A spatial marine climate change vulnerability assessment to inform marine spatial planning

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Climate Smart CMSP Symposium, Inaugural National Adaptation Forum
April 2-4, 2013, Denver Marriott City Center

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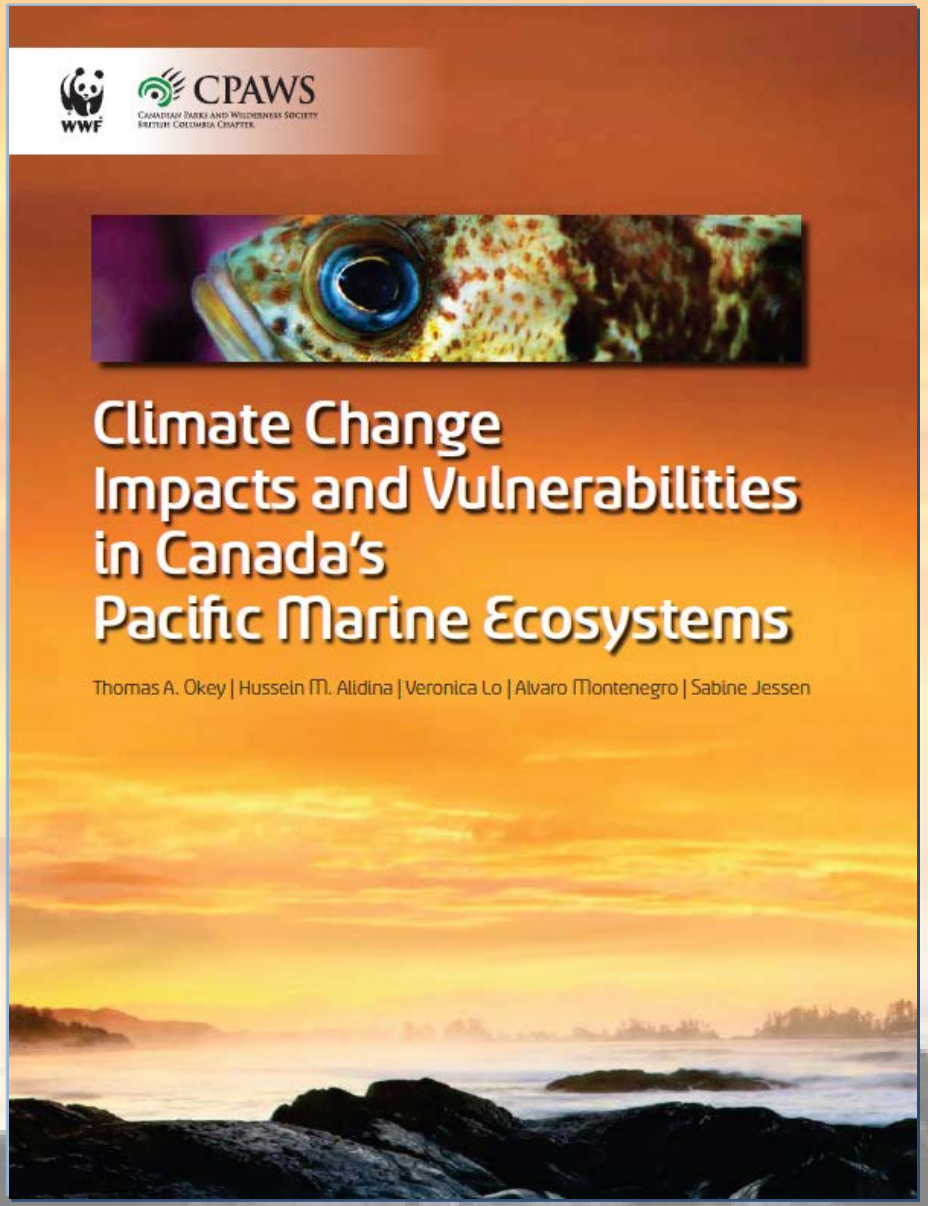
BRITISH COLUMBIA CHAPTER

WWF

PEW FELLOWS PROGRAM
IN MARINE CONSERVATION

University of Victoria



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1. **Physical changes**
   - Literature review
   - Model projections
2. **Biological changes**
   - Literature review
   - Observations
3. **Preliminary Vulnerability Assessment**
   - Qualitative & Quantitative
   - Summaries by Habitat & Ecosection

Talk outline

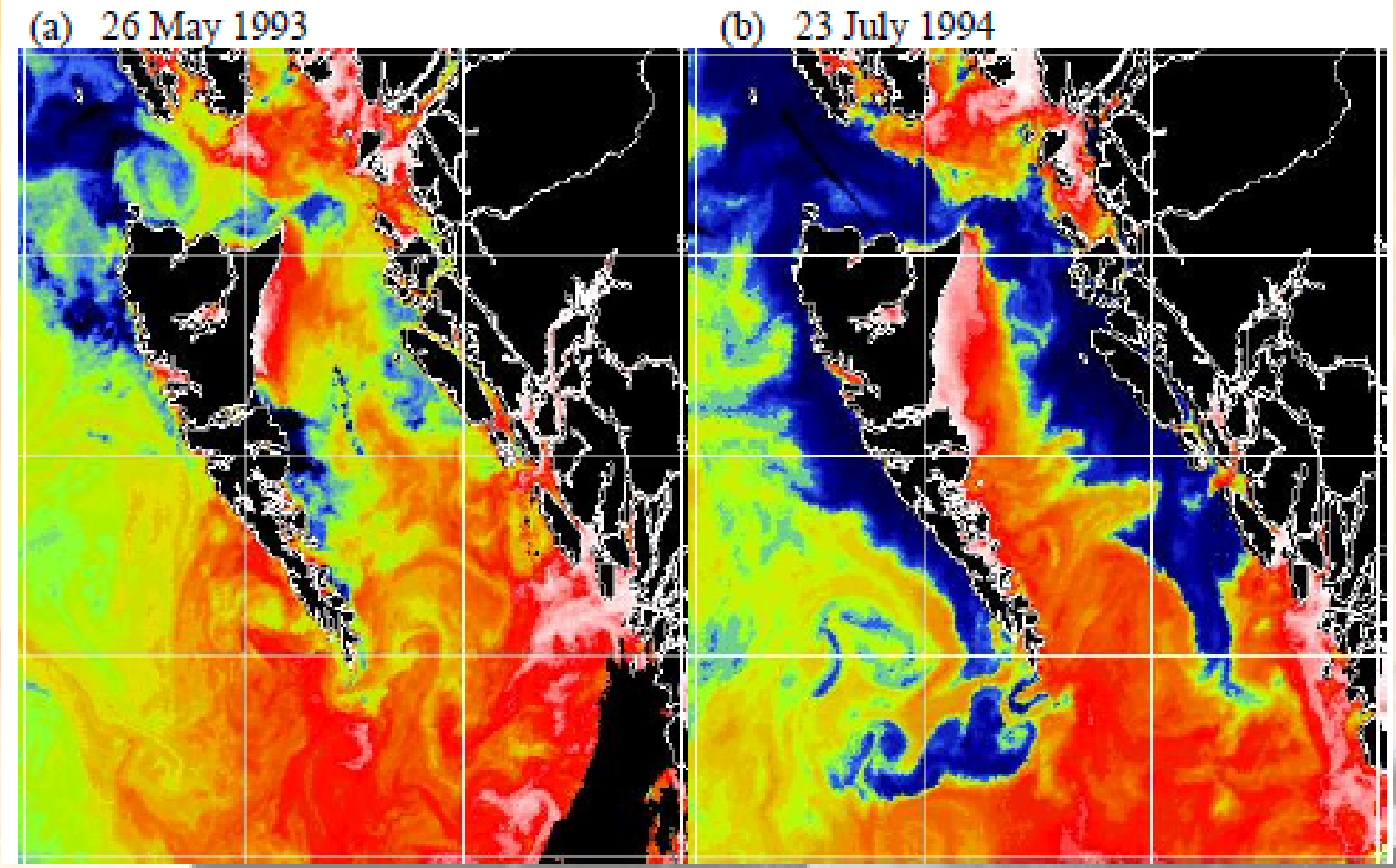
- Regional context
- Vulnerability approach/methods
- Some outputs
- Next steps


Canada's Pacific Ecosystems
Canada
United States
Mexico
Mongolia
China
Japan
South Korea
Thailand
Vietnam
Philippines
Malaysia
Indonesia
Papua New Guinea
Australia
Peru
Chile
Colombia
Ecuador
Cuba
Guatemala
Nicaragua
Bering Sea
Gulf of Alaska
Sea of Okhotsk
East China Sea
Philippine Sea
South China Sea
Java Sea
Banda Sea
Arafura Sea
Solomon Sea
Coral Sea
Gulf of California
Gulf of Mexico
Caribbean Sea
Hudson Bay
Northwestern Passages
Great Australian Bight
Pacific Ocean
South Pacific Ocean

A dynamic coastal transition zone

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

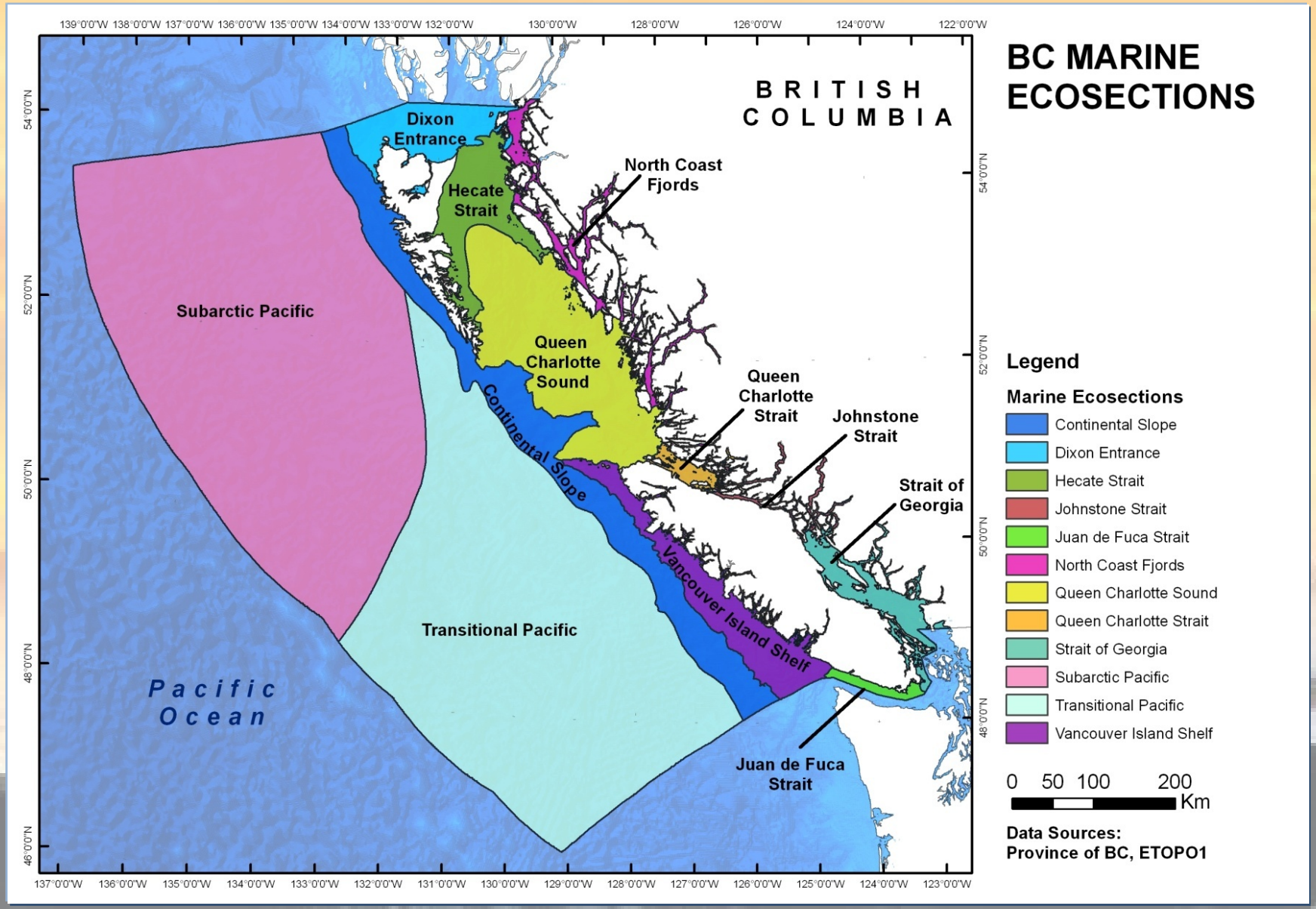
Highly textured: e.g. SST



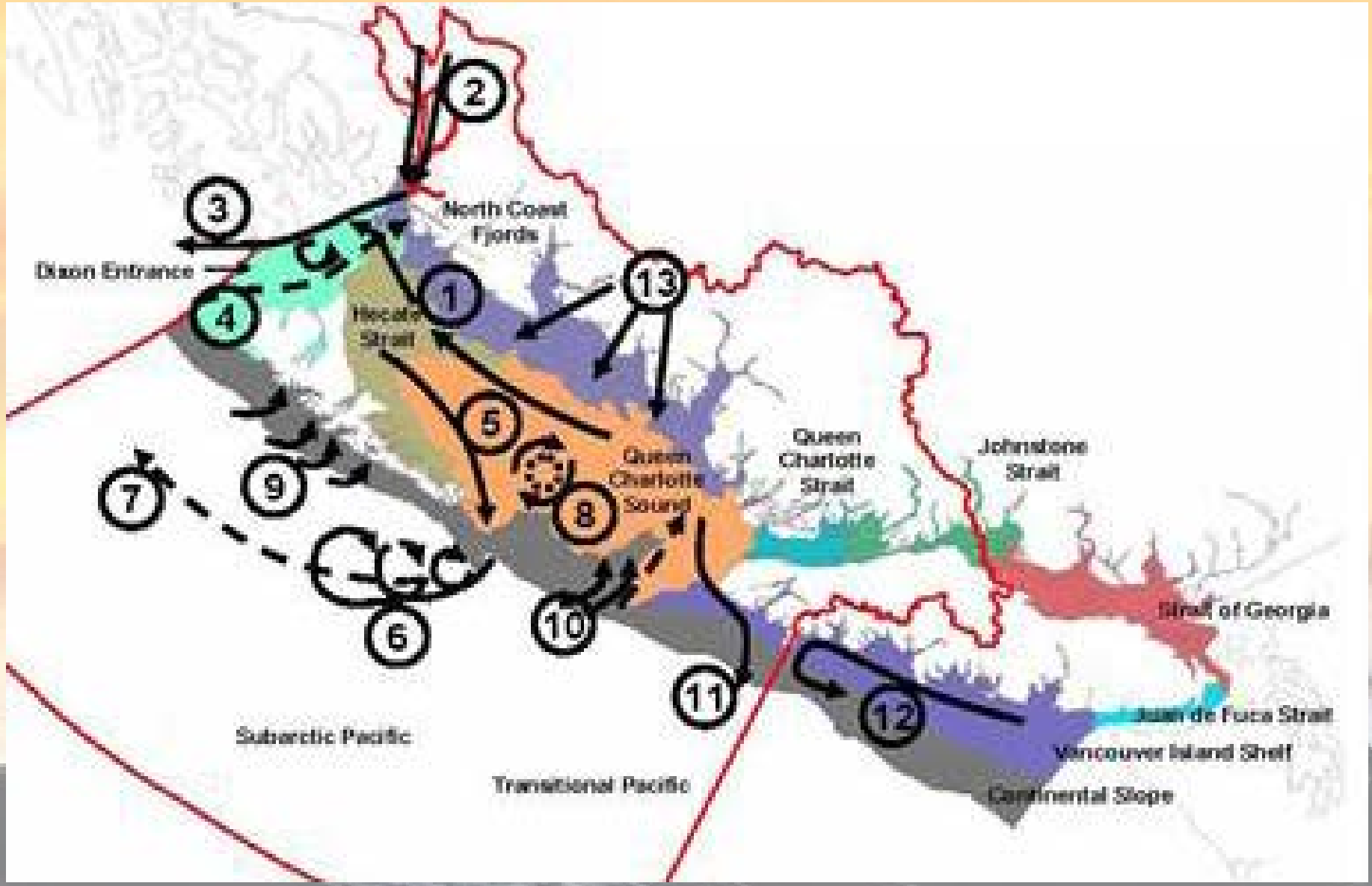
Sea surface temperature (SST) images of observations by AVHRR sensor on NOAA satellites

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.

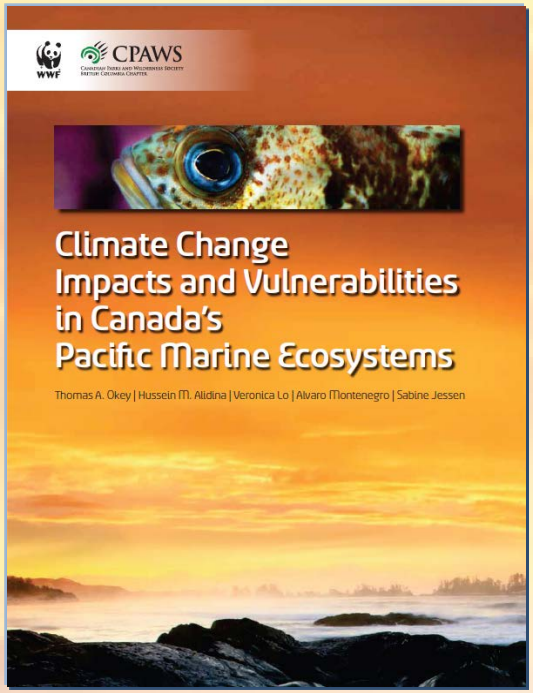
Marine Ecosections of BC



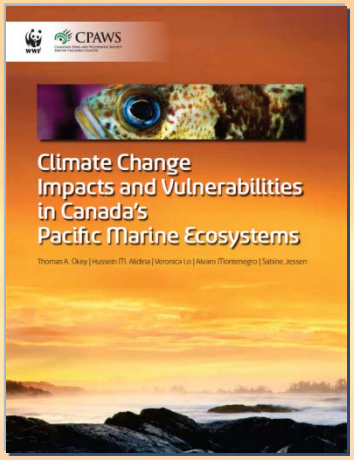
Unique features and dynamics



Expected physical changes



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



Types of biological effects

Shifts in species distributions and community structure

- Poleward shift of species ranges
- Changes in phenology
- Mis-matches and re-assembly of communities

Increased occurrence and establishment of new species

- Anomalous occurrences, southern species range expansion
- Invasive species and disease

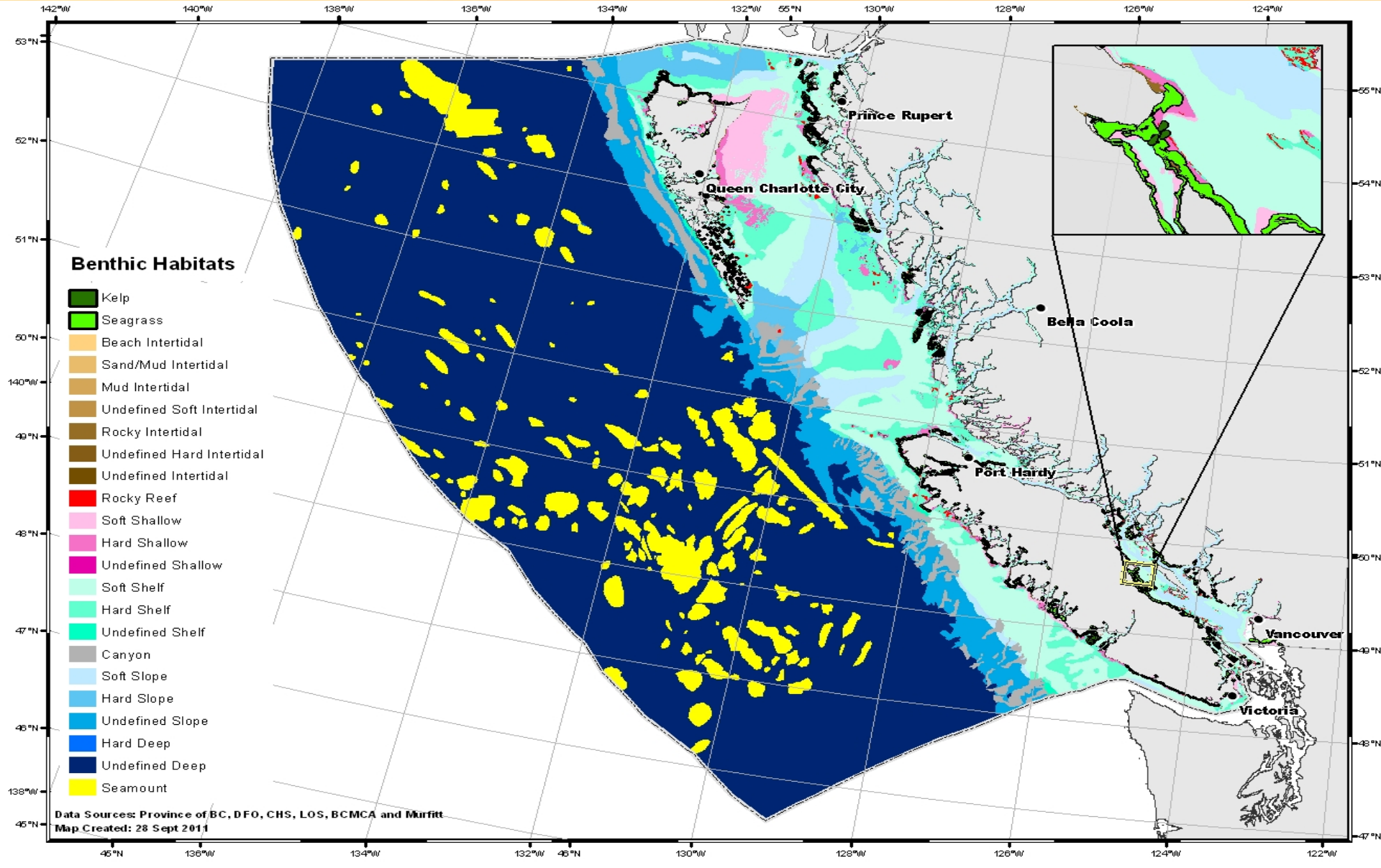
Loss of biodiversity and changes in favourable conditions

- Physiological stress (Temperature, pH, O_2)
- Increased extinction risk
- Effects of exposure to toxins
- Nutrient enrichment and algal blooms

Changes due to Interactions with other stressors

- Increased vulnerability to other anthropogenic stressors
- Decreased resilience to climate changes

Habitat-based approach



Expert-based sensitivity ratings

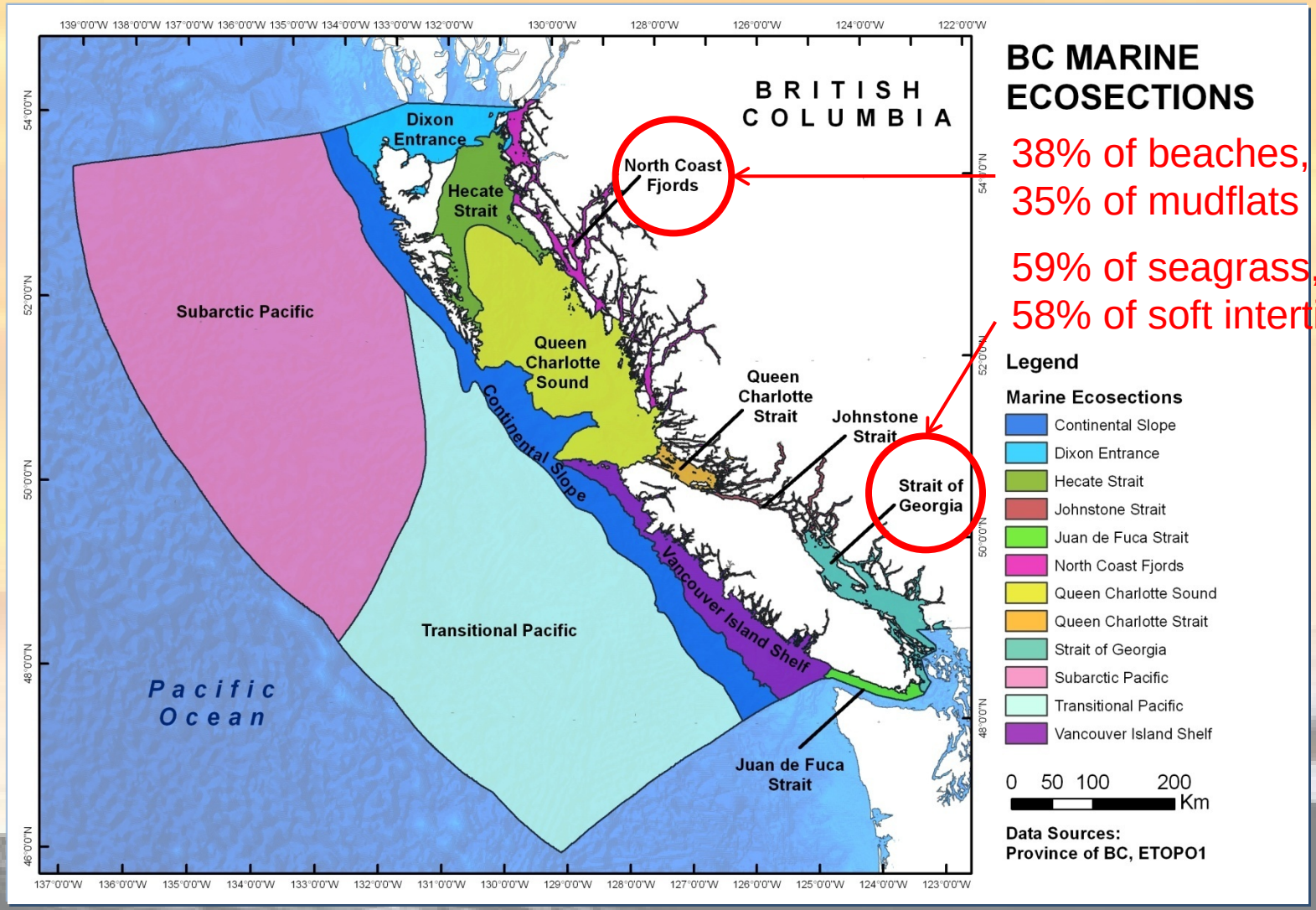
CLIMATE VARIABLE	HABITAT TYPE | BOTTOM TYPE																	
	SALT MARSH	MUDFLATS	BEACH	ROCKY INTERTIDAL	KELP	SEA GRASS	ROCKY REEF	SUSPENSION REEF	SOFTSHELF	SOFT SLOPE	SOFT DEEP	HARD SHELF	HARD SLOPE	HARD DEEP	CANYON	SEAMOUNT		SURFACE WATERS		DEEP PELAGIC WATERS
Temperature	1.8	1.8	1.7	3.1	2.9	1.9	2.2	2.2	1.7	0.6	0.5	1.9	1.2	0	1.7	0		2.5		1.9
Acidification	2.4	2.4	1.8	2.7	2.0	2.1	2.2	2.5	2.6	3.4	2.5	2.7	3.4	3.4	2.6	2.6		3.2		2.7
UV light	1.9	1.7	1.8	2.3	1.6	1.5	1.7	1.8	0	0	0	0	0	0	0	0		2.5		0.8

(Halpern et al 2008, Teck et al. 2010)

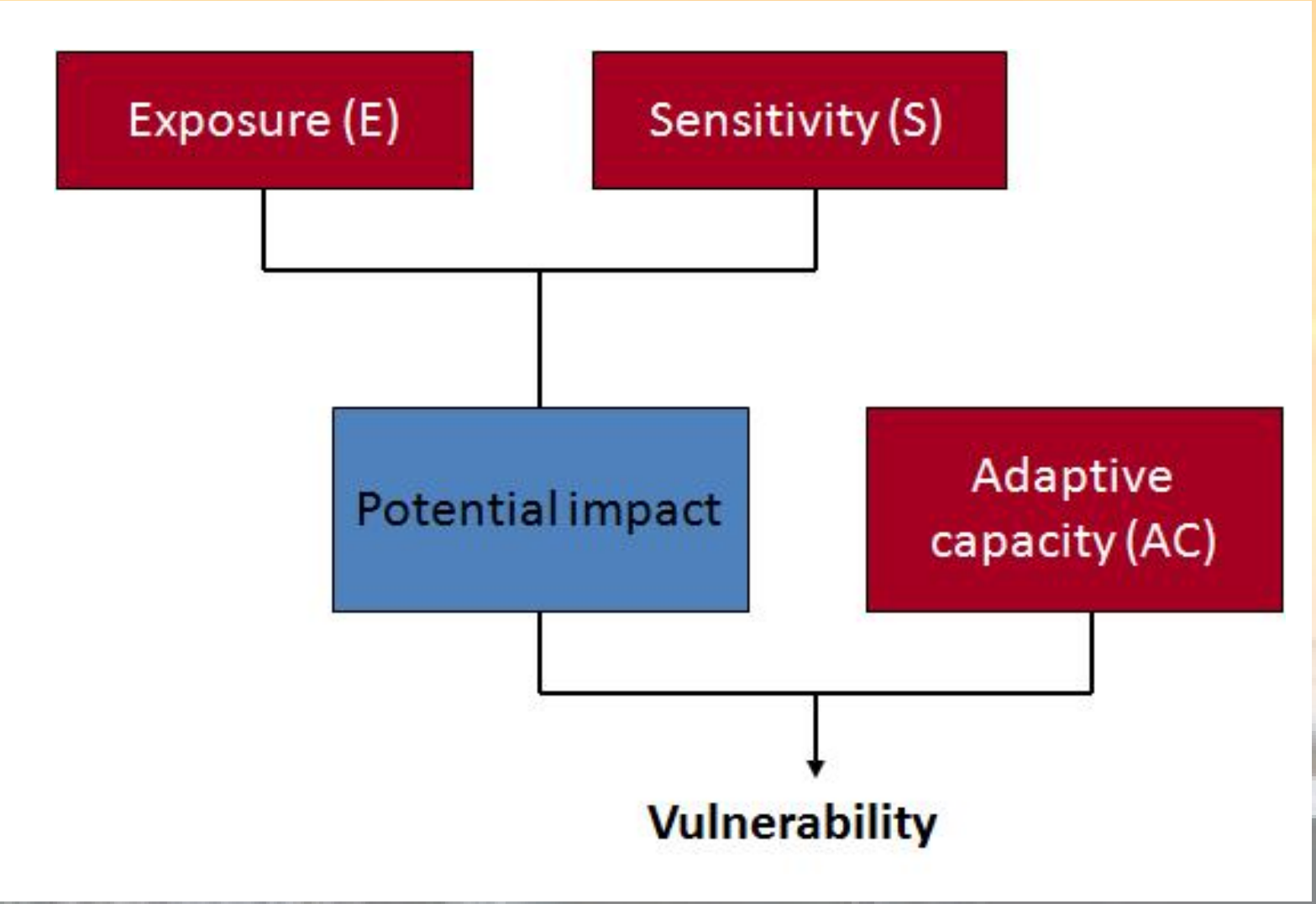
Percent of each habitat in each Ecosection of Pacific Canada

	Dixon Entrance	*Hecate Strait*	*North Coast Fjords*	*Queen Charlotte Sound*	*Queen Charlotte Strait*	*Johnstone Strait*	*Vancouver Island Shelf*	*Juan de Fuca Strait*	*Continental Slope*	*Strait of Georgia*	*Subarctic Pacific*	*Transitional Pacific*
Kelp	24	13	8	18	11	0	21	3	1	2	0	0
Seagrass	4	3	7	2	2	4	18	0	1	59	0	0
Beach	1	14	38	0	10	11	14	0	8	5	0	0
Mudflats	0	1	35	0	13	38	9	0	1	2	0	0
Soft Intertidal	5	7	5	0	4	6	12	1	1	58	0	0
Rocky Intertidal	13	17	15	6	5	5	21	2	4	12	0	0
Soft Shallow	7	57	6	3	2	3	9	2	1	10	0	0
Hard Shallow	7	27	6	31	1	1	19	2	1	5	0	0
Shallow Rocky Reef	4	13	16	9	0	4	30	1	2	21	0	0
Deep Rocky Reef	11	44	5	32	0	3	0	2	3	0	0	0
Soft Shelf	4	10	10	34	2	2	25	2	4	7	0	0
Hard Shelf	10	9	4	40	2	1	13	1	19	2	0	0
Canyon	0	0	0	0	0	0	1	0	89	0	2	8
Soft Slope	4	0	10	25	1	3	1	1	45	11	0	0
Hard Slope	57	0	0	23	0	0	0	0	19	0	0	0
Undefined Slope	0	0	0	0	0	0	0	0	76	0	2	21
Deep	0	0	0	0	0	0	0	0	1	0	56	44
Seamount	0	0	0	0	0	0	0	0	0	0	39	61
Total area	2.4	2.8	2.0	8.0	0.5	0.5	3.7	0.3	7.4	1.8	37.7	32.8

Marine Ecosections of British Columbia



Vulnerability

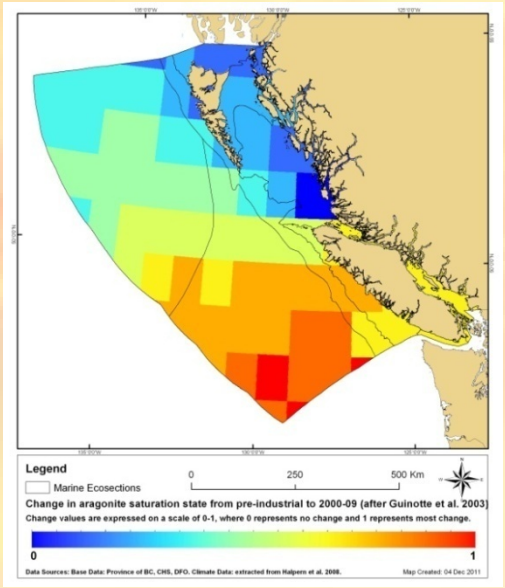


Allen report (2005)

Exposure

(Acidification)

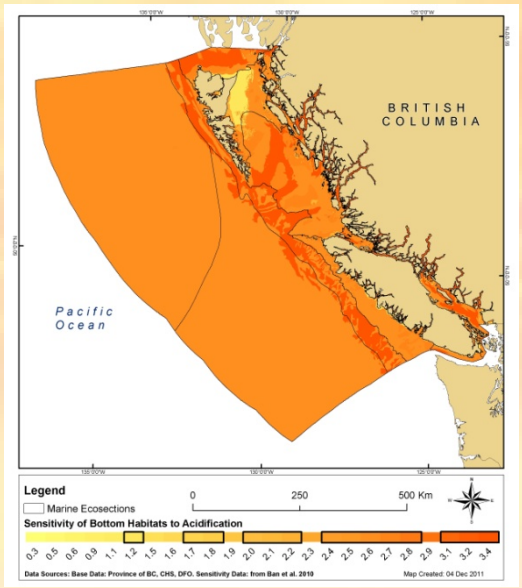
Predicted change in Aragonite Saturation State

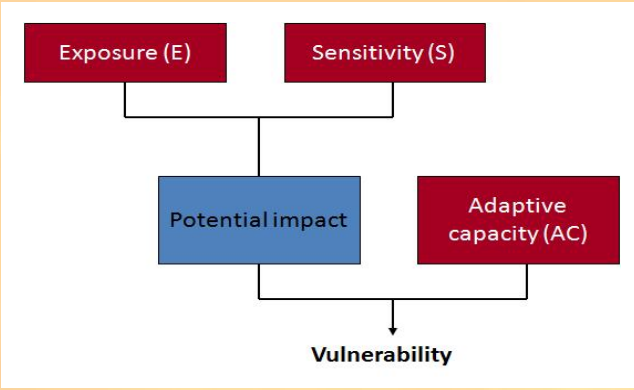


Sensitivity

of Habitat to Acidification

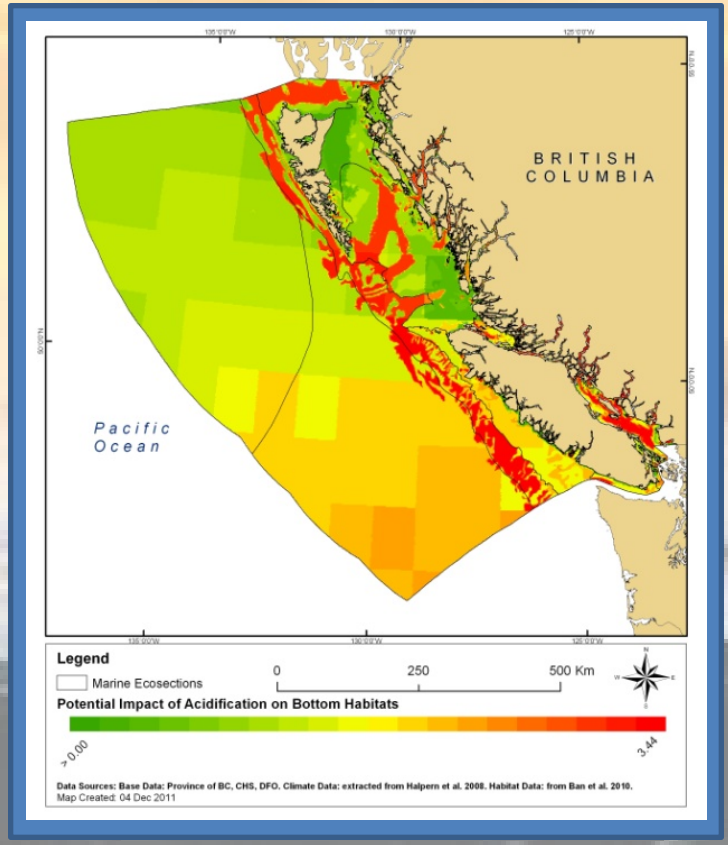
After Teck et al. 2010



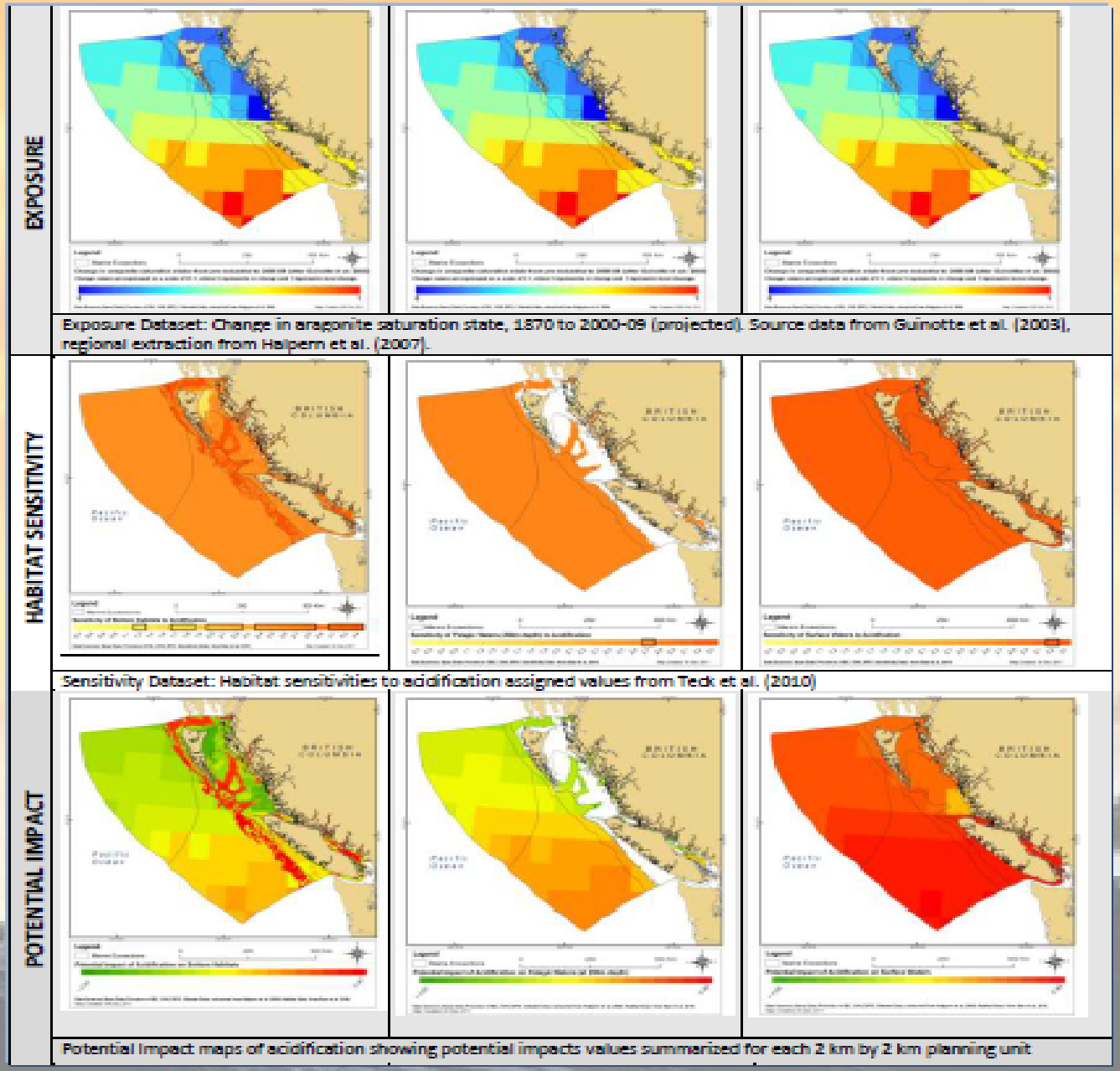


Potential Impact

of Acidification on Habitats



Sea floor Water column Surface



Mean potential impact on **habitats**

DEPTH RANGE	HABITAT/BOTTOM TYPE	TEMPERATURE CHANGE	ACIDIFICATION	UV CHANGE	SUM
	Surface Waters	0.37	0.55	0.45	1.37
← Intertidal	Beach (Intertidal)	0.26	0.55	0.52	1.33
	Mudflats (Intertidal)	0.11	0.51	0.32	0.94
	Rocky Intertidal	0.32	0.92	0.60	1.84
	Soft Intertidal	0.19	0.70	0.46	1.35
	Undefined Intertidal	0.28	1.02	0.65	1.95
0-30m →	Kelp	0.36	0.33	0.30	0.99
	Seagrass	0.23	0.38	0.30	0.91
	Hard Shallow	0.23	0.45	0.35	1.03
	Soft Shallow	0.00	0.22	0.00	0.22
	Undefined Shallow	0.14	0.50	0.24	0.88
	Rocky Reef (Shallow)	0.27	0.38	0.33	0.98
← 30-200m →	Rocky Reef (Non-Shallow)	0.29	0.37	N/A	0.66
	Hard Shelf	0.26	0.47	N/A	0.73
	Soft Shelf	0.22	0.46	N/A	0.68
	Undefined Shelf	0.24	0.56	N/A	0.8

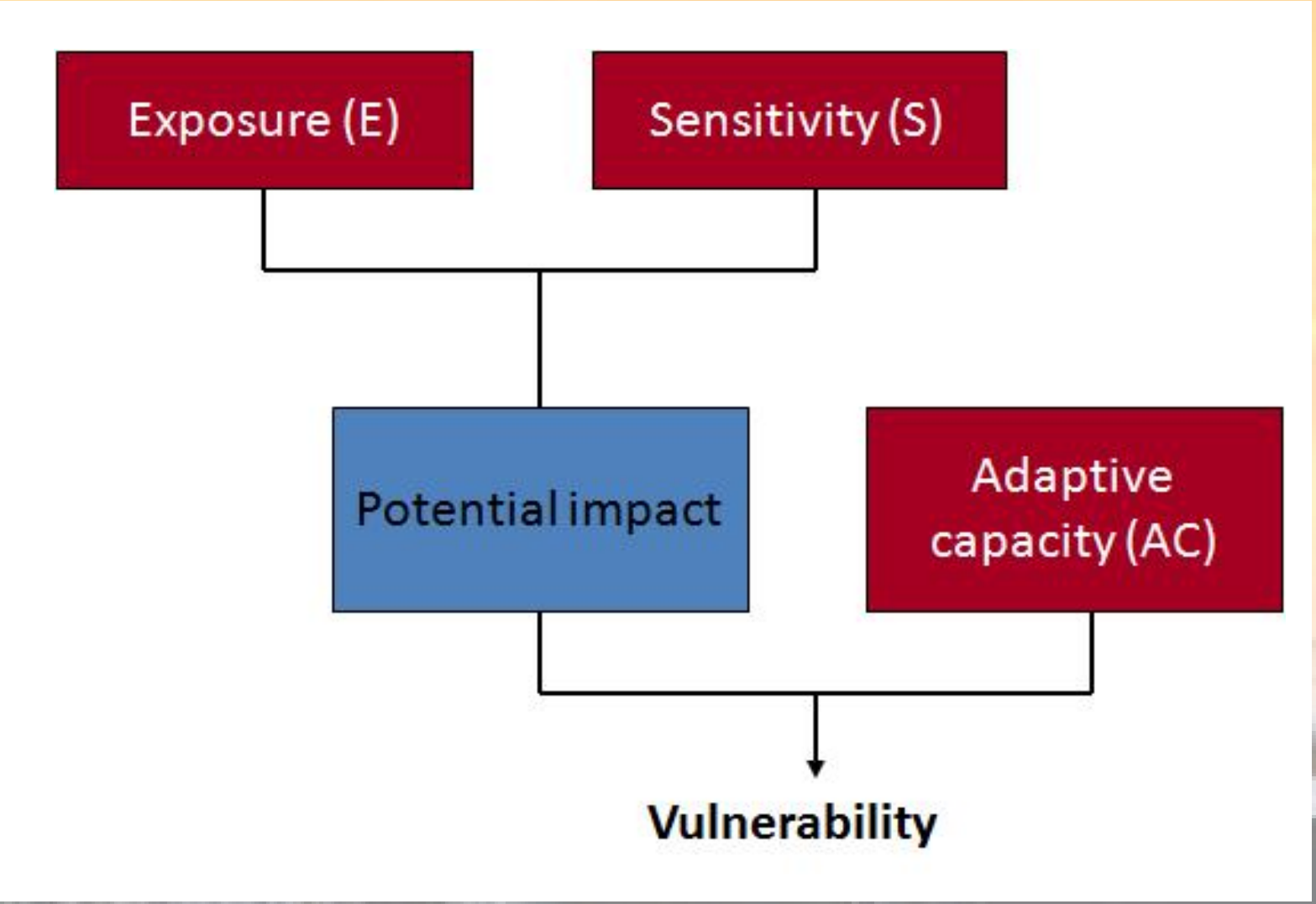
Potential impacts by **Ecosection**

Bottom habitats Water column Surface

ECOSECTION SUMMARY

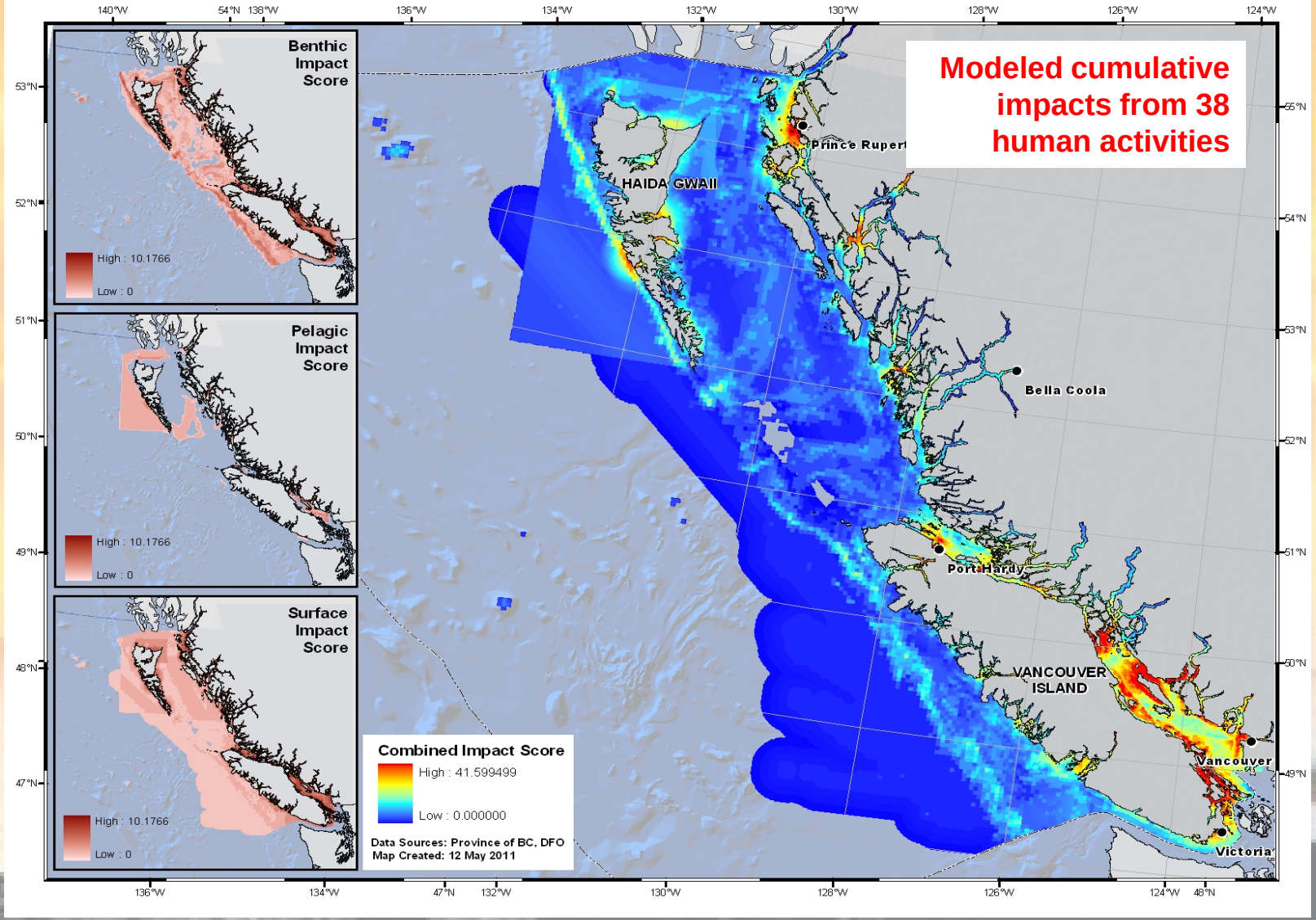
Mean Potential Impact of Acidification / km² on Bottom Habitats		Mean Potential Impact of Acidification/ km² on Pelagic Waters (> 200m)		Mean Potential Impact of Acidification/ km² on Surface Waters	
Ecosection	Impact/km²			Ecosection	Impact/km²
Continental Slope	0.56	Continental Slope	0.46	Continental Slope	0.58
Queen Charlotte Sound	0.46	Queen Charlotte Sound	0.44	Queen Charlotte Sound	0.52
Subarctic Pacific	0.44	Subarctic Pacific	0.46	Subarctic Pacific	0.54
Transitional Pacific	0.47	Transitional Pacific	0.48	Transitional Pacific	0.57
Vancouver Island Shelf	0.50	Vancouver Island Shelf	0.45	Vancouver Island Shelf	0.57
Dixon Entrance	0.49	Dixon Entrance	0.43	Dixon Entrance	0.52
Hecate Strait	0.38	Hecate Strait	0.44	Hecate Strait	0.53
Johnstone Strait	0.54	Johnstone Strait	0.37	Johnstone Strait	0.44
Juan de Fuca Strait	0.53	Juan de Fuca Strait	0.47	Juan de Fuca Strait	0.59
North Coast Fjords	0.49	North Coast Fjords	0.31	North Coast Fjords	0.43
Queen Charlotte Strait	0.51	Queen Charlotte Strait	0.37	Queen Charlotte Strait	0.49
Strait of Georgia	0.49	Strait of Georgia	0.45	Strait of Georgia	0.50

Vulnerability

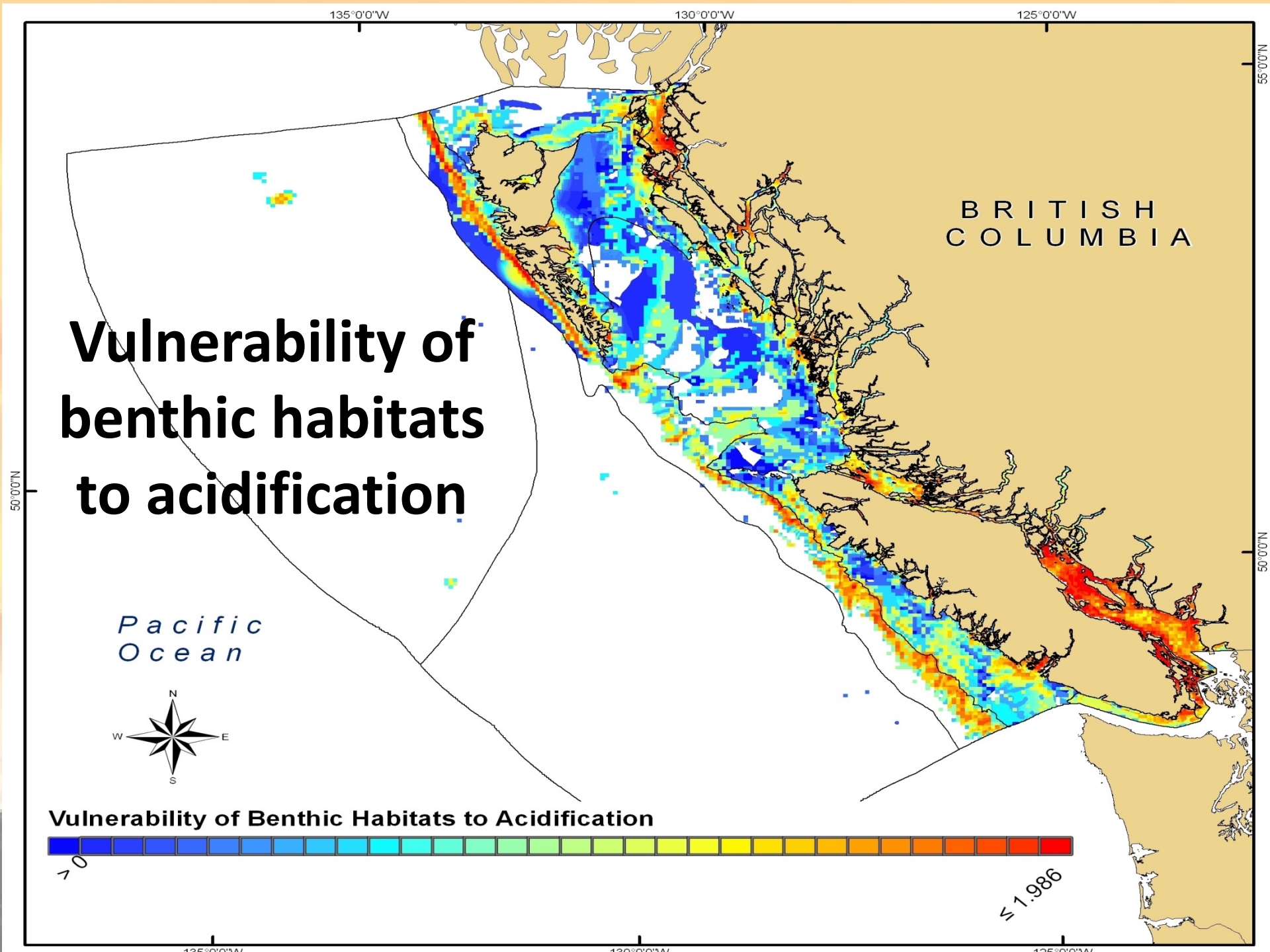


Allen report (2005)

Incorporating non-climate stressors



Ban, N.C., H. M. Alidina, and J.A. Ardron. 2010. Cumulative impact mapping: Advances, relevance and limitations to marine management and conservation, using Canada's Pacific waters as a case study. Marine Policy 34: 876–886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Vulnerability of benthic habitats to acidification
Pacific
Ocean
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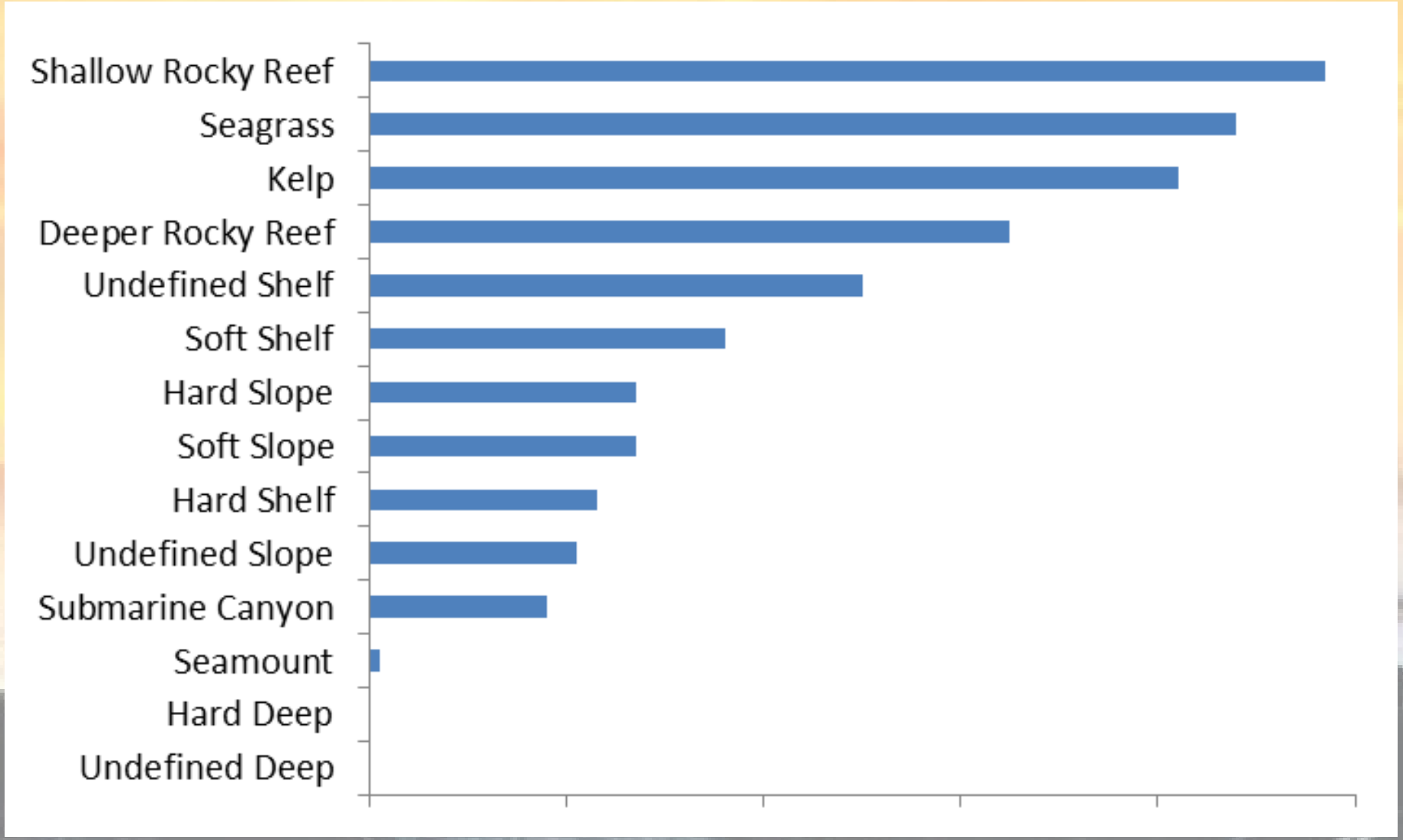
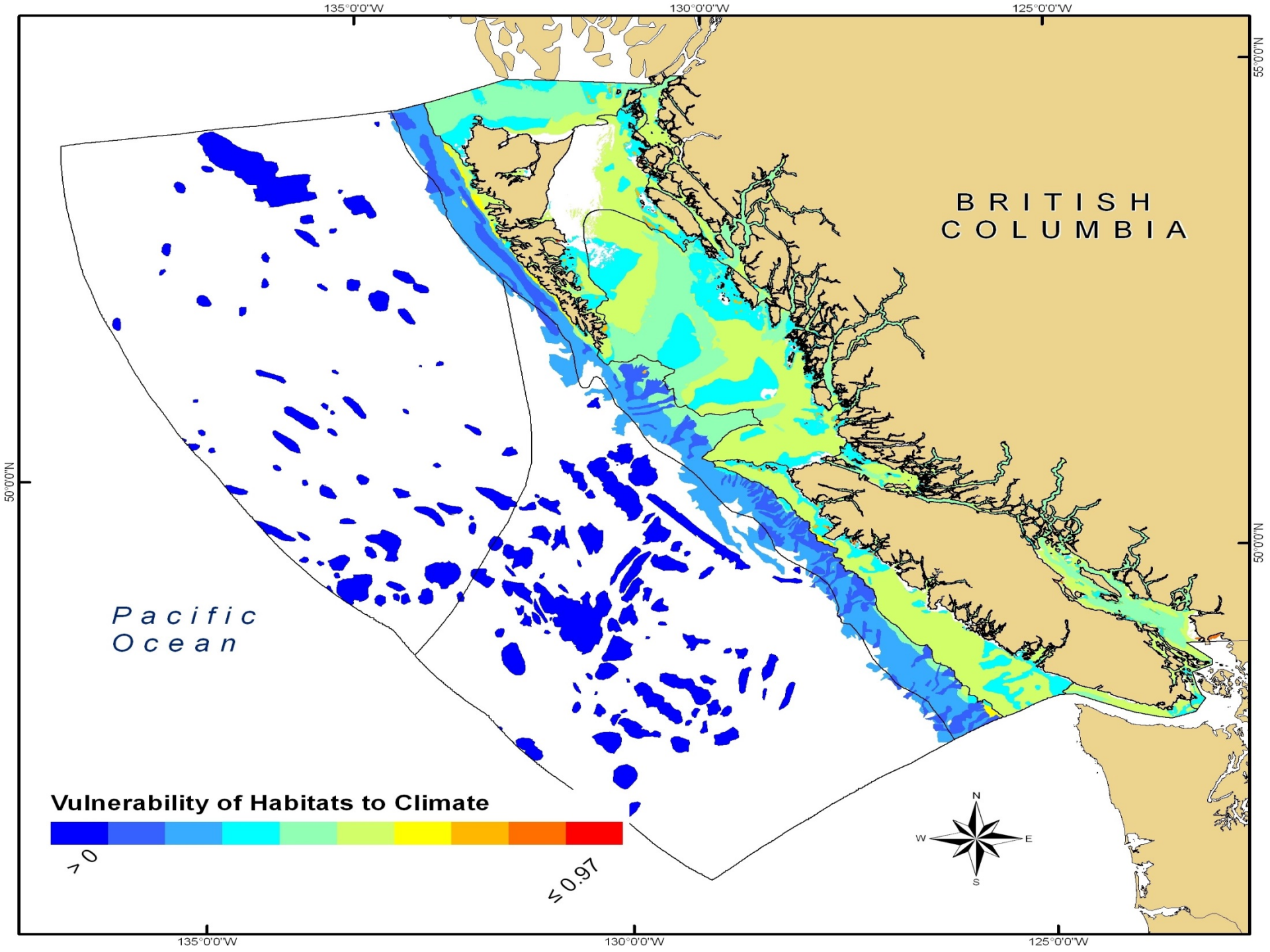
Vulnerability of Benthic Habitats to Acidification
> 0
≤ 1.986

Estimation of vulnerability of **habitats** to climate change

	Standardized scores for mean potential climate impact/km^2 by habitat/bottom type			Sum of standardized potential climate score (S)	Standardized anthropogenic impact score (CI)	Habitat vulnerability to climate S ÷ (1/CI)
	Acidificat-ion	Temperature Change	UV Change			
Kelp	0.32	0.35	0.29	0.96	0.86	0.82
Seagrass	0.37	0.23	0.29	0.89	1.00	0.88
Rocky Reef (Shallow)	0.38	0.27	0.33	0.97	1.00	0.97
Rocky Reef (Non-Shallow)	0.36	0.28	n/a	0.65	1.00	0.65
Hard Shelf	0.46	0.25	n/a	0.71	0.33	0.23
Soft Shelf	0.45	0.22	n/a	0.67	0.54	0.36
Undefined Shelf	0.55	0.23	n/a	0.78	0.64	0.50
Soft Slope	0.55	n/c	n/a	0.55	0.49	0.27
Hard Slope	0.56	n/c	n/a	0.56	0.47	0.27
Undefined Slope	0.60	n/c	n/a	0.60	0.35	0.21
Undefined Deep	0.44	n/c	n/a	0.44	0.00	0.00
Hard Deep	0.44	n/c	n/a	0.44	0.00	0.00
Seamount	0.44	n/c	n/a	0.44	0.01	0.01
Canyon	0.46	n/c	n/a	0.46	0.39	0.18

Estimated relative vulnerabilities of **Habitats** to climate change

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Vulnerability of Habitats to Climate
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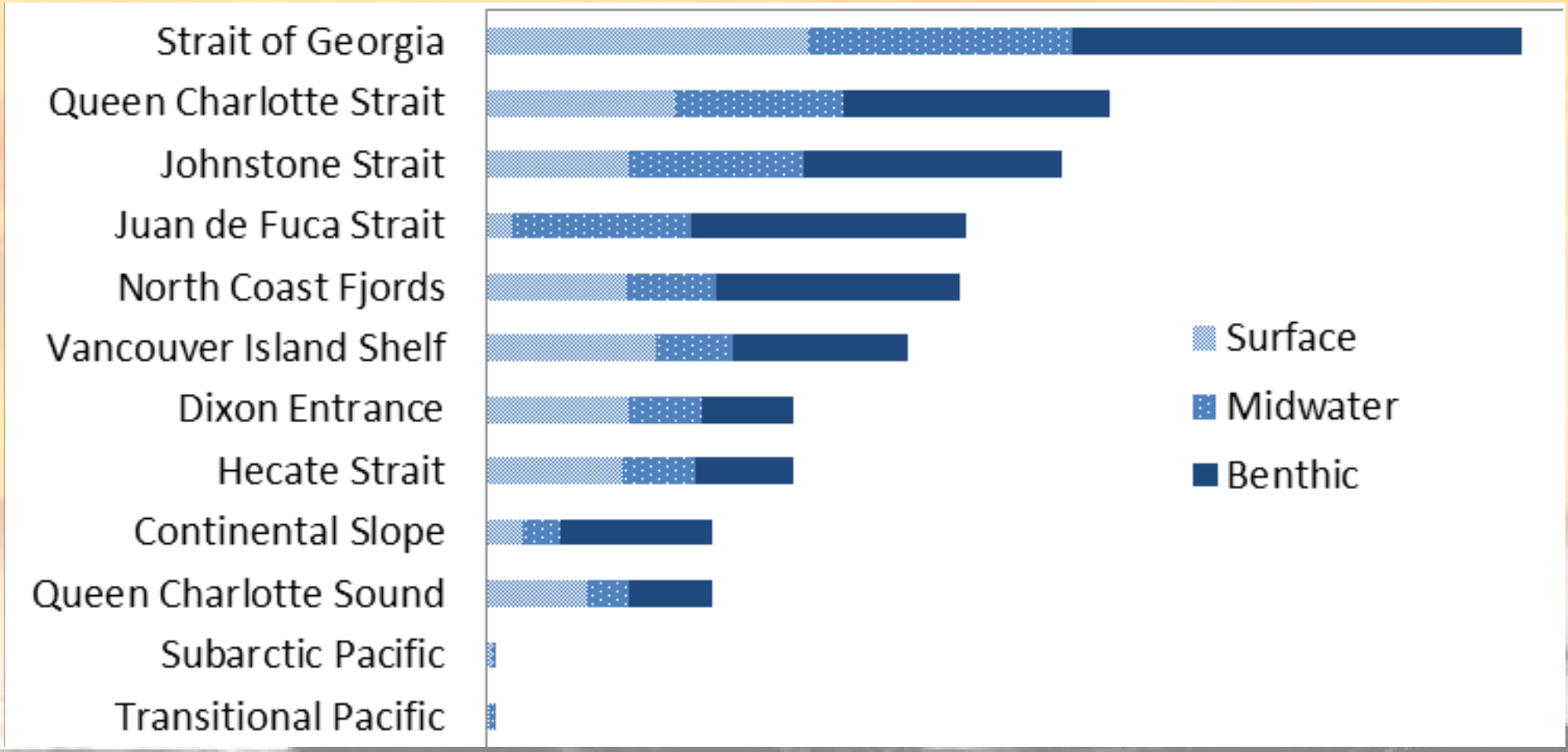
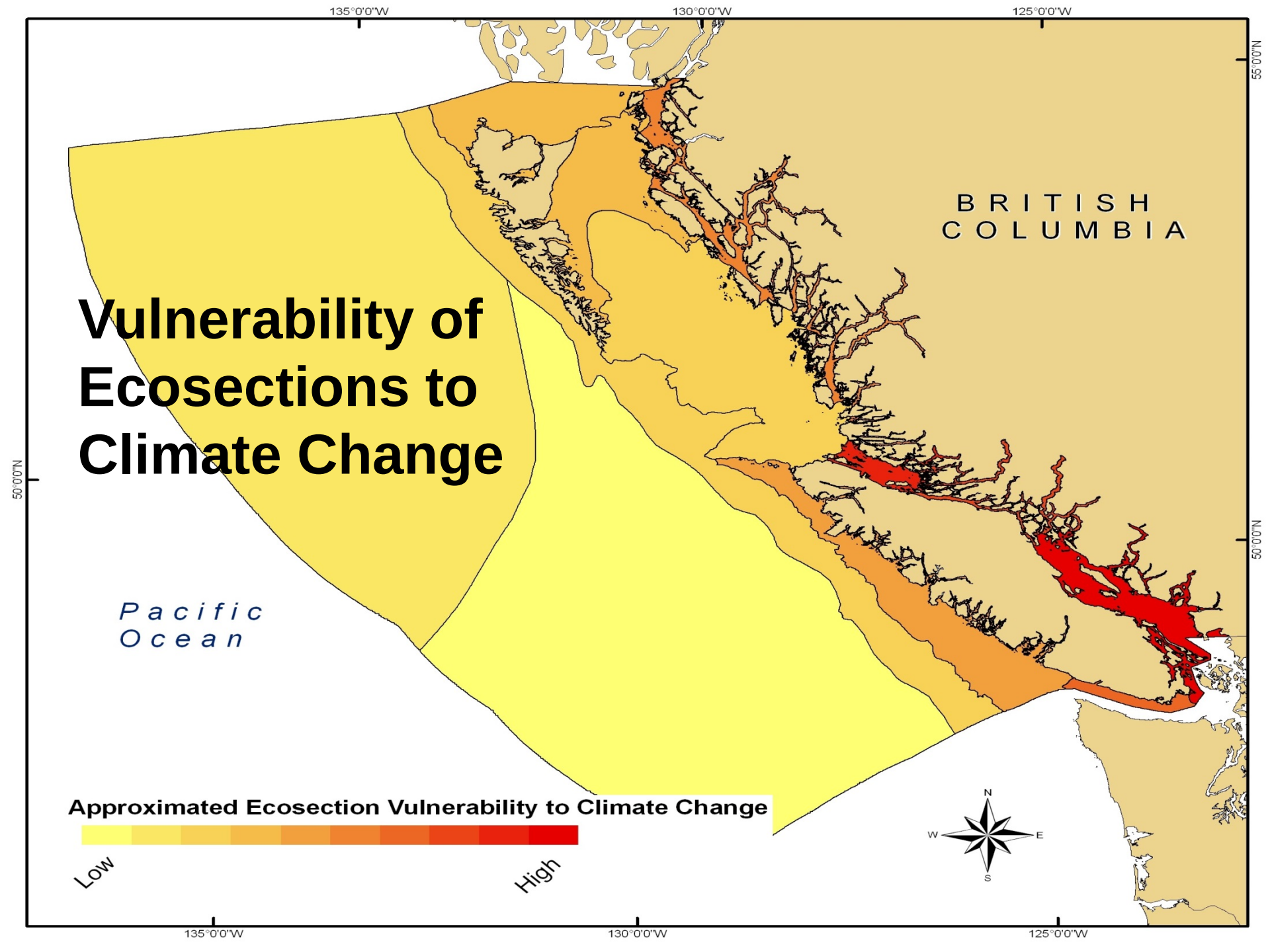
Estimation of vulnerability of **Ecosections** to climate change

		Standardized scores for mean potential climate impact/km^2 by ecosection			Sum of standardized potential climate score (S)	Standardized anthropogenic impact score (CI)	Ecosection vulnerability to climate S ÷ (1/CI)
		Acidificat -ion	Temperature change*	UV change			
SURFACE WATERS	Continental Slope	0.98	0.66	0.85	2.50	0.04	0.11
	Queen Charlotte Sound	0.89	0.62	0.79	2.30	0.13	0.30
	Subarctic Pacific	0.93	0.66	0.74	2.33	0.01	0.02
	Transitional Pacific	0.98	0.64	0.76	2.39	0.00	0.01
	Vancouver Island Shelf	0.98	0.56	0.84	2.37	0.21	0.50
	Dixon Entrance	0.88	0.66	0.80	2.35	0.18	0.42
	Hecate Strait	0.91	0.61	0.83	2.35	0.17	0.40
	Johnstone Strait	0.74	0.35	0.58	1.67	0.25	0.42
	Juan de Fuca Strait	1.00	0.40	0.82	2.22	0.04	0.08
	North Coast Fjords	0.74	0.43	0.68	1.85	0.22	0.41
	Queen Charlotte Strait	0.84	0.42	0.62	1.88	0.29	0.55
	Strait of Georgia	0.85	0.46	0.73	2.05	0.46	0.94

Estimated relative vulnerabilities of **Ecosections** to climate change

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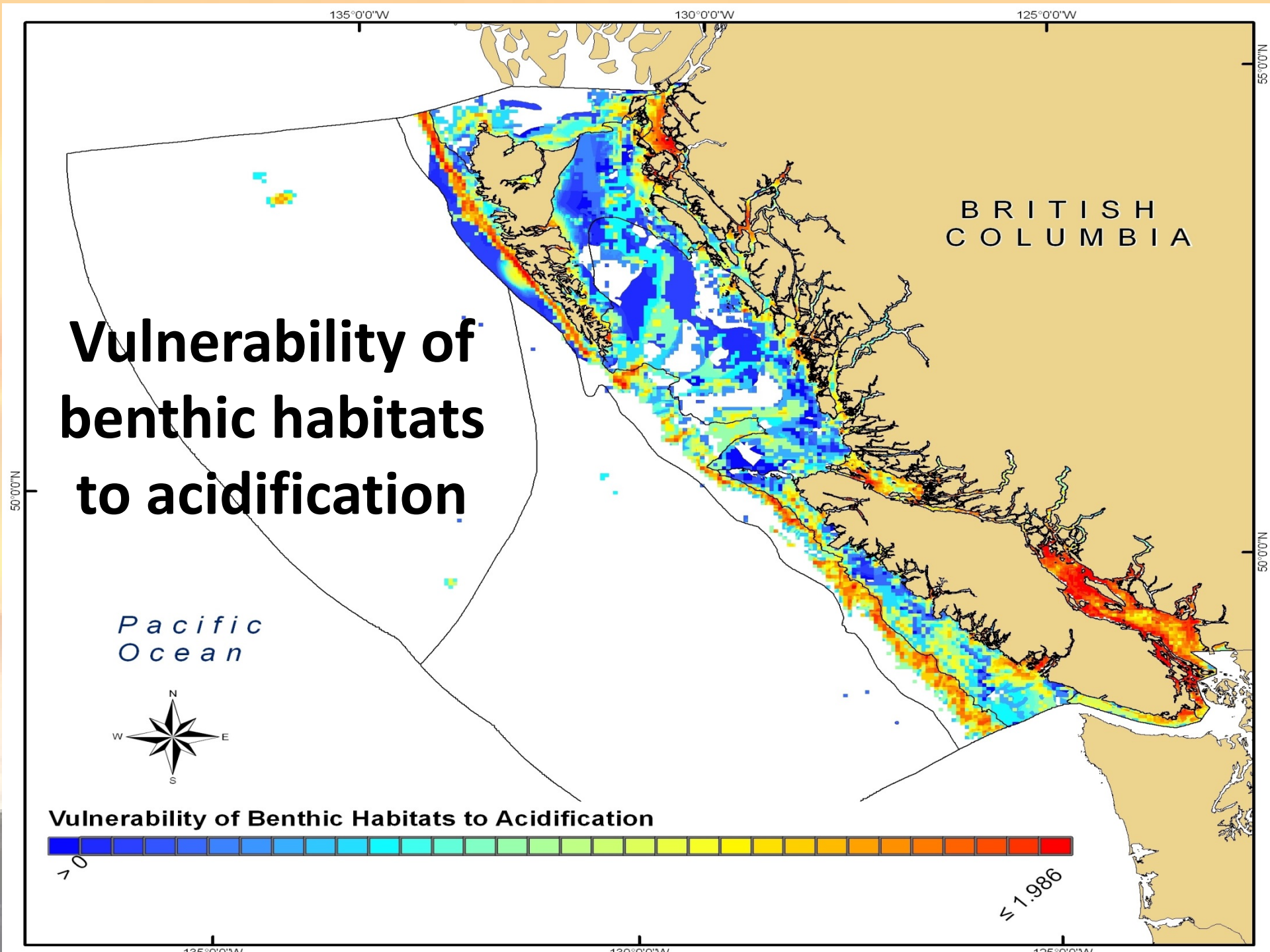
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Vulnerability of Benthic Habitats to Acidification
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≤ 1.986

Refining the analysis

- Additional climate variables (downscaled regional projections)
- Regional habitat types
- Regional stressors / pressures / sensitivities
- Improved understanding of Indirect and interactive effects through ecosystem models
- Increased monitoring of changes across scales, relevant indicators

Acknowledgements

Agencies
Fisheries and Oceans Canada, Environment Canada (Canadian Wildlife Services), Natural Resources Canada (Geological Survey of Canada), Parks Canada, the B.C. Ministry of Environment, Royal Roads University, Simon Fraser University, the University of British Columbia, and the University of Victoria.

People
Philip Hill, Ben Kangasniemi, Dave Preikshot, Vaughn Barrie, Doug Biffard, Robin Brown, Frank Whitney, Mark Zacharias, Ken Morgan, Brian Bawtinheimer, Chris Harley, Marc Trudel, Kim Hyatt, Ian Perry, Bill Crawford, Robin Sydneysmith, Richard Carson, Audrey Dallimore, Colin Campbell, Isabel Côte, Caihong Fu, John Holmes, Cliff Robinson, Charlie Short, Kelly Francis, Sean Darling, Brian Hunt, and Desiree Tommasi, Robin Brown, Frank Whitney, Chris Harley, Doug Biffard, John Davis, Bill Crawford, Ian Perry, and Barry Smit, John Bones (J.G. Bones Consulting), Selina Agbayani (WWF-Canada), Amelia Paisley, Anne Rutherford, Maureen Vo, Emilia Hurd, Pamela Allen, Natalie Ban, Jeff Ardron.

Funders
Gordon & Betty Moore Foundation, Pew Fellows Program in Marine Conservation, Pew Environment Program, Pew Charitable Trusts

GORDON AND BETTY MOORE FOUNDATION

PEW FELLOWS PROGRAM IN MARINE CONSERVATION

ECO-SECTION	POTENTIAL MAJOR CLIMATE CHANGES	SOME SENSITIVE ELEMENTS
Dixon Entrance	Increase in runoff and stratification. Reduction in salinity and associated changes to the buoyancy driven flow. Ocean warming. Sea level rise.	Larval Gyre (Dungeness Crab), pattern of nutrient entrainment from oceanic water, productivity
Hecate Strait	Ocean warming, Sea level rise, changes in runoff and salinity. May be sheltered from deeper acidic & anoxic waters	Productivity; spawning areas, sedimented shorelines and shoreline dependent species (shorebirds, forage fishes e.g. sandlance, smelt)
Queen Charlotte Sound	Oceanic warming. Intrusion of low anoxic and acidic waters into canyons	Slope communities including invertebrates and fishes, biogenic habitat (coral and sponges)
Vancouver Island Shelf	Oceanic warming. Changes to the nearshore buoyancy driven flow and offshore ocean circulation.	Productivity, neritic and benthic community - northern limit for many southern species
Continental Slope	Acidification and anoxia in the deep layers. Ocean warming. Changes to ocean currents.	Primary productivity, Slope Communities including invertebrates, fishes, structure forming biogenic habitats (corals and sponges). Commercial species including Sablefish

HABITAT	SOME SENSITIVITIES
Intertidal habitats	Sensitive to increasing temperature, freshwater, increased wave heights/surge, sea-level rise
Kelp Forests	Sensitive to Increased temperatures, UV levels, stratification and reduced upwelling, potentially storminess. May be avoured by increased upwelling
Seagrasses	Sensitive to increased turbidity, sediment deposition, changes in flow. May be favoured by increased CO2
Estuaries	Sensitive to changes in mixing and estuarine regimes (flow and timing), freshet timing effects on other species and habitats. Bioavailability of trace metals under acidic conditions
Salt Marshes	Sensitive to salt water intrusion, inundation, sea-level rise, erosion or excessive deposition.
Corals and Sponge Reefs	Sensitive to increased acidification, dexoxygenation, increased sediment transport in nearshore areas. May benefit from nutrient upwelling
Seamounts	Exposed to wide variety of conditions. May be sensitive to a variety of changes, pH, anoxic waters, turbidity
Soft Shelves and Slope	Sensitive to acidification, freshwater input, changes in water chemistry, current dynamics (soft sediment systems)
Submarine Canyons	Acidified and anoxic water and conditions for benthic communities

Qualitative assessed vulnerabilities

- **Oceanographic processes** in areas critical for larval retention and transport that are sensitive to intensification of estuarine conditions (Dixon Entrance, Queen Charlotte Sound Ecosections, Juan de Fuca Strait);
- **Sediment shorelines and other nearshore habitats** that serve as important spawning habitats for forage fishes and are sensitive to erosion and sea-level rise (Hecate Strait, Strait of Georgia, other Ecosections);
- **Biogenic coral habitats in canyons and channels** between slope and shelf areas, which are prime points for exposure to acidic water (Queen Charlotte Sound, Continental Slope Ecosections);
- **Areas where topographically induced upwelling of deeper water** supports productivity and diversity; for example, the shelf break and seamounts where species and habitats would be sensitive to increases of oxygen-depleted and acidic water (Continental Slope Ecosection);
- **Commercially harvested groundfish species**, other non-commercial species and their habitats between 250-400m depth, where increasing levels of oxygen-depleted water are already reducing suitable habitat for these species and will continue to do so;
- Areas considered important as **nursery and juvenile rearing habitats** (estuaries, seagrass, and other nearshore habitats) that would be sensitive to changing physical conditions, particularly temperature, salinity, turbidity, and stratification;
- **Areas through which migrating species transit in large** numbers for part of their life cycle, which will be sensitive to changing physical conditions and/or new predators that arrive as a result of climate changes (Queen Charlotte Strait, Johnstone Strait, some fjords); and
- **Harvested species that are longer-lived** and more resistant to short-term climate variability because they can afford to have long periods of low or no recruitment, but that are more sensitive to longer-term directional change in a given location because they cannot adapt as fast as shorter-lived species (e.g., Pacific Ocean perch, rockfishes, sablefish).

STRESSORS UNPACKED

Agriculture
land-based effects
pollution from fertilizer, animal waste

Aquaculture
Nutrient enrichment
Toxic pollutants
habitat effects
parasites
genetic mixing

Boats and ships
antifouling paint
catastrophic oil spills
fuel and oil leakage
sewage

Watershed modification
other watershed modification
Coastal development & bulkheading
Commercial Buildings
Residential buildings
Roads, High voltage transmission lines, natural gas pipelines, seismic lines
Urban Sprawl
Water body alteration: damming, diking, channelizing, or culverting lakes, rivers, streams, etc.

Diseases: Marine organisms

Fishing
Bycatch
Commercial
Habitat damage
Recreational
Sport fishing
Subsistence
Illegal and unreported

Forestry
log booms
nutrient changes
sediment runoff
water temp changes

Global change
Changes in upwelling & productivity
Lowered oxygen in ocean
Ocean acidification
Salinity changes
Sea level rise
Snowpack and precipitation changes
Storm activity changes
Water temperature changes

Pollution
Bio-concentrating trace pollutants
Dioxin contamination
excessive nutrients
From energy use: drilling, hydroelectric,
Mercury contamination
nutrient enrichment
Plastics
Point-source chemical
Pulp-mill effluent
Sewage effluent
Styrofoams
toxic biochemicals
Urban runoff
Noise

Recovery of sea otters
Recovery of seals / sea lions

Non-extractive recreation and tourism
Interference with animal behaviour

Scientific research and educational

Governance: Dysfunctional

Harmful algal blooms

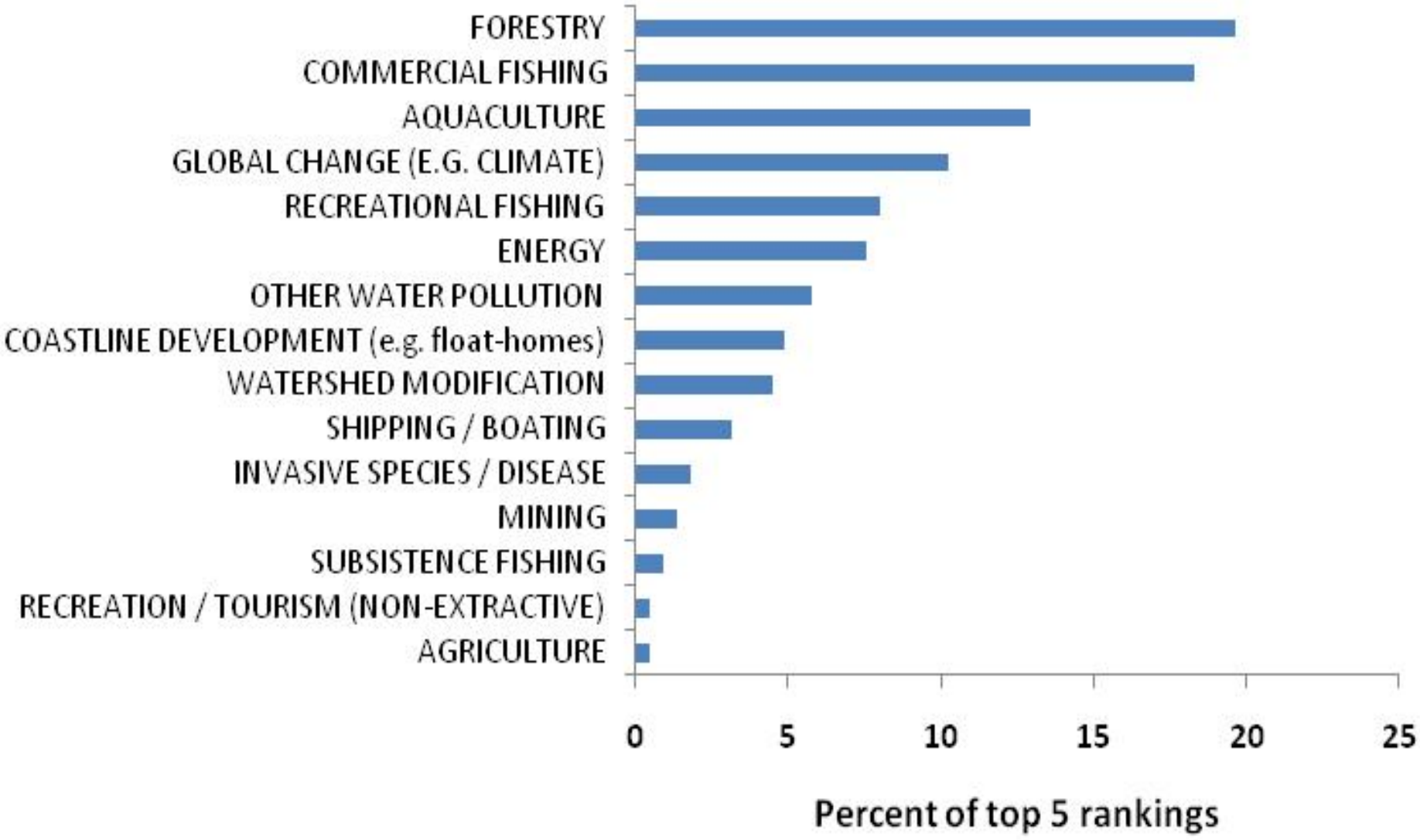
Invasive species

Military and strategic

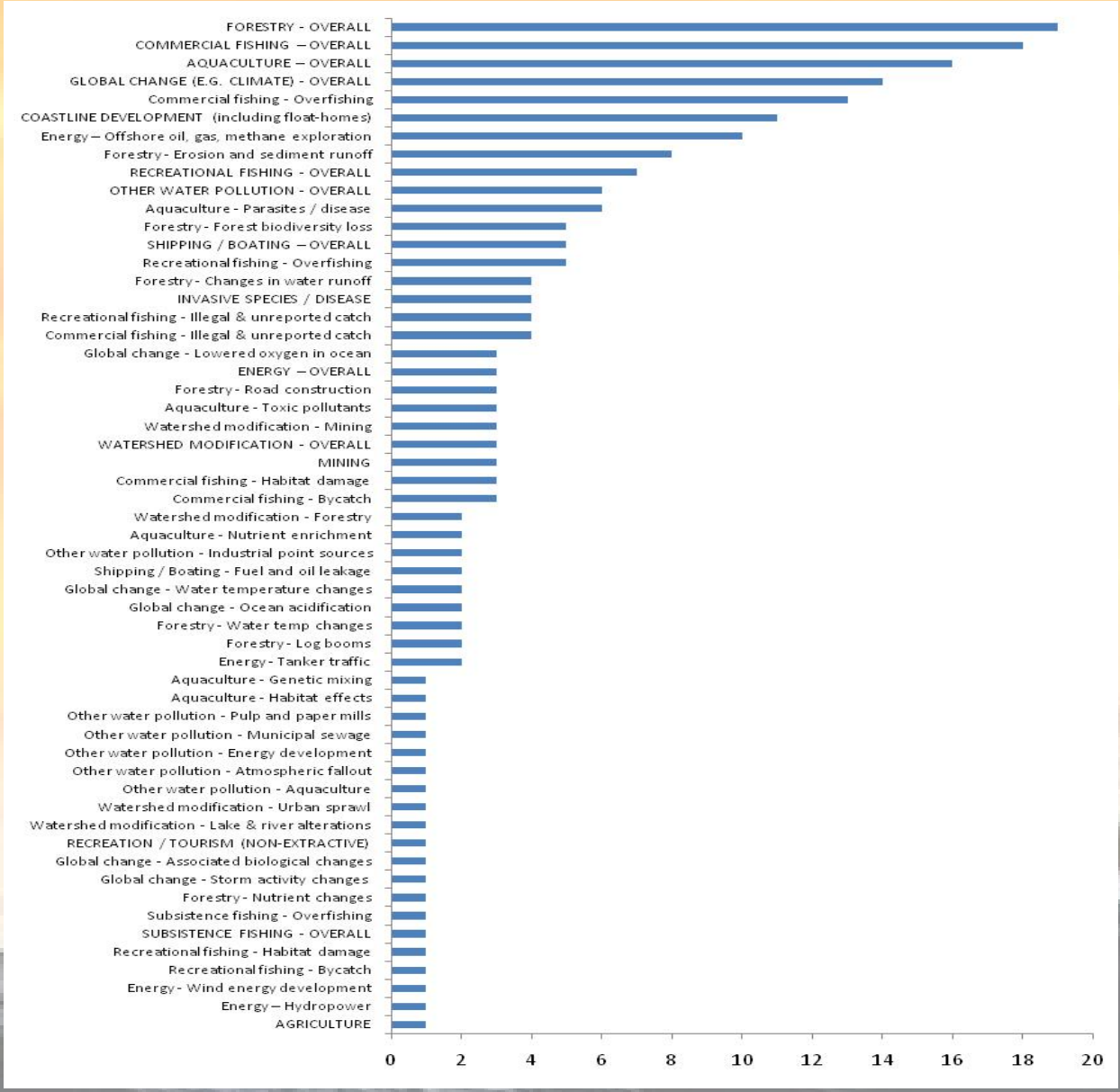
Poaching

Management of natural resources: Poor

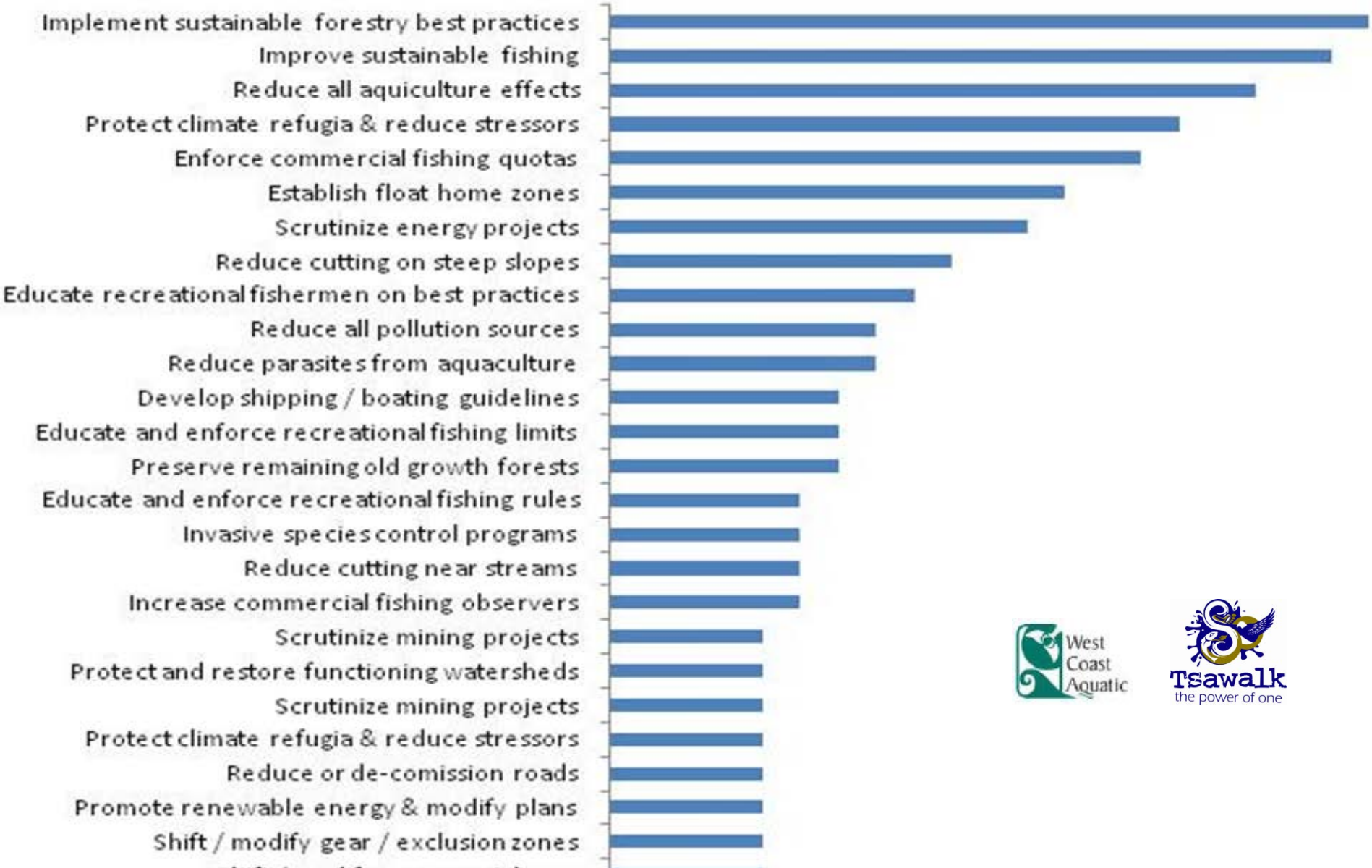
Percent of top 5 rankings



Frequency of top 5 stressors



Prioritizing management strategies



West Coast Aquatic

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