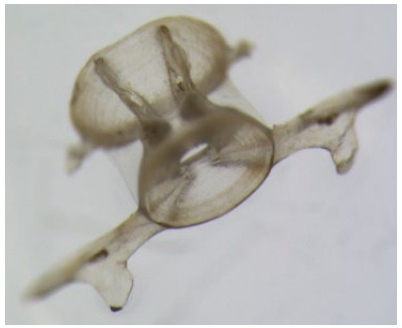
A paleoceanographic perspective on the future of fish productivity in the Humboldt Current system

Renato Salvatteci, Arnaud Bertrand,
Dimitri Gutierrez, David Field



Kiel University CAU

Center for Ocean and Society

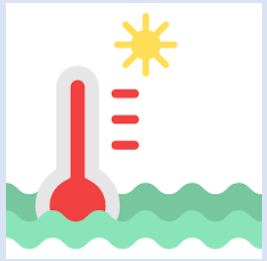
Lisbon, SPF Symposium - November, 2022

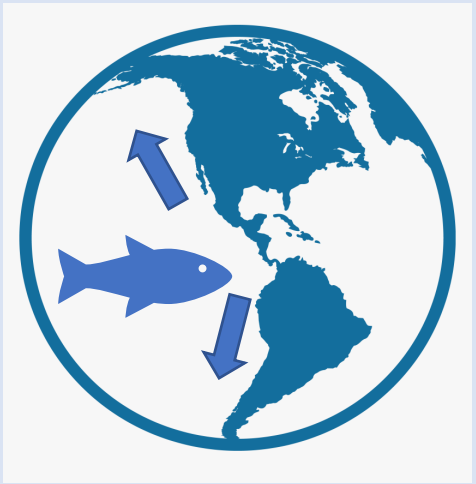
Overarching question - Motivation

What is the response of fish populations in terms of abundance, distribution and diversity to climate change?

- Climate change will affect fish and their habitats
- Warmer temperatures will influence the abundance, migratory patterns and mortality rates of wild fish stocks

The oceans are warming: Change in distribution of some species





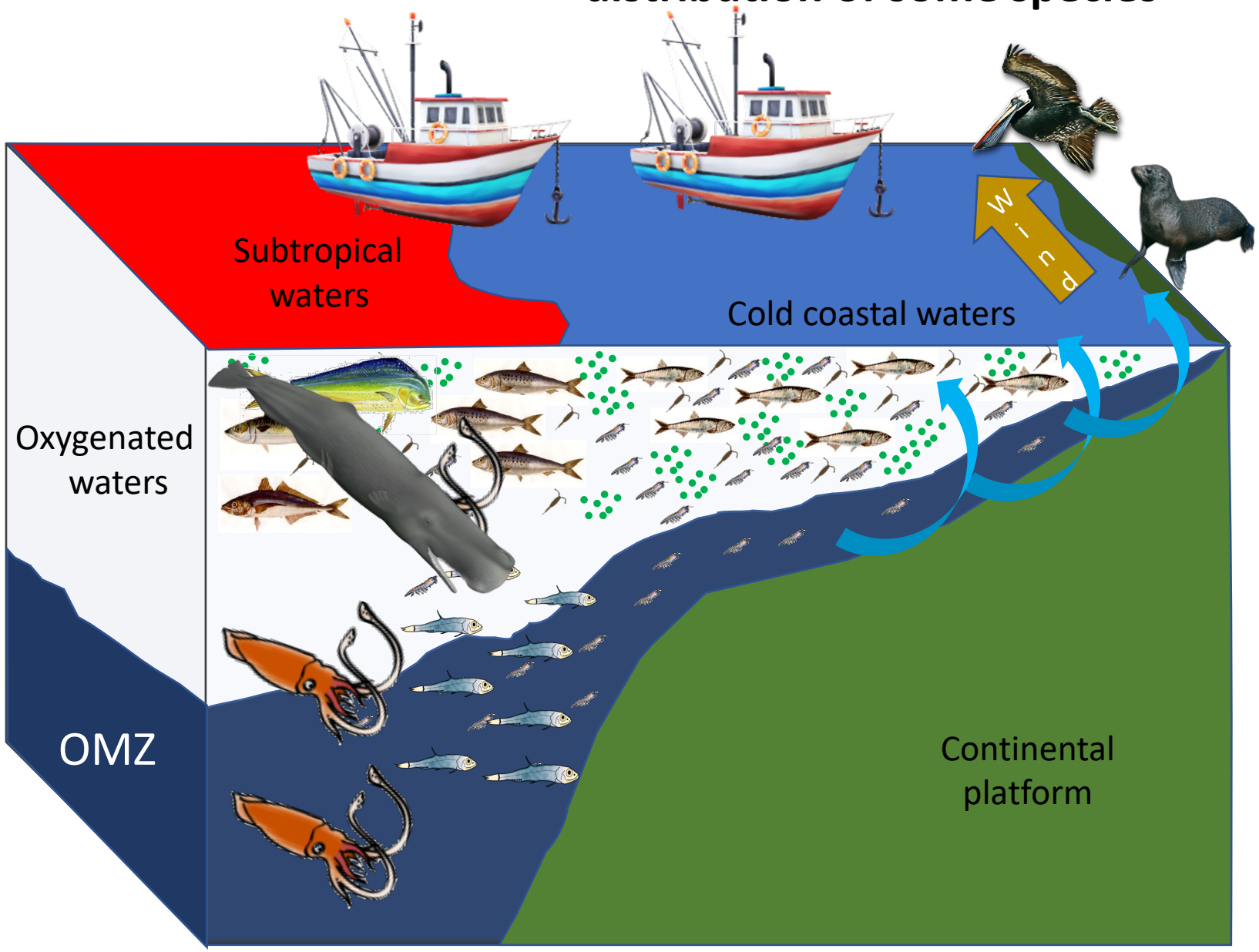
Oceans are losing oxygen: Habitat compression for most species

Why fish and fisheries?

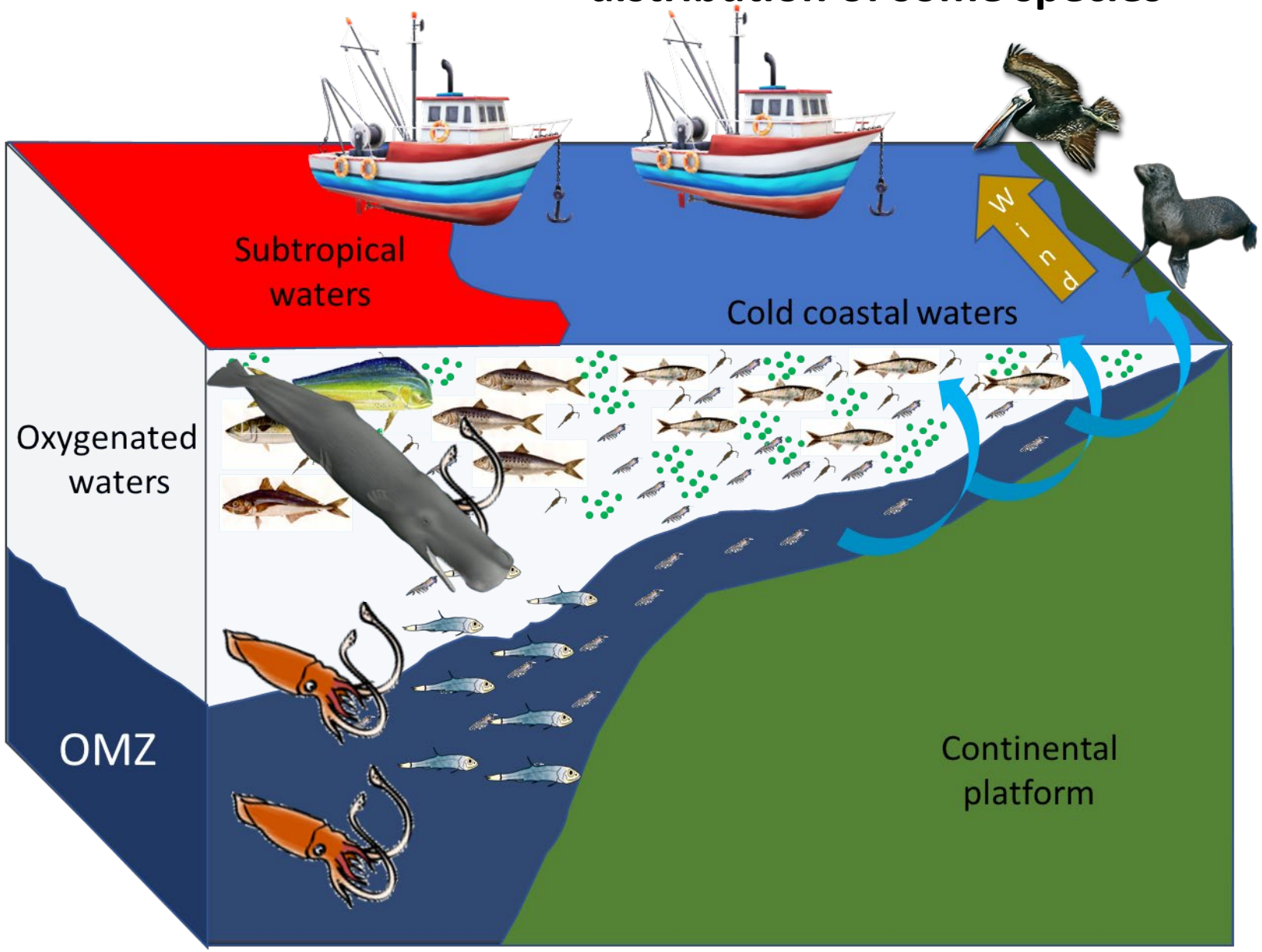
Food security and nutrition, specifically in developing countries (In Peru could be better!)

Provide income and livelihood for 12% of the world's population, Peru 100 000 direct jobs

Distribution of the main actors in the Humboldt Current: oxygen plays a major role in the distribution of some species



Distribution of the main actors in the Humboldt Current: oxygen plays a major role in the distribution of some species

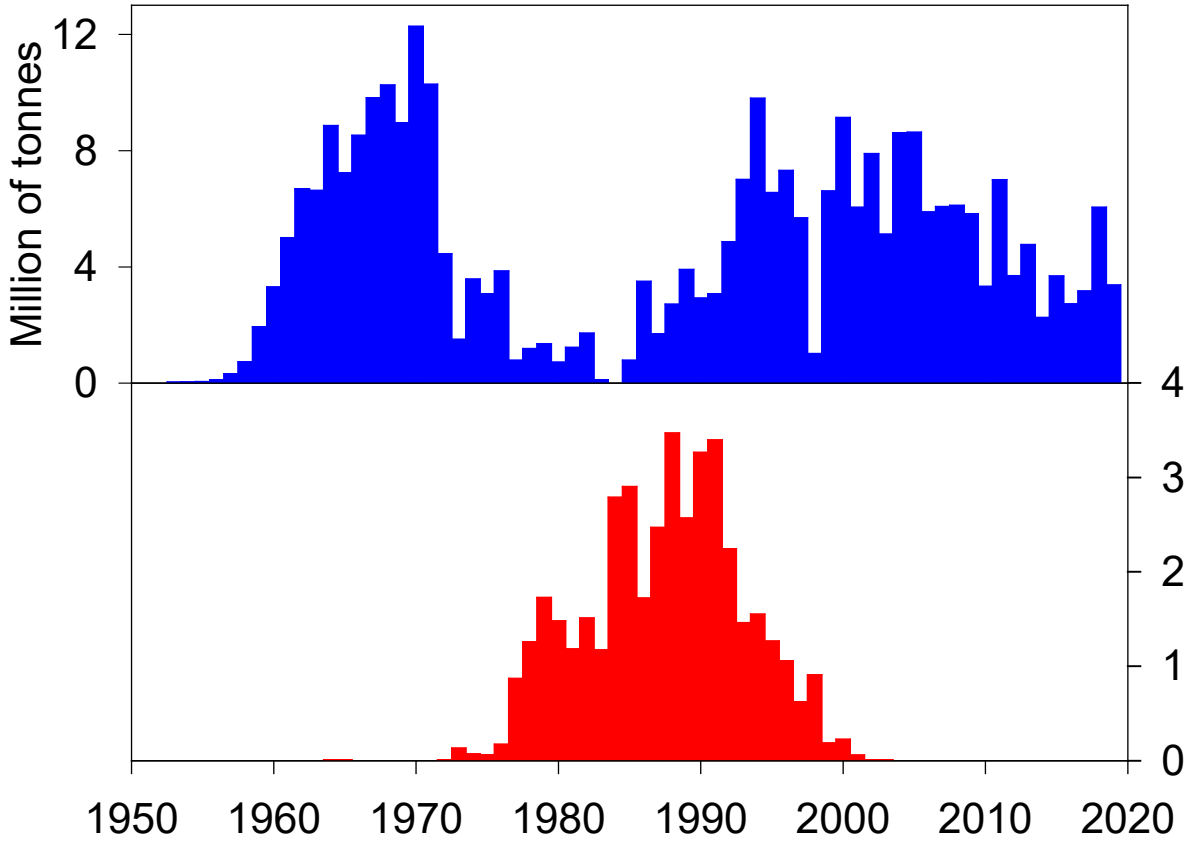


- Largest monospecific fishery in the world (anchovy)
- Anchovy used for fish meal and fish oil production (export)
- Peru produces up to 35% of worldwide fish meal production
- Most of the fish > 90% is exported (both direct and indirect human consumption)
- HCS Important for food security
- **What happens in Peru has local and global impacts**

Regime shifts in the Humboldt Current System – Is PDO a driver?

Anchovy

Sardine



Regime shifts in the Humboldt Current System – Is PDO a driver?

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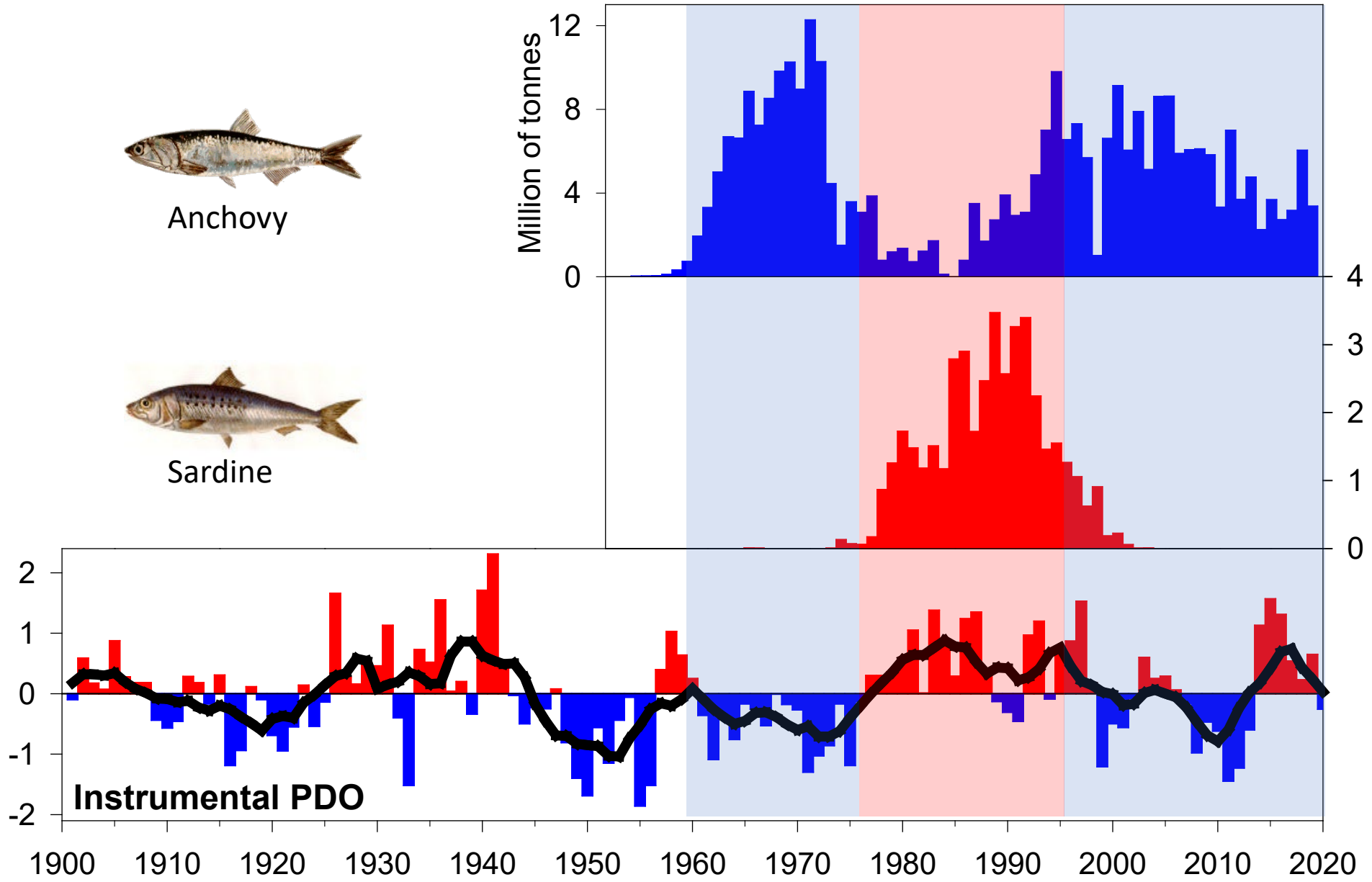
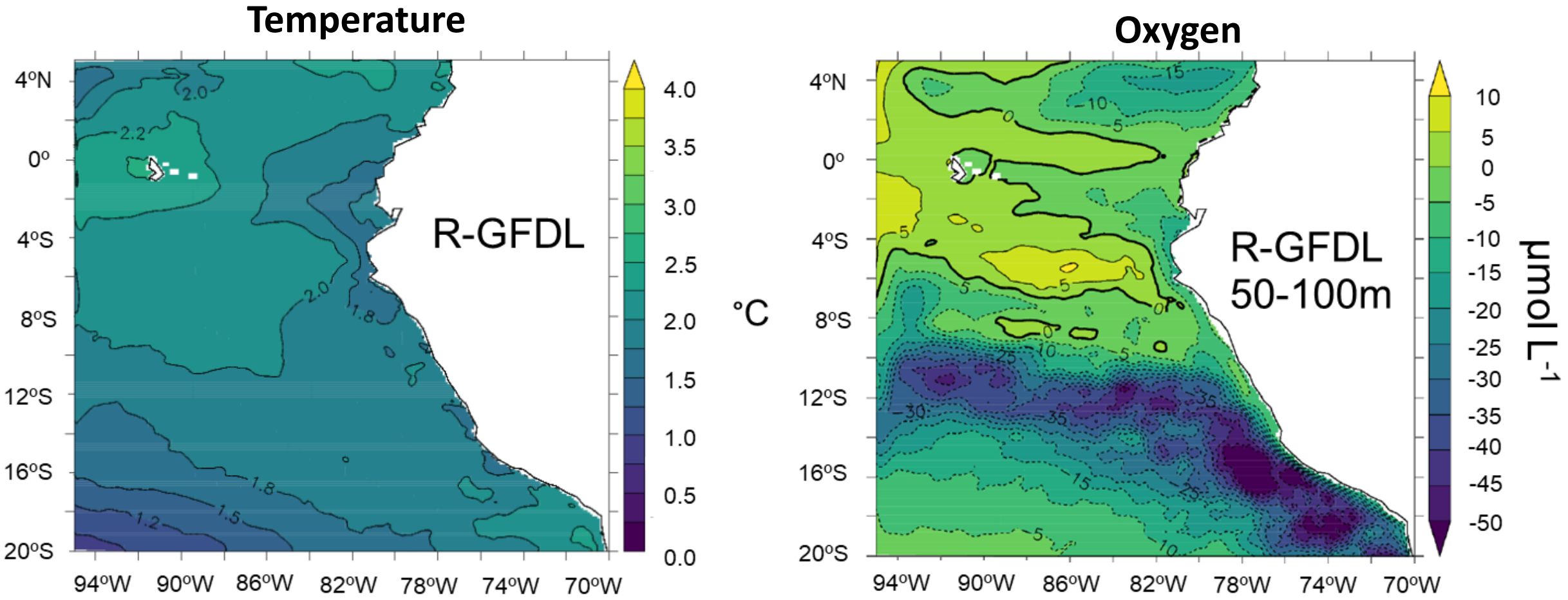


Model projections using high emissions scenarios suggest that by the end of the 21st century the Humboldt Current will be warmer and less oxygenated than has been in modern times



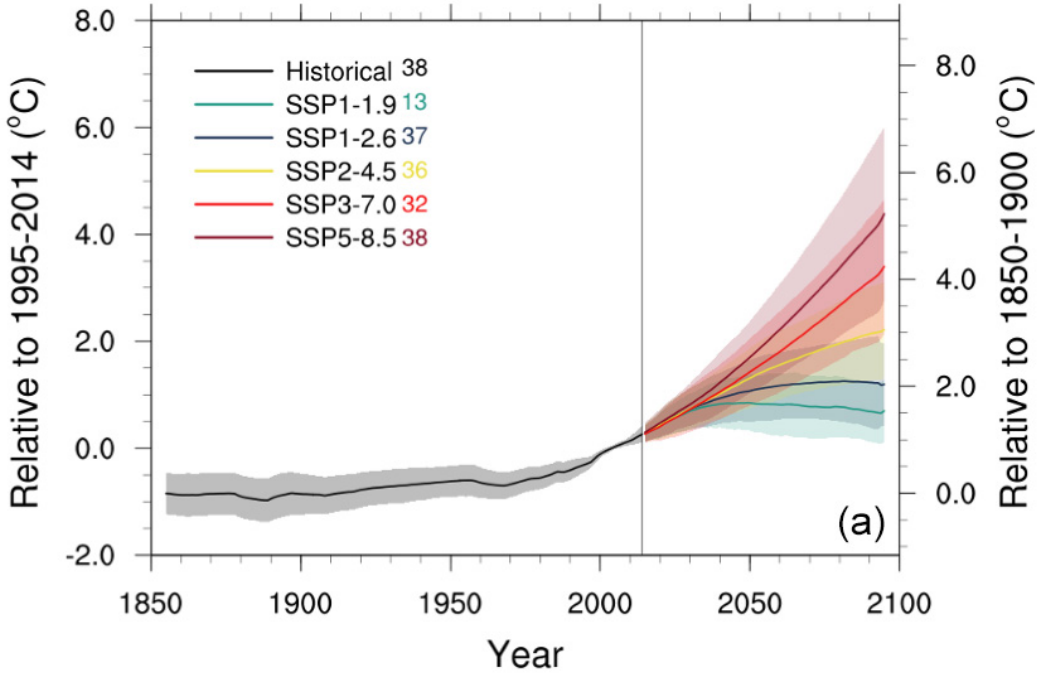
Salvatteci et al. (2022, Science)

How these environmental conditions will affect the abundance and the fish community composition in the HCS?

Approaches: Modelling - Paleoceanography

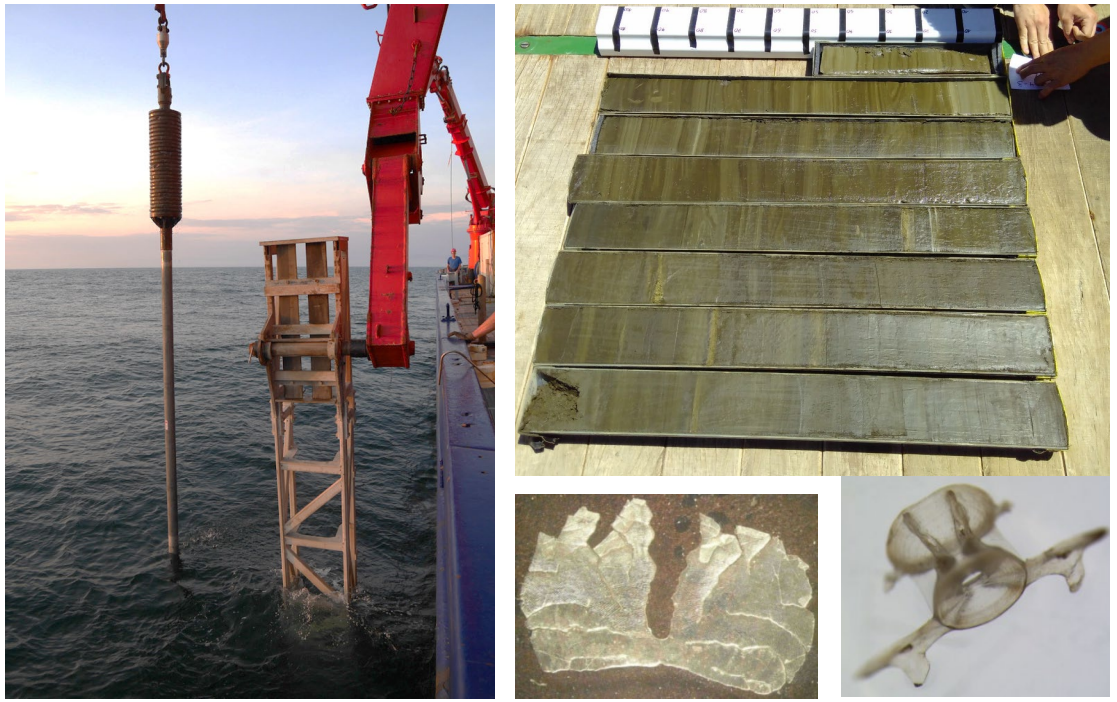
- Model assumptions are based on observations of the interactions between climate and living resources during the last decades

- The limitation is remarkable given that future impacts of global warming will by far exceed those observed during the last decades



- Paleoceanographic approach i.e. study the history of the ocean in the geologic past

- We reconstruct ocean conditions and fish population variability in the geological past, and deduce potential scenarios for the near future

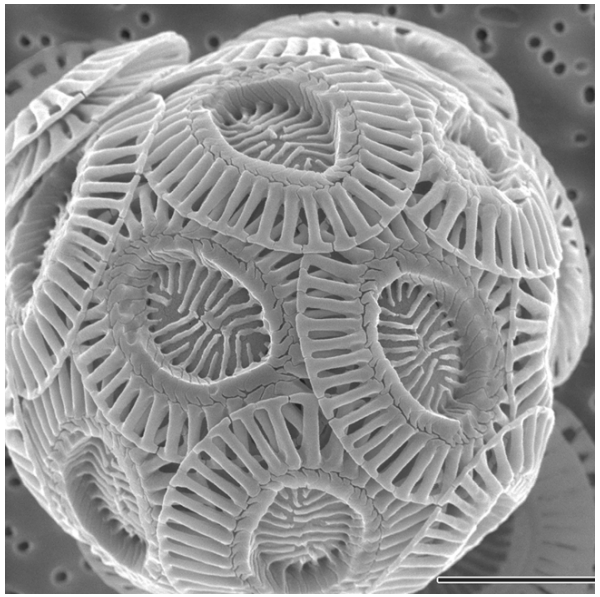


The response of fish populations to time periods warmer than present can give insights on the future of fish productivity

Paleoceanographic proxies

Temperature proxies
Biomarker

Alkenone
group of long-chained organic molecules produced by haptophyte algae



https://www.eumetsat.int/big-blooms-coccolithophores-along-uk-south-coast

Proxy for water column N_2-loss processes

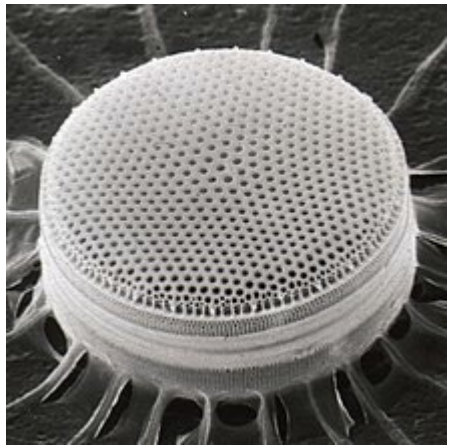
$\delta^{15}N$ bulk organic matter

Sediment redox condition

Mo, Re, U

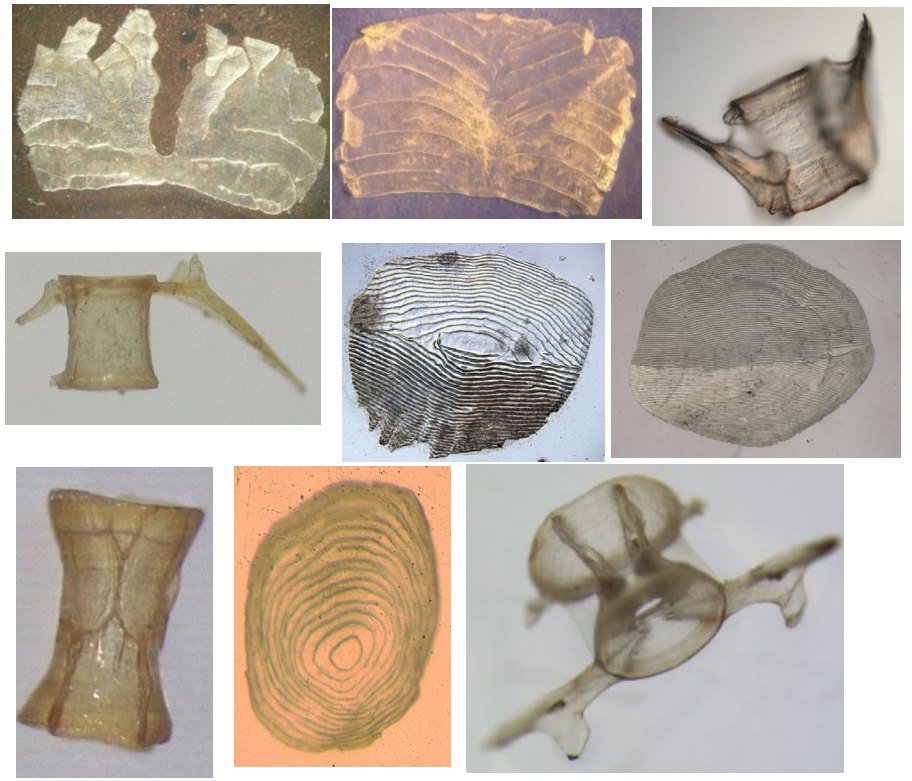
Primary producers

Diatom community composition



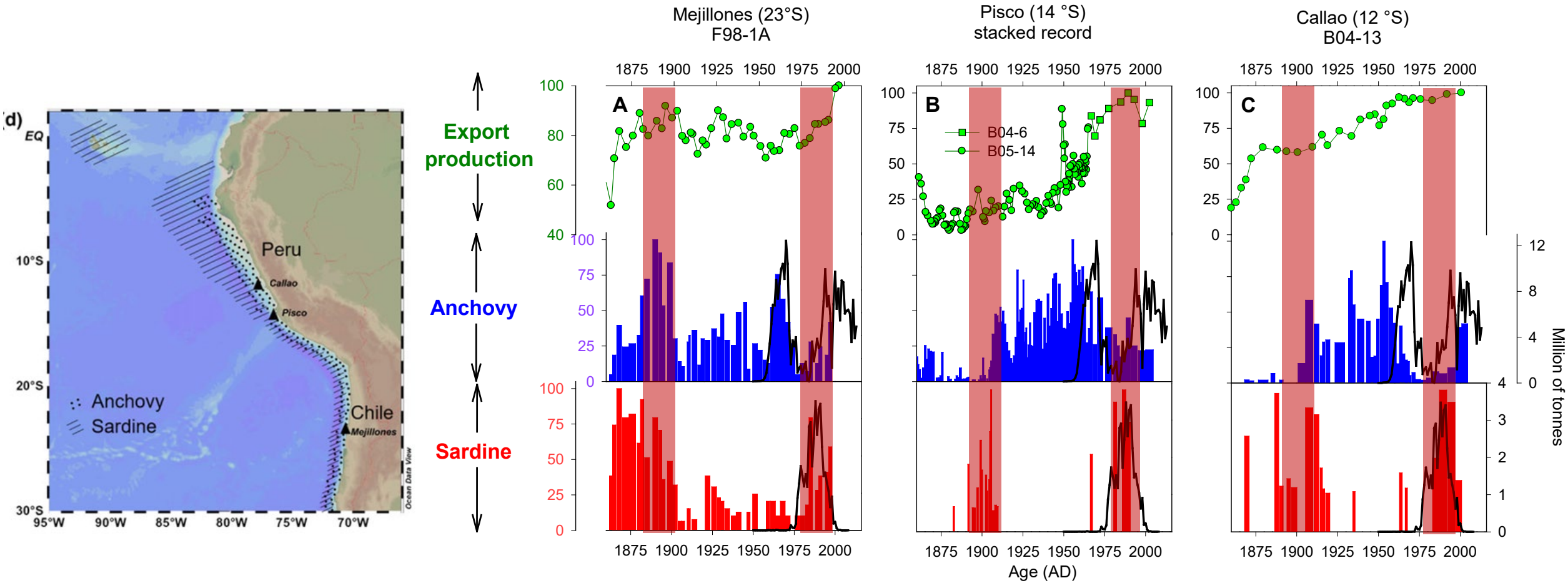
Fish debris accumulating in marine-laminated sediments provide long-term records of population variability

Fish debris (scales and vertebrae)



Salvatteci et al. (2012 Paleobiology, 2018 Global change biology, 2019 Progress in Oceanography)

Paleoceanographic reconstructions of export production and fish productivity along the Humboldt Current System, last 150 years

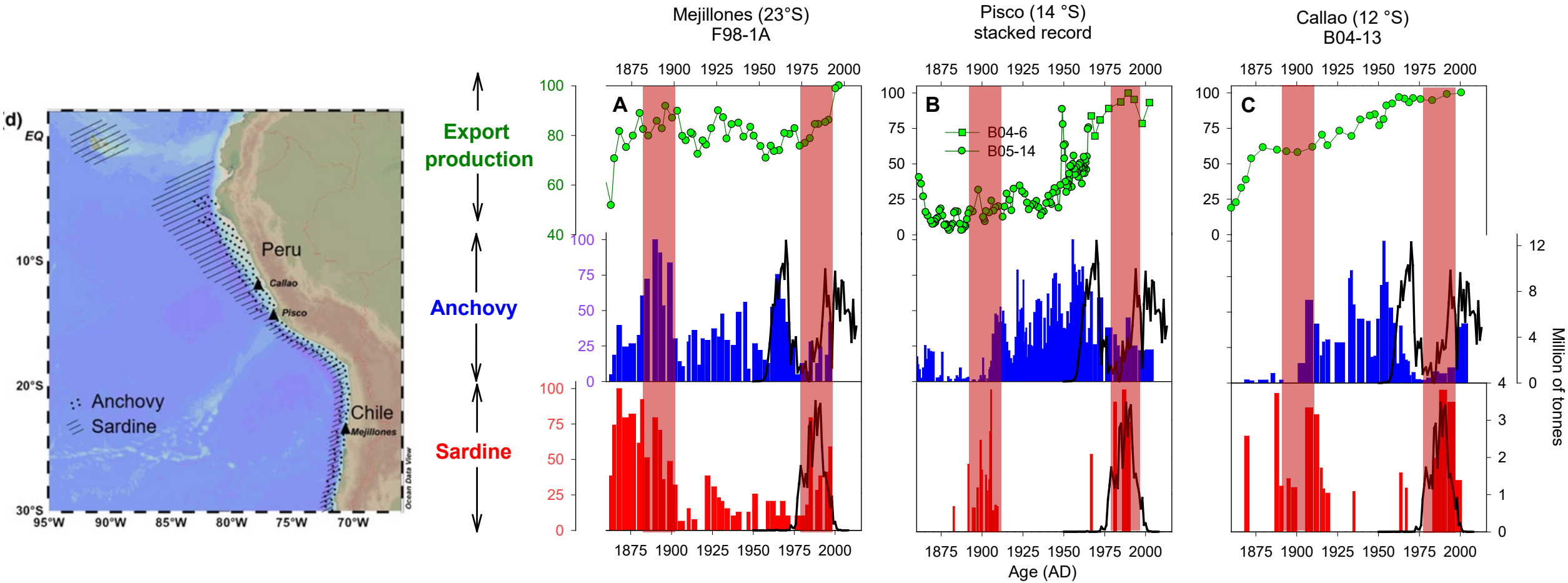


The records show two anchovy and two sardine regimes

Multiple combinations of anchovy and sardine abundances are apparent in the HCS at decadal to multidecadal time scales, rather than simple alternations

Salvatteci et al. (2018, GCB)

Paleoceanographic reconstructions of export production and fish productivity along the Humboldt Current System, last 150 years



The duration of the anchovy and sardine regimes display irregular lengths of time

Salvatteci et al. (2018, GCB)

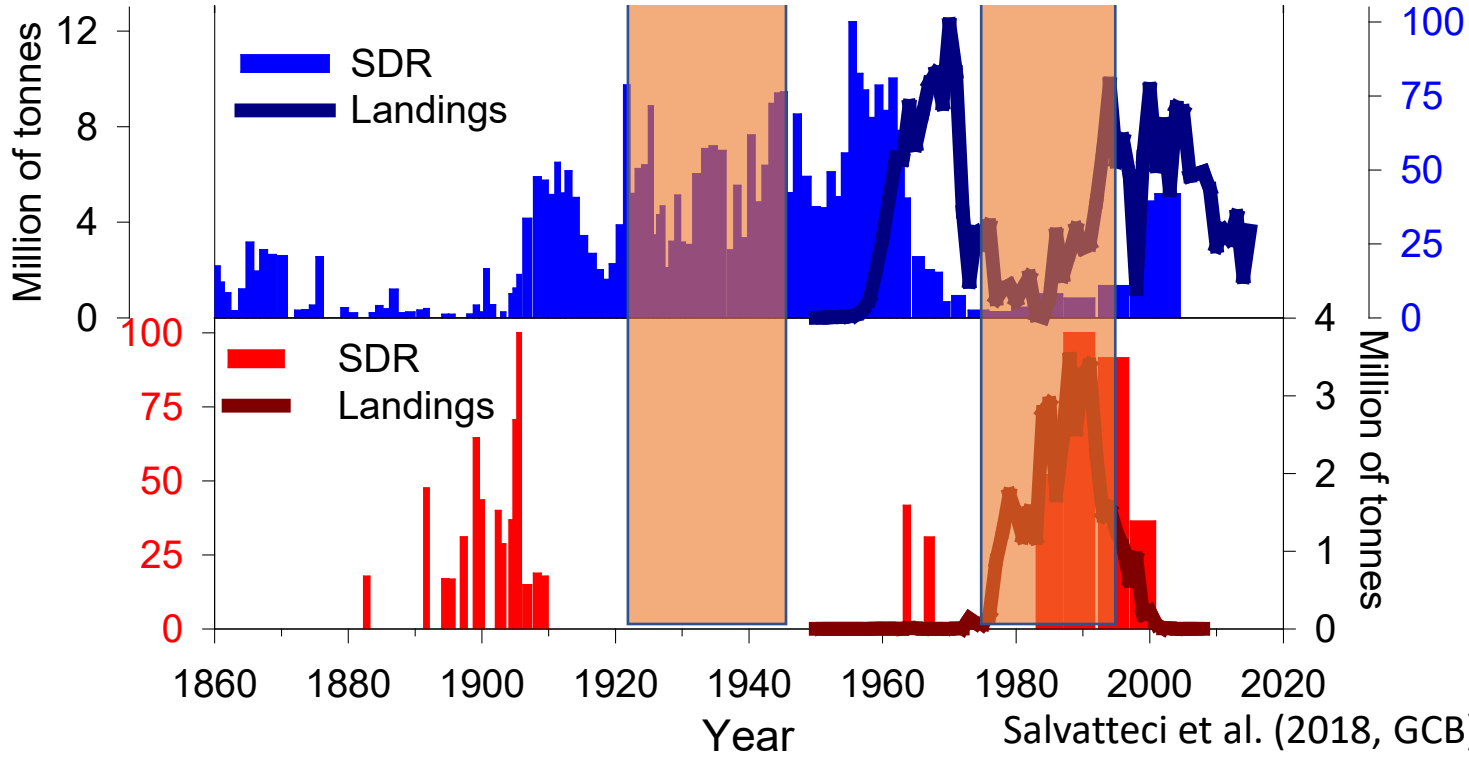
Anchovy and sardine population variability during the last 150 years

- No clear relationship with PDO
- No periodicity detected

Anchovy

Sardine

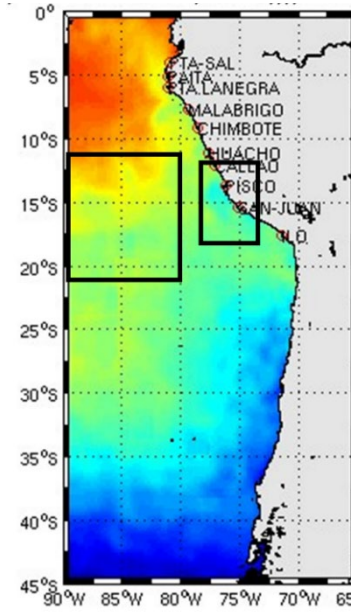
Fish abundance



Salvatteci et al. (2018, GCB)

Regional dynamics are strongly associated with anchovy-sardine fluctuations

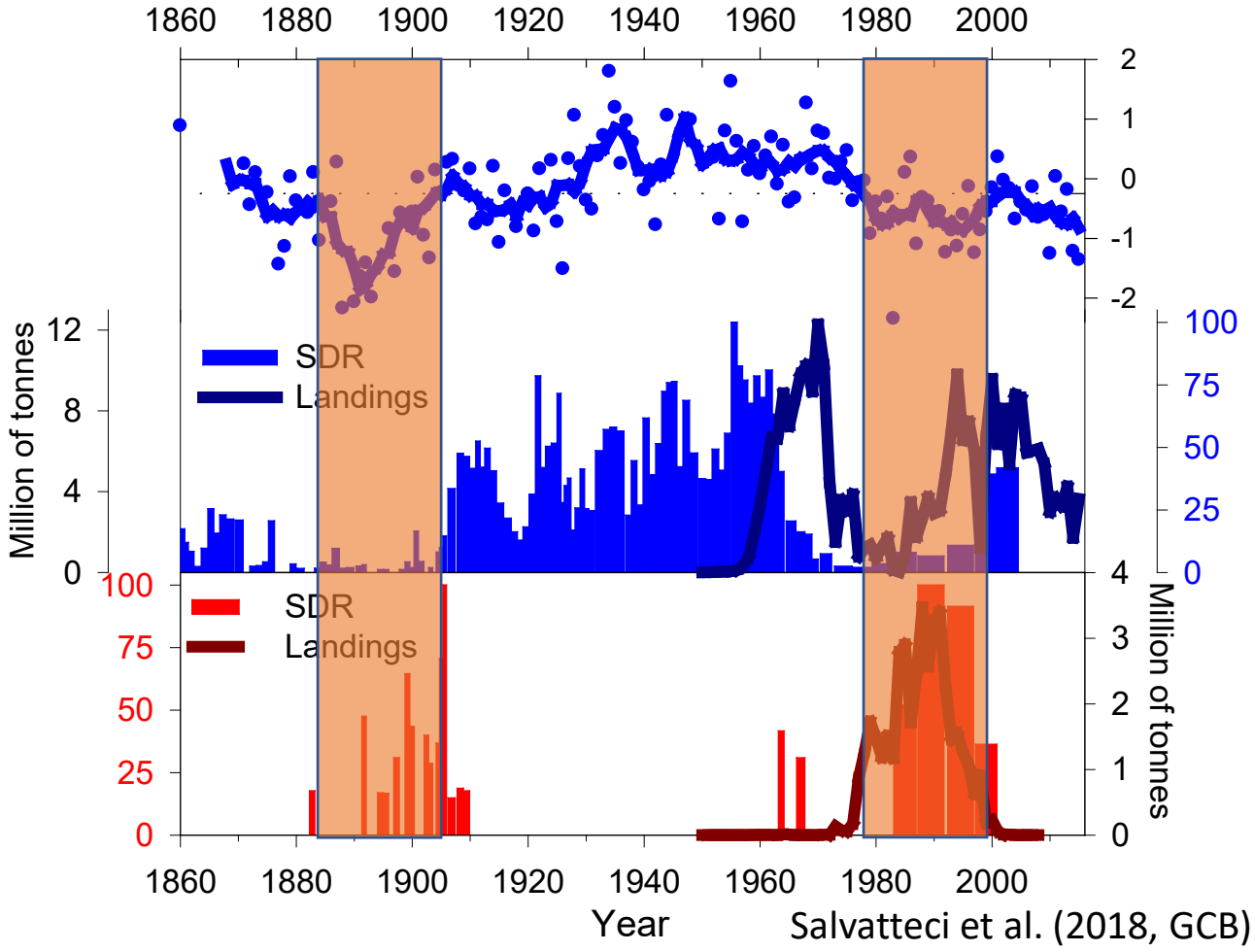
Weaker gradient (suggesting weaker upwelling) associated with sardine
Stronger gradient (suggesting stronger upwelling) associated with anchovy
Changes in upwelling intensity modify the 3-D habitat (thermocline, size of food)



ICOADS data base

Cross-shore SST gradient

Fish abundance



Salvatteci et al. (2018, GCB)

Multidecadal scale variability and trends in the HCS during the last 150 years: *Bottom-up process: From upwelling to guano birds*

UPWELLING

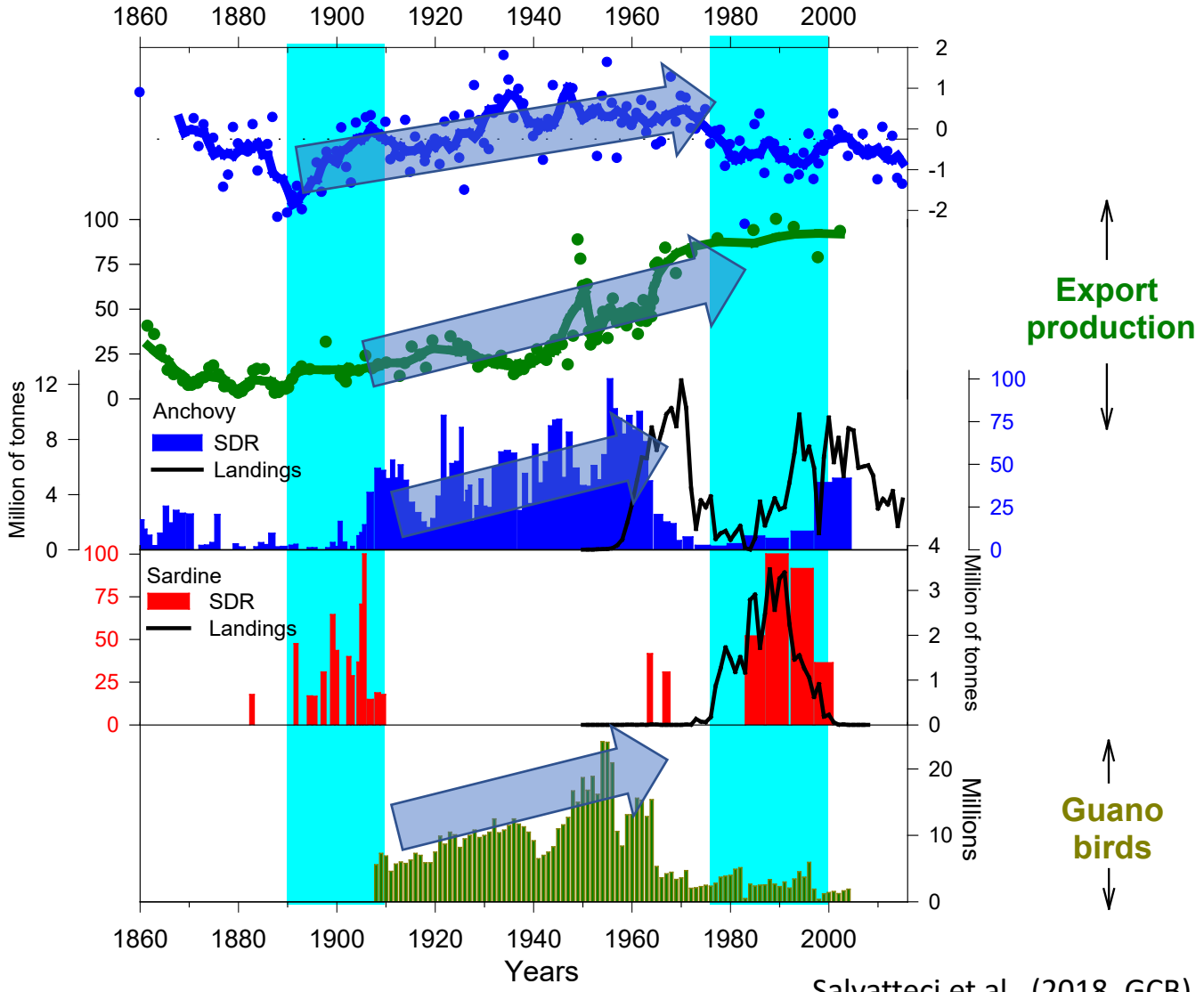
Anchovy

Sardine

Peruvian booby

Cross-shore SST gradient

Fish abundance

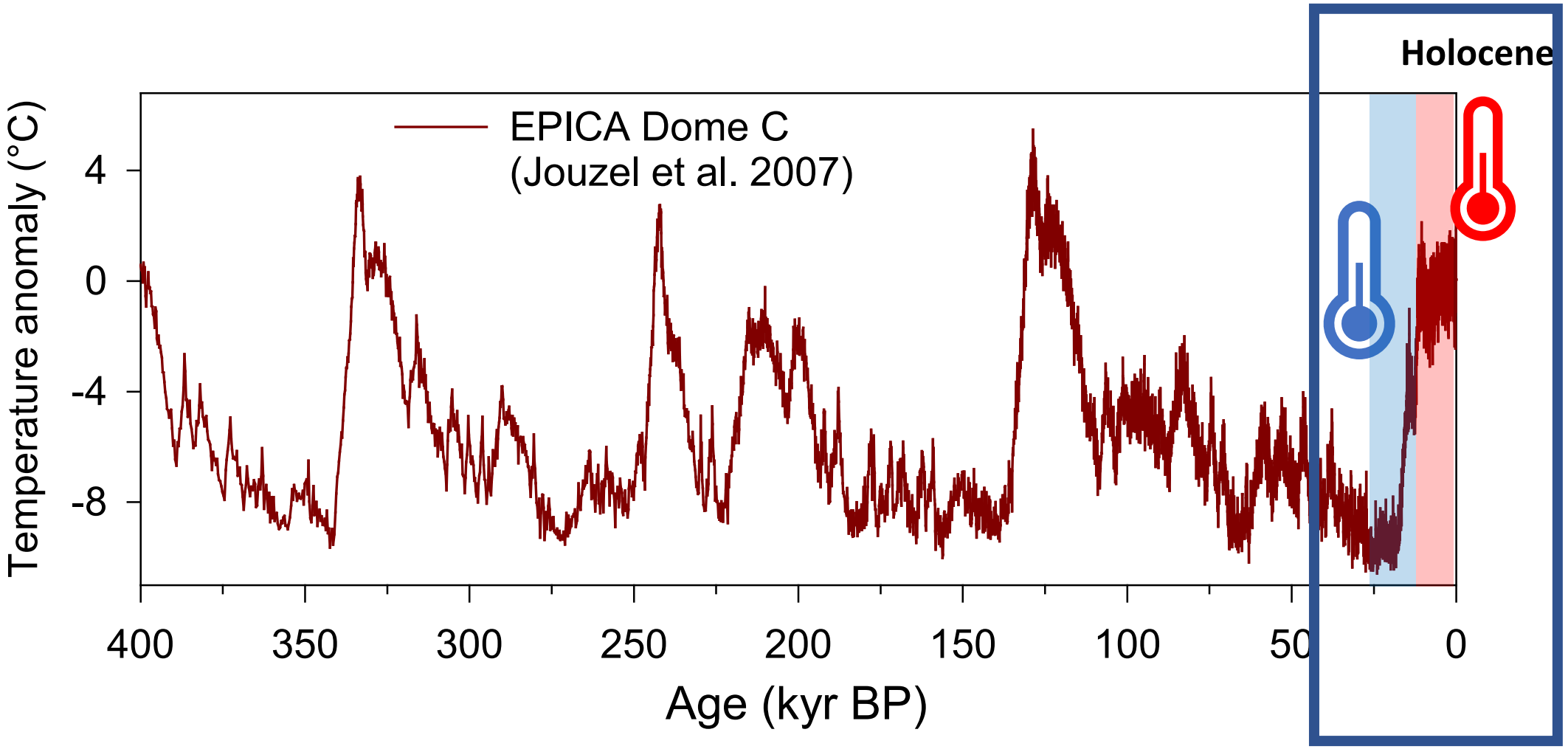


Export production

Guano birds

Salvatteci et al. (2018, GCB)

Fishery-independent data from sediment records offer the opportunity to better understand the preferred environmental conditions for a variety of fish species



Antarctica Dome C ice core, temperature estimates

Centennial to millennial-scale changes in fish populations during the last 25 kyr

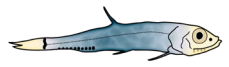
Water column denitrification

Export production

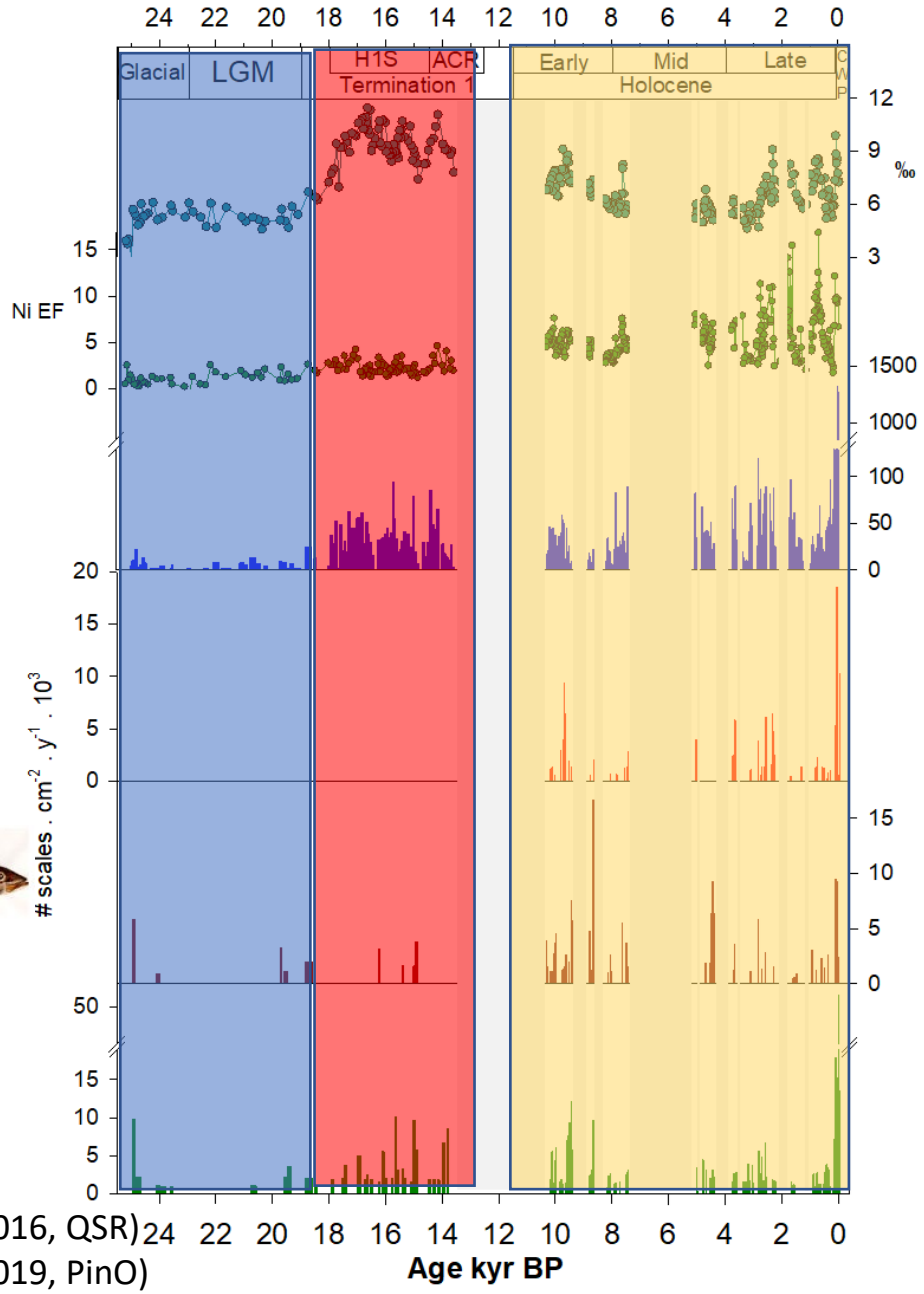
Anchovy

Sardine

Jack mackerel



Mesopelagic fishes



Salvatteci et al. (2016, QSR)
Salvatteci et al. (2019, PinO)

Last Glacial Maximum

Very cold world
Oxygenated Waters
Low productiviy
Low abundance of fishes

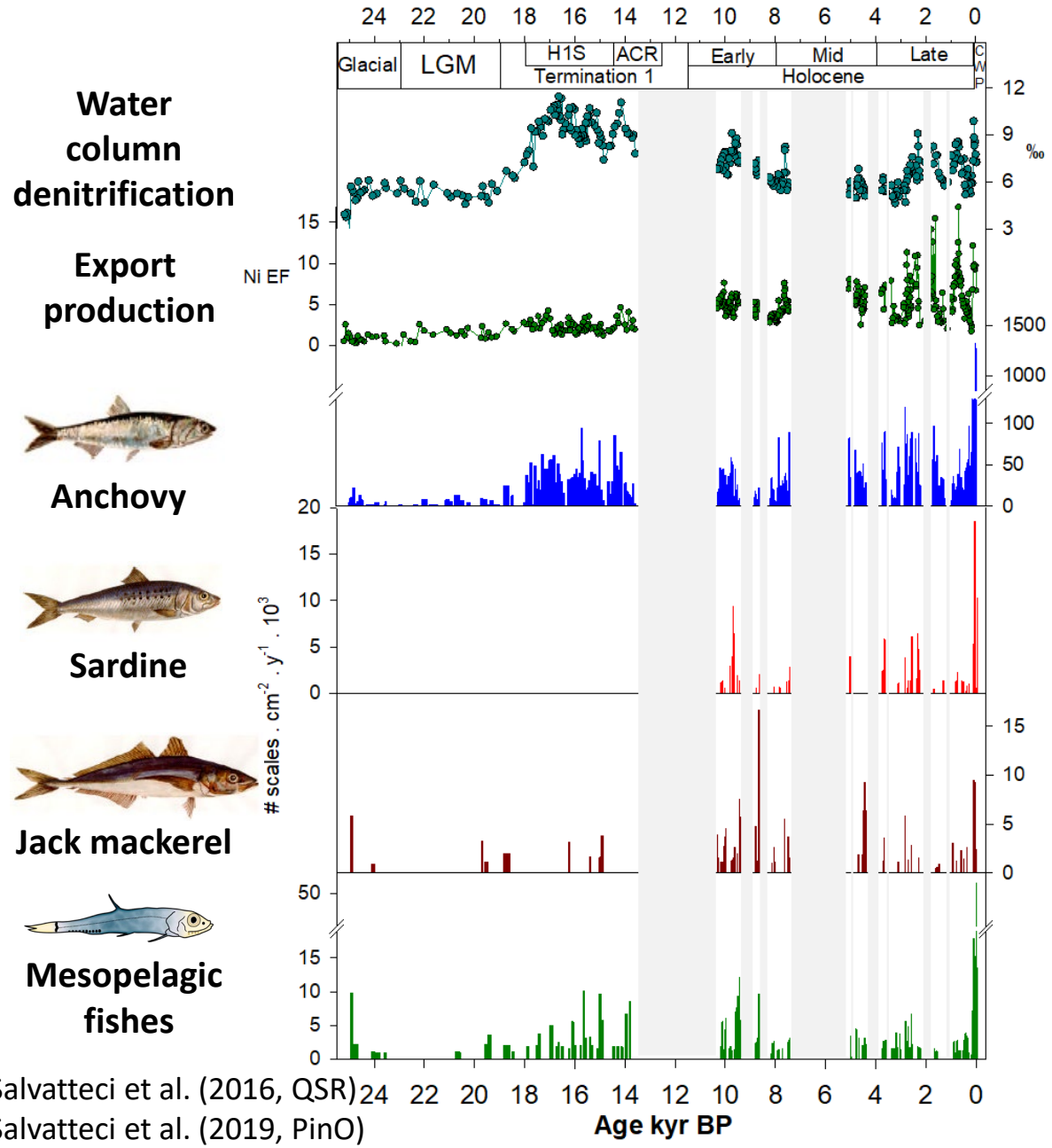
Deglaciation

The world warms up
Low oxygen and low productivity
Relatively high abundance of anchovy and meso-pelagic fishes
No sardines

Holocene

World climate more stable compared to the deglaciation
High productivity
Strong OMZ but highly variable
High abundance of pelagic and mesopelagic fishes

Centennial to millennial-scale changes in fish populations during the last 25 kyr



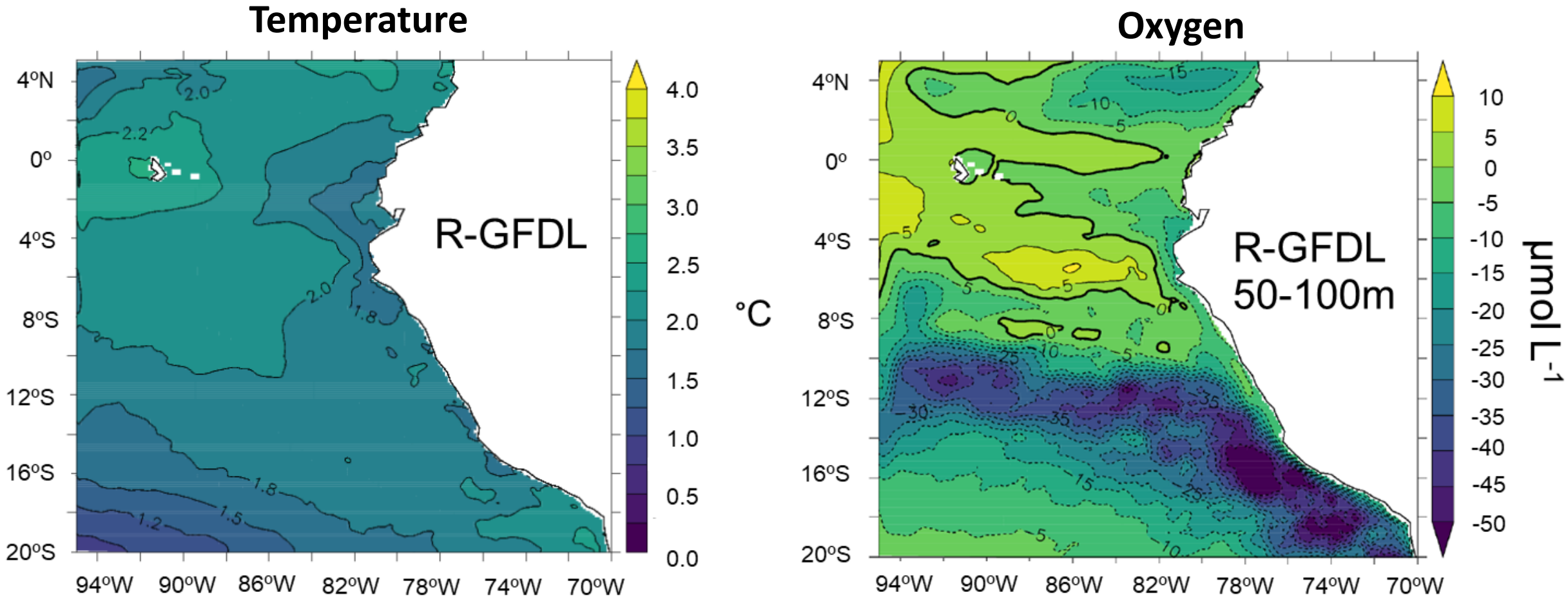
Salvatteci et al. (2016, QSR)
Salvatteci et al. (2019, PinO)

- Productivity appears as the main factor controlling small pelagic fish abundance
- Sub-surface oxygenation seems to play a role in a species-dependent way
- Multiple regime and tipping points!

Anchovy have been present in the HCS in large abundance since at least 18 000 years ago as evidenced in the paleo record and also in archeologial studies like in Caral

But the last 25 000 including the observational period (i.e. last decades) were very different to what we expect for the next decades

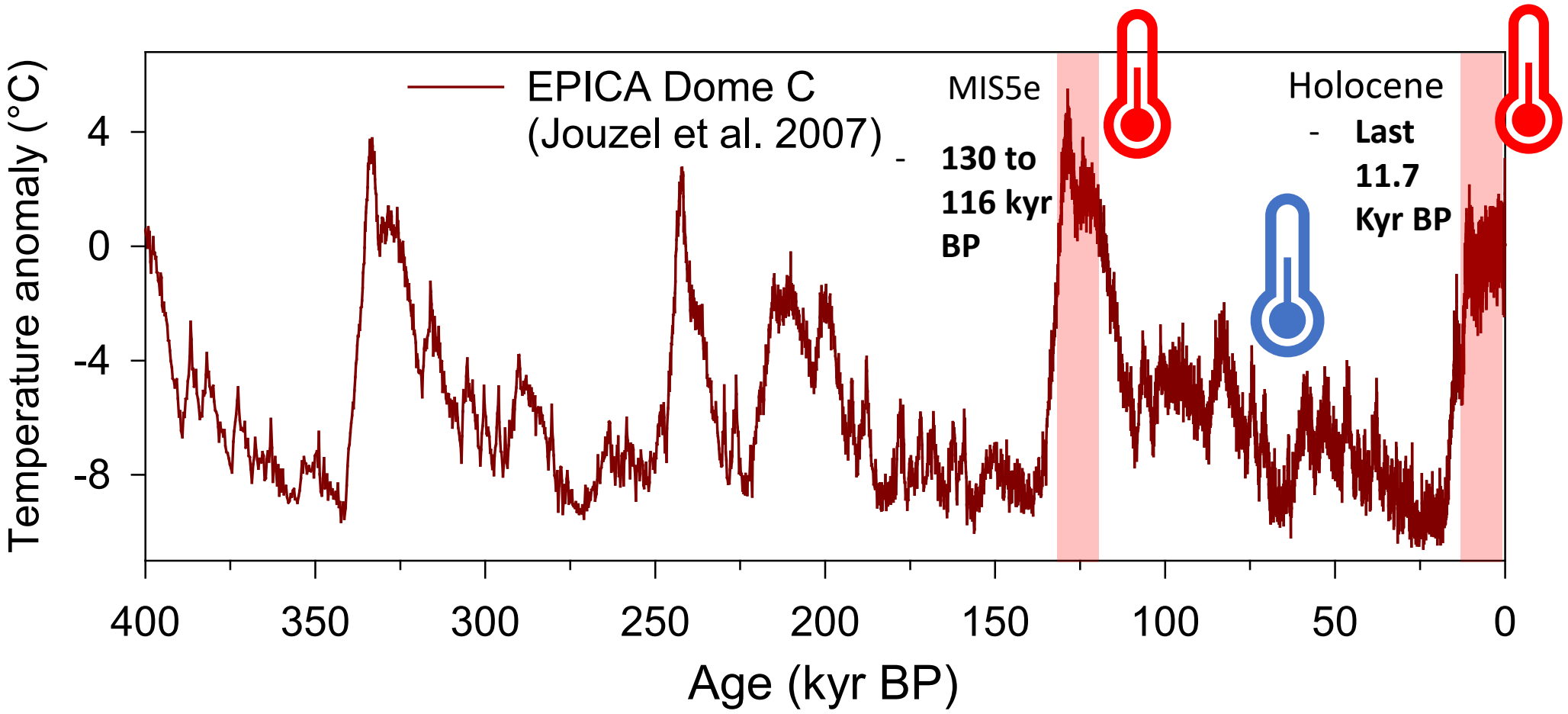
Model projections (RCP 8.5) suggest that by the end of the 21st century the Humboldt Current will be warmer and less oxygenated than has been in modern times



Salvatteci et al. (2022, Science)

How these environmental conditions will affect the abundance and the fish community composition in the HCS?

Fishery-independent data from sediment records offer the opportunity to better understand the response of the fish community to a warmer world



Antarctica Dome C ice core, temperature estimates

Hypothesis regarding the impact of warming on fish body size

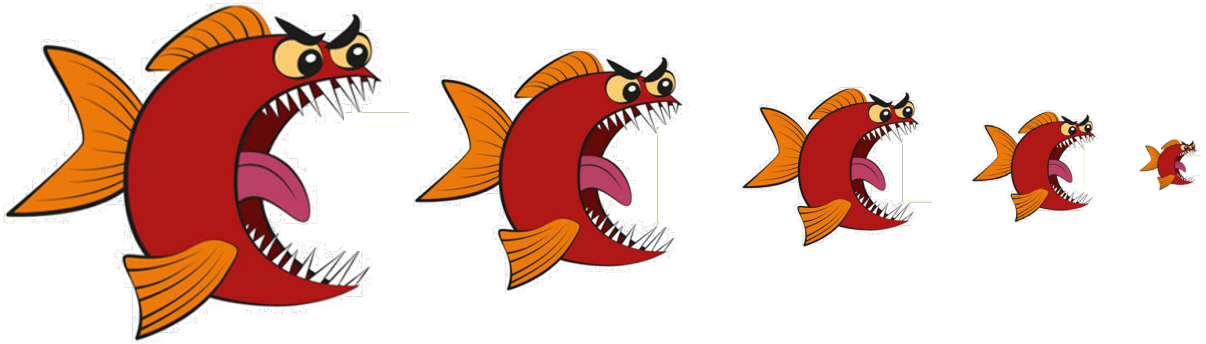
↗ T°C → ↘ dissolution of oxygen in the water

↗ T°C → ↗ metabolism → ↗ oxygen needs

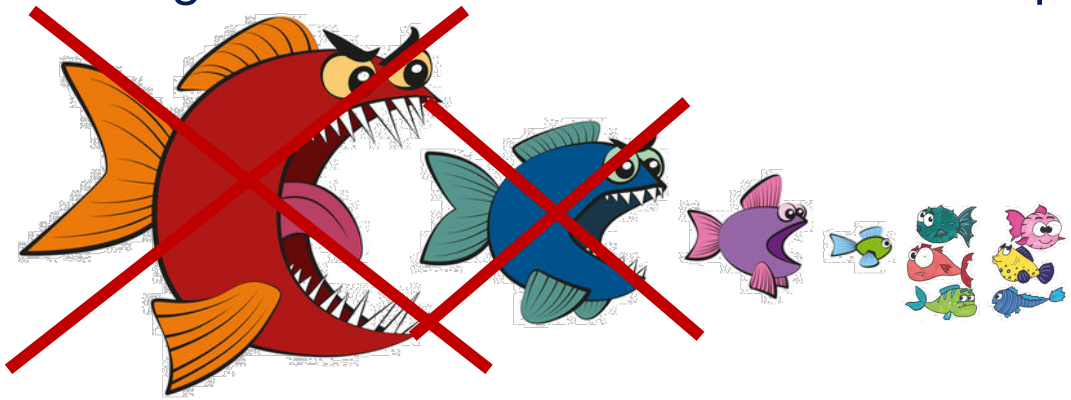
The larger the fish, the more expensive it is to transport oxygen to all its cells

In a warmer and less oxygenated ocean, fish size is expected to decrease

H1. The size of the fish of each given species will decrease

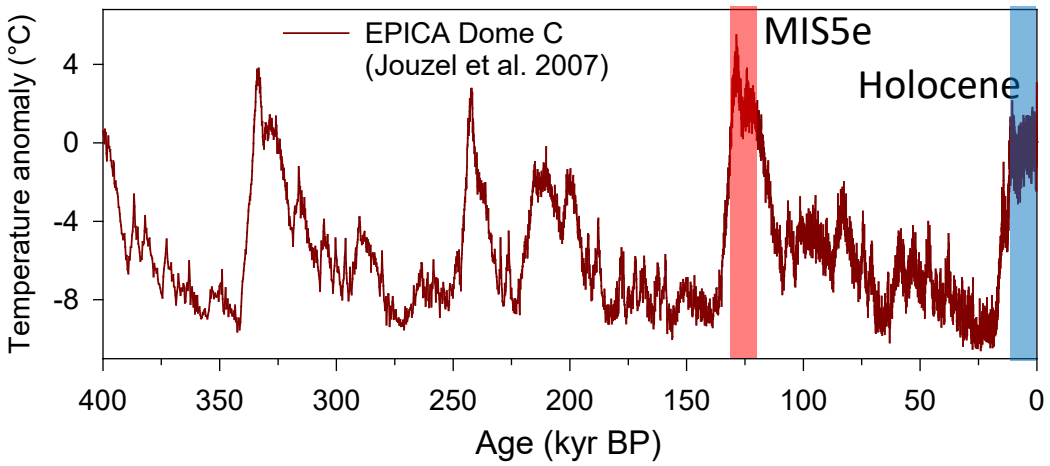


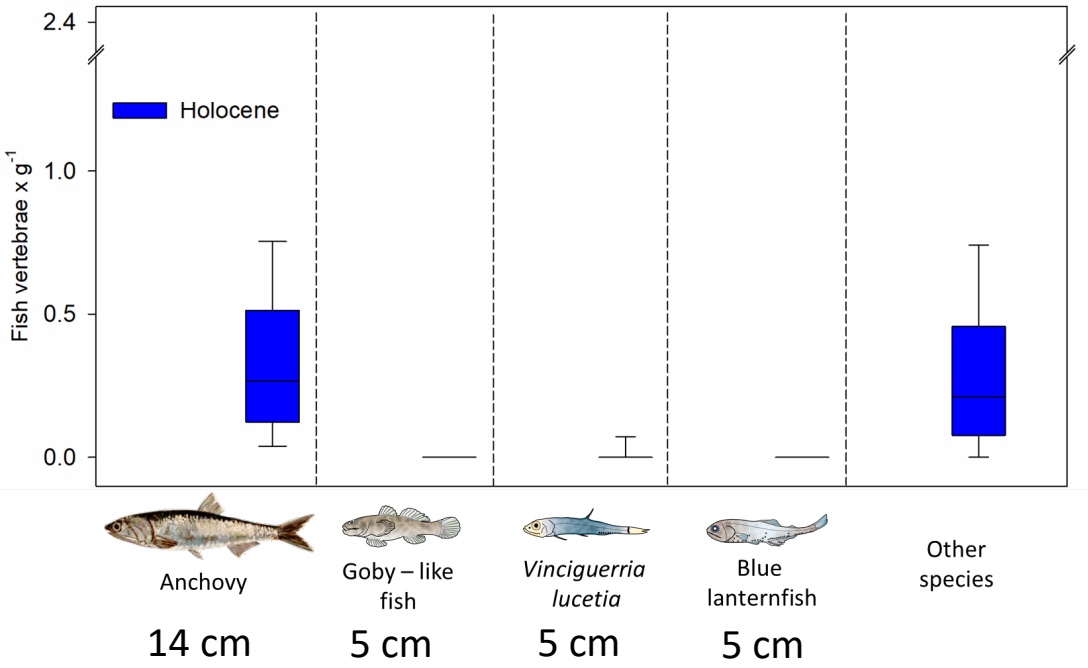
H2. Change of communities towards smaller species



Historical data: difficult to test these hypotheses as fishing has both effects

The fish community inhabiting the HCS during the last interglacial differed dramatically from the communities found during the Holocene





MIS5e

- **High sea-level**
- **Warm temperatures**
- **Low sub-surface oxygenation**
- **Sulfidic conditions**
- **Similar conditions to the RCP8.5 scenario**

Salvatteci et al. (2022, Science)

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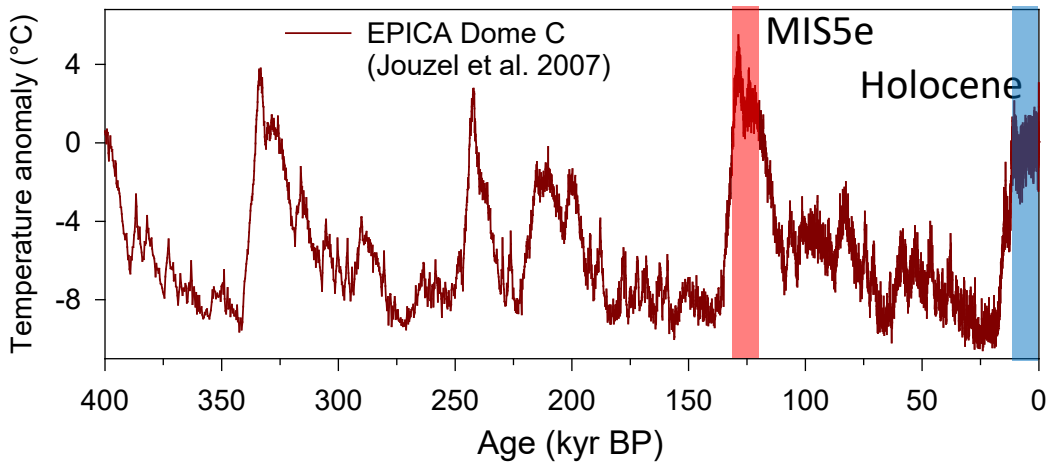

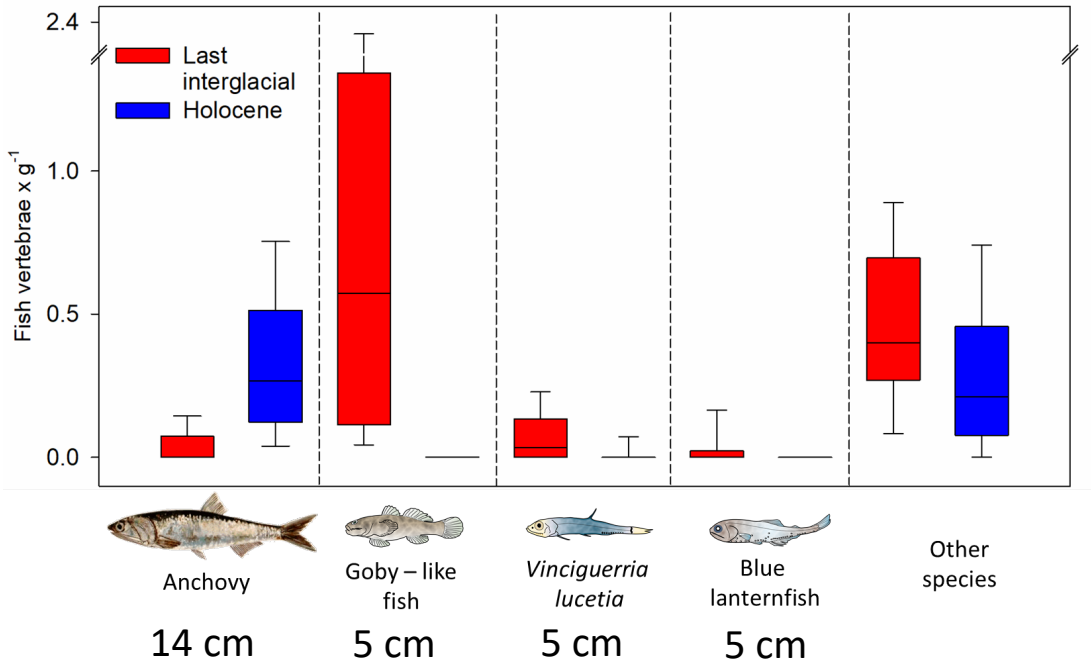

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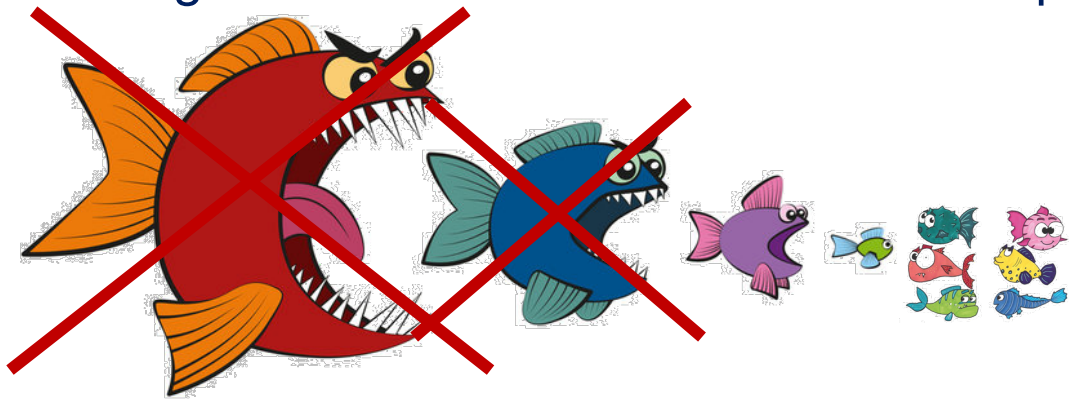
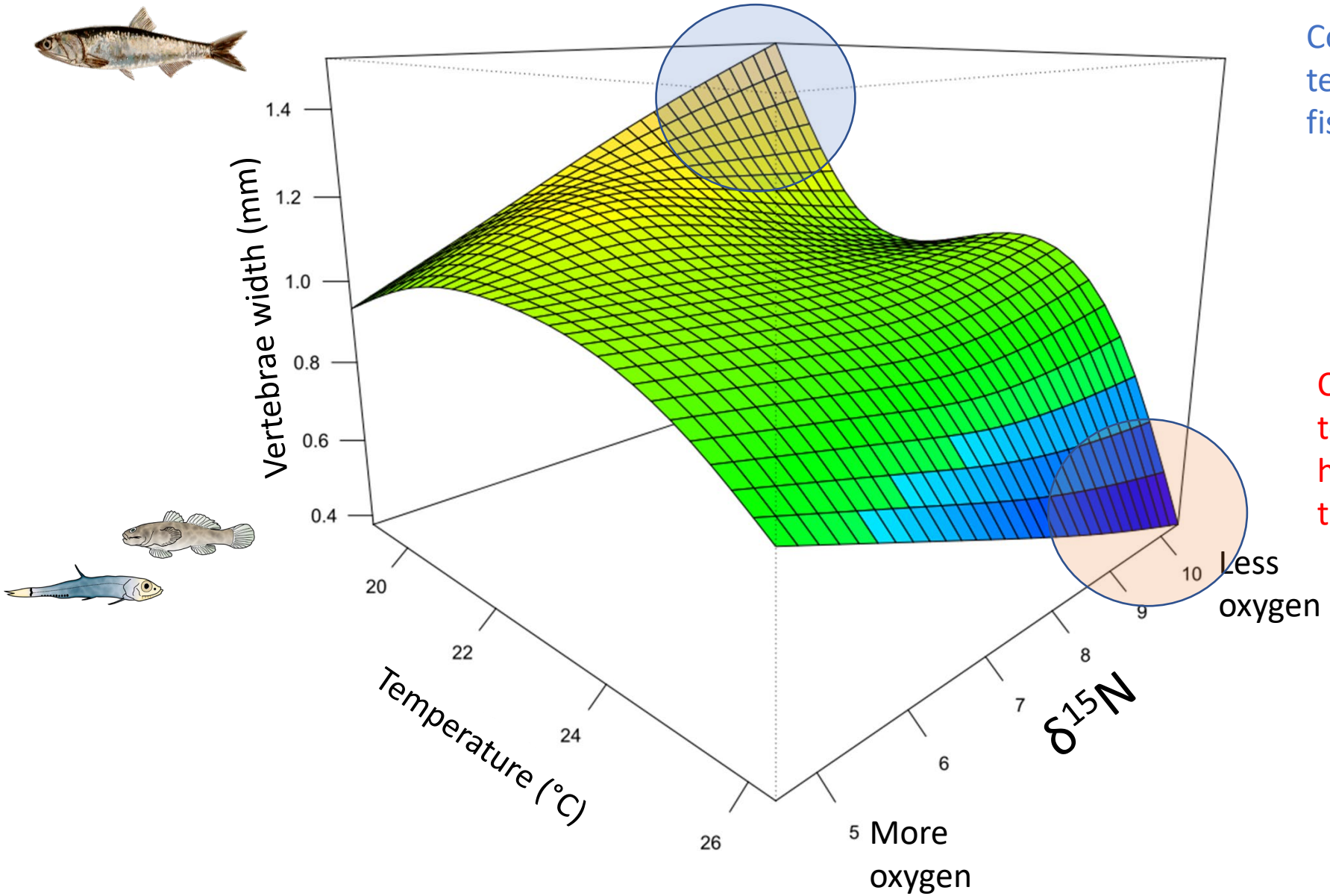


Salvatteci et al. (2022, Science)

Generalized additive model describing the significant relationship between vertebrae width and an interaction between temperature and oxygen



Combination of less oxygen and low temperatures associated with large fishes (conditions last century)

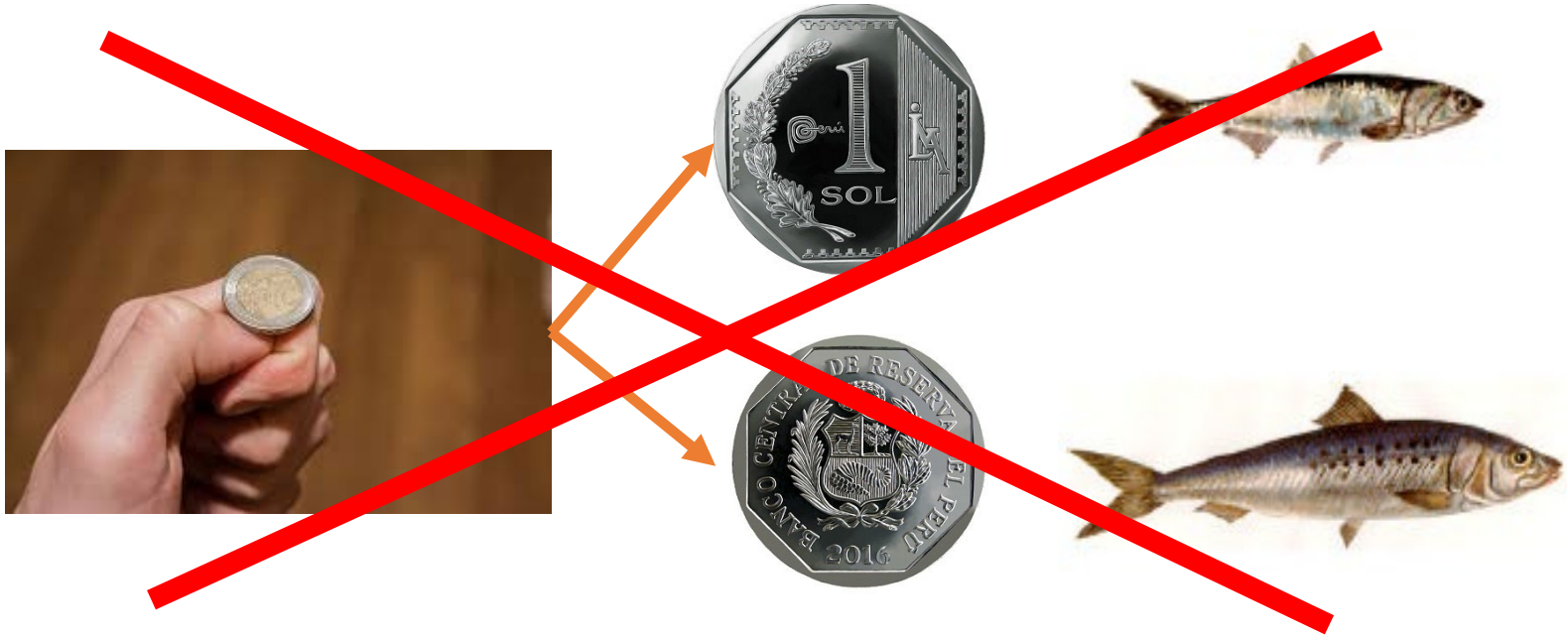
Combination of less oxygen and high temperatures (not seen in the historical record!) associated with the smallest fishes (MIS5e)

Salvatteci et al. (2022, Science)

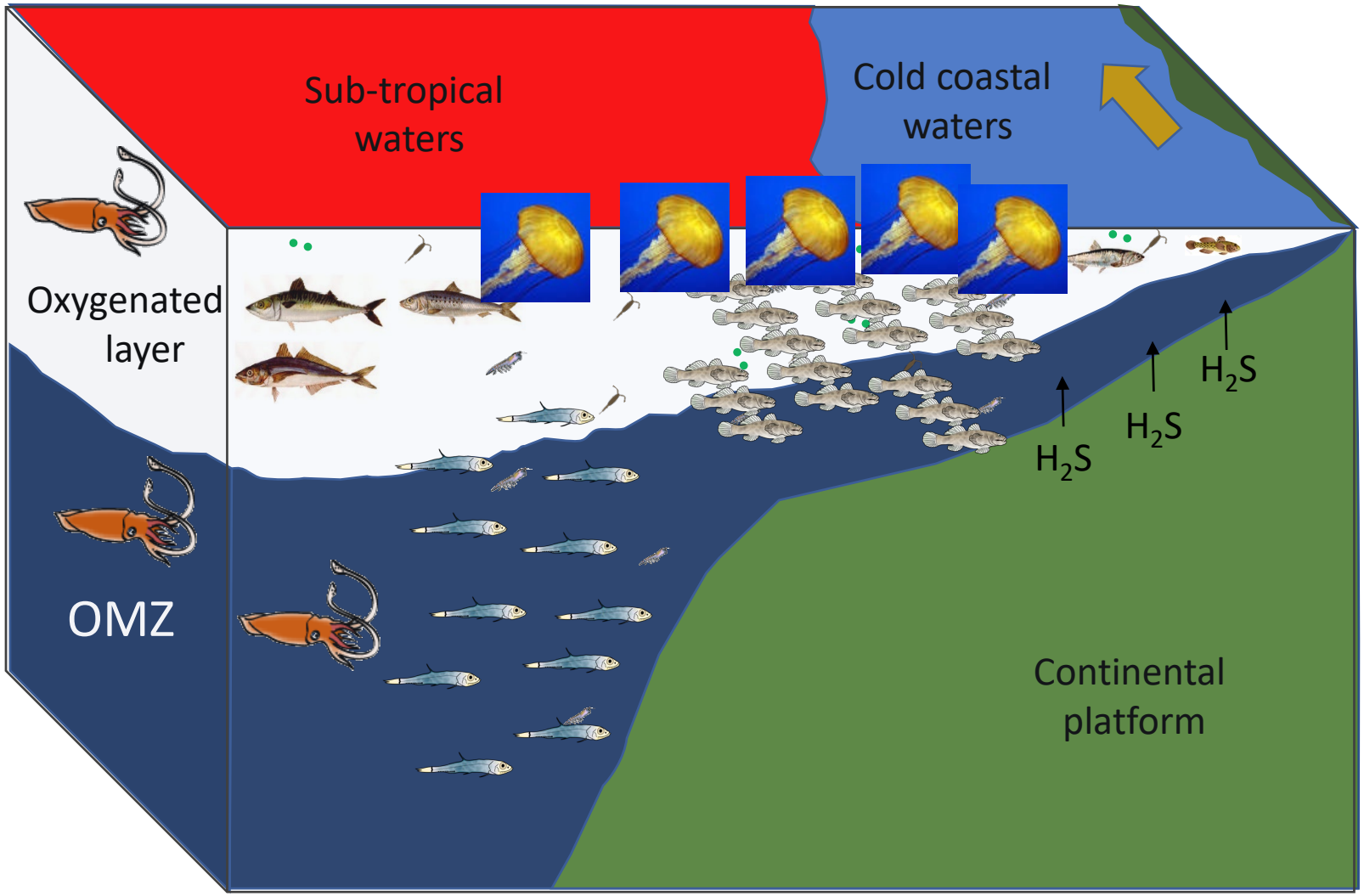
Expected scenarios in the Humbolt current System

There were multifarious regime shifts in the HCS as indicated by the paleoceanographic records with no periodicities:

Periods with anchovy, periods with sardine, with both species, with low abundance of small pelagic fishes, with small fishes, with huge abundance of mesopelagic fishes, etc.



The Humboldt Current system: Potential scenario in a warm and oxygen-poor ocean: Goby world!

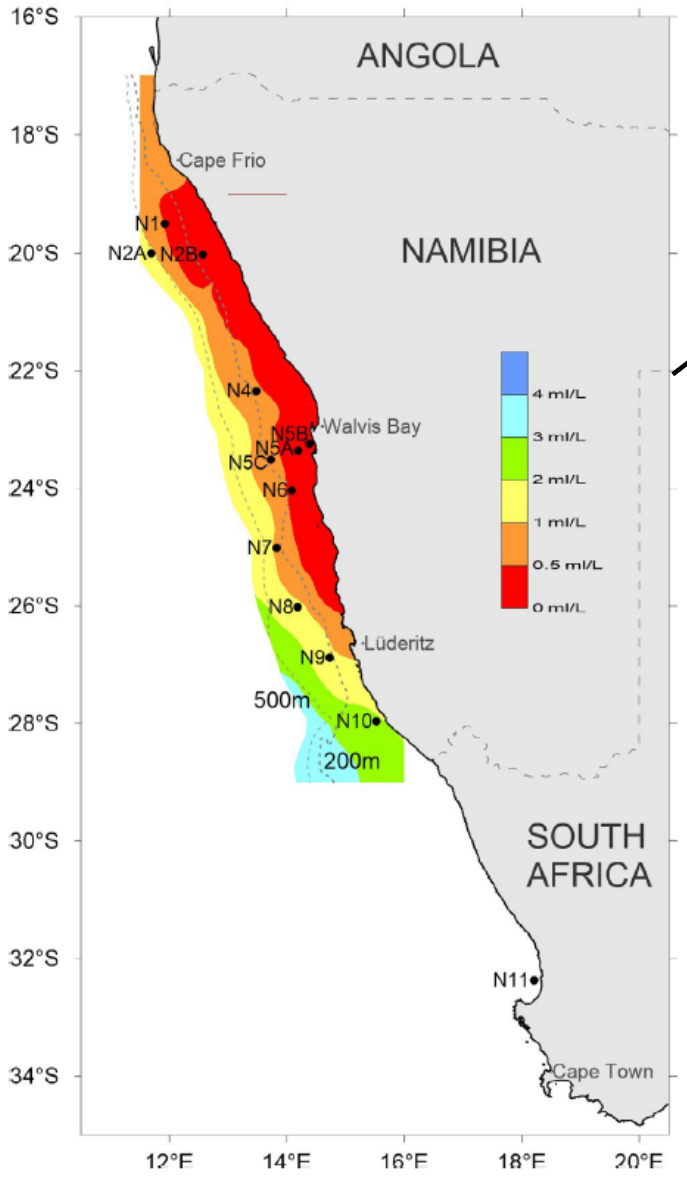


Bearded goby

- Mesopelagic fishes and gobies are **extremely difficult to harvest and less palatable** than anchovy

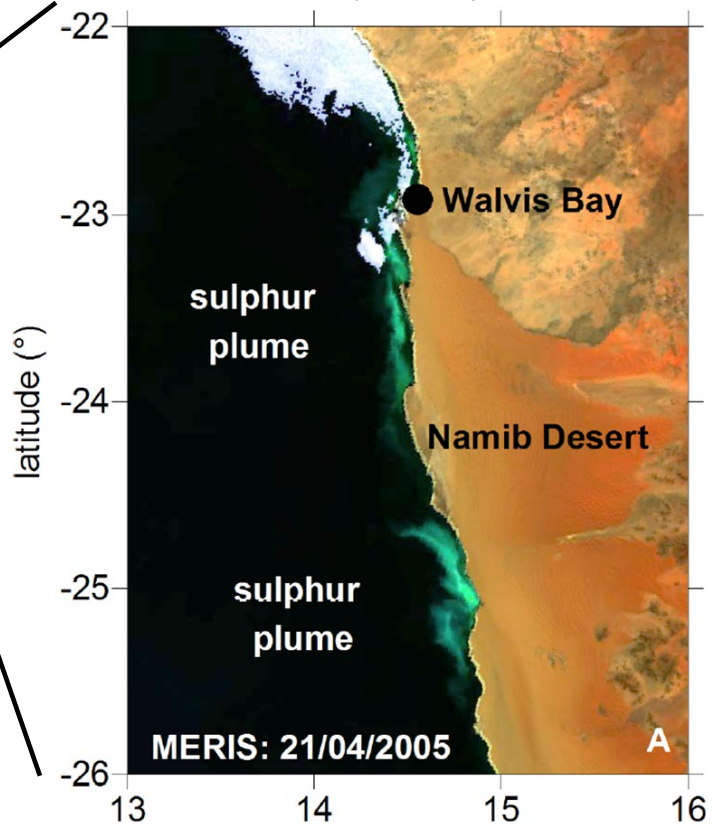
- This observation suggests reduced fishing capacity and a **threat to the global fish supply**

Potential scenario in the HCS is very similar to what we see now in the Benguela System



Suneetha Gunawickrama et al. (2020)

Sulphur plumes (toxic!)



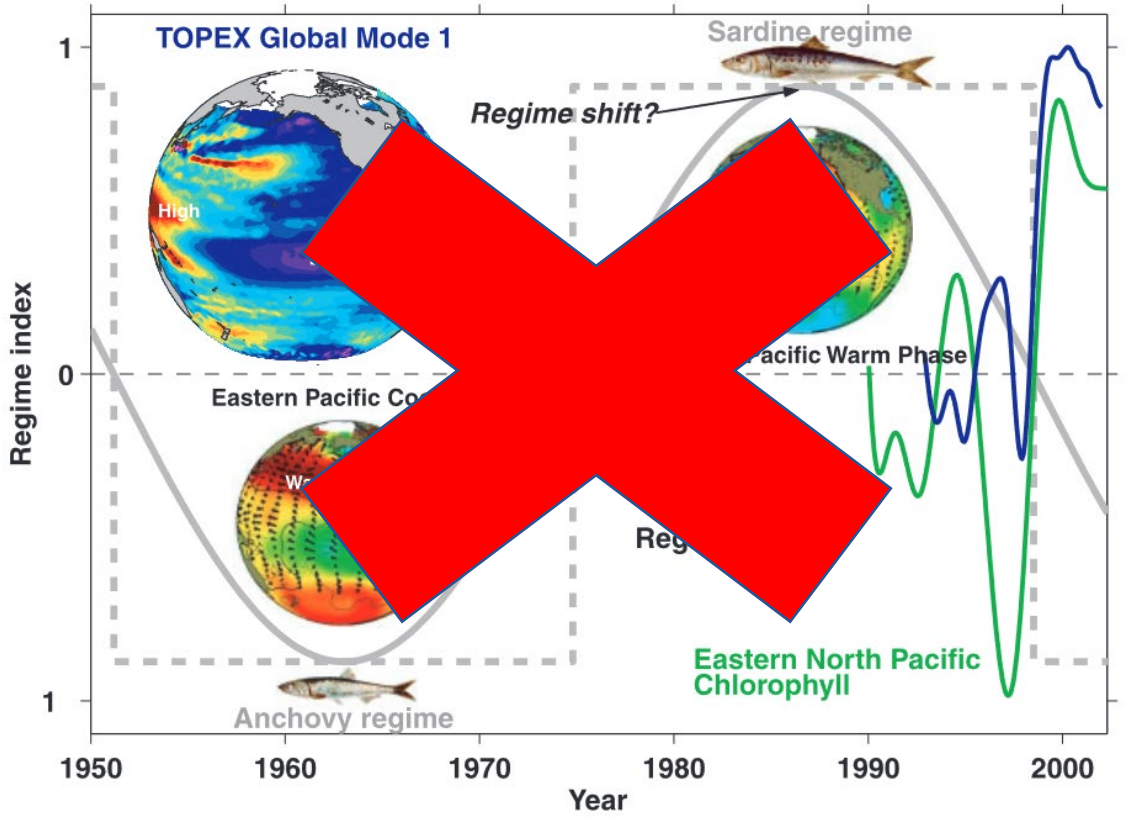
Ohde and Dadou (2018)

Jellyfish

Bearded goby

Breaking paradigms

PDO is not the main driver of anchovy and sardine fluctuations



From producing fish meal…….

…….to producing a meal of fish (DHC)

Take home messages

- Multiple tipping points and multifarious regime shifts were observed in the HCS as indicated by the paleoceanographic records

- Future conditions in the HCS (warm waters and low oxygen) will not be favorable for anchovy productivity, but will probably be favorable for small fish species (gobies and mesopelagic fishes)

- These fishes are extremely difficult to harvest and less palatable than anchovy, suggesting reduced fishing capacity and a threat to the global fish supply (specially aquaculture!)

- Paleoceanographic results need to be discussed and taken into account for fishery management in a warming world