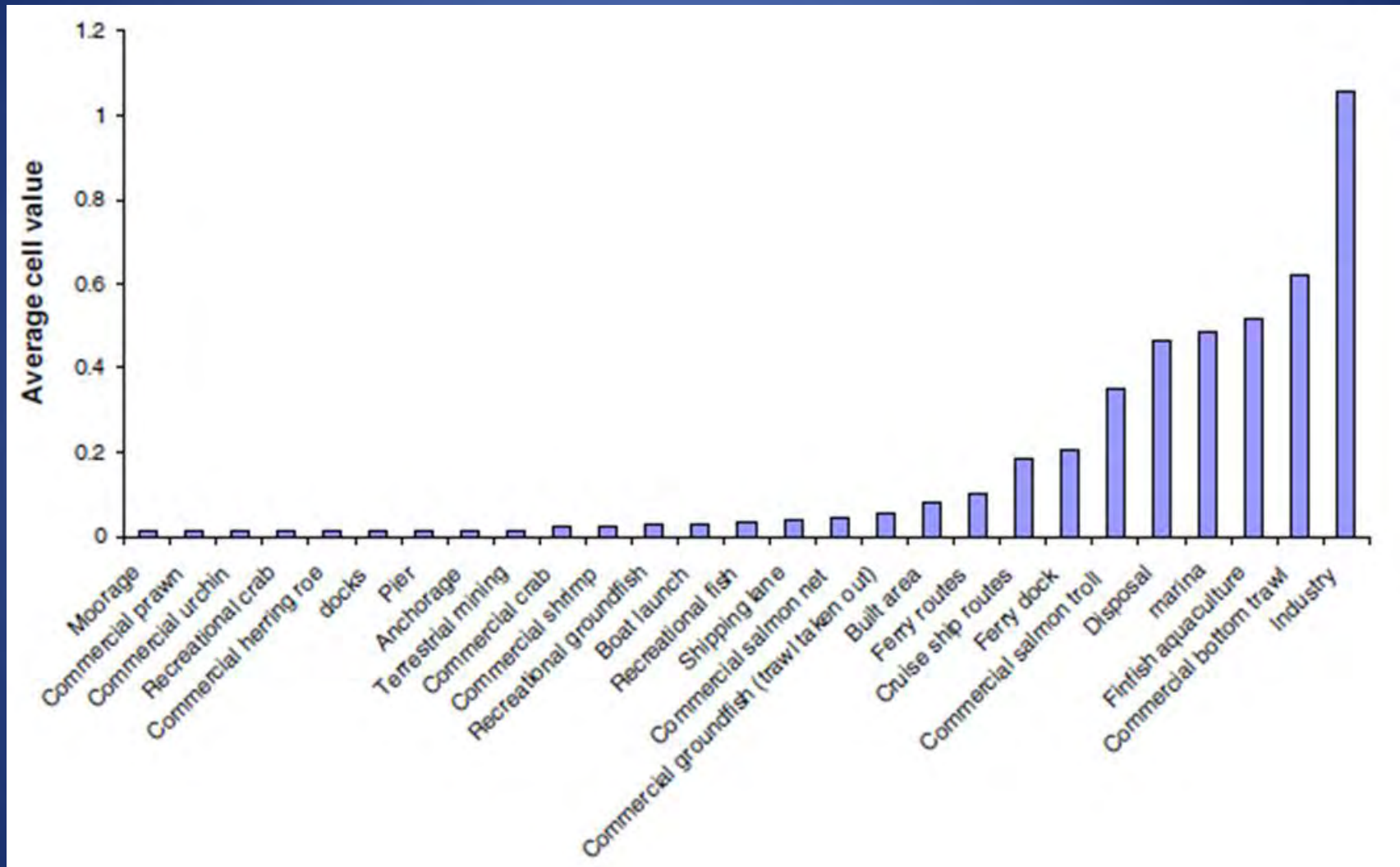
Jameal F. [Samhuri](#), Cameron H. Ainsworth, D. Shallin Busch, William L. Cheung, John Dunne, and Thomas A. Okey, (In prep) Potential impacts of climate change on Northeast Pacific marine ecosystems. Session B2, Effects of Climate Change on Fish and Fisheries, Sendai, Japan, April 2010.

## Spatial distribution of groundfish catch per unit effort (CPUE)



Perry, R. I., B. Crawford, and A. Sinclair. 2007. Chapter 1: Ecosystem Description. Pages 3-45 in B. G. Lucas, S. Verrin, and R. Brown, editors. Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA). Can. Tech. Rep. Fish. Aquat. Sci. 2667: xiii + 104 p.

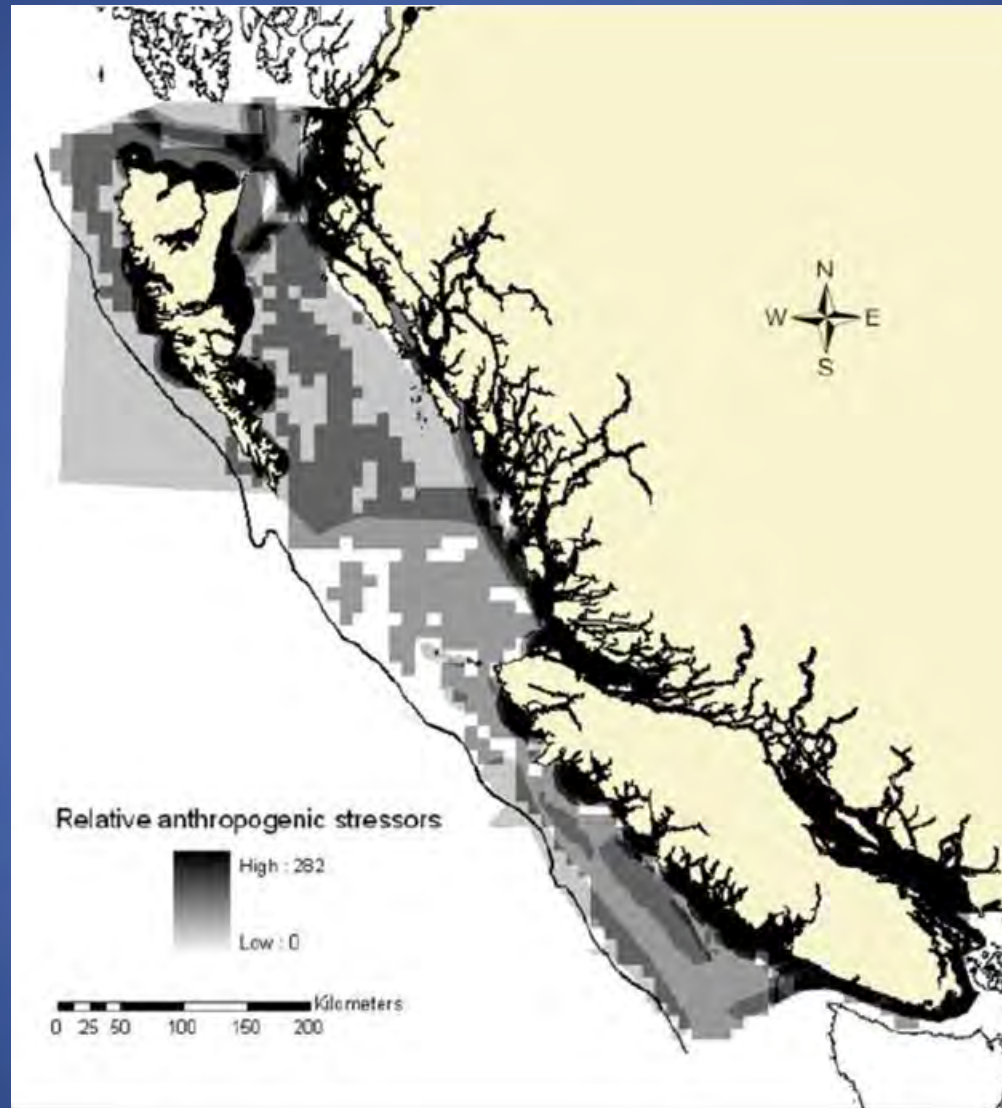
# Relative intensity of anthropogenic activities



Ban, N. and J. Alder. 2008. How wild is the ocean? Assessing the intensity of anthropogenic marine activities in British Columbia. *Aquatic Conservation: Marine and Freshwater Ecosystems* 18:55-85.

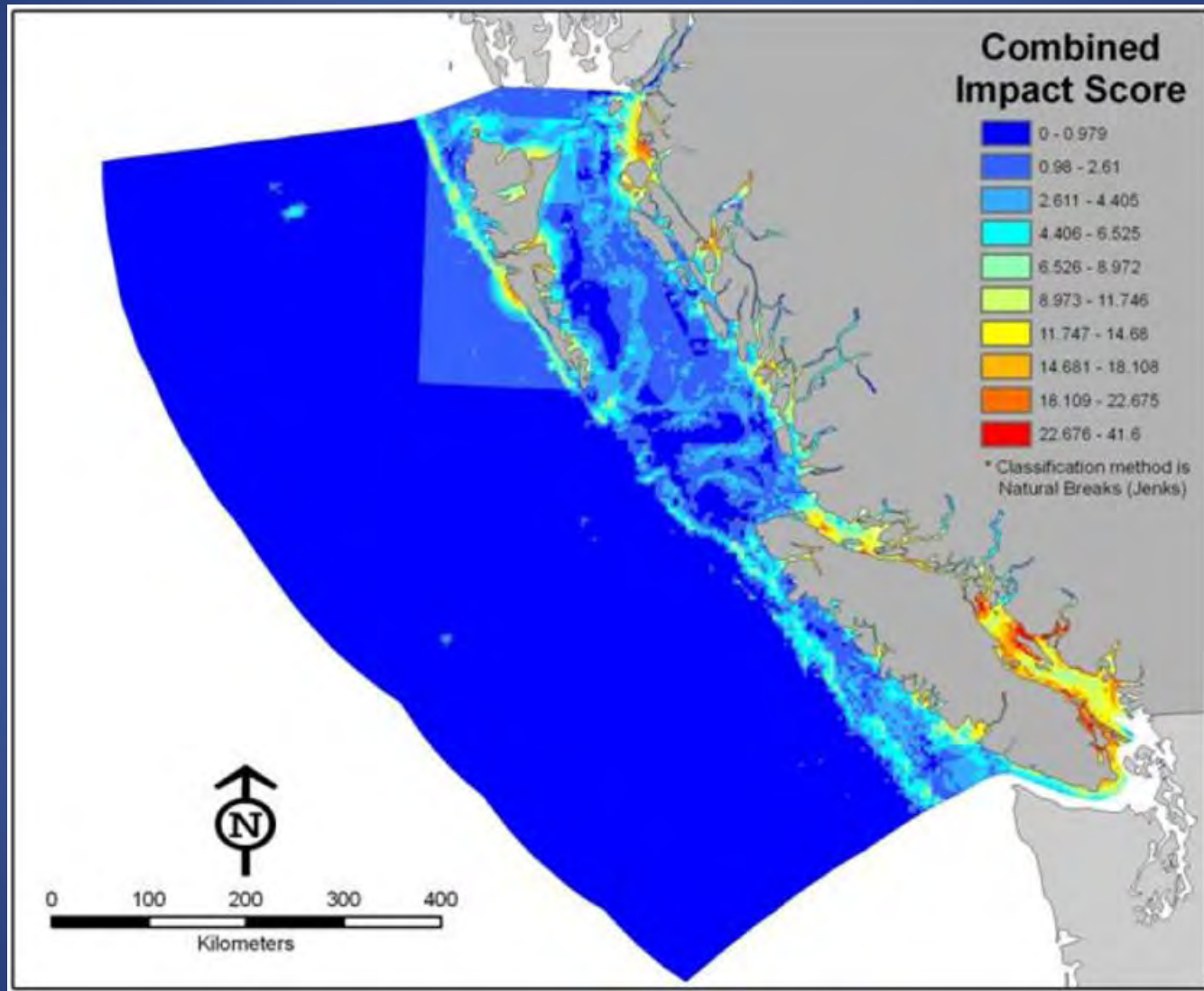


# Intensity of anthropogenic activities



Ban, N. and J. Alder. 2008. How wild is the ocean? Assessing the intensity of anthropogenic marine activities in British Columbia. *Aquatic Conservation: Marine and Freshwater Ecosystems* **18**:55-85.

# Cumulative impacts analyses



Ban, Alidina, & Ardron In prep

# Need a tiered framework

1. **Screening-level assessments** of relative vulnerabilities of system components
2. **Focused assessments & vulnerability reduction** for priority areas or components;
3. **Cost-benefit and feasibility/risk analyses** to identify sets of strategies for sectoral management plans
4. **A climate adaptations implementation plan** which incorporates monitoring and adaptive feedback.

Credit: Paul Marshall and others in IMAGINE group

# Acknowledgements



PEW FELLOWS PROGRAM  
IN MARINE CONSERVATION

- Pew Fellows Program in Marine Conservation
- William Cheung, Ric Brodeur, Daniel Pauly, etc
- Jameal Samhuri, Cameron Ainsworth, Shalin Busch, William Cheung, and John Dunne
- Joint PICES/ICES Working Group on Forecasting Climate Change Impacts on Fish and Shellfish (Anne Hollowed and many others)
- IMAGINE Group
- Gordon and Betty Moore Foundation
- CSIRO Marine Climate Impacts Group
- West Coast Aquatic
- NOAA / NMFS
- CPAWS / WWF
- DFO
- Paul Marshall, IMAGINE group, and many others...

GORDON AND BETTY  
**MOORE**  
FOUNDATION

