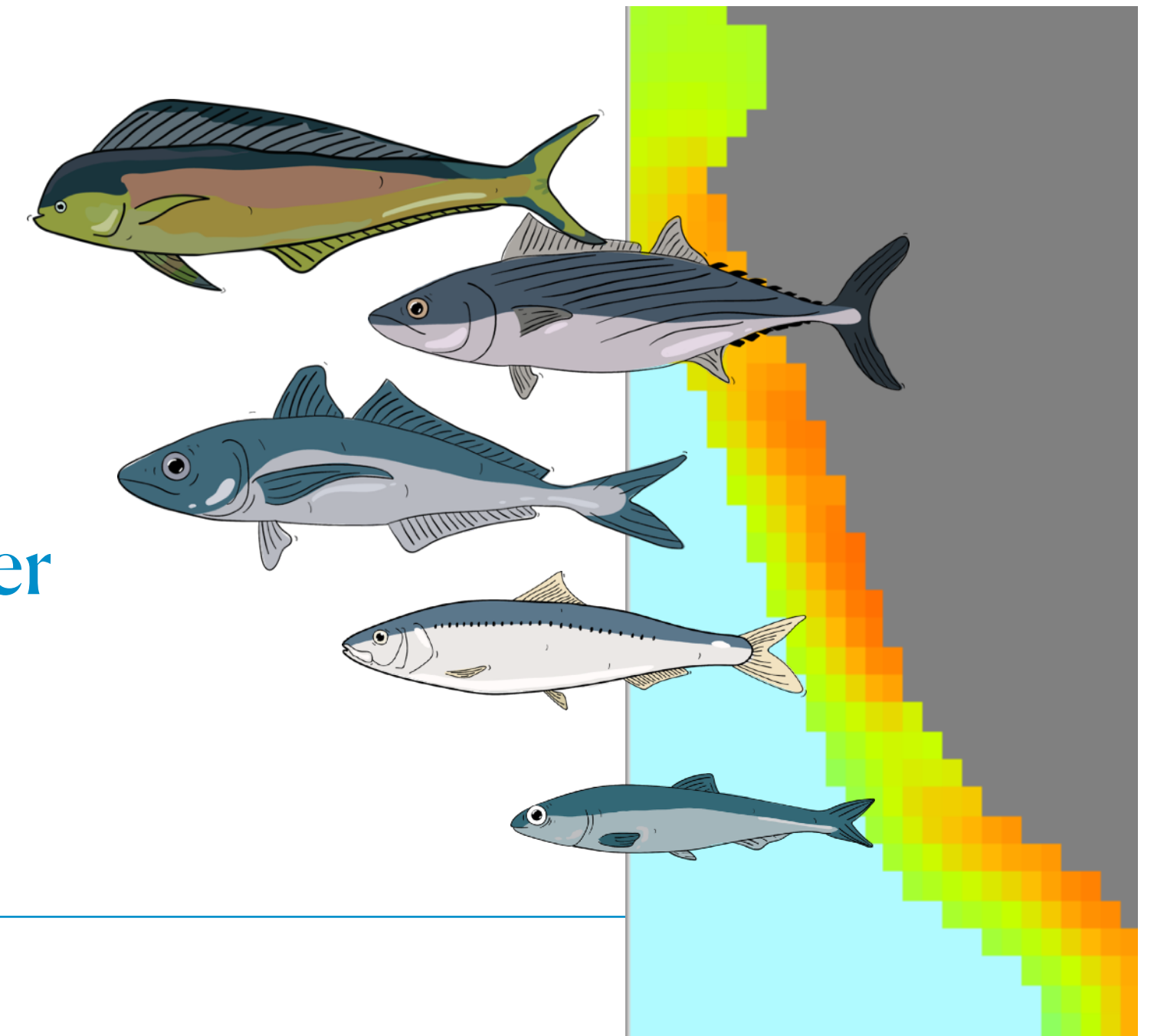


Modeling trophic dynamics and climate-driven shifts in the Northern Humboldt Current Ecosystem

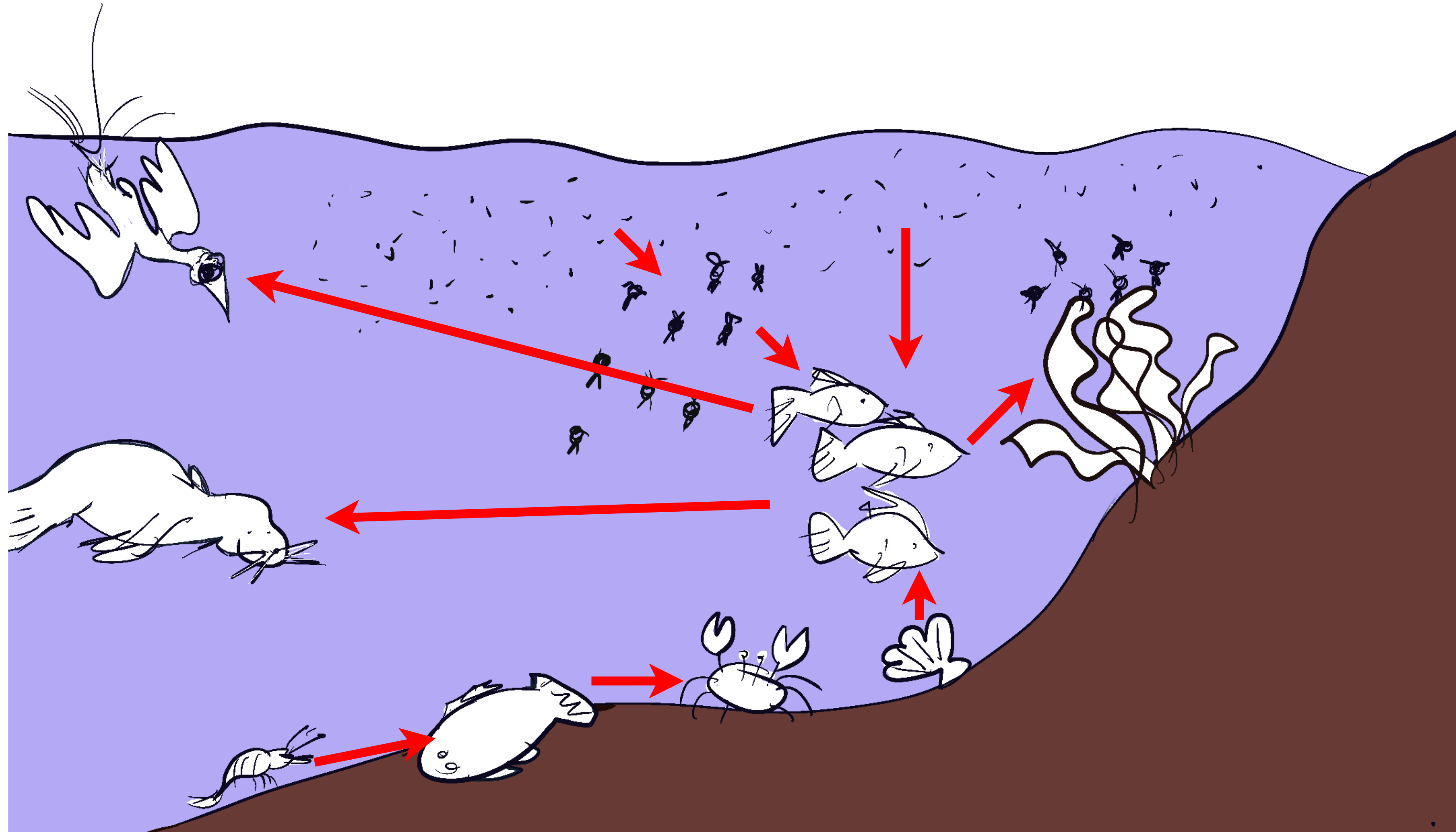
Stefan Koenigstein, Giovanni Romagnoni, Jorge Tam, Adolfo

Chamorro, Dante Espinoza-Morriberón, Marc Taylor, Hauke Reuter

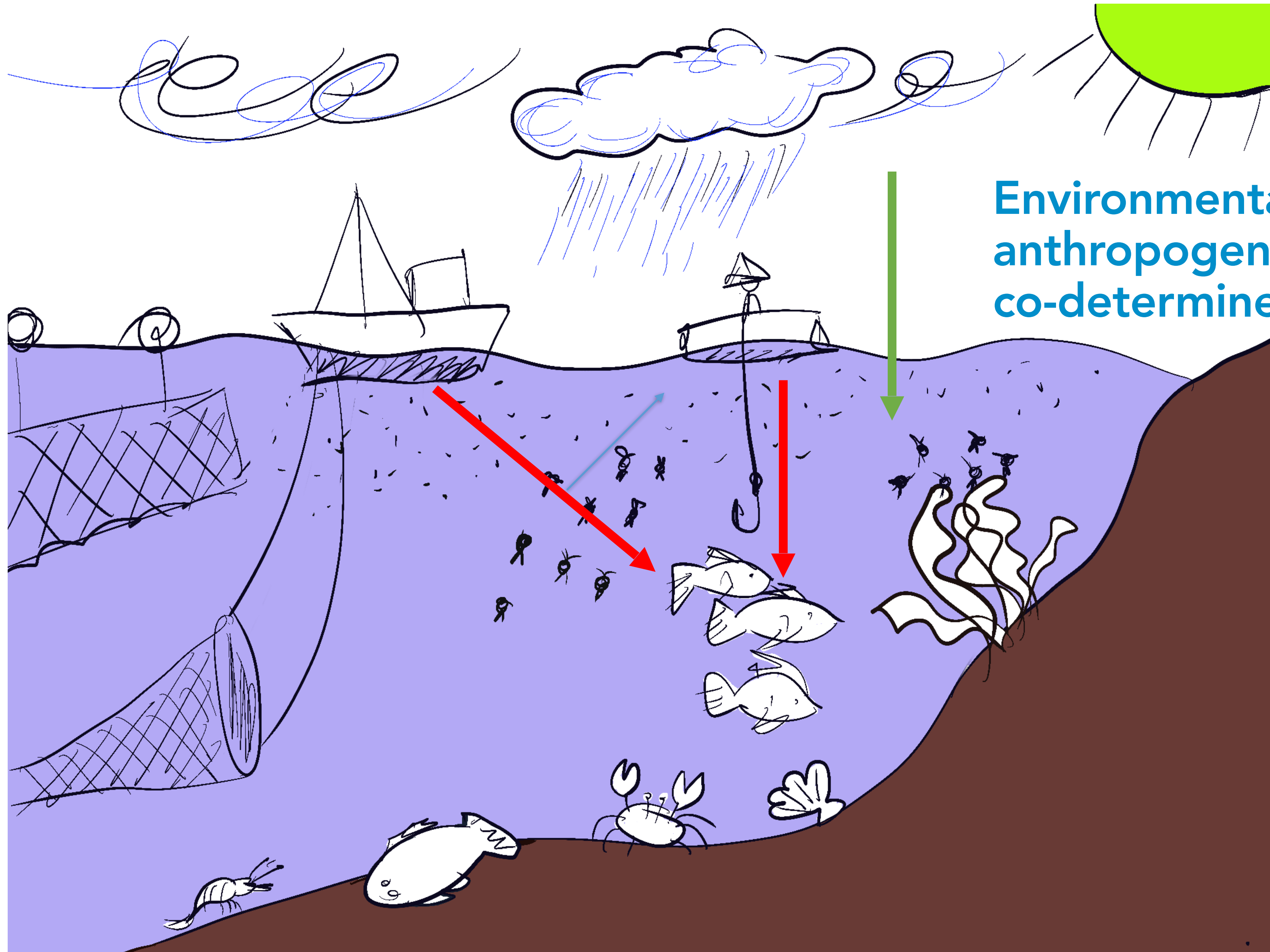
SPF Symposium La Paz, 08.05.2026



Ecological interactions drive marine ecosystems



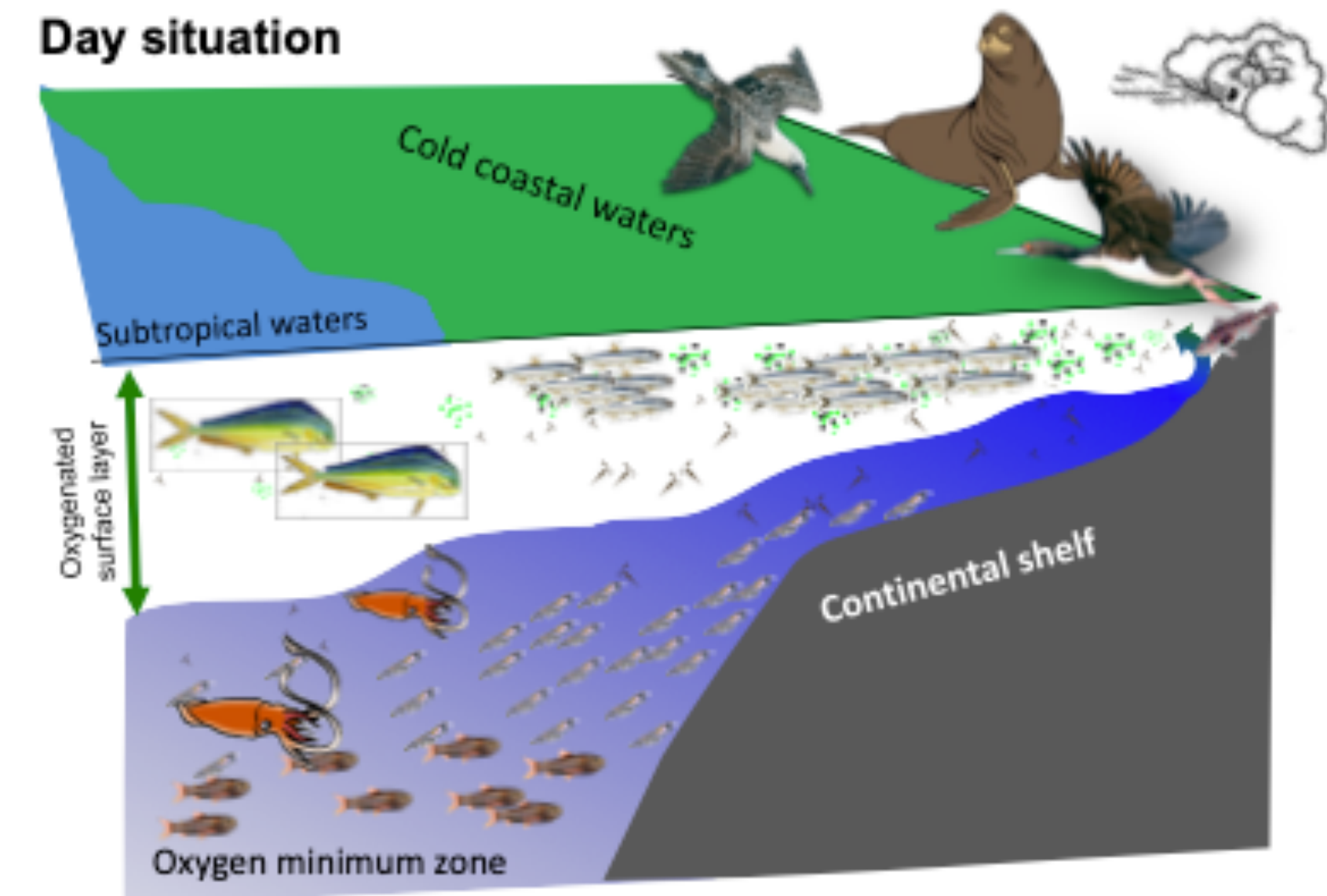
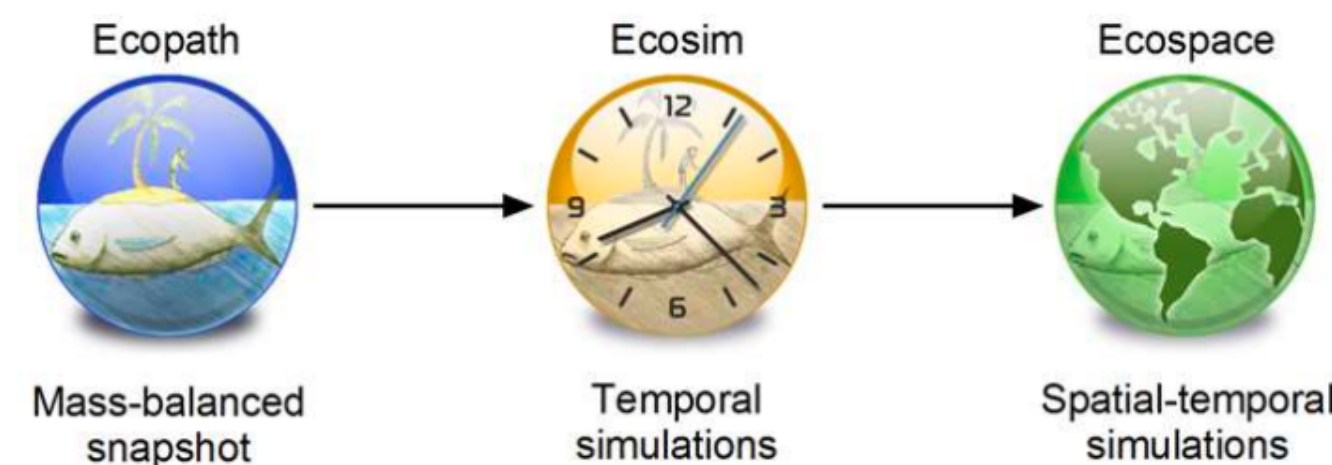
Alonso del Solar



Environmental and anthropogenic drivers co-determine dynamics

Northern Humboldt Current (Peru)

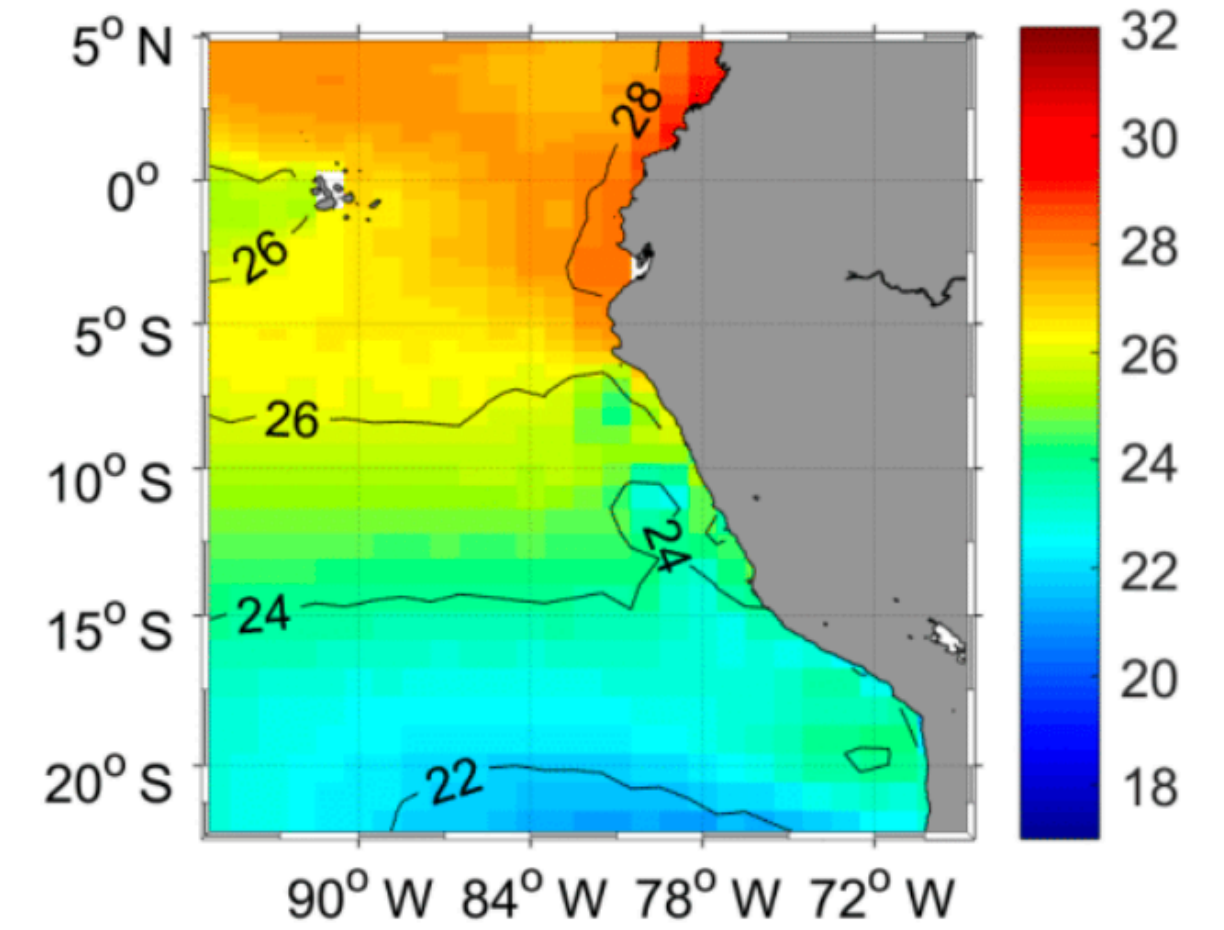
- Eastern boundary upwelling system (EBUS), highly dynamic and environment-driven
 - Peruvian anchoveta: high biomass, important for energy transfer in food-web: one of the largest fisheries in the world
 - Diverse small-scale fisheries very important for coastal communities
- To assess climate change impacts on the food-web, we need to couple lower trophic level production to productivity of planktivores
- A spatial, coupled food-web model ('Ecopath with Ecosim & Ecospace') to understand productivity and variability of the NHC



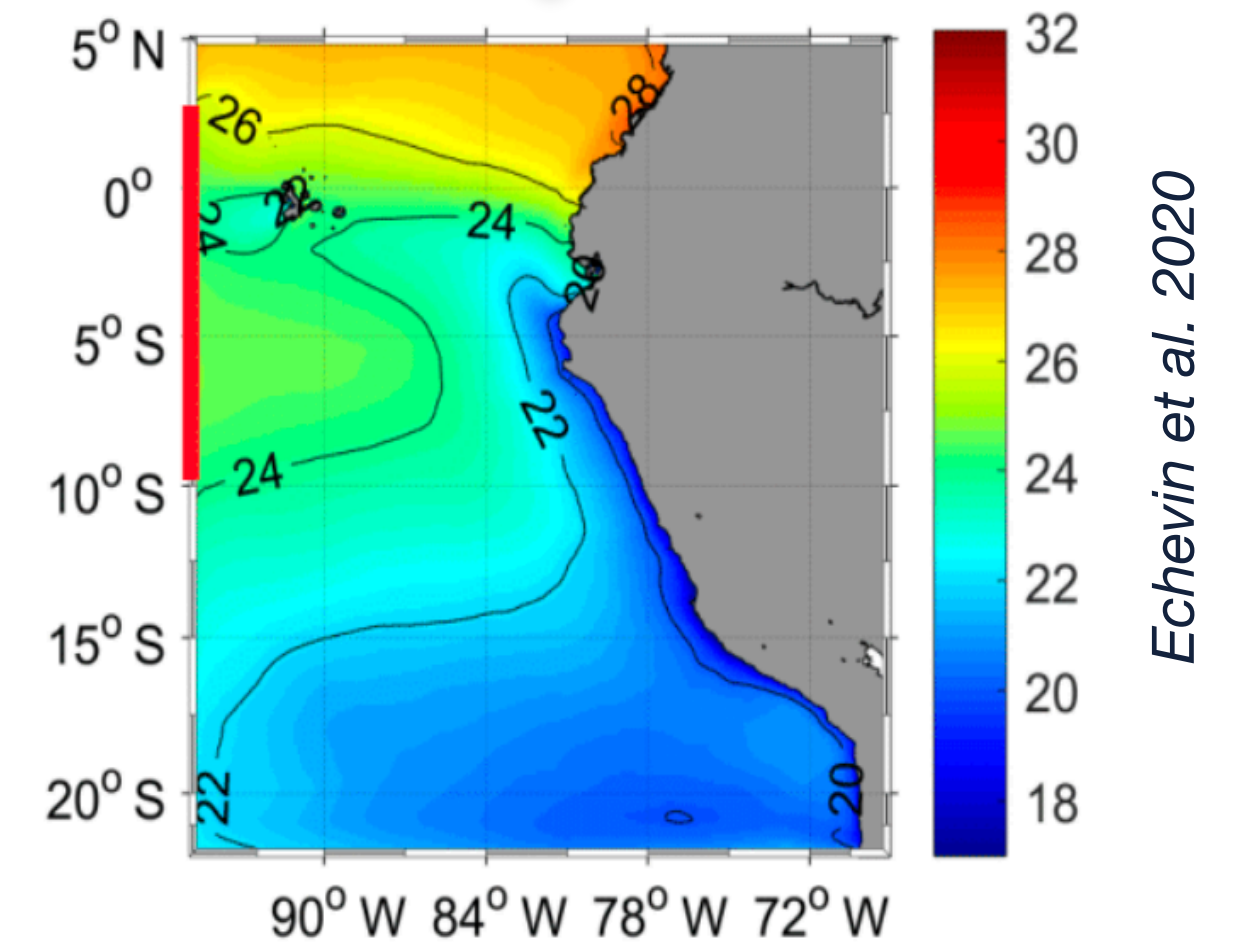
Environmental drivers

- High-resolution regional ocean-biogeochemical model (CROCO-PISCES) for environmental driving
 - Ocean temperature,
 - oxygen & oxycline depth
 - phyto- and zooplankton biomasses
- Physiological responses of species in the model:
 - Ocean temperature (at different depths)
 - Dissolved oxygen / depth of oxycline
- Biomass of phytoplankton and zooplankton groups forced

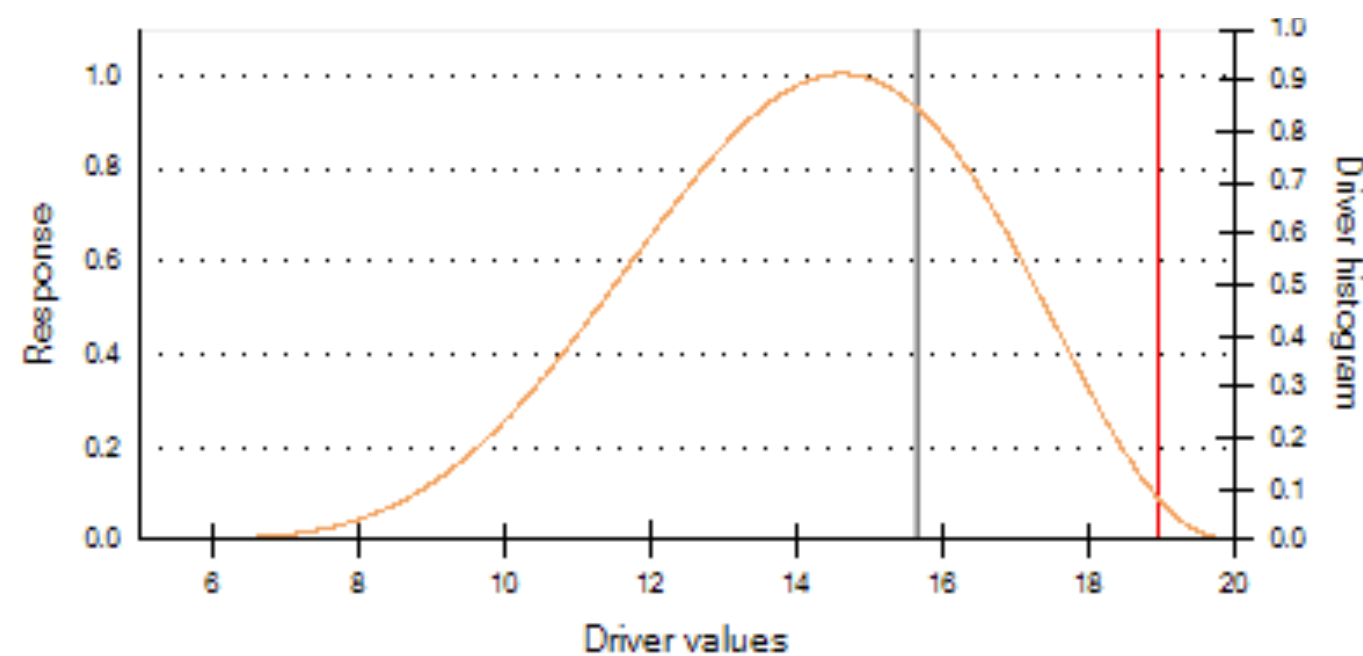
Global model CNRM, 0.5° resolution



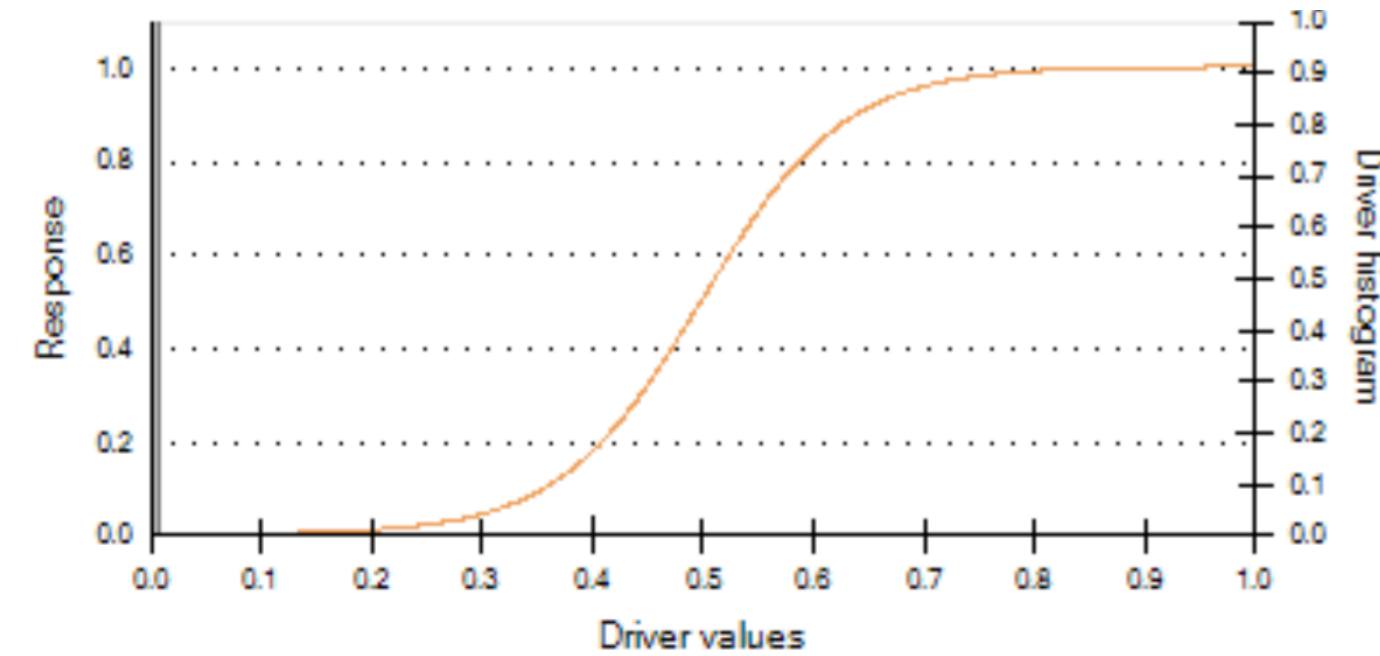
regional model CROCO-PISCES, 0.083° resolution



Temperature: productivity response



Oxycline depth: impact on availability for predators



IMARPE
INSTITUTO DEL MAR DEL PERÚ

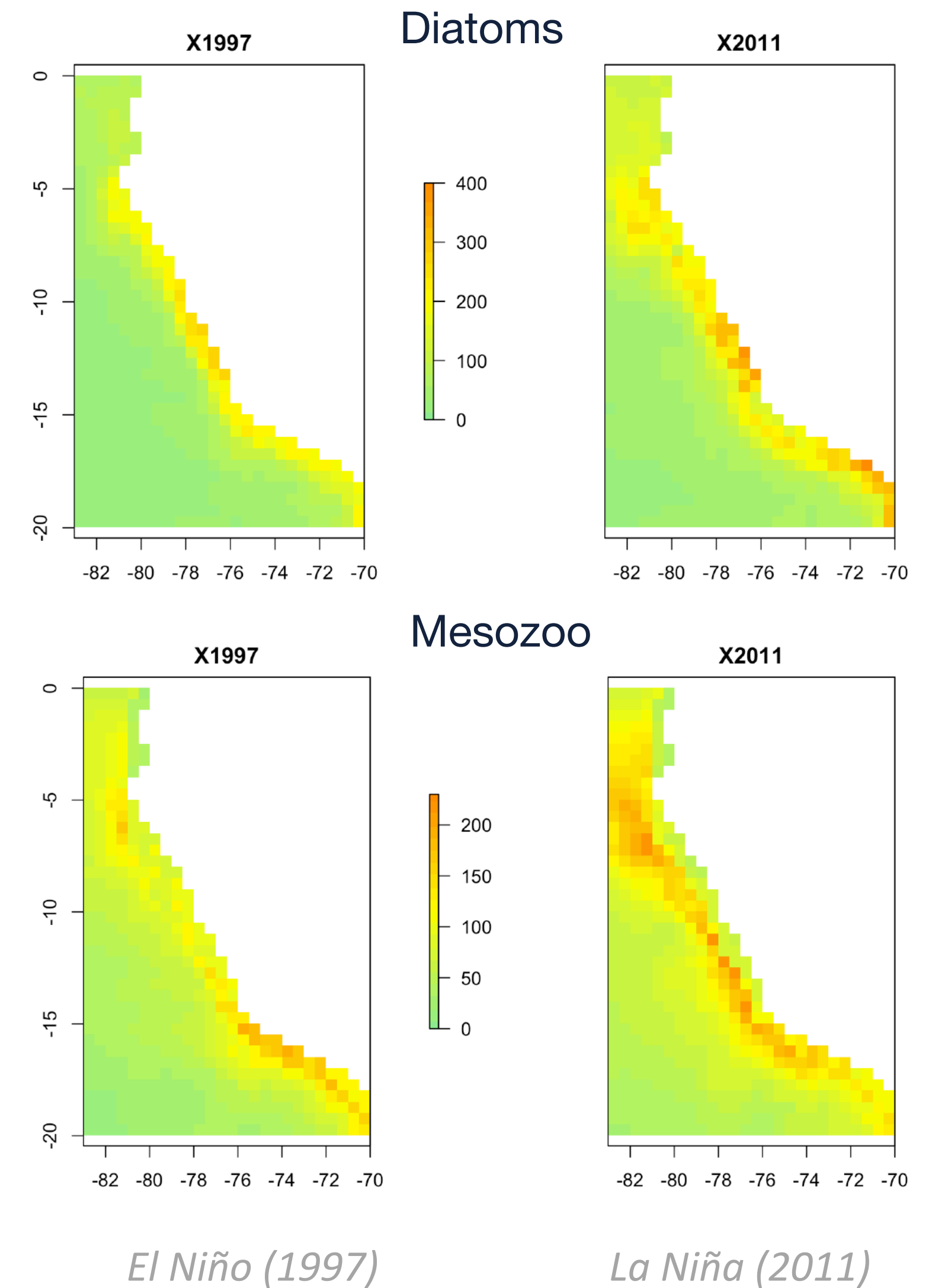
Dante Espinoza, Adolfo Chamorro, Rodrigo Mogollón, Richard Soto



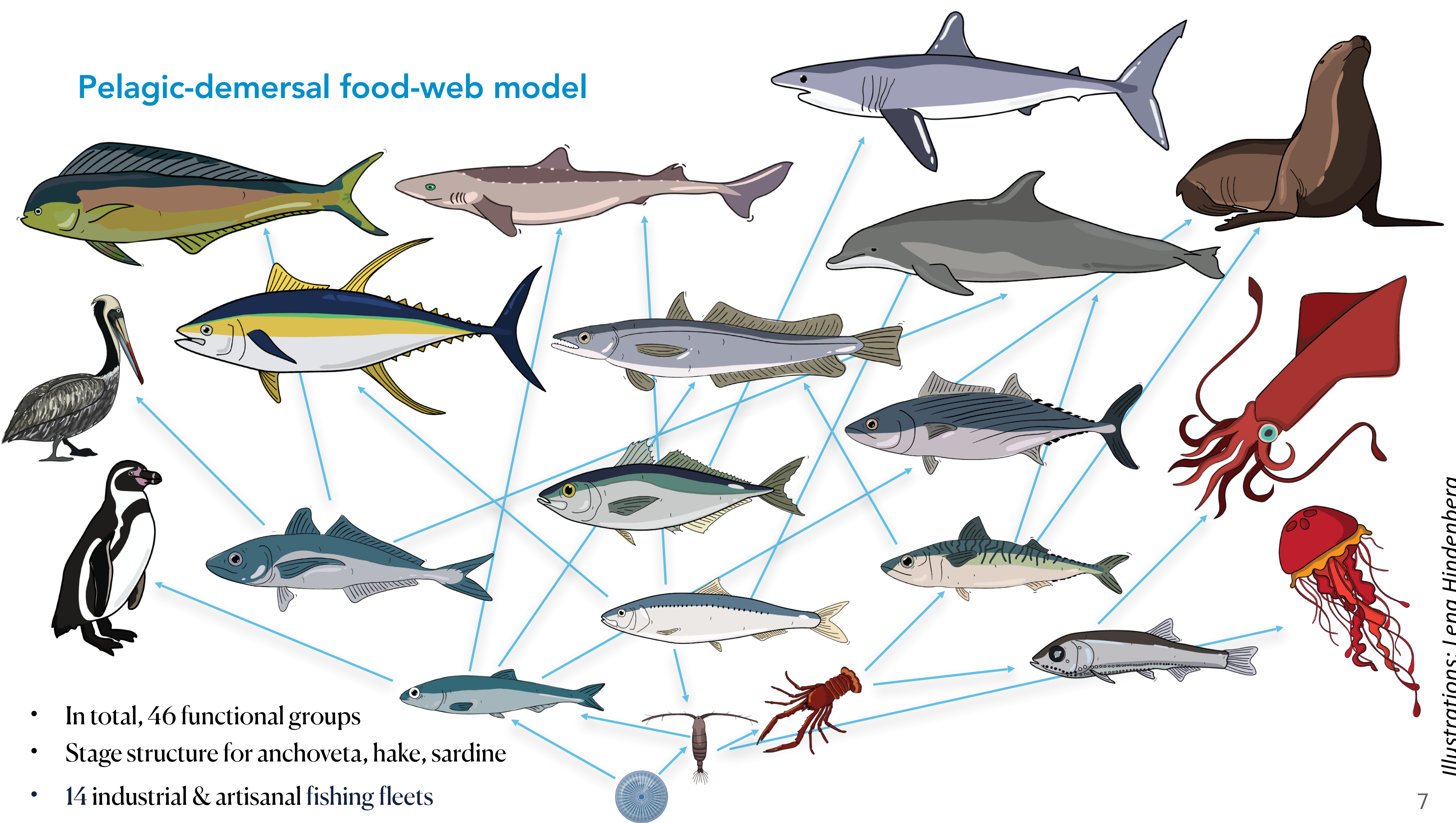
Vincent Echevin, Francois Colas

Planktonic prey for higher food-web

- Larger plankton groups (diatoms and mesozoo) dominate upwelling zone and total biomass, smaller groups more offshore
 - negatively correlated, and with Temp/upwelling (size- and T-dependent nutrient uptake rates in biogeochemical model PISCES)
- Upwelling-driven coastal large plankton vs. offshore small plankton trophic pathways



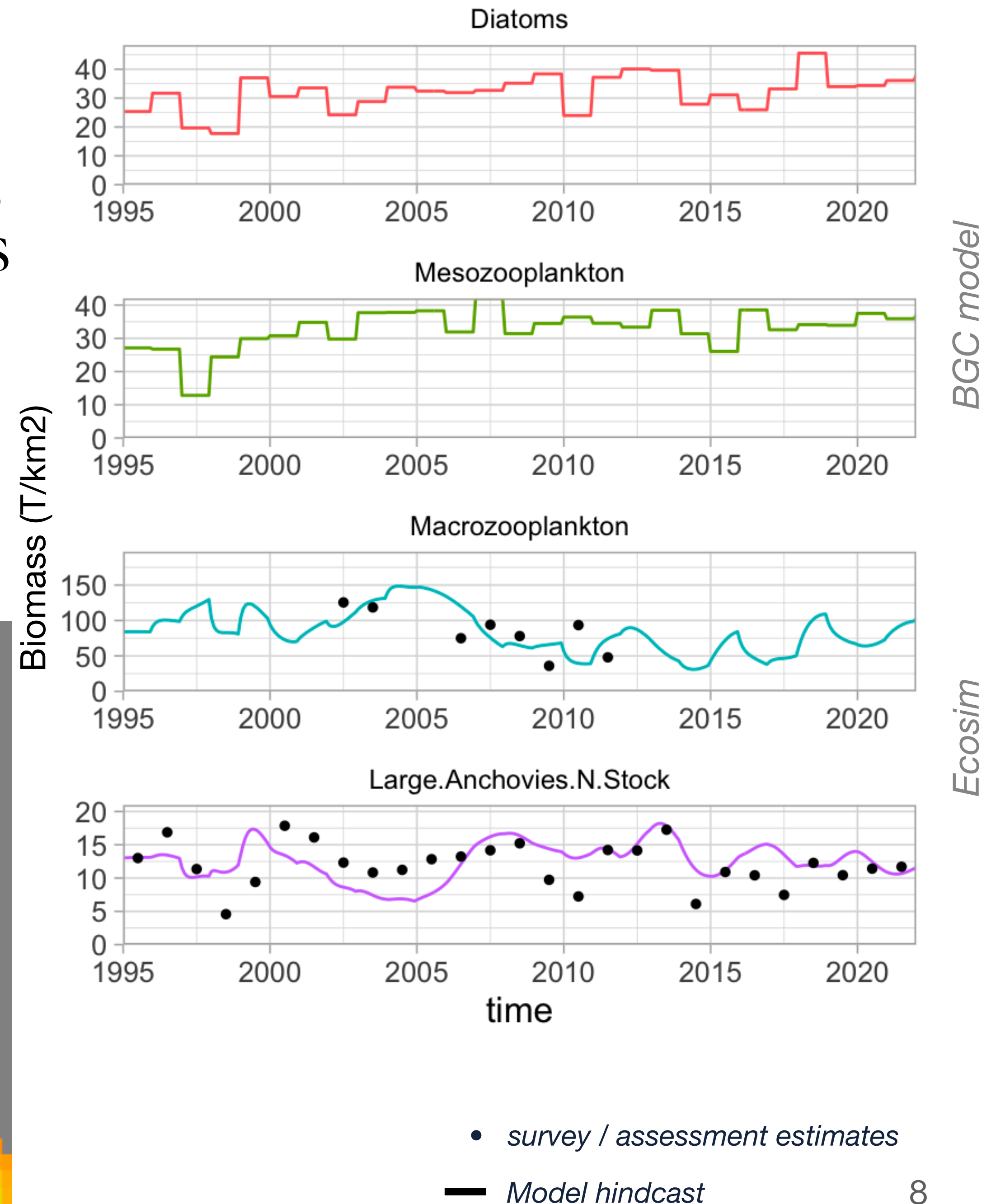
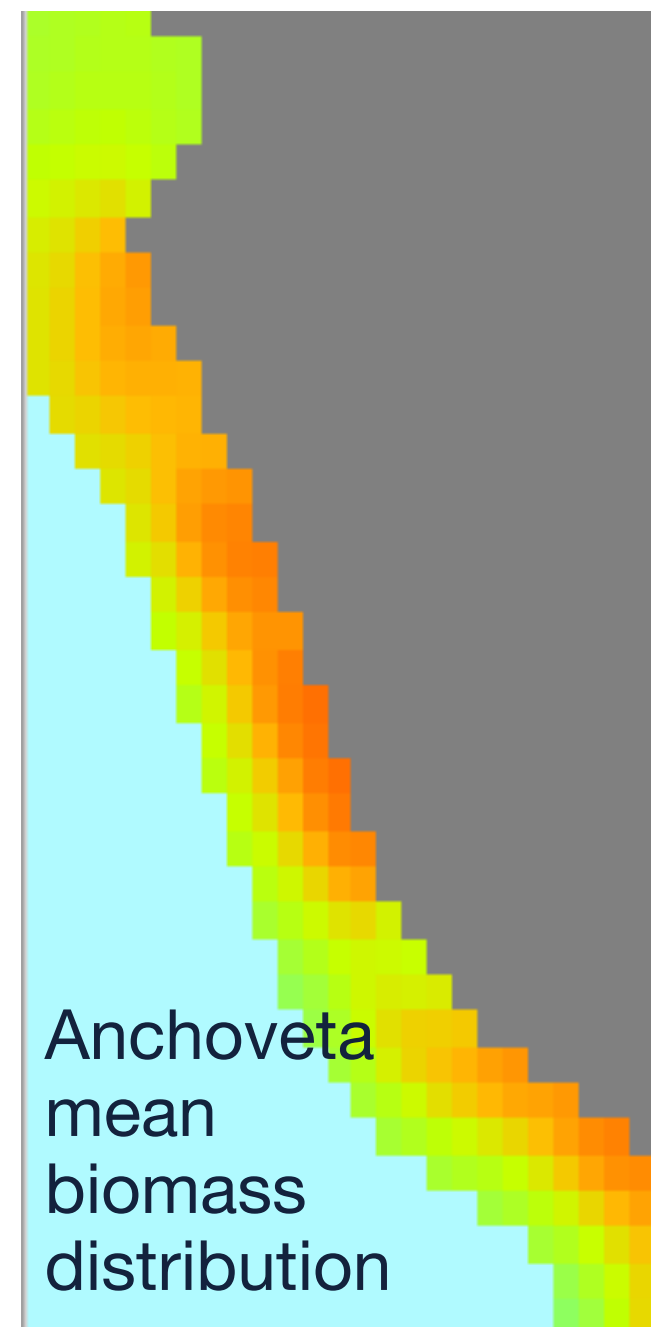
Pelagic-demersal food-web model



- In total, 46 functional groups
- Stage structure for anchoveta, hake, sardine
- 14 industrial & artisanal fishing fleets

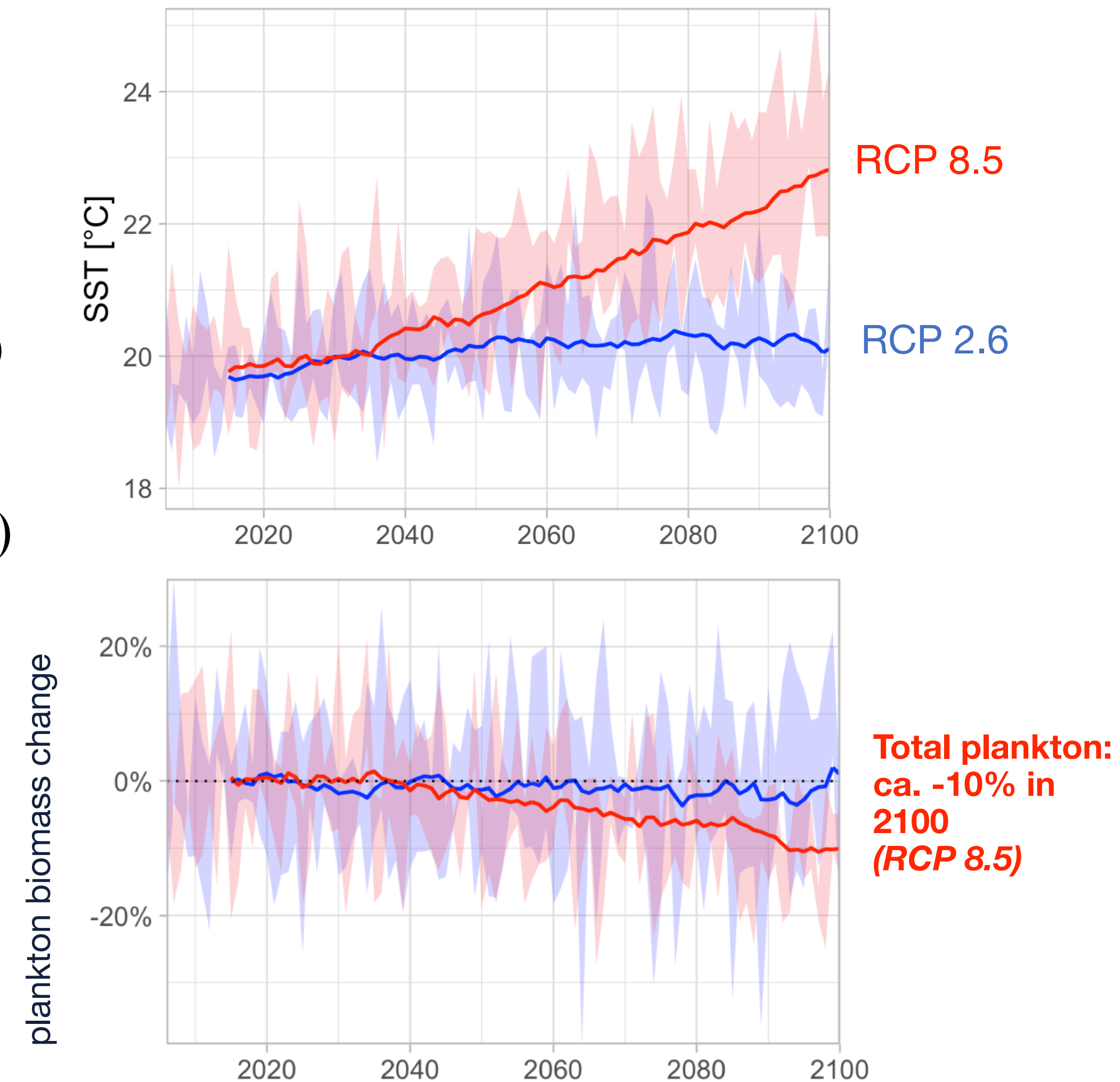
NHC food-web model calibration

- Forcing with temperature, oxycline depth and biomasses of two phytoplankton and two zooplankton groups (CROCO-PISCES hindcast 1993-2022)
- Model fit to survey, stock assessment and landings data (IMARPE)
- Re-creating variability and approx. spatial distribution for most important species
- Recent analyses point to (macr- & meso-) zooplankton being more important for anchoveta diets than previously thought



Climate change projections

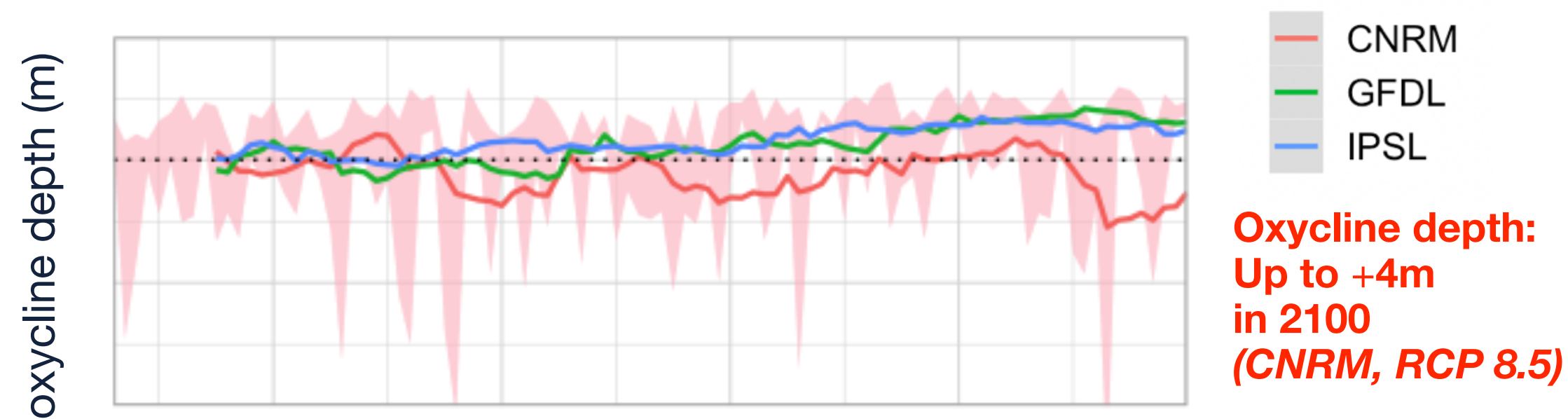
- CROCO-PISCES regionally downscaled projections until 2100, for the Northern Humboldt Current System (1/12°)
- Ocean warming
 - +1.7°C–3.2°C by 2100, under high greenhouse gas emissions (RCP 8.5)
 - +0.3-0.6°C under low emissions (RCP 2.6)
- Plankton productivity decreases (by 10-20% in 2nd half of century) under high emissions for diatoms and mesozooplankton (most important prey for fish)



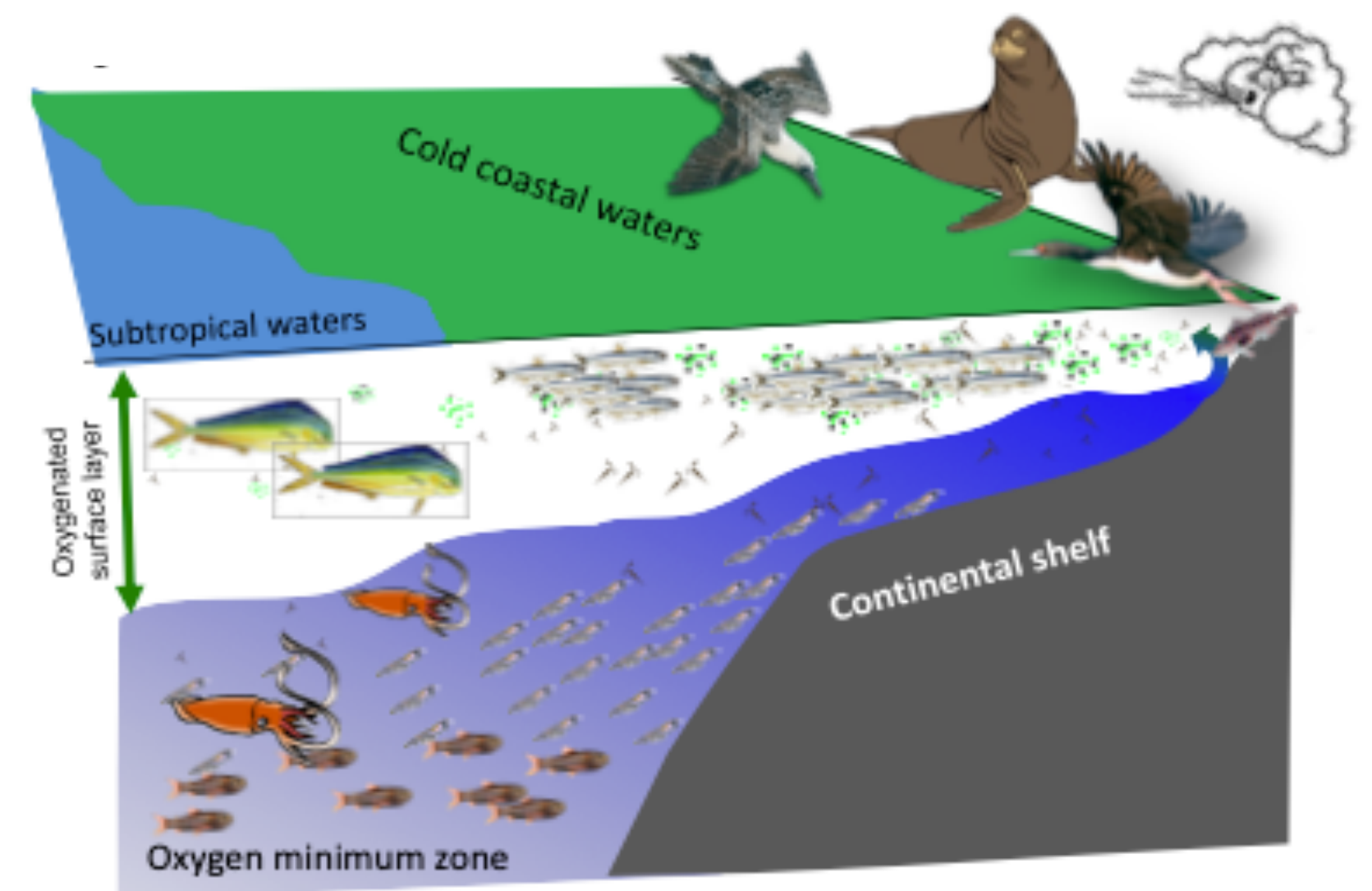
CROCO-PISCES (annual range & 10y mean of 3 ESMs)

Climate change trends in the NHC: oxygen

- Under high emissions, a slight shoaling of the oxycline (in 1-2 of 3 ESMs) by 2100
- Impacts fish habitat, availability to predators and fisheries
- Interannual variability (e.g. El Niño) important
- Deoxygenation is an additional risk associated with high emissions



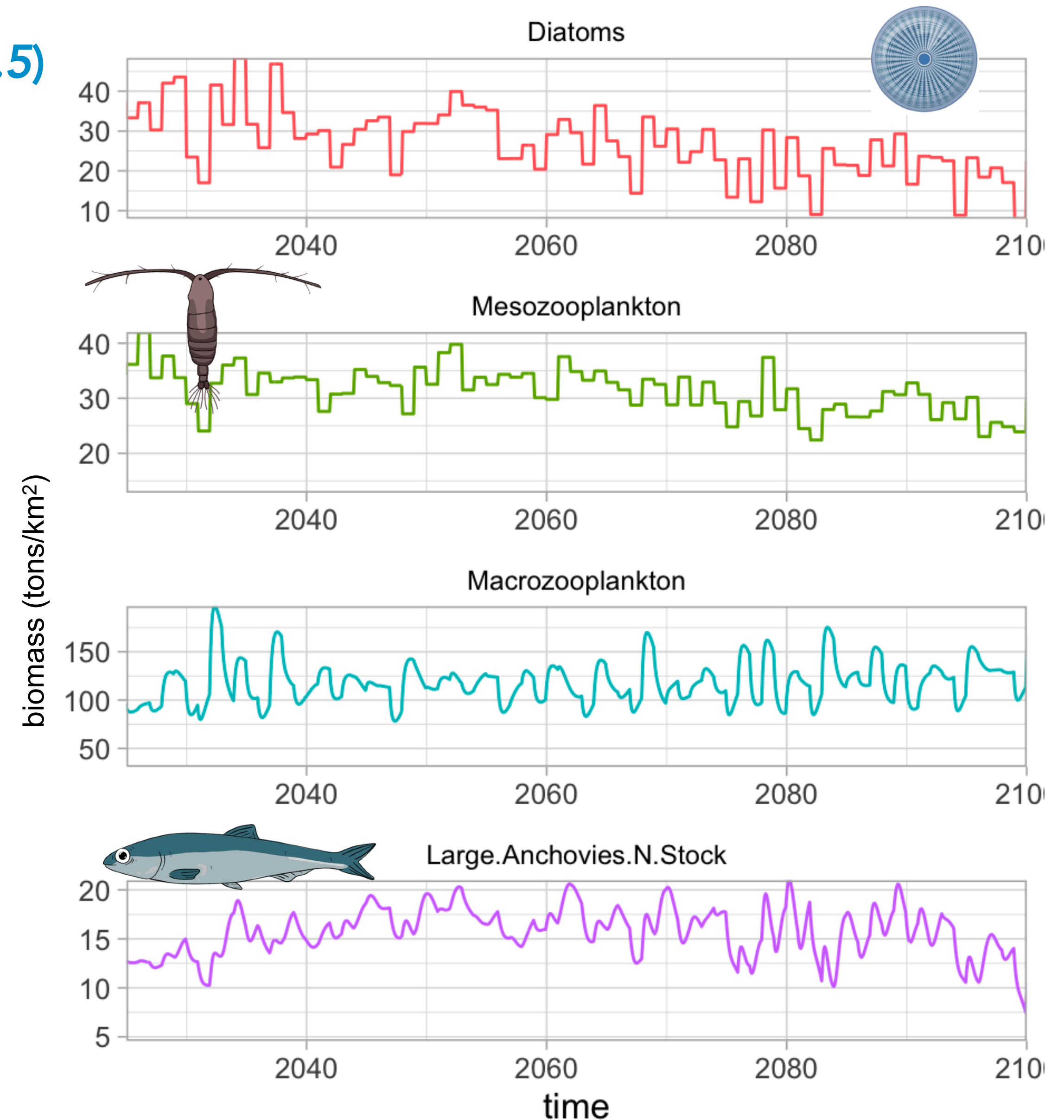
CROCO-PISCES (annual range & 10y smoothed)



Based on Guevara-Carrasco & Bertrand (2017)

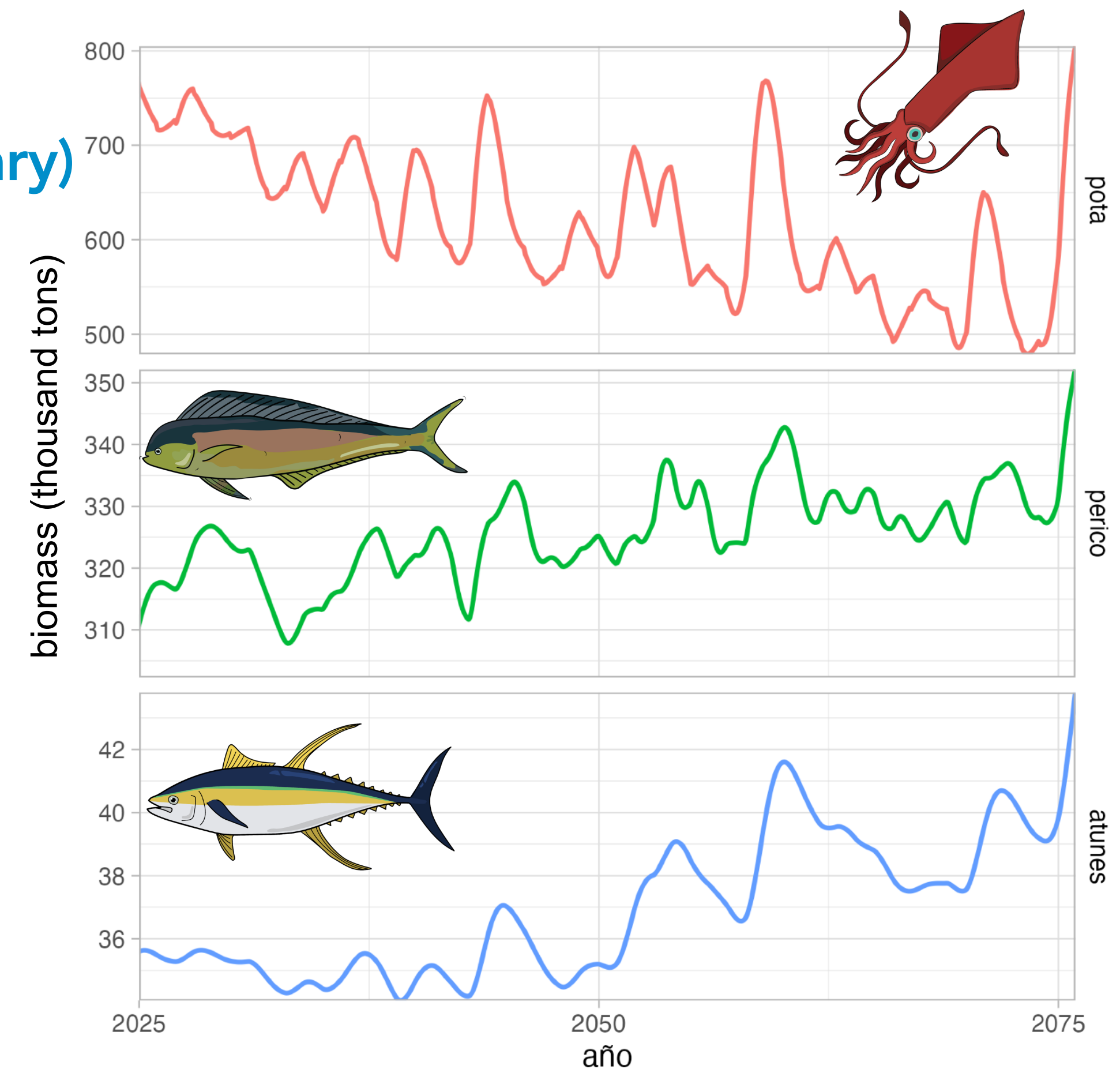
Future biomass projections (preliminary, RCP8.5)

- Decrease in diatom and mesozooplankton biomass
- (Preliminary) indication for buffering of effects rather than amplification in the food-web
- Increase in variability and decreasing trend in anchoveta biomass – combined direct (temp response) & food-web effect (+ increasing availability to predators)
 - Due to decreasing mesozooplankton biomass, declining proportion in anchoveta diet
- Ocean warming causes poleward shifts in species distributions, impacting e.g. small-scale fisheries in the North -> *Ecospace* work in progress



Predator species and stakeholder assessment (preliminary)

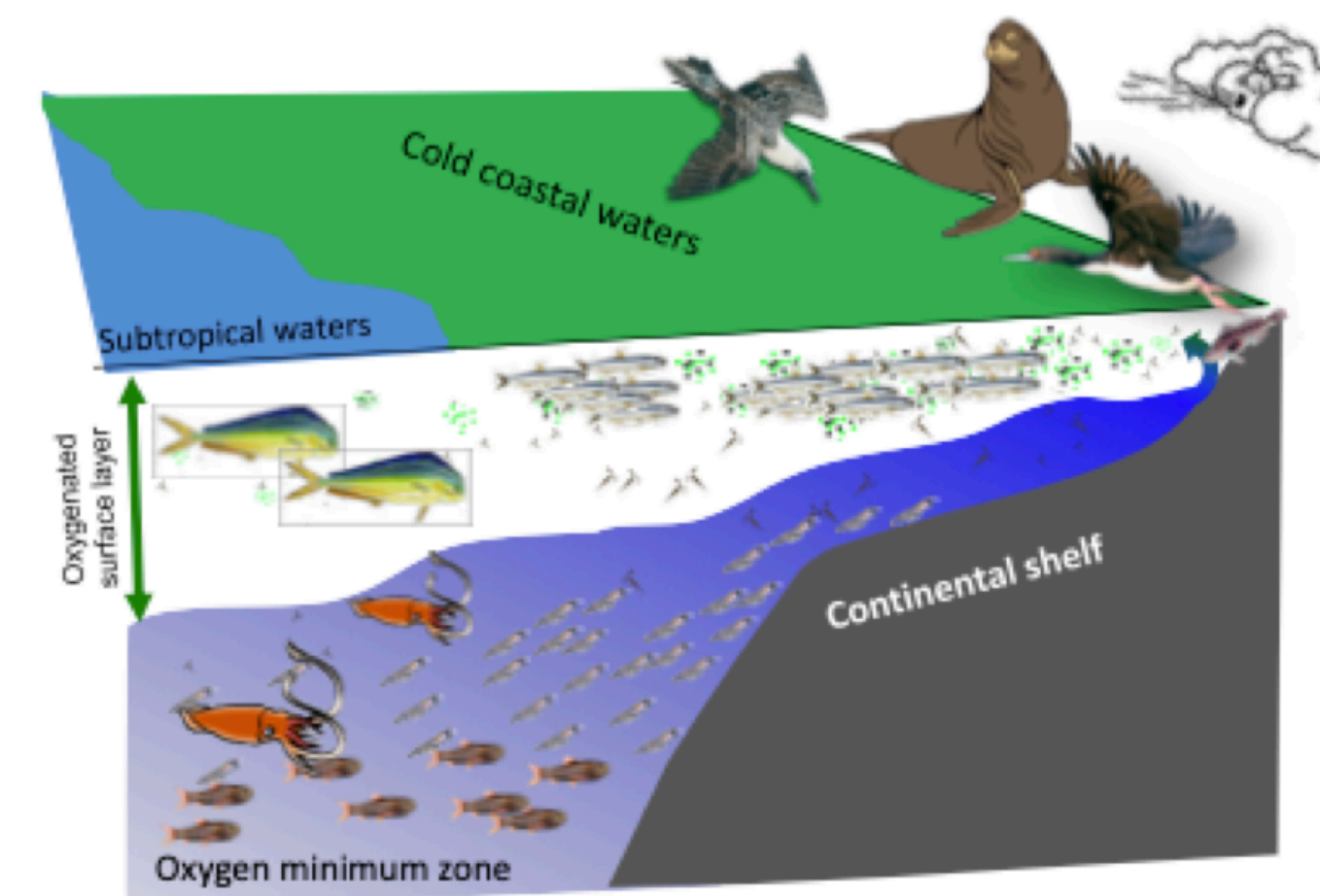
- Co-assessment of model projections together with stakeholders from small-scale fisheries
 - changes in warm-water associated resources (tunas, mahi mahi), decrease in Humboldt squid
- Co-design and co-evaluation of impacts, conflicts, and possible ecosystem-based governance strategies
- Use of regionalized socio-economic scenarios for assessment of adaptation options (sustainability vs. regional rivalry)
 - Combined effects of climate change & fisheries changes
- Shifts in species distributions strongly felt in this transitional area
 - > *Ecospace* work in progress



Piura, Peru, Nov 2025

Conclusions

- Upwelling systems are complex and dynamic ecosystems – food-web models can be coupled to biogeochemical models to simulate their dynamics
- Coupled models can be projected into the future under different downscaled scenarios
 - Clear general warming trend in the NHC, strength depending on greenhouse gas emissions
 - Slight reduction in phytoplankton and zooplankton productivity, deoxygenation an additional risk under high emissions
- Changes in the food-web and fisheries of the NHC will be a combined result of species' environmental tolerances and trophic interactions
 - Reductions in some typical upwelling system species (e.g. anchoveta), and some increases in warm-water species projected
 - Integrating socio-economic scenarios & drivers enables (co-)assessment of ecosystem-based governance strategies



Thank you!



Contributors:

Giovanni Romagnoni, Moritz Stäbler, Alonso del Solar, Hauke Reuter (ZMT), Marc Taylor (Thuenen Institute)

Jorge Tam, Adolfo Chamorro, Dante Espinoza-Morriberón, Rodrigo Mogollón, Richard Soto, Erich Diaz, Hans Jara, Martin Salazar, et al. (IMARPE)

