

From the Holocene and towards the future: Tracking changes in the composition and dynamics of rocky shore intertidal communities on the Southeastern Pacific

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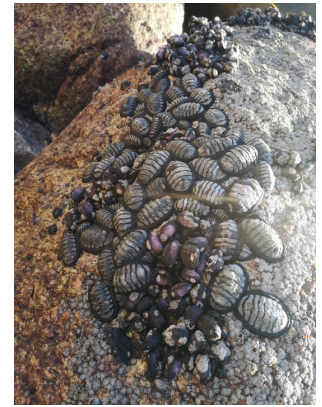
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Viña del Mar, Chile

Millenium Nucleus UPWELL – Millenium Institute SECOS





Outline



Ecological patterns: Holocene (25°S) & recent (25 yrs – 28 – 36°S)

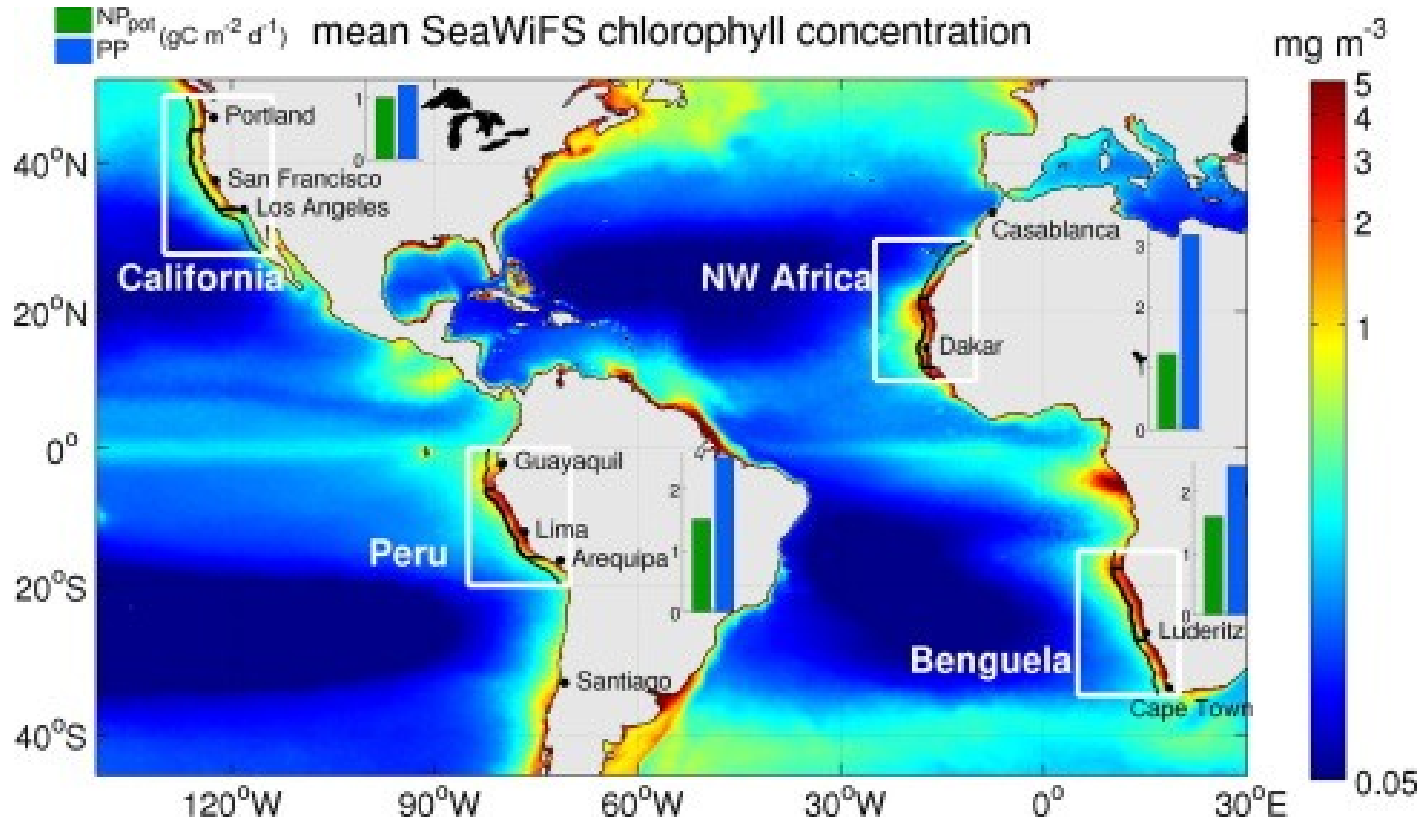
Environmental forcing: Paleoceanography & recent climate change

The interplay of humans choices and ecological processes





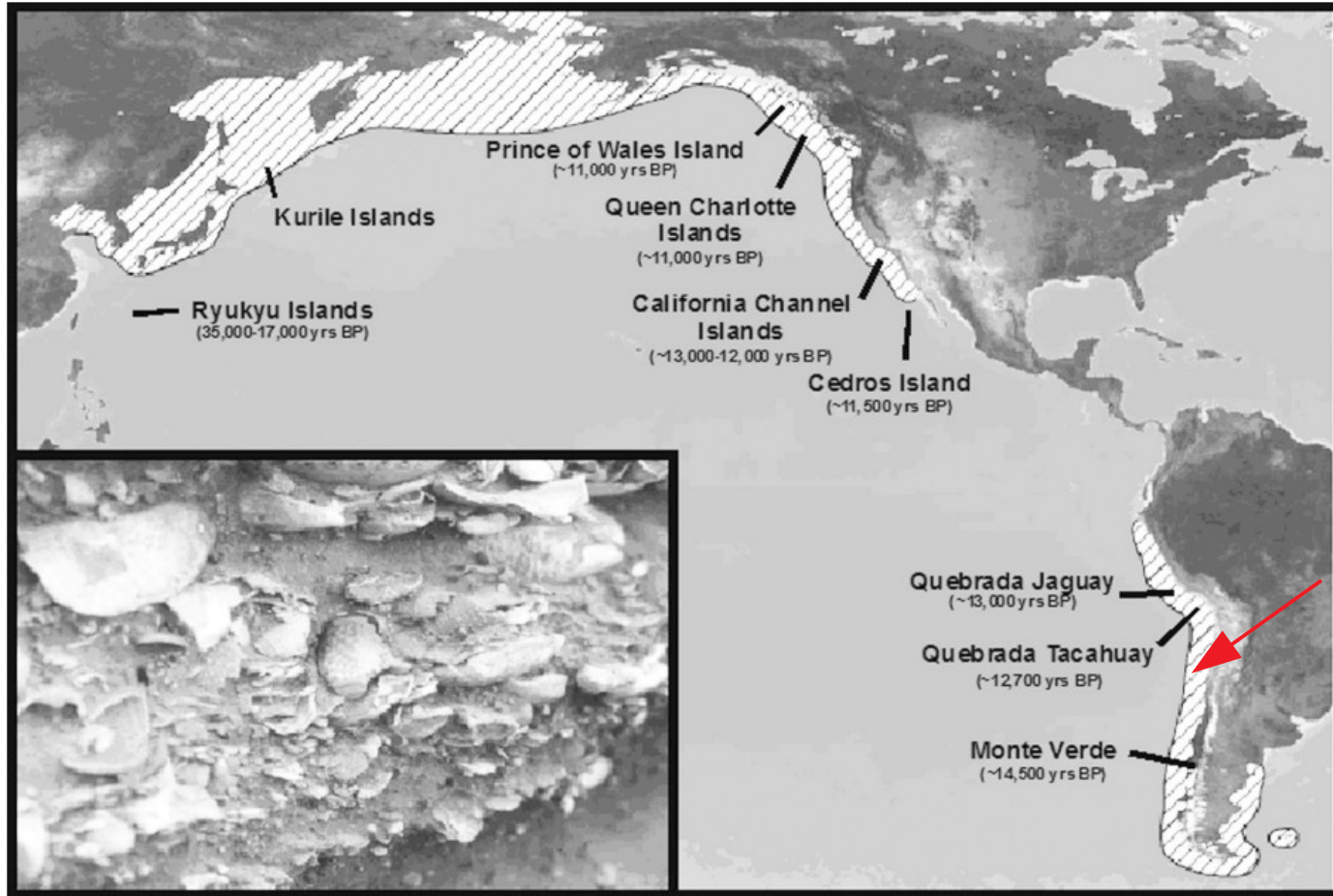
Upwelling regions worldwide



Basin-wide spatially and temporally persistent processes



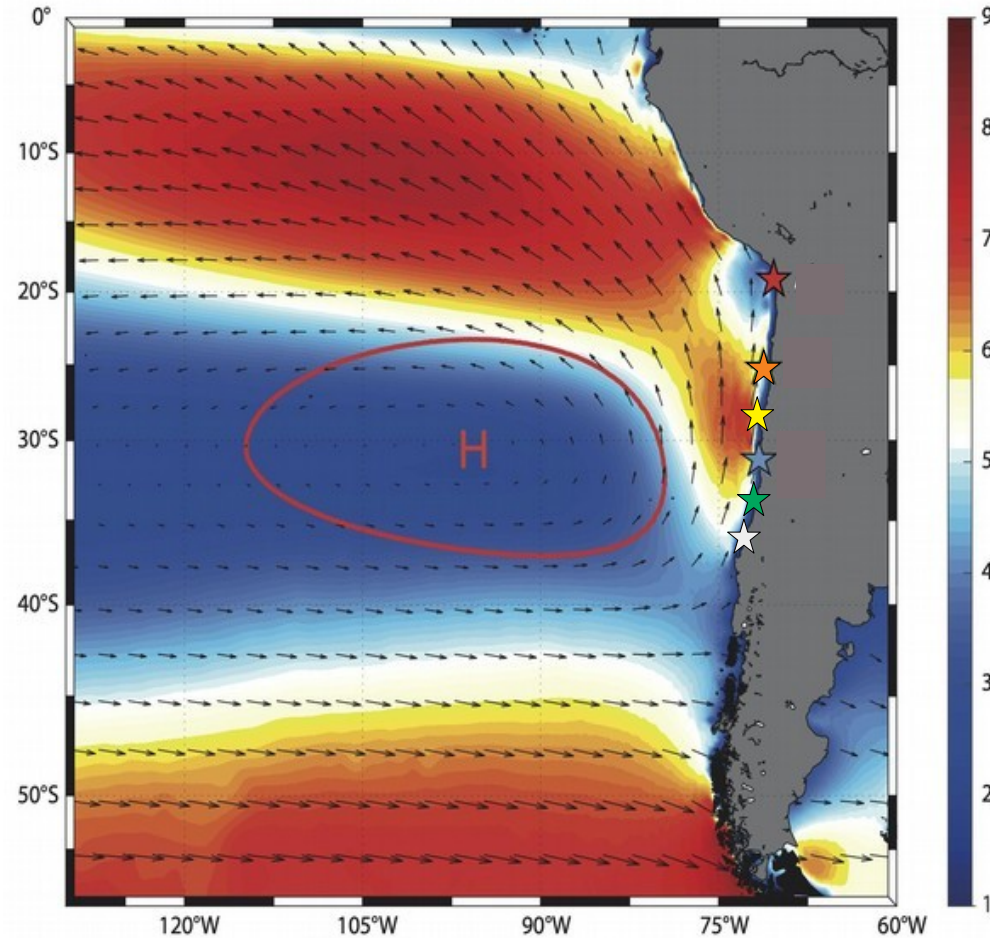
Pacific upwelling regions: a corridor?



“coastal highway” hypothesis: a stable habitat



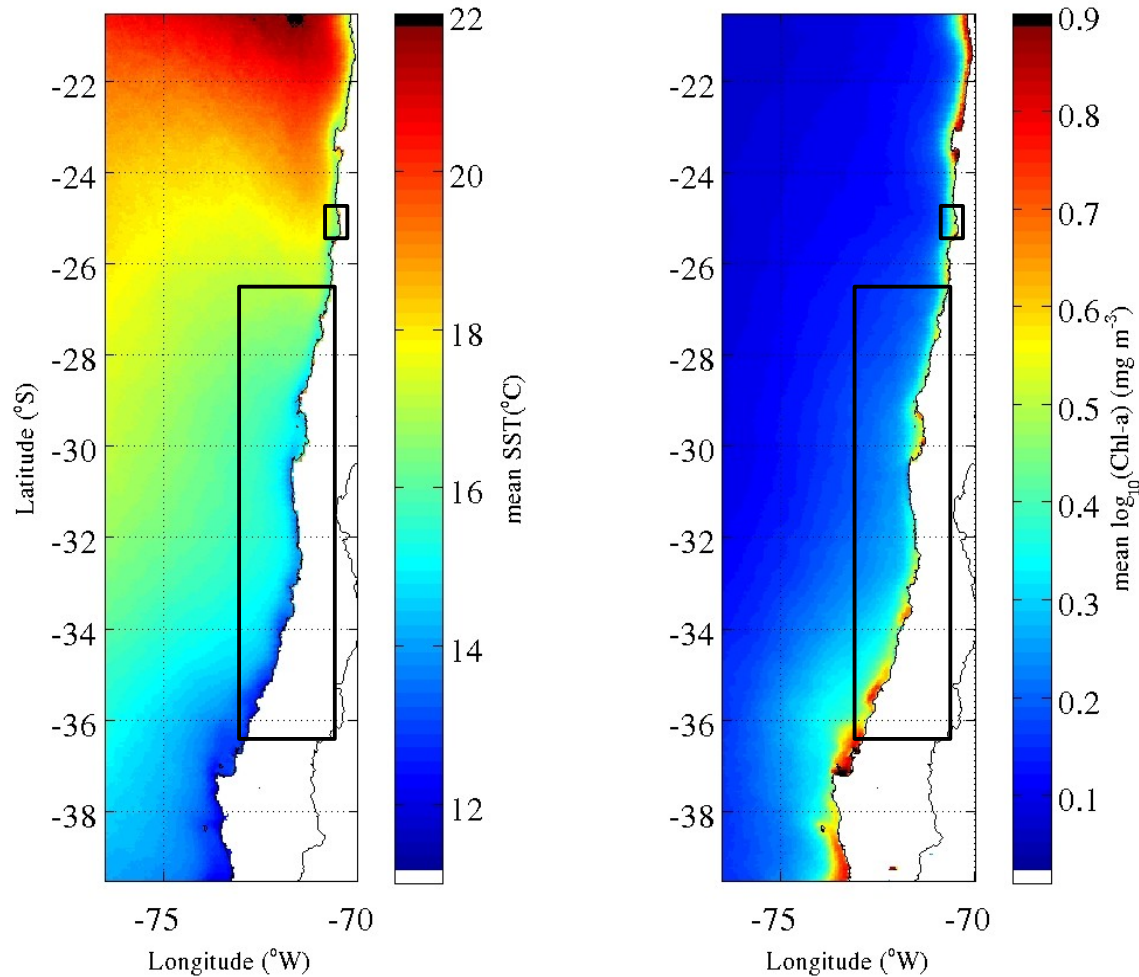
Large structure of the mean wind field



Large-scale heterogeneity in mean conditions



SST & chl-a variability in space (modern)



Humboldt current: archaeological and ecological studies

**The archeological record:
a trans-Holocene view of the nearshore ecosystem**





The Atacama coastal desert

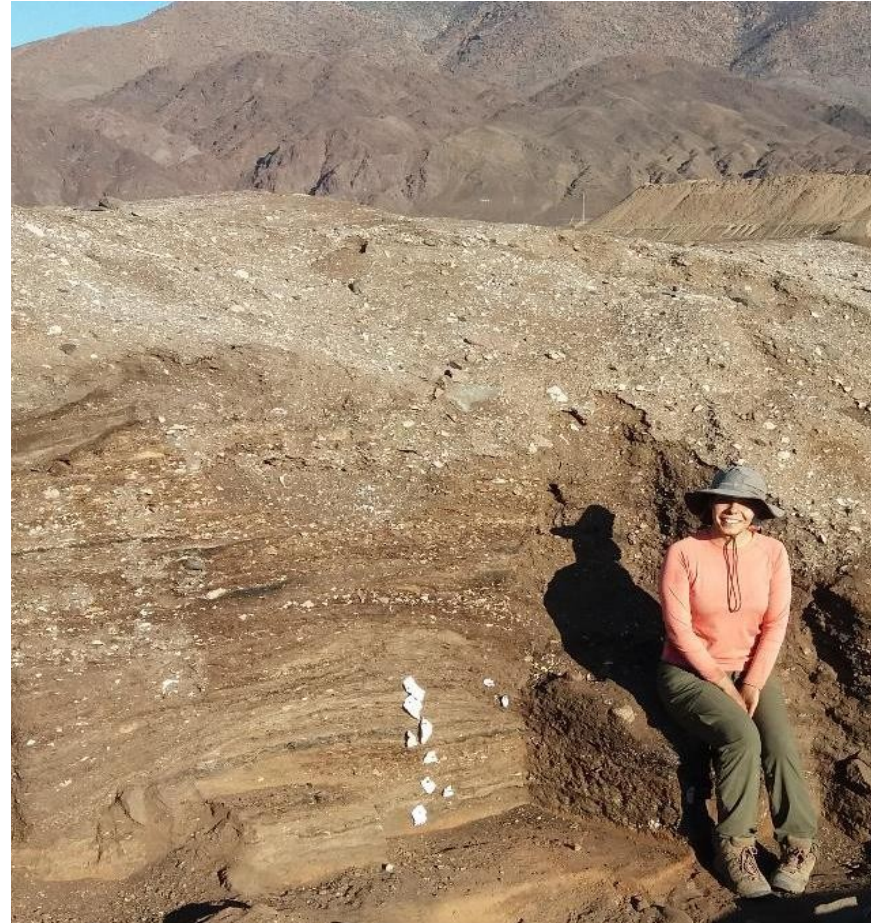
Arreic coast (no rivers) – Hyperarid conditions ($<1\text{mm}/\text{yrs}$ rain)

Narrow coastal platform – high (2.000 m) and steep coastal range & shelf
Aguadas, only source of fresh water





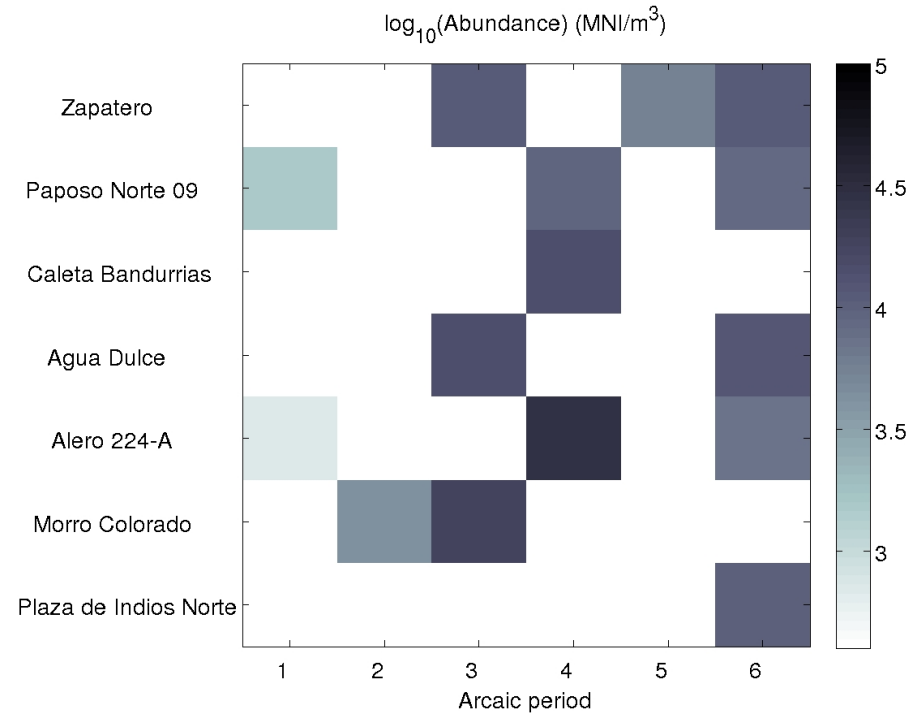
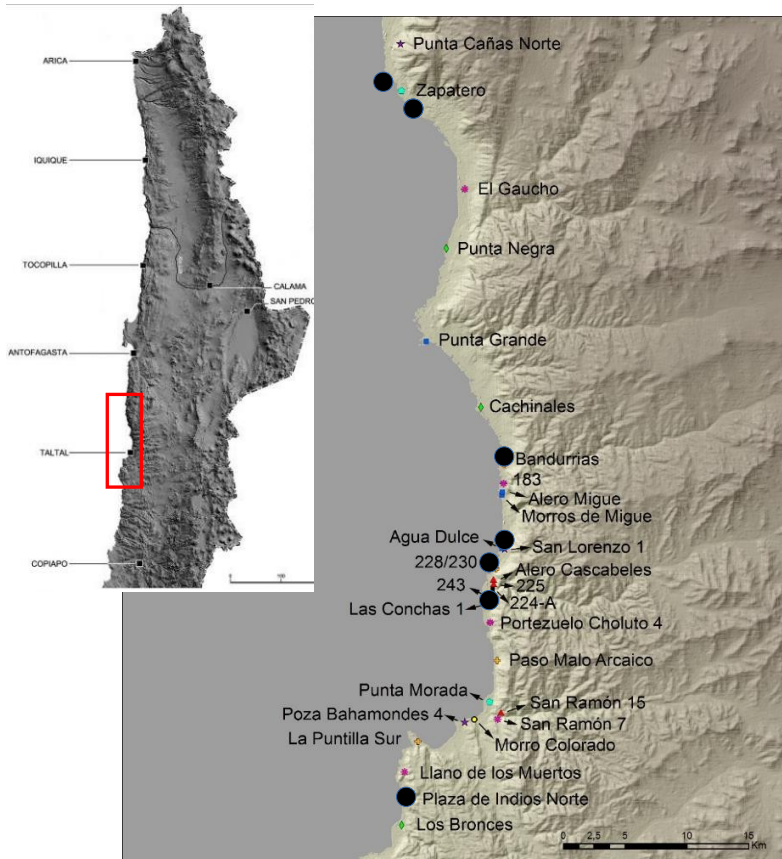
Shellfish middens of the Atacama coastal desert



>1300 species records – 65 taxa, intertidal, subtidal, rock, sand, etc
Column sampling, 7 sites (50 kms), ca. 11.000 yrs



Taltal: long-term archaeological studies



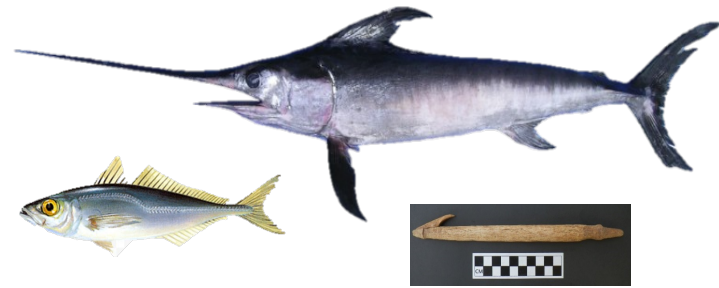
Large diversity of occupational environments, continuous coverage



Atacama desert archaeological periods (Taltal)



	Period	years ka cal BP
Late Holocene	Archaic VI	3.5-1.5
	Archaic V	4.5-3.5
Middle Holocene	Archaic IV	5.5-4.5
	Archaic III	7.5-5.5
	Archaic II	8.5-7.5
Early Holocene	Hiatus	
	Archaic I	12-10



Late Holocene
Diversified economy



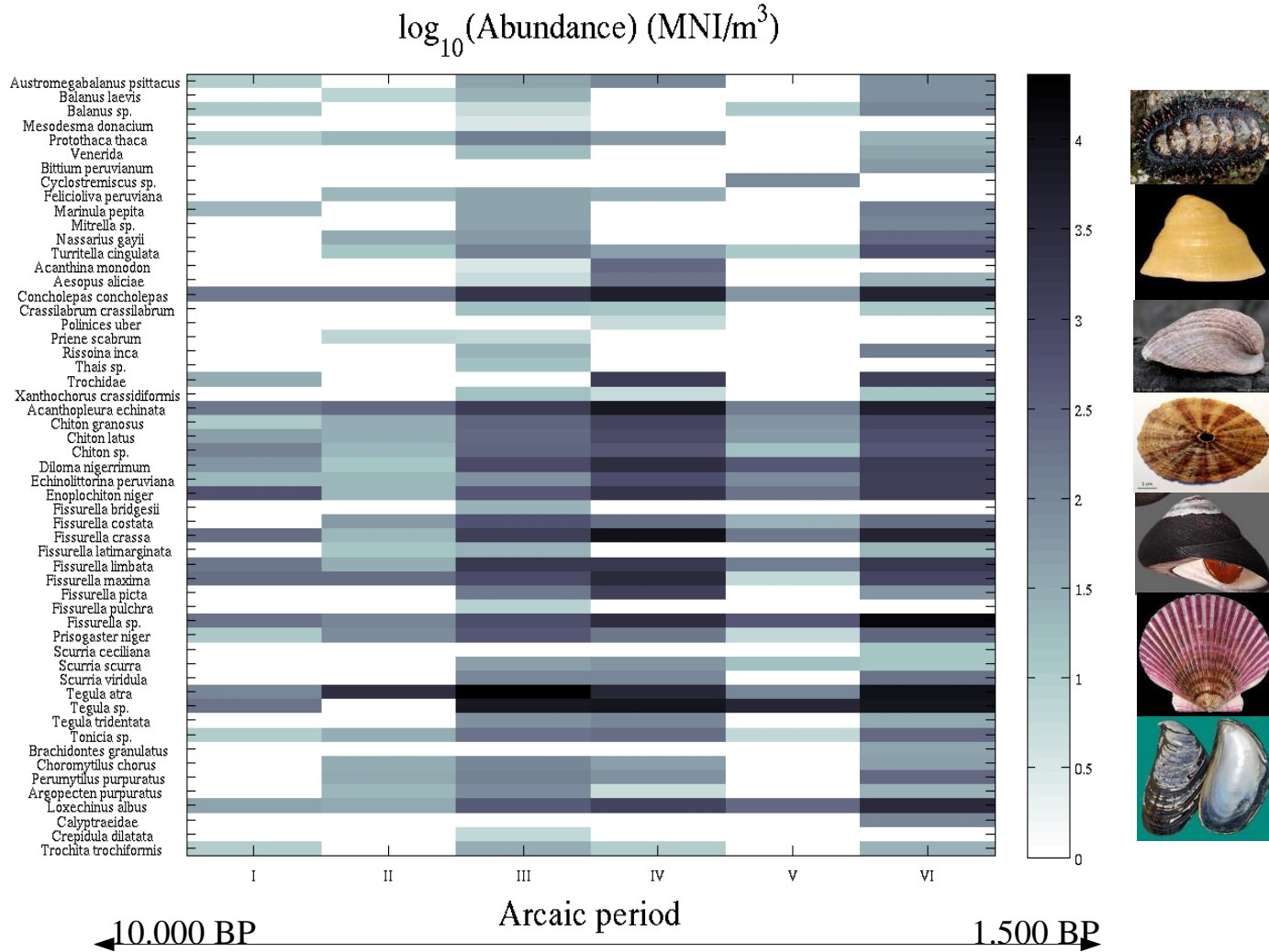
Middle Holocene
Specialized maritime economy

Early Holocene
Generalized coastal economy



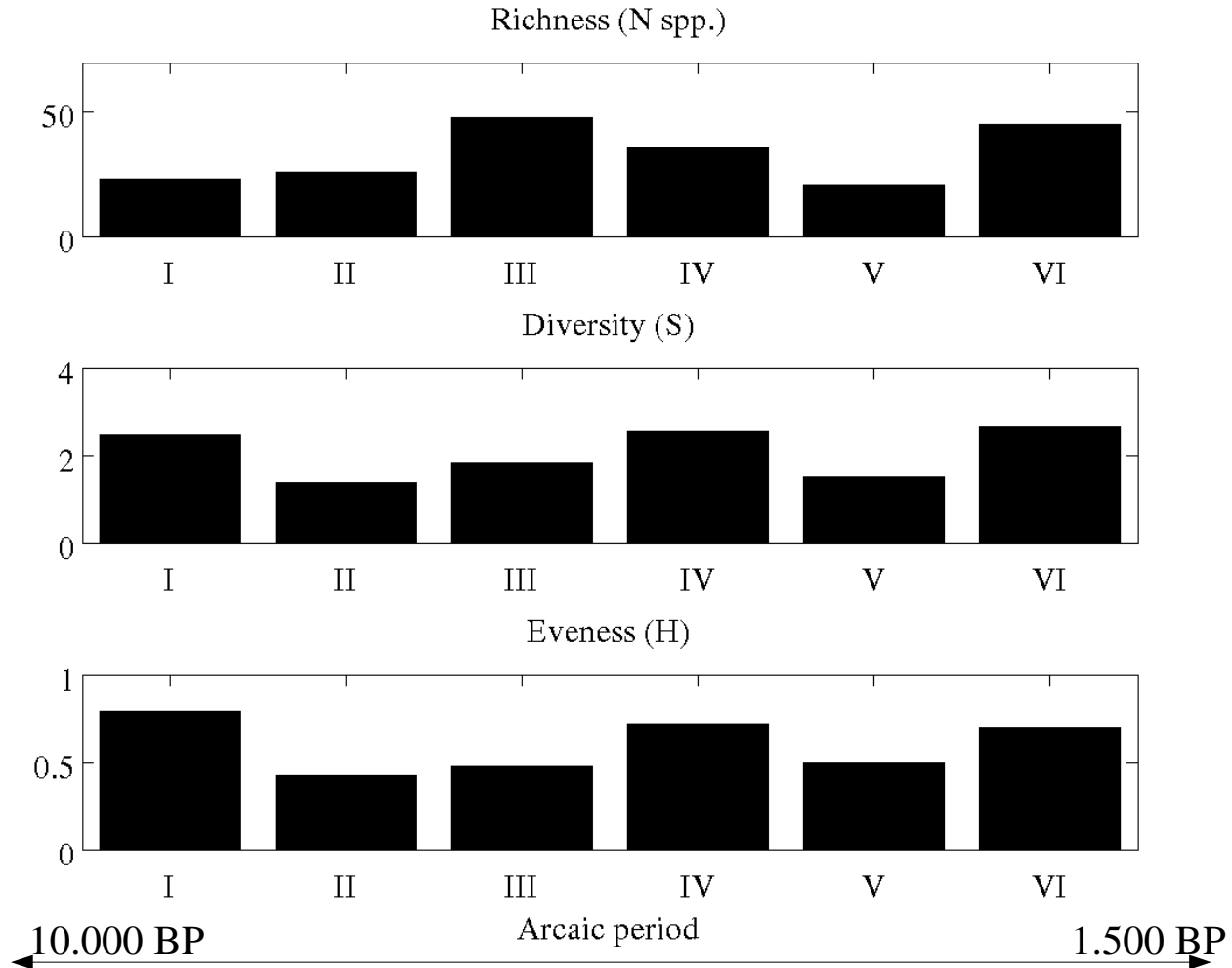


Mollusks in the archaeological record





Shellfish diversity & abundance





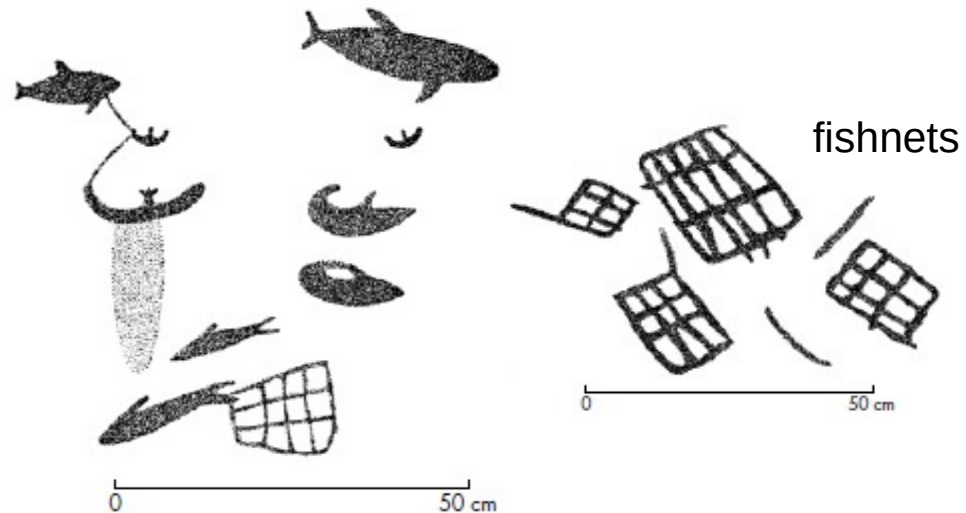
Across the Holocene (12.000 yrs)



Large changes in *relative* and *overall* abundances

Subtle *compositional* changes

Clear association with the *cultural* epochs





What is happening now?



Limarí (30.75°S, June 2011)



Long-term monitoring (25 yrs)

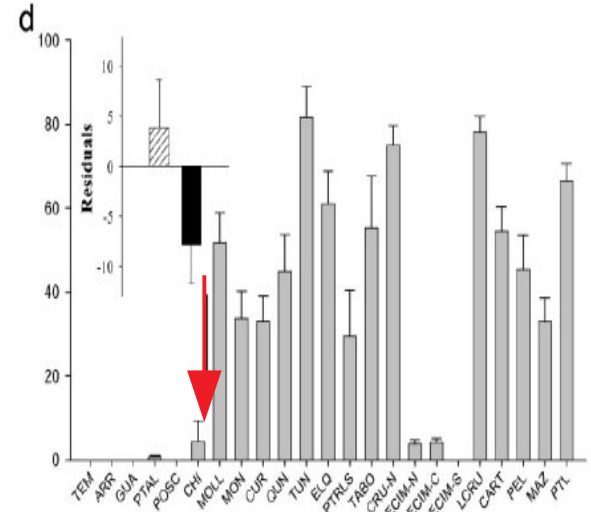
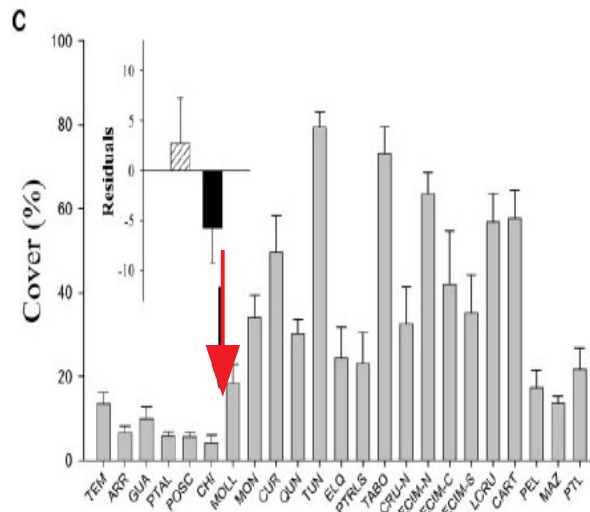
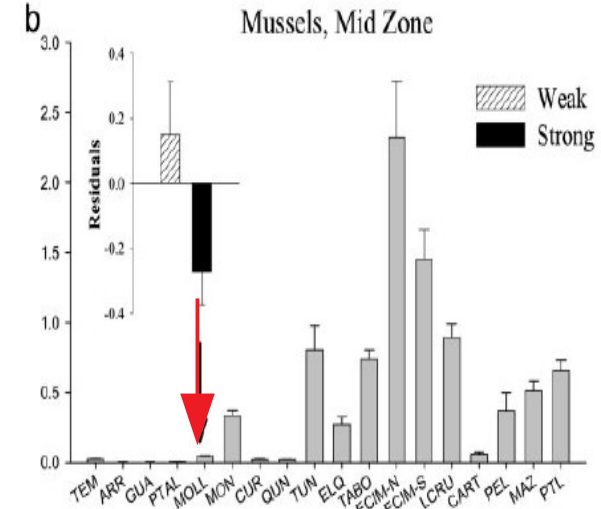
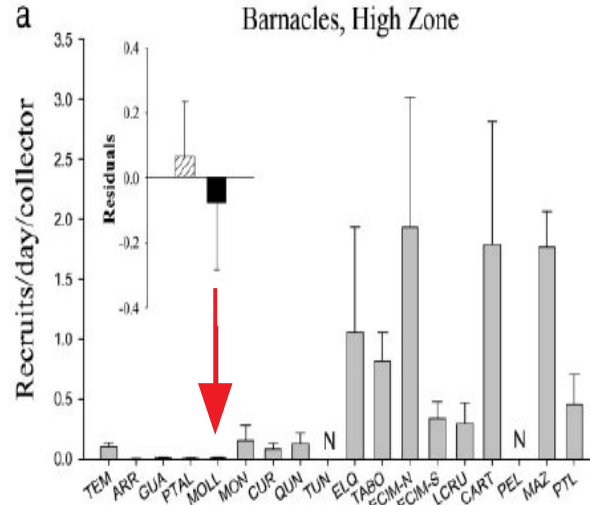
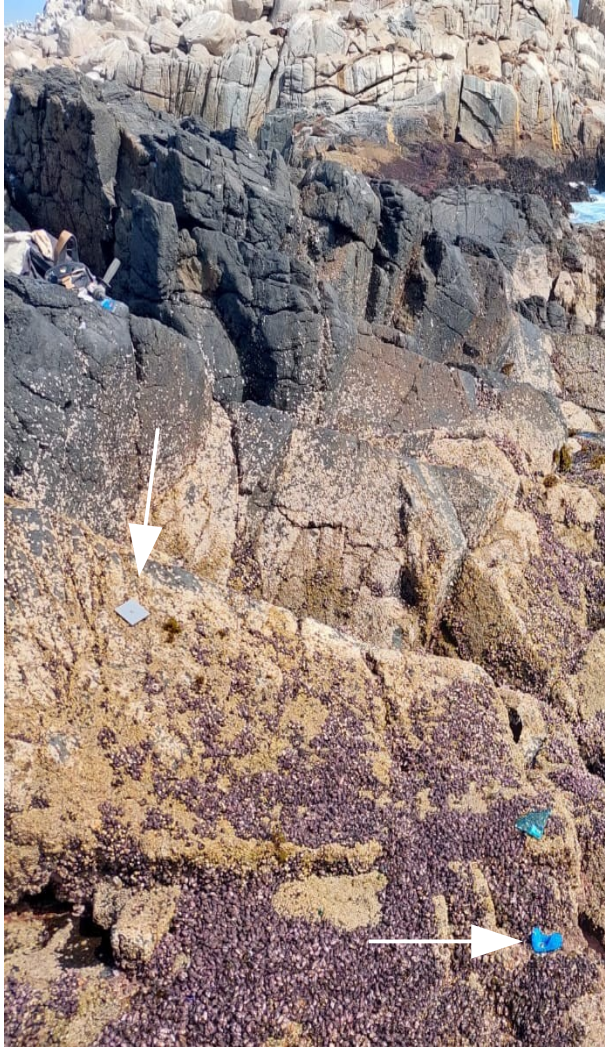


>6500 quadrats – 35 taxa, rocky shore intertidal
25 locations – monthly monitoring of invertebrate larval supply

Montemar (32.95°S, September 2022)



Larval supply and community structure





A spatial transition in community structure



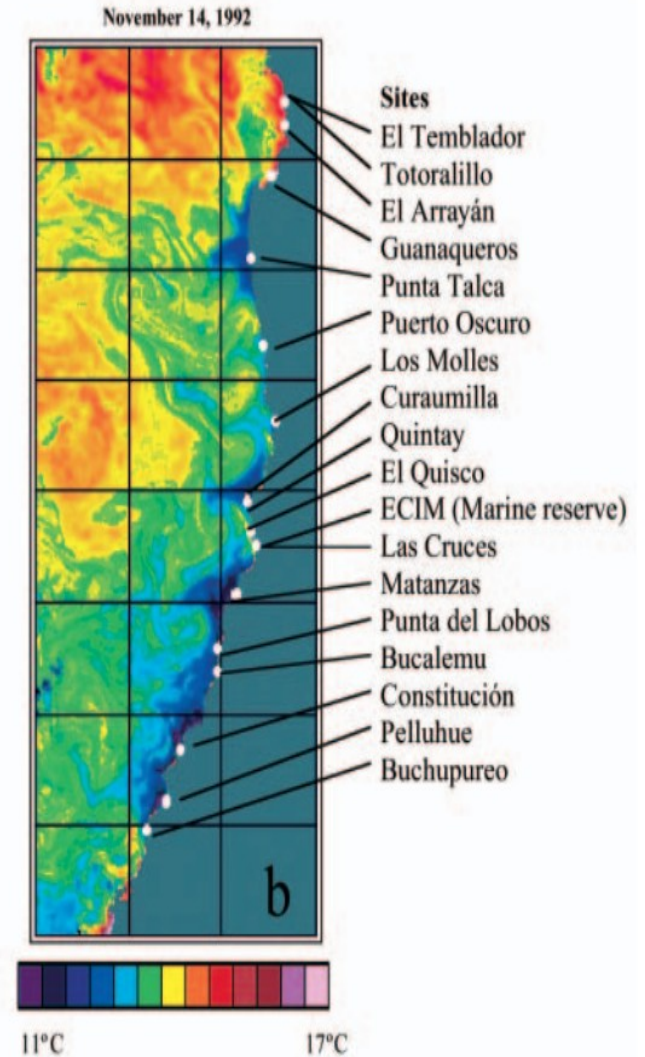
north



center



south

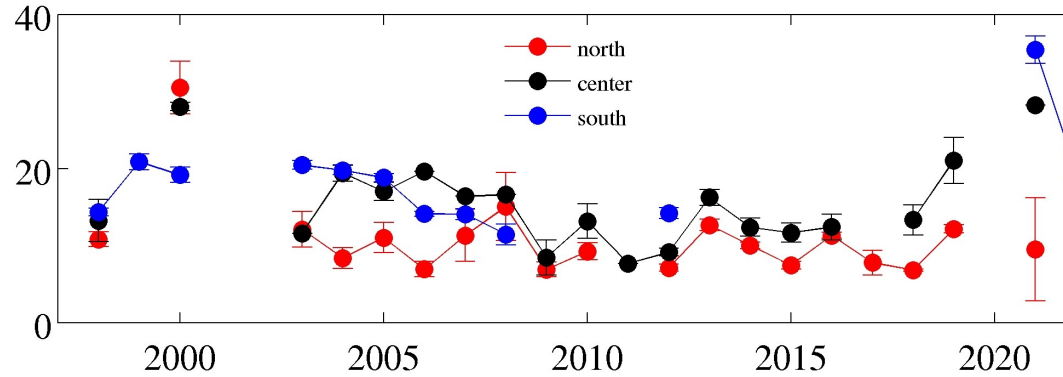




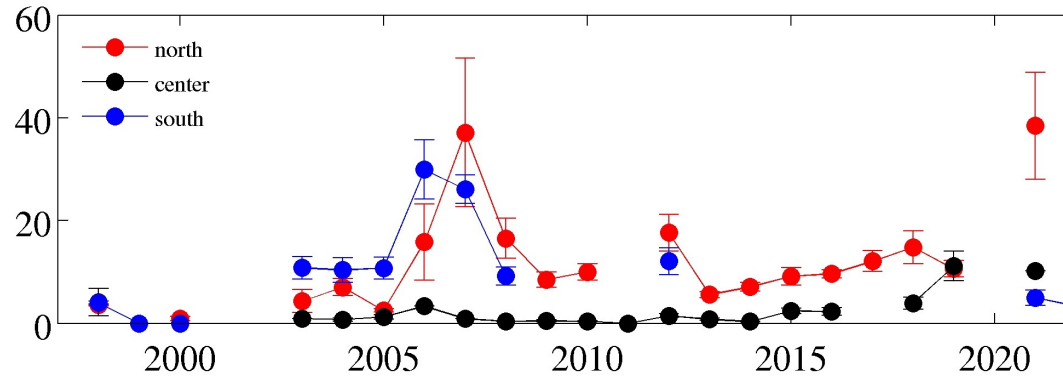
Long-term persistence of spatial patterns



Kelp- Low Intertidal zone



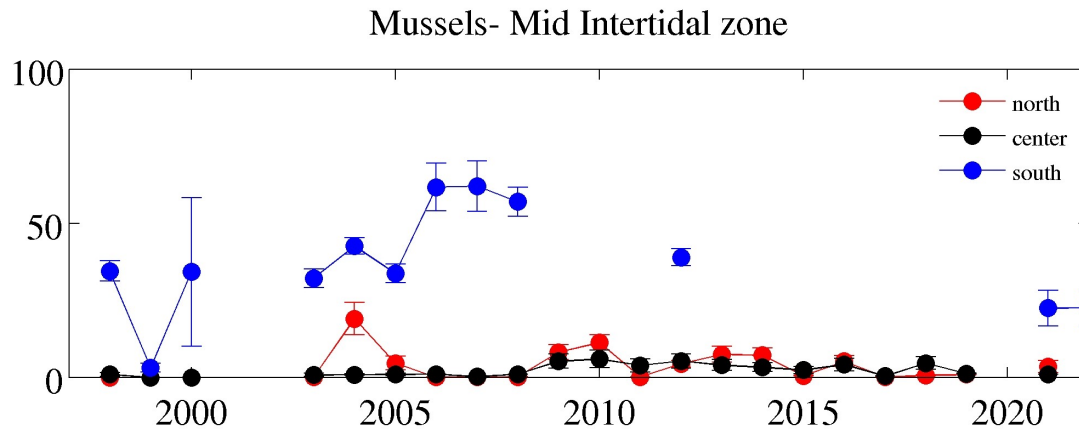
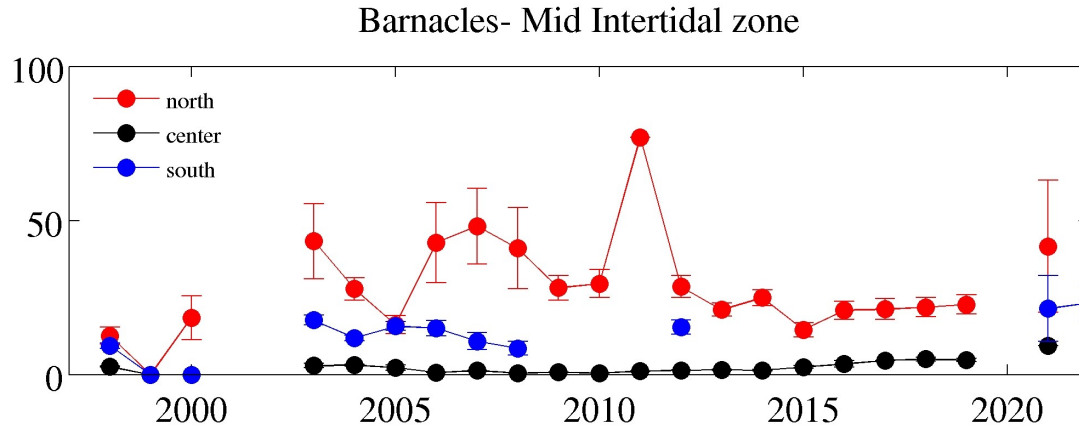
Barnacles- Low Intertidal zone



Interannual changes – recent increases



Long-term persistence of spatial patterns



Reflected in long-term changes on adult abundance



Over recent times (25 yrs)



Minor changes in *relative* and *overall* abundances

Subtle *compositional* changes

Some hint of *interannual* changes



What is the role of environmental forcing as a driver?



Carbonate (Calcite) samples from *Fissurella* shells



Fig. 2. *F. maxima* shell. The square marks carbonate microsamples.

UC Davis. Instrument precision (1σ) ± 0.03 ‰ for $\delta^{13}\text{C}$ and ± 0.05 ‰ for $\delta^{18}\text{O}$

Date calibration: Calib 8.1, SHCal 20 curve, ΔR 31 ± 156 (Early and M. Holocene) and ΔR 165 ± 107 (L. Holocene) (Carre et al. 2016).

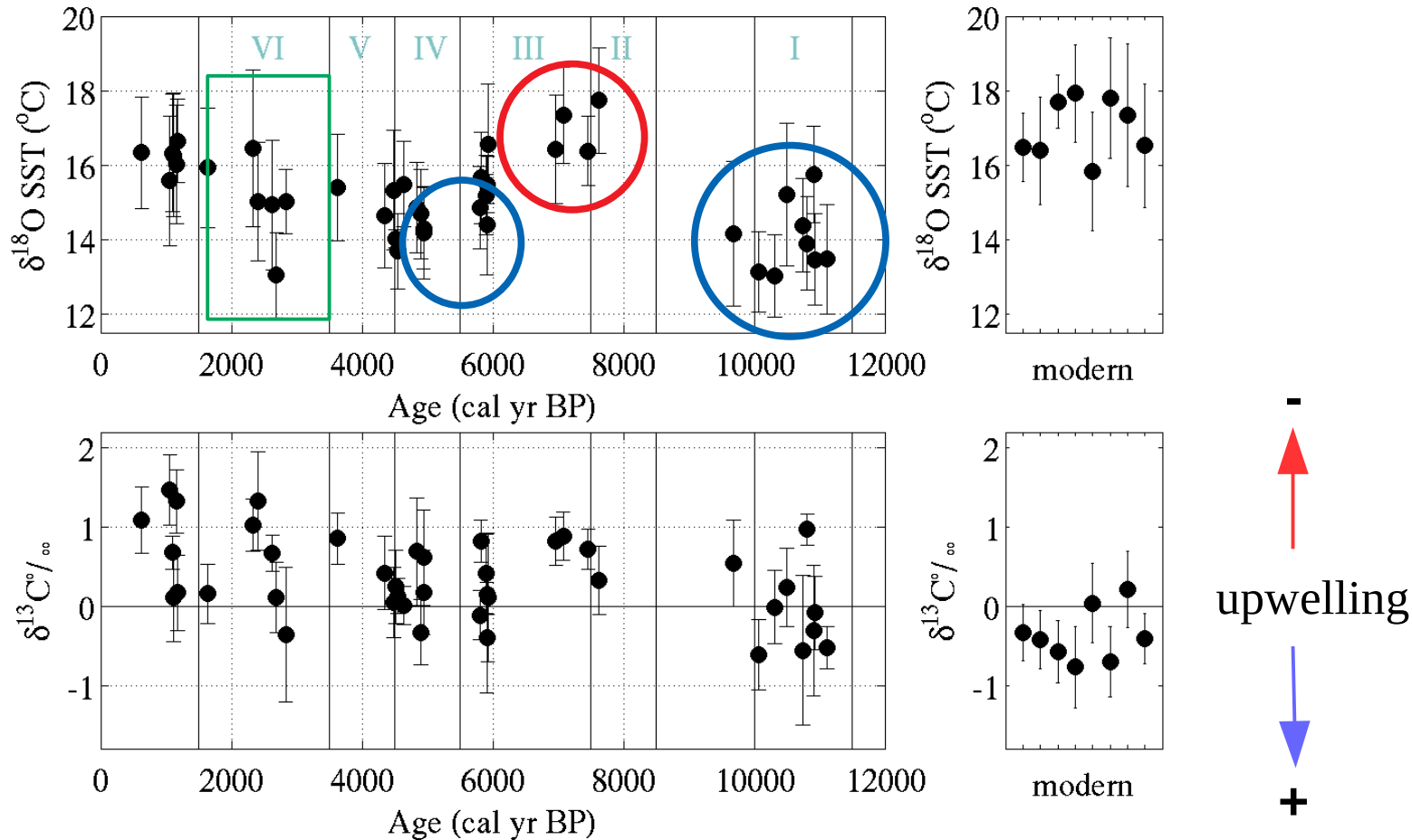
$\delta^{18}\text{O}$ values corrected for Ice volume effect (Lambeck and Chappel 2001).

Modern shell's $\delta^{13}\text{C}$ corrected for Suess effect (0,5‰).

Temperature equation for calcite obtained from Carre et al. 2005



$\delta^{18}\text{O}$ SST & $\delta^{13}\text{C}$ through time in Taltal (25°S)



Significant correlation between $\delta^{18}\text{O}$ SST & $\delta^{13}\text{C}$ ($r = 0.137$, $F = 6.16$, $df = 39$)

Major changes from the early Holocene until late mid Holocene

Modern upwelling is the strongest on record

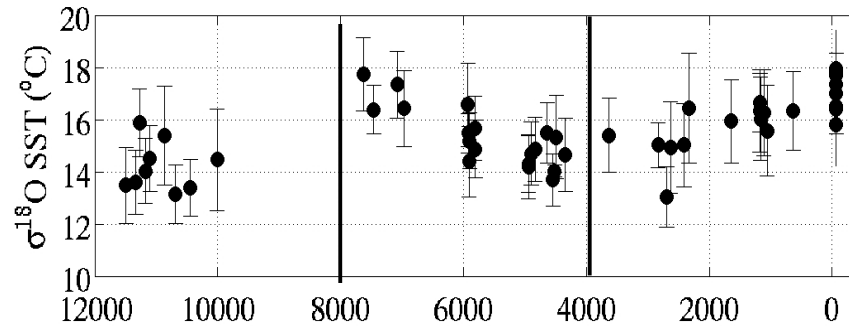


A regional SST pattern over time & space



25°S

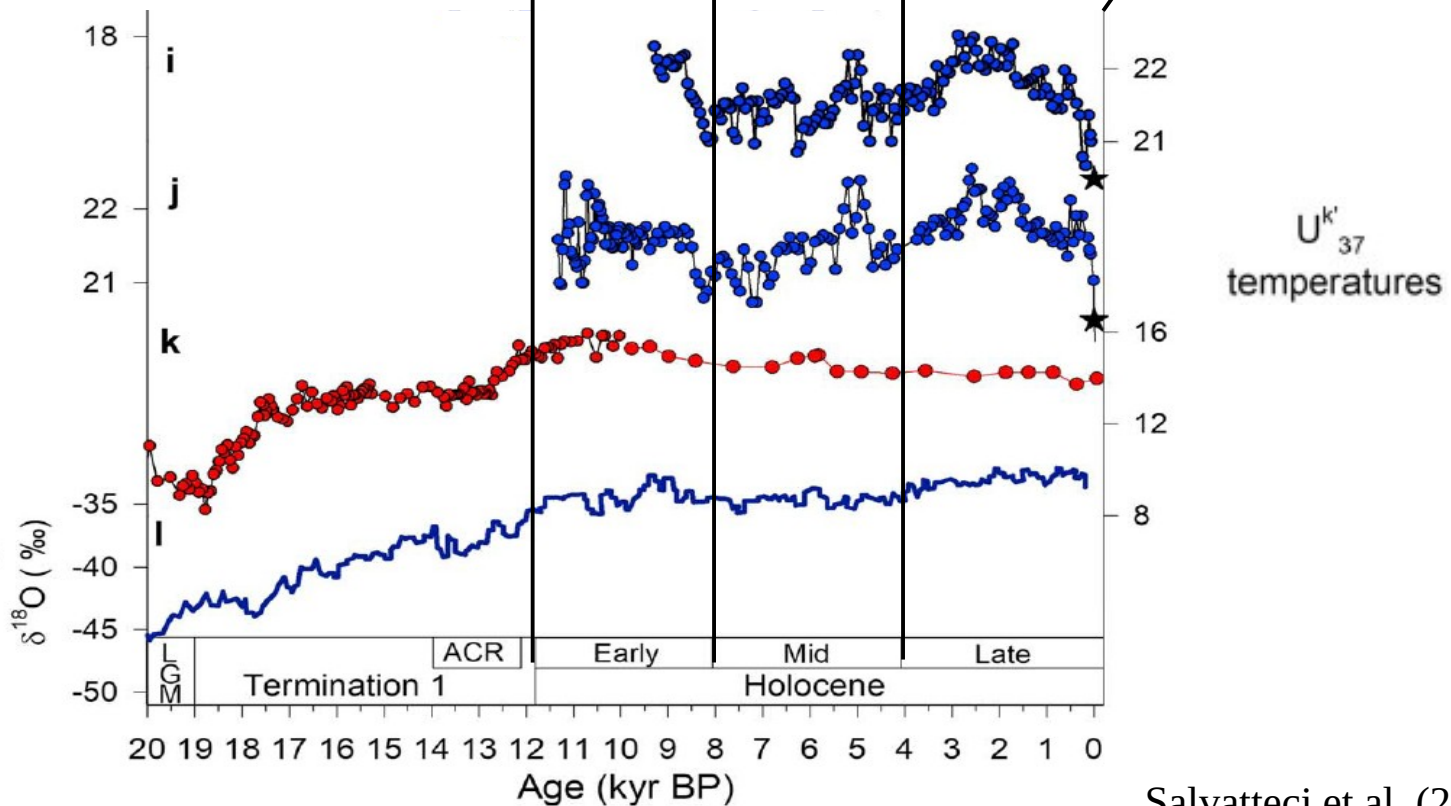
Flores & Broitman (2021) *PPP*



17°S
M135-004-3
M135-005-3

41°S
ODP-1233

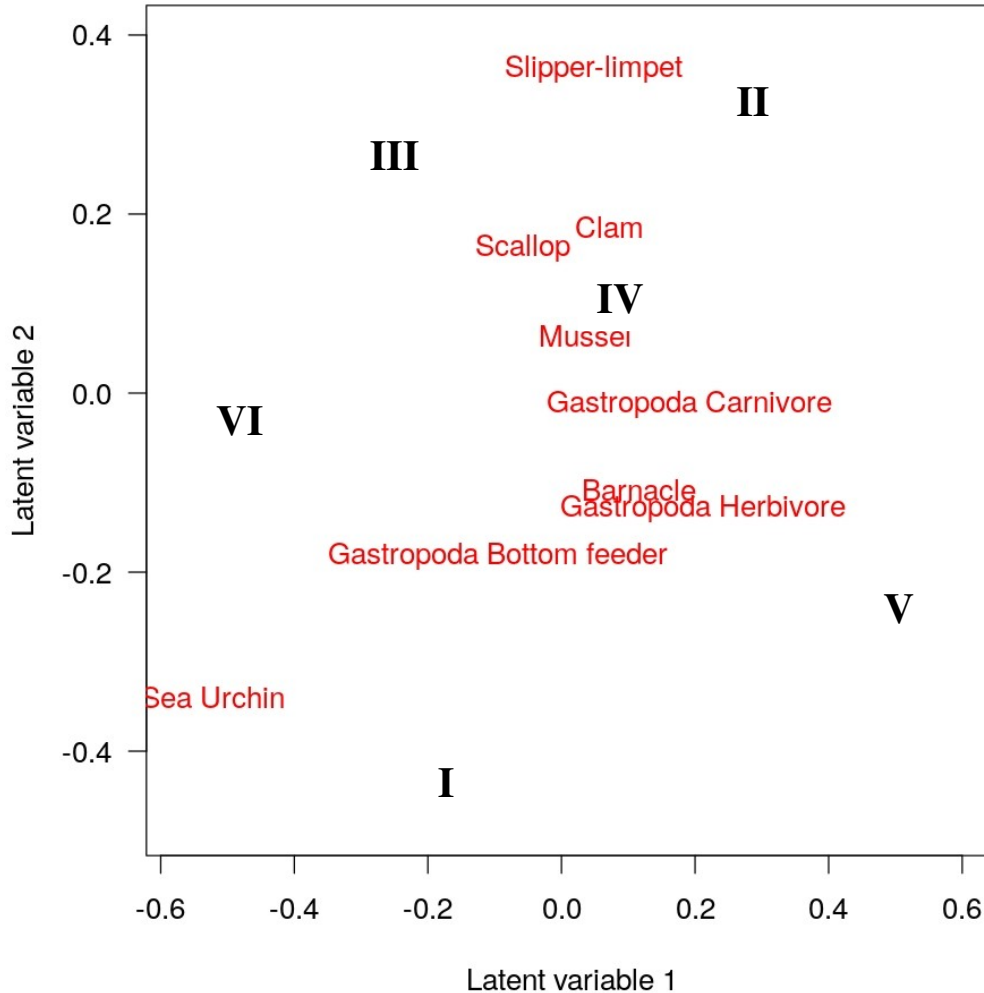
Byrd Station
Antarctica



Salvatteci et al. (2019) *GRL*



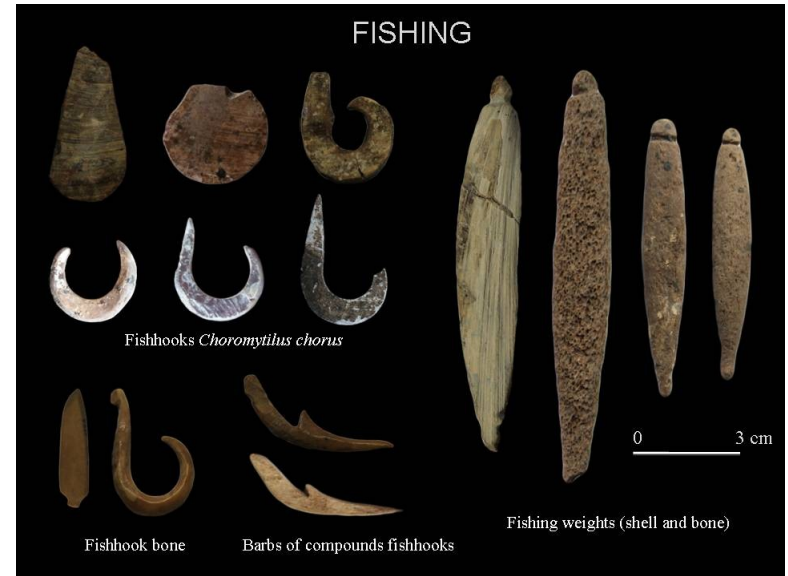
$\delta^{18}\text{O}$ SST & Molluscs by fisheries group



Early Holocene distinct (I)

Mid Holocene periods together (II, II & IV)

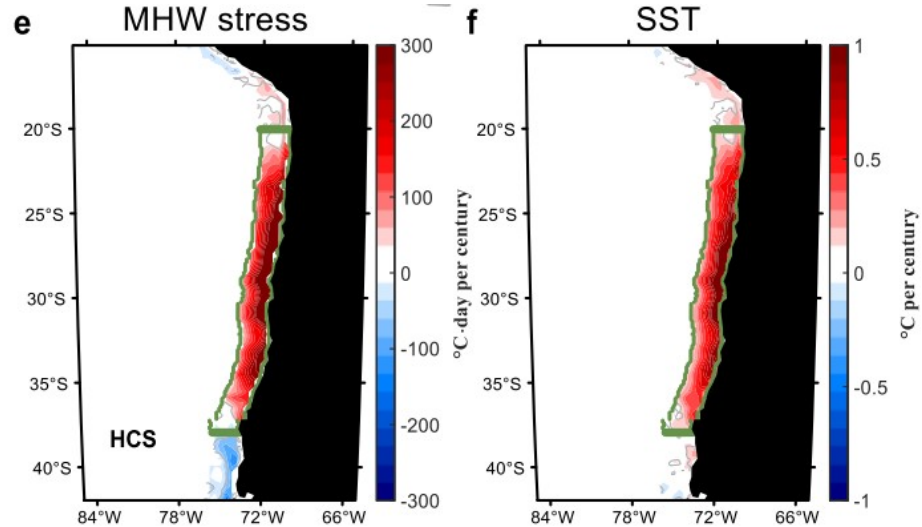
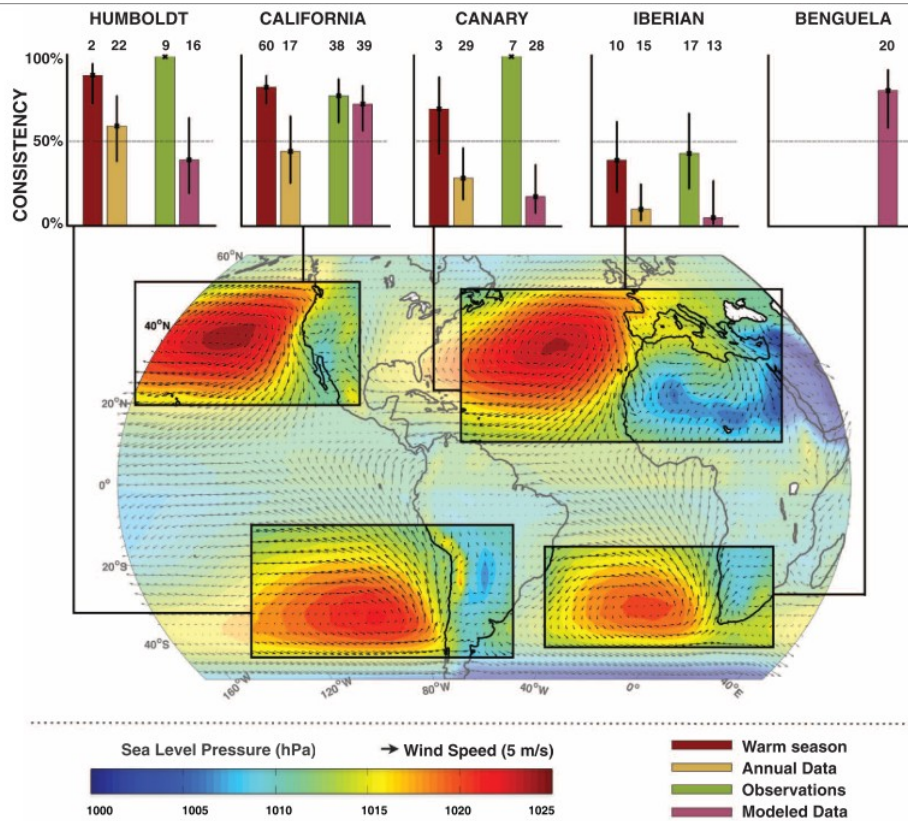
Late Holocene periods dissimilar (V & VI)



Model-based unconstrained ordination using min SST as a latent variable (Hui (2015) *Meth. Ecol. Evol.*)
AIC/BIC criteria for model selection



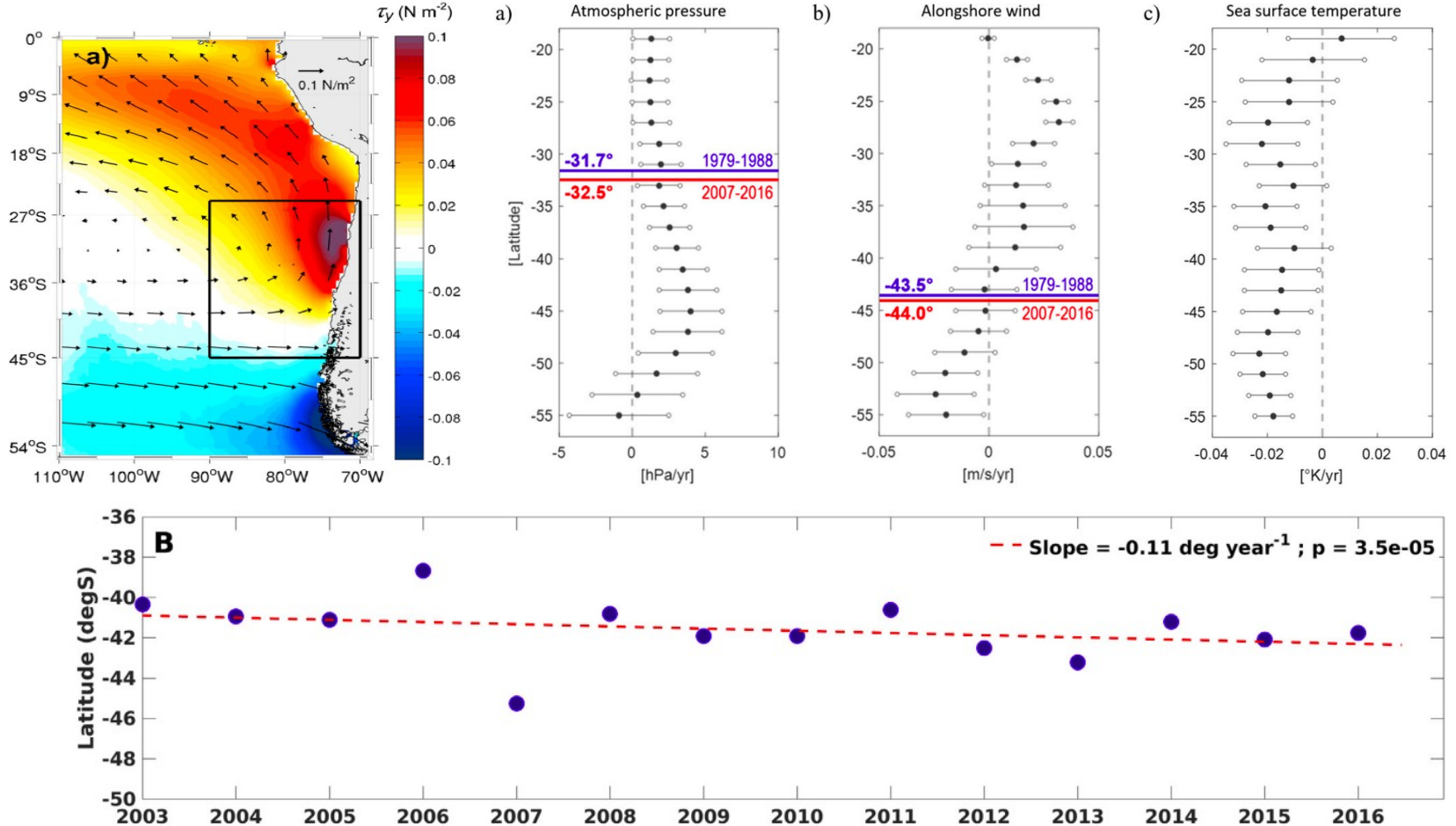
Observations, trends & predictions



Consistent intensification of upwelling along the Humboldt current
Potential for large change towards mid-century



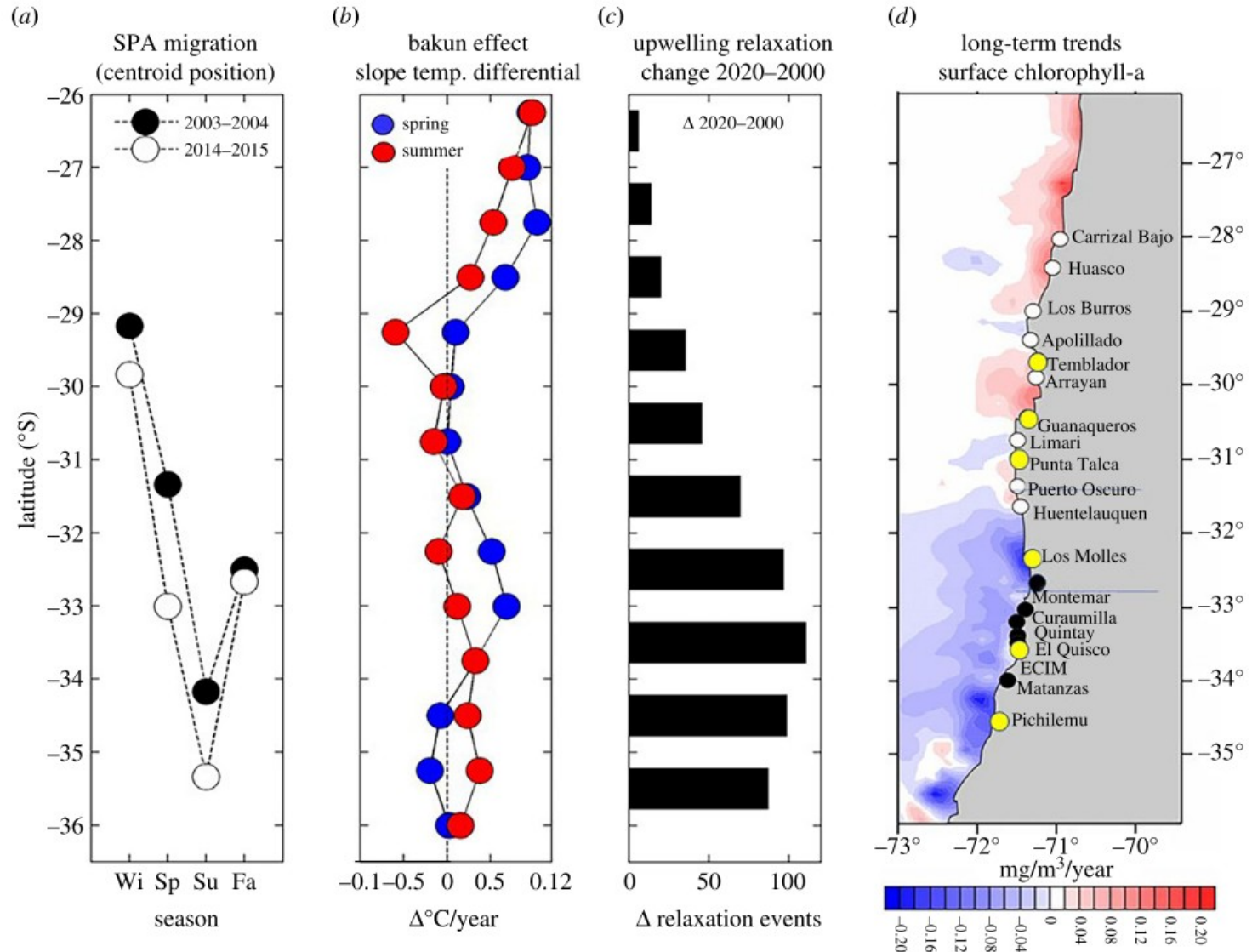
Recent climate trends



Poleward displacement of upwelling-favorable winds
Decreasing SST nearshore



Recent trends: Climate patterns

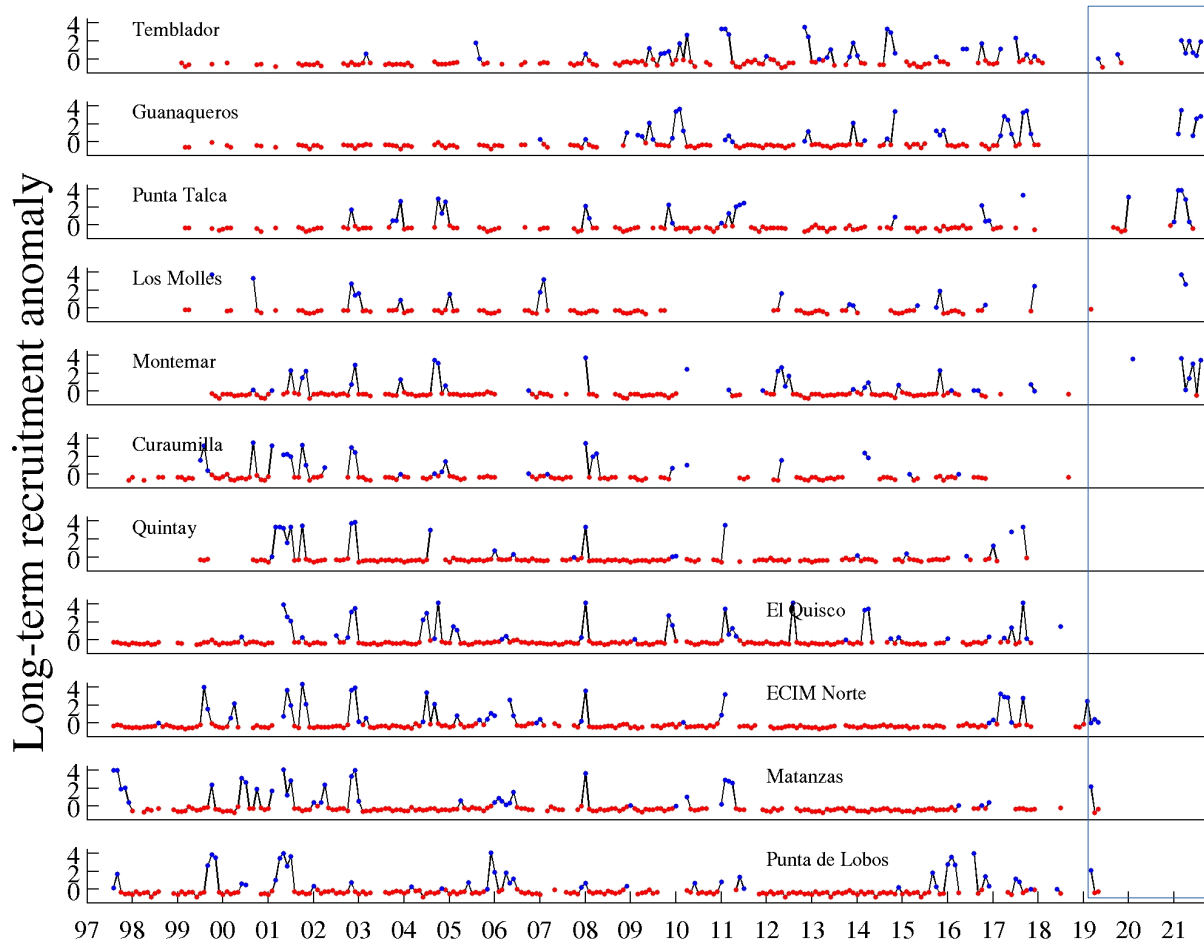




Recent trends



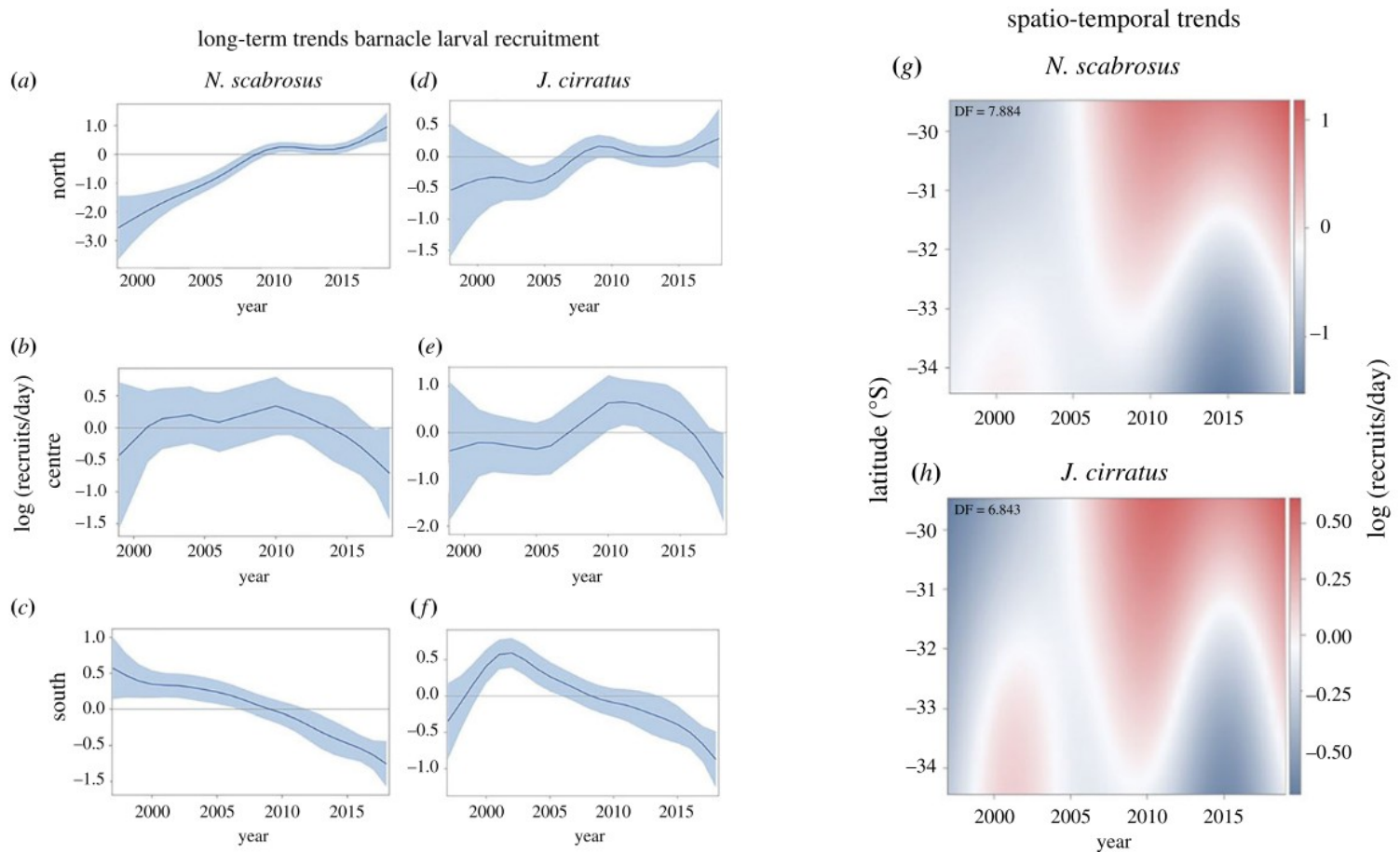
Jehlius cirratus



Analyses submitted with data until December 2019, trends ongoing...



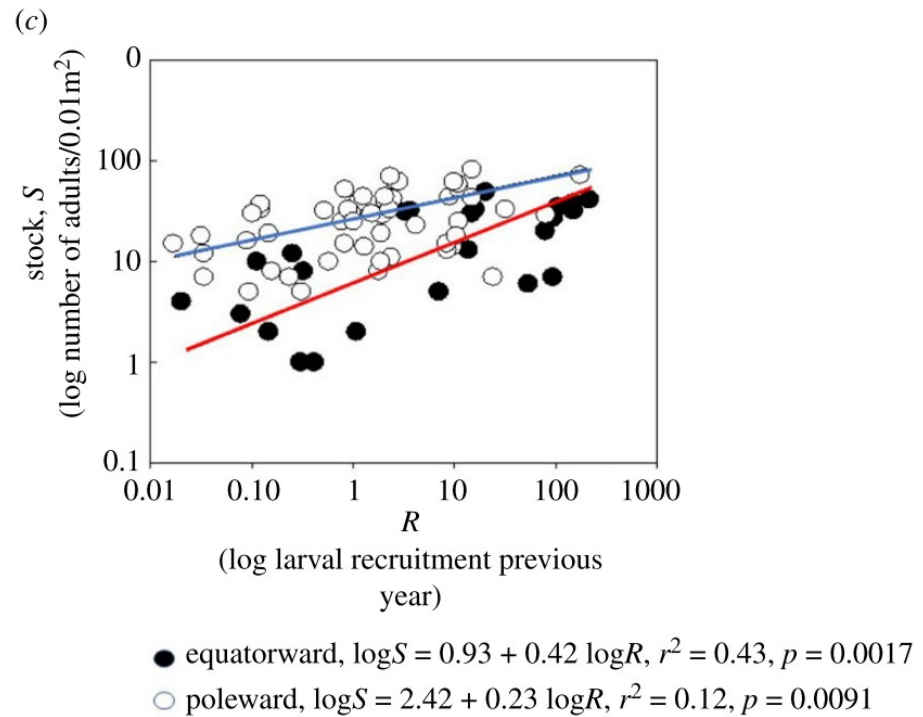
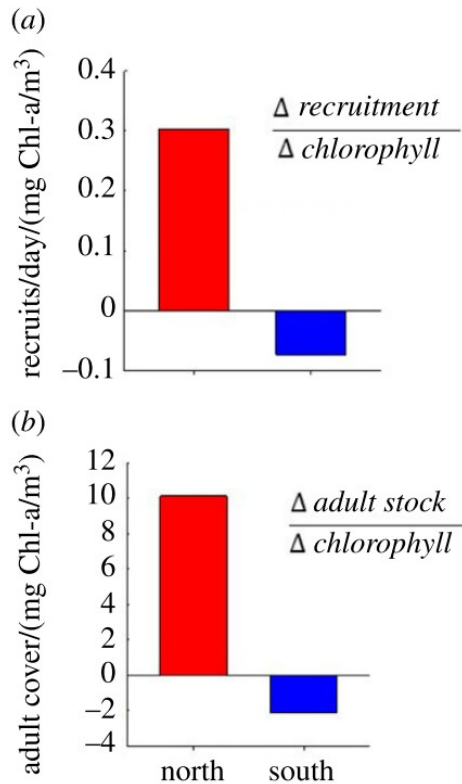
Contrasting populational trends



Marked latitudinal differences in trends of larval supply



Contrasting populational trends



Divergent population trajectories around the transition zone



Back in 2004



Los Molles (32.8°S, March 2004) photo: R. Wieters



The new kids on the block



Austromegabalanus individuals at Los Molles (32.8°S, April 2022)



Changing communities



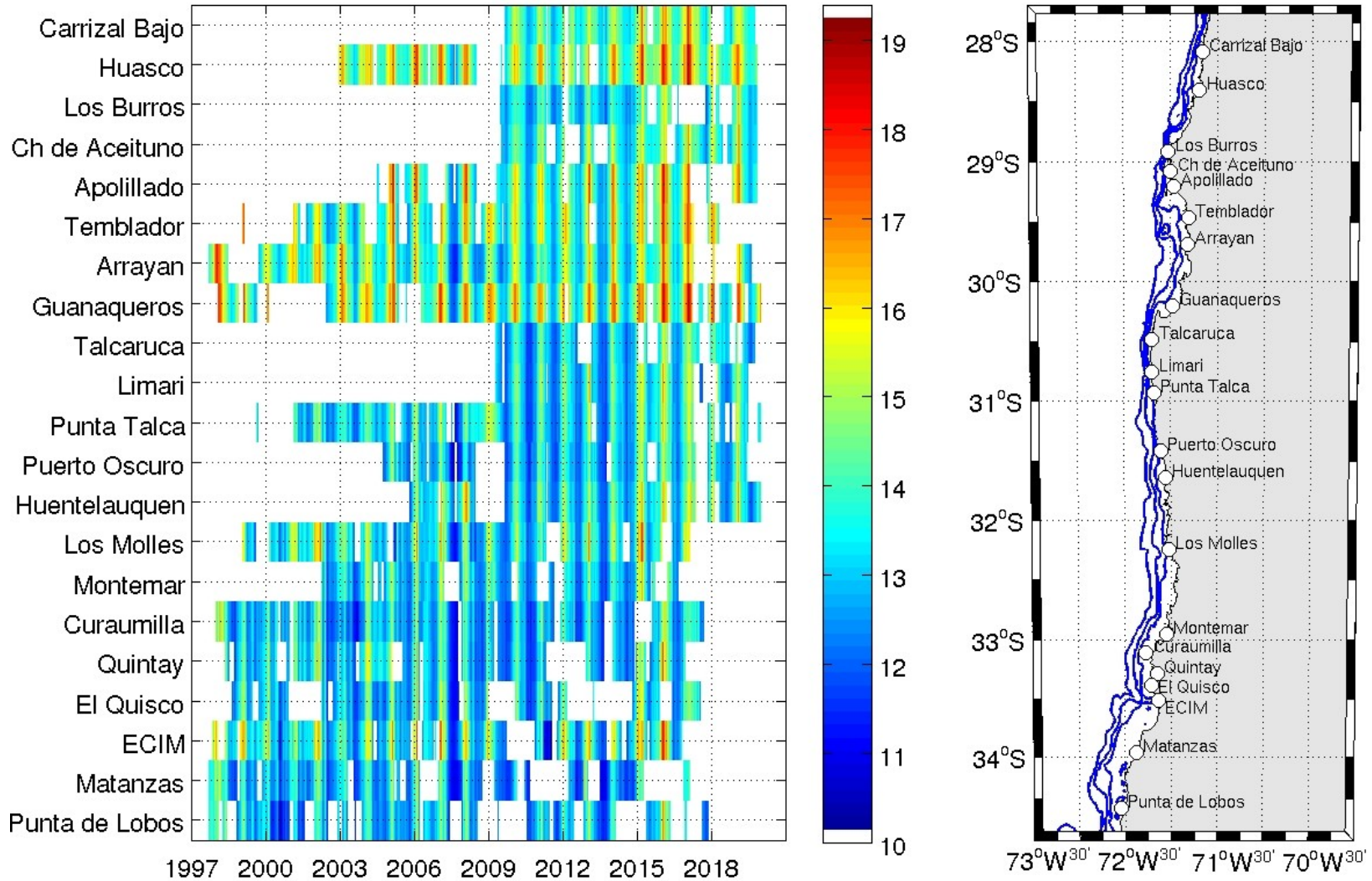
Austromegabalanus individuals at Los Molles (32.8°S, November 2022)

What are the implications of human choices and environmental forcing on community structure?



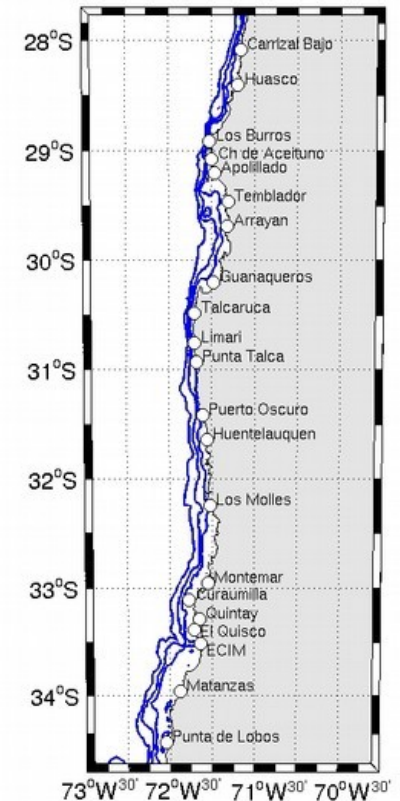
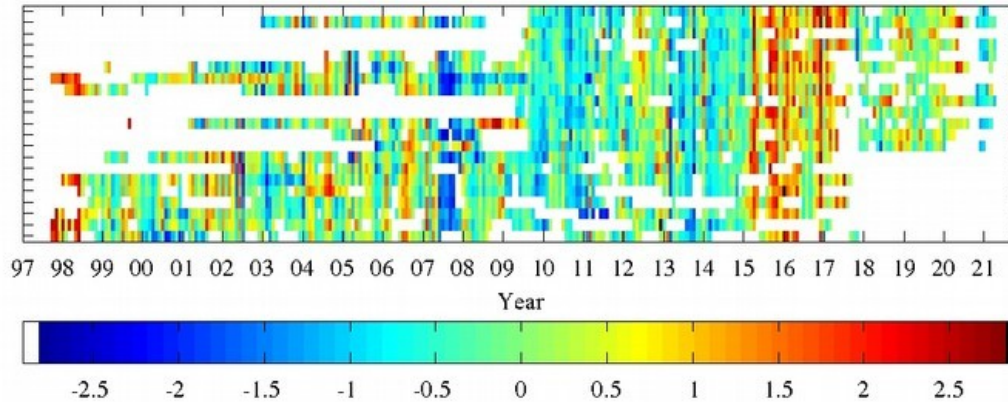
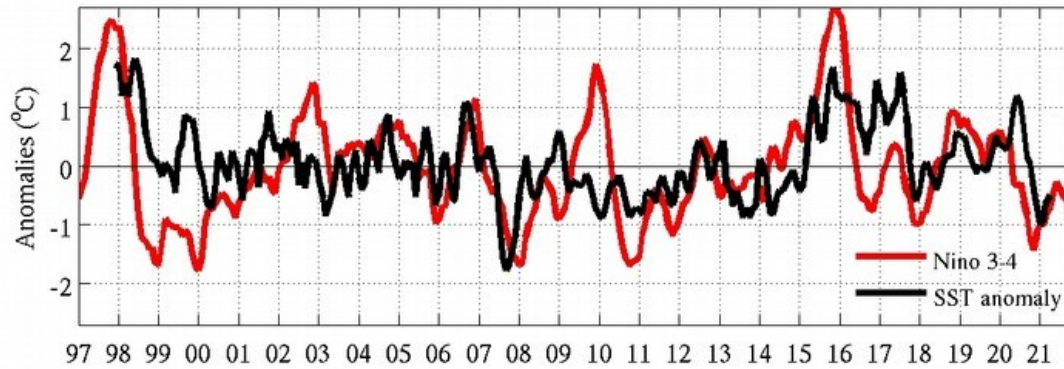


Persistent spatial structure of SST





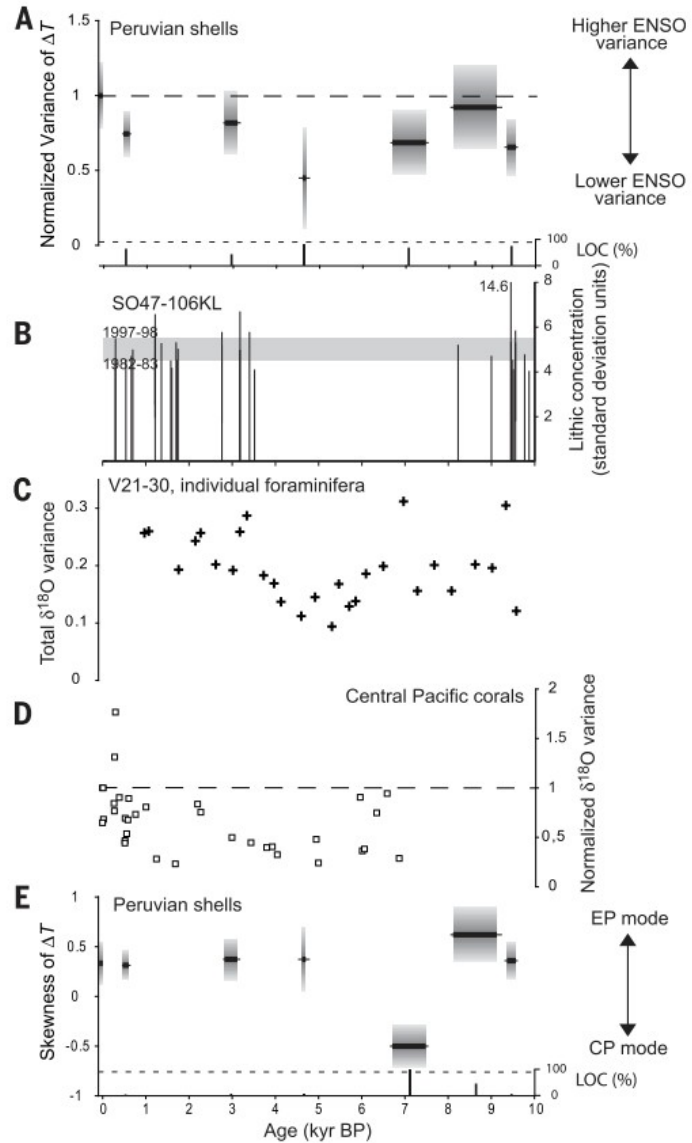
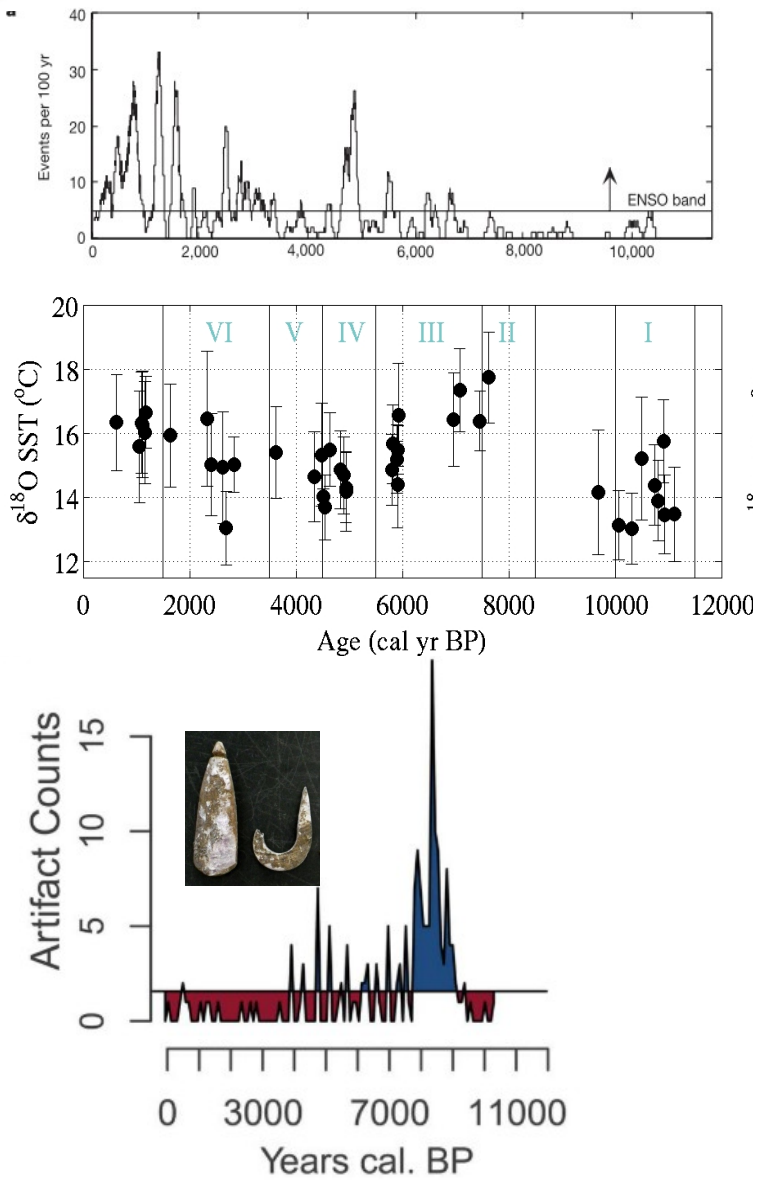
SST anomalies mirror ENSO signal



Over interannual time scales ENSO dominates regional SST anomalies
EP ENSO is predicted to increase in strength under greenhouse warming



ENSO & human-environment relationships?

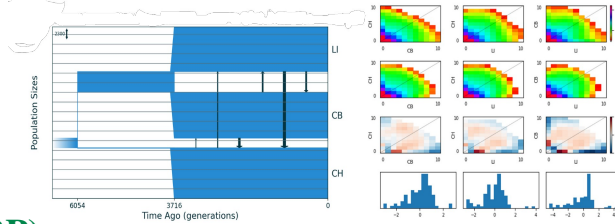




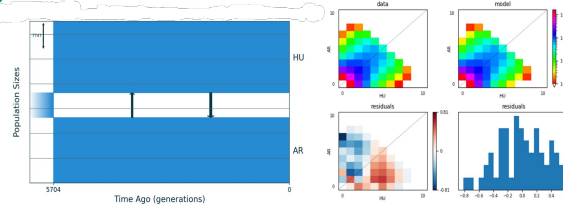
Spatial and temporal structure in popn' genetics



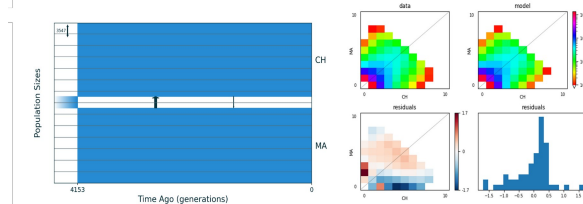
S. scurra (3700BP)



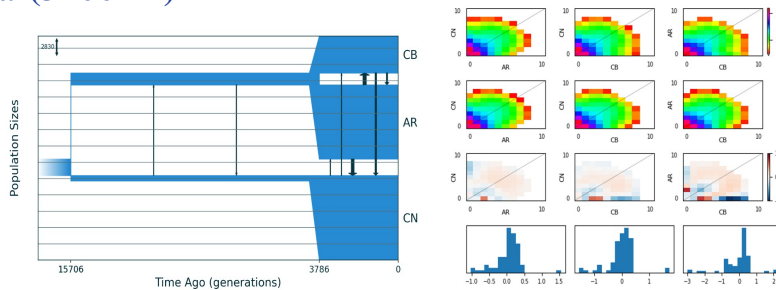
S. variabilis (5700BP)



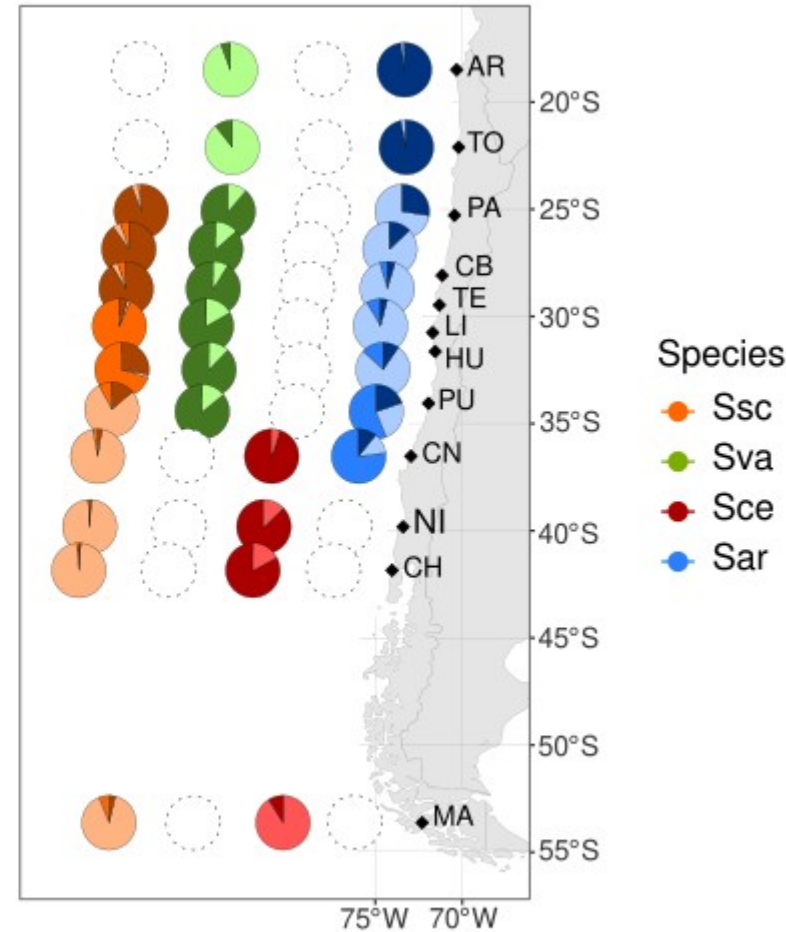
S. ceciliana (4100BP)



S. araucana (3700BP)



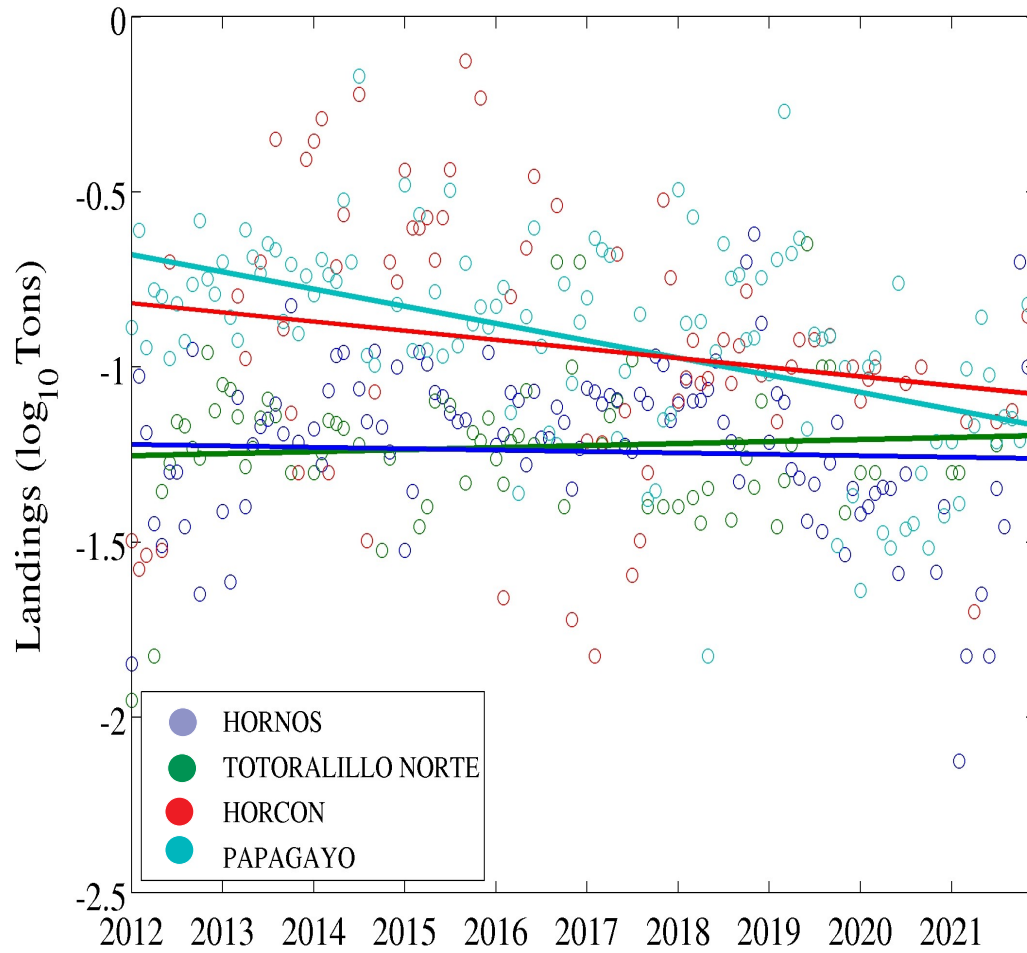
c)



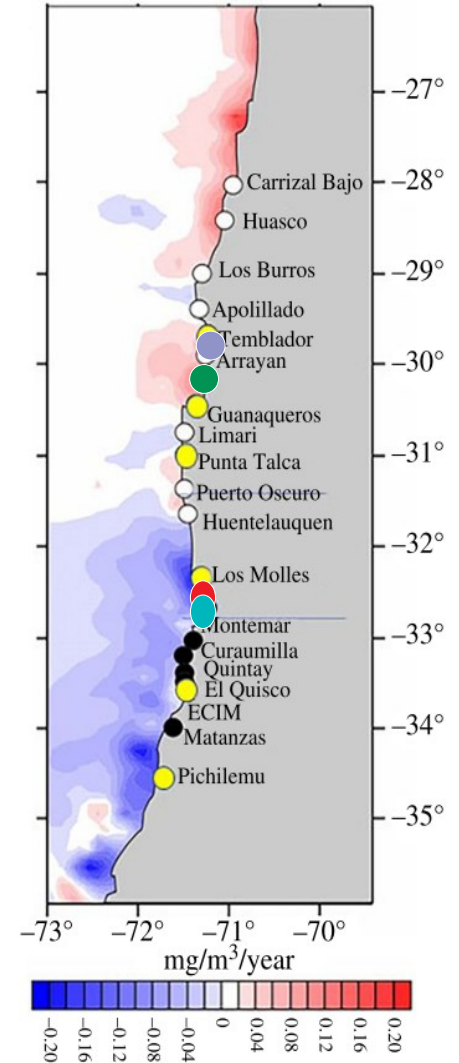
Onset of the modern ENSO regime & intensification in resource use



Austromegabalanus trends (artisanal fishery)

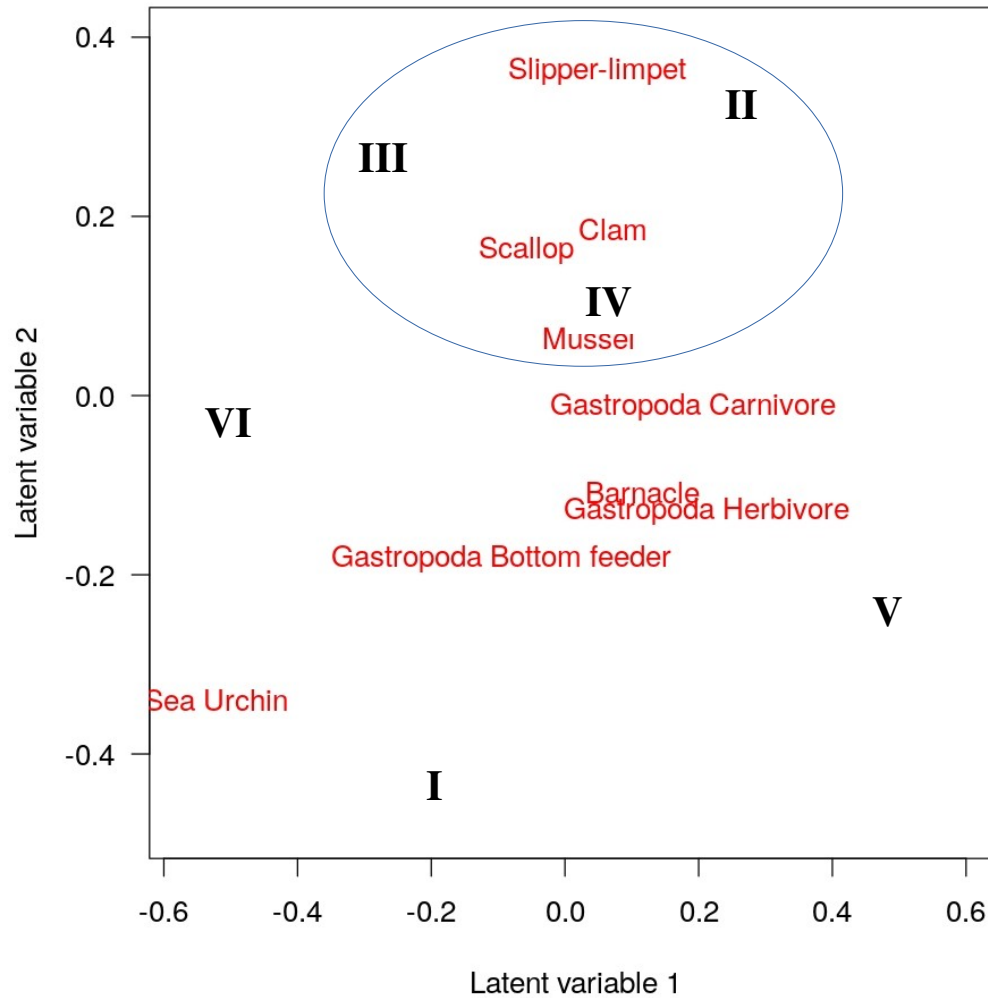


Fishers are already responding
Mixture of long-term and interannual trends





Changes follow technological change



Climate was not the main driver of harvesting decisions



Technology?





Technology!



Sea Lion skin raft reconstruction (1965)



7.500 BP

Miniature wood rafts in funerary offerings
3.000 & 3.450 BP



D'Orbigny 1835-1847





Lessons from the Holocene



Human decisions have major implications

Technological innovations can shape conservation strategies

Interdisciplinary work is hard but hugely insightful

Forget about decolonizing, go native!



Experimental fishing with the Chango nation people

Muchas Gracias!

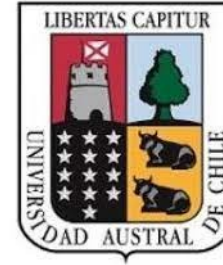


Funerary offering. Cifuncho site, Taltal



FONDECYT # 1151203, 1150210, 3170913, 1181300, 1221699

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Past coastal upwelling system, environmental local and lasting impacts

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