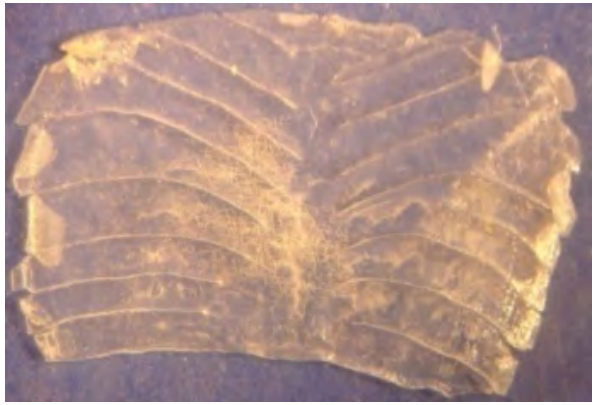
# Multifarious anchovy and sardine regimes in the Humboldt Current System during the last 150 years

Renato Salvatteci, David Field, Dimitri Gutierrez, Tim Baumgartner, Vicente Ferreira, Luc Ortlieb†, Abdel Sifeddine, Arnaud Bertrand



*"Drivers of dynamics of small pelagic fish resources'* Victoria (March 2017)

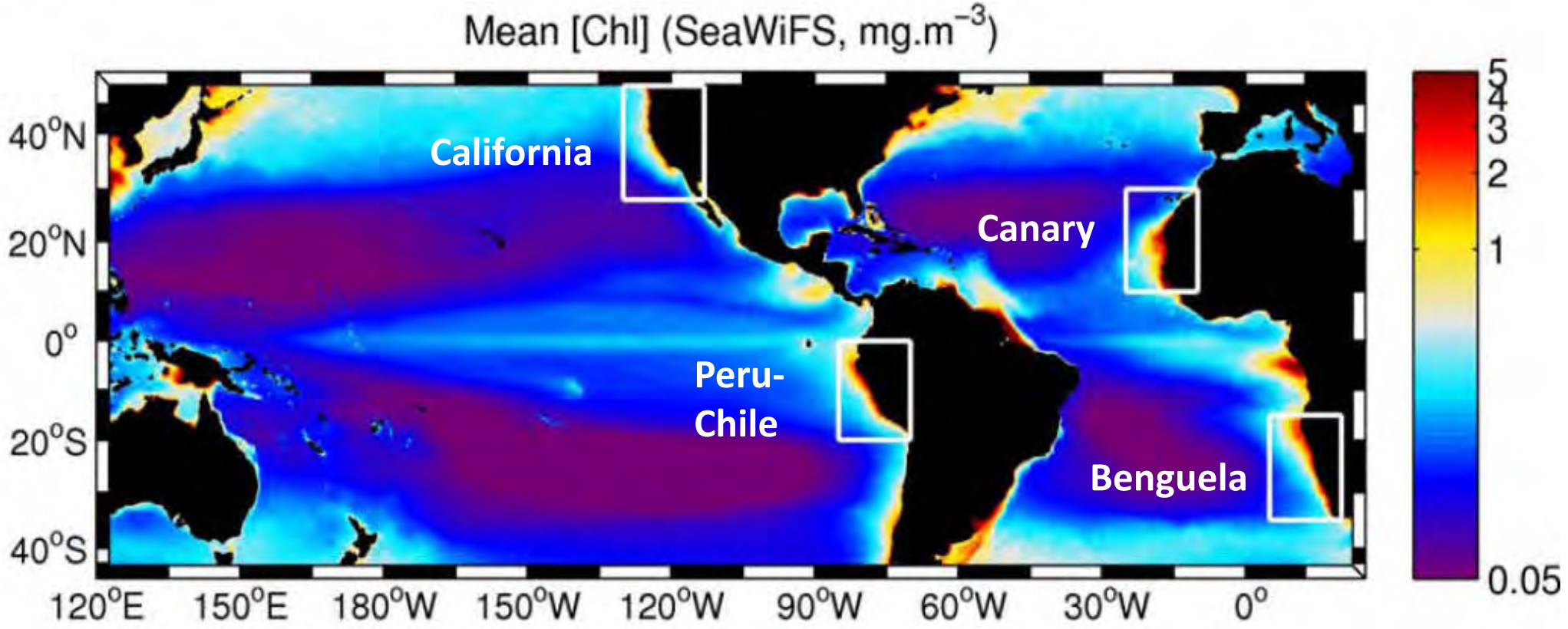
# Eastern Boundary Upwelling Systems (EBUS)

-Upwelling of cool waters, driven by trade winds, brings nutrients to the surface, increasing biological productivity.

-Area < than 1% of the world's oceans but accounts for ~20% of global fish catch

-The Peruvian upwelling system yields 10% of the global fish catch and offers 125 000 direct jobs

-The EBUS are highly sensitive to climate change

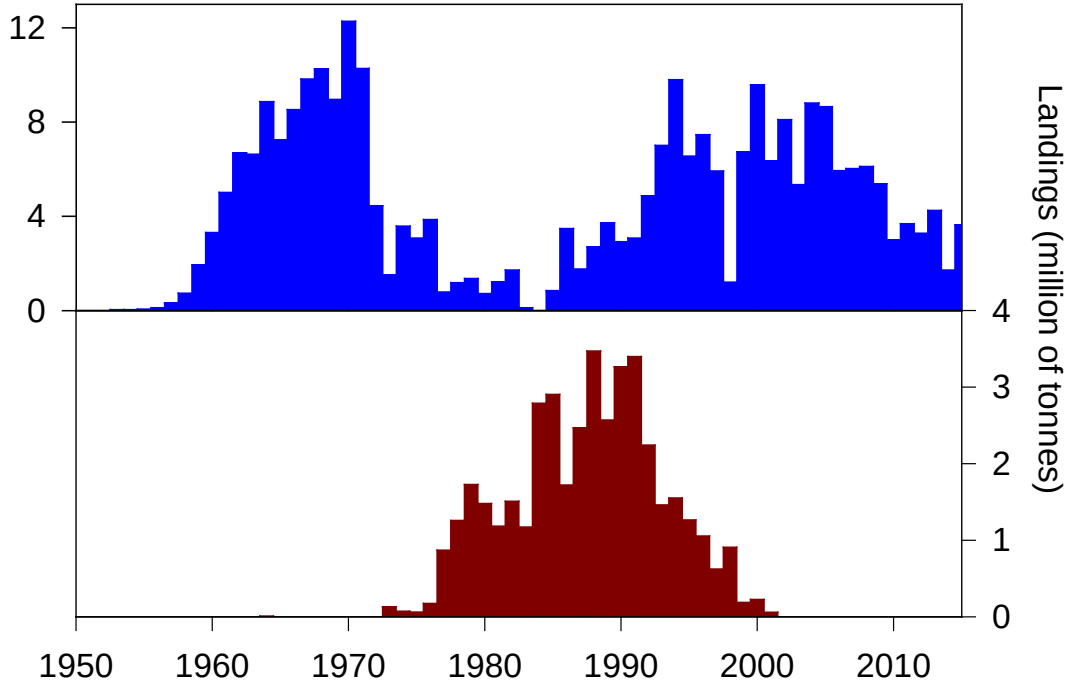



Chavez and Messié (2009)

# Multi-decadal fluctuations in anchovy and sardine landings in the Peruvian Upwelling Ecosystem

Anchovy

Sardine



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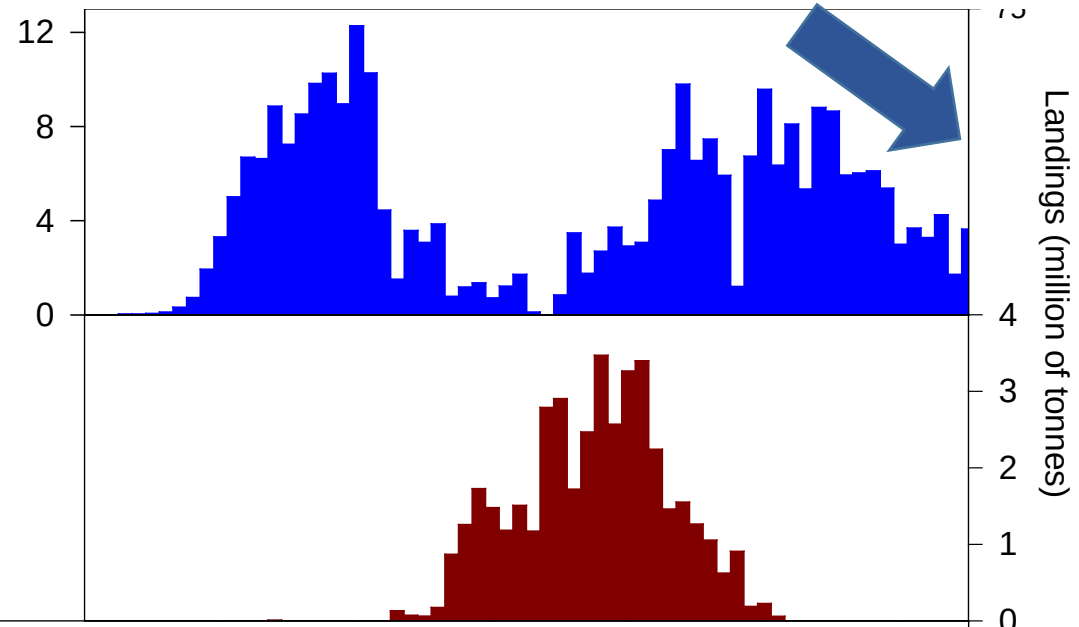
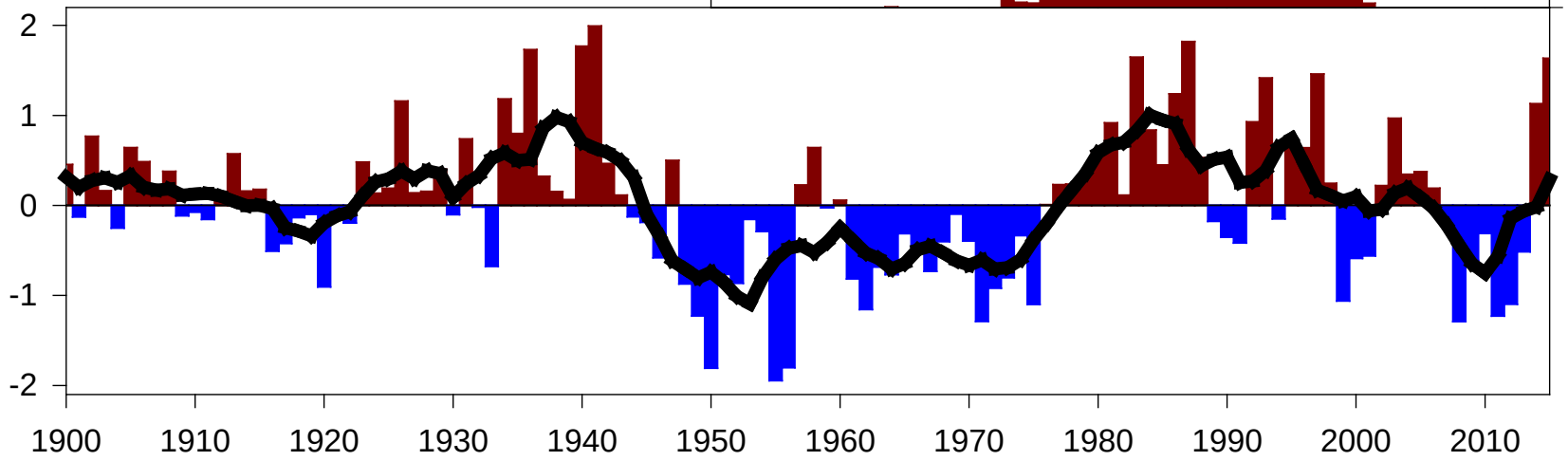
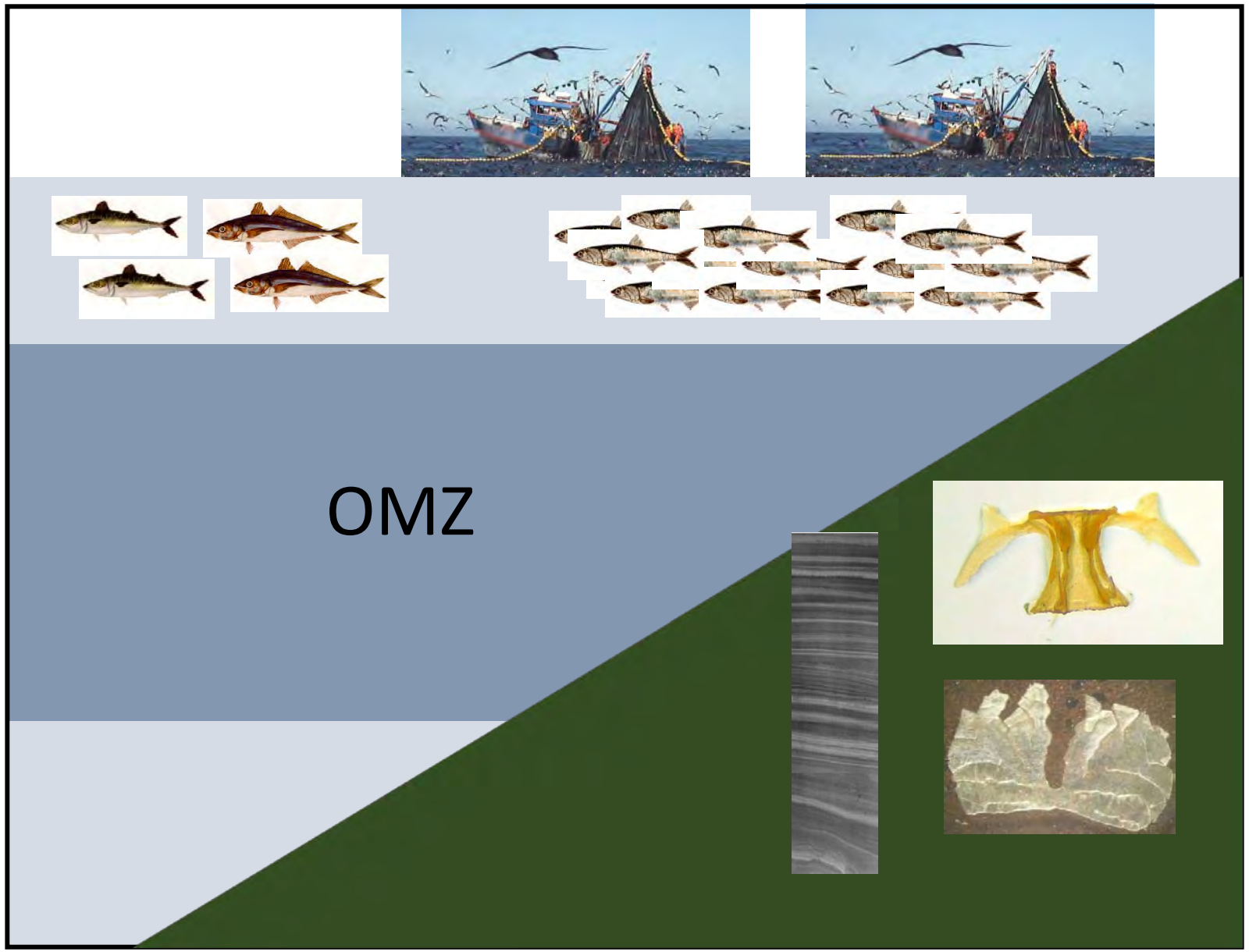



PDO



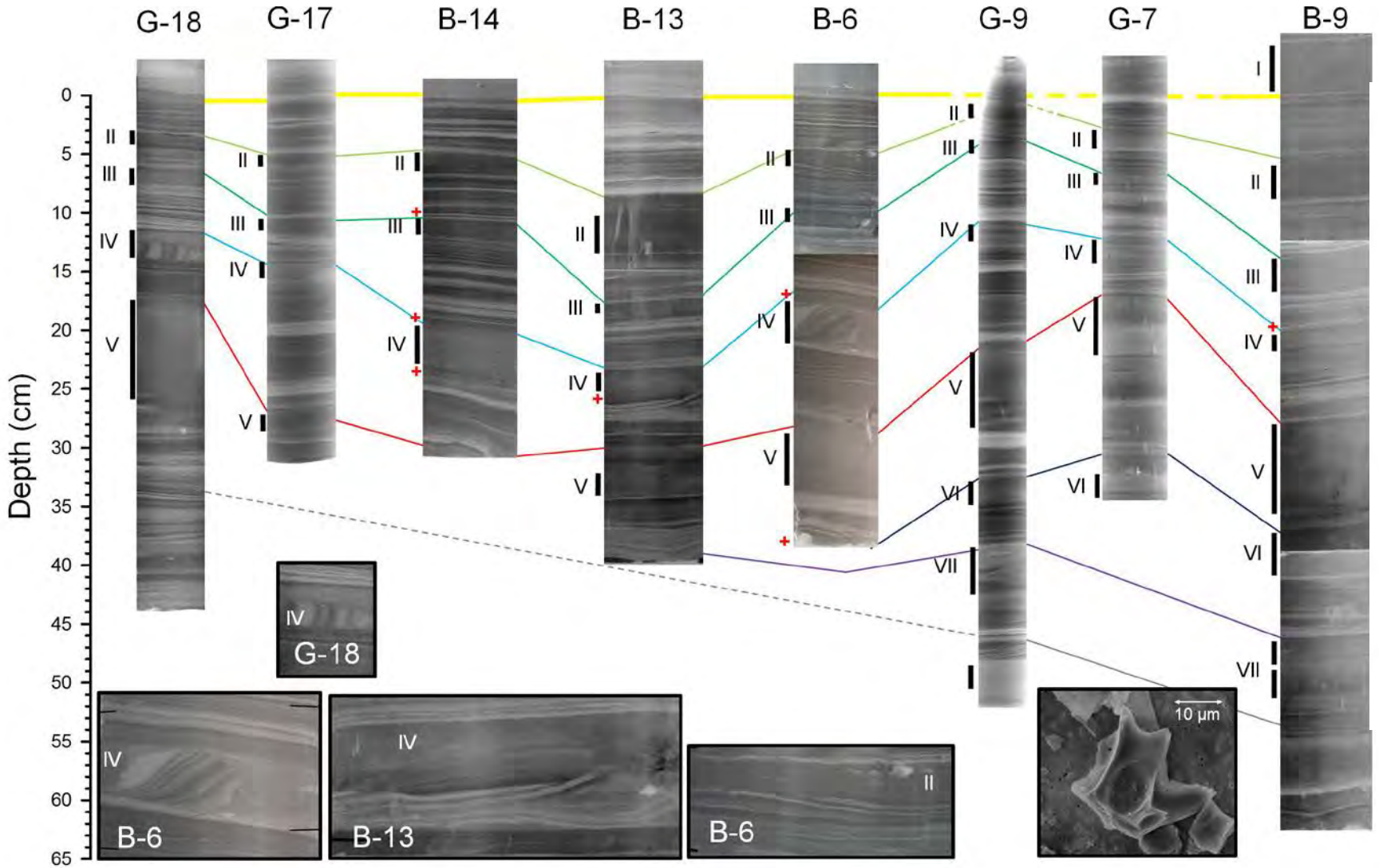

Chavez et al., 2003

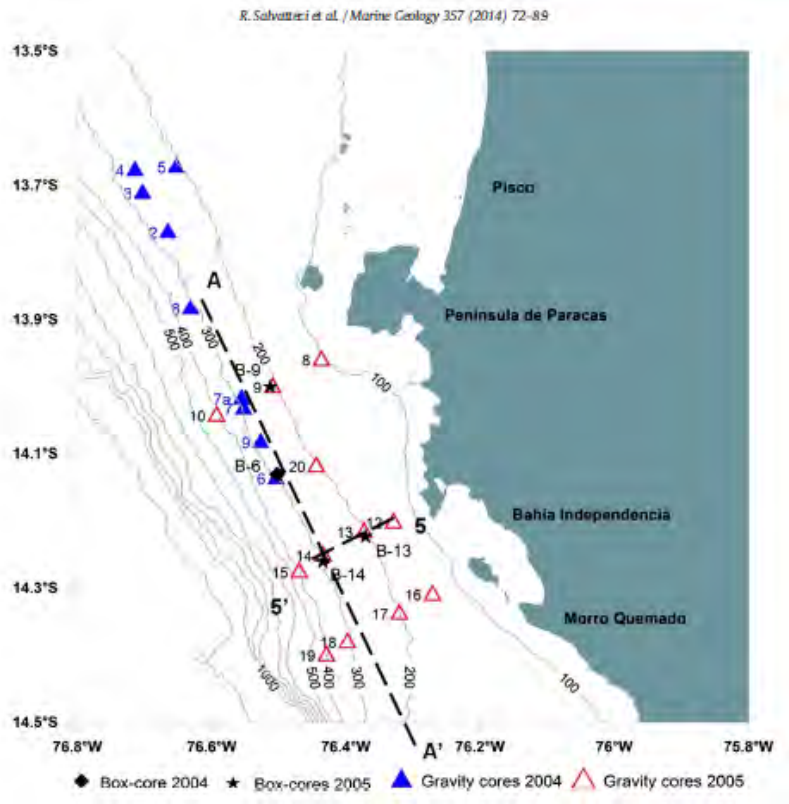
# Fish scales accumulating in marine laminated sediments provide long-term records of population variability




To understand the physical mechanisms underlying small-pelagic fluctuations and middle- to long-term trends in the HCS since 1860 AD, we reconstruct high-resolution records of marine productivity and anchovy and sardine biomass fluctuations from several sediment cores from Pisco and compare them with other previously published records in the HCS (Valdes et al., 2008 and Gutierrez et al., 2009)

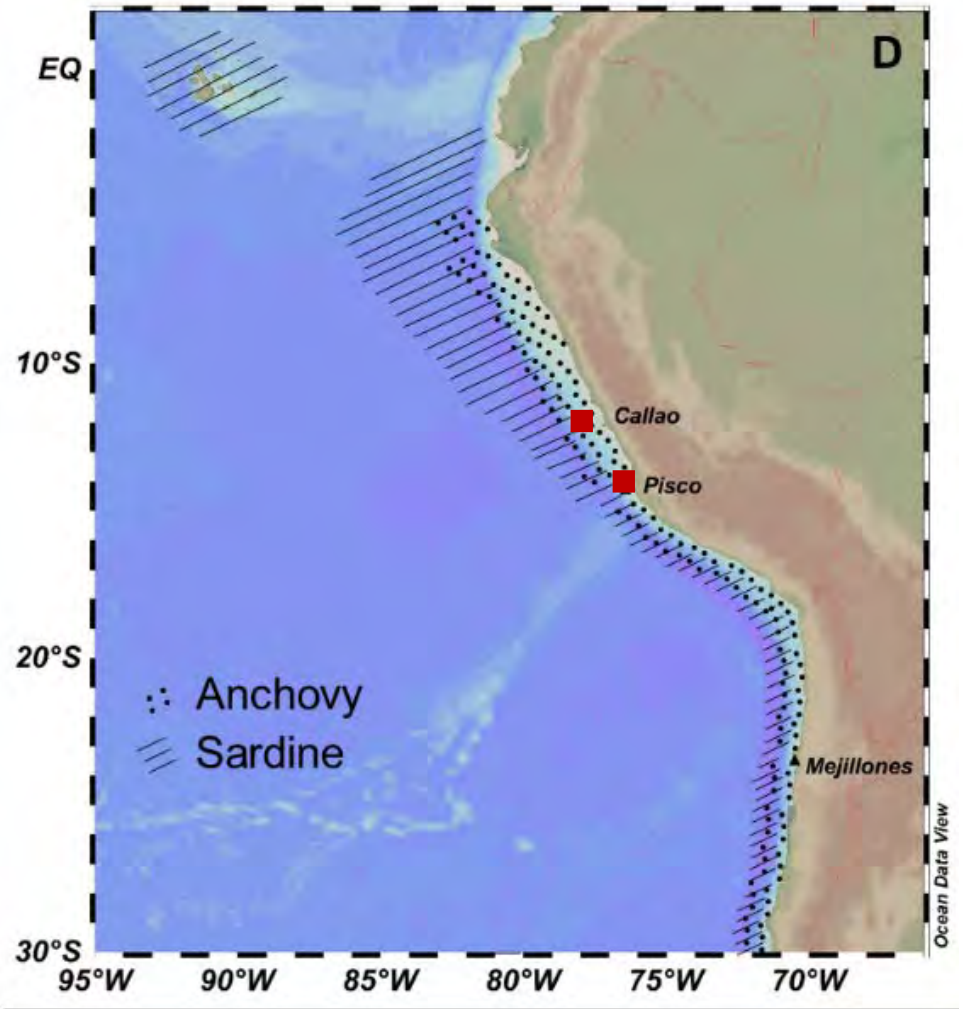
# Cross-stratigraphies indicate horizontal extensions of laminae, missing sequences and a need for multiple cores for high resolution records

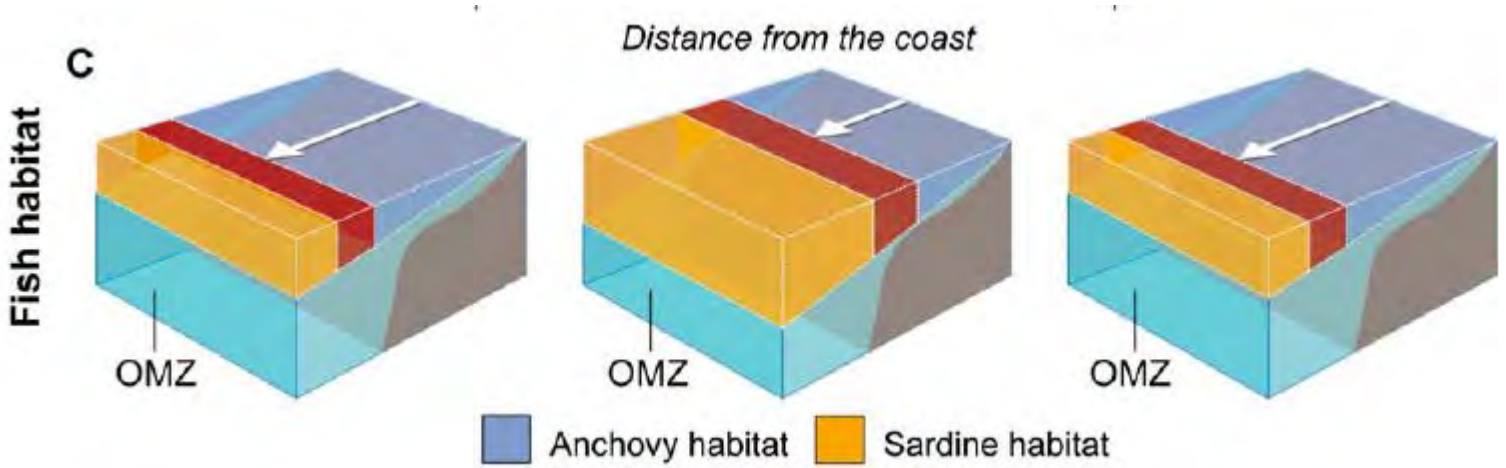



Salvatteci et al. (2014, Marine Geology)

# The sampling of the cores was congruent with the spatial range of anchovy and sardine, with sediment cores spanning a range of the preferred water masses




Bertrand et al., 2011

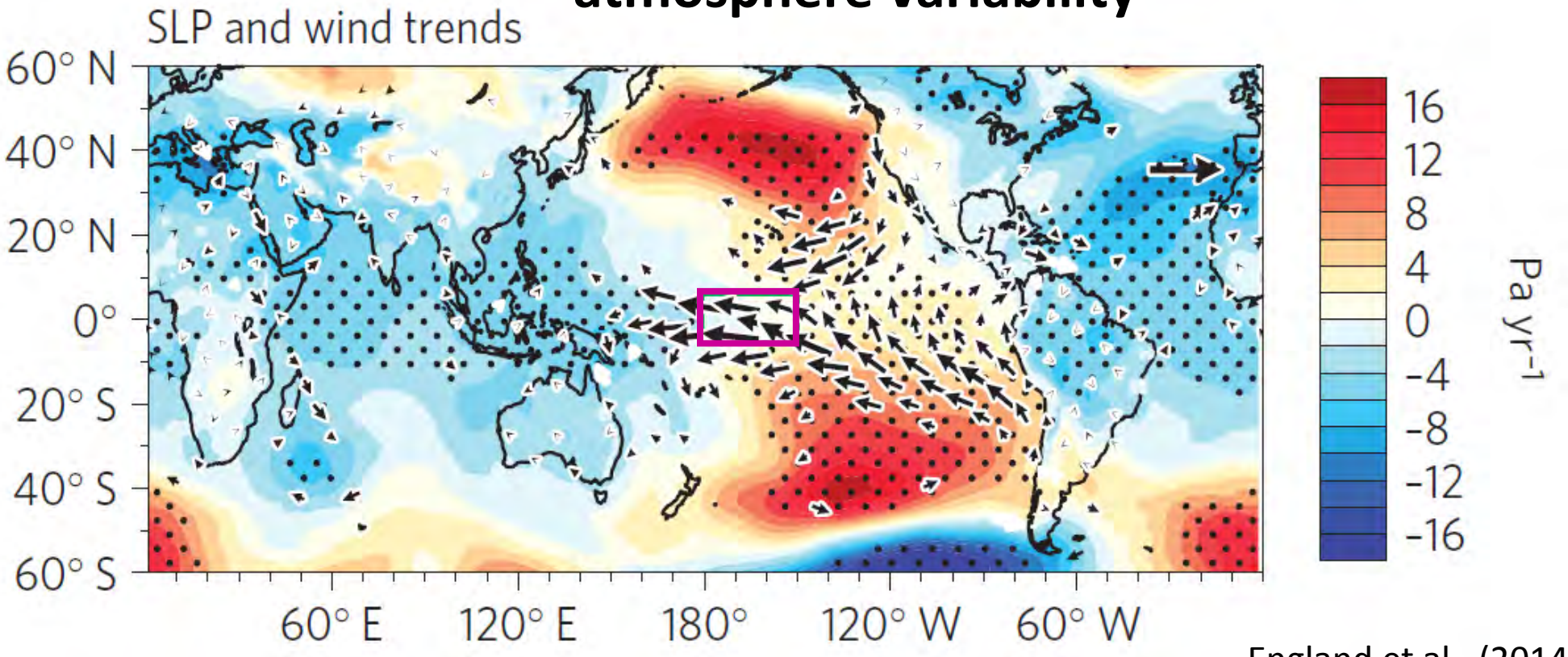
Anchovy

Sardine

- Anchovy are more adapted to productive, cold coastal waters

Sardine prefer the oceanic waters and the front between oceanic and coastal waters

# To understand the cause of multidecadal variability in fish populations, we compared the reconstructed fish SDR with tropical and regional indices of ocean-atmosphere variability




England et al., (2014)

The Tropical Pacific zonal wind stress record (computed from 6°N to 6°S and 180° to 150°W) serves as an indicator of the Walker circulation strength, with stronger (lighter) winds toward the west indicating a stronger (weaker) Walker circulation

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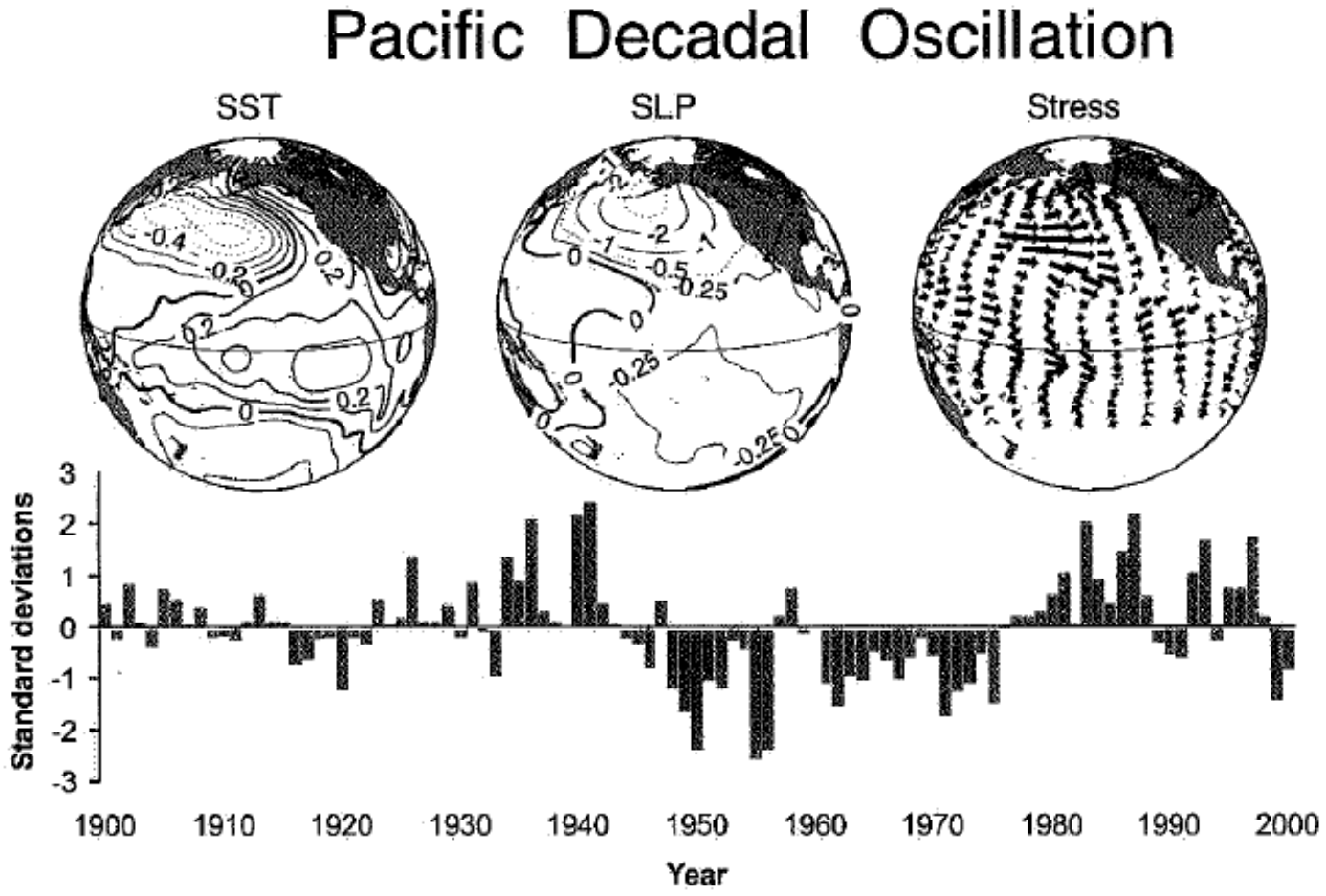
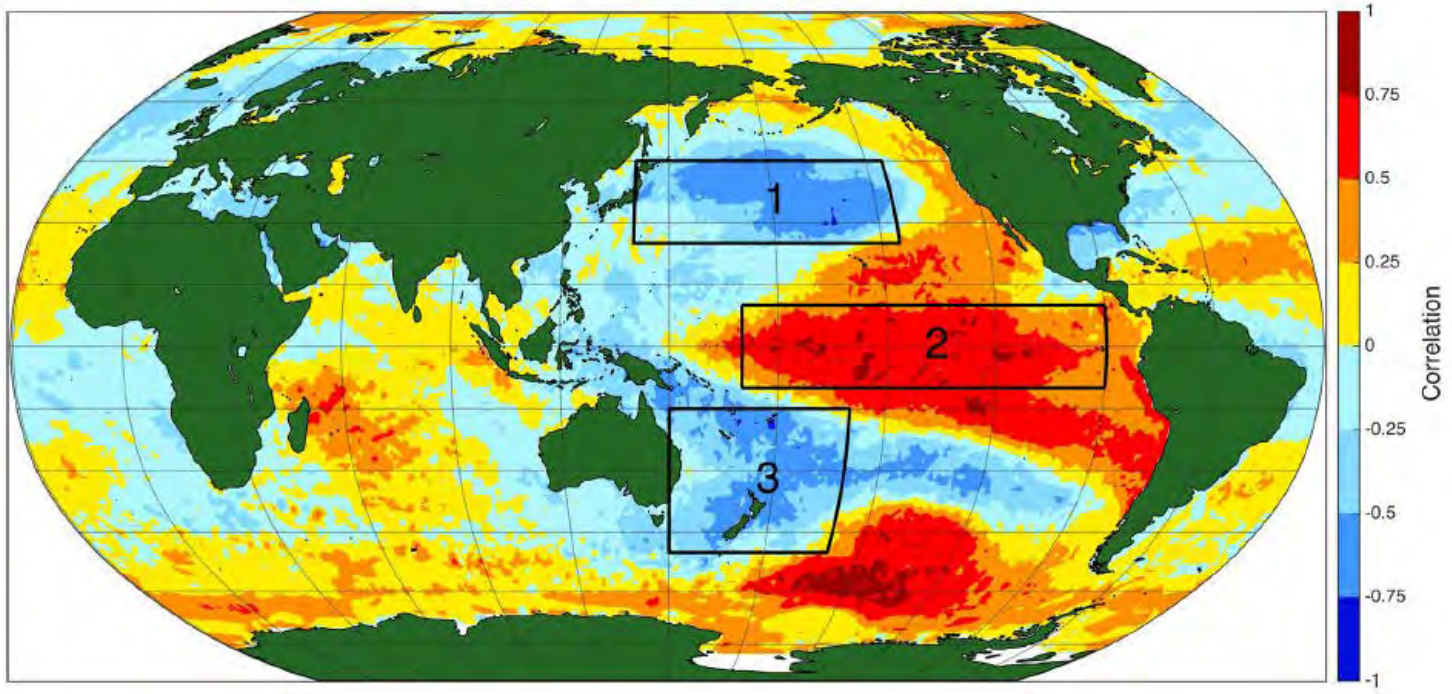



Ocean–atmosphere climate variability centered over the midlatitude North Pacific basin. Mantua and Hare (2002)

# To understand the cause of multidecadal variability in fish populations, we compared the reconstructed fish SDR with tropical and regional indices of ocean-atmosphere variability

## Tropical Pacific Index (TPI)



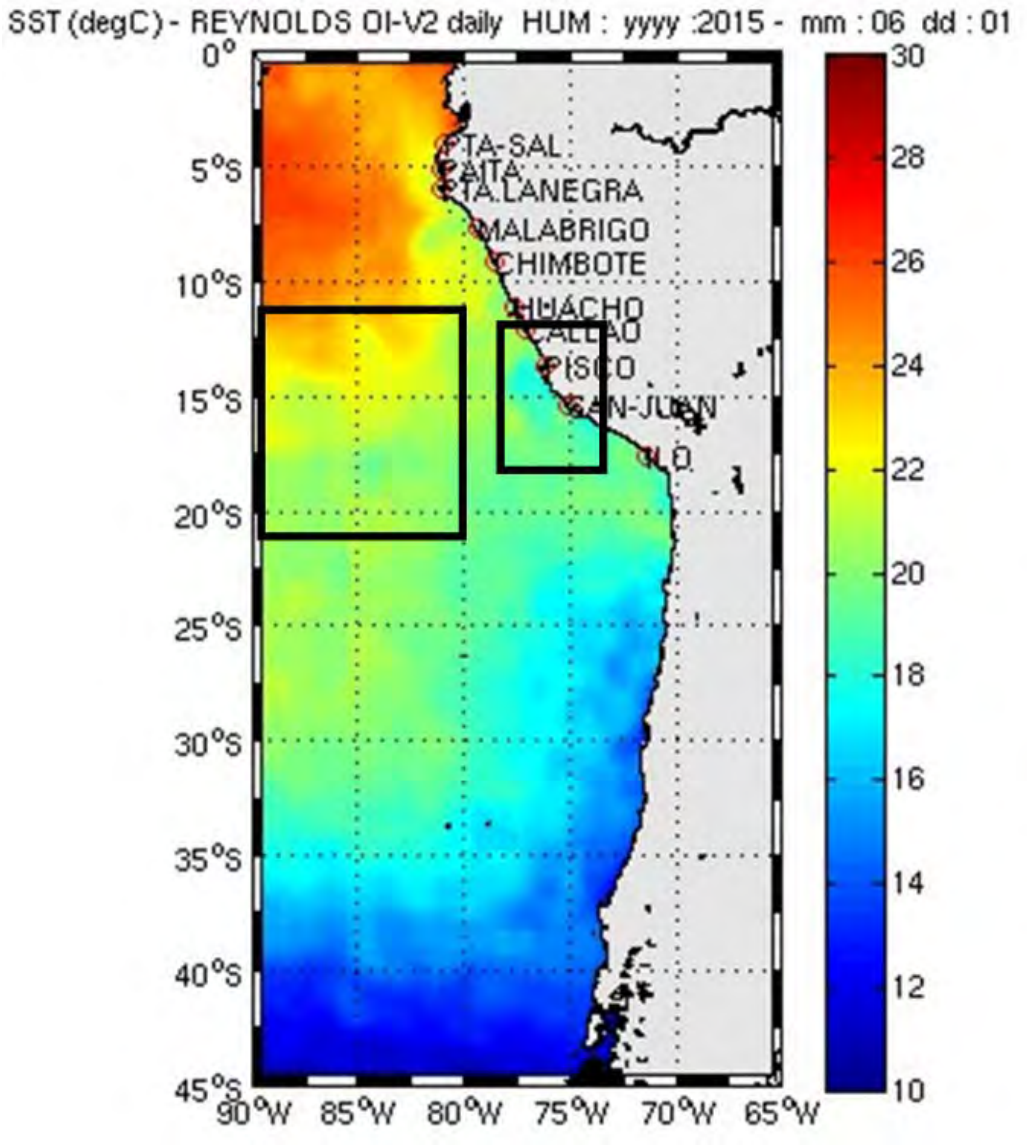

The TPI (Henley et al., 2015), is based on the difference between sea surface temperature anomalies (SSTA) averaged over the central equatorial Pacific and the average SSTA in the Northwest and Southwest Pacific (Henley et al., 2015).

The TPI resembles a multidecadal “El Niño-like” pattern of climate variability. During its positive phase, the tropical Pacific is warm and trade winds are weak, whereas during its negative phase the tropical Pacific is cool and the trade winds are strong.

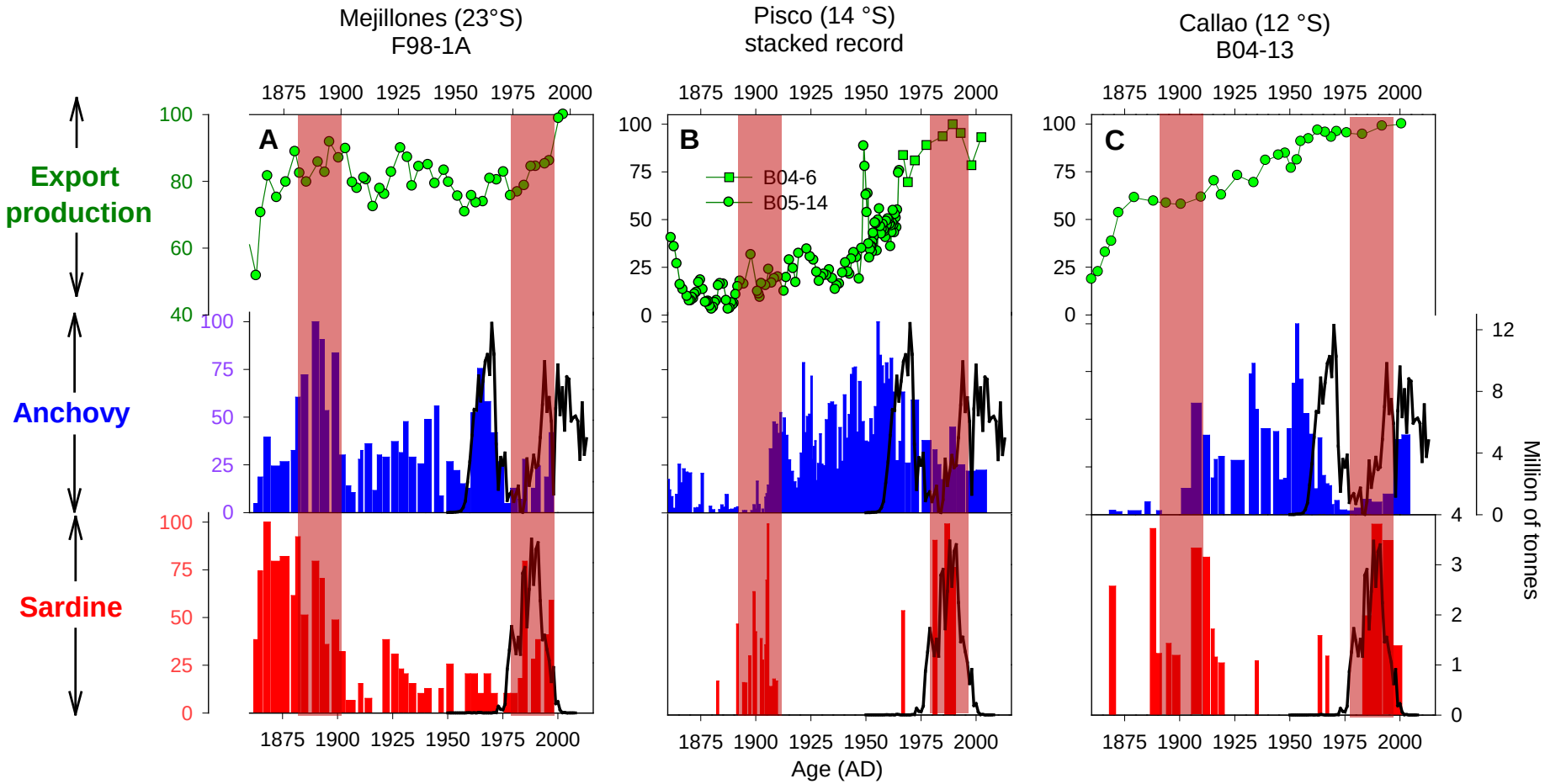
# To understand the cause of multidecadal variability in fish populations, we compared the reconstructed fish SDR with tropical and regional indices of ocean-atmosphere variability

Finally we show:

- Offshore and coastal SST anomalies from the ICOADS dataset,
- and a difference between the offshore and coastal area that we refer as a cross-shore temperature gradient and is used as a proxy to infer upwelling intensity

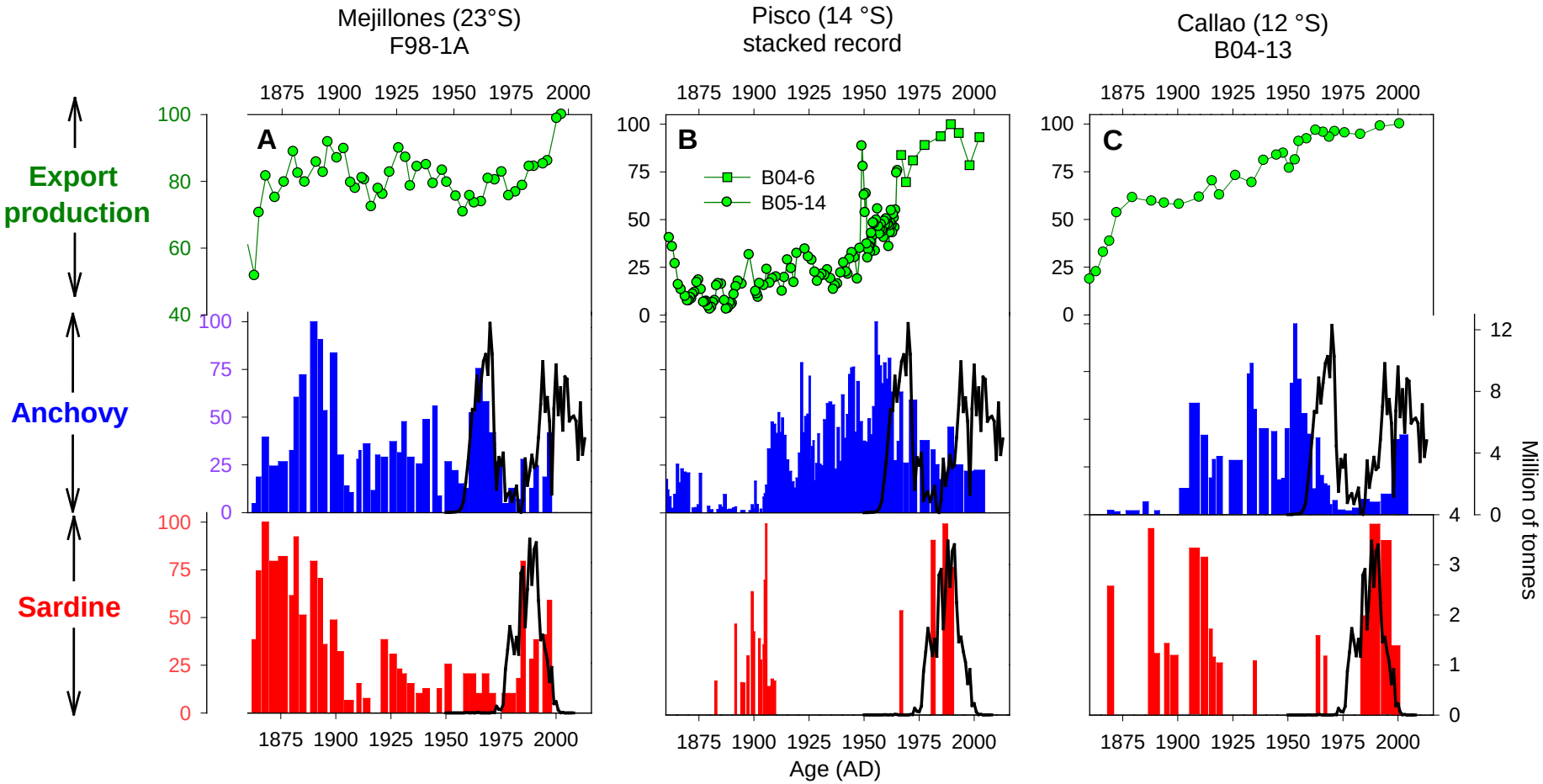


# Paleoceanographic reconstructions of export production and fish productivity along the Humboldt Current System




The records show two anchovy (~1910-mid 1970s, and from the late 1990s to the date) and two sardine regimes (~1890–1910, and mid 1970s–late 1990s). High sardine scale fluxes in Pisco indicate the period of time of maximal expansion of sardine in the HCS

# Paleoceanographic reconstructions of export production and fish productivity along the Humboldt Current System




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

- Periods of both high anchovy and sardine abundances (e.g. Callao and Mejillones)
- Period of high anchovy and no sardine (e.g. Pisco, ~1920 to 1960)
- High sardine and low anchovy (e.g. Pisco, ~1890-1900)

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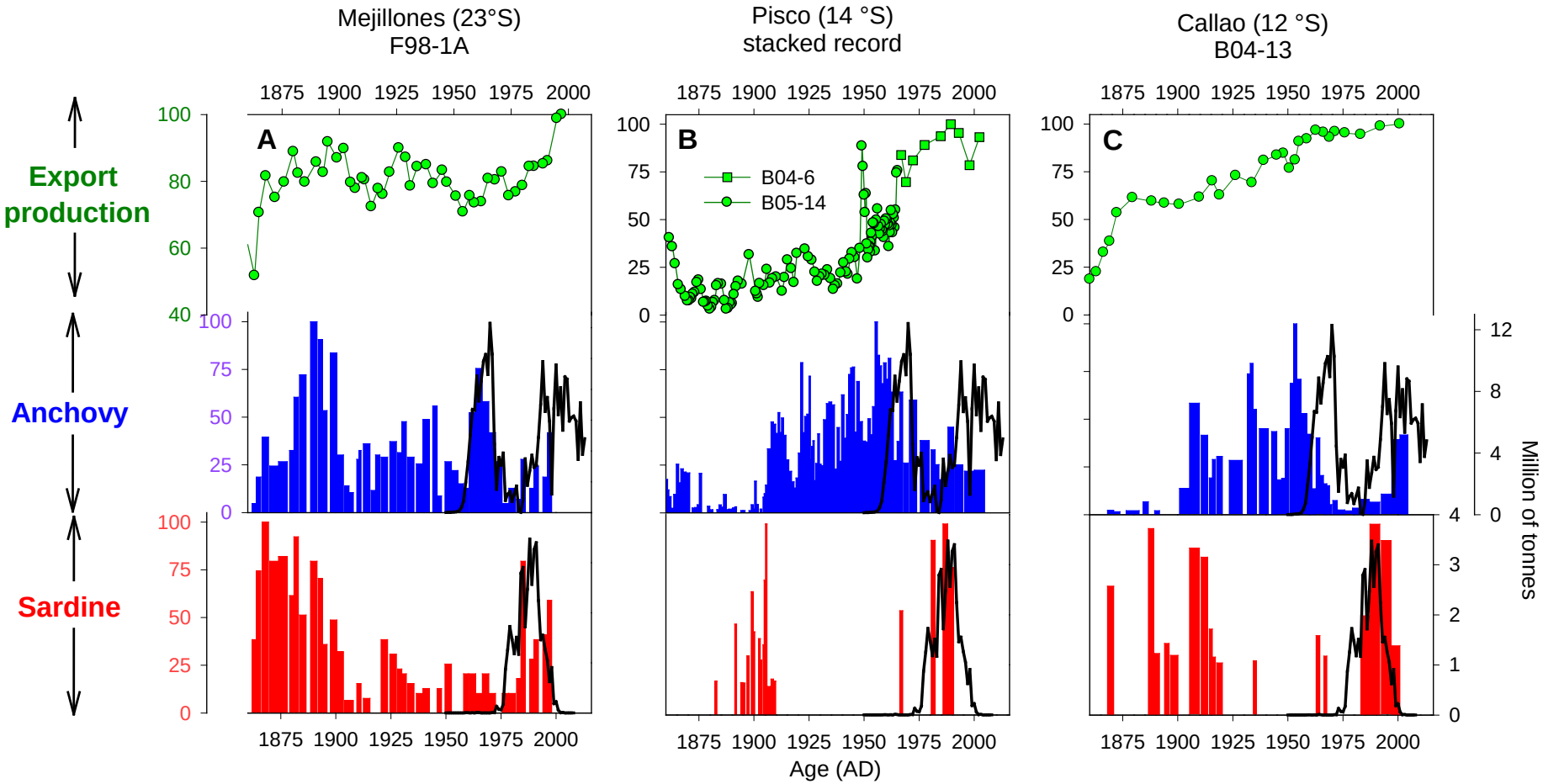
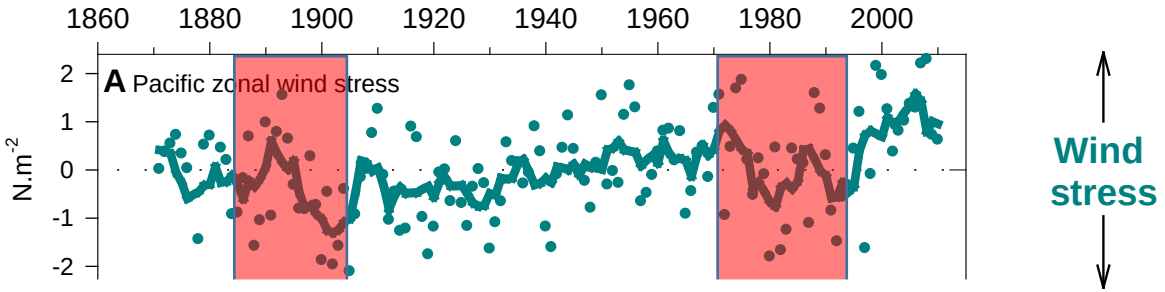



The duration of the anchovy and sardine regimes display irregular lengths of time in contrast to the suggested 50-60 years periodicity of anchovy and sardine fluctuations derived from fishery .

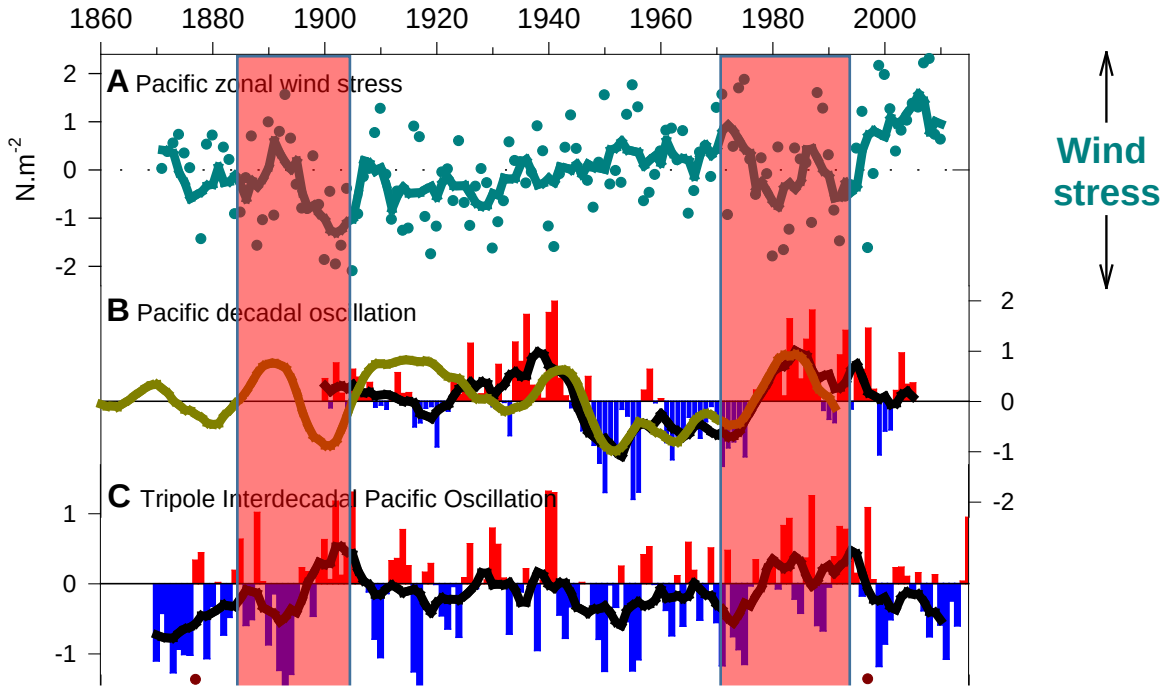
# Multidecadal changes in tropical and regional indices of ocean-atmosphere variability




The two sardine regimes, from ~1890–1910 and mid-1970s–late 1990s) are generally contemporaneous with time periods of weaker zonal Pacific wind stress, however the correlation of sardine SDR with the Tropical wind stress (r=-0.06, n=35, $p$<0.74) is not significant.

# Multidecadal changes in tropical and regional indices of ocean-atmosphere variability

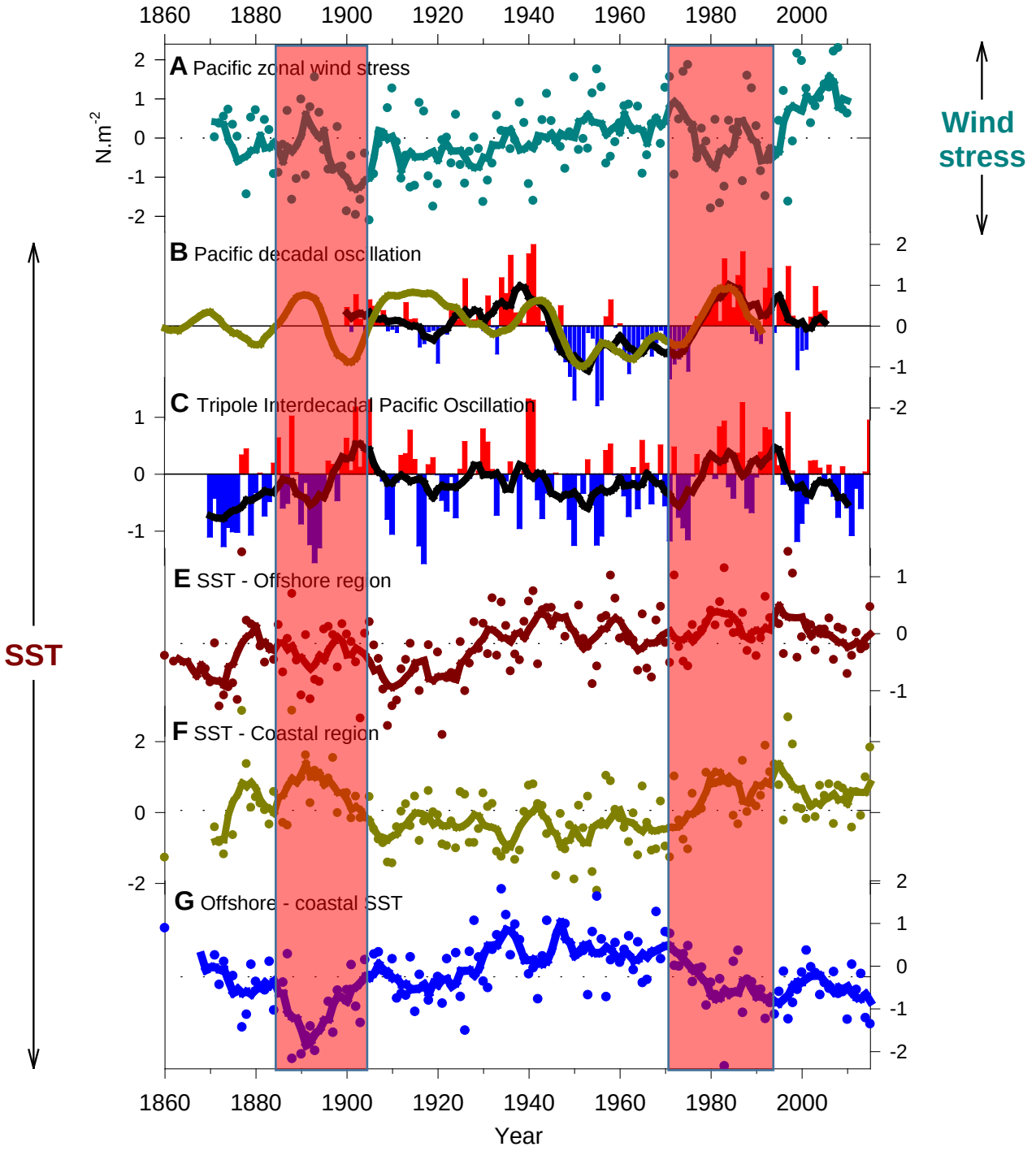
No relationship of anchovy and sardine with either the PDO or the TPI



# Multidecadal changes in tropical and regional indices of ocean-atmosphere variability

The proxy for upwelling intensity more consistently coincide with anchovy and sardine fluctuations throughout the records

***Mechanisms: Changes in the regional 3-D habitat (e.g. T/S and oxygenation of coastal waters) as a driver of anchovy and sardine fluctuations***



# Multidecadal scale variability and trends in the HCS during the last 150 years:

## *Bottom-up process: From upwelling to guano birds*

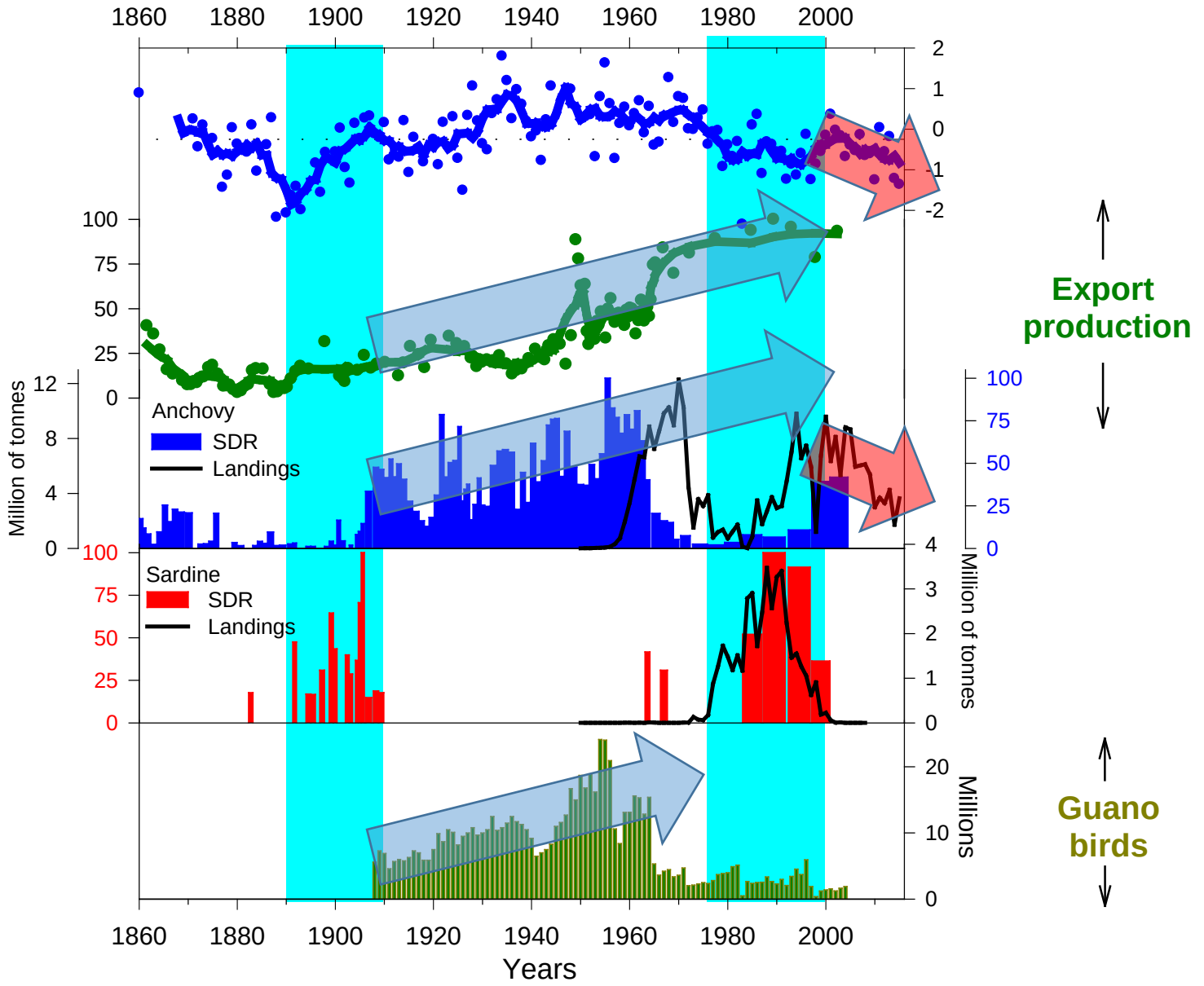
**UPWELLING**


Anchovy

Sardine

**Cross-shore SST gradient**

**Fish abundance**




**Export production**

**Guano birds**

# Summary and conclusions

- The modes and timescales of variability observed in our records demonstrate that the range of variations observed in the late 20$^{th}$ century are only part of the multiple responses of the HCS to climatic and oceanographic changes

- The different combinations of anchovy and sardine abundances, and especially the non-alternating fluctuations, do not support the paradigm of regular anchovy and sardine alternations

- Regional dynamics as important as basin scale dynamics underlying anchovy-sardine fluctuations. These findings refute a linear driving effect of the PDO in fish fluctuations in the HCS.

- Changes in the local 3-D habitat, triggered by decadal to multi-decadal changes in upwelling intensity from either basin-scale and/or regional forcing, may be the main driving factor explaining anchovy and sardine fluctuations in the HCS.