

Mapping widespread hypoxia off the Pacific Northwest during the 2021 summer upwelling season:

A necessary ingredient to informing sustainable use of the ocean

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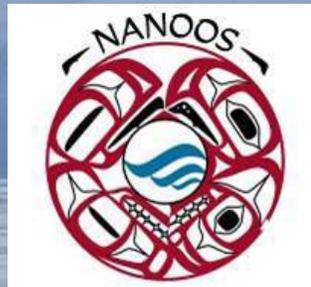
with Stephen D. **Pierce**¹, Brendan **Carter**², Anatoli **Erofeev**¹, Jennifer **Fisher**³, Richard **Feely**², Kym **Jacobson**³, Aimee **Keller**³, Cheryl A. **Morgan**³, John **Pohl**³, Leif **Rasmuson**⁴, and Victor **Simon**³

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SUSTAINABLE DEVELOPMENT GOALS



“Conserve and sustainably use the oceans, seas and marine resources for sustainable development”



Cannon Beach, OR



MMHSRP 18786-04



Yaquina Head, Sep. '07

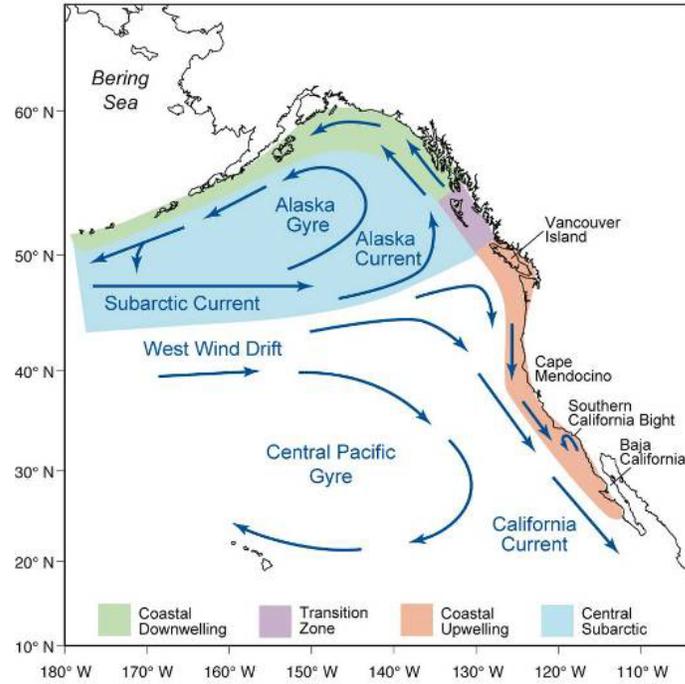
J. Barth



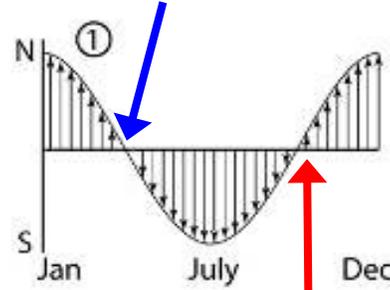
Neskowin Reef

R. Hallman

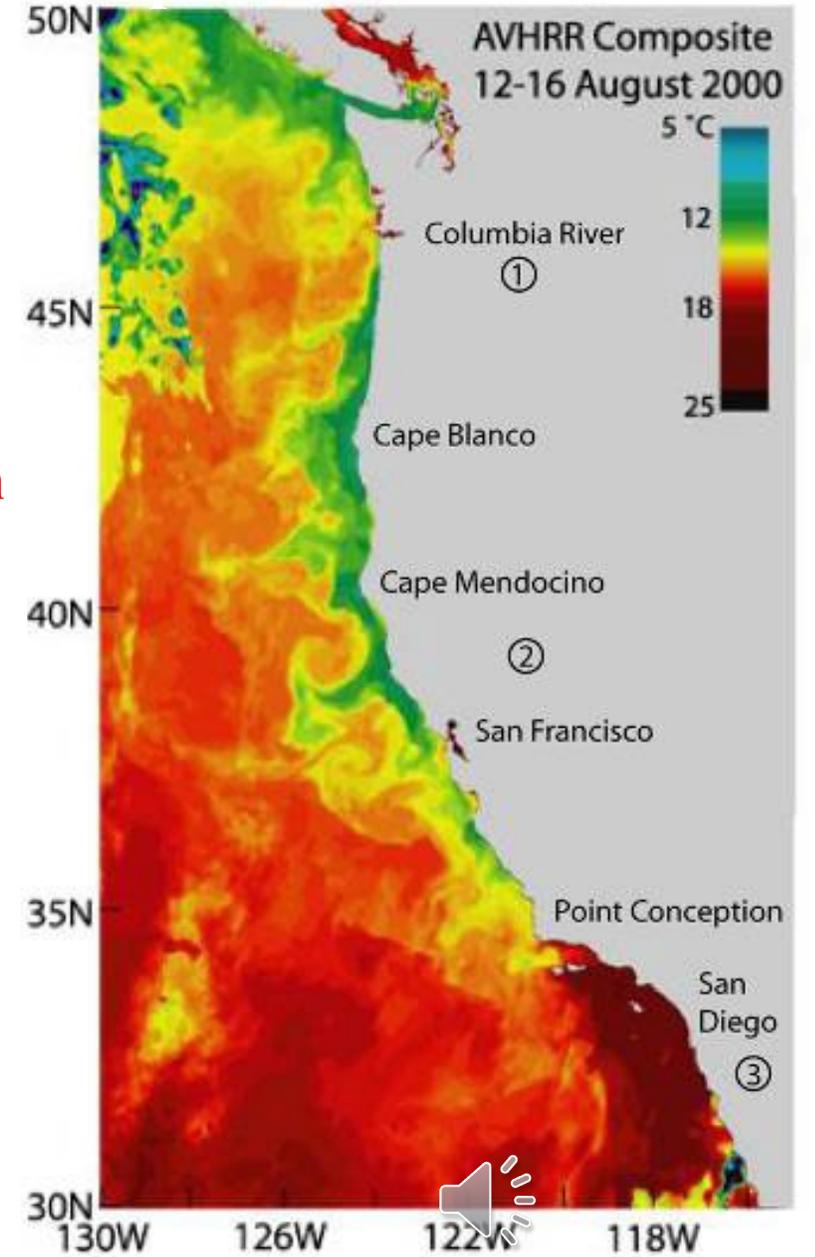
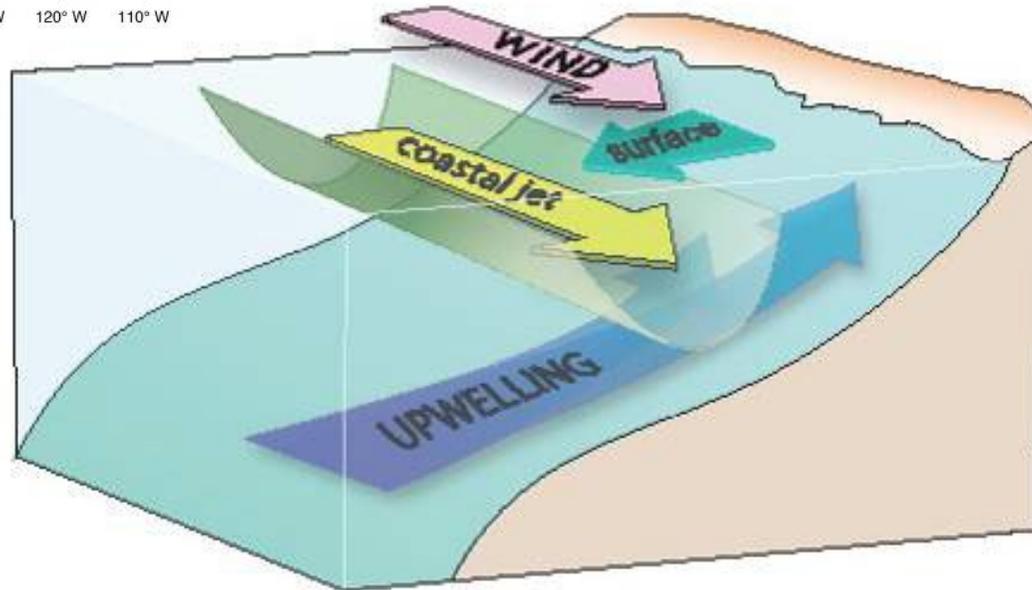
Upwelling and productivity in the Northern California Current



spring transition



fall transition



Oregon Seafood Value

Commercial Fisheries (\$124M total/year)



Pink Shrimp \$27M



Dungeness Crab \$74M



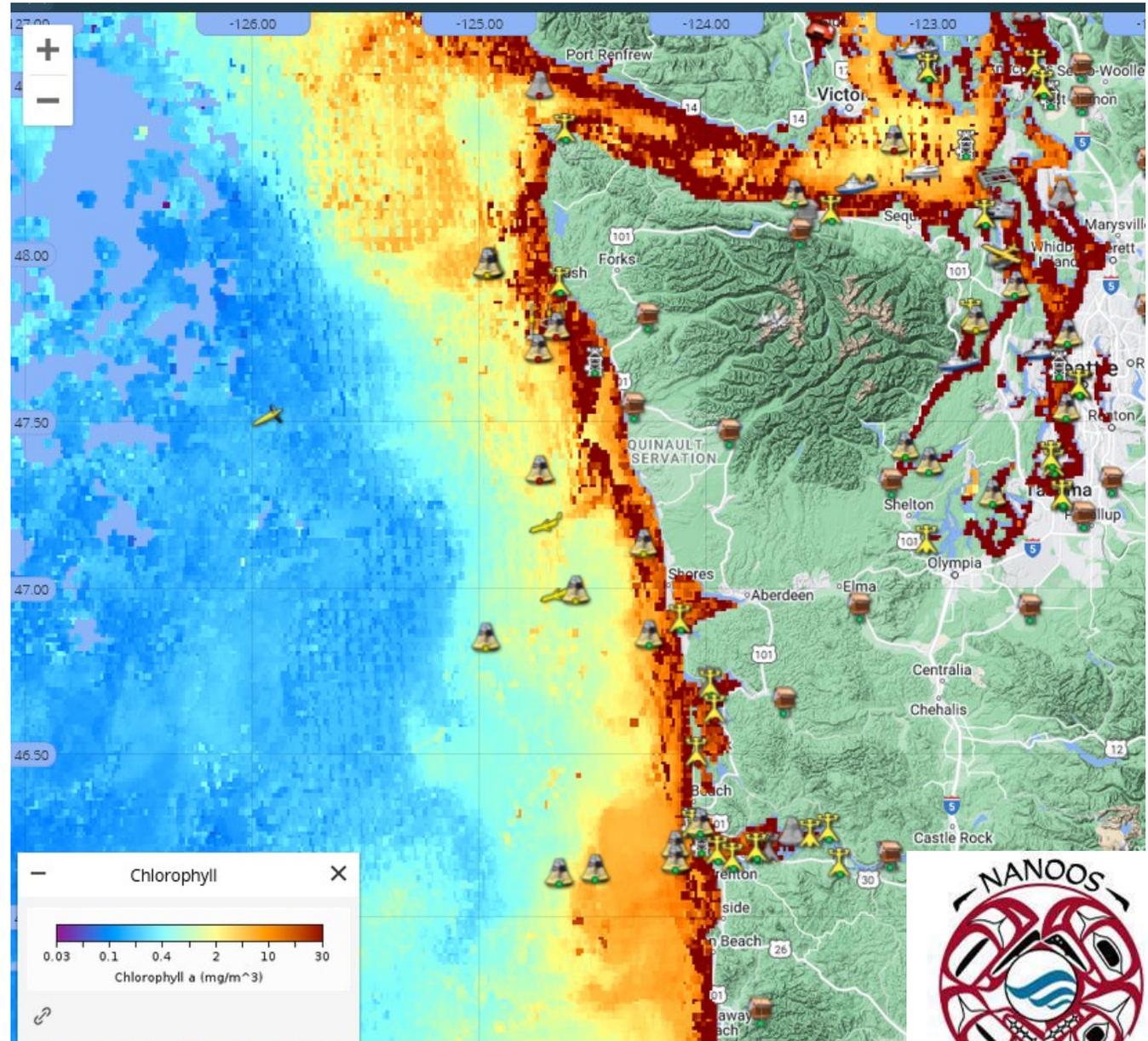
Salmon \$2M



Groundfish \$21M

**Annual Ex-Vessel Values
(2018)**

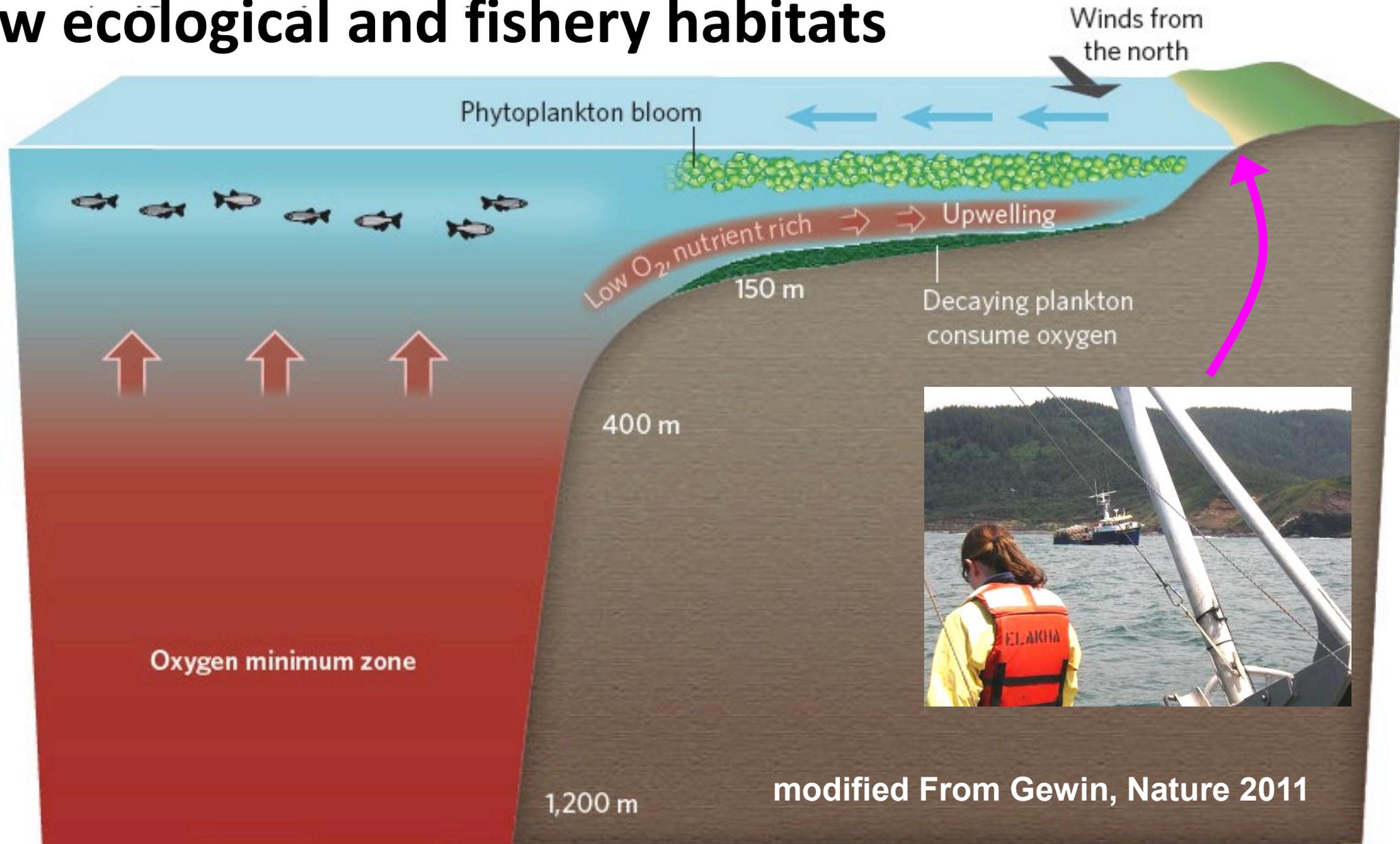
Satellite chlorophyll from July 17, 2022



<http://nvs.nanoos.org/Explorer>



Low-oxygen (hypoxia) threatens important shallow ecological and fishery habitats



What are hypoxia zones?



Photo: ODFW



Photo: Larry Workman

Areas of the coastal ocean where dissolved oxygen levels are ≤ 1.4 ml/l

(1 ml/l = 1.33 mg/l = $44\mu\text{M}$ = 15% saturation)

The Biologist = mg/g

The Oceanographer = ml/l

The Chemist = μM

The Physiologist = % Saturation

Measuring dissolved oxygen at sea



PICES

2013 PICES Summer School

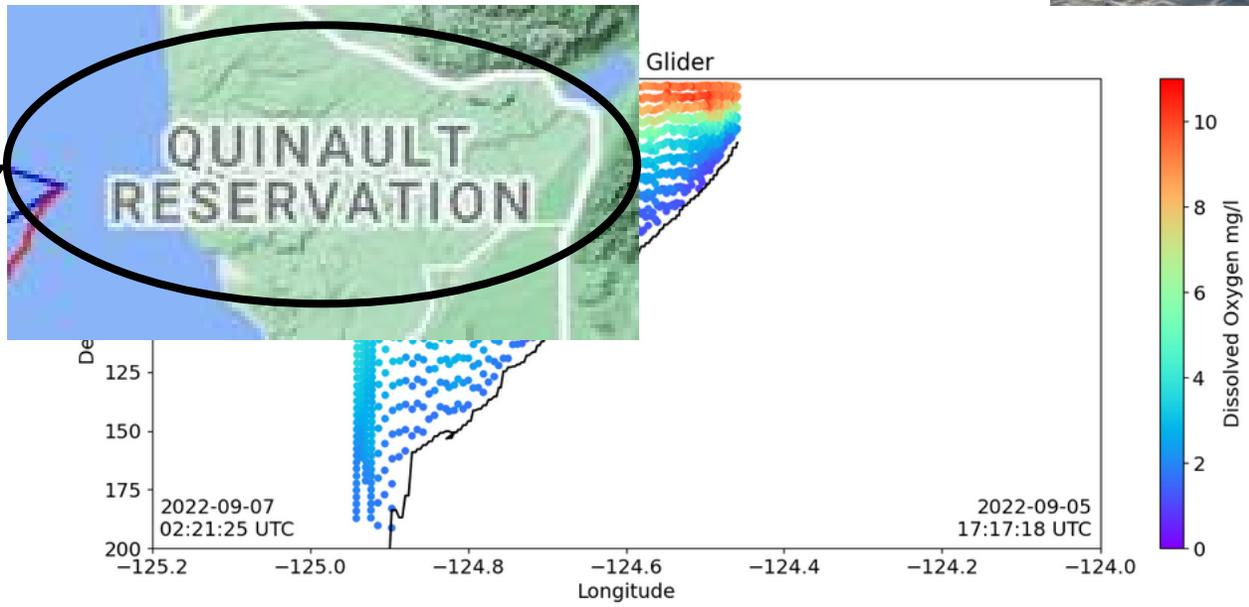
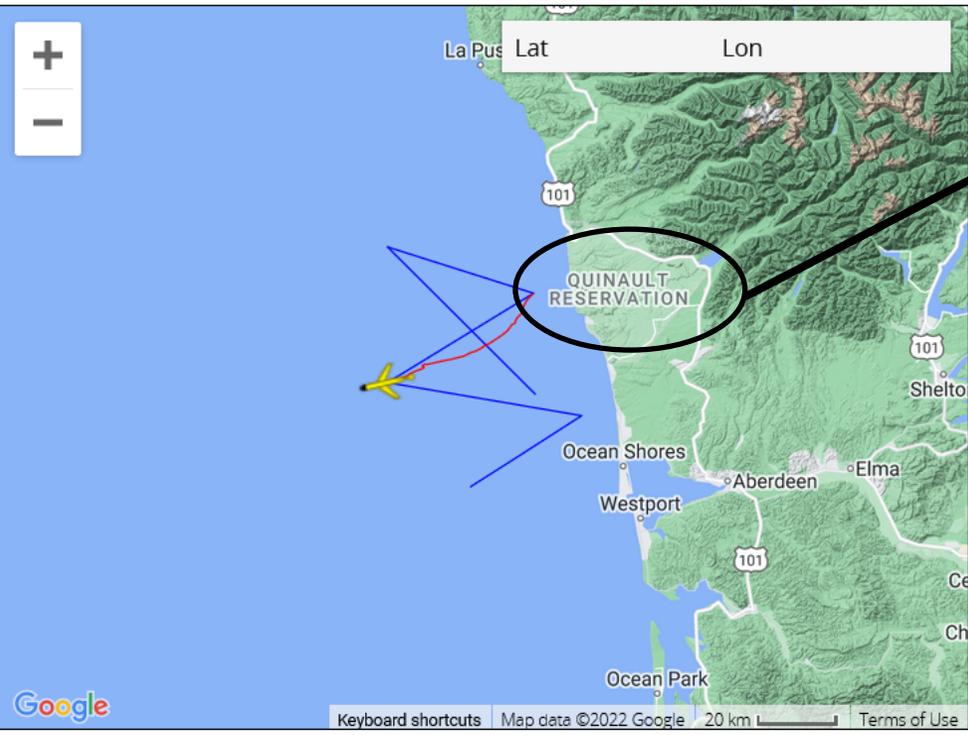
Ocean Observing Systems & Ecosystem Monitoring

Glider data from a recent (Sep. 1-16, 2022) mission off the Washington coast

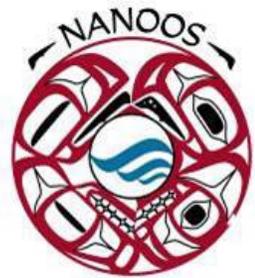
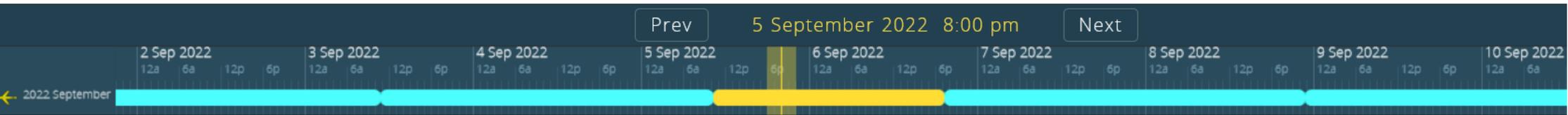
Missions **2022 September** Type: Slocum Provider: CEOAS Oregon State University Contact: Jack Barth



Temperature Salinity Density **Dissolved Oxygen** Chlorophyll CDOM Backscatter



Download Data
Glider DAC



Taholah School, WA, Quinault Indian Nation - Sep. 16, 2022



Photo by Joe Schumacker

Previous work using NOAA survey data

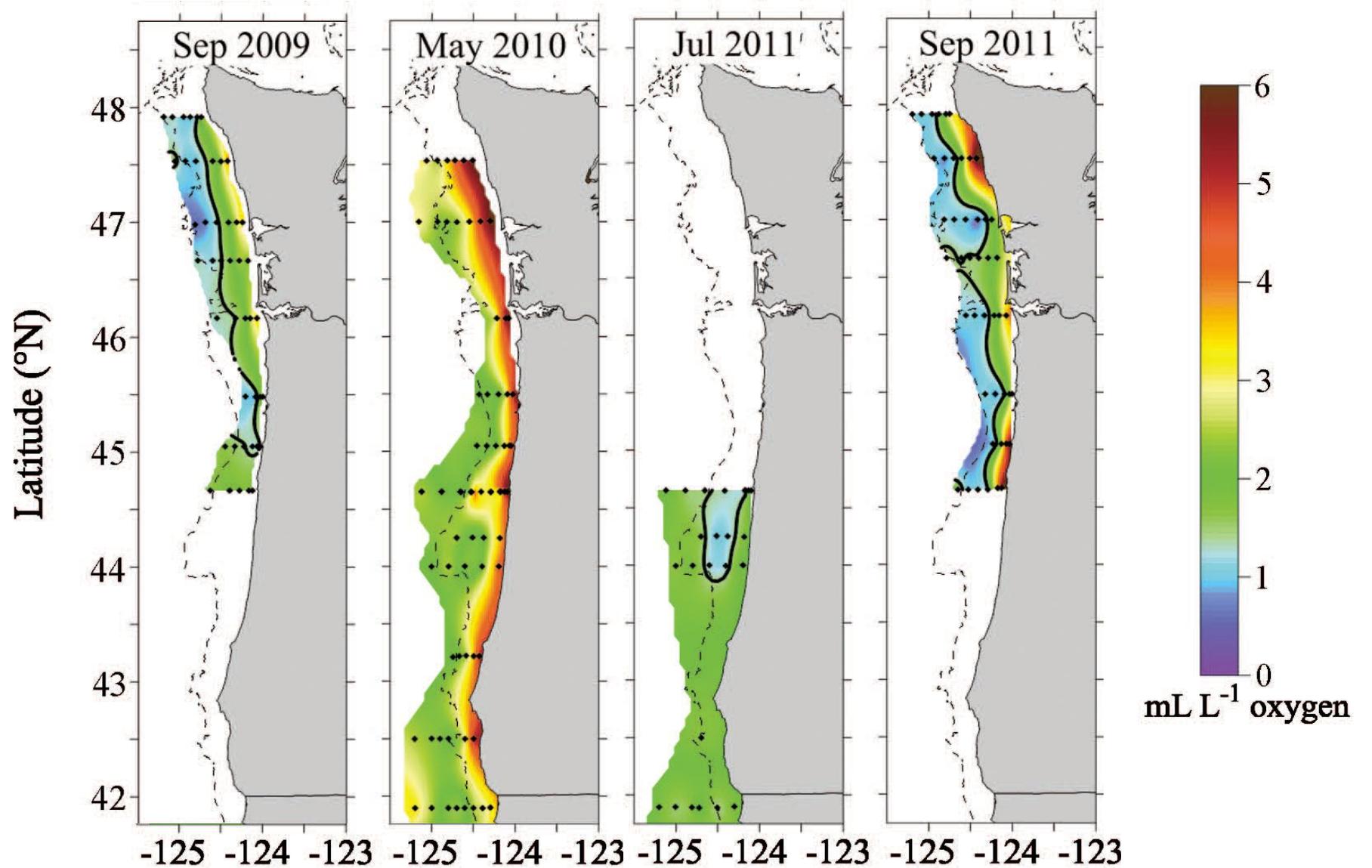
J. Peterson, C. Morgan, W. T. Peterson and E. Di Lorenzo (2013, *Limnology and Oceanography*)

1998-2012

~40-60 stations per map

Broke analysis into north and south of Newport, OR (44.6N)

Found maximum area of hypoxia on the continental shelf of ~60%



2021 was a remarkable year for at-sea sampling !!

→ Total of about 800 vertical profiles

NOAA cruises

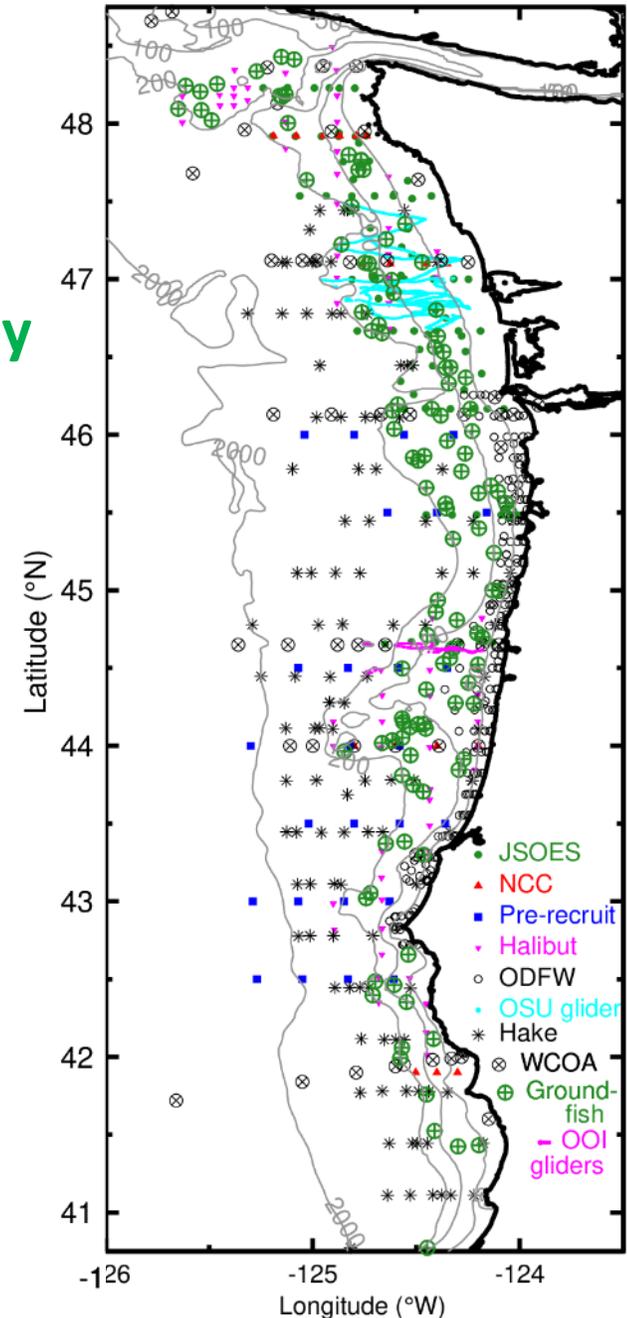
- JSOES – Juvenile Salmon and Ocean Ecosystem Survey
- Pre-recruit survey
- NCC – Northern California Current
- Hake
- Groundfish
- WCOA – West Coast Ocean Acidification survey

IPHC – International Pacific Halibut Commission

ODFW – Oregon Department of Fish and Wildlife

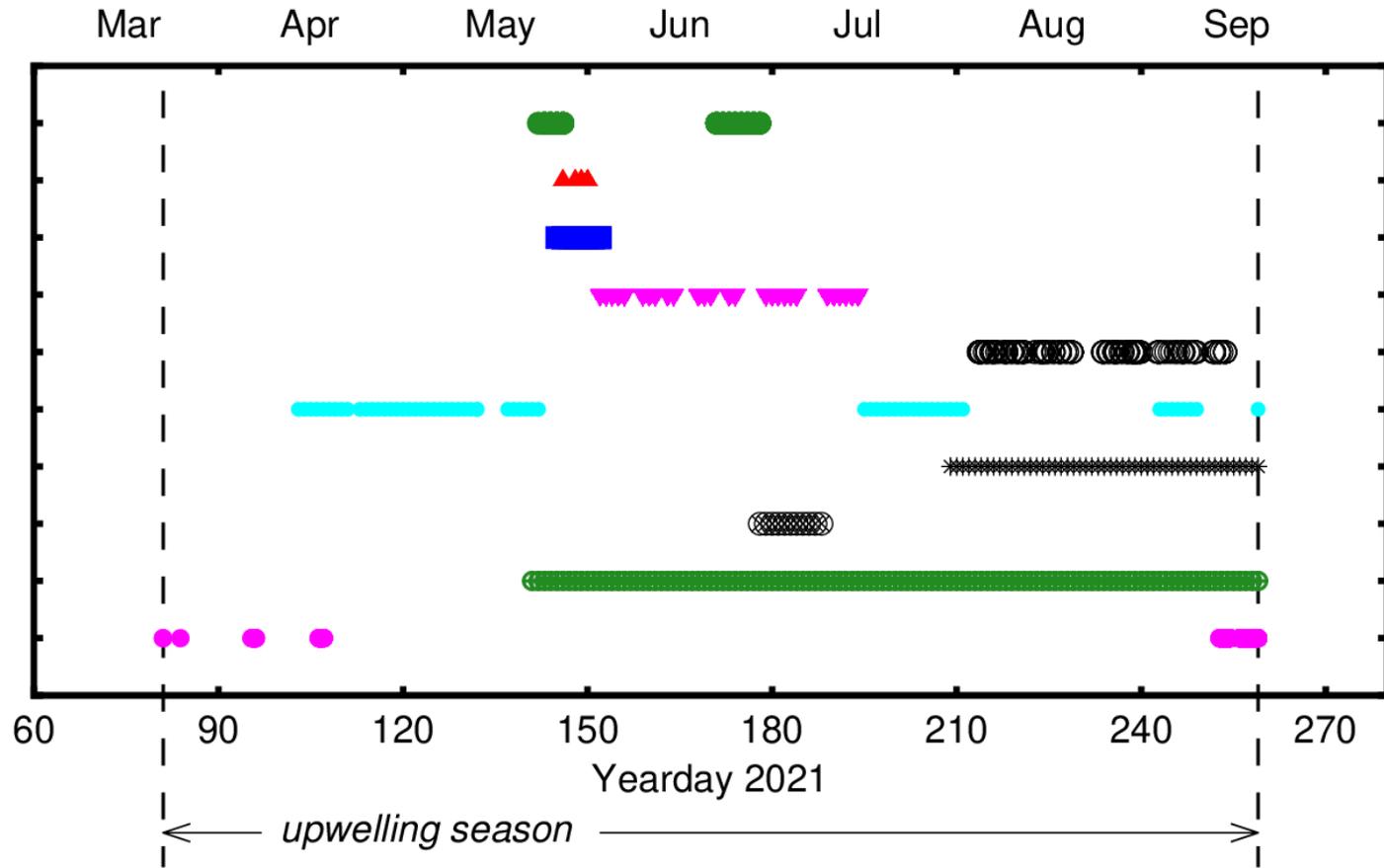
gliders

- OSU WA shelf
- OOI – Ocean Observatories Initiative

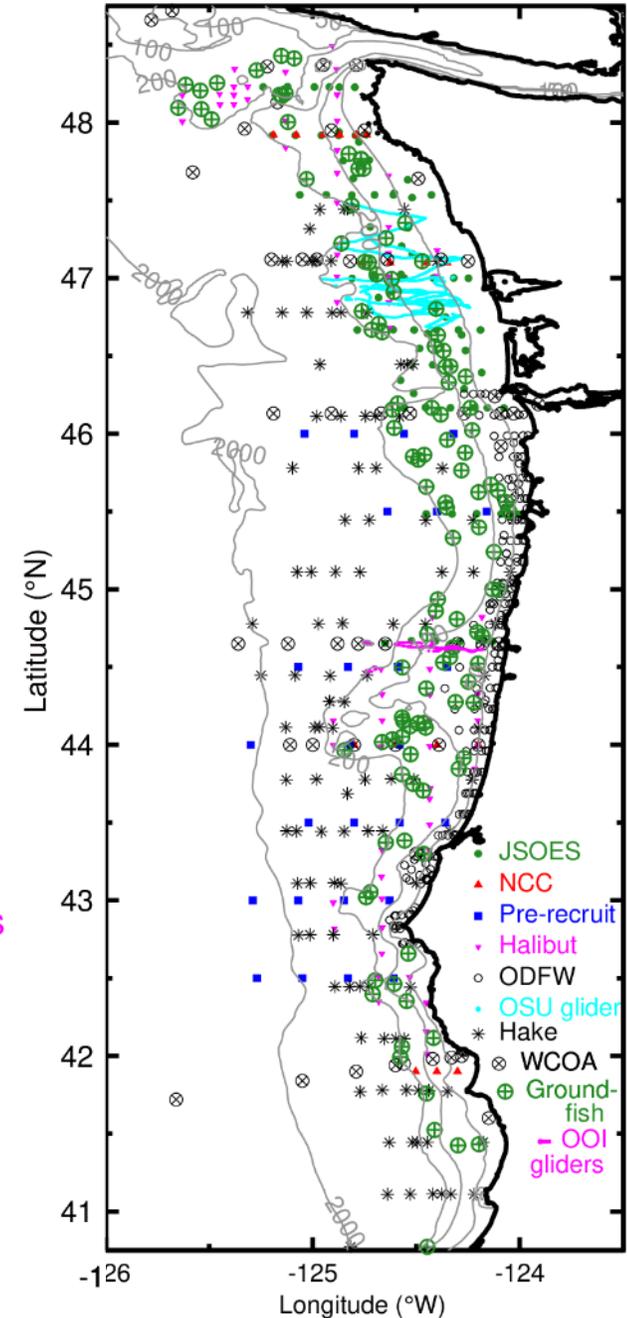


2021 was a remarkable year for at-sea sampling !!

→ Total of about 800 vertical profiles



- JSOES
- NCC
- Pre-recruit
- Halibut
- ODFW
- OSU glider
- Hake
- WCOA
- Groundfish
- OOI gliders

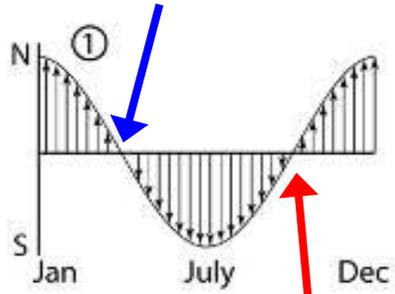


- JSOES
- NCC
- Pre-recruit
- Halibut
- ODFW
- OSU glider
- Hake
- WCOA
- Groundfish
- OOI gliders

2021 was also a remarkable year for upwelling !!

Started early and persisted late

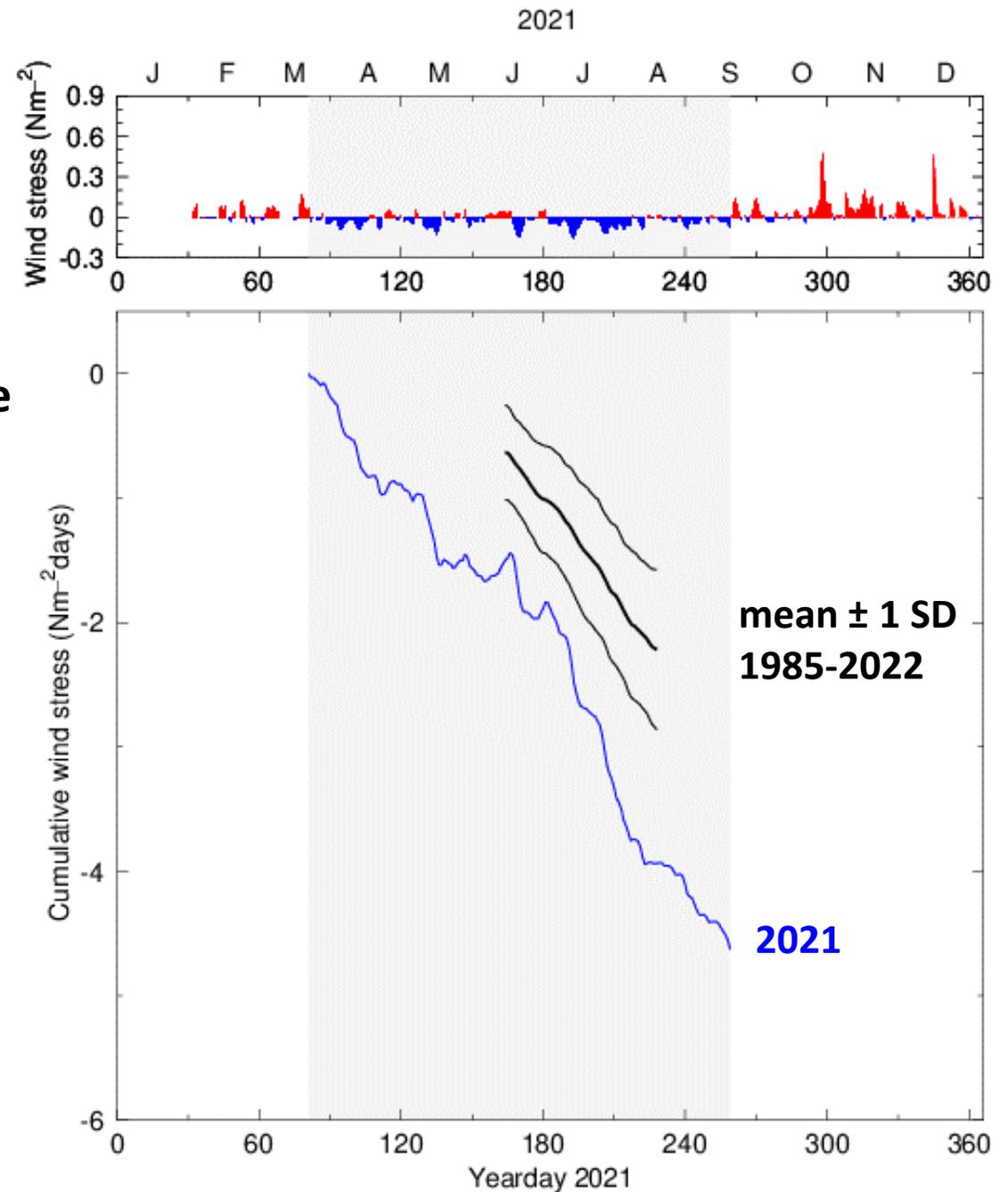
spring transition



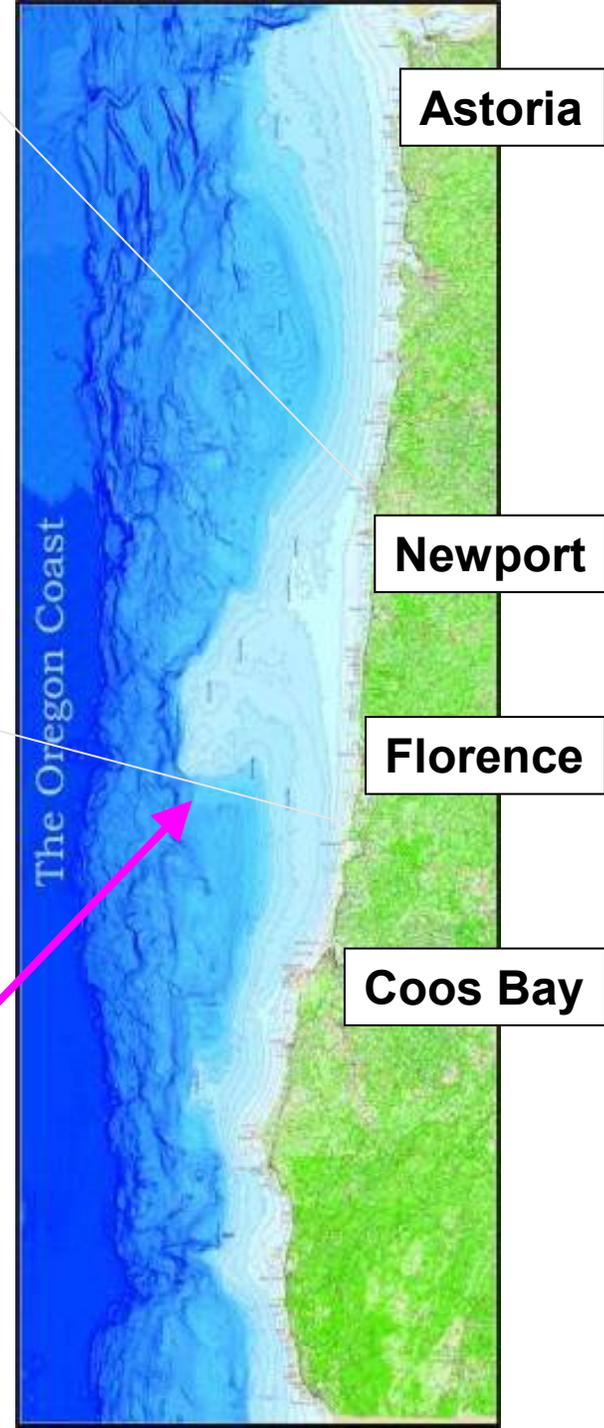
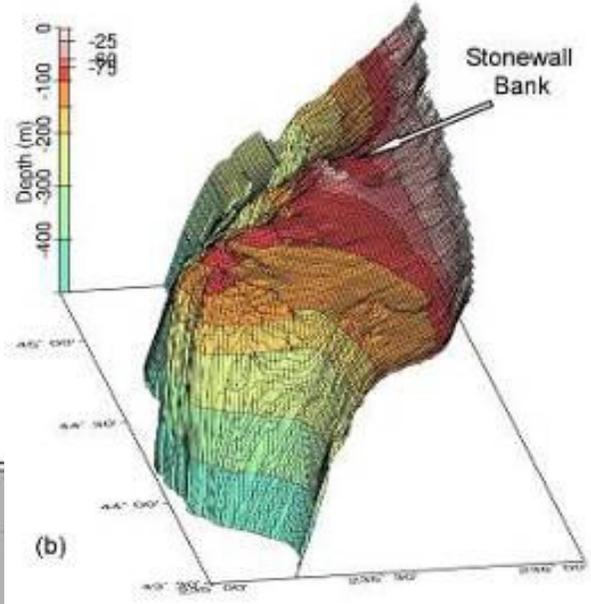
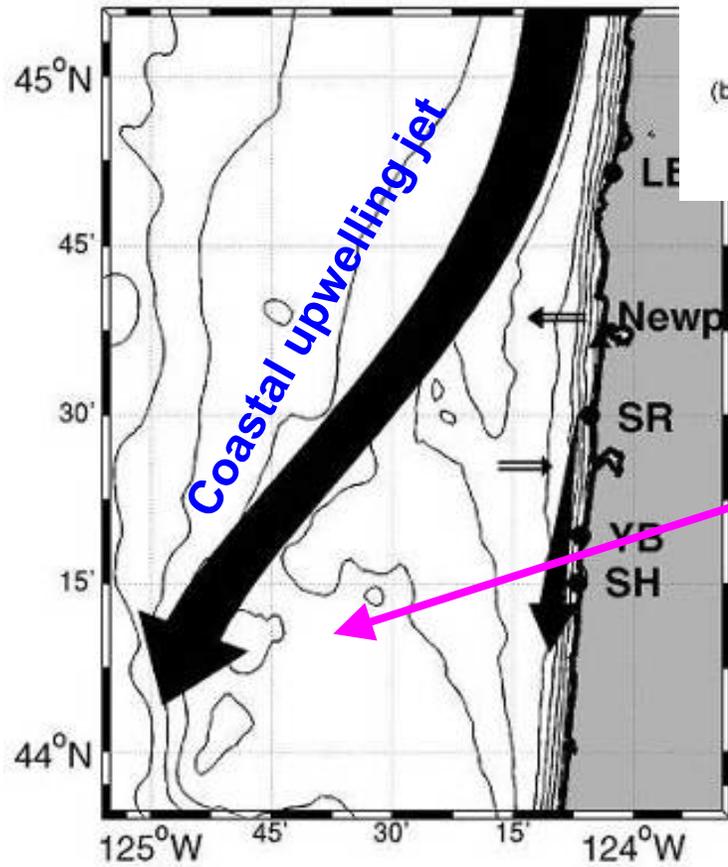
fall transition

Calculated
between
spring and fall
transitions

Cumulative
Upwelling
Index

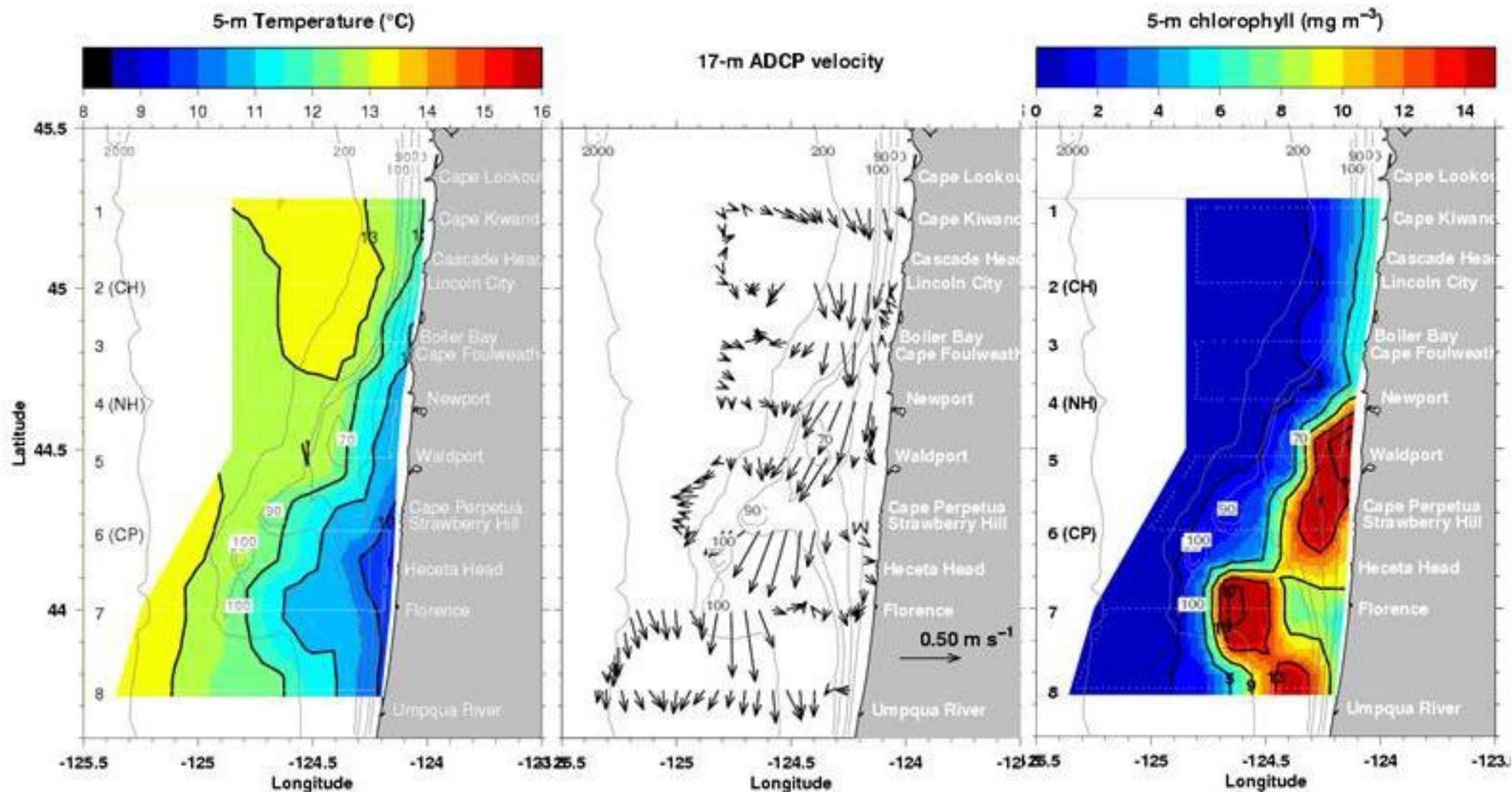


Flow-topography interaction creates retention areas



Heceta Bank

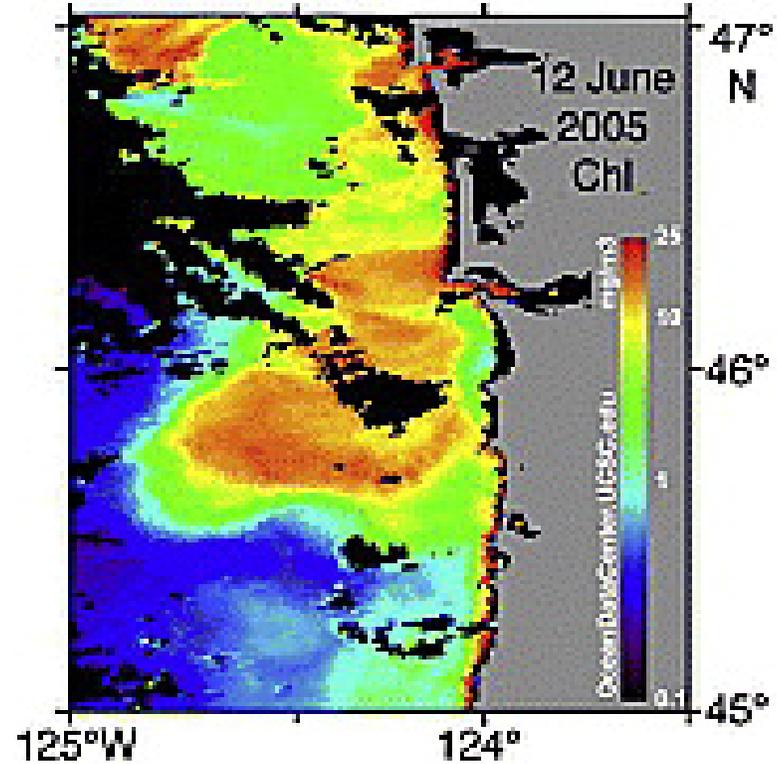
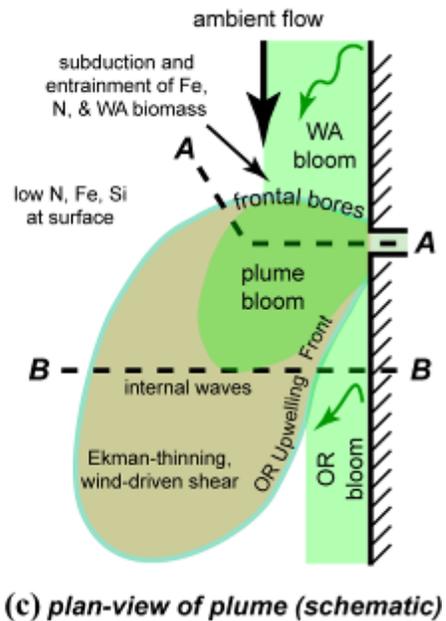
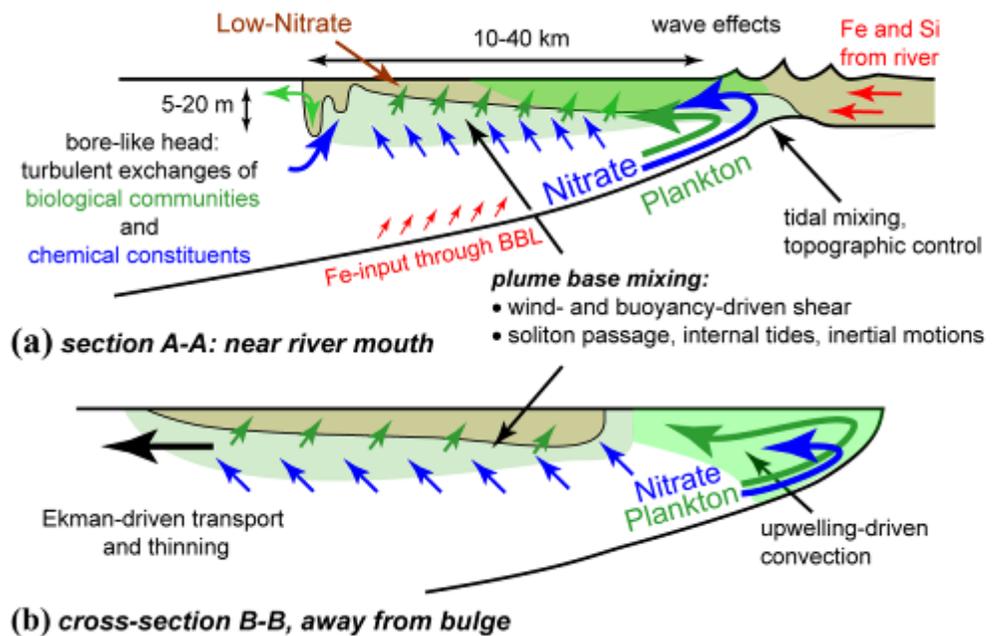
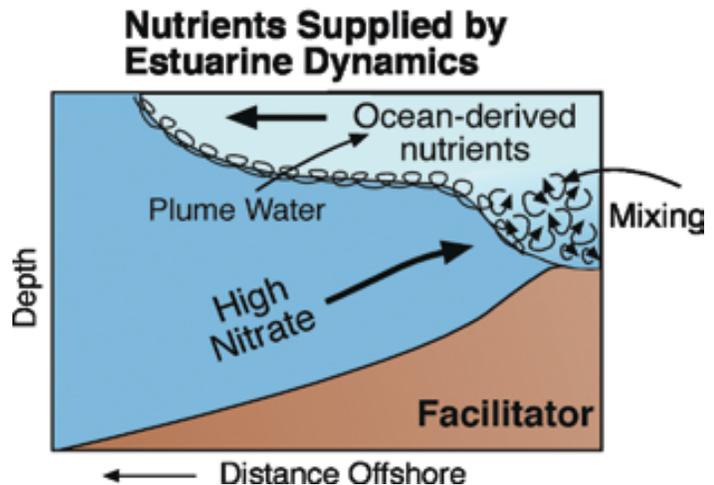
Flow-topography interaction creates regions with low velocities and enhanced surface primary production



Barth et al. (2005)

River plume facilitates mixing of ocean-supplied nutrients up into euphotic zone

Hickey and Banas (2008, *Oceanography*)



Hickey et al. (2010, *J. Geophysical Research - Oceans*)

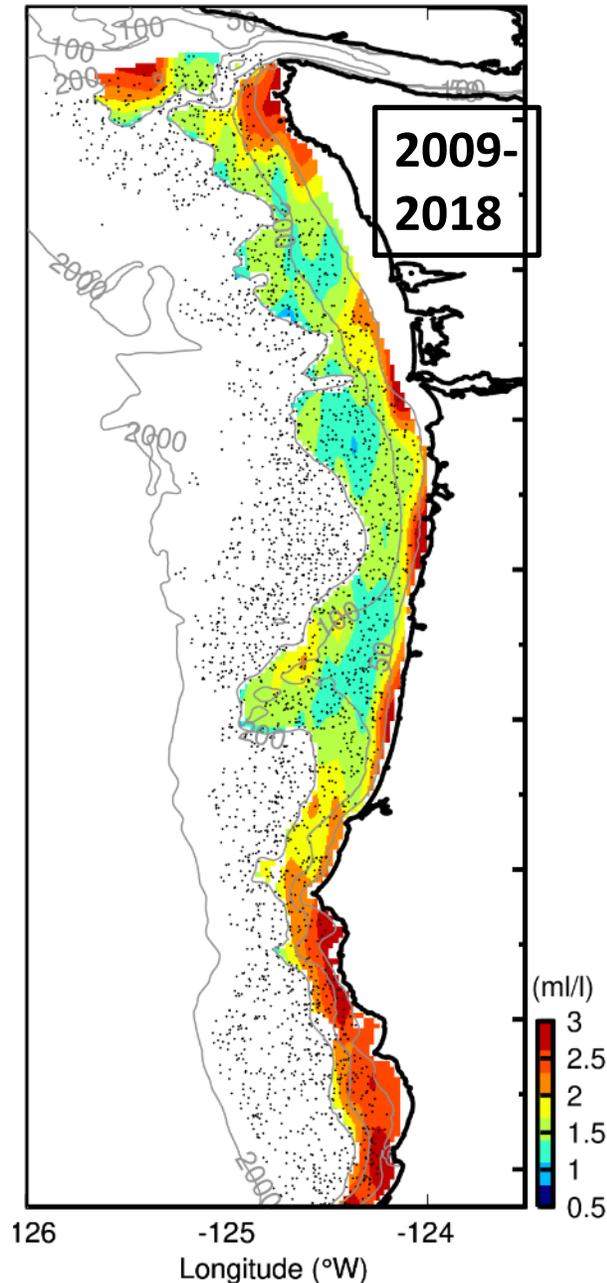
A quick look at changes over time

Similar pattern emerges from historic (2009-2018) groundfish survey data

But 2009-2018 near-bottom dissolved oxygen is higher than in 2021 ... thus, oxygen levels decreasing over time

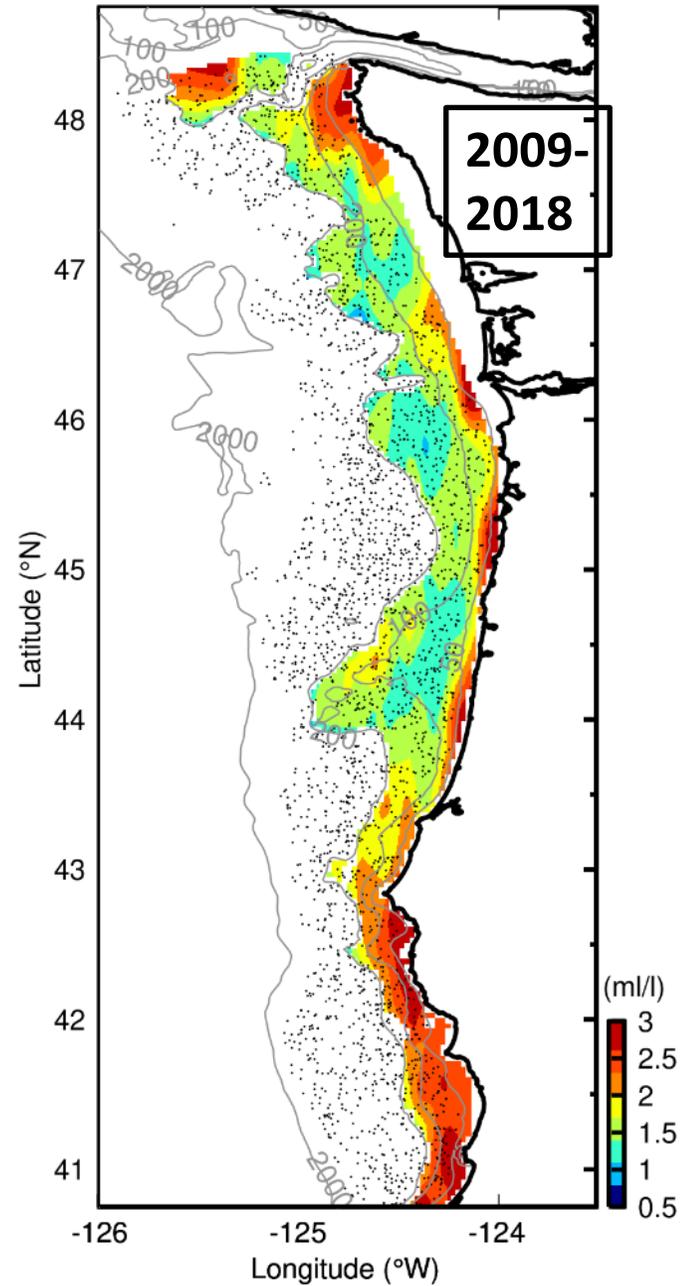
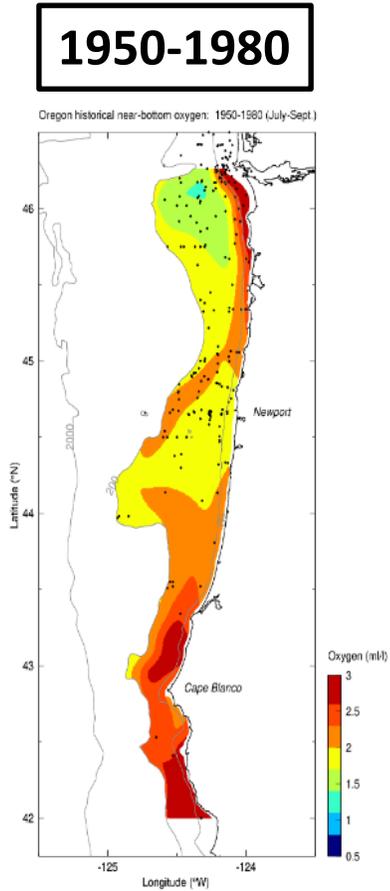
For groundfish survey results, see Keller et al. (2017, *Marine Ecology Progress Series*) and references therein

Near-bottom dissolved oxygen
NOAA NMFSC West coast groundfish survey: 2009-18



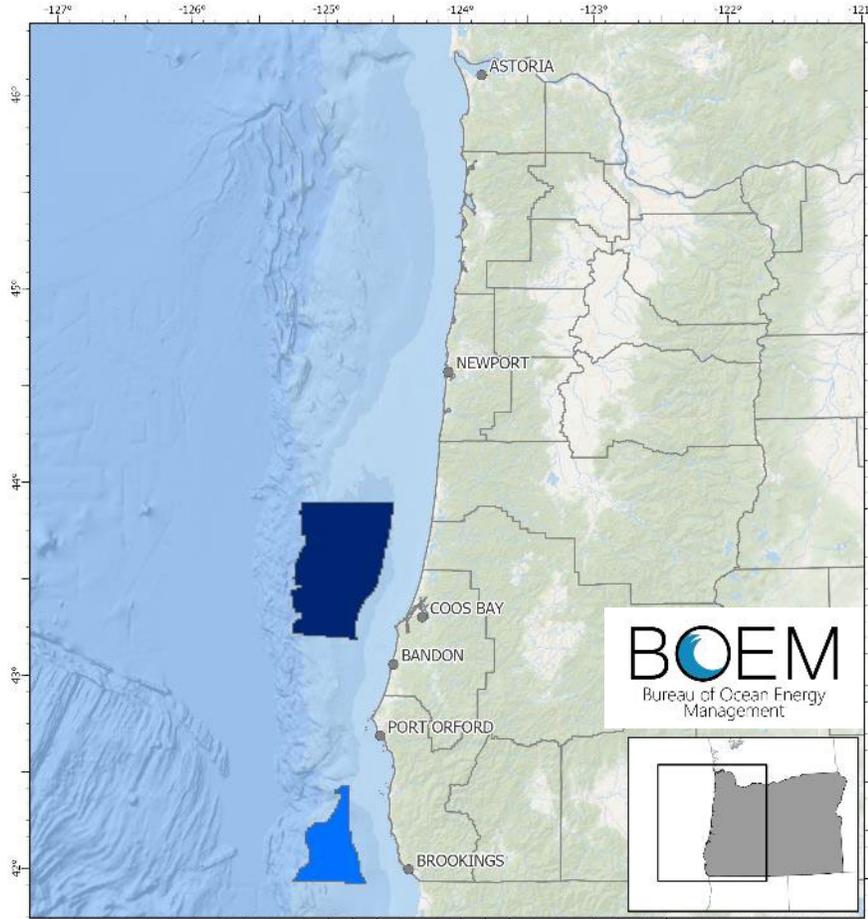
And similarly for the oldest data in the national archives: 1950-1980

Near-bottom dissolved oxygen
NOAA NMFS West coast groundfish survey: 2009-18



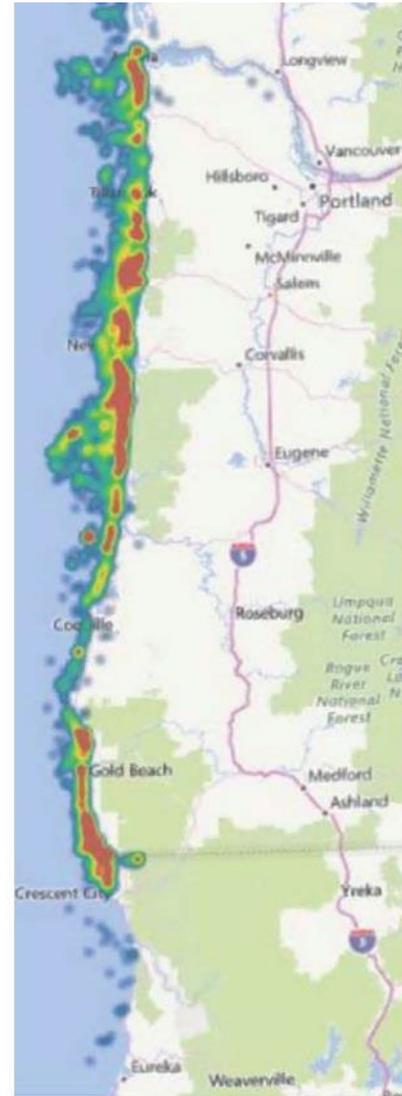
Combine spatial maps

to inform sustainable management



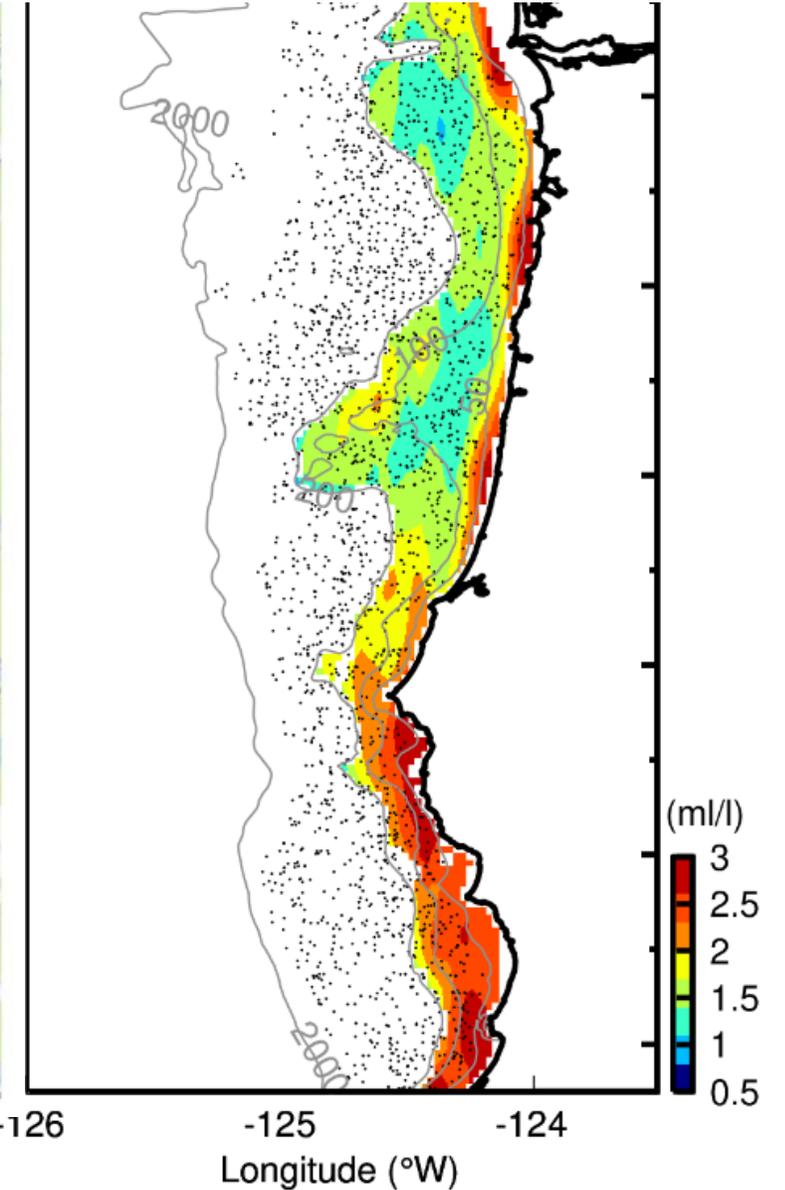
U.S. Bureau of Ocean Energy Management “Call Areas” for offshore wind development

Oregon Dungeness Crab Fishing Intensity Map



effort per 5x5 km block
2012-2013
Davis (2017)

2009-2018 near-bottom dissolved oxygen



Summary and Conclusions

- Robust **at-sea sampling** of dissolved oxygen (DO)
 - Ships, gliders, moorings
- **Near-bottom hypoxia widespread** during summer upwelling season
- **Spatial patterns of near-bottom hypoxia** are robust and associated with oceanographic processes
 - Near-coast high-DO refuge
 - High DO over narrow shelf regions
 - Low DO associated with submarine banks, wide shelf and river plume
- **Near-bottom oxygen decreasing with time**
- **Maps of ocean stressors** like low dissolved oxygen **inform sustainable use of our ocean resources**
- **Next steps:** multiple stressors (marine heat waves, ocean acidification, HABs ...)



Thanks for your attention!