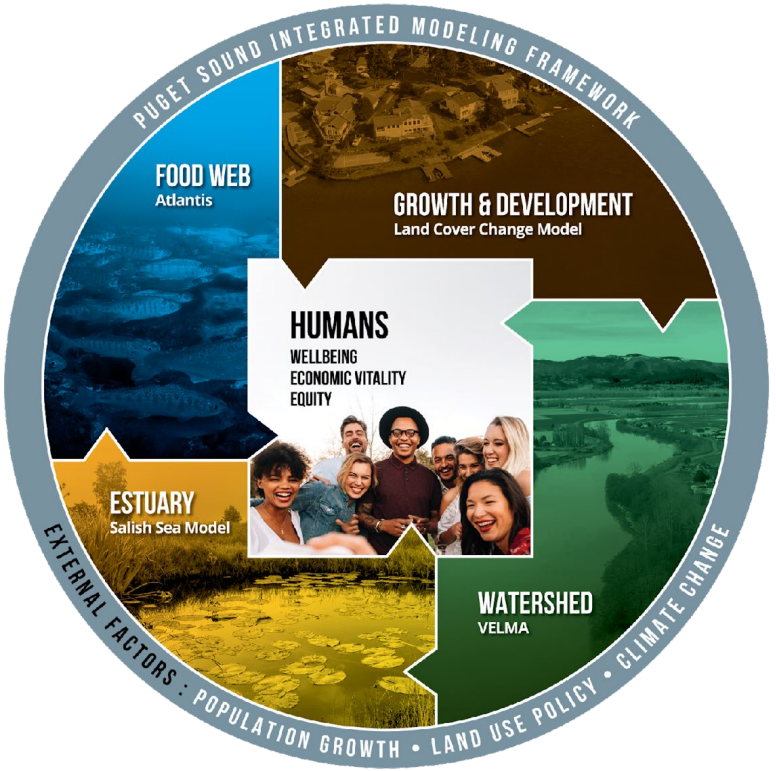
Development of an integrated modeling framework for the Puget Sound basin to evaluate cross-ecosystem impacts of environmental change



Hem Nalini Morzaria-Luna, Ph.D.
Long Live the Kings. Seattle, WA.

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5 CSIRO

4 Inoventures, LLC. Innovate. Perform. Excel.

6 NOAA FISHERIES

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11 SCHOOL OF AQUATIC & FISHERY SCIENCES — W

10 THORNWELL LABS CONSULTING

9 GEOMAR

8 HEALTHY WATERSHEDS LLC

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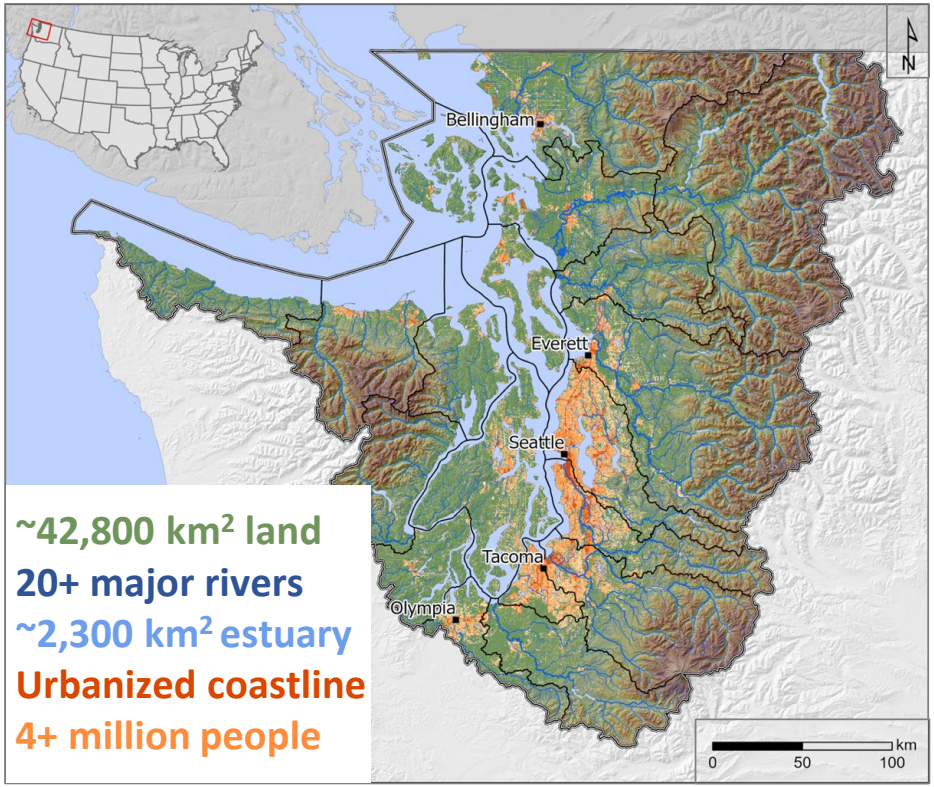
Puget Sound



~42,800 km² land
20+ major rivers
~2,300 km² estuary
Urbanized coastline
4+ million people

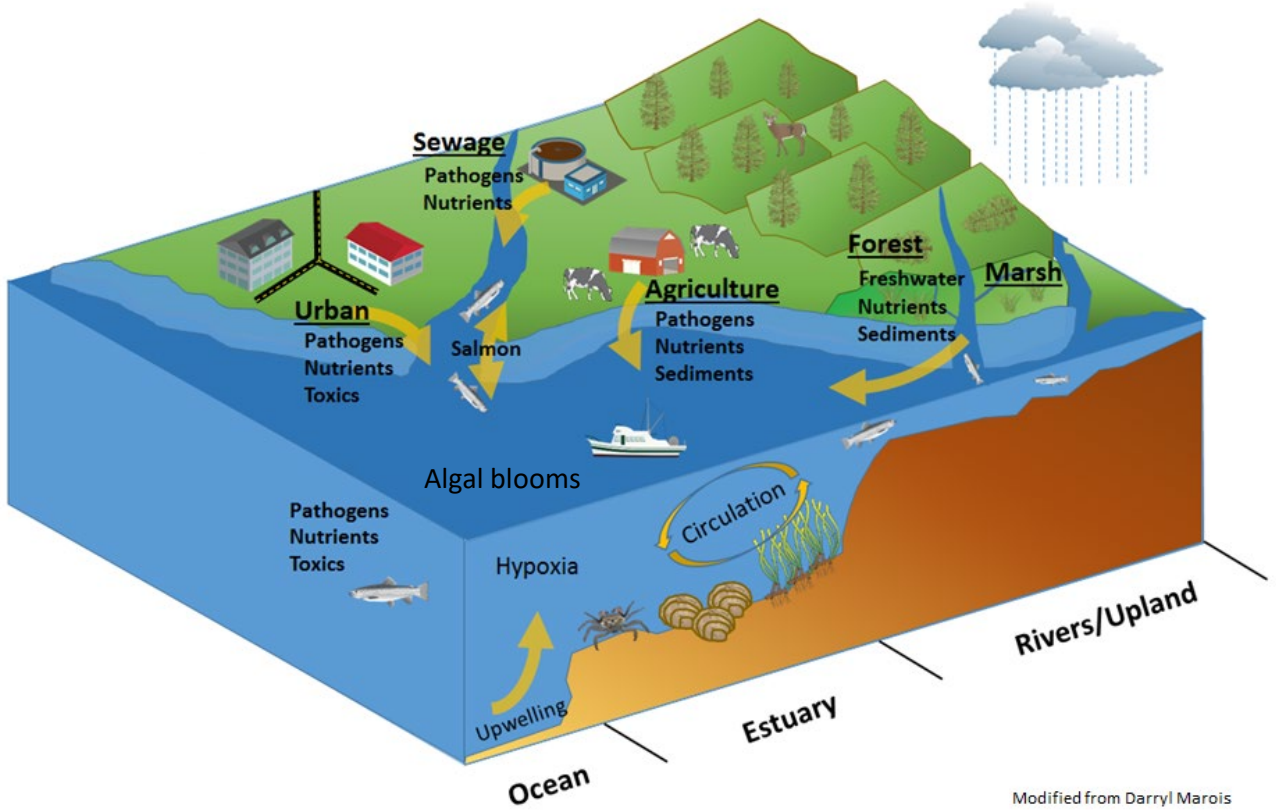




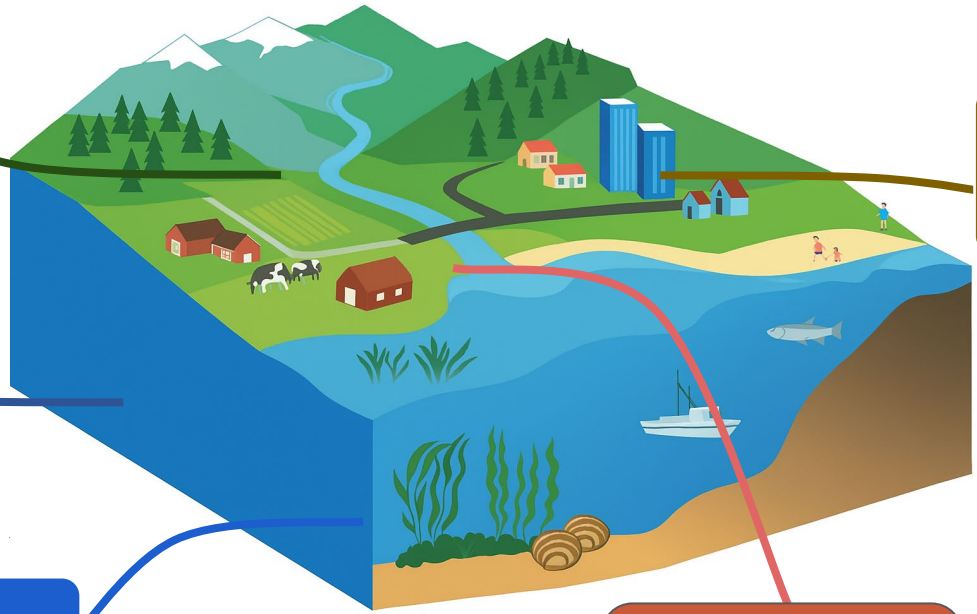


Puget Sound Integrated Modeling Framework

How will Puget Sound be affected by future environmental conditions and our decisions to manage them?



Puget Sound Integrated Modeling Framework



Watershed model

Land cover model

Ocean biogeochemistry model

Human system model

Marine ecosystem model

Salmon habitat model

Model linkage

Salmon recruitment

Atlantis Model for Puget Sound

Marine food web, fisheries, ecosystem indicators

Land Cover Change Model

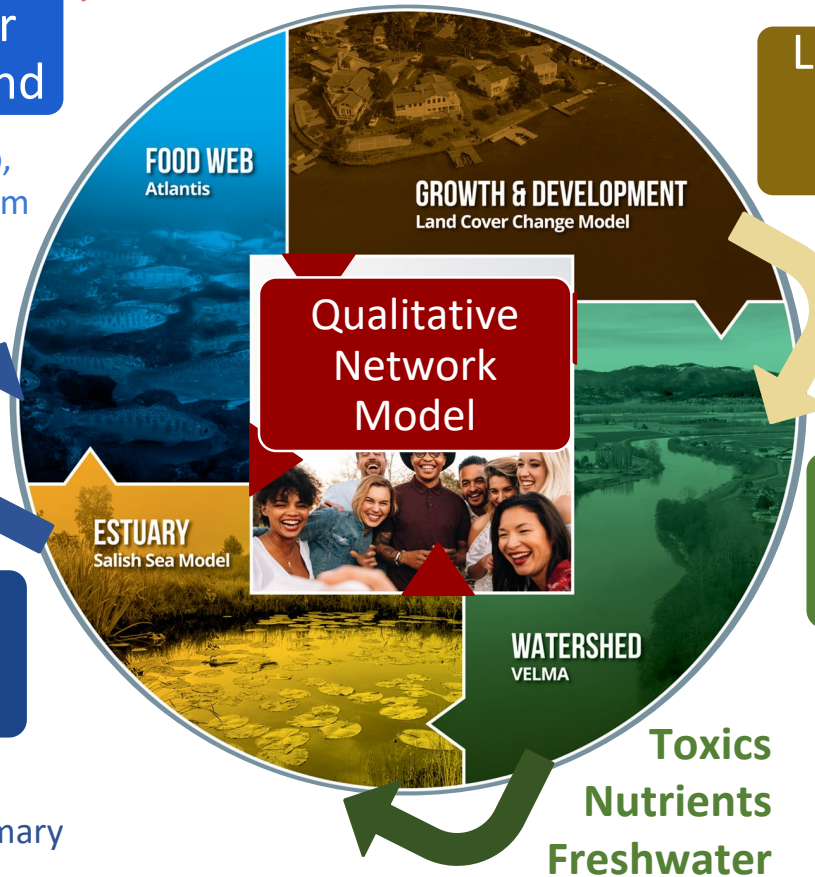
Population & development

HARP

Habitat changes

Land cover

Nutrients
Toxics
Temperature



VELMA

Hydrology, land use, green infrastructure

Salish Sea Model

Circulation, biogeochemistry, primary production

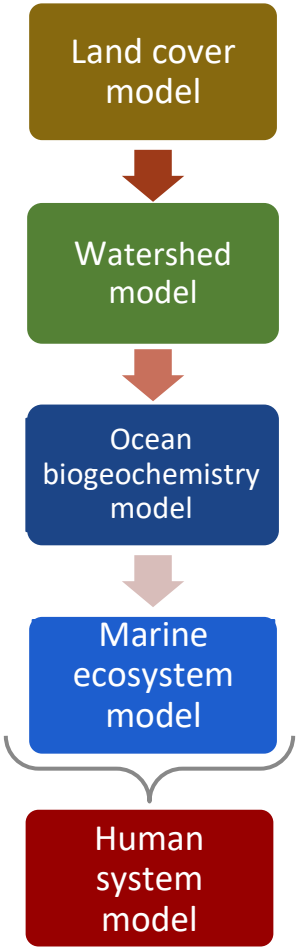
Toxics
Nutrients
Freshwater

Two scenarios: 2010 – 2099

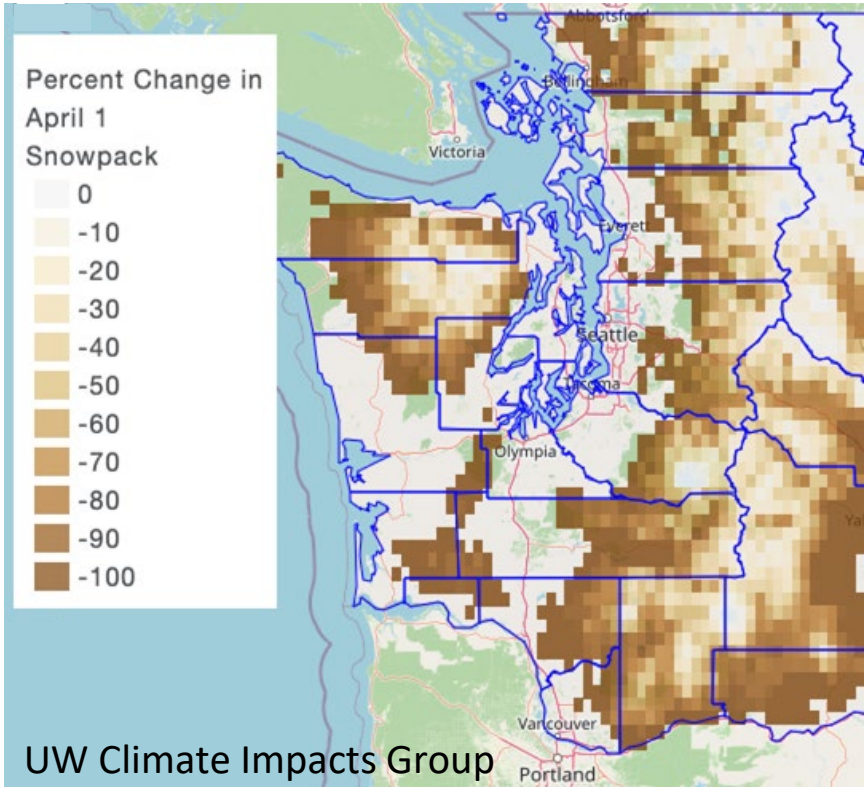
1. **Status quo**
   - Land cover: past development trends projected forward
2. **Riparian management**
   - Land cover: past development trends projected forward but *excludes* riparian zones

Both

- Moderate population growth drives development & wastewater treatment plant nutrient loads
- High emissions scenario: CMIP5 RCP 8.5 scenario



Climate change in Puget Sound



By mid-century:

- Up to 6 ° C warmer in summer
- Above freezing year-round – no spring snowpack
- Less total precipitation

Morzaria-Luna. PICES 2026 Annual Meeting. S4. Development of an integrated modeling framework for the Puget Sound basin to evaluate cross-ecosystem impacts of environmental change

Status quo scenario 2010-2040

Land cover model

Watershed model

Ocean biogeochemistry model

Marine ecosystem model

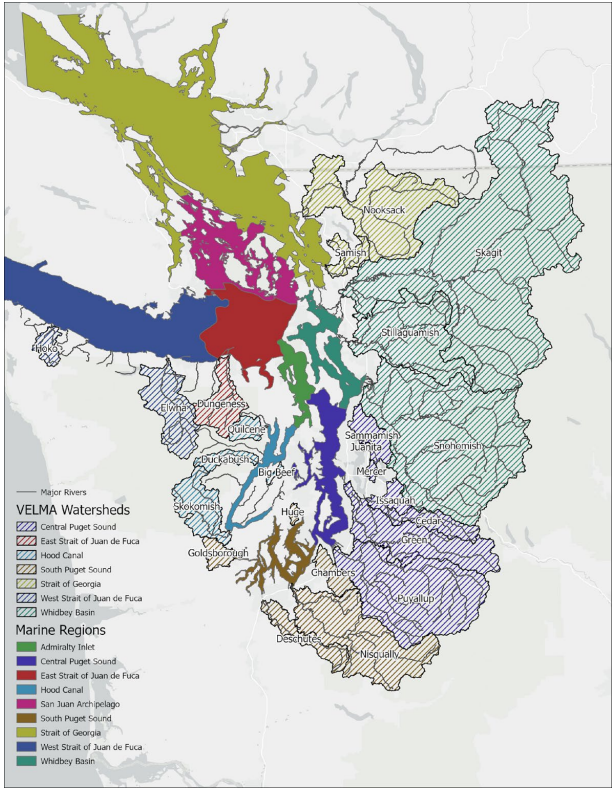
Moderate population growth WA

Land cover: past development trends projected forward

Streamflow and temperature

Future climate forcing (high emissions scenario) and river boundary conditions

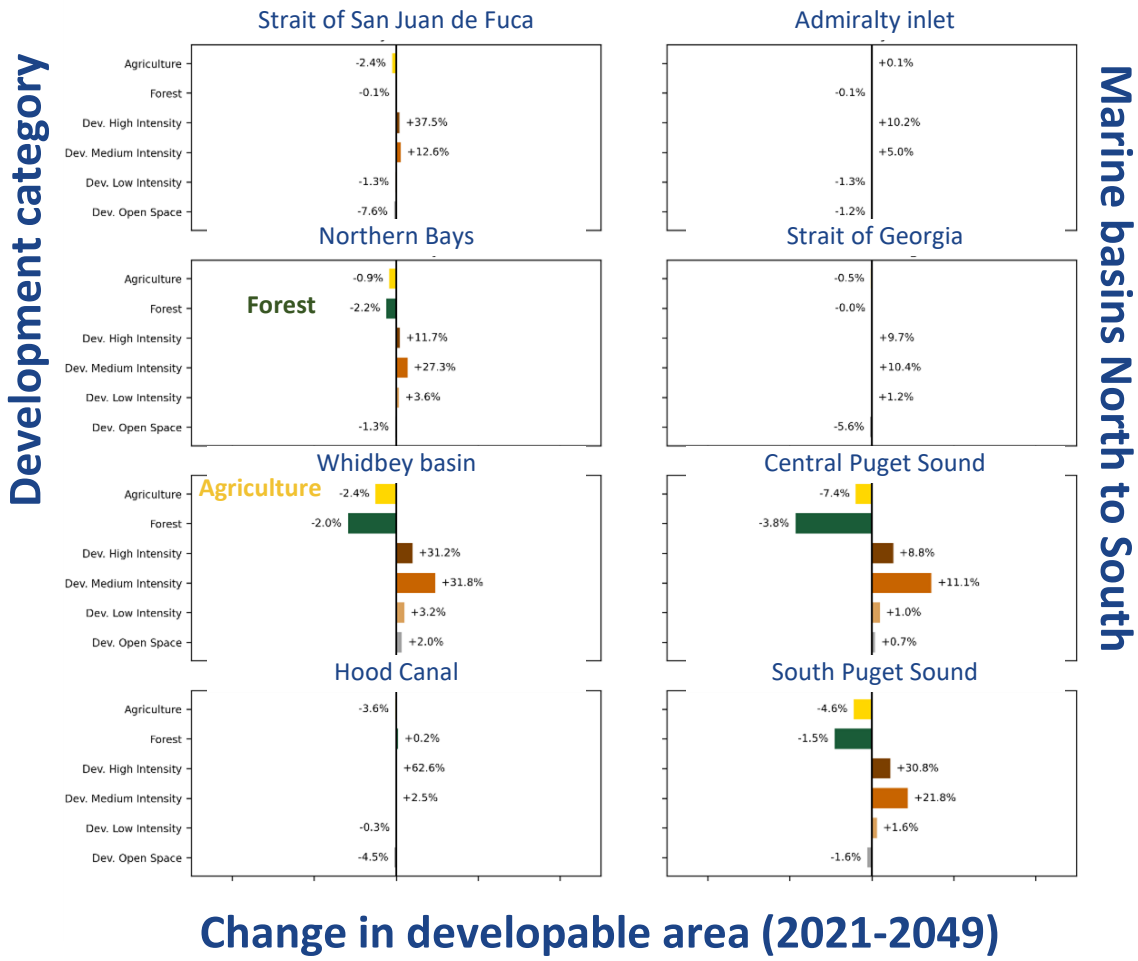
Temperature, nutrients, salinity, dissolved oxygen, phytoplankton



Status quo scenario results

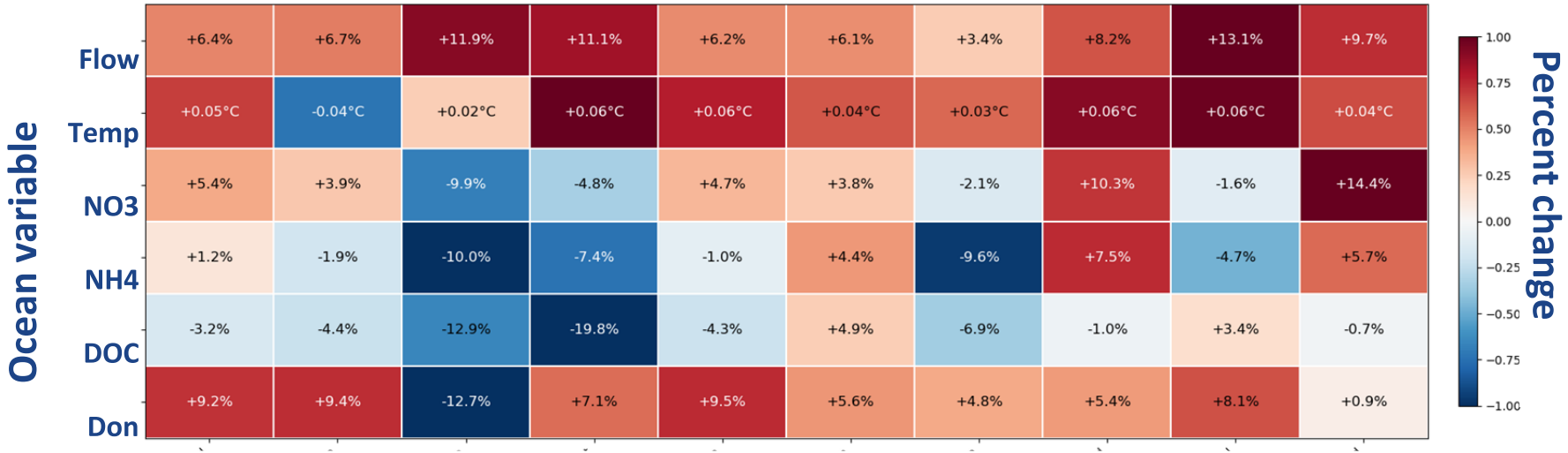
We demonstrated a proof-of-concept approach to integrate models of terrestrial, freshwater, and marine processes for the Puget Sound region.

Land cover model → Watershed model



Status quo scenario results

Integrated framework was able to capture geographic variation in physical and biogeochemical processes

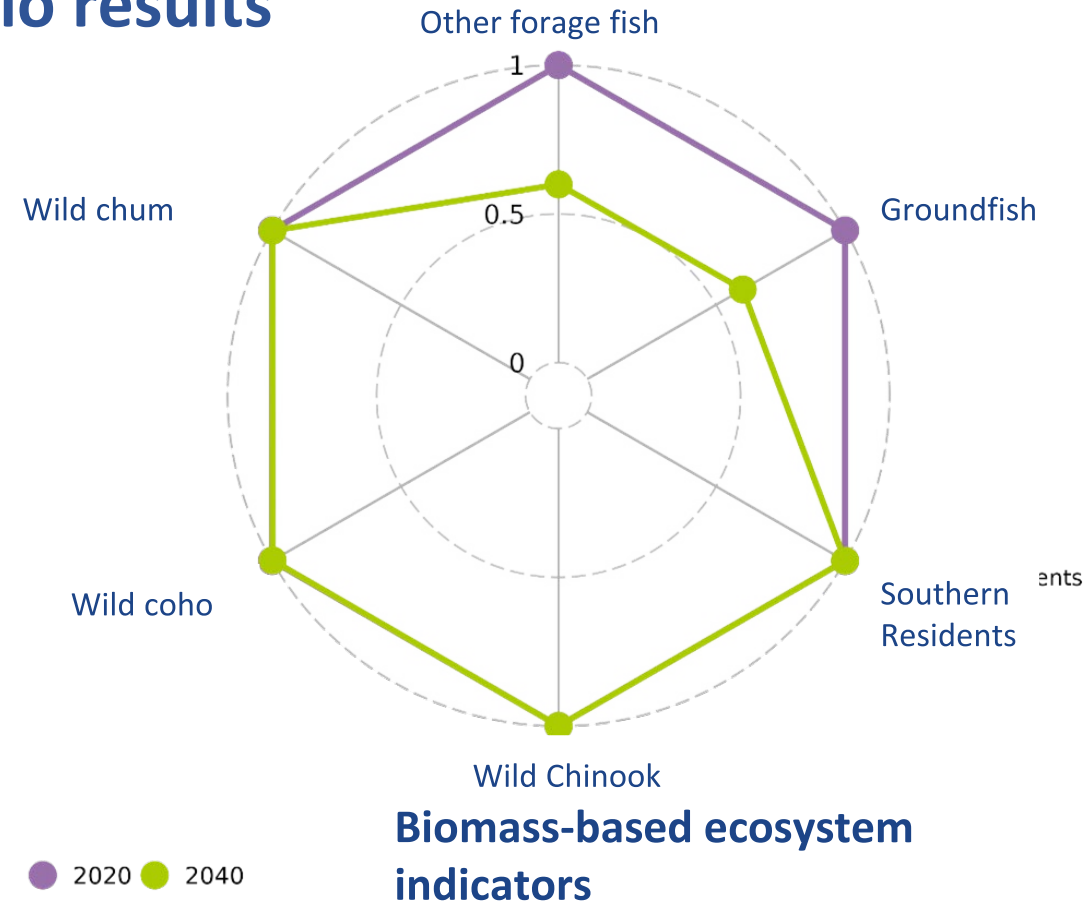


Marine basins North to South

Watershed model → Ocean biogeochemistry model

Status quo scenario results

Cumulative impacts of warming and eutrophication restructured the marine food web by increasing productivity of lower trophic level species



Ocean biogeochemistry model → Marine ecosystem model

Biomass-based ecosystem indicators

Status quo scenario results

Effects on salmonids, and associated impacts on human well-being remain hard to predict reflecting the complexity of their life cycle and multiple drivers

Human system model

Human system outcome

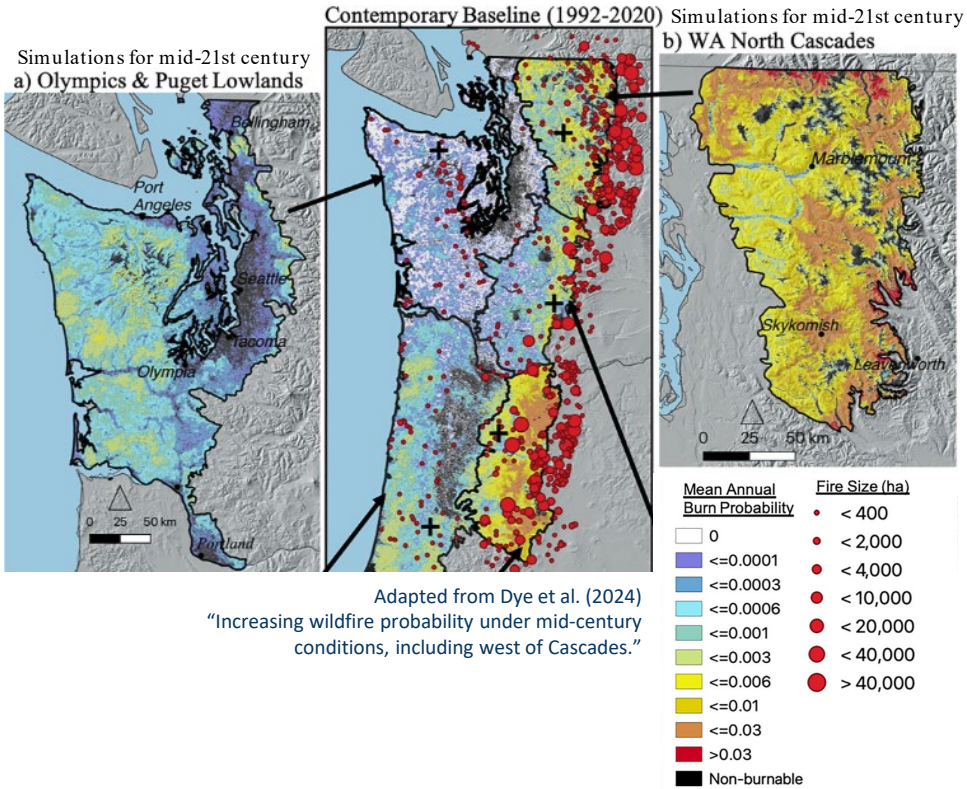
Category	Node	S1. Population growth scenario	S2. Climate scenario	S3. Combined scenario
A. Land use and terrestrial system	A1 Human population	+46%	-2%	+22%
	A2 New land development	+20%	-15%	-2%
	A3 Urban redevelopment	+27%	-14%	+3%
	A4 Forest and ag land conversion	+20%	-15%	-2%
B. Freshwater and estuary ecosystem	B1 Impaired riparian func	+20%	-15%	-2%
	B2 Nutrients local scale	+46%	-2%	+22%
	B3 River temp	+20%	+37%	+37%
	B4 Shift in flow quantity/timing	+20%	+39%	+38%
	B5 Toxics/ Bacteria	+20%	+30%	+32%
	B6 Instream habitat conditions	-33%	-30%	-35%
C. Puget Sound ecosystem	C1 Nutrients PS	+46%	+27%	+35%
	C2 Water temp PS	N/A	+50%	+50%
	C3 Hypoxia / reduced DO	+40%	+38%	+41%
	C4 Phytoplankton/Detritus	+41%	+40%	+43%
	C5 Zooplankton	+9%	+2%	+4%
	C6 Bivalve shellfish	-1%	-13%	-11%
	C7 Other food fish	-8%	-9%	-10%
	C8 Anadromous fish PS	-1%	+8%	+6%
	C9 Marine mammals	-12%	-11%	-13%
D. Economic outcomes	D1 Jobs / livelihoods	+9%	+11%	+13%
	D2 Wages / Income	-32%	-33%	-38%
	D3 Property values/ costs	+15%	-27%	-13%
	D4 Construction capacity	-38%	+22%	-4%
	D5 Housing supply	+33%	-20%	+2%
	D6 Economic productivity	+3%	-36%	-25%
	D7 Place-based economy	-19%	-38%	-36%
	D8 Knowledge-based economy	N/A	N/A	N/A
E. Ecosystem services	E1 Products of working lands/waters	-8%	-9%	-9%
	E2 Water provision/ security	-20%	-35%	-35%
	E3 Food provision/ security	-21%	-26%	-27%
	E4 Outdoor recreation	-25%	-30%	-32%
	E5 Wild-caught fisheries	-28%	-34%	-35%
F. Human wellbeing outcomes	F1 Environmental hazards	+20%	+30%	+31%
	F2 Cultural identity and sense of place	-21%	-25%	-26%
	F3 Human health	-23%	-31%	-32%
	F4 Tribal fishing access	-17%	-22%	-23%
	G1 Drivers of social change	+23%	+31%	+31%

Pink: Decrease in indicator
Green: Increase in indicator

Planning for wildfires in Puget Sound

How will wildfires impact the region and affect recovery goals for Puget Sound?

How can we synergize ecosystem recovery strategies and wildfire resilience planning?



Adapted from Dye et al. (2024)
"Increasing wildfire probability under mid-century conditions, including west of Cascades."

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Long Live the Kings
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longlive.kings

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