Offshore Wind Farm Impacts on Pacific Upwelling, Nutrients, and Productivity

NOAA FISHERIES

BOEM
Bureau of Ocean Energy Management

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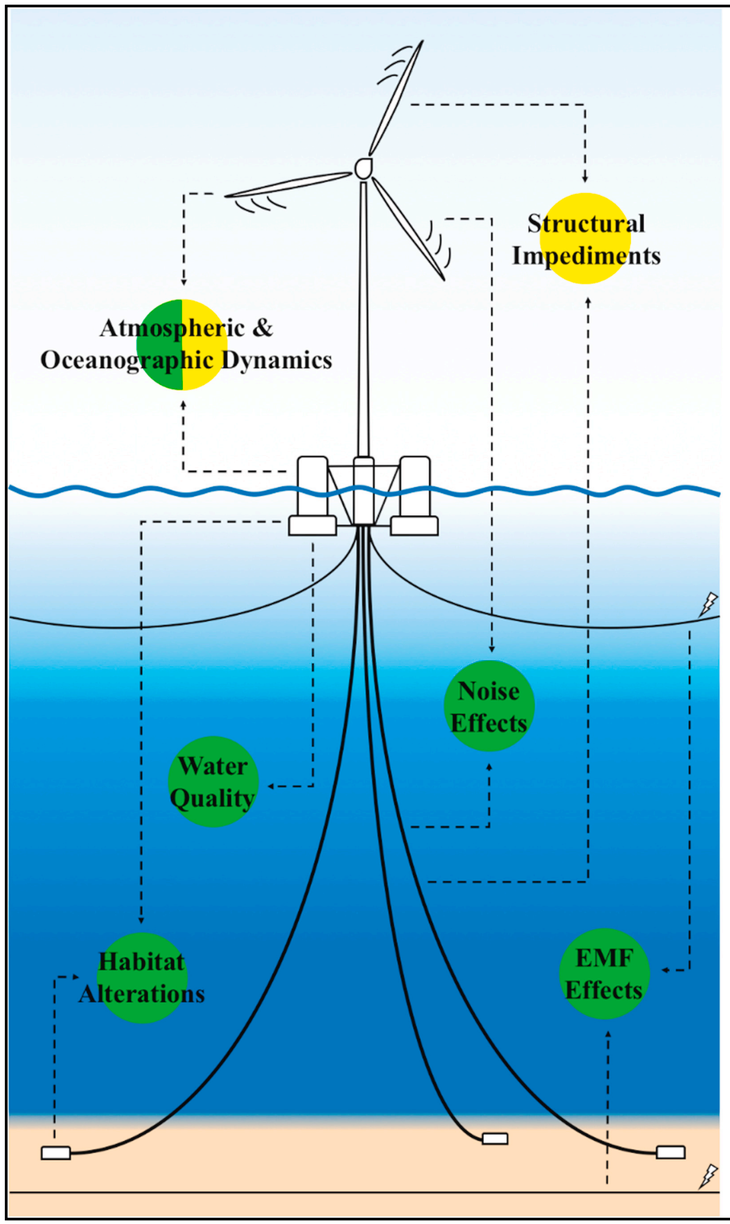
Background and Motivation



Potential Magnitude of Environmental Effect

Negligible *Minimal* *Moderate* *Major*

Potential Environmental Effect

EMF Effects
- Potential to affect animal behavior, but unlikely to substantially alter survival and reproduction.

Habitat Alterations
- Potential for structures along the seafloor to provide new habitat via the "reef effect", though the installation of artificial substrates may also invite colonization by non-native species.
- Potential for bottom, midwater, and surface structures to act as fish aggregation devices and for OWFs as a whole to act as *de facto* marine protected areas.

Noise Effects
- Unlikely to pose risk to marine species as operational noise of OWFs is low frequency and at low levels.
- Empirical measurements still needed for deepwater, floating OWFs.

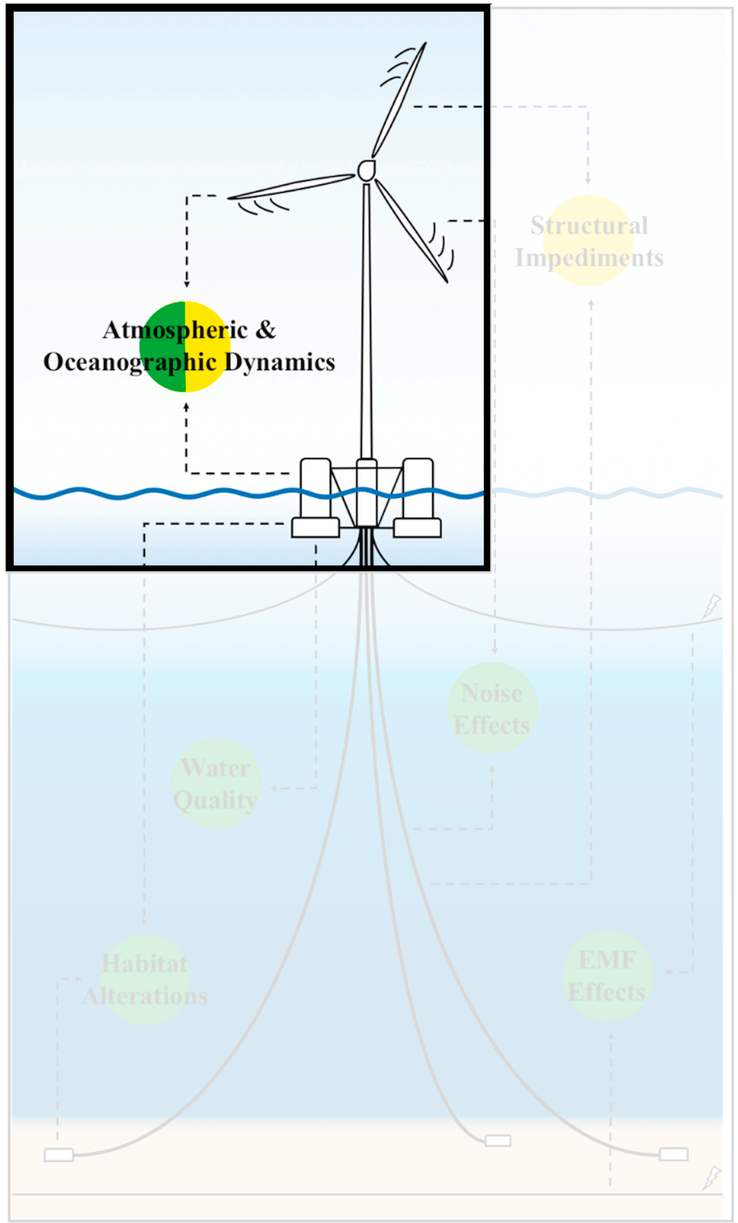
Water Quality
- Preemptive measures to prevent biofouling and corrosion may introduce toxins on a local scale, though adoption of environmentally-friendly alternatives can reduce risk to marine species.

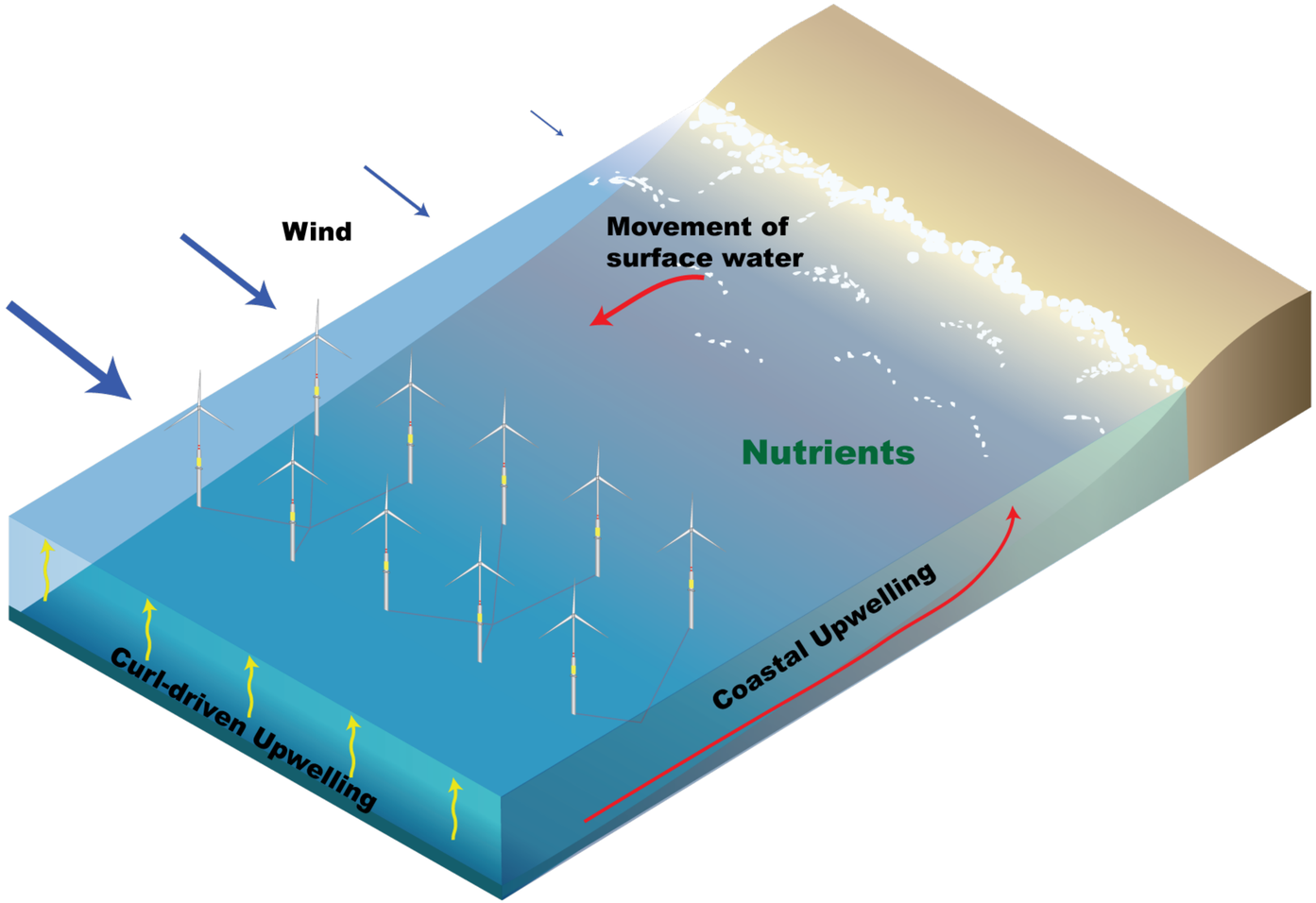
Atmospheric & Oceanographic Dynamics
- Expected to reduce downstream wind speed, though existing literature rarely report concordant estimates.
- Potential to alter local wave patterns, vertical mixing, and seasonal stratification, which could have cascading effects on carbon pump, biomass distribution, and sediment dynamics.

Structural Impediments
- Potential to increase avoidance, displacement, collision, and entanglement risk for many marine species.
- Use of promising, albeit minimally tested, mitigation measures may substantially reduce impacts on species' behavior, fitness, and survival.

Farr et al. (2021)

Background and Motivation

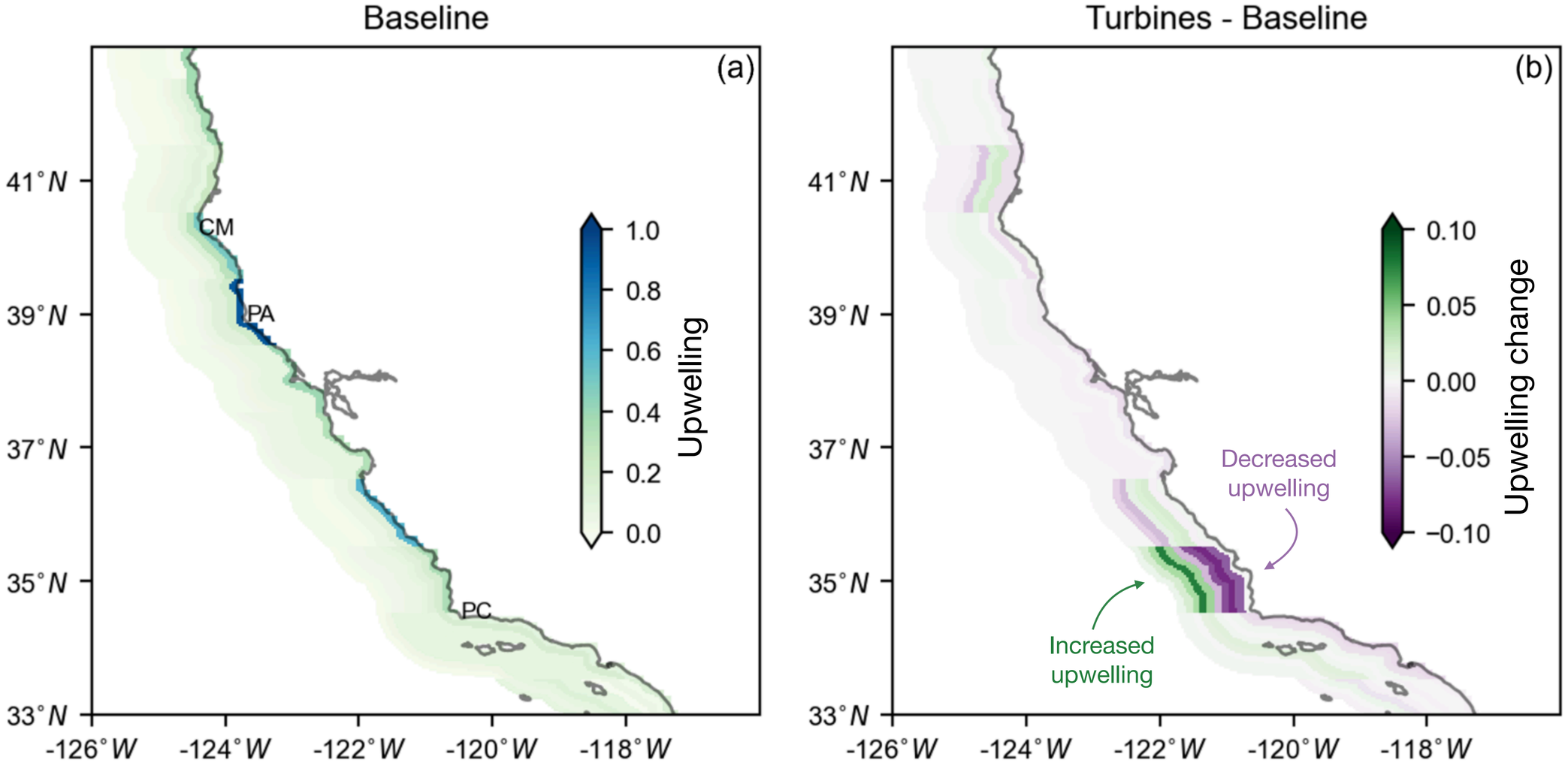




Do offshore wind turbines have the potential to impact coastal upwelling and consequently nutrients and productivity?

Background and Motivation

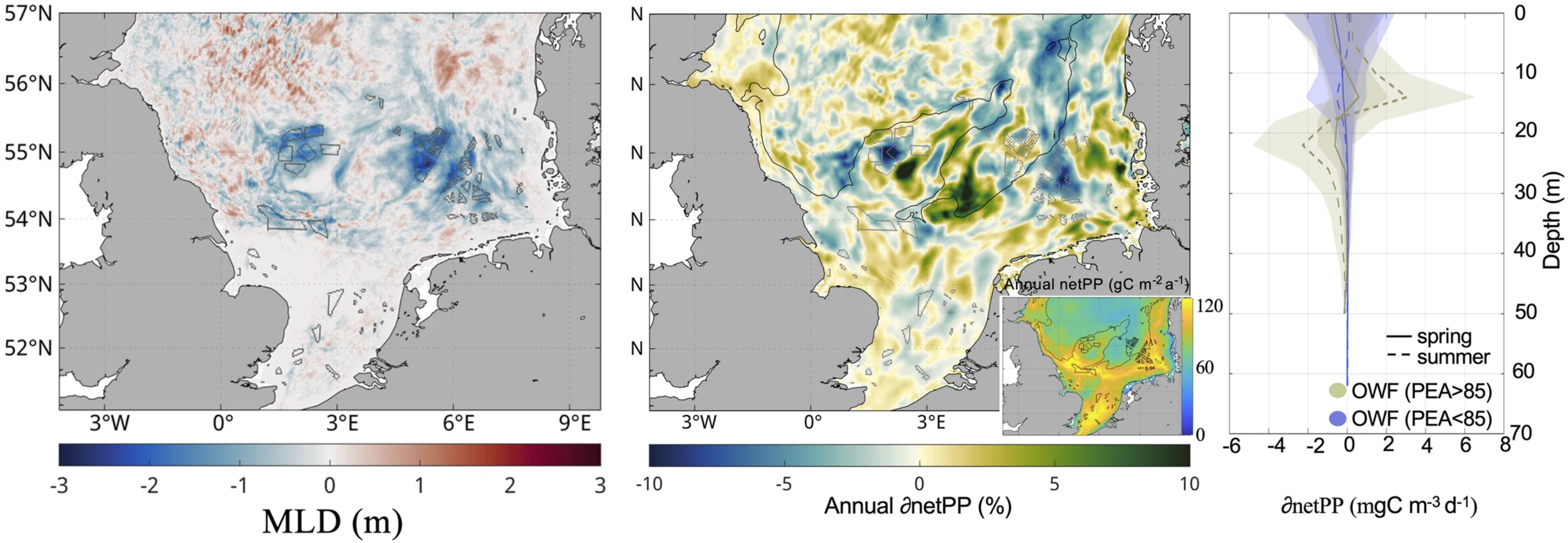
Project funded by California Energy Commission (2020-2023)



Raghukumar et al. (2023)

Background and Motivation

Modeled wind-farm induced changes in the North Sea



Daewel et al. (2022)

Project Goals and Objectives

1. Evaluate the potential effects of California OSW farms on circulation (i.e., upwelling) and biogeochemistry (nutrients, productivity) off the U.S. west coast.

2. Compare simulated biogeochemical impacts of OSW farms with impacts projected due to climate change in coming decades.

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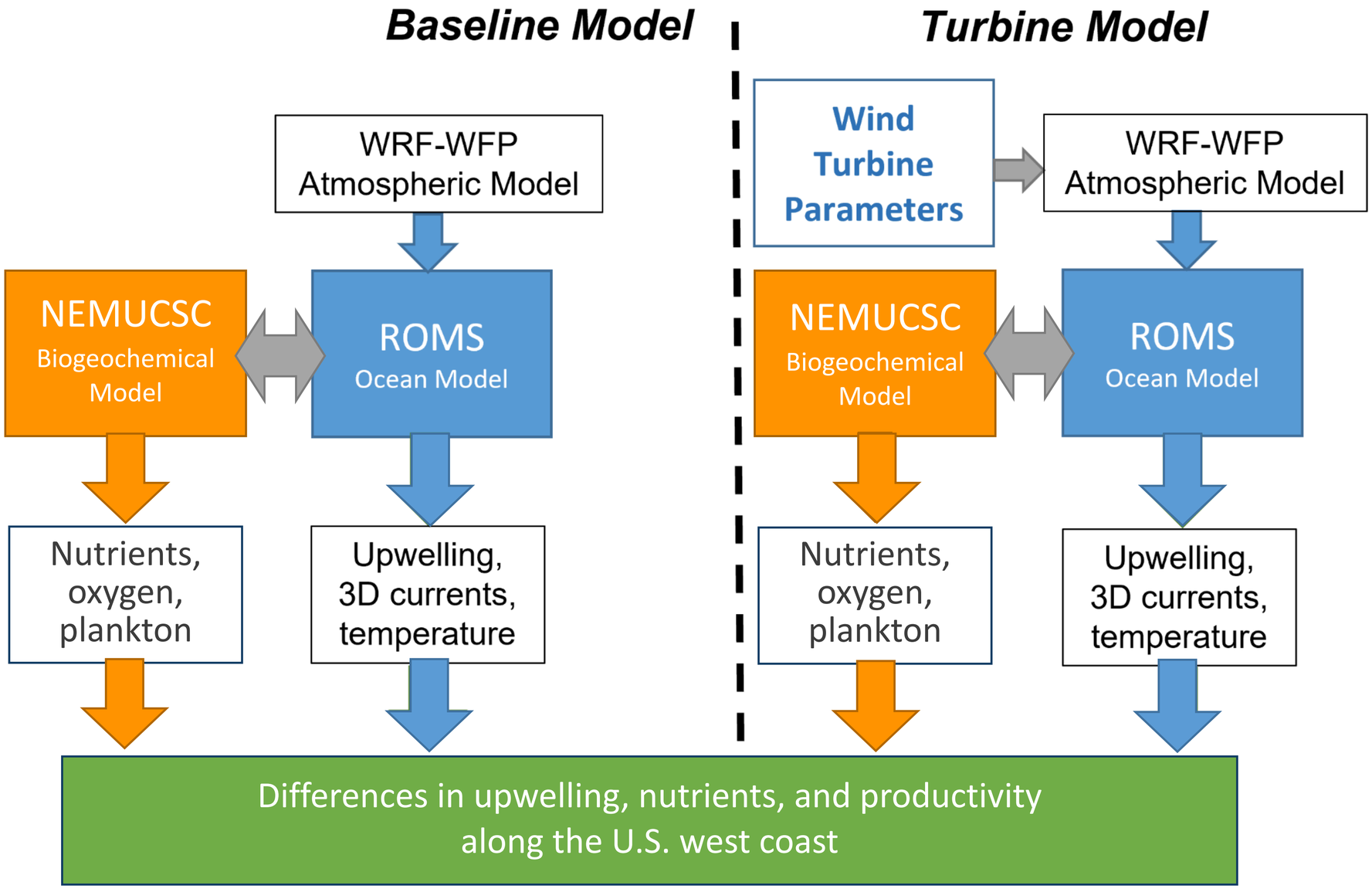
Modeling Configuration



Atmospheric Modeling

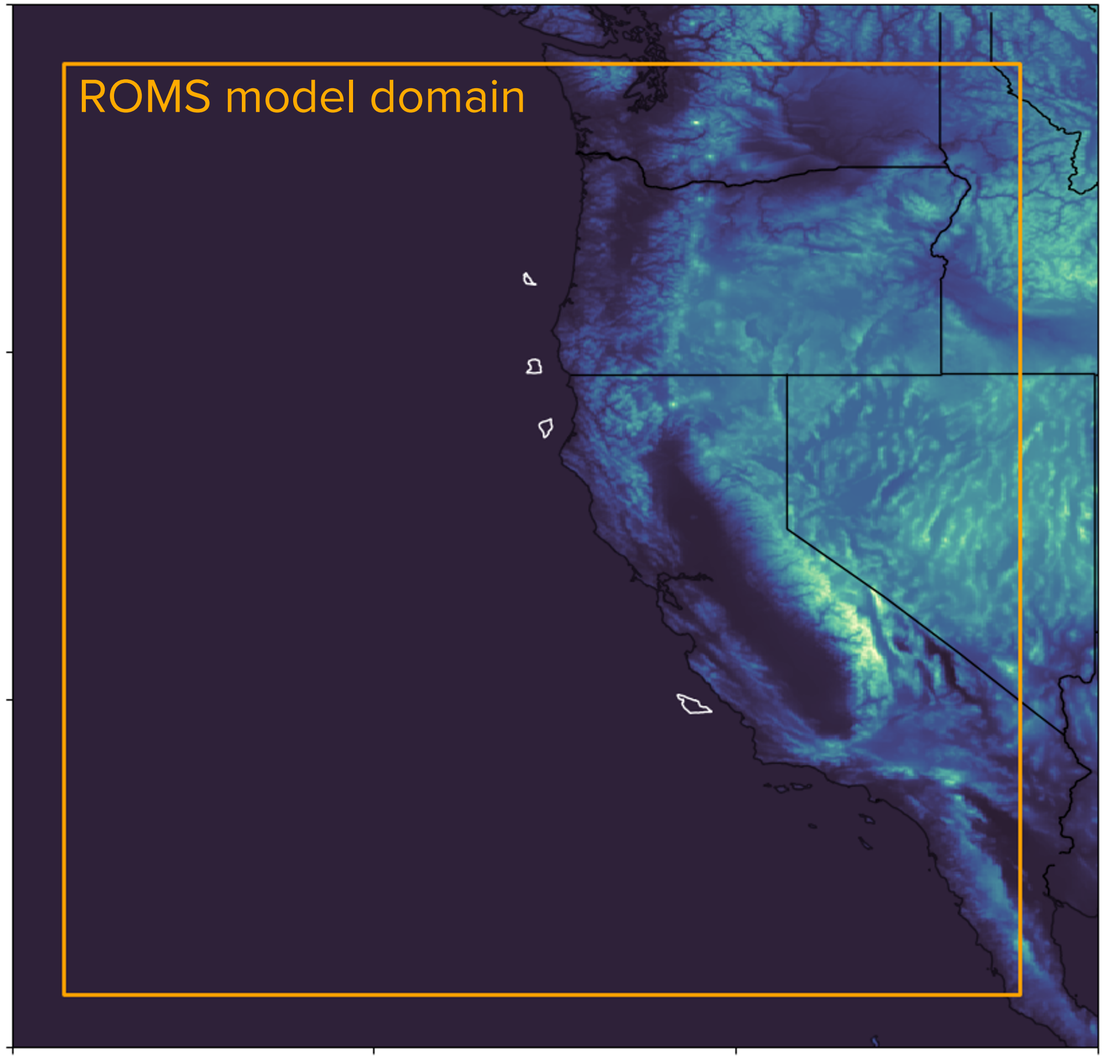
Weather Research and Forecasting (WRF) model with Wind Farm Parameterization

Morro Bay, Humboldt, Coos Bay, Brookings wind energy areas

15MW and 20MW turbine build-outs

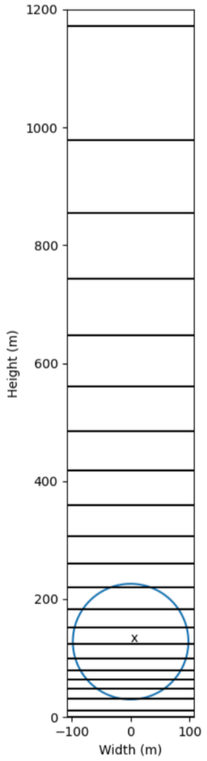
3km resolution for full domain

1995-2019



Atmospheric Modeling - Wind Farms

PRIOR STUDY

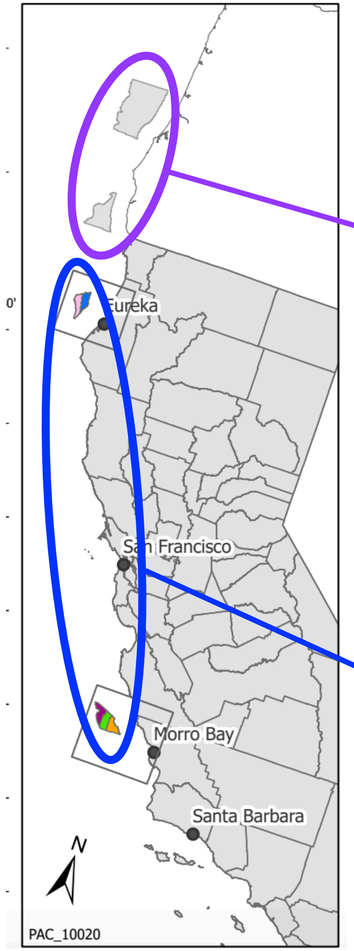


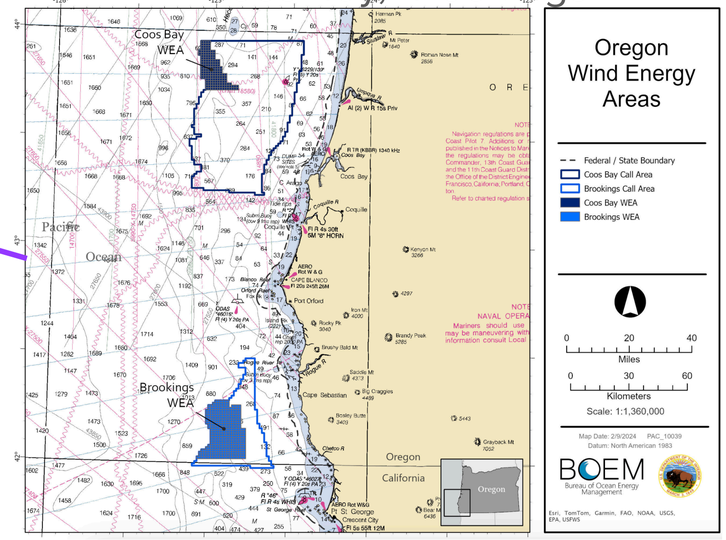
Humboldt, Morro Bay, Diablo Canyon

10 MW Turbines; 9D spacing

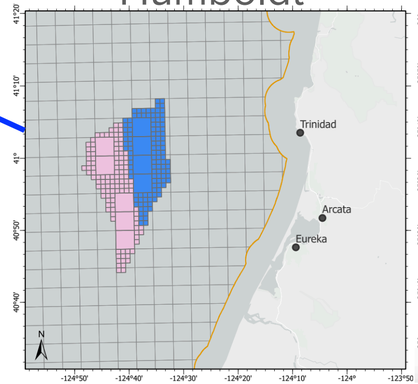
THIS STUDY

Coos Bay, Brookings

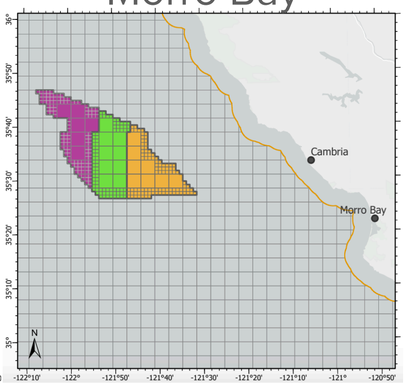




Humboldt



Morro Bay



15 MW or 20 MW Turbines; 10x4D elliptical spacing

Ocean Modeling

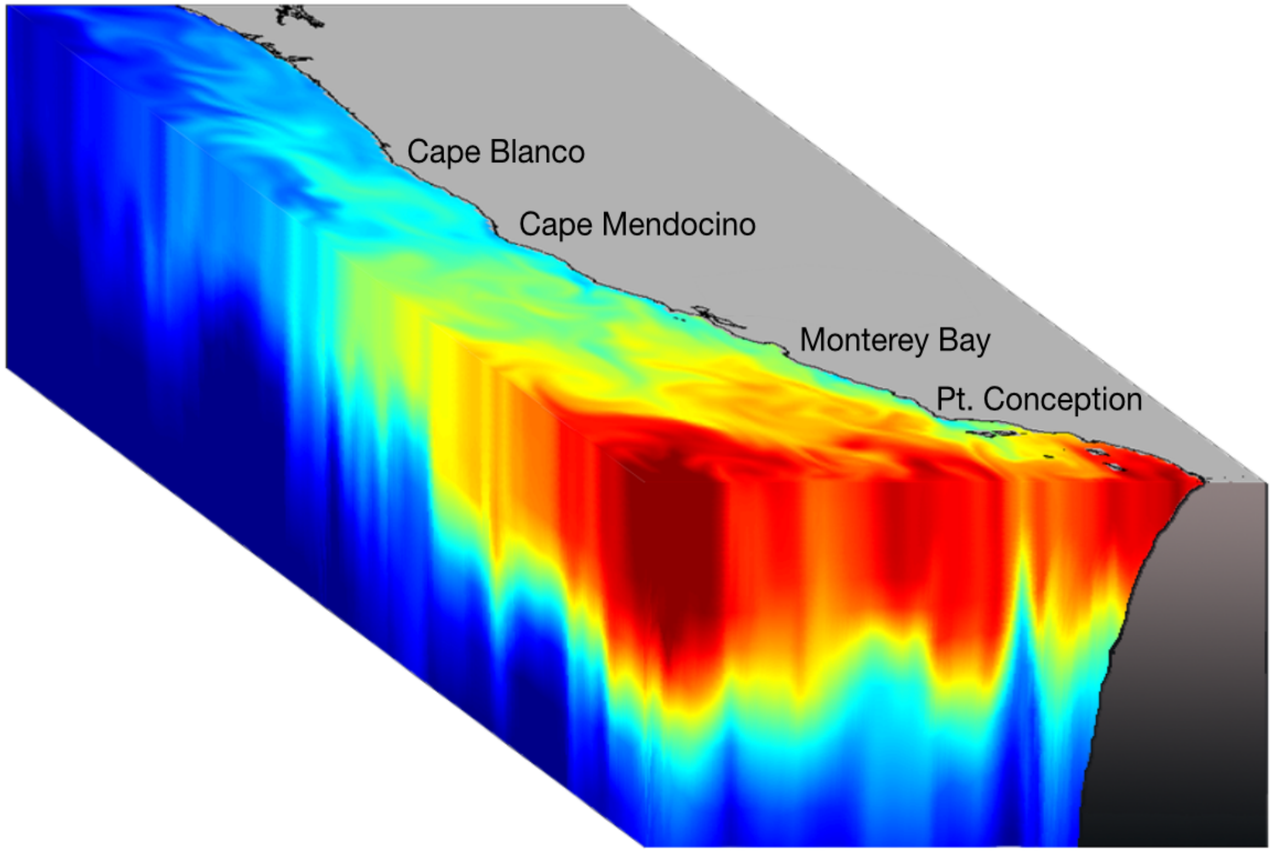
3km resolution for full domain

1995-2019

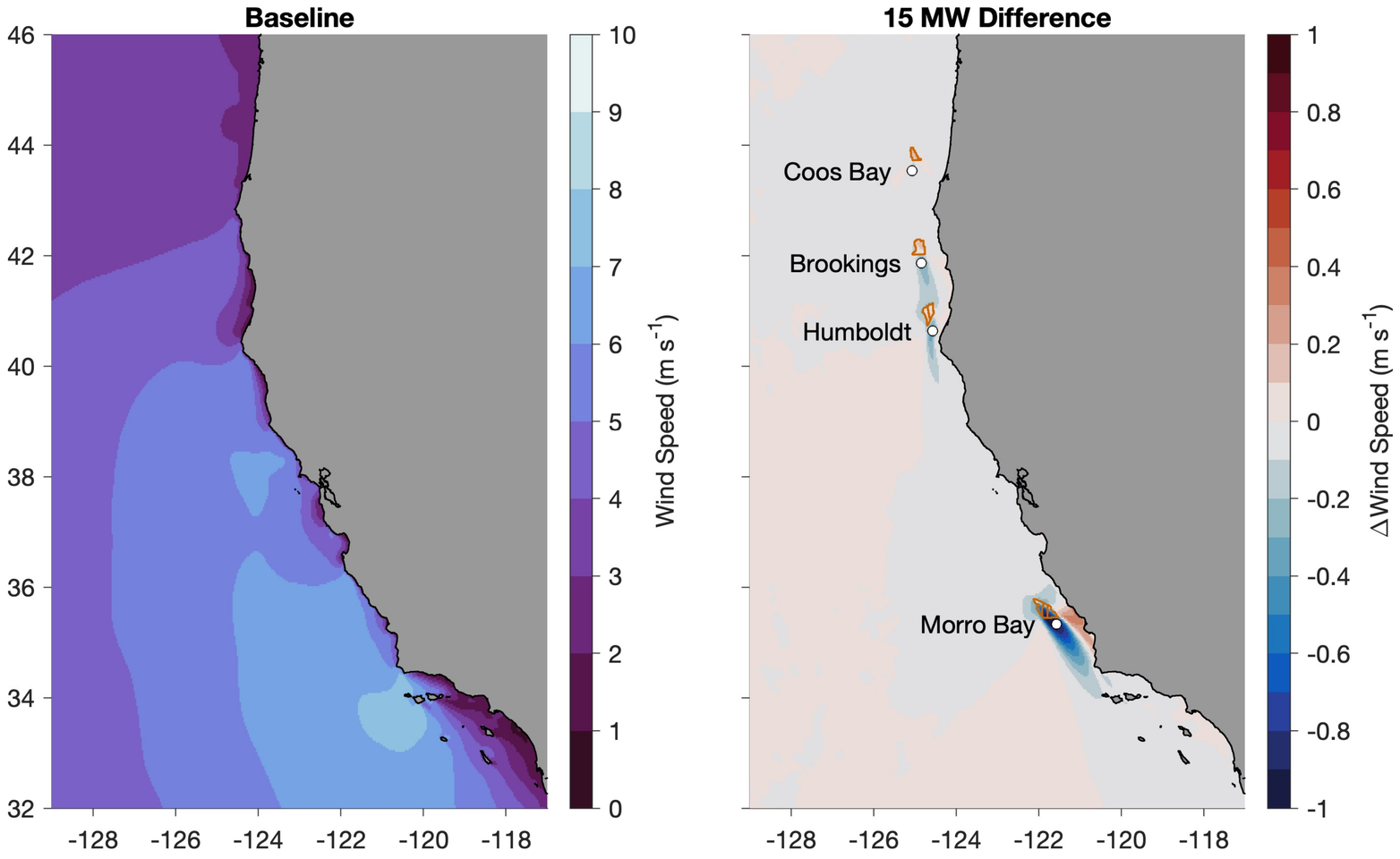
Atmospheric forcing w/ and w/out turbines

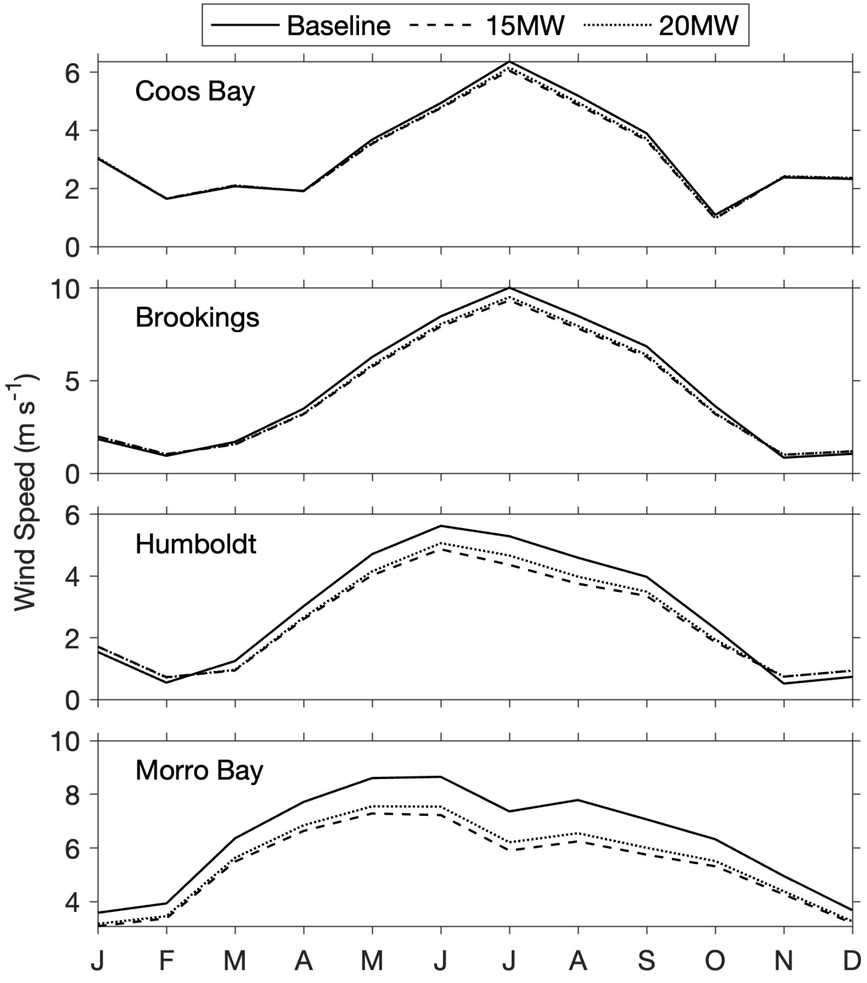
Physics (ROMS) + Biogeochemistry (NEMUCSC)

- Nutrients
- Oxygen
- Two phytoplankton groups
- Three zooplankton groups



Wind Speed



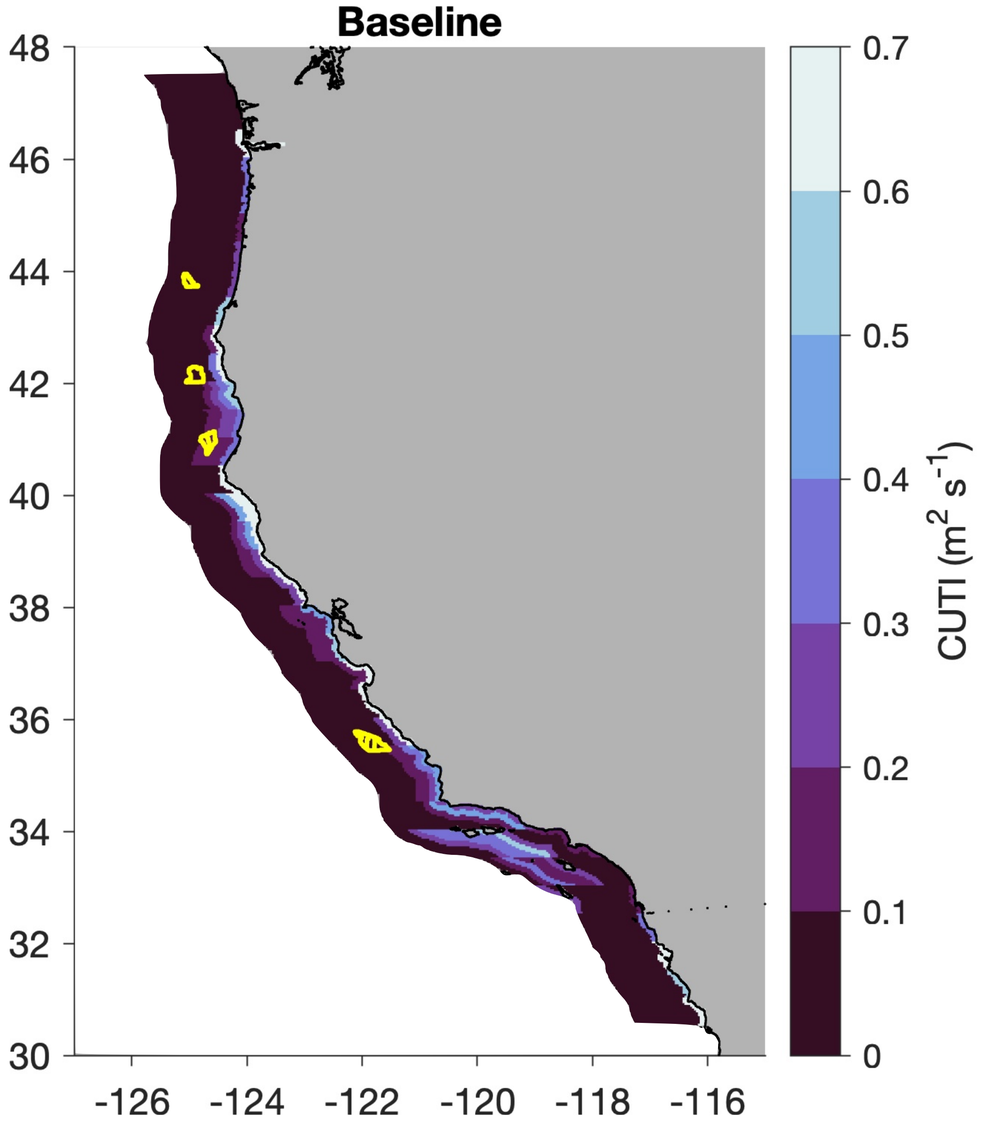


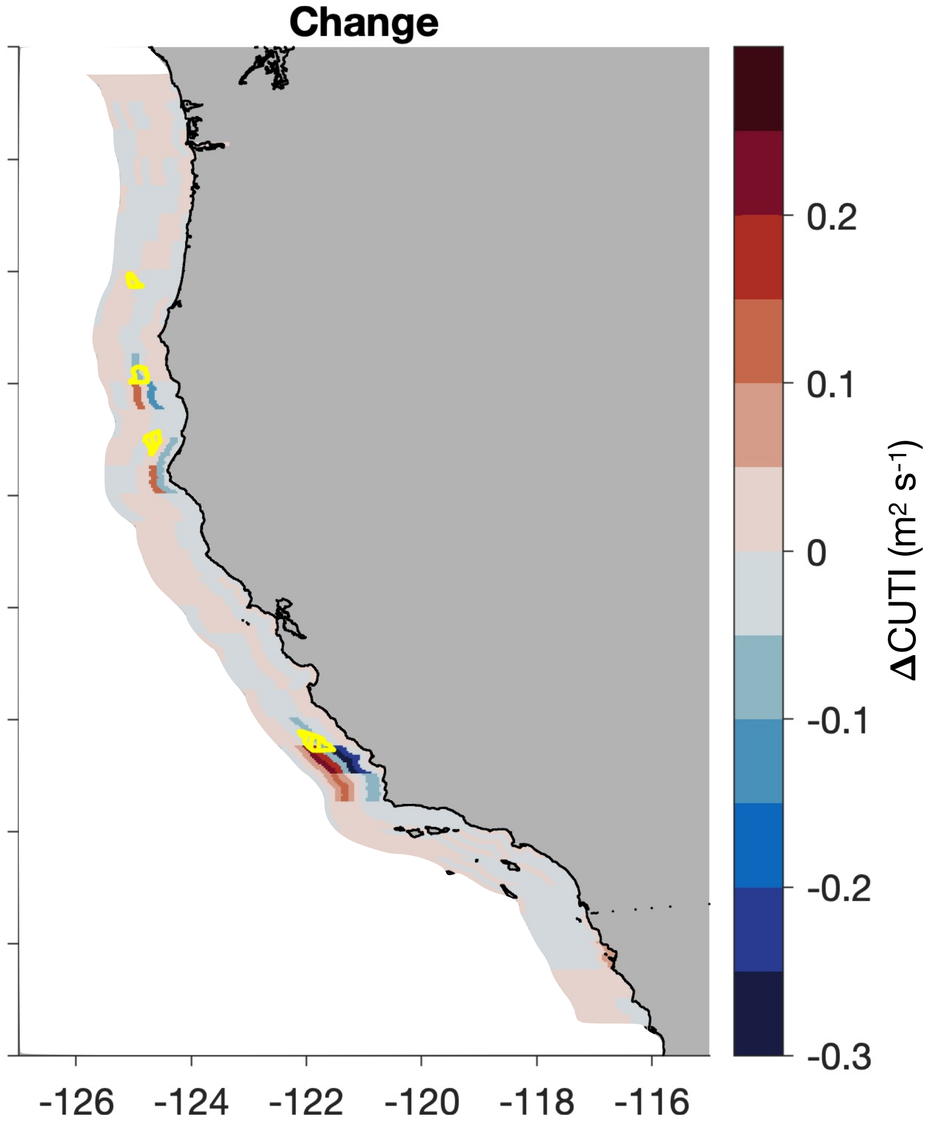
972 x **15 MW** turbines = **14.6 GW total**

595 x **20 MW** turbines = **11.9 GW total**

Upwelling Intensity

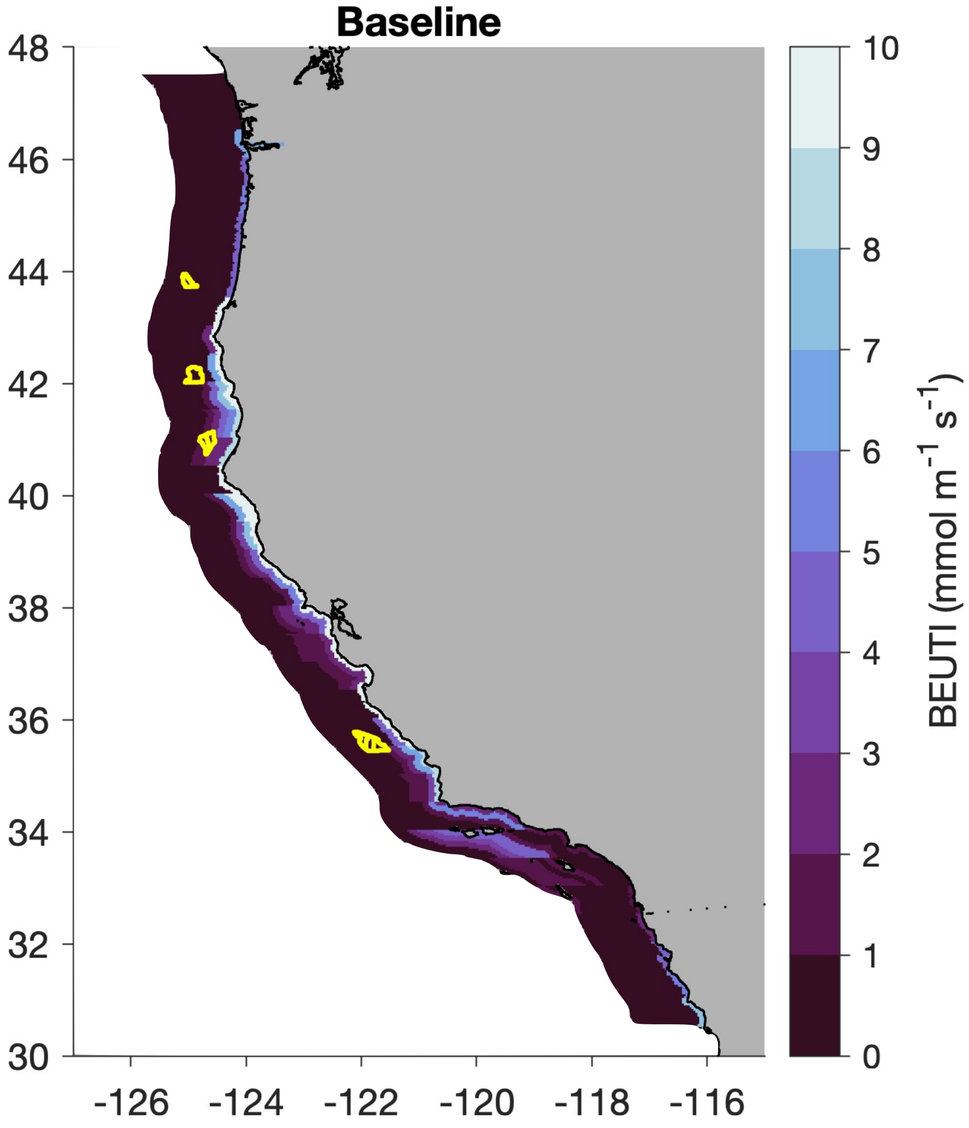
Upwelling Season (March - July)
Average of 15MW and 20MW simulations

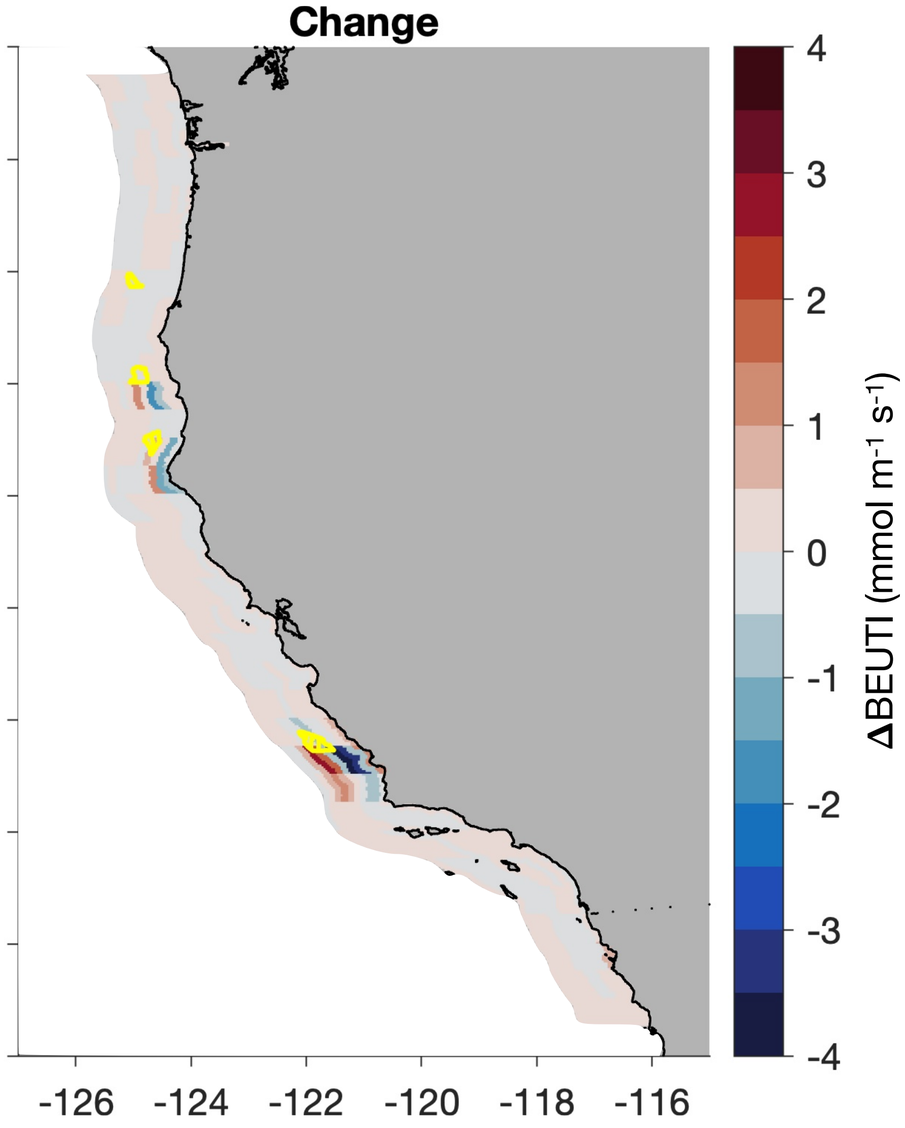




Nitrate Supply

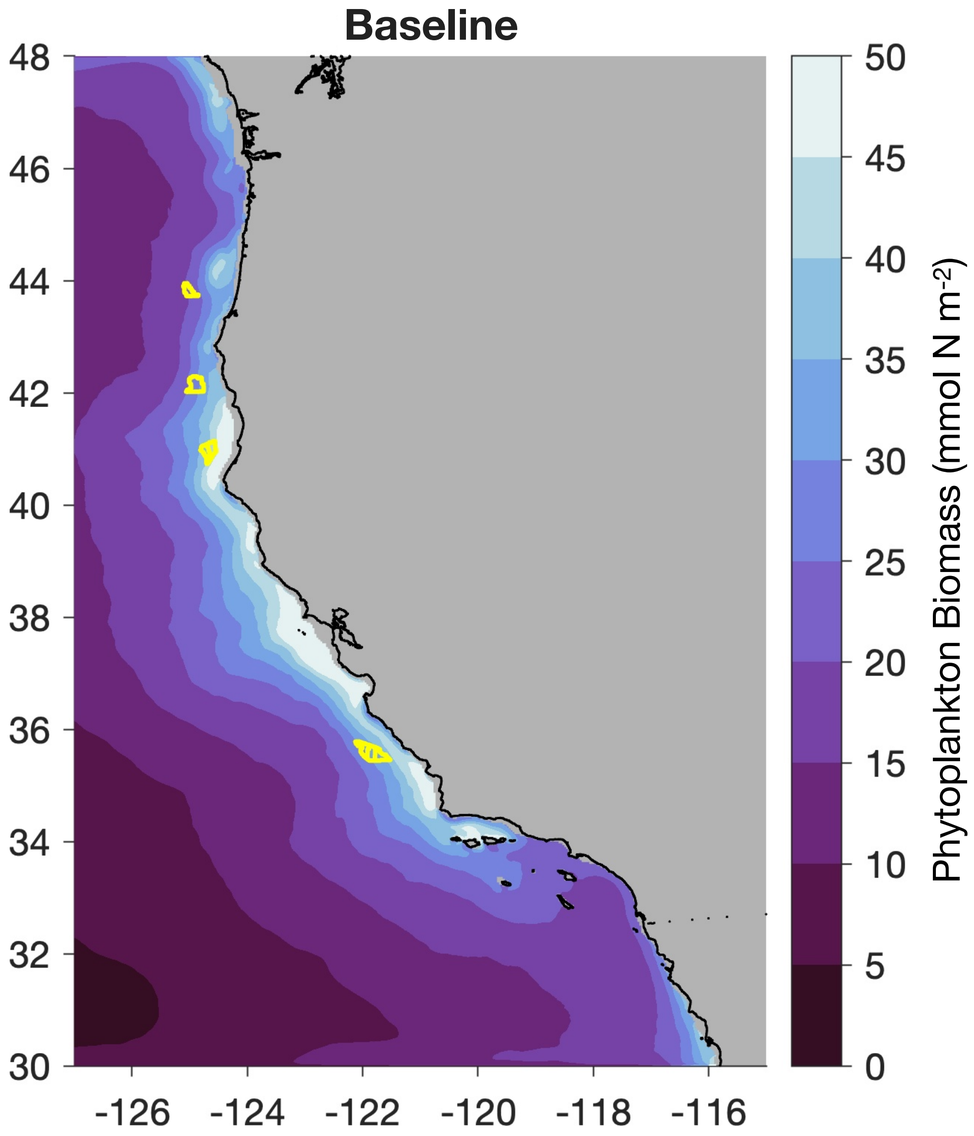
Upwelling Season (March - July)
Average of 15MW and 20MW simulations

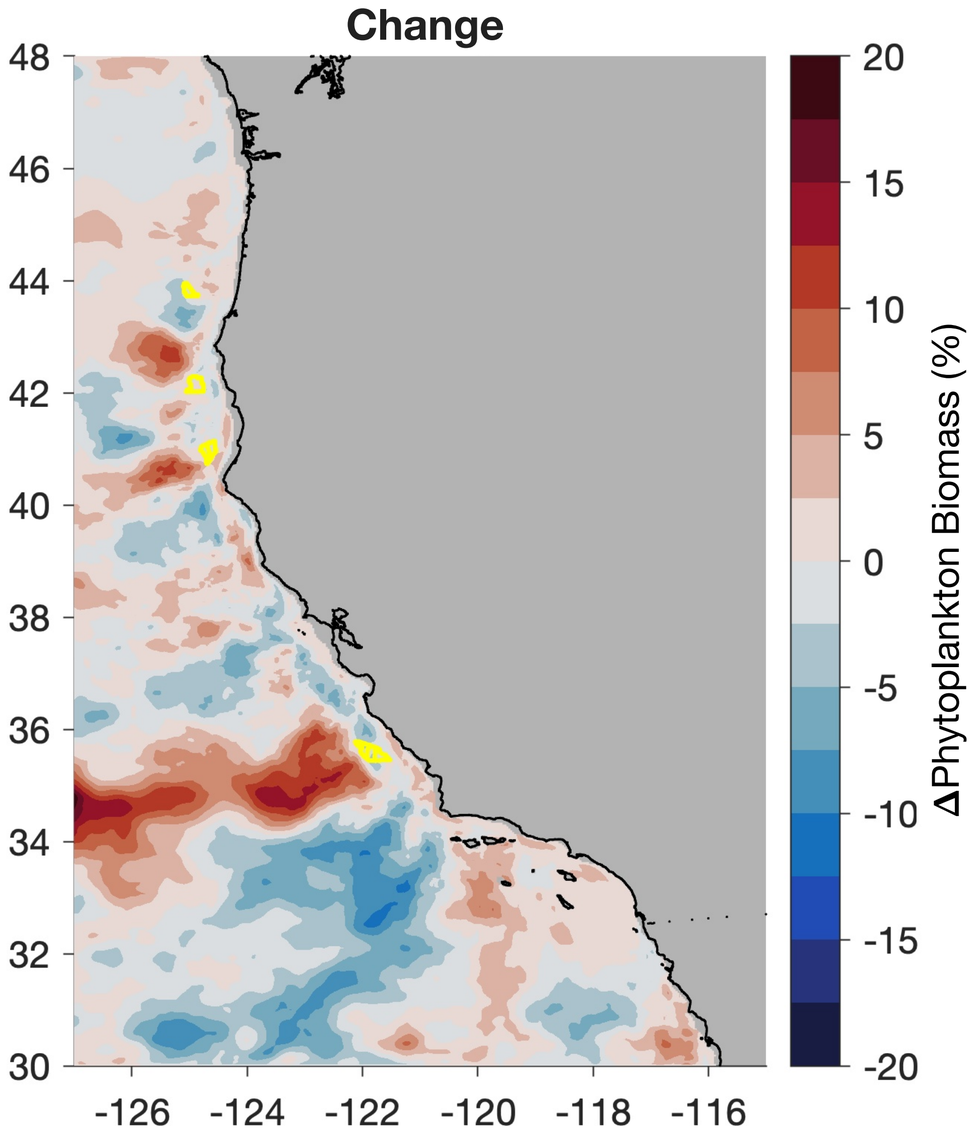




Phytoplankton Biomass

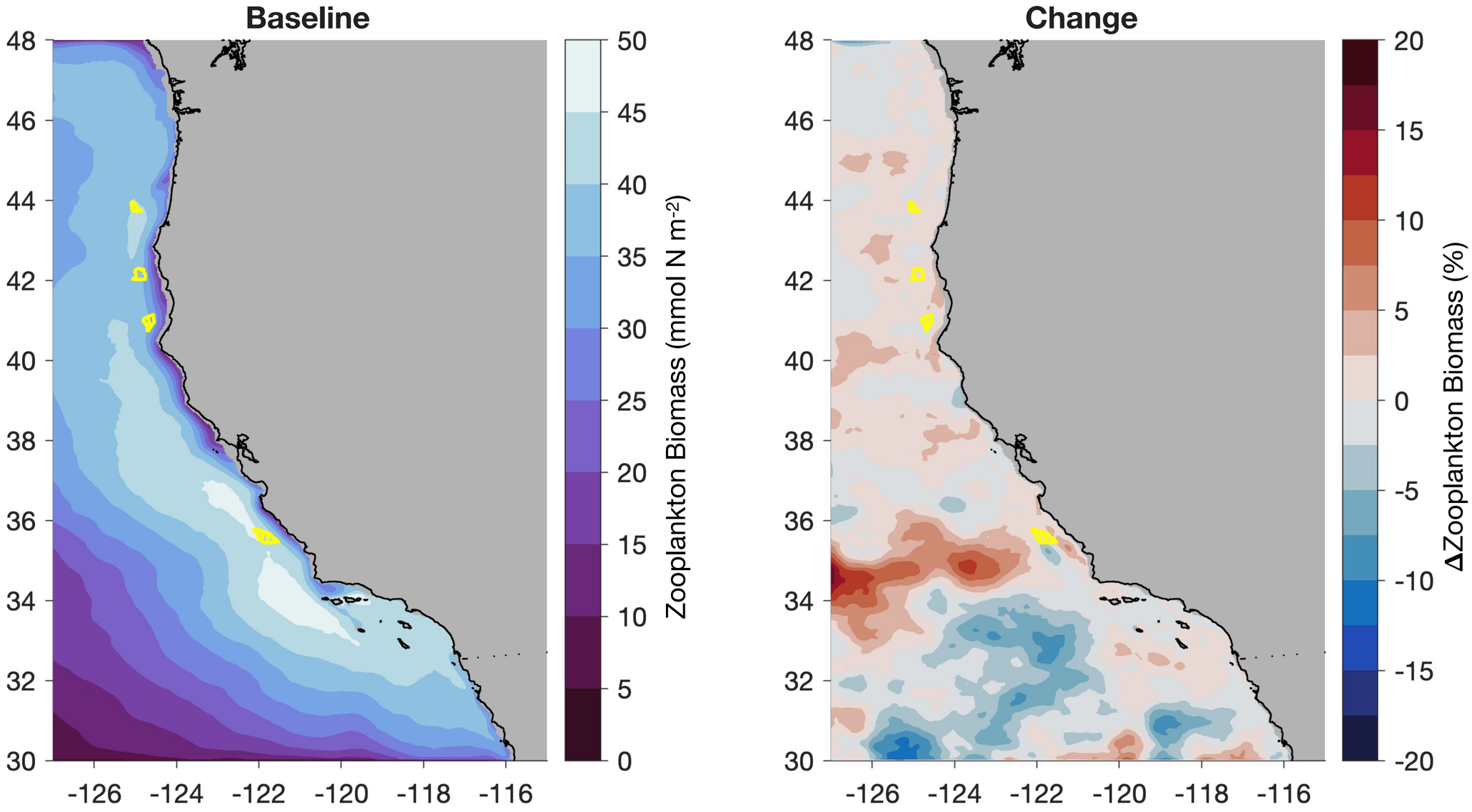
Upwelling Season (March - July)
Average of 15MW and 20MW simulations





Zooplankton Biomass

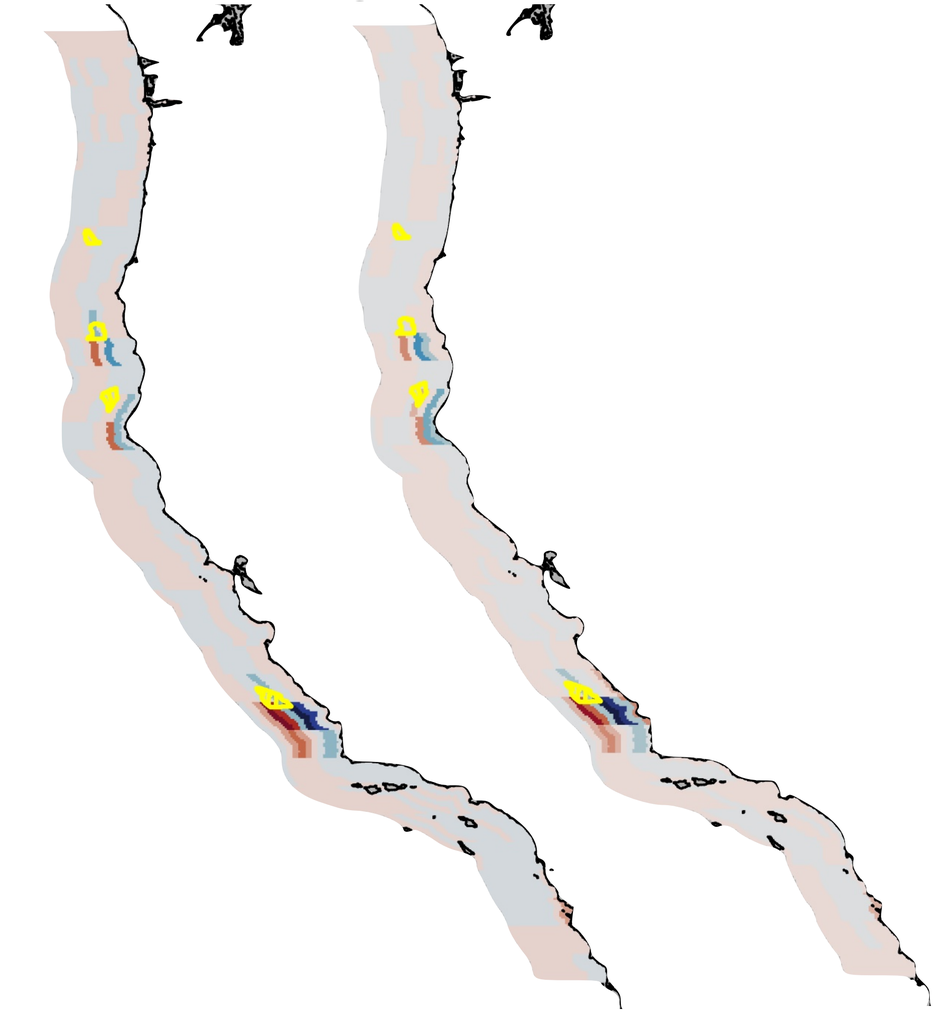
Upwelling Season (March - July)
Average of 15MW and 20MW simulations



Summary Impacts

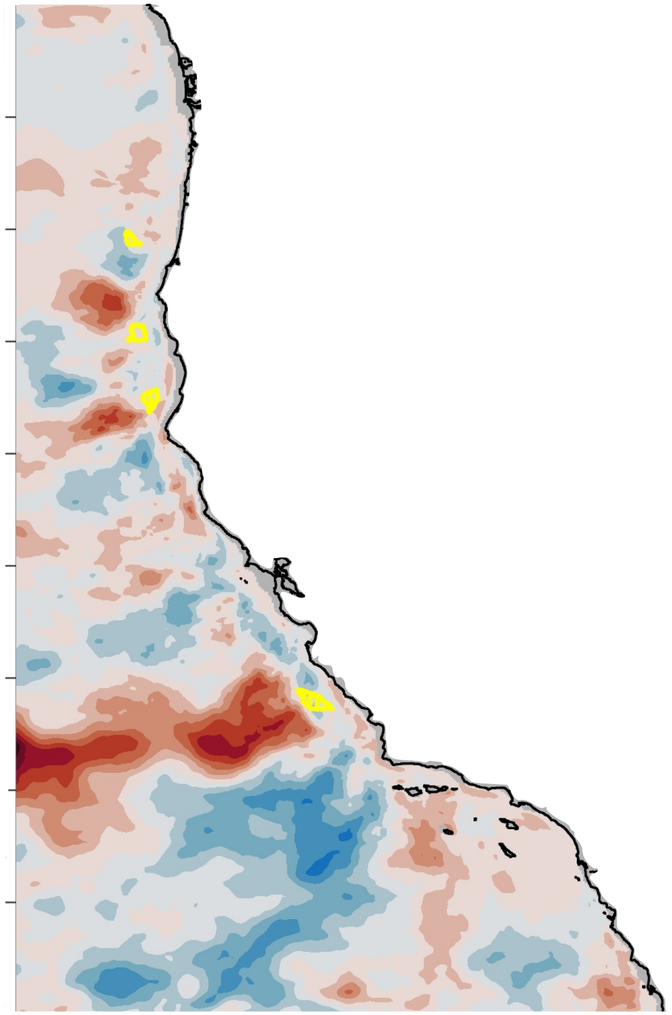
Upwelling Season (March - July)
Average of 15MW and 20MW simulations

Upwelling

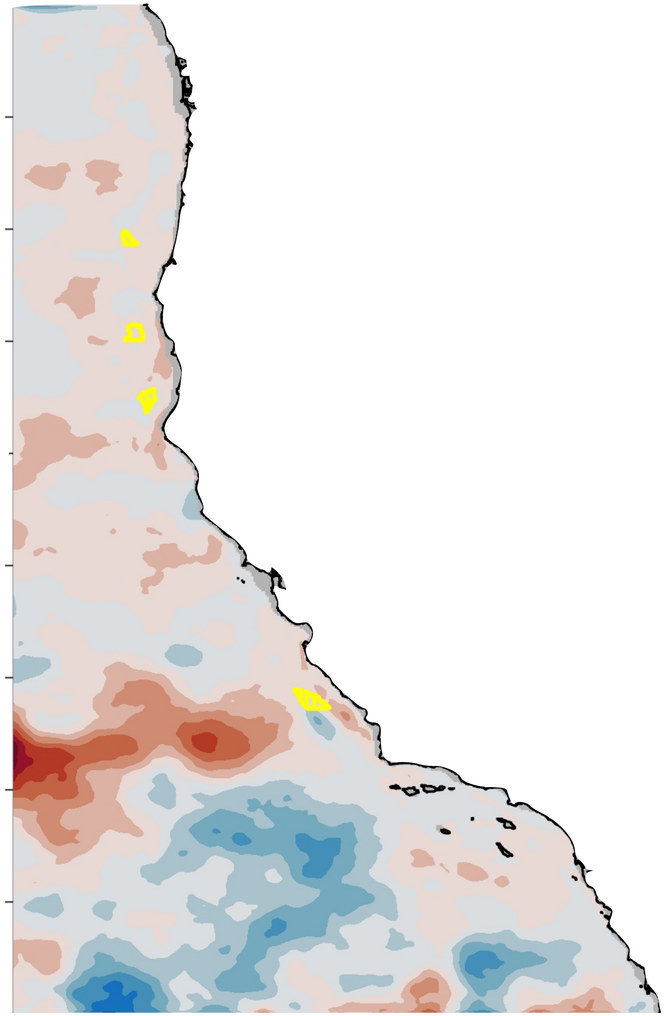


Nitrate Supply

Phytoplankton

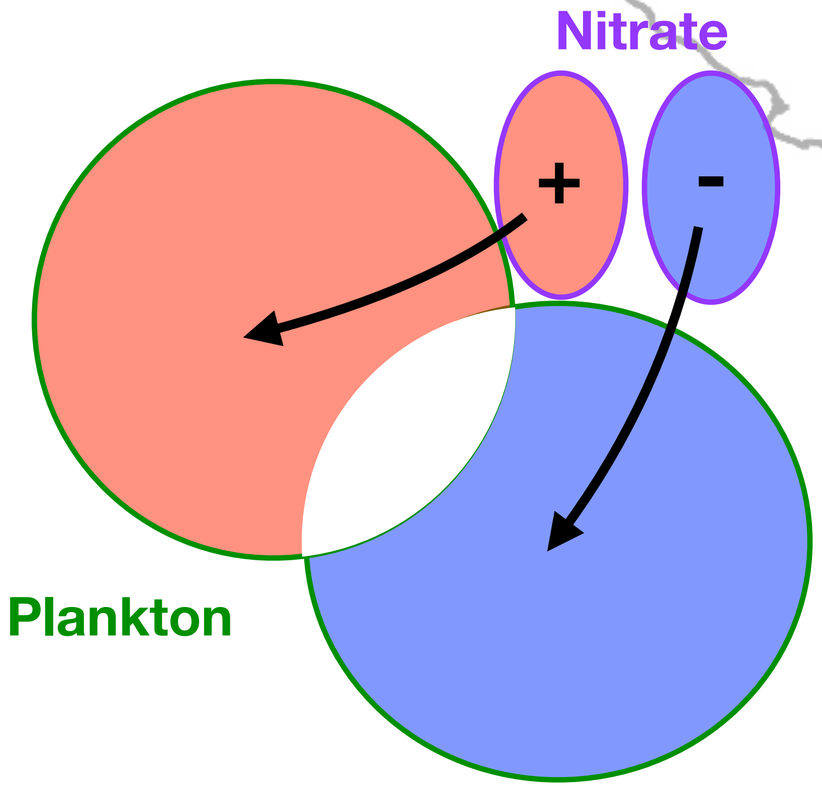


Zooplankton



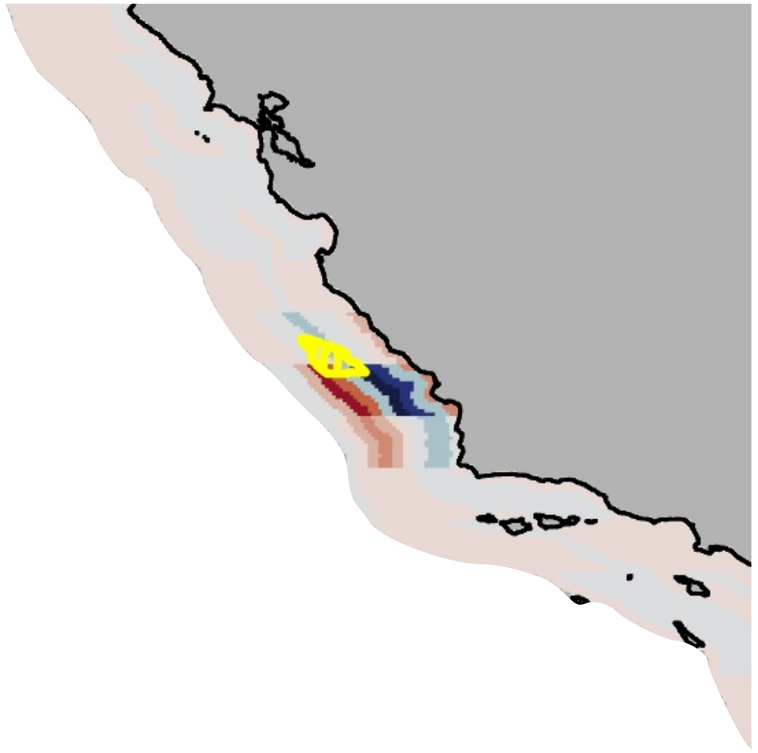
Working Hypothesis

Plankton changes are offset from upwelling changes due to temporal lags + advection



Working Hypothesis

Changes in upwelled nitrate



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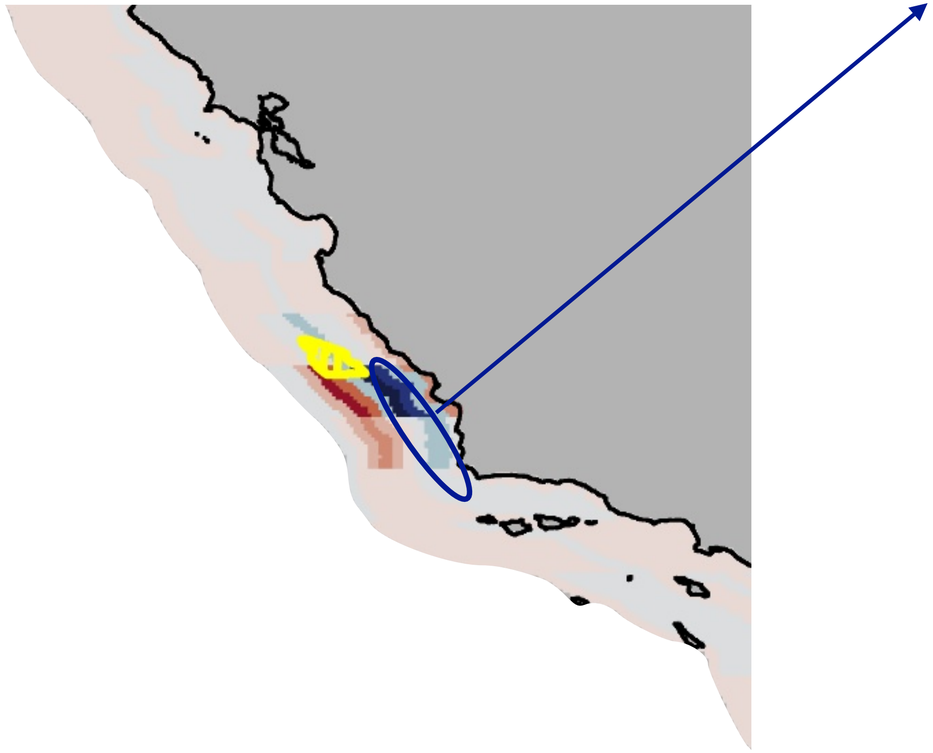
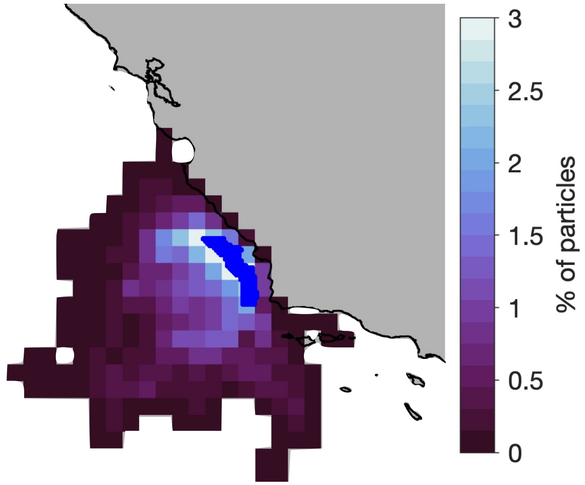


Particles released in area of decreased nitrate supply



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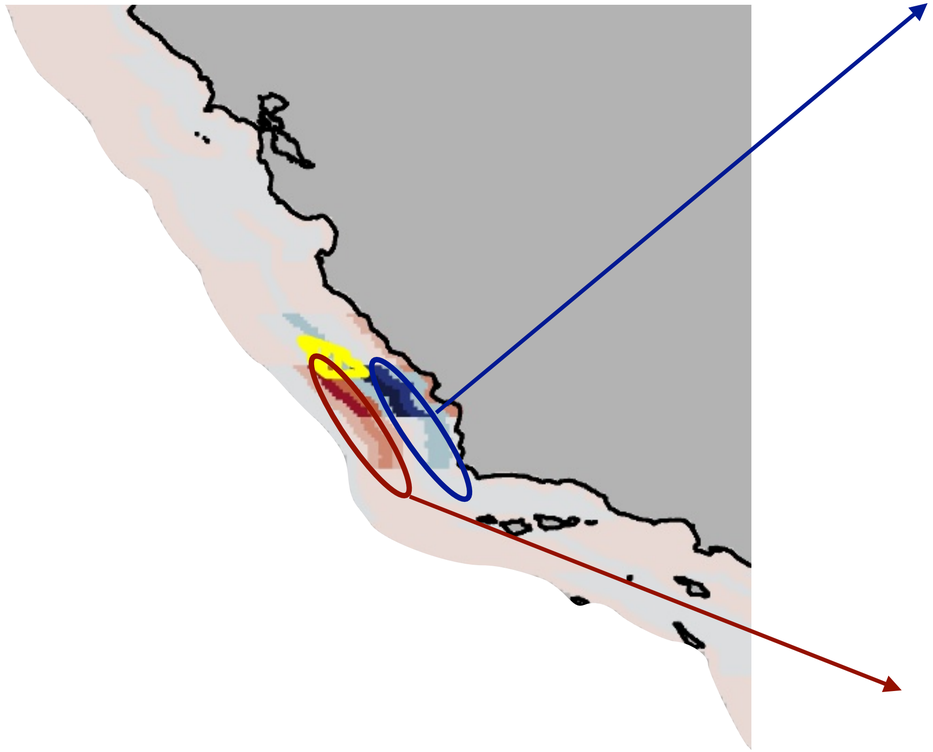

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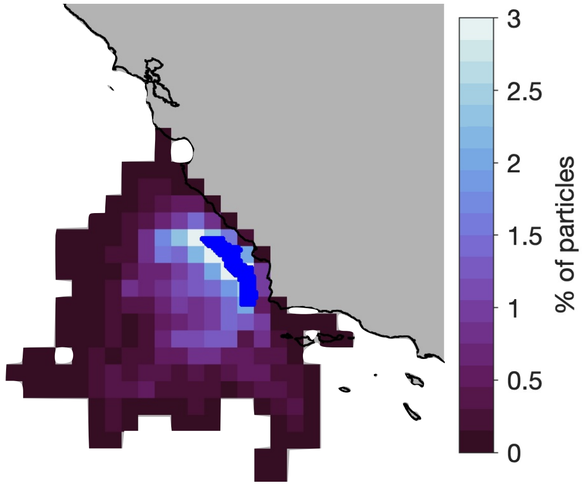
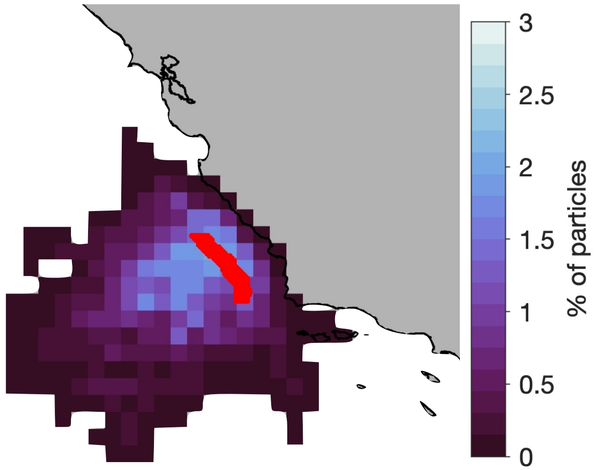
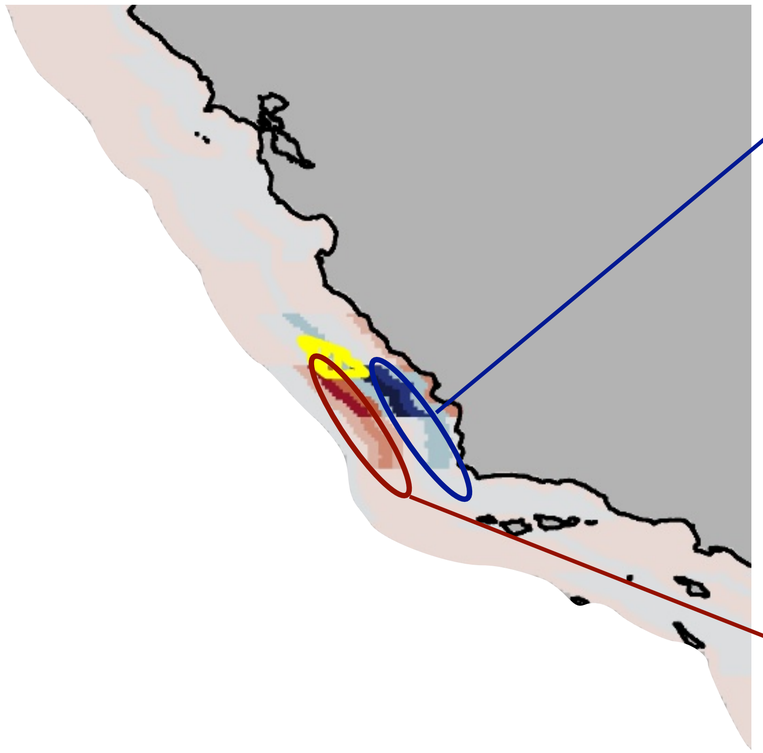


Particles released in area of increased nitrate supply

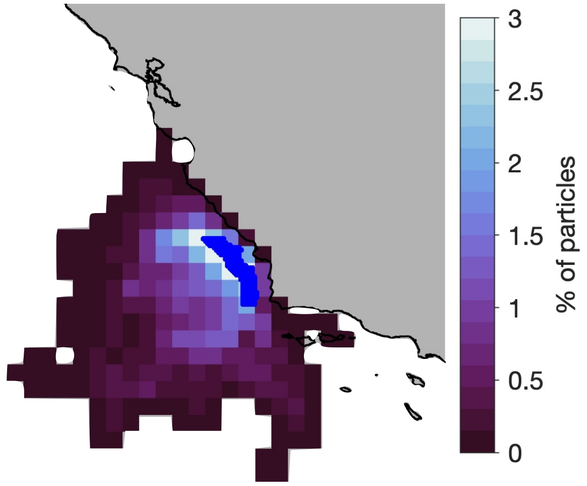


Working Hypothesis

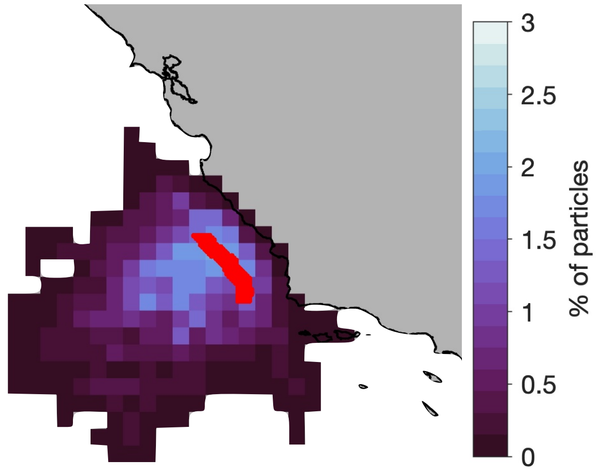
Changes in upwelled nitrate



Particles released in area of decreased nitrate supply

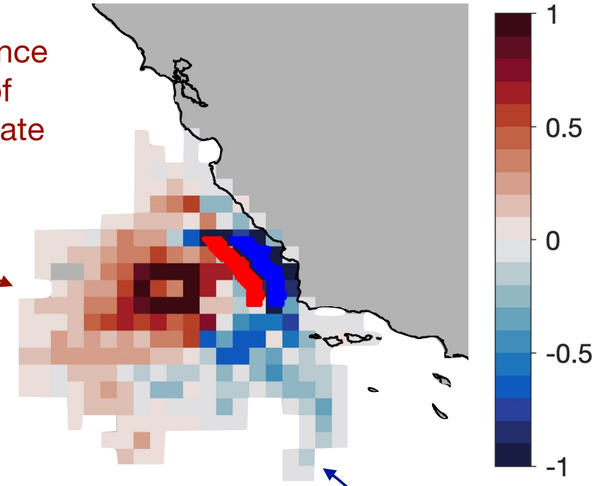


Particles released in area of increased nitrate supply



Difference

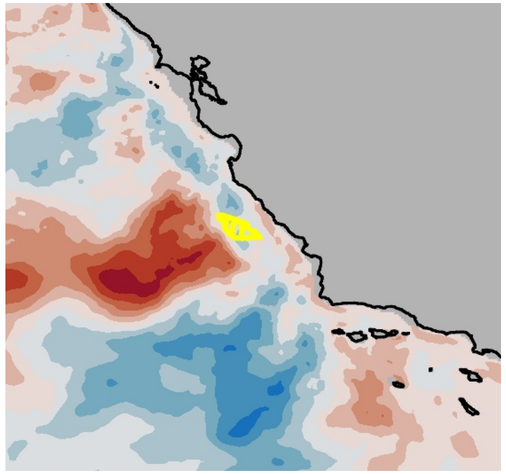
Greater influence from area of increased nitrate



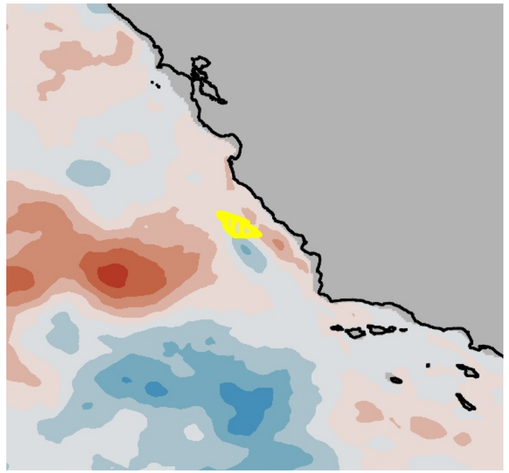
Greater influence from area of decreased nitrate

Working Hypothesis

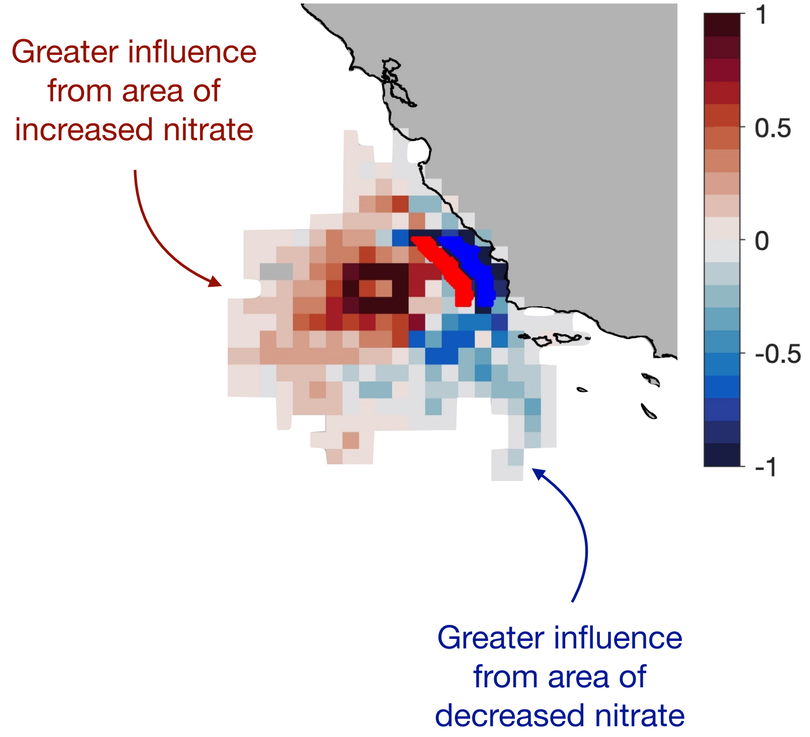
Changes in phytoplankton



Changes in zooplankton



Difference



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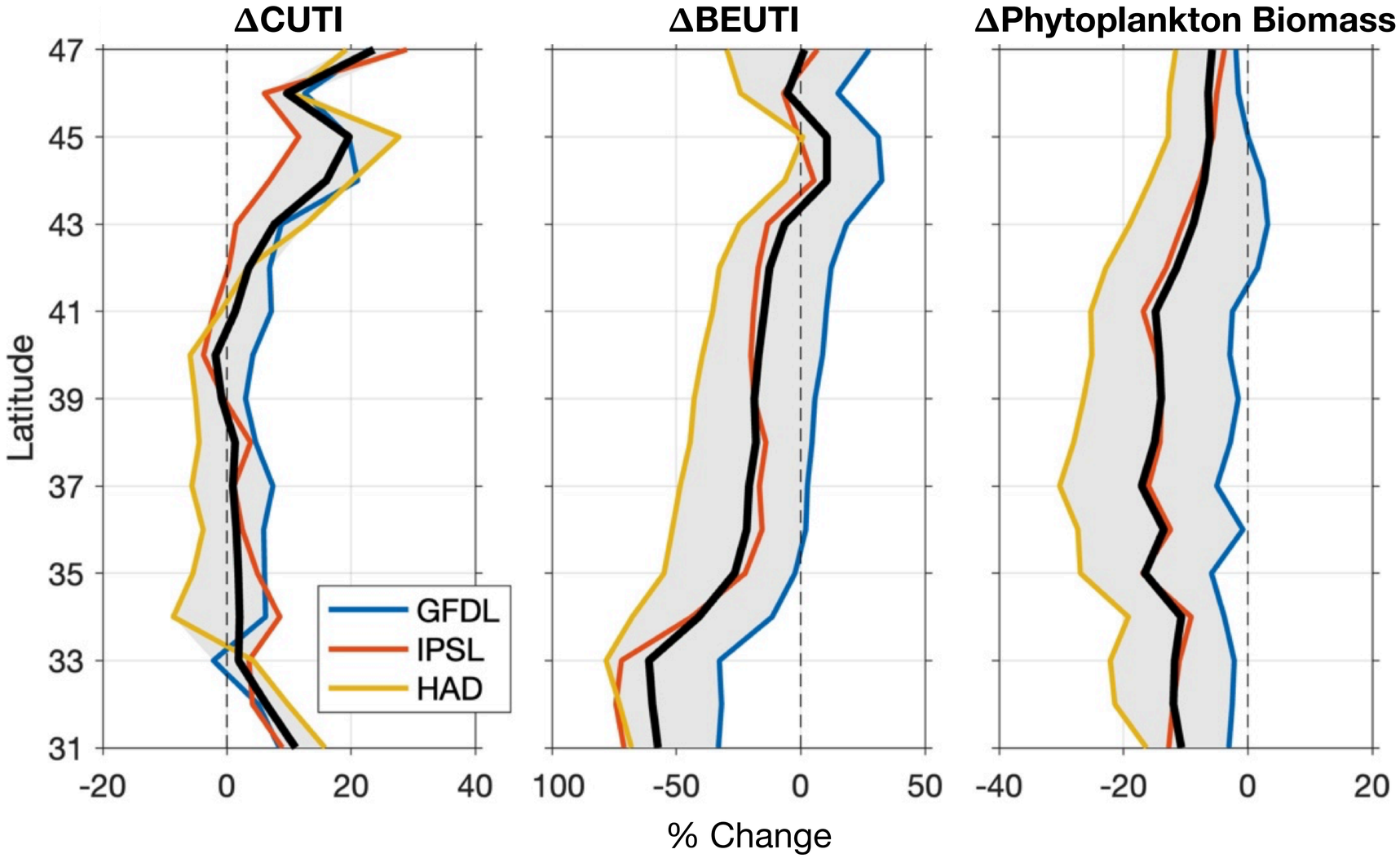
Offshore Wind Impacts in the Context of Climate Change

Projected end-of-century changes under high emission scenario

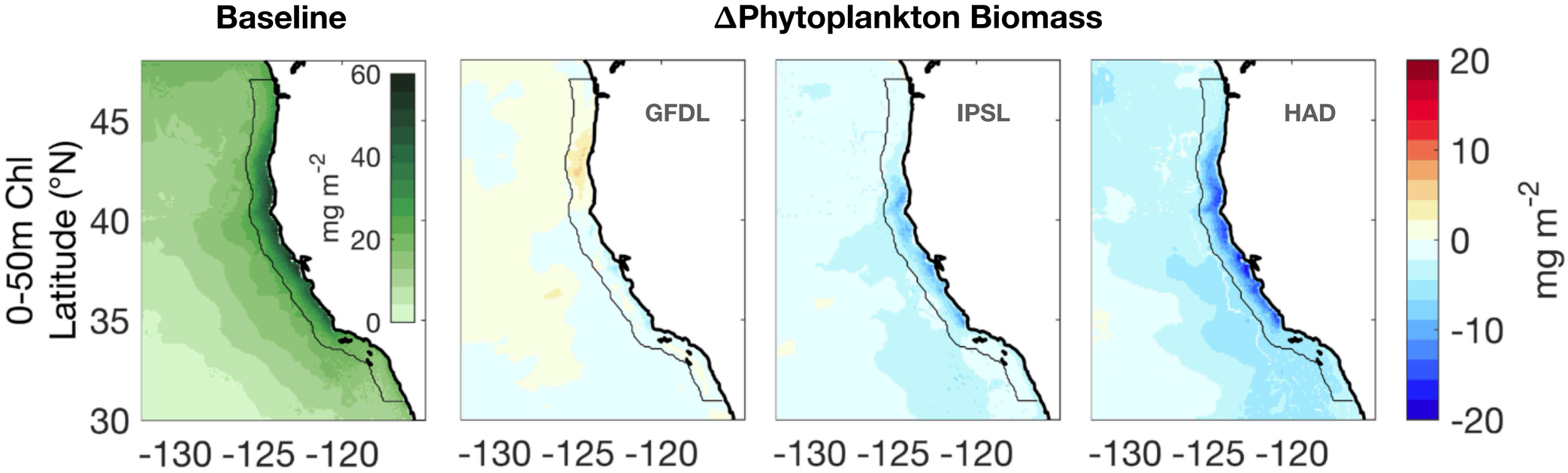


* all changes are for 0-75 km from shore

Jacox et al. (2024)

Offshore Wind Impacts in the Context of Climate Change

Projected end-of-century changes under high emission scenario



Pozo Buil et al. (2021)

Offshore Wind Impacts in the Context of Climate Change

Wind farm impacts are patchy mosaics of positive and negative. Neither natural variability nor climate change induce similar patterns in upwelling.

Impacts of northern areas (Humboldt, Coos Bay, Brookings) are harder to discern, likely because they are smaller and interact with each other.

Nearshore, wind farm impacts on phytoplankton are smaller than projected climate change impacts (under high emissions scenario). Offshore, they can be comparable.

Presumably, more offshore wind development accompanies lower emissions scenarios. If so, the relative impact of offshore wind will increase as emissions decrease.