Aquatic and Fishery Sciences
University of Washington

Puget Sound Institute
University of Washington | Tacoma

Photos courtesy of: Conrad Gowell, WFC; Kathleen Reed; and J Brew.

Impact of oxygen and temperature on Puget Sound marine life

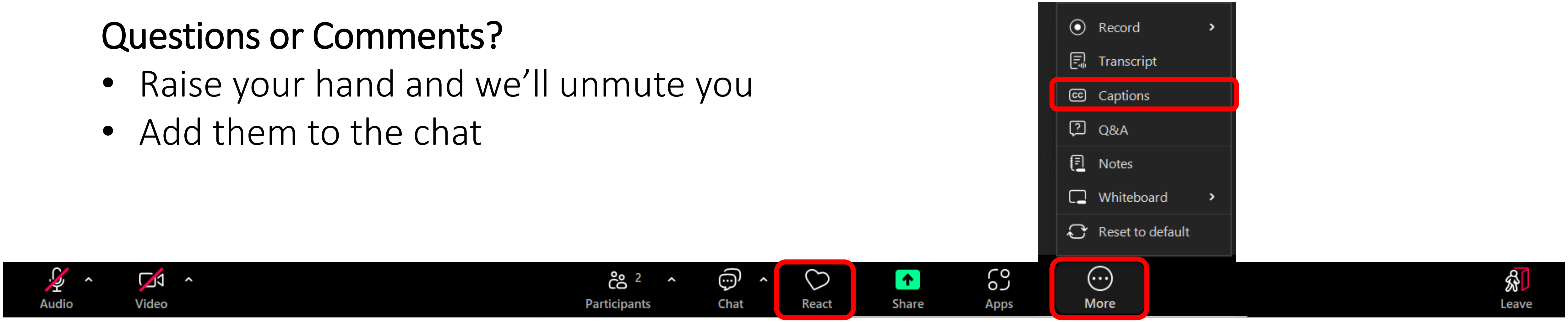
Impact of oxygen and temperature on Puget Sound marine life

Welcome! While we wait, please:

- Update your name with your pronouns and organization
- Introduce yourself in the chat and share your favorite dessert
- Message Marielle with any access needs

Questions or Comments?

- Raise your hand and we'll unmute you
- Add them to the chat



The slides and recording will be available on [Puget Sound Institute's website]

Land Acknowledgement

The UW Tacoma community acknowledges that we learn, teach, work and live on the ancestral land of the Coast Salish people. In particular, our campus is situated on traditional lands of the Puyallup Tribe of Indians. We recognize that this is a difficult and painful history, and we understand we must play an active role in remembering, not just what happened to Indigenous communities; post settlement, but also the rich history that existed long before colonization. This land acknowledgement is one small act in an ongoing process of honoring the past while working together with local Tribes to build a more inclusive and thoughtful community.

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Some causes of aquatic habitat loss

Physical

- Watershed alterations
- Shoreline hardening
- Increase sedimentation
- Altered timing, duration and magnitude of flows, mixing, and stratification
- Temperature
- Corrosion protection anodes

Biological

- Disease
- Invasive species

Chemical (water quality)

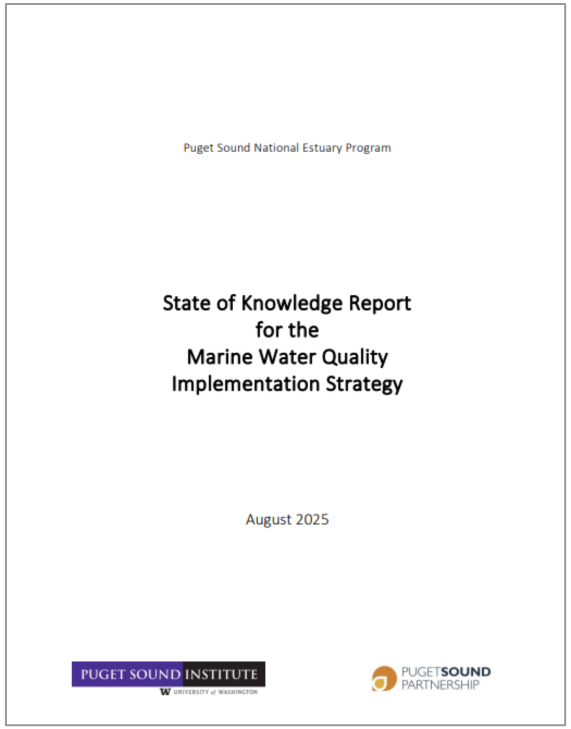
- Excess nutrients (i.e., nitrogen in the estuary)
- Metals (e.g., copper from brake pads)
- Persistent organic chemicals (e.g., PCBs in the Duwamish and elsewhere; creosote)
- Tire wear components (6PPD-quinone, etc.)
- Pharmaceuticals, PFCs, etc.

Possible impacts from nutrients may also include

- Compounding ocean acidification impacts
- Changes in seagrass community structure and abundance
- Increases in harmful algal blooms
- Changes in benthic community structure
- Changes in pelagic species and food webs
- Change in primary production and phytoplankton species and abundance

Puget Sound Institute is advancing scientific uncertainties identified by regional experts

Marine Water Quality Implementation Strategy



Puget Sound National Estuary Program

State of Knowledge Report
for the
Marine Water Quality
Implementation Strategy

August 2025

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PUGETSOUND PARTNERSHIP

Grand Uncertainties Matrix

Question	Priority Level
What is the expected interannual variability in the reference state? How inherently variable are reference state Puget Sound nutrient loadings and dynamics and the resulting dissolved oxygen concentrations as a result of ocean dynamics and weather at any given location (location = lat,long/depth)?	High
What are the confidence limits around the reference condition dissolved oxygen concentrations at any given location (location = lat,long,deph)?	High
How can the uncertainties in the current watershed nitrogen loads be quantified for current conditions at a given location (lat/long/depth, for each of 3 years modeled 2006, 2008, 2014)	High
how can the uncertainties in the current marine point source nitrogen loads be quantified for current conditions at a given location (lat/long/depth, for each of 3 years modeled 2006, 2008, 2014)?	High
What is the best way to propagate total uncertainty when calculating the difference between model-derived current and reference DO concentrations?	High

Puget Sound Institute Nutrients & Dissolved Oxygen Research

- Led scientific journalism
- Facilitated 8 scientific workshops
- Convened Model Evaluation Group
- Modeled additional nitrogen reduction scenarios
- Developed aerobic habitat compression analysis

Today's focus

The report and related resources are available at:
pugetsoundinstitute.org/nutrients/

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AQUATIC AND FISHERY SCIENCES
UNIVERSITY of WASHINGTON

Technical Memorandum

Quantifying species-specific changes in aerobic habitat associated with seasonal dissolved oxygen depression in Puget Sound and the Straits

July 21, 2026

Contributing Authors: Stefano Mazzilli, Tim Essington, Marielle Kanojia, Joel Baker

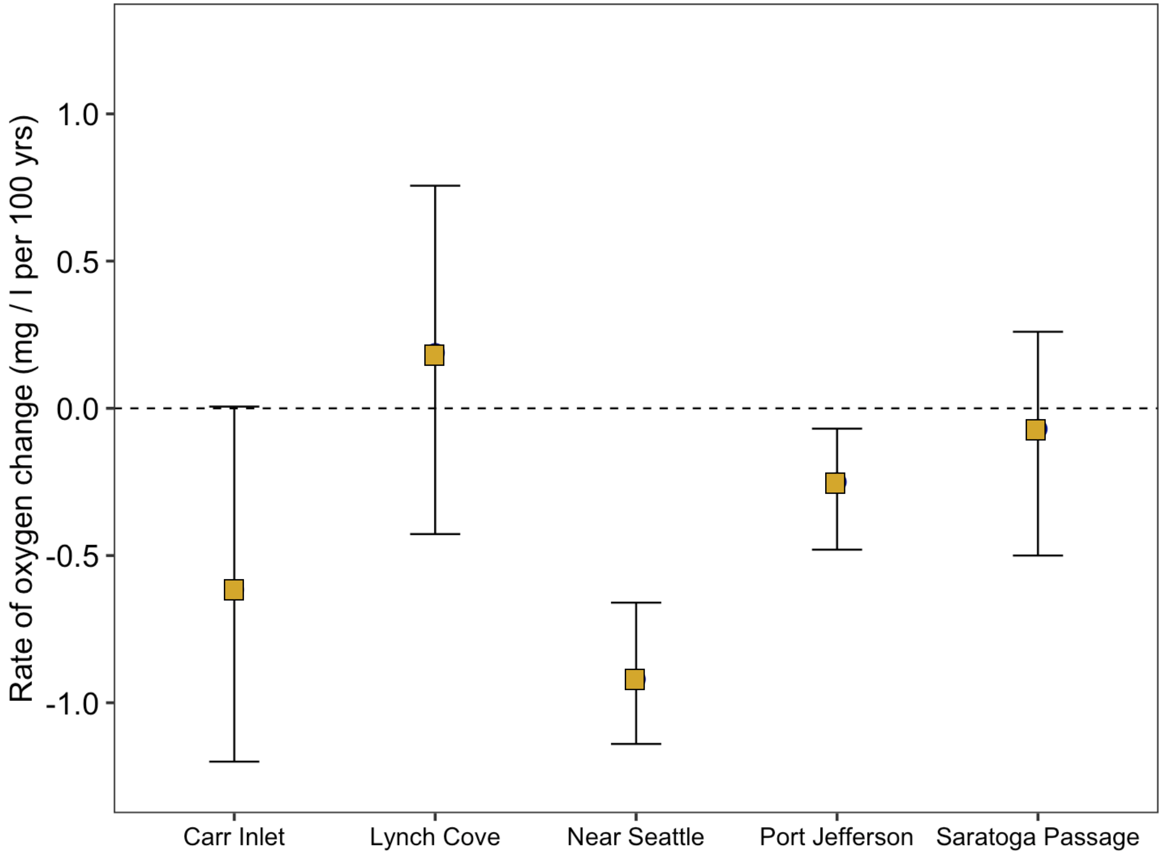
Funding: This Technical Memorandum was funded in part by King County in conjunction with a series of online workshops exploring Puget Sound water quality. Its content does not necessarily represent the views of King County or its employees.

Full report

Summary

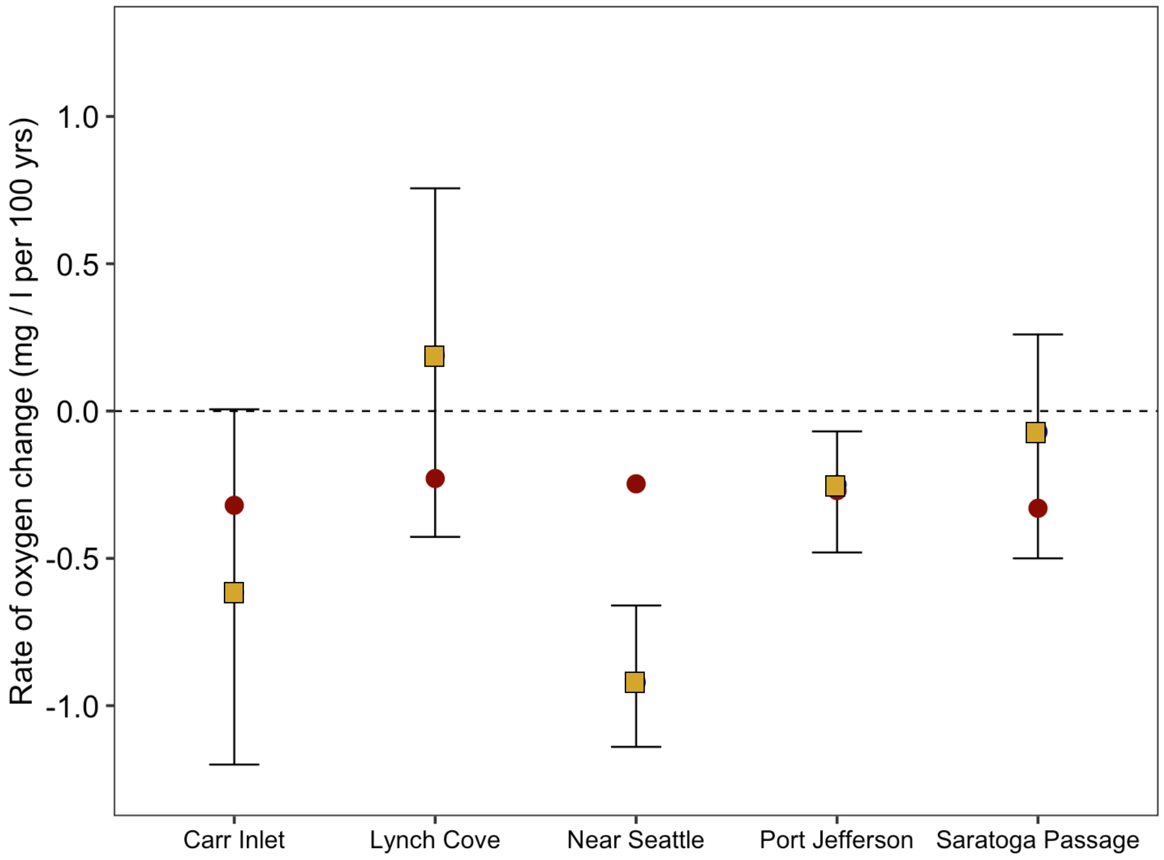
Scope of the problem: declining oxygen levels in some parts of Puget Sound

Dakota Mascarenas analyzed Ecology, King County, NOAA, and Collias (UW) data [Mascarenas and others (2025, in review)]



And > 50% of this decline is due to increased temperature

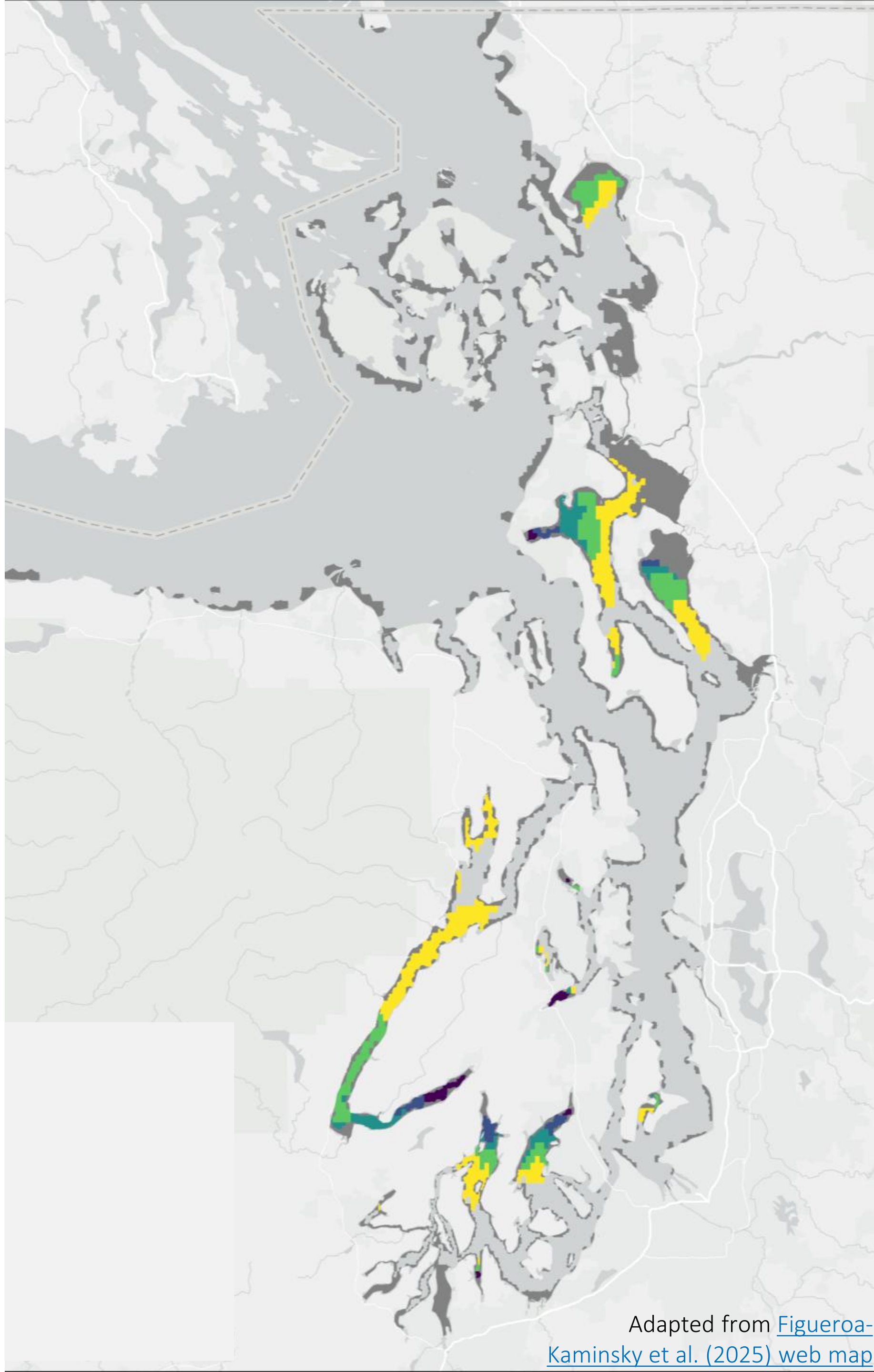
Dakota Mascarenas analyzed Ecology, King County, NOAA, and Collias (UW) data [Mascarenas and others (2025, in review)]



Predicted based on warming alone

Change in oxygen due to nutrients from human activities

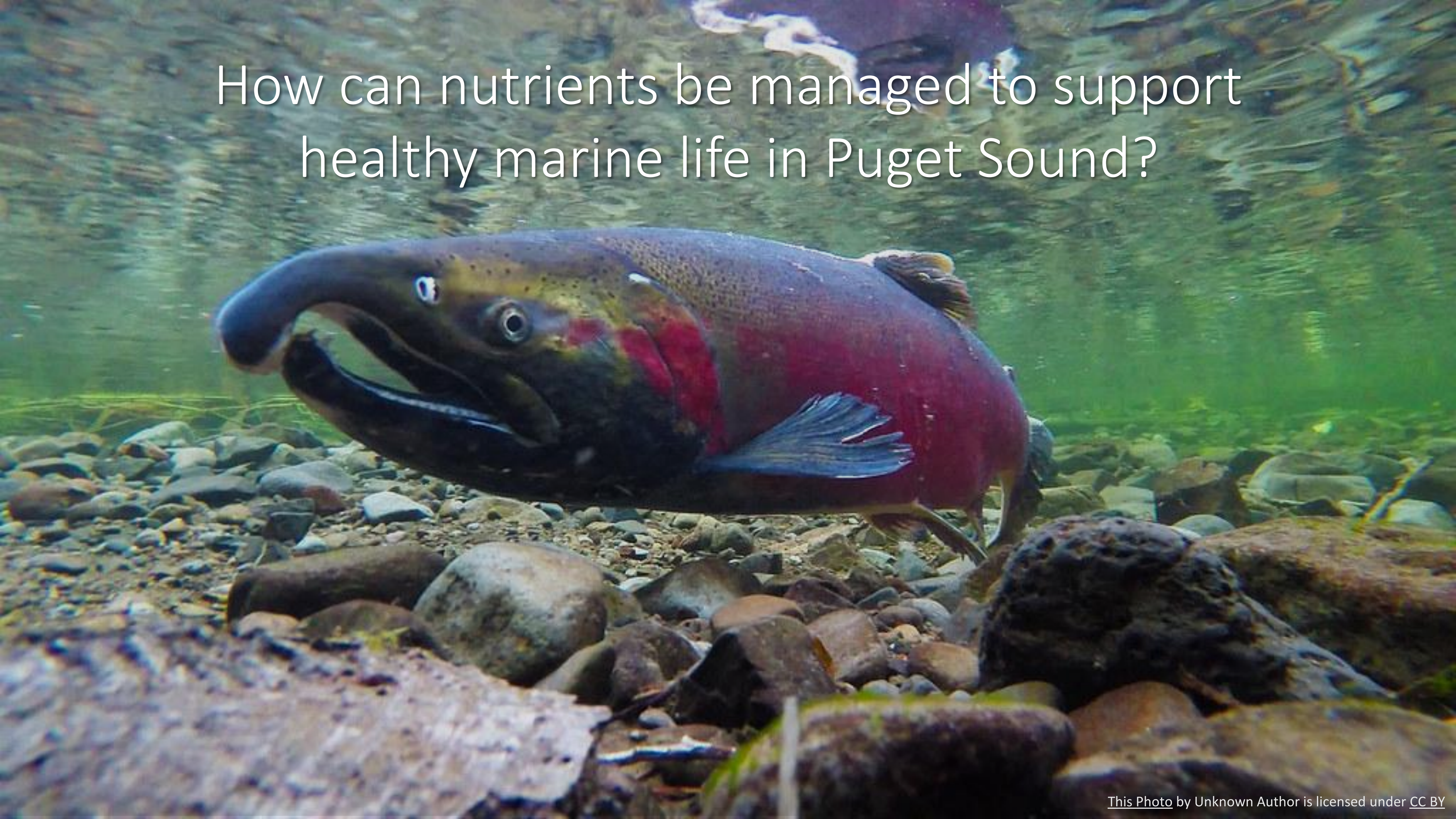
- **9% of nitrogen inputs** tied to human activities (watersheds, wastewater treatment)
- Sensitive areas:
  - Shallow embayments
  - Deep fjord-like basins like southern Hood Canal



Adapted from [Figueroa-Kaminsky et al. (2025) web map]

[Encyclopedia of Puget Sound]

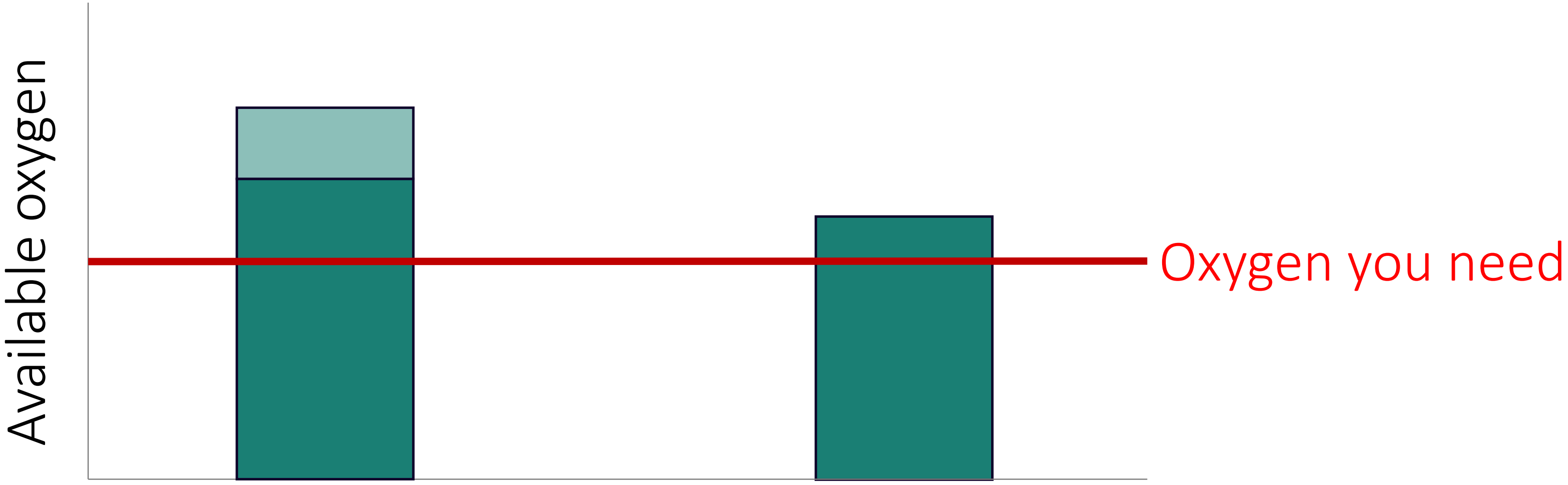
How can nutrients be managed to support healthy marine life in Puget Sound?



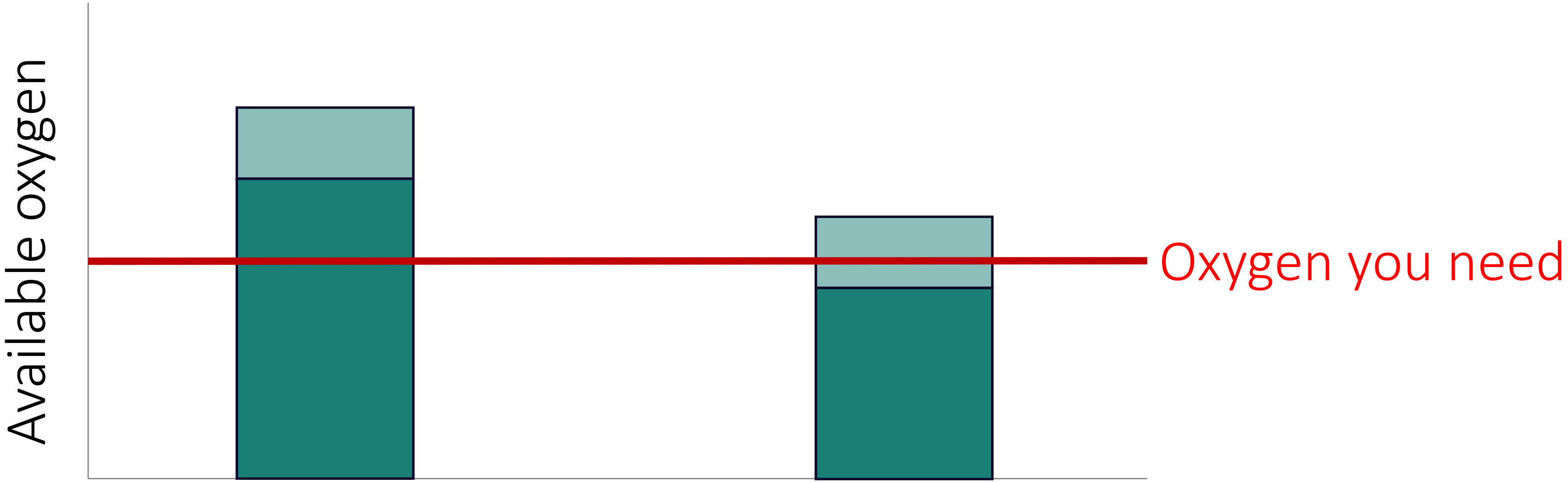
Low oxygen is problematic when it falls below physiological thresholds

Low oxygen is problematic when it falls below physiological thresholds

Low oxygen is problematic when it falls below physiological thresholds



Low oxygen is problematic when it falls below physiological thresholds



Modeling aerobic habitat compression

Our analysis predicts when and where the oxygen available for respiration is insufficient to support a species’ metabolic demand.

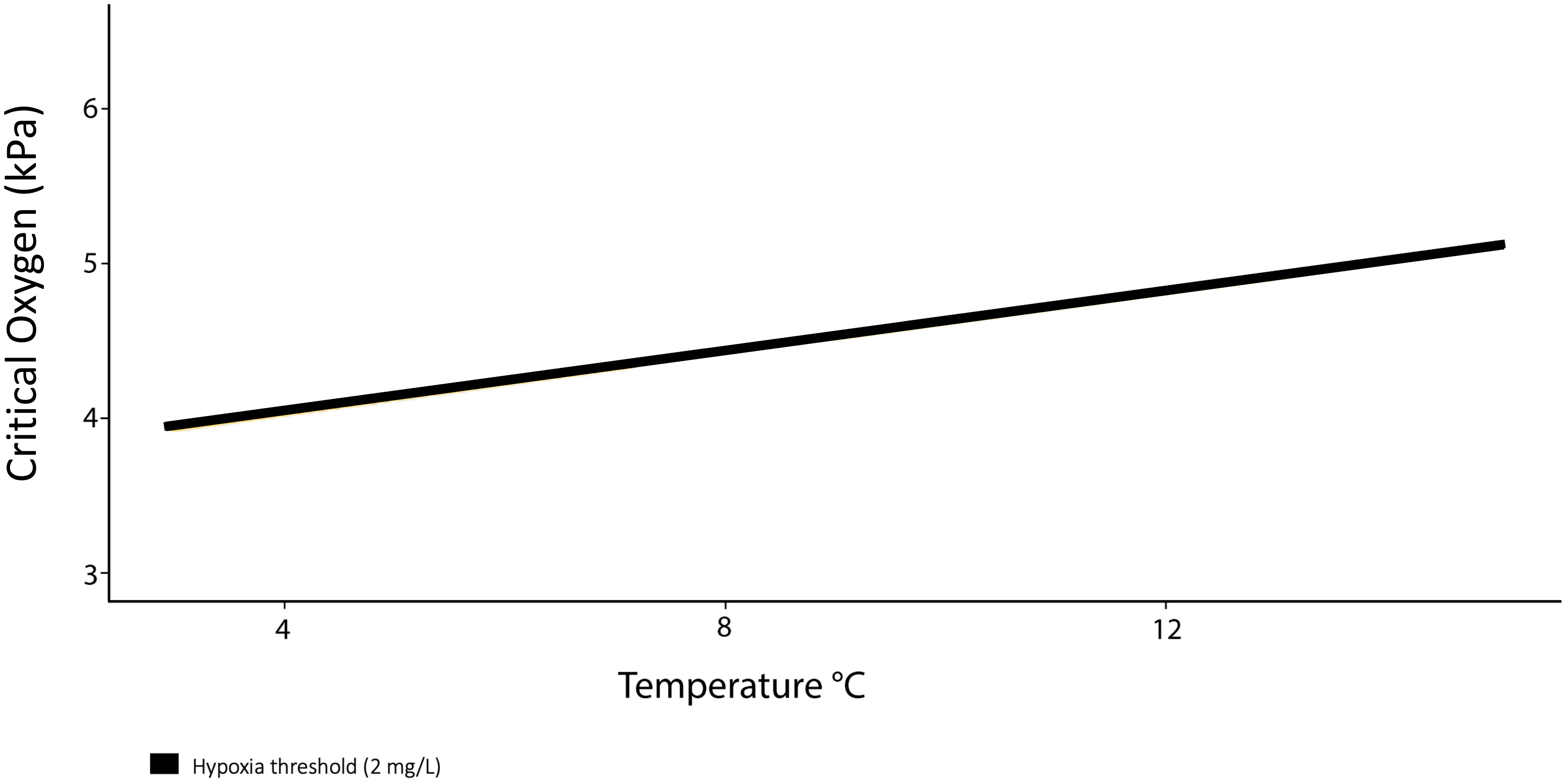
Environmental oxygen (pO_2)

<

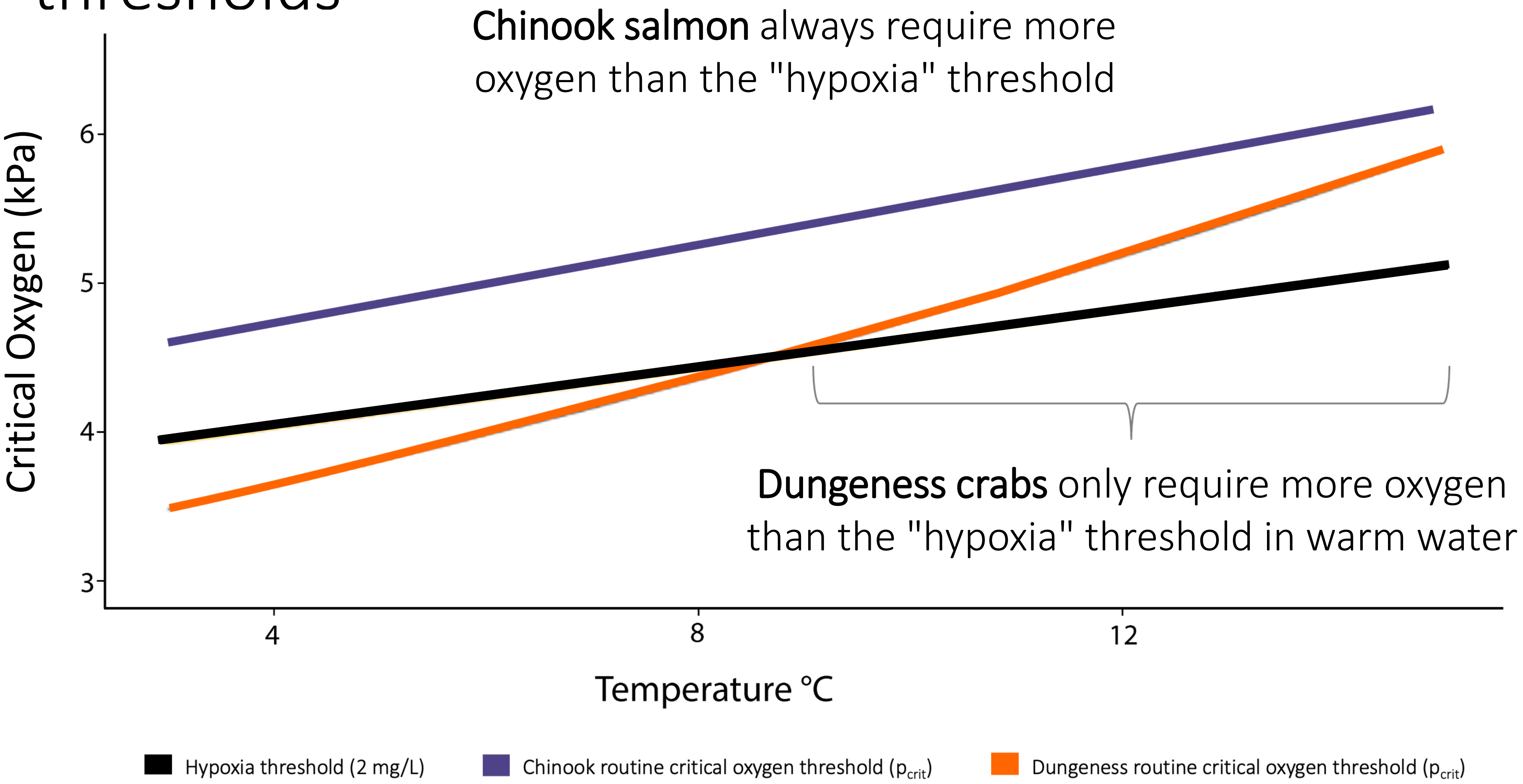
Species-specific and temperature-dependent oxygen threshold (p_{crit})

Photo Conrad Gowell, WFC

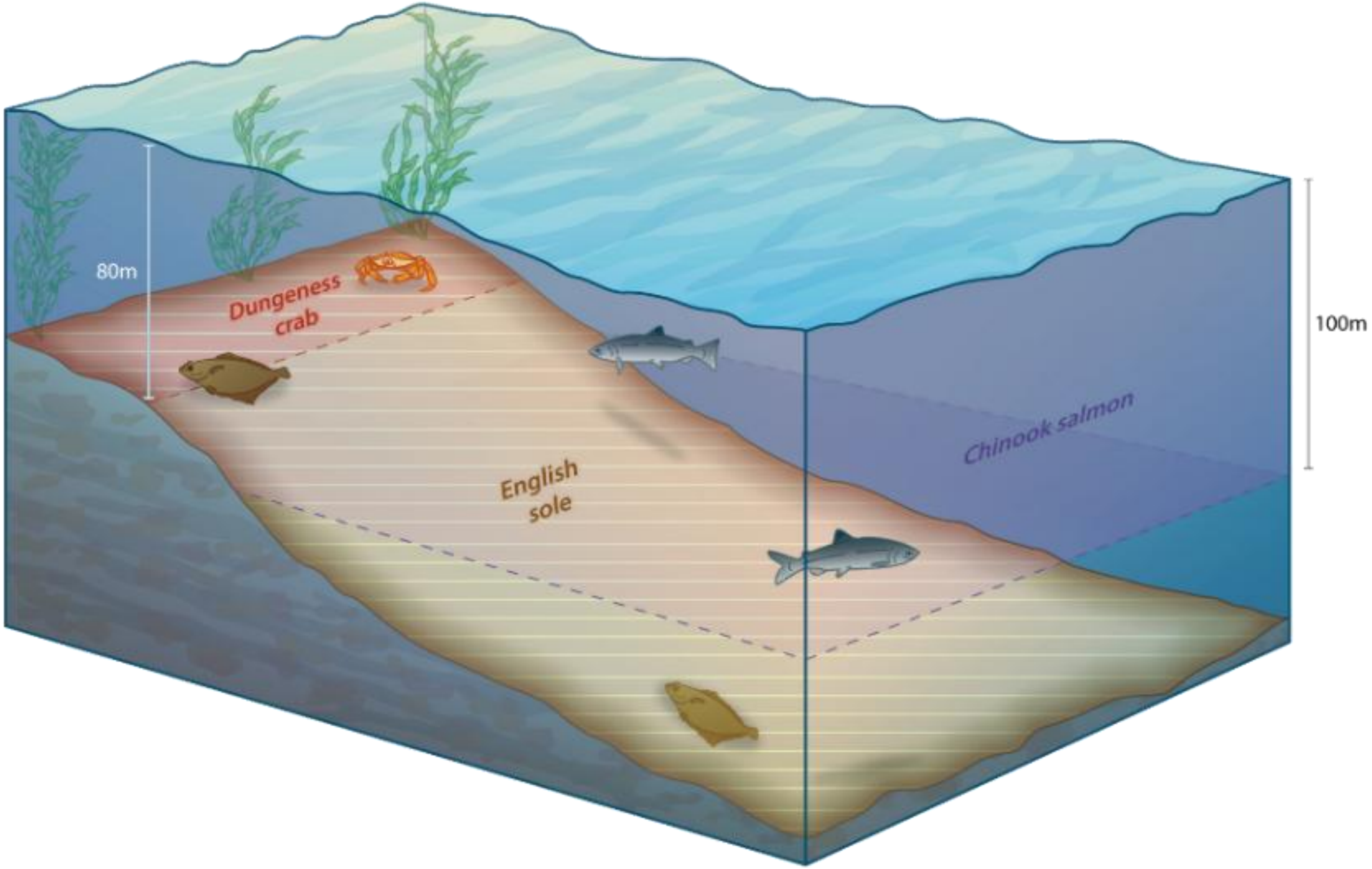
Common “Hypoxia” thresholds do not predict species’ thresholds



Common “Hypoxia” thresholds do not predict species’ thresholds



Considers how habitat drives exposure



Focuses on **direct** impacts on aerobic habitat

Does not consider indirect impacts:

- Predator-prey overlap
- Fisheries overlap
- Growth, reproduction

Methods

Selected species

Selected species with economic, ecological, and cultural importance that also had physiological inputs for the metabolic index available.

Dungeness crabs

English sole

Chinook salmon

**Analysis is for the adult life stage*

Main questions

Identify when and where the oxygen available for respiration is insufficient to support a species' metabolic demand.

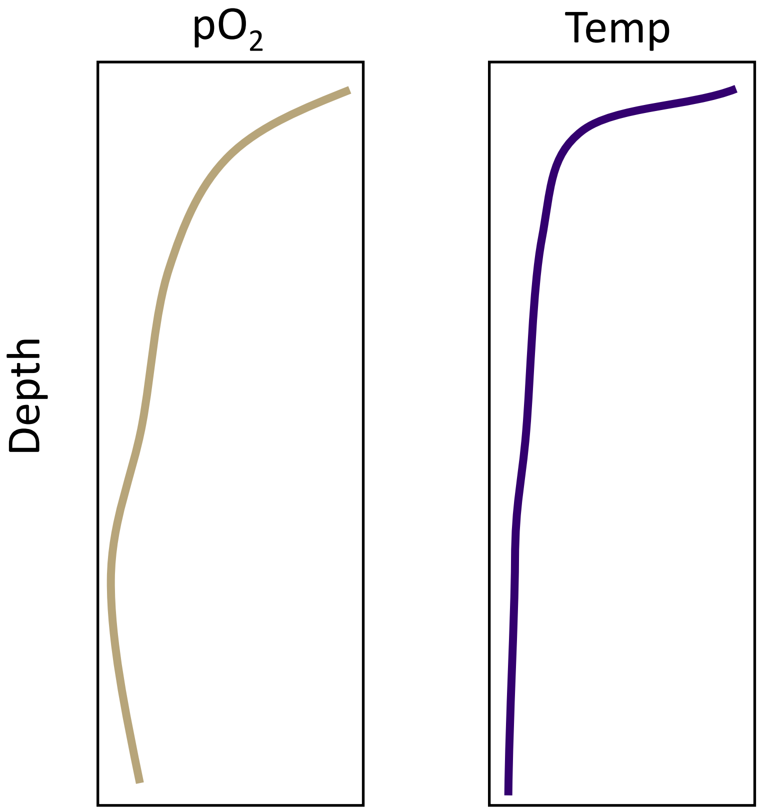
Environmental oxygen (pO_2) < Species-specific and temperature-dependent oxygen threshold (p_{crit})

Doing this means we need to have a structured approach to consider

- Daily variation
- Variation with depth
- How to estimate p_{crit}
- Potential aerobic habitat for each species

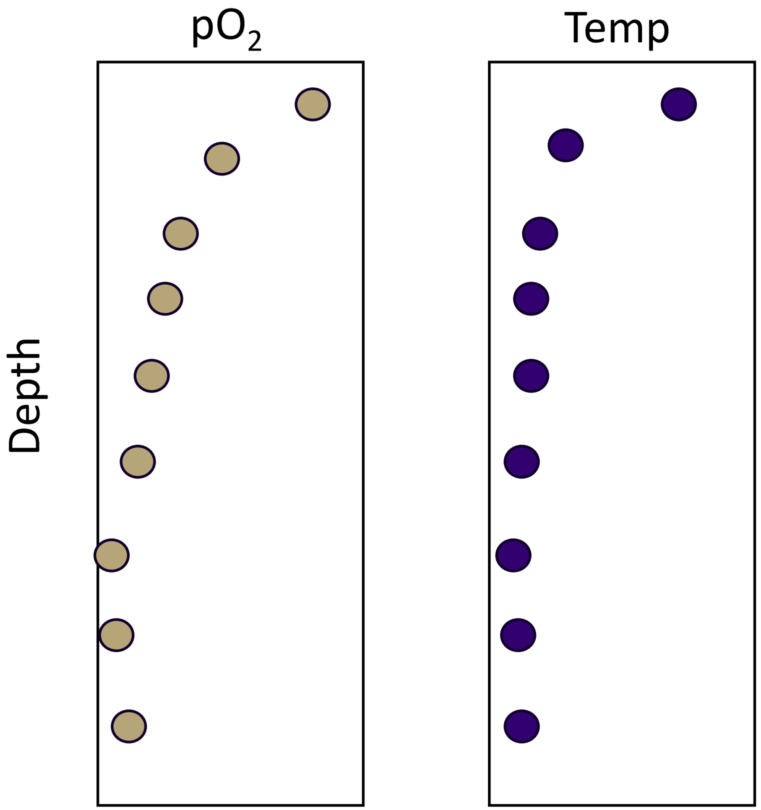
Photo Conrad Gowell, WFC

Hypothetical profile: one location on one day



In the model world: the profile becomes 10 points

The model has 10 layers per location

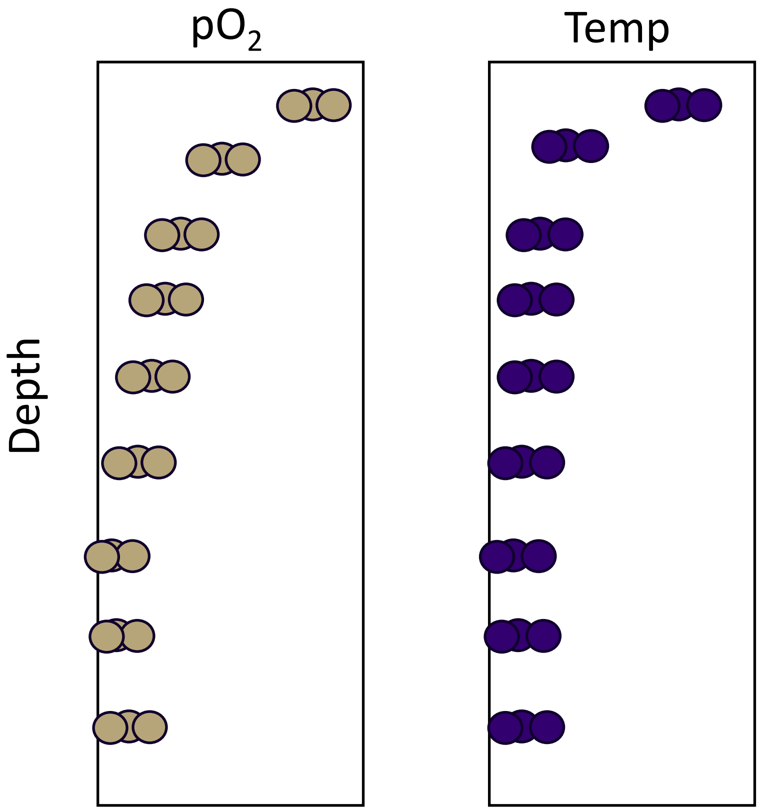


And there is a time dimension as well

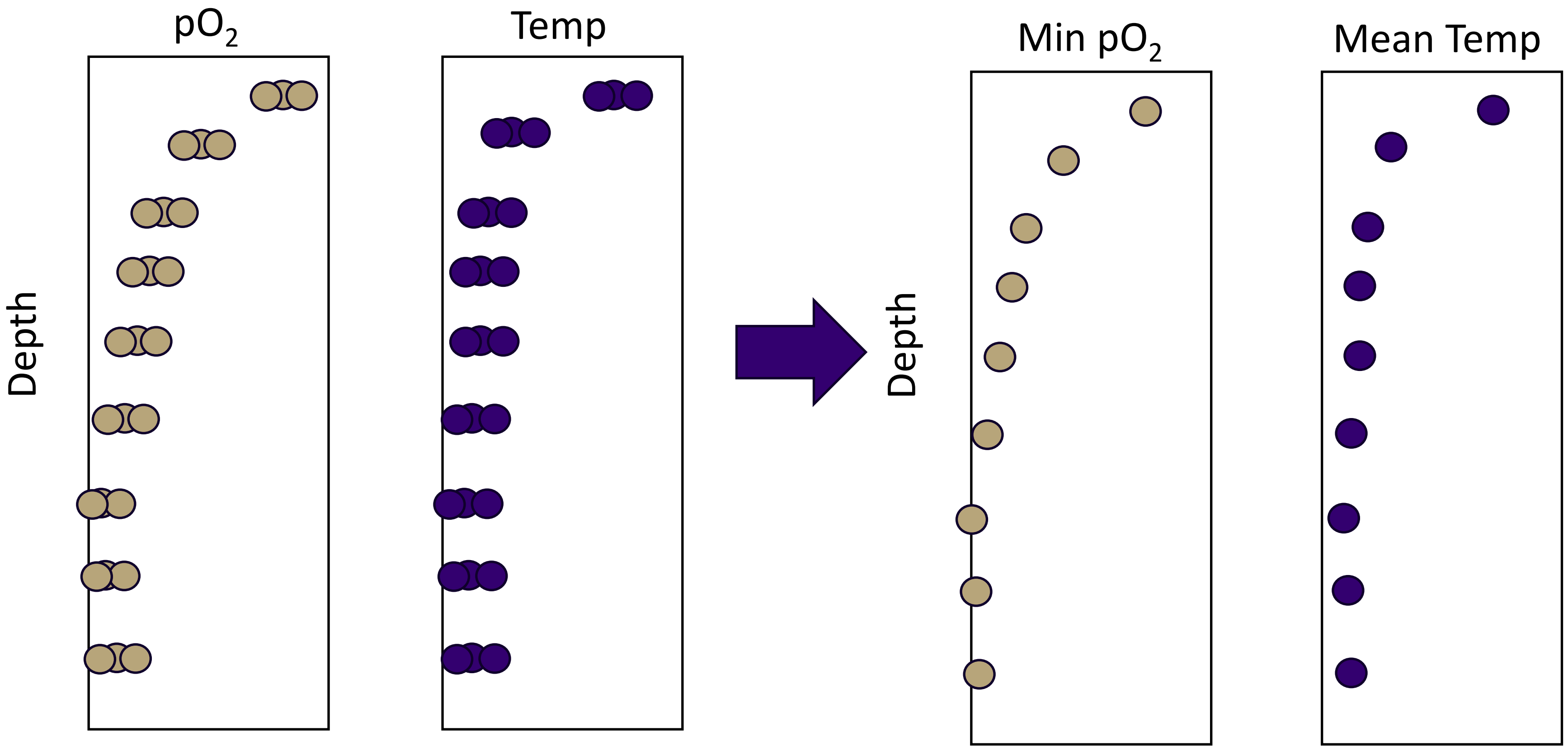
Because the model operates on a 24 hour cycle ….

There are 24 pO_2 and Temperature values per depth layer for each **day**

We needed to collapse this into a single number for each layer



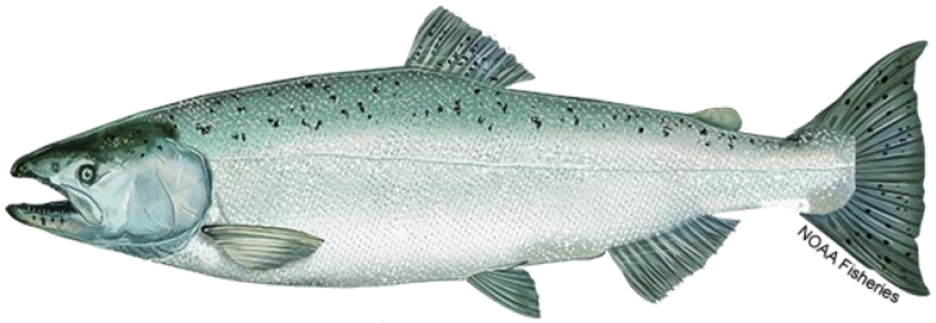
Simple and conservative approach: use smallest pO_2, average temperature



Limited concurrent in situ data to determine p_{crit}

Sullaway & Essington (2025) found only four datasets in the Salish Sea where abundance, oxygen, and temperature were measured concurrently.

Interestingly, Chinook salmon were observed at low oxygen levels, even though more oxygen was available just above them.



Chinook salmon
2.06 - 4.06 DO mg/L*

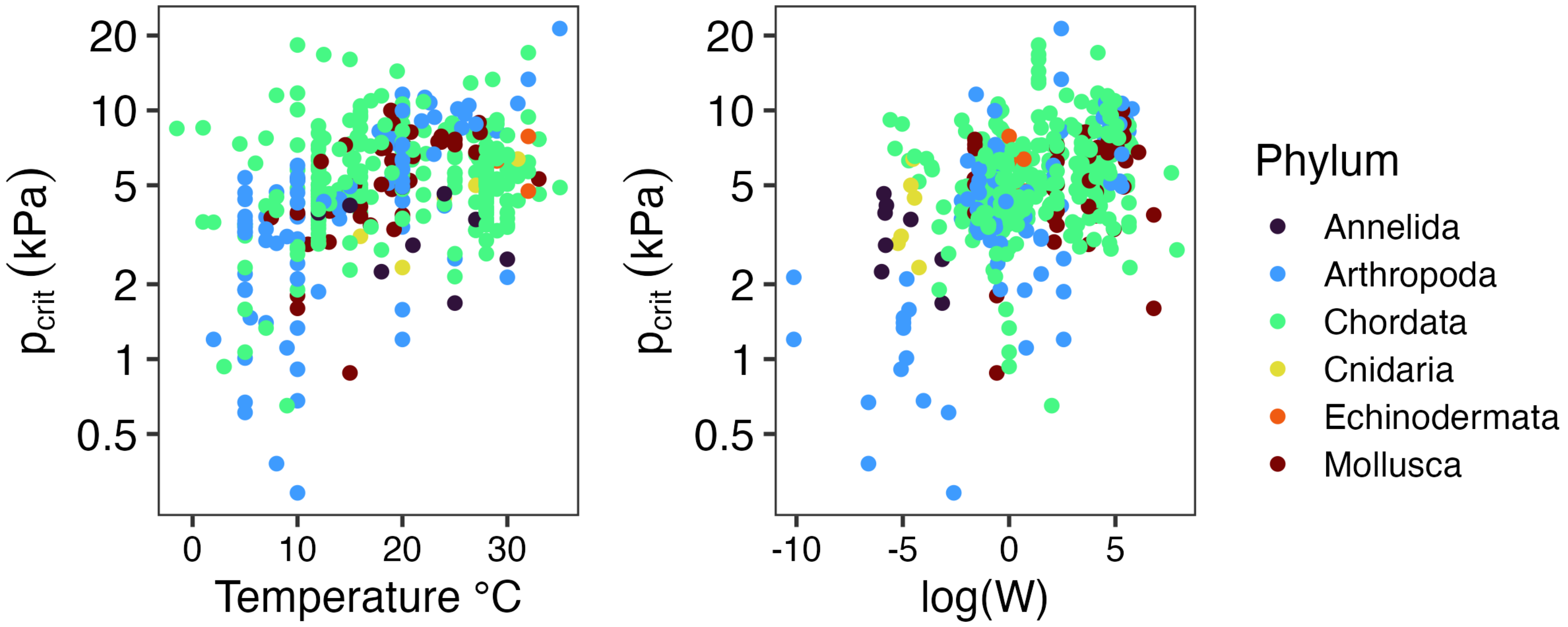
How is p_{crit} estimated?

- [Essington et al. (2026)] summarized data from 150+ species, over 450 laboratory measurements
- Developed a computational approach to estimate p_{crit} for any organism based on:
  - Taxonomy (related species should have similar pcrit)
  - Temperature
  - Body size
  - Laboratory method
- Considers species-specific temperature sensitivity, body size effects, and overall sensitivity to low pO_2

This study: re-ran the taxonomic trait imputation model with all additional p_{crit} estimates to improve the 3 taxa

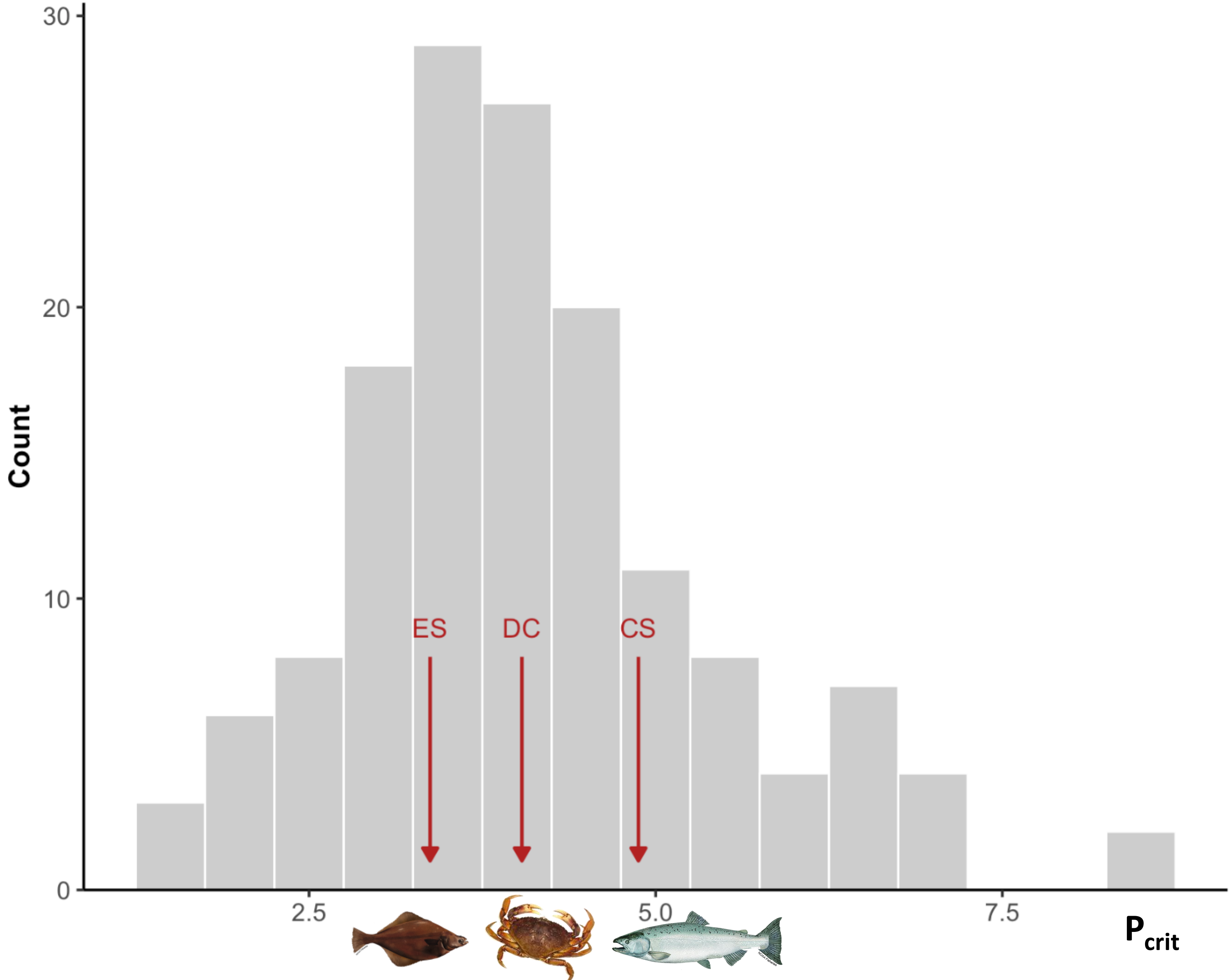
Approach: Essington, T. E., Thorson, J. T., & Deutsch, C. (2026)

P_{crit} threshold varies among taxa



Essington et al. (2026)

P_{crit} for the selected species



Mazzilli et al. (2026) based on Essington et al. (2026)

Focusing on routine p_{crit} is more protective

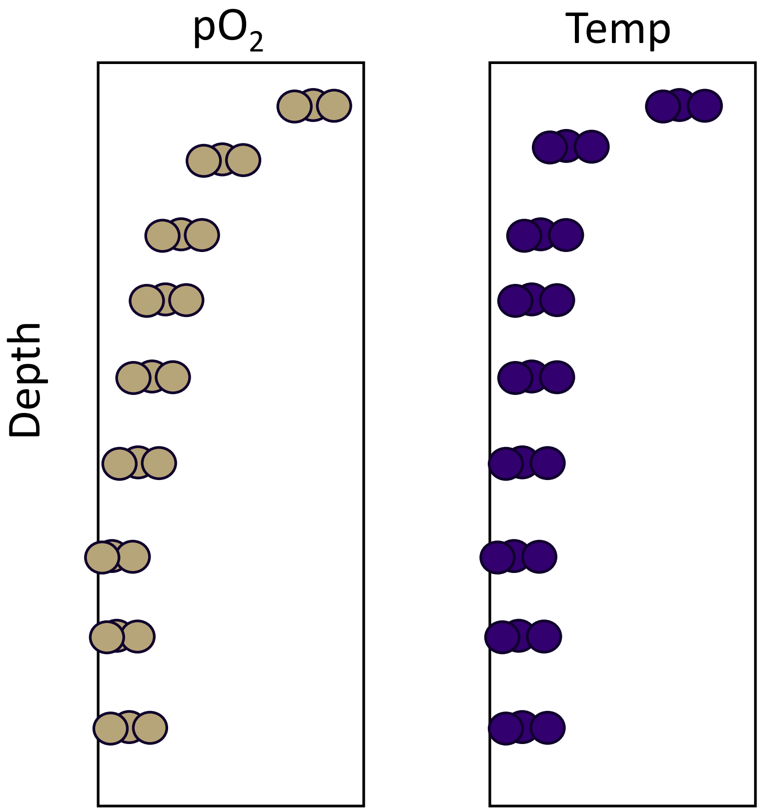
Basal
Minimum energy to maintain essential physiological functions at rest

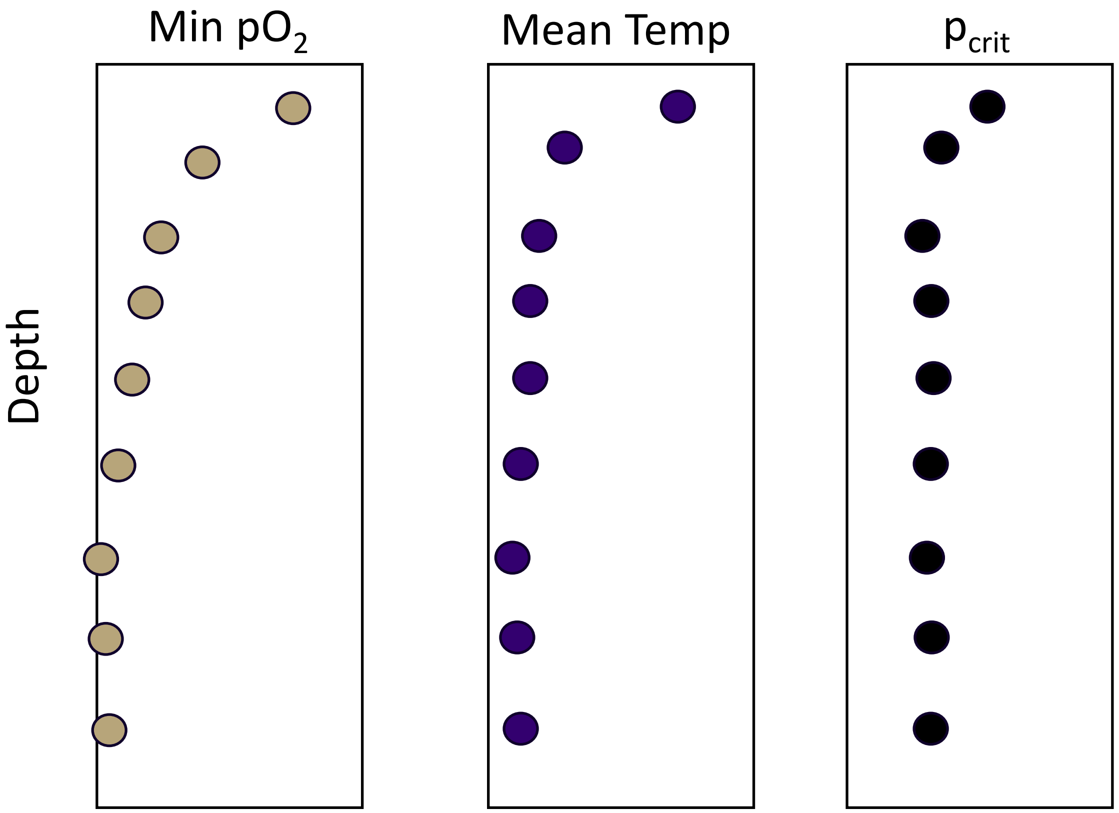
<

Routine
Minimum energy to maintain basal functions and routine activities like feeding and swimming

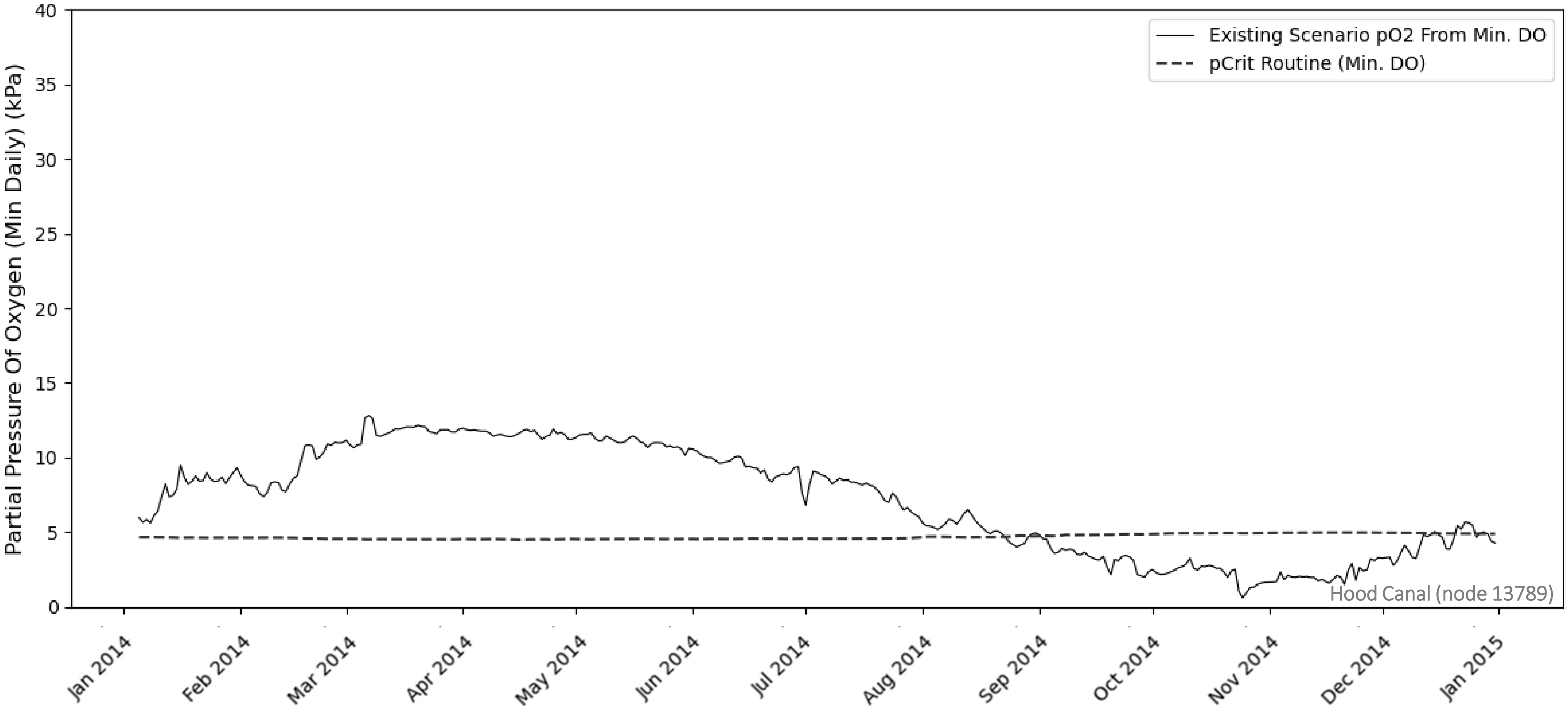
While the energy needed for reproduction and growth may be higher, laboratory-based measurements do not account for physiological acclimation

p_{crit} for a species is estimated at each layer from temperature

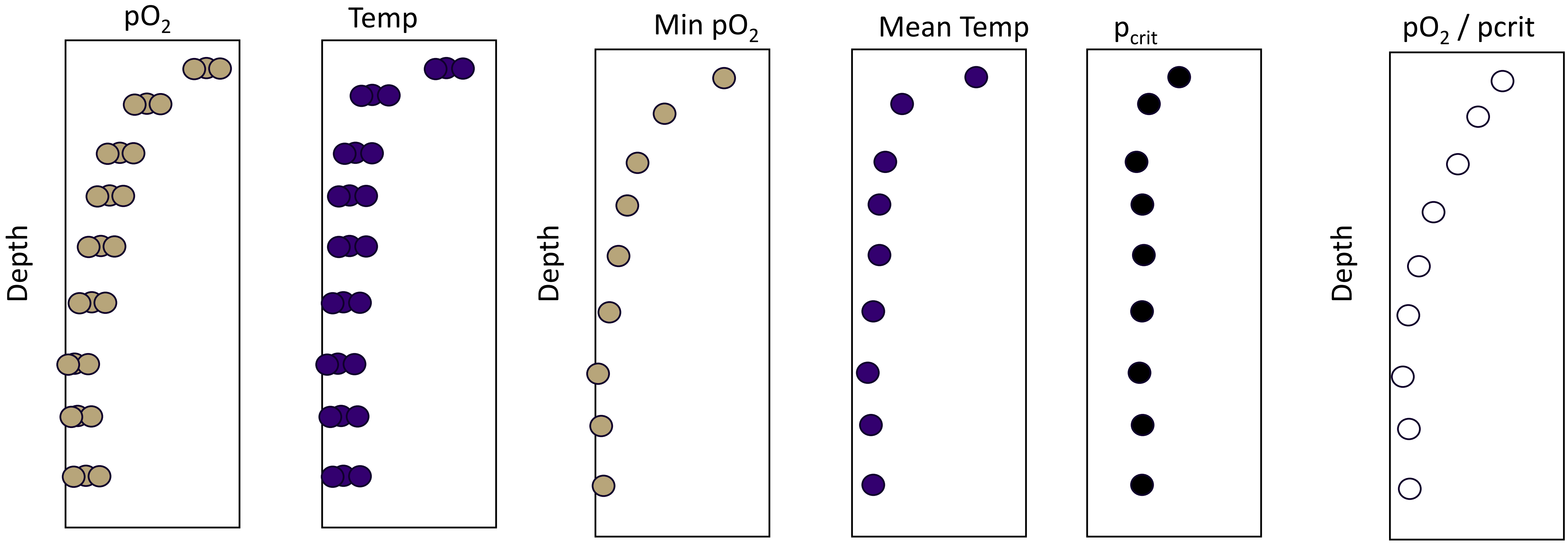




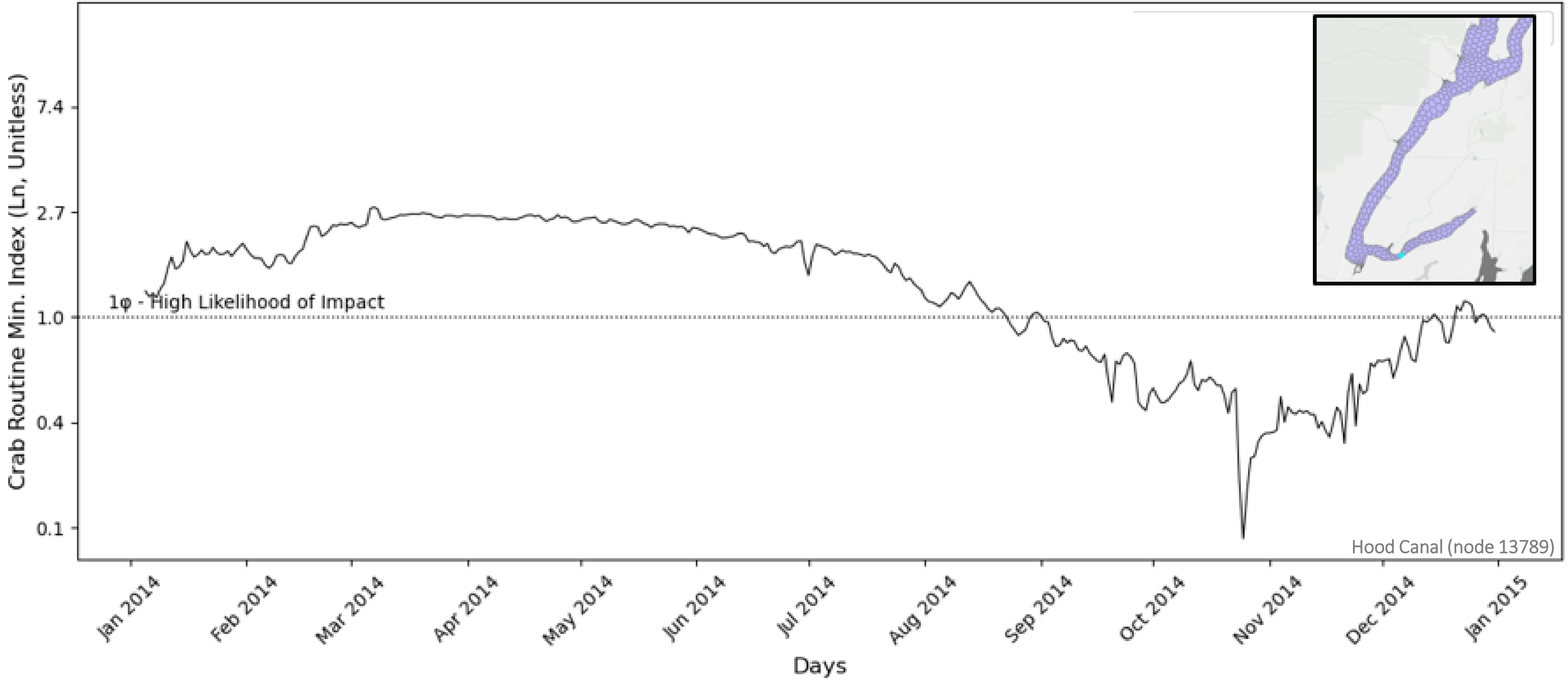
Are environmental conditions above the threshold oxygen level?
Dungeness crabs in Hood Canal



Take the ratio of pO_2 / p_{crit} for each layer



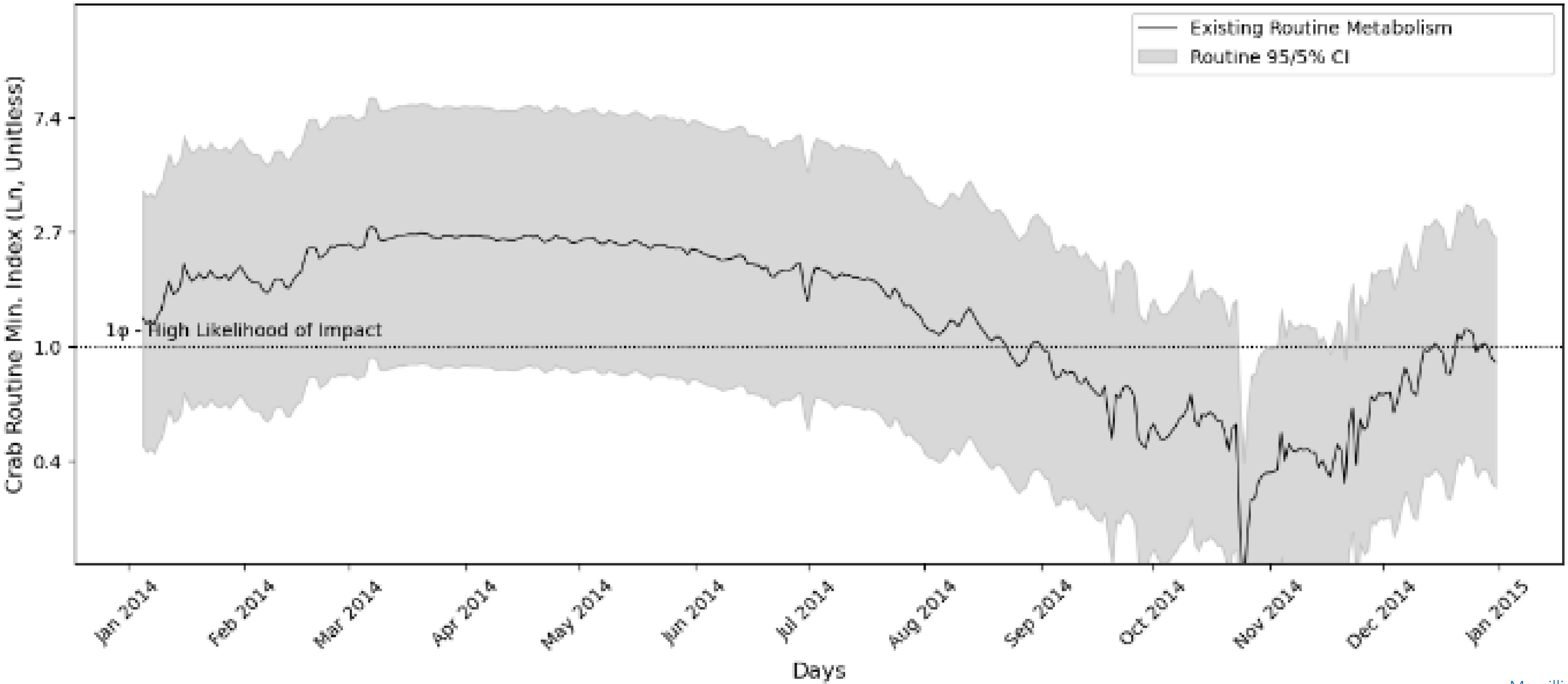
Ratio of p_{O2} / p_{crit}
Dungeness crabs in Hood Canal



[Mazzilli et al. (2026)]

Confidence in metabolic demand
Dungeness crabs in Hood Canal

Next phase: evaluate probabilistic risk



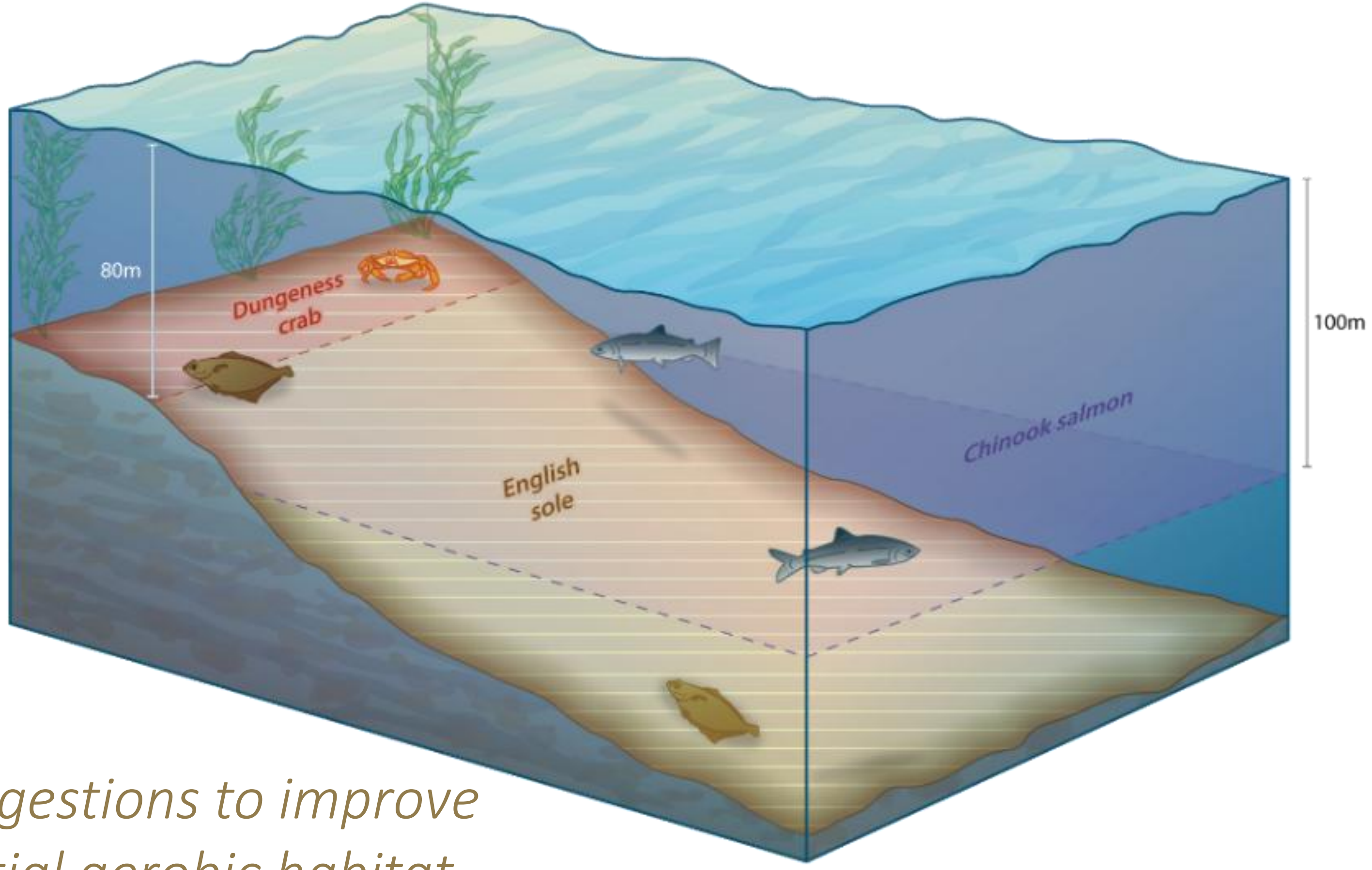
Mazzilli et al. (2026)

Using depth to define potential aerobic habitat

Dungeness crab: Area along the bottom of the Sound if < 80 m

English sole: Area along the bottom of the Sound

Chinook salmon: Volume in the top 100 m of the water column



Reach out if you have suggestions to improve how we've defined potential aerobic habitat

**Analysis only considers one of several characteristics to define potential habitat.*

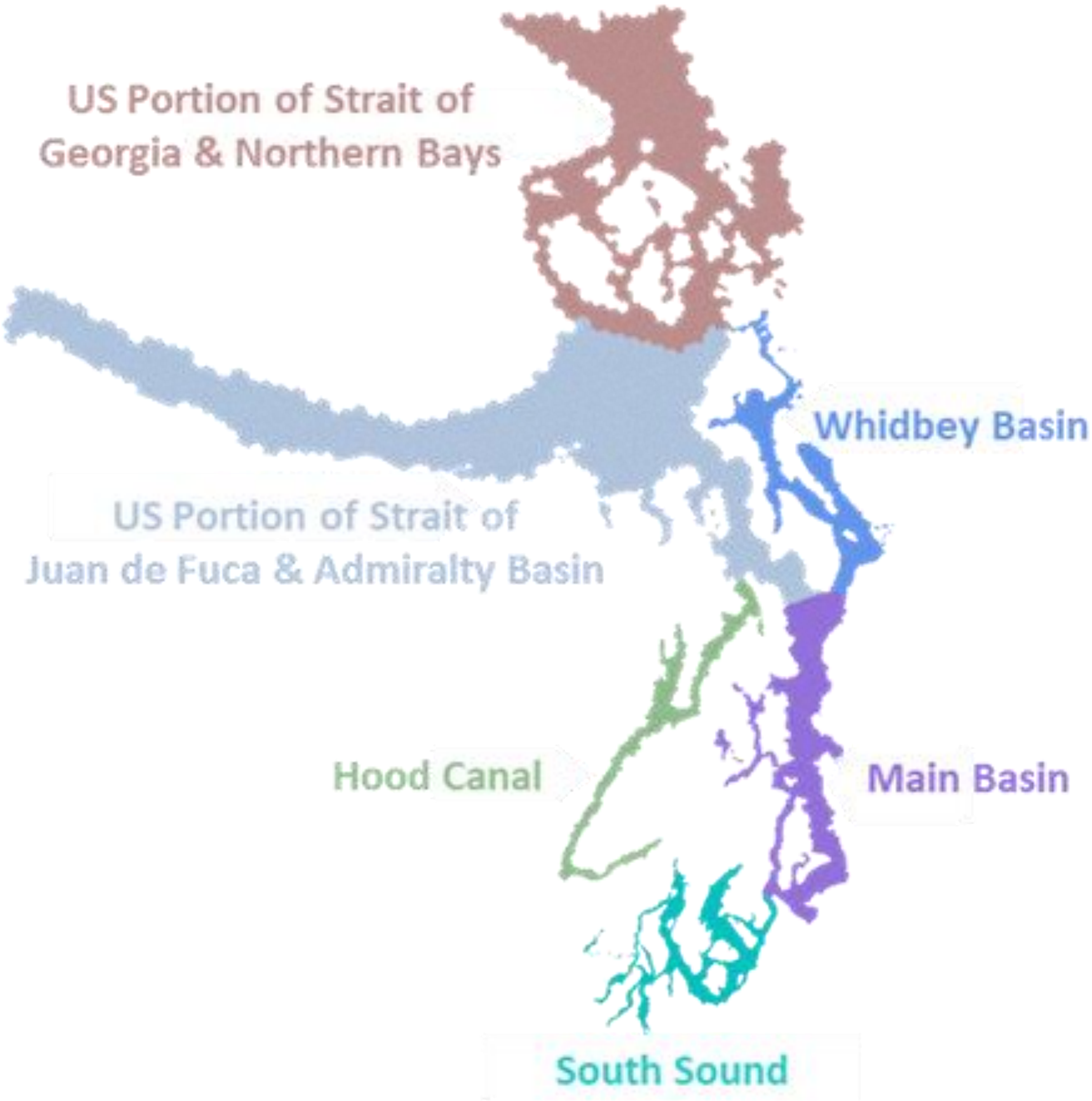
Ramuson (2013); Armstrong et al., (1988); Blaine et al., (2024) ; Freshwater et al., (2024); Smith et al., (2015)

Results

Modeled habitat compression

Analyzed **2014 model outputs*** from the Salish Sea Model for Puget Sound and the Straits.

6 regions within Washington State waters
Total: Area of 6378 km^2 assessed
(excluding masked near shore areas)



Salish Sea Model outputs consistent with [Ahmed et al. (2021)]

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SSM outputs within each species habitat
3021 km^2 benthic area for Dungeness crab - excluding those areas >80m (grey)

**Salish Sea Model outputs consistent with [Ahmed et al. (2021)]*

Modeled habitat compression

Analyzed **2014 model outputs*** from the Salish Sea Model for Puget Sound and the Straits.

- 6 regions within Washington State waters
  Total: Area of 6378 km^2 assessed
  - SSM outputs within each species habitat
    3021 km^2 benthic area for Dungeness crab - excluding those areas >80m (grey)
    - For each cell for each day, determine where **Metabolic Index <1**

**Salish Sea Model outputs consistent with [Ahmed et al. (2021)]*

Dungeness crabs

Dungeness crabs

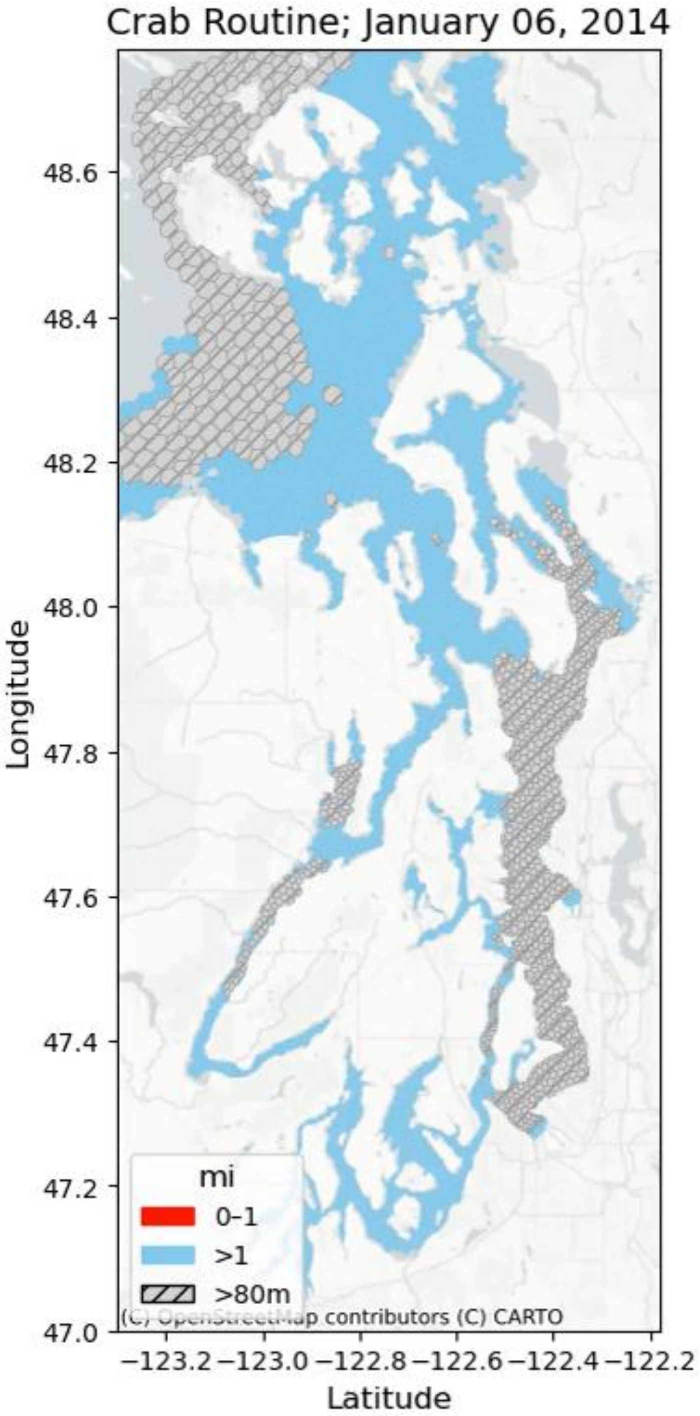
English sole

Chinook salmon

Seasonal aerobic habitat compression for Dungeness Crab

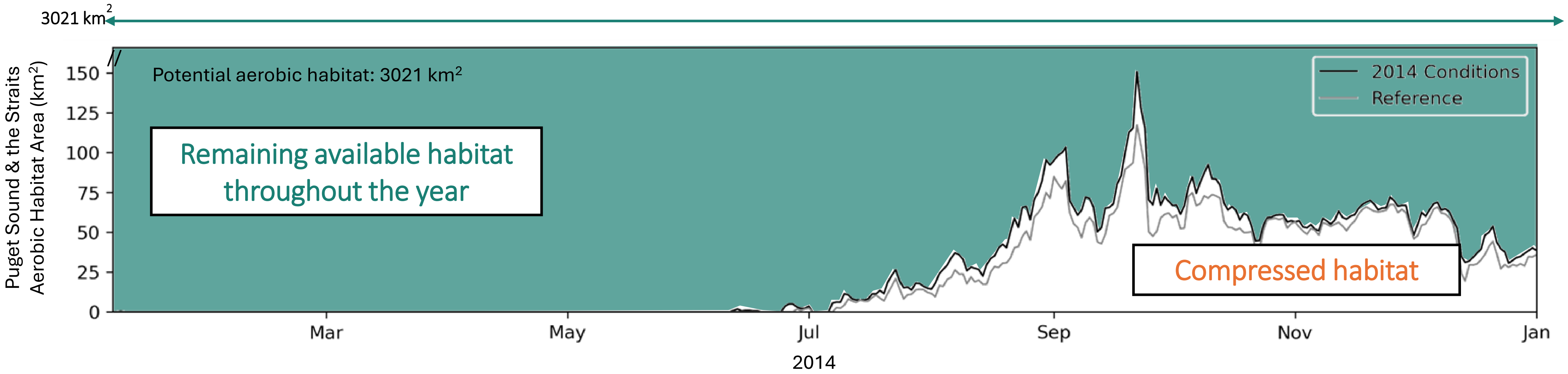
- Hood Canal from summer through the end of the year
- Several embayments in the summer and fall

	Compressed habitat
	Available habitat
	Too deep



Interpreting aerobic habitat compression in 2014

Dungeness crabs



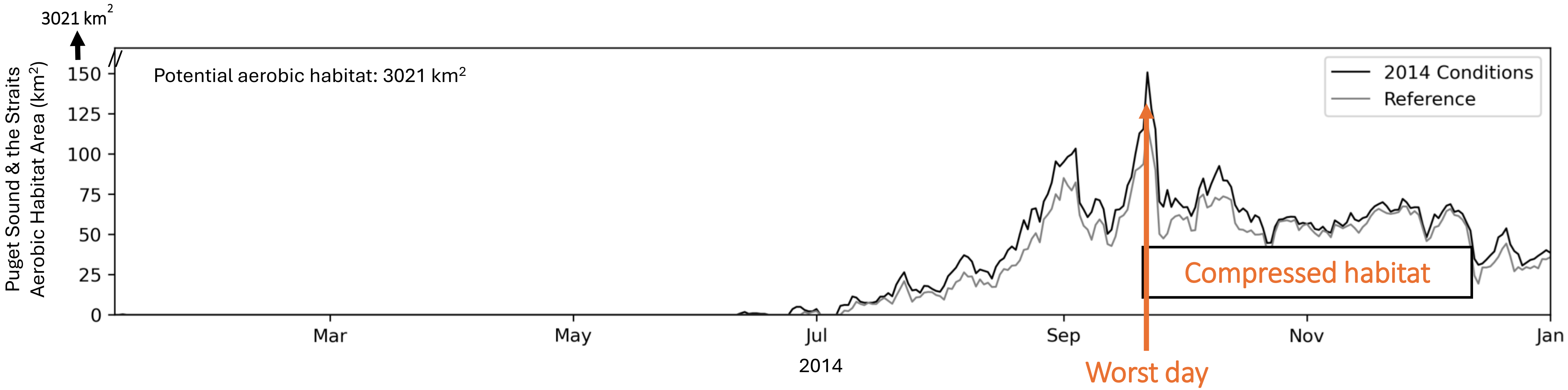
Mazzilli et al. (2026)

Worst day of aerobic habitat compression

Dungeness crabs

151 km^2 or 5.0%

of potential aerobic habitat



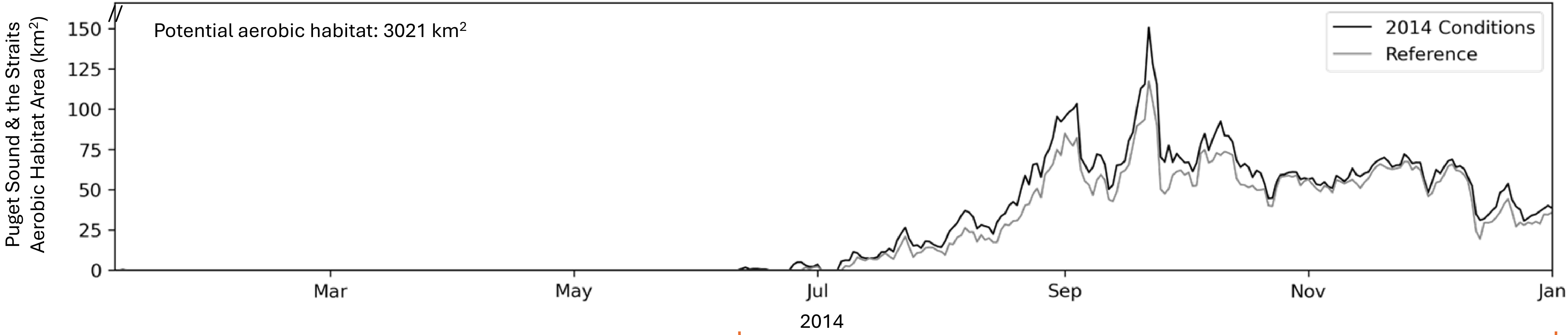
Mazzilli et al. (2026)

Average during the period of compression

Dungeness crabs

47 km^2 or 1.6%
of potential aerobic habitat

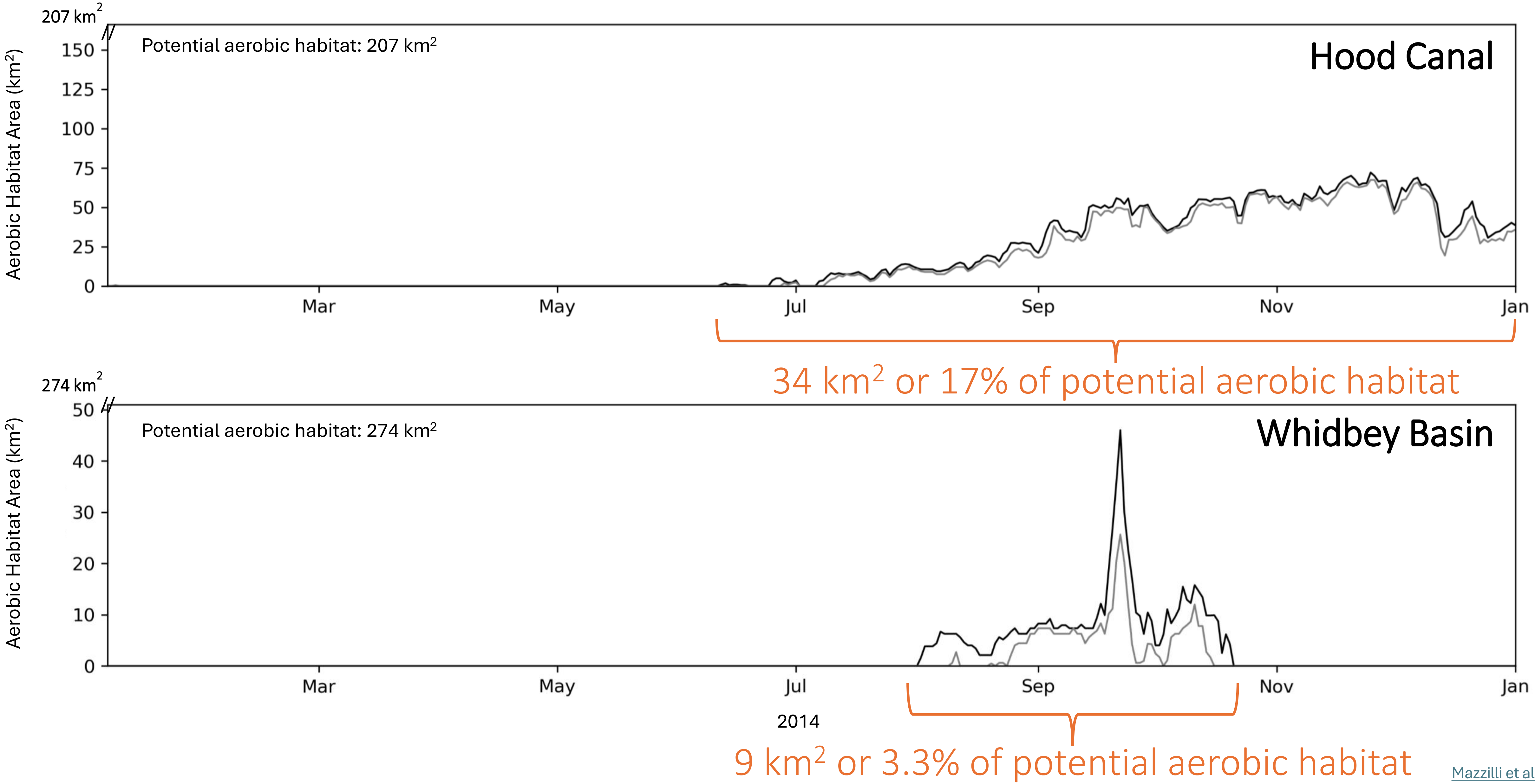
3021 km^2



Period of compression

Mazzilli et al. (2026)

Compression varies within regions



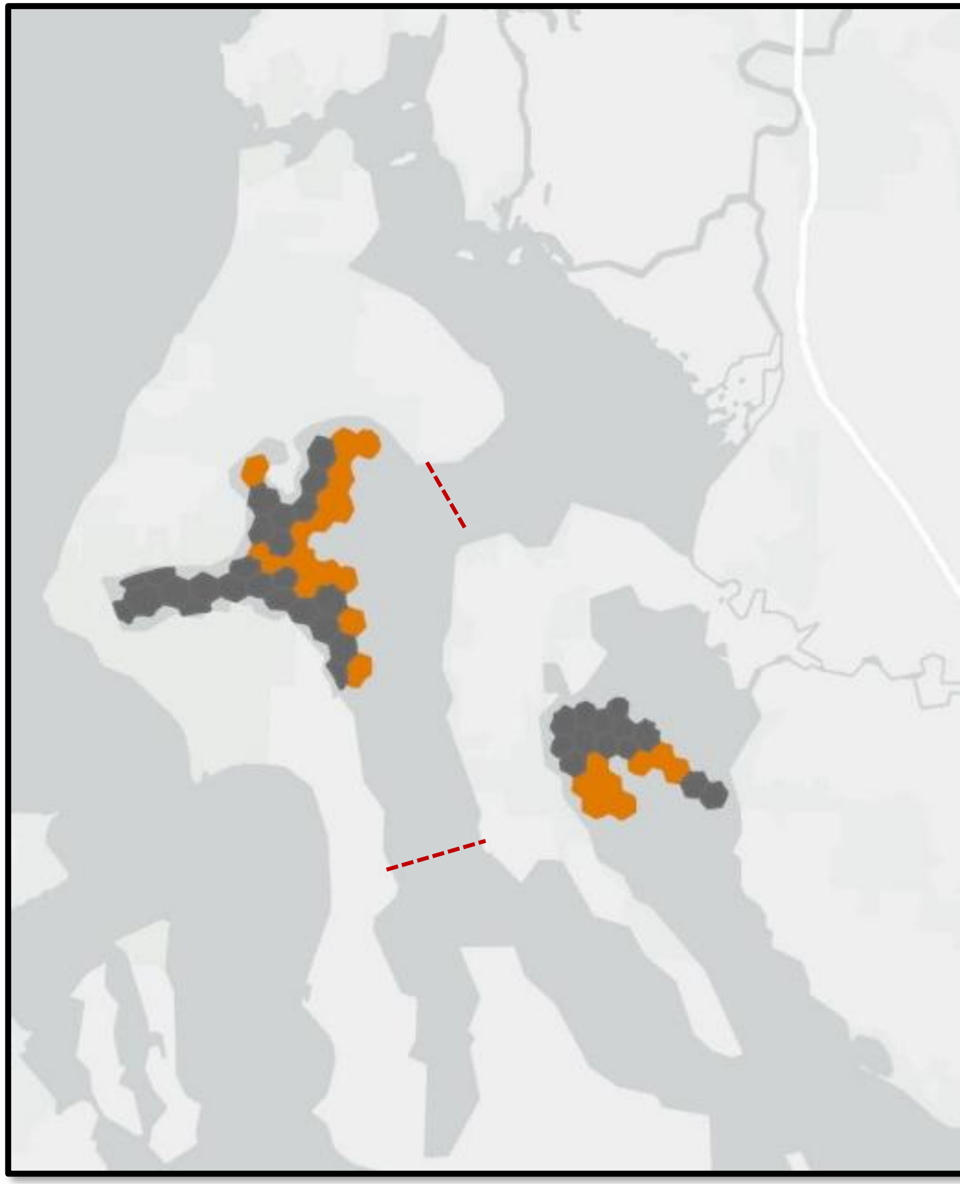
Mazzilli et al. (2026)

Important to drill down locally on impacts

Worst day

33 km^2 or 31%

of potential aerobic habitat in Penn Cove



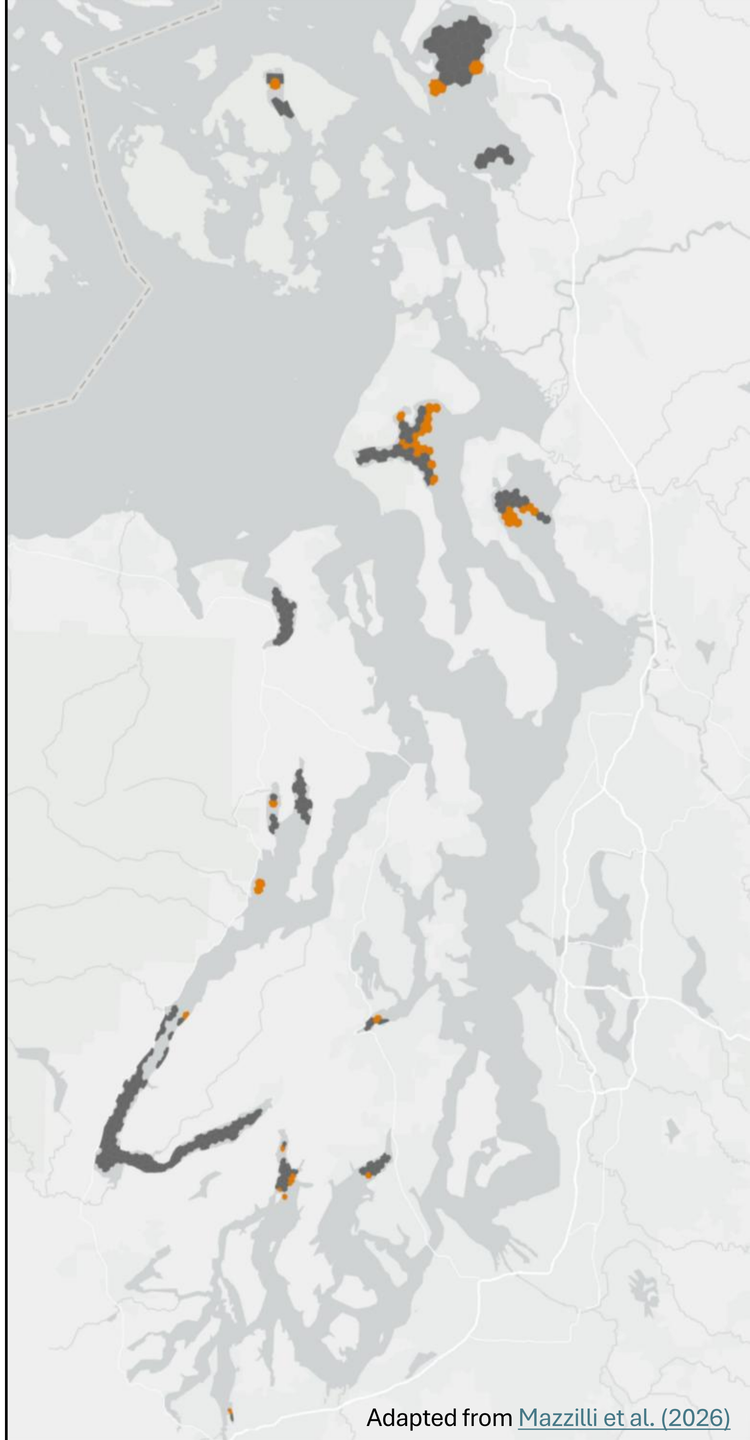
Mazzilli et al. (2026)

Loss of habitat due to nutrients from human activities in Washington State

Dungeness crab (2014)

Habitat compression under both Reference and Existing conditions

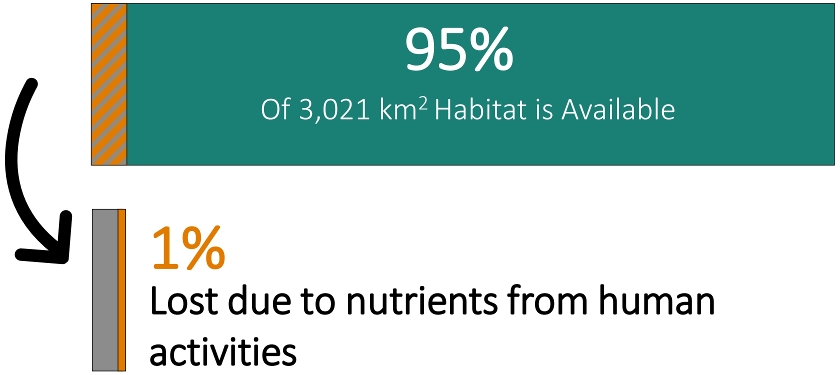
Habitat loss due to nutrients from human activities in Washington



Adapted from [Mazzilli et al. (2026)]

Loss of habitat due to nutrients from human activities in Washington State

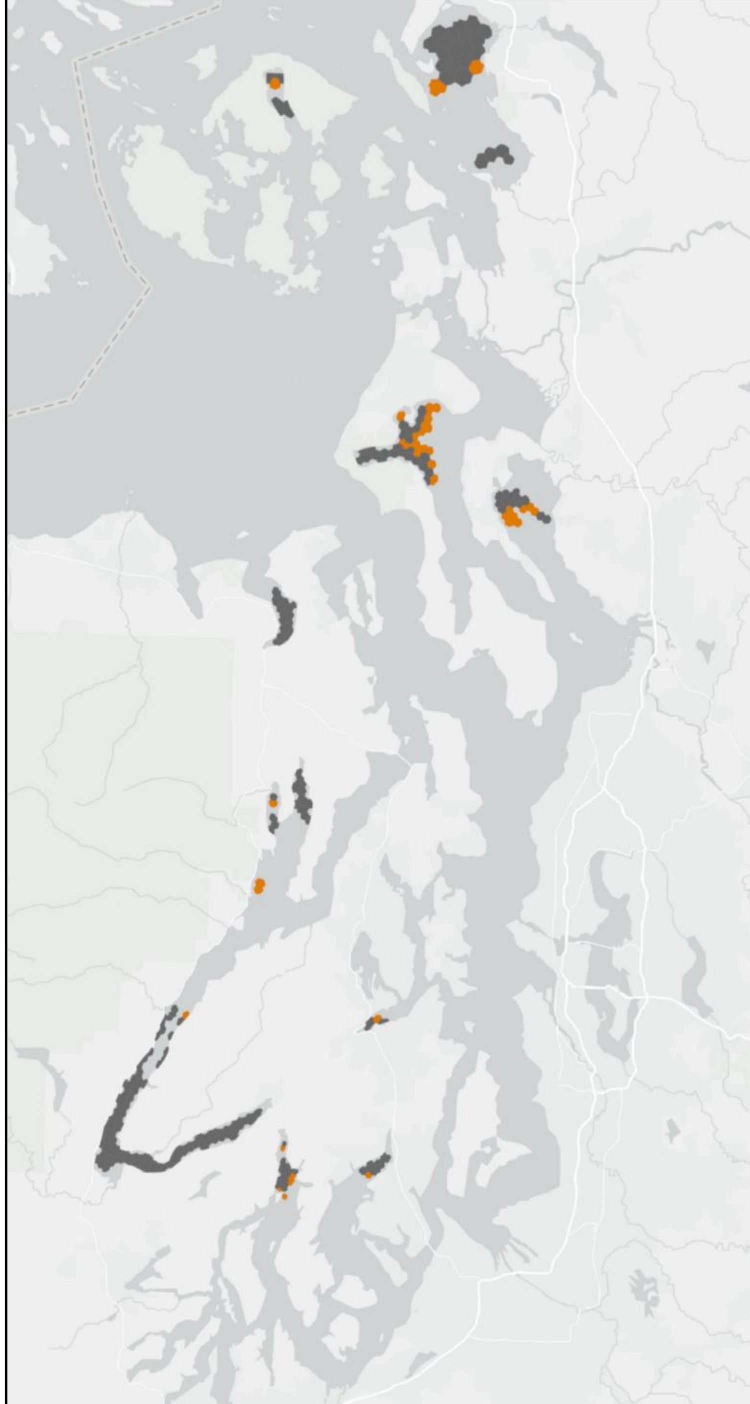
Worst day



4%
Compression under reference conditions

Dungeness crab (2014)

- Habitat compression under both Reference and Existing conditions
- Habitat loss due to nutrients from human activities in Washington



Adapted from Mazzilli et al. (2026)

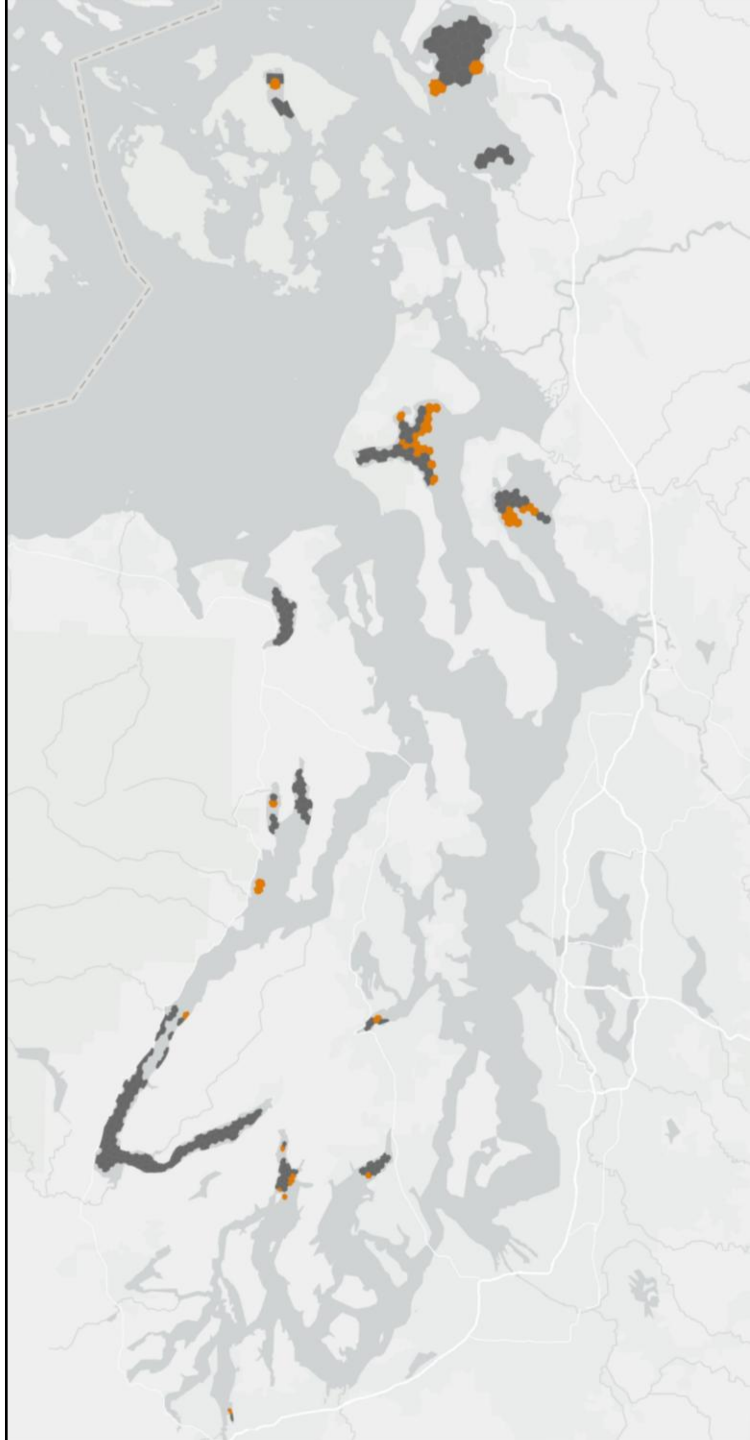
Loss of habitat due to nutrients from human activities in Washington State

Habitat compression under existing conditions **reflects other human impacts**, some of which may be actionable, including:

- Nutrients from human activities in Canada and the ocean
- Watershed disturbances
- Climate change

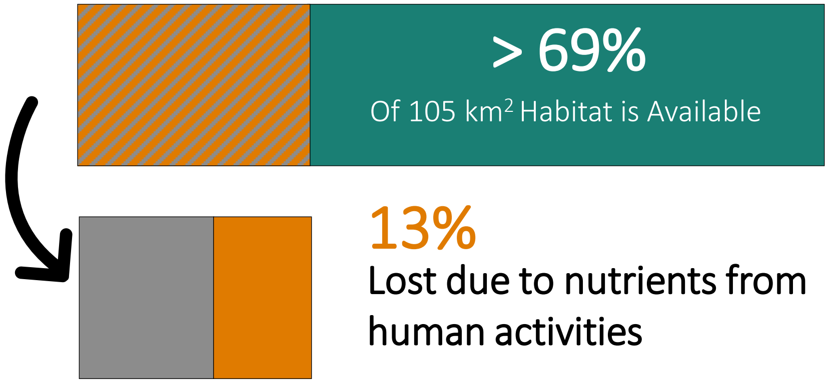
Next phase: future climate conditions

See Ahmed et al. (2019), Ahmed et al. (2021), and Figueroa-Kaminsky et al. (2026) for additional information on reference conditions



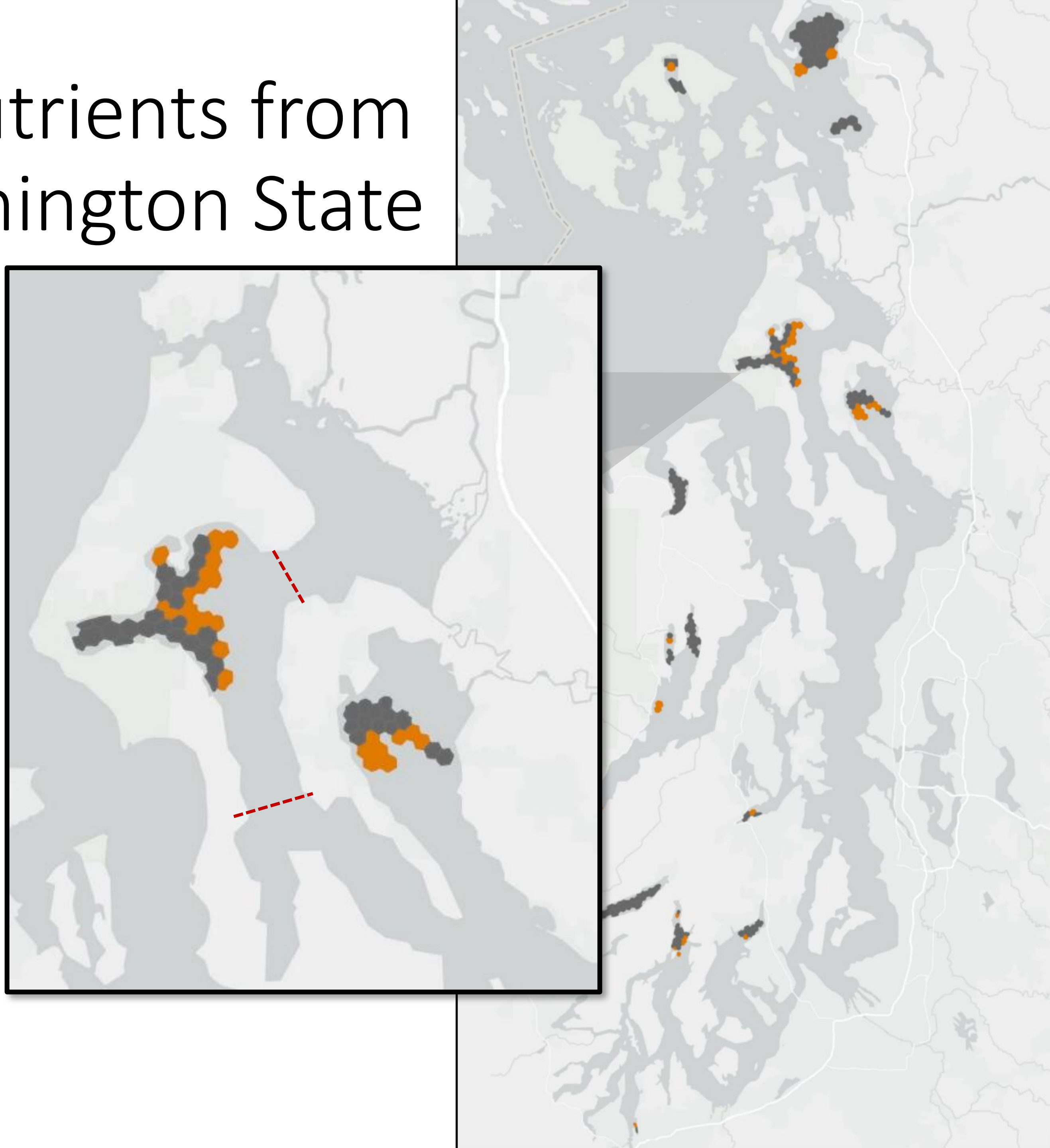
Loss of habitat due to nutrients from human activities in Washington State

Worst day



13%
Lost due to nutrients from human activities

18%
Compression under reference conditions



English sole

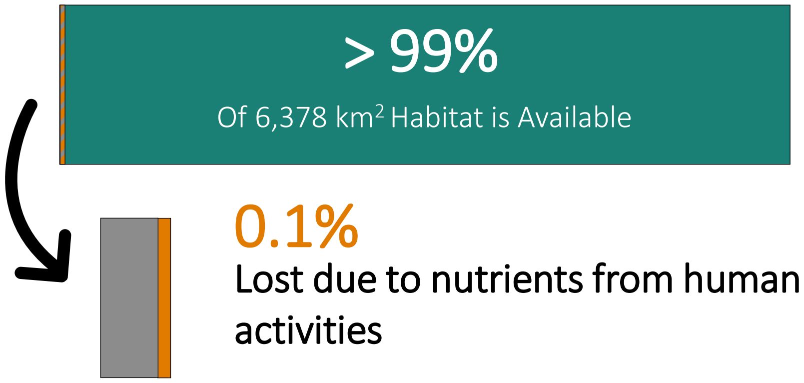
Dungeness crabs

English sole

Chinook salmon

English sole

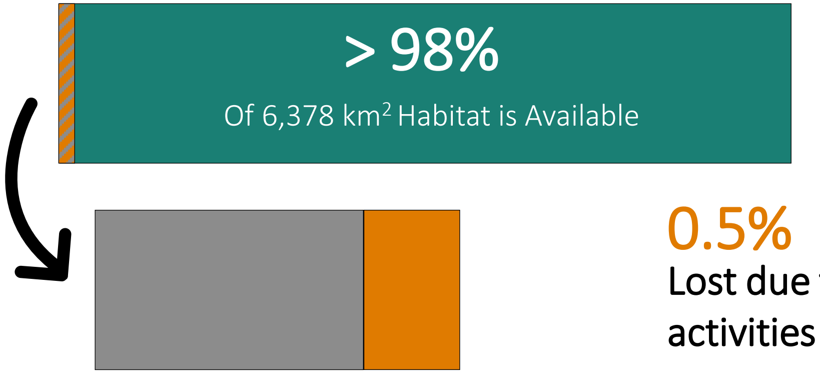
During period of compression



0.1%
Lost due to nutrients from human activities

0.5%
Compression under reference conditions

Worst day



0.5%
Lost due to nutrients from human activities

1%
Compression under reference conditions

Mazzilli et al. (2026)

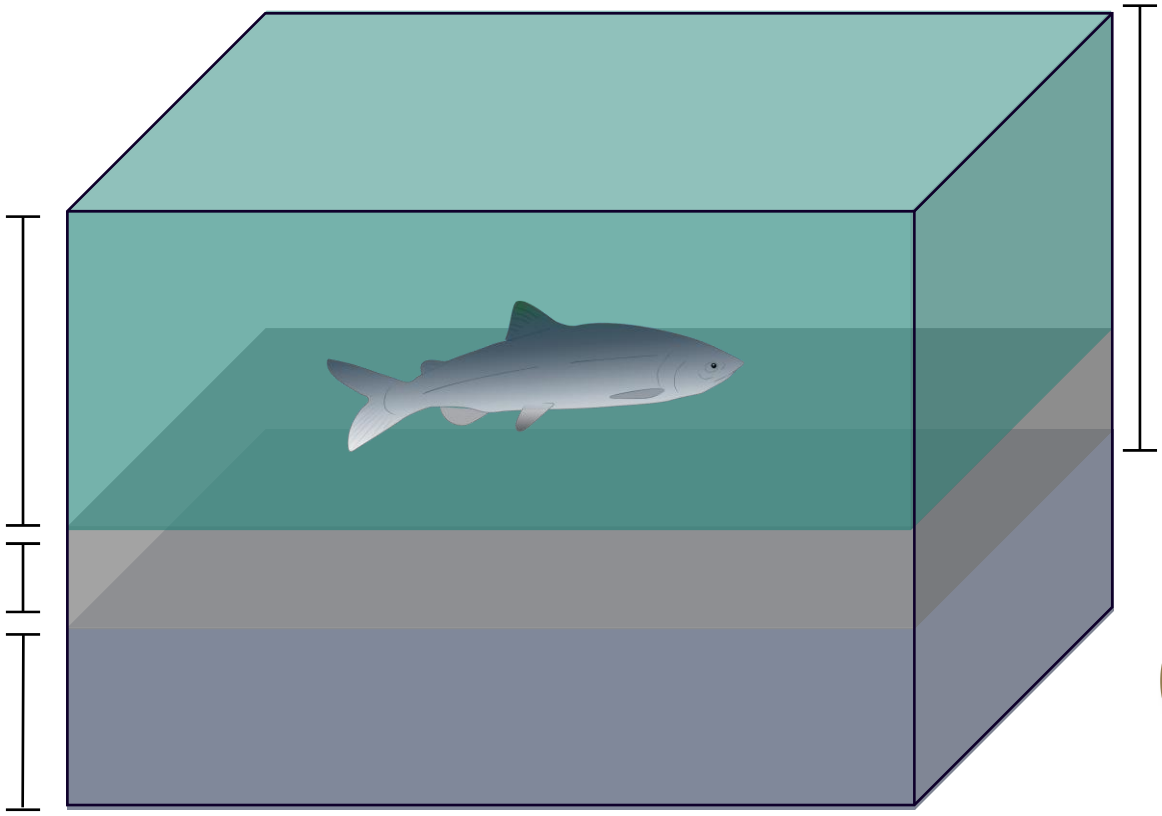
Chinook salmon

Dungeness crabs

English sole

Chinook salmon

< 1% of Chinook salmon habitat is compressed vertically, but they always have sufficient oxygen



Alternative metric: habitat thickness

Throughout Puget Sound & the Straits in 2014

- **Seasonal habitat compression** occurred in several embayments in the summer and fall, with greater compression in Hood Canal that extended into the winter
  - During this, there is sufficient oxygen in more than 98% of Dungeness crab, English sole, and Chinook salmon's aerobic habitat to support routine activities
- During the **worst time of the year** in late summer, up to:
  - 5% of Dungeness crabs habitat
  - < 2% of English sole habitat
  - < 0.84% of Chinook habitat
  - < 1.1% of Dungeness crab, English sole, and Chinook salmon habitat was **lost due to nutrients from human activities**

Mazzilli et al. (2026)

Discussion

In process

- Evaluate probabilistic risk
- Explore the influence of future climate conditions and nutrient reductions

Potential opportunities for collaboration e.g.

1. Evaluate habitat compression for other life species or the crab larval life stage.
2. Use abundance data and additional habitat information to refine the extent that a species might be impacted by aerobic habitat compression.
3. Quantify habitat thickness for mobile species like Chinook salmon.

QUESTIONS OR SUGGESTIONS?

Feel free to reach out

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- Stefano Mazzilli mazzilli@uw.edu
- Marielle Kanojia marlars@uw.edu
- Joel Baker jebaker@uw.edu