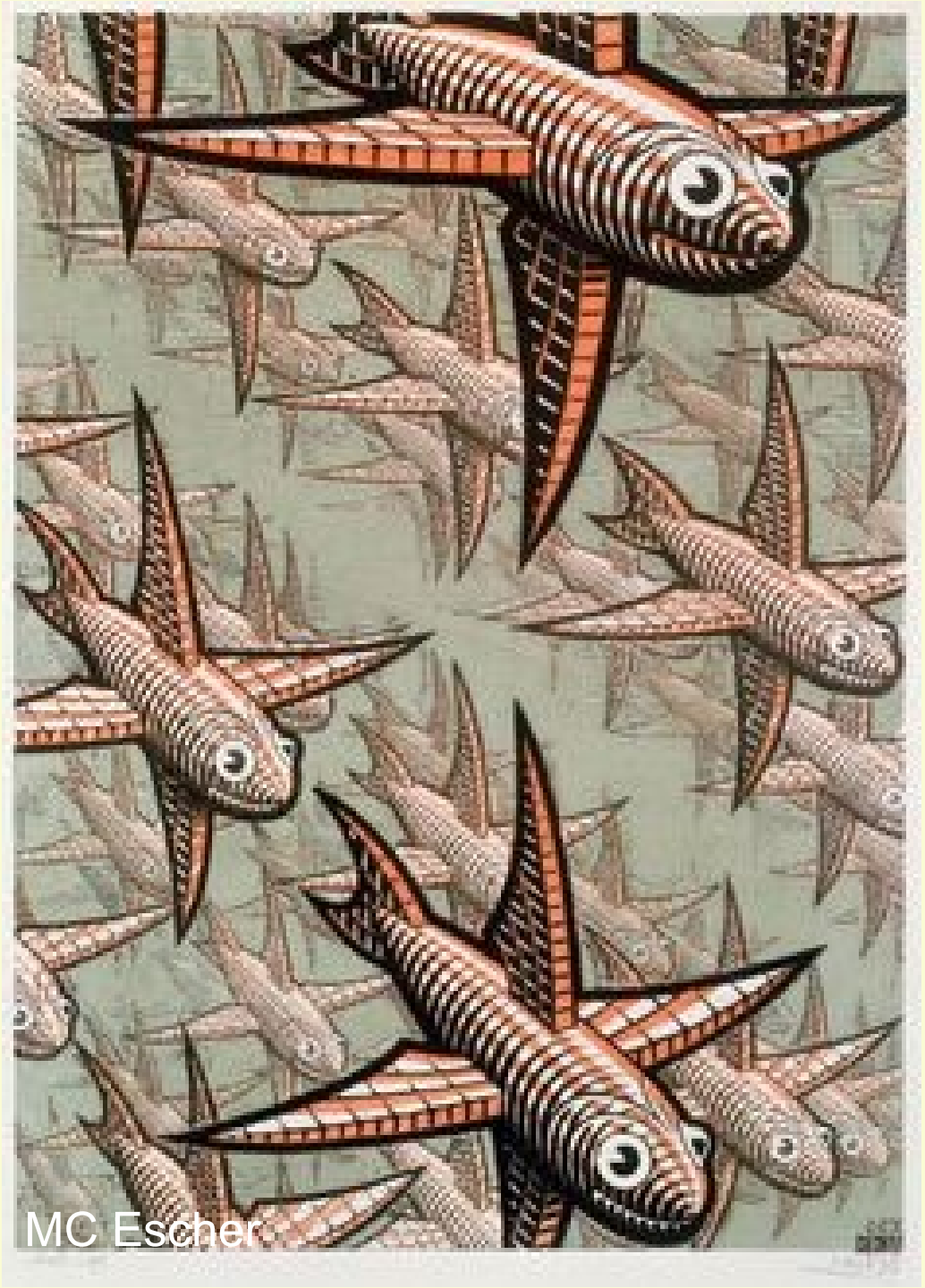

Small Pelagic Fish:
New Frontiers in Science and Sustainable Management
November 7 - 11, 2022
Lisbon, Portugal

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The metamorphosis of small pelagic fish

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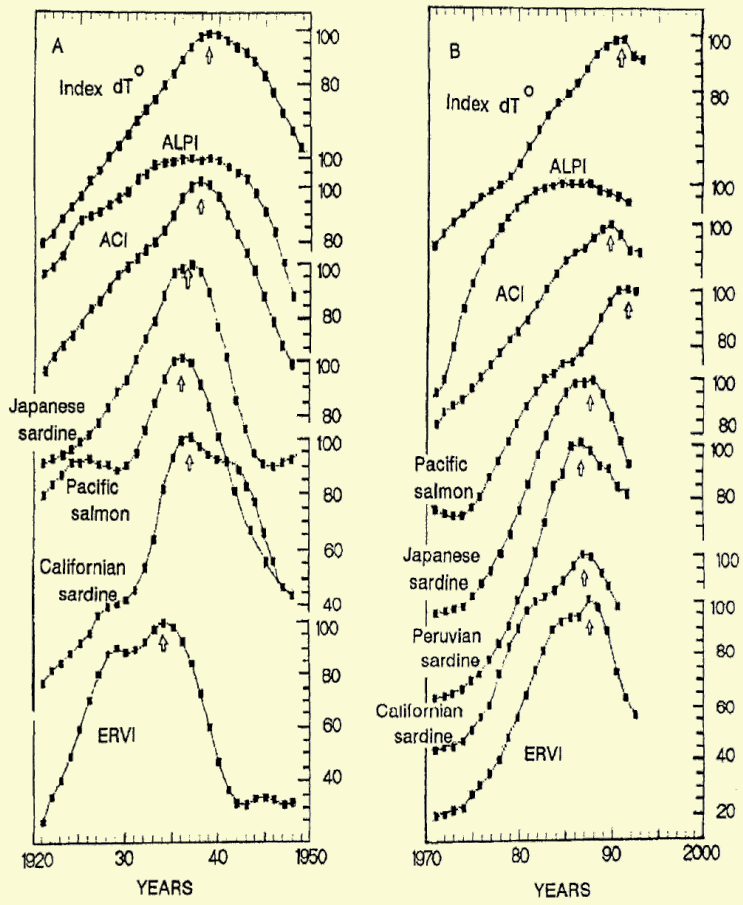
marbec — marine biodiversity exploitation & conservation

The ‘good news’

SPF populations do fluctuate in synchrony

Klyashtorin (1998, Fish Res)



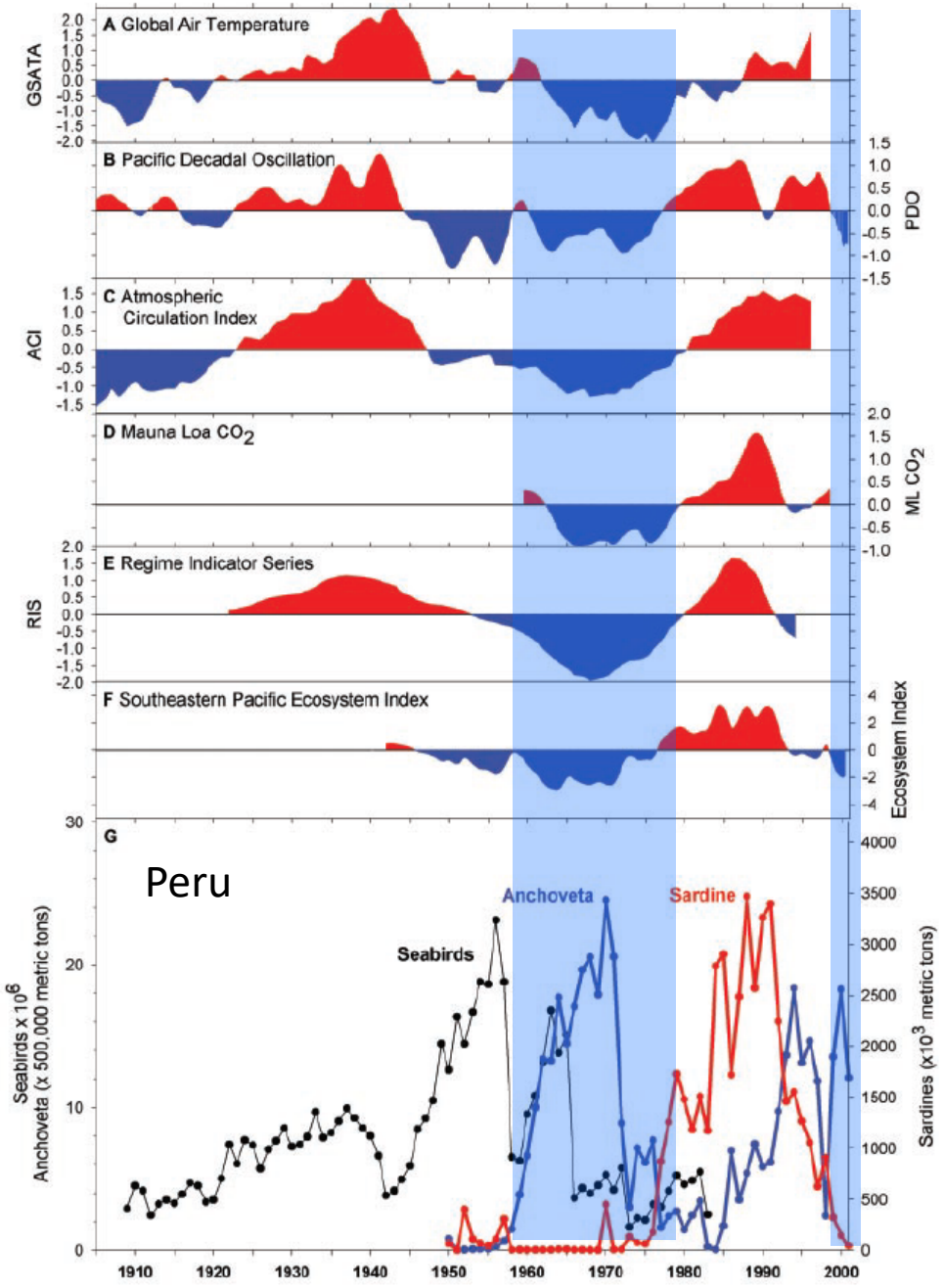
→ Dynamics modulated by global climate forcings observable through ‘simple’ parameters, e.g., TºC (e.g. *Schwartzlose et al., 1999, SAJMS*).

→ This was “**good news**” since:

“the implication…/… would seem to be that **the biological dynamics involved must be very simple**. The synchrony must be a rather direct effect of the external physical forcing acting either on the fish themselves, or very directly on a primary food source, at some sensitive life stage.

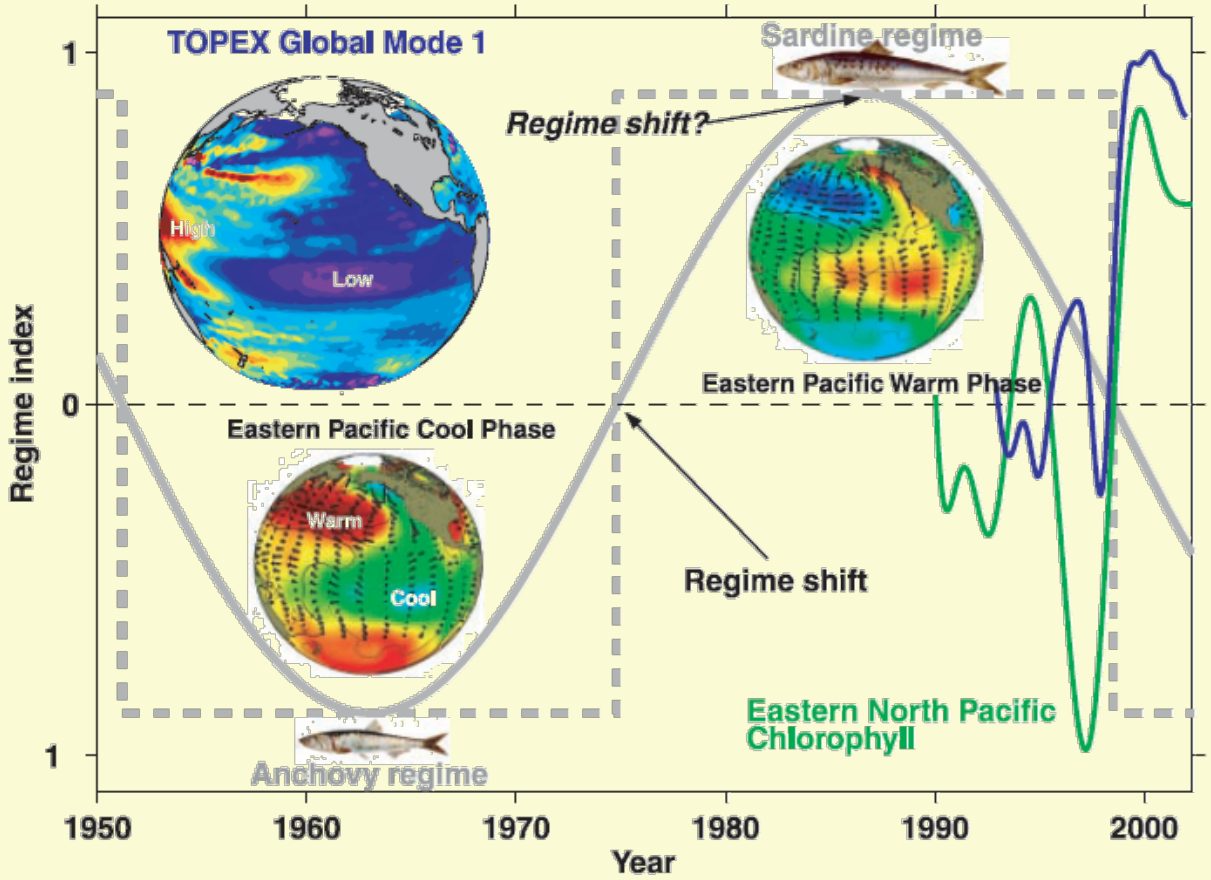
It must not be, for example, an effect working through a complex food web” (*Bakun, 1999*)

The ‘good news’



Anchovy/sardine alternation are controlled by large scale climatic drivers (Moran effect) such as the PDO that fluctuates at a decadal scale

Chavez et al. (2003, Science)

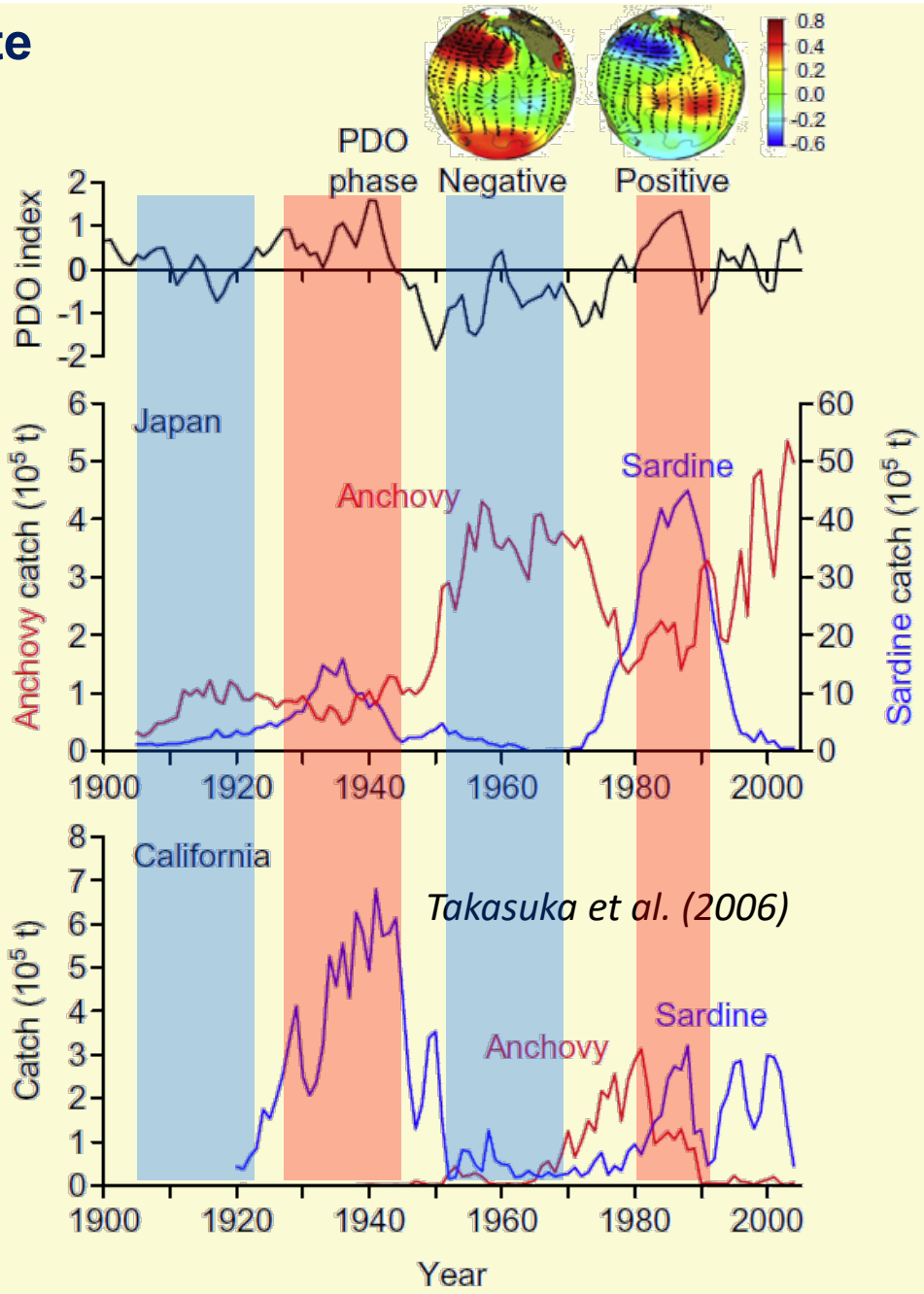


The ‘good news’

Anchovy and Sardine do alternate

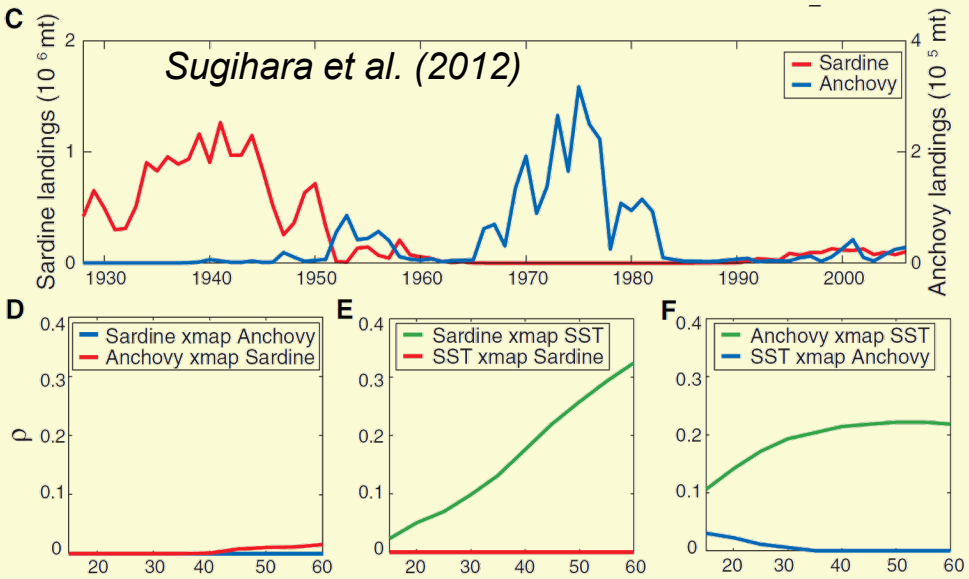
Positive PDO favours Sardine

Negative PDO favours Anchovy



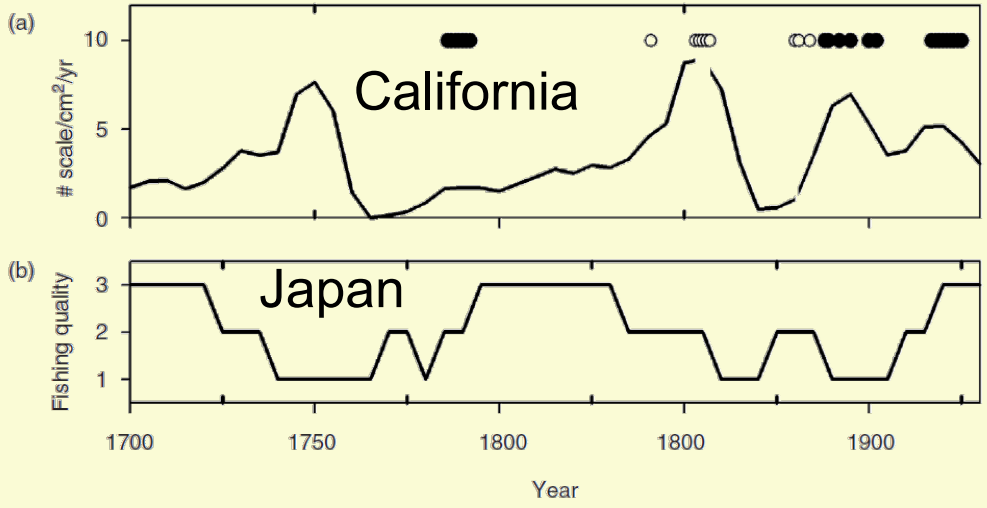
From ‘good news’ to complex processes

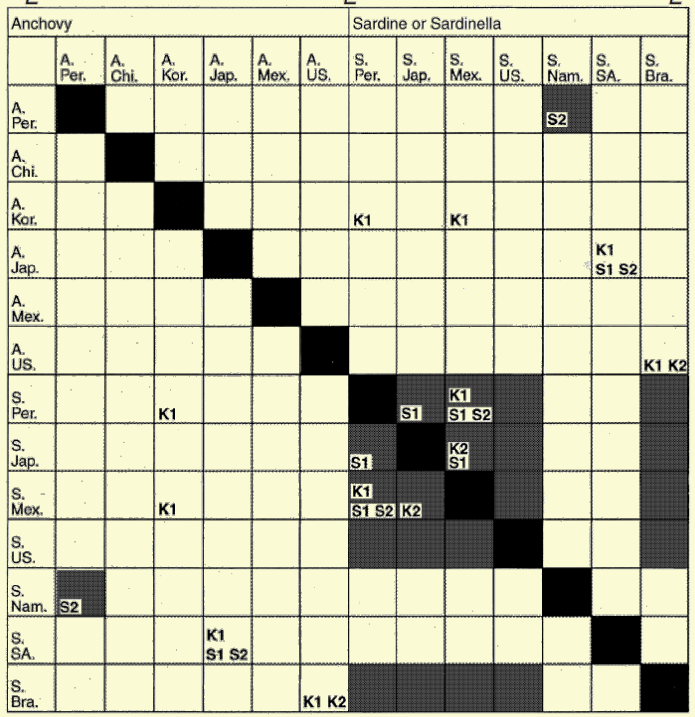
Later, studies focused on determining causality (e.g. *Sugihara et al., 2012, Science*) → weak coupling of TºC to SPF, still TºC can be use as a viable proxy. But since **processes are nonlinear → risk of mirage correlations**.



Actually **most ‘synchronies’ are not statistically robust** (e.g. *Fréon et al., 2003, FO)*: “most of the synchronies observed occurred just by chance”

or were **questioned when extending time series** - paleostudies (e.g. *Field et al., 2009*)

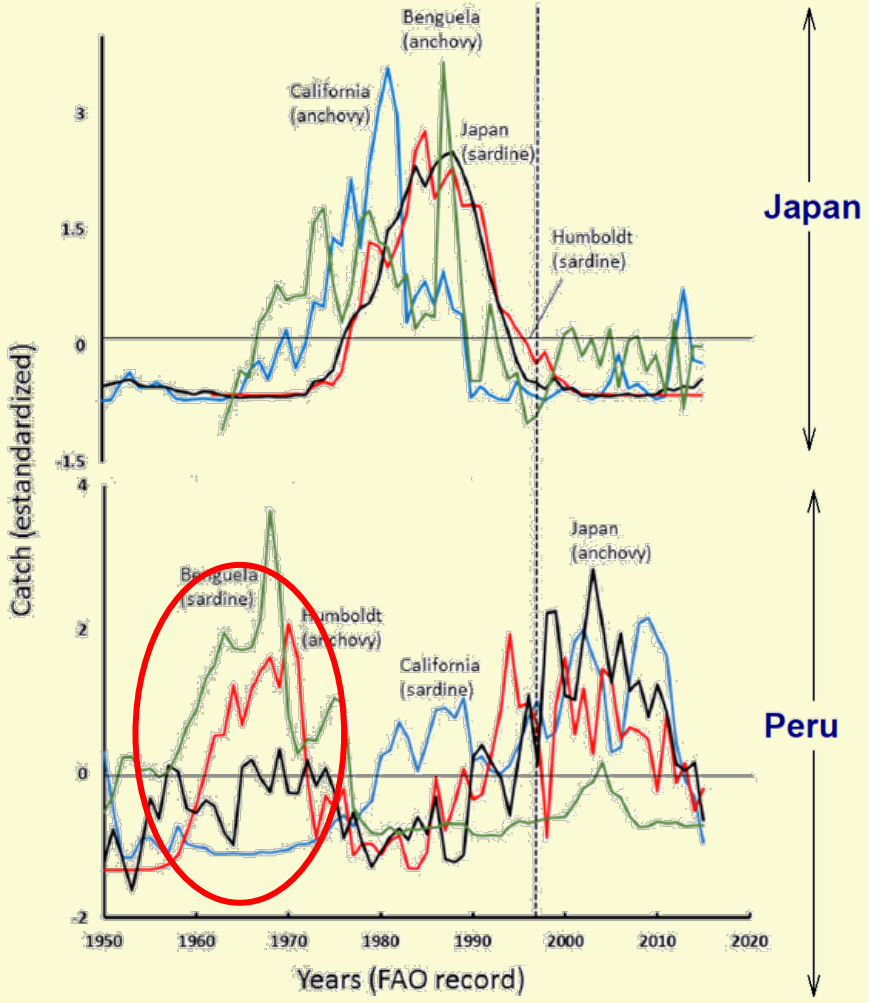


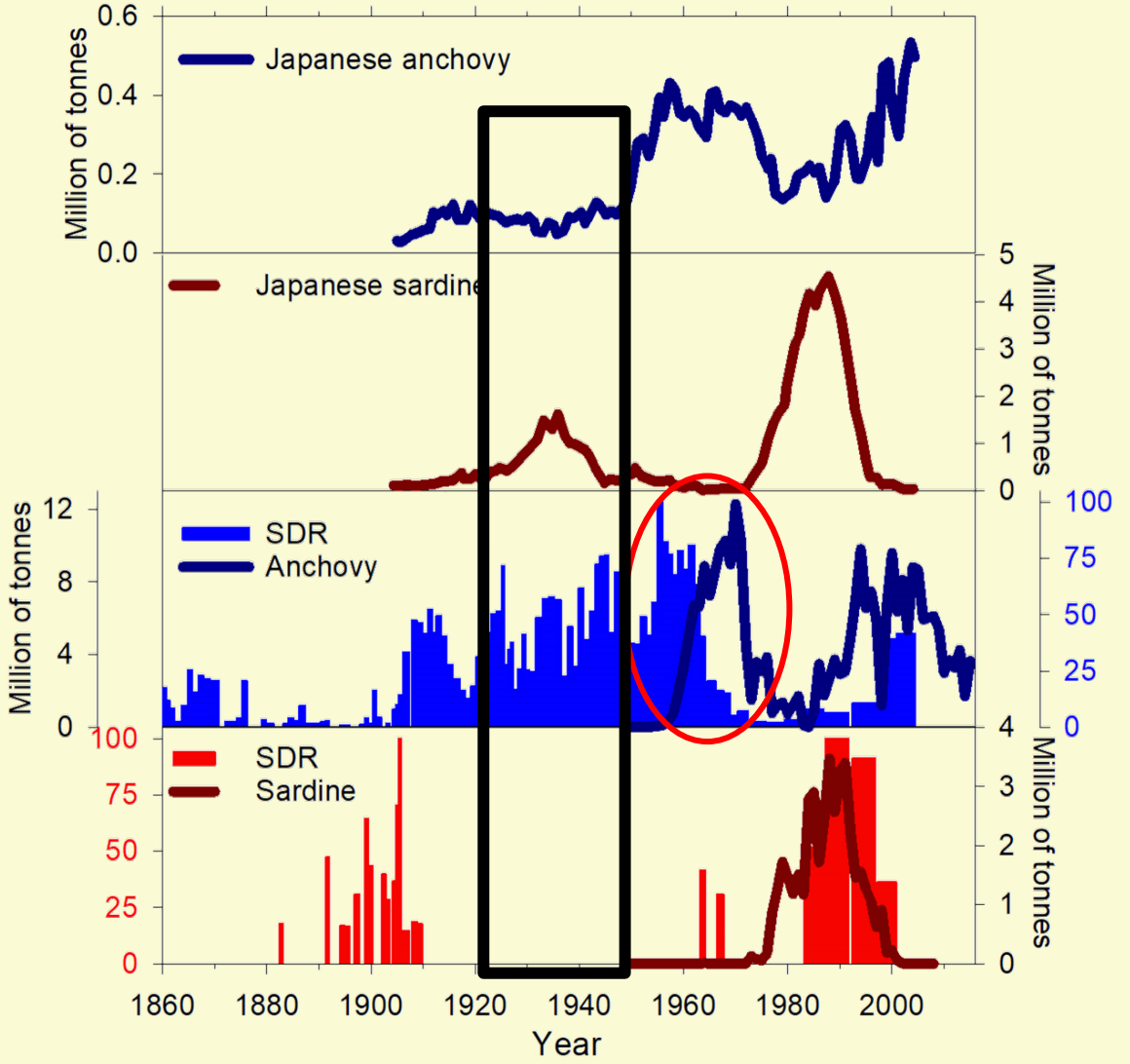


From ‘good news’ to complex processes

Recent statistical re-analysis based on catch data: “multidecadal **synchrony** between systems and **alternation** between species remains clear for the Kuroshio and Humboldt systems” *(Izquierdo-Peña et al., 2019, DSRII)*

Beginning of time series: cannot decipher between actual increase in abundance or fisheries development

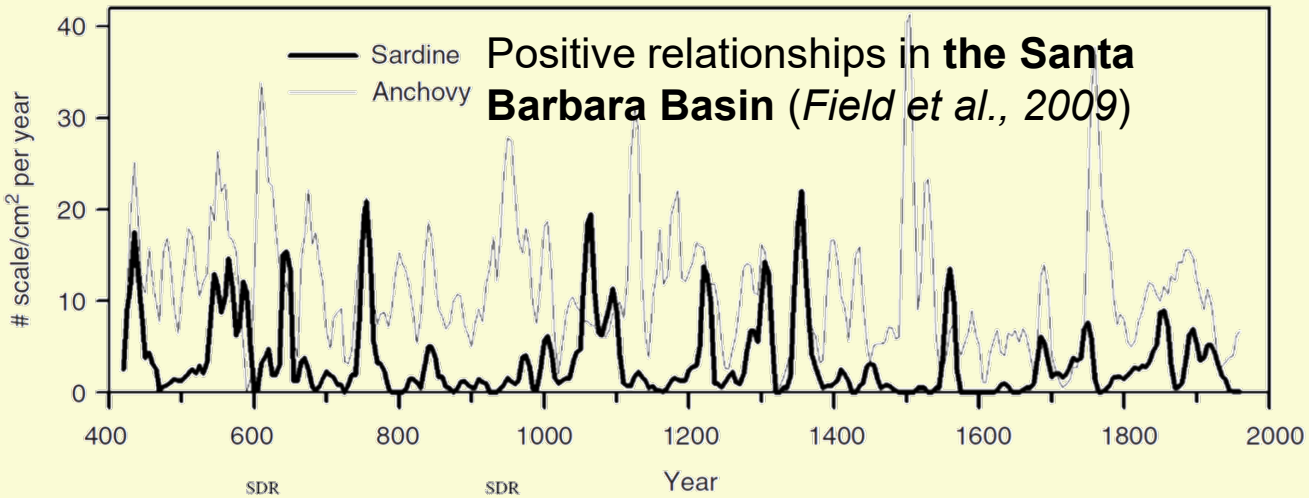


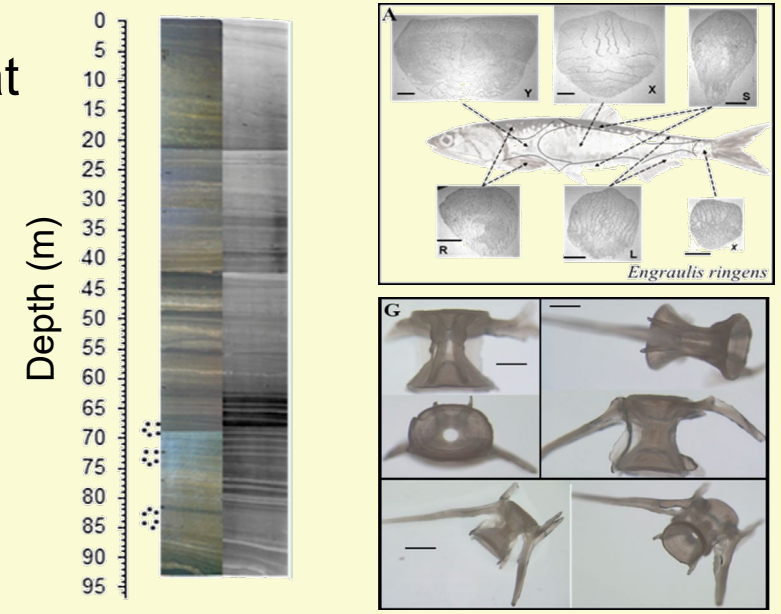


From ‘good news’ to complex processes

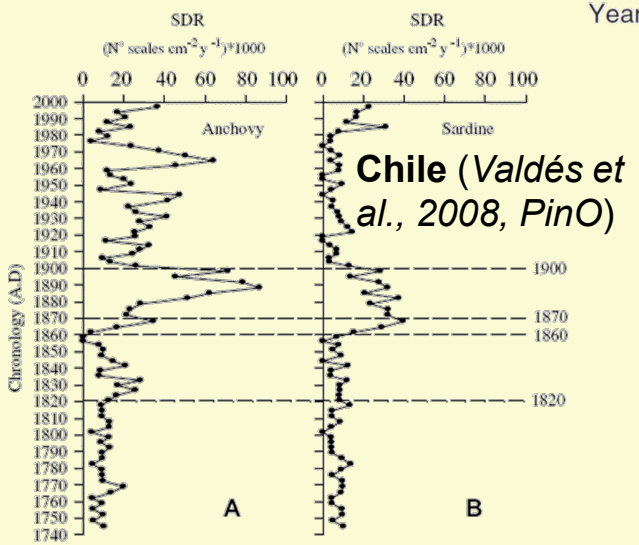
Paleostudies have broken new ground by extending the time series, dramatically

→ In addition to questioning certain synchronies, demonstration that **anchovies and sardines do not alternate**

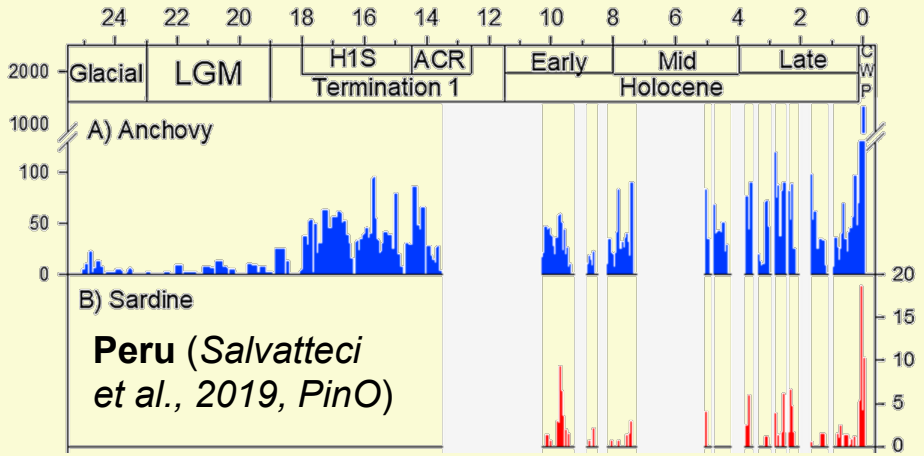




Salvatteci et al. (2019, PinO)

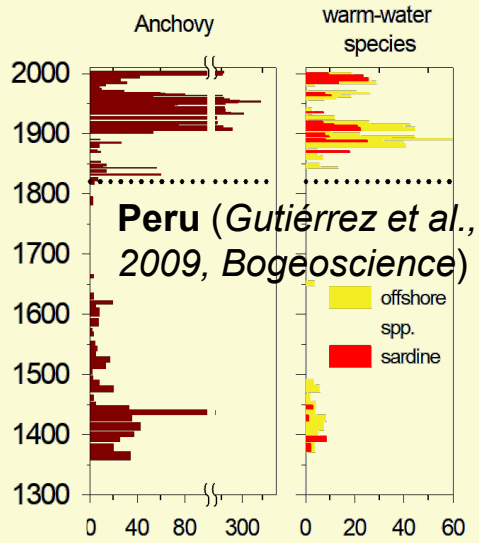


Chile (*Valdés et al., 2008, PinO*)



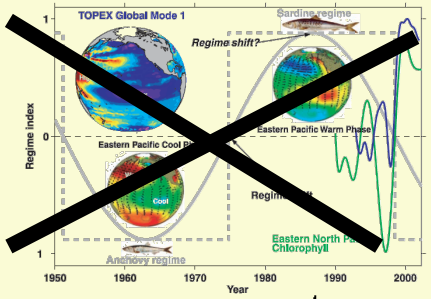
Peru (*Salvatteci et al., 2019, PinO*)

fish scale DR



Peru (*Gutiérrez et al., 2009, Bogeoscience*)

From ‘good news’ to complex processes



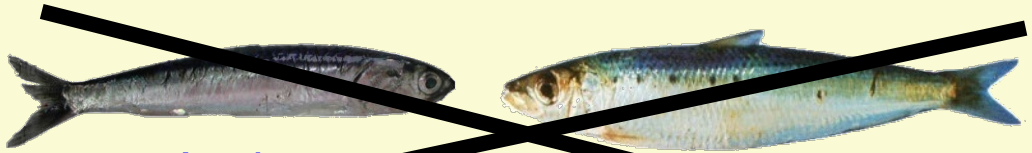
PDO

Warm PDO phase 1920 – 1940 is associated with anchovy abundance

Fish abundance

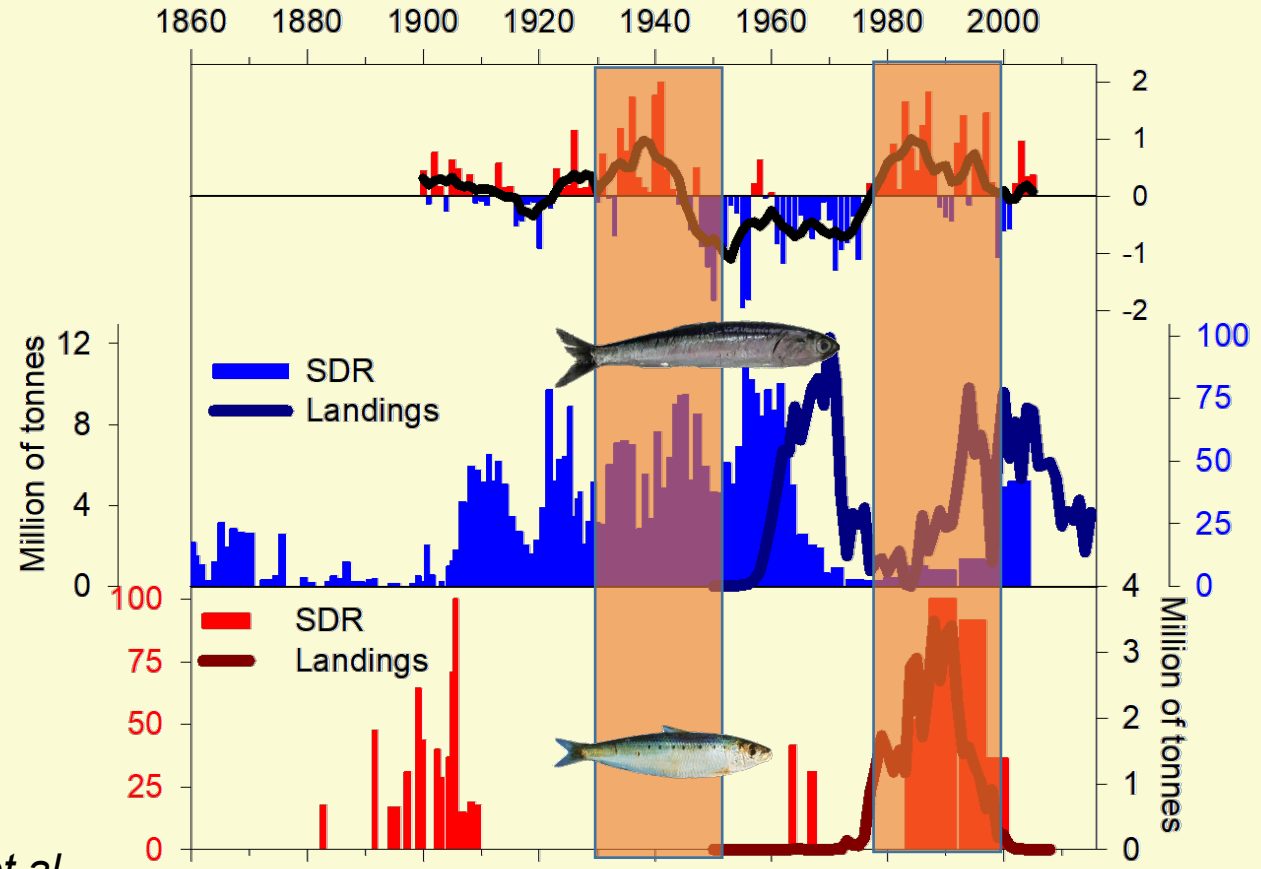
Salvatteci et al. (2018, GCB)

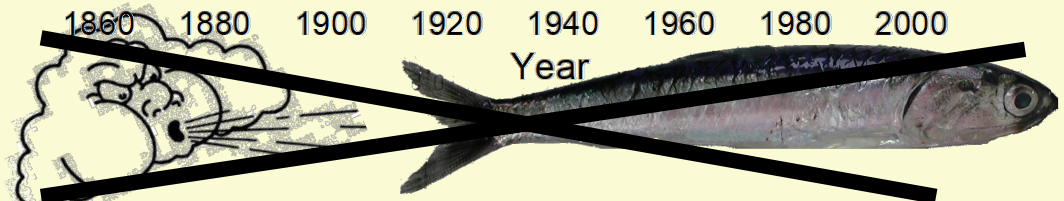
Expected:



Anchovy
Cool PDO phase

Sardine
Warm PDO phase

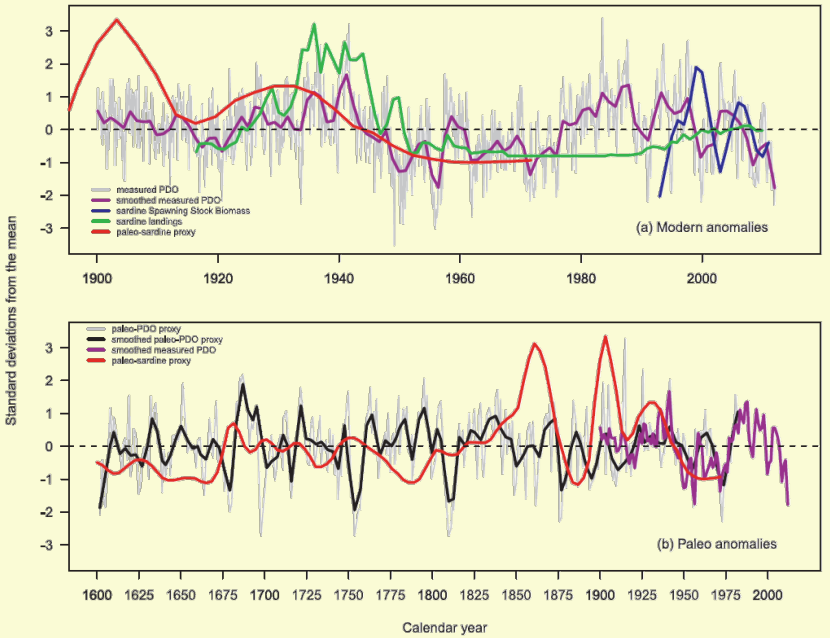




Some relationships may ‘occur’ sometimes but are not necessarily a pattern

No ‘simple’ direct driving factor (see Takasuka talk)

California



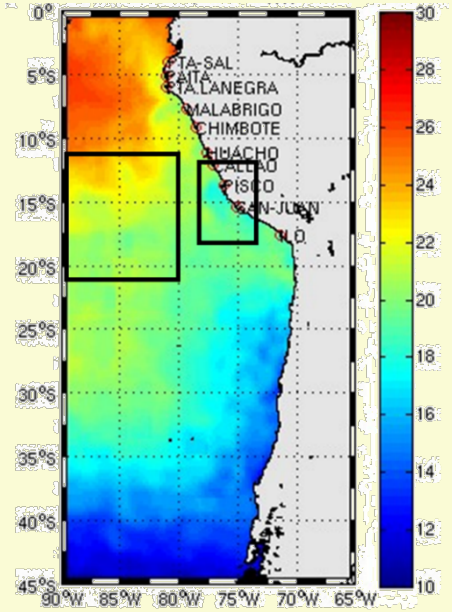
McClatchie (2012, GRL)

Other, more local and complex factors are in play

From ‘good news’ to complex processes

Anchovy-sardine fluctuations coincide better with regional dynamics than with basin-scale indices

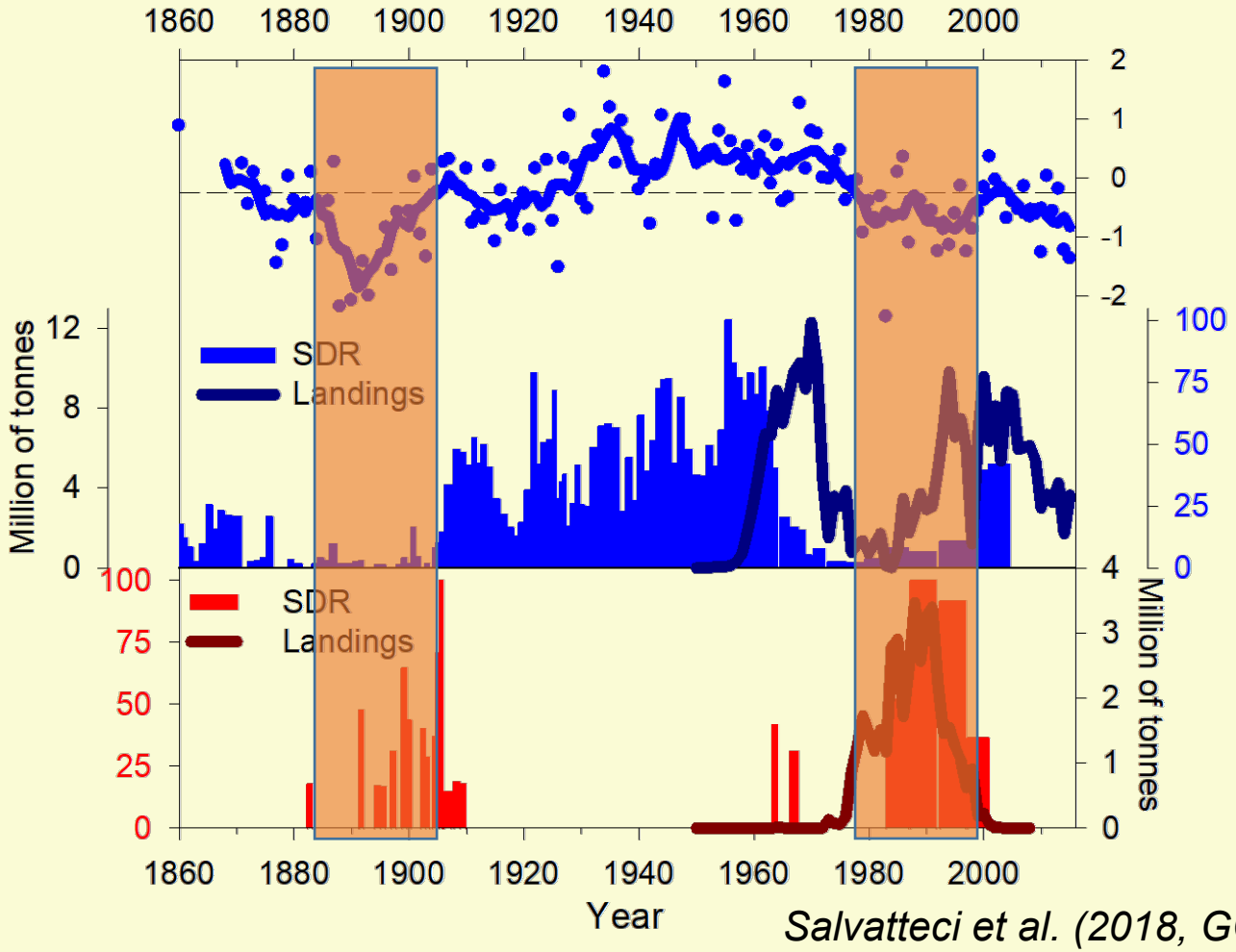
Weaker SST gradient (suggesting weaker upwelling) associated with sardine
Stronger gradient (suggesting stronger upwelling) associated with anchovy
Changes in **upwelling intensity modify the 3-D habitat** (thermocline, oxygen content, food size)



ICOADS
data base

Cross-shore SST gradient

Fish abundance



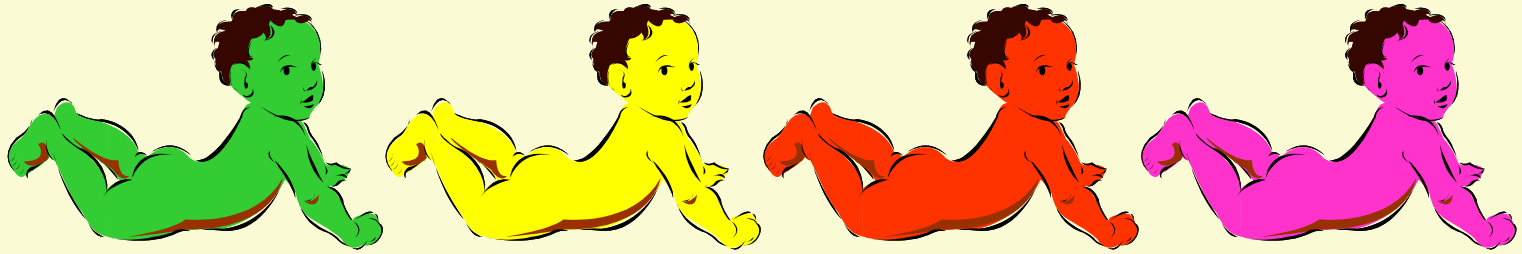
Salvatteci et al. (2018, GCB)

Interannual modulation: same story…

Sardine do better than anchovy and even success during warm, less productive, El Niño conditions
(e.g. *Bakun and Broad, 2003, FO*)

This simplified vision has to be put into perspective as

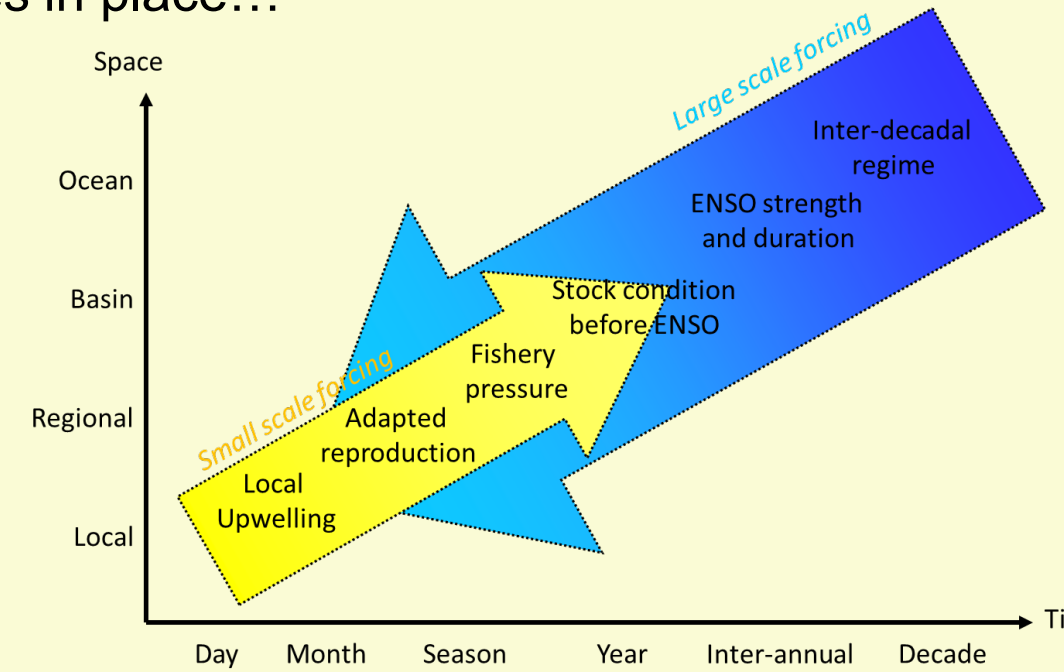
Each Niño is different...



As well as the complex non-linear processes in place…

E.g., extreme El Niño 1982-83 and 1997-98: the first had a strong negative impact on anchovy while the second had a much weaker impact (inverse for sardine).

→ Various factors occurring at different spatiotemporal scales have to be considered (*Bertrand et al., 2004, Fish Fish*)



Interannual modulation: same story…

Anchovy and the El Niño 1997-98

El Niño 1997-98 during a productive period

Very strong El Niño but higher thermal anomalies did not coincide with Austral summer

ENSO onset: anchovy abundant

Weak natural and fishing predation

Spawning just before shift El Niño-La Niña; good recruits development

Not massive adult die-off; efficient spawning by adapted reproductive behaviour

Large scale forcing

Inter-decadal regime

ENSO strength and duration

Stock condition before ENSO

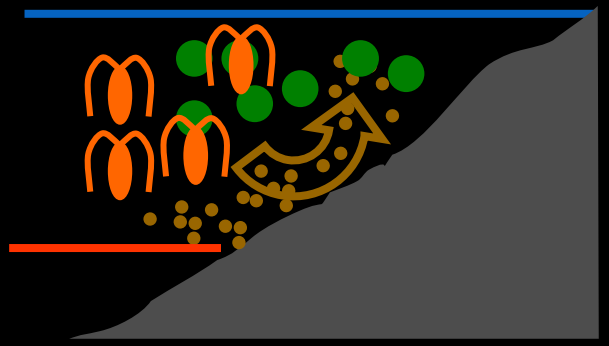
Predation and fishing pressure

Small scale forcing

Adapted reproduction

Local Upwelling

BINGO!



Presence of local zones with efficient upwelling

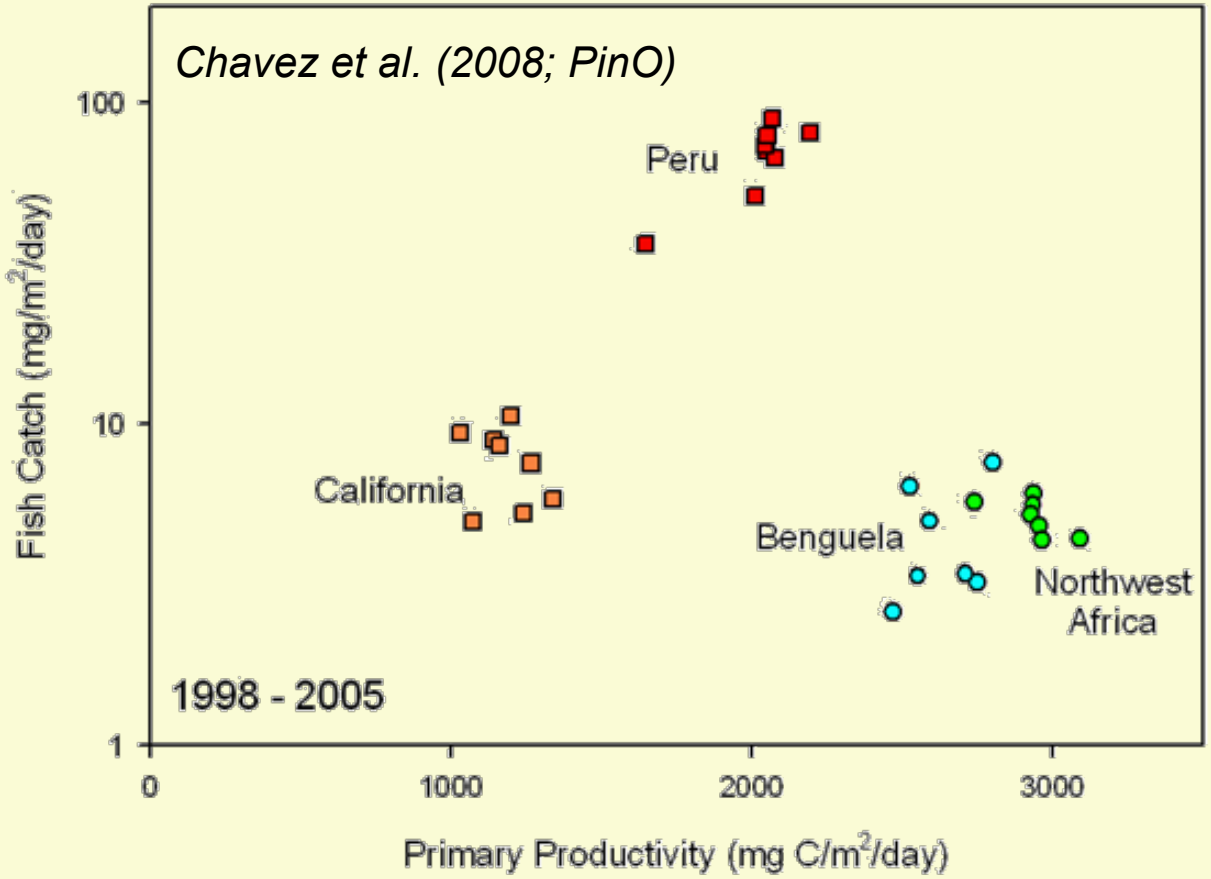
➔ good level of production I and II.

Anchovy concentrated in these refuge zones.

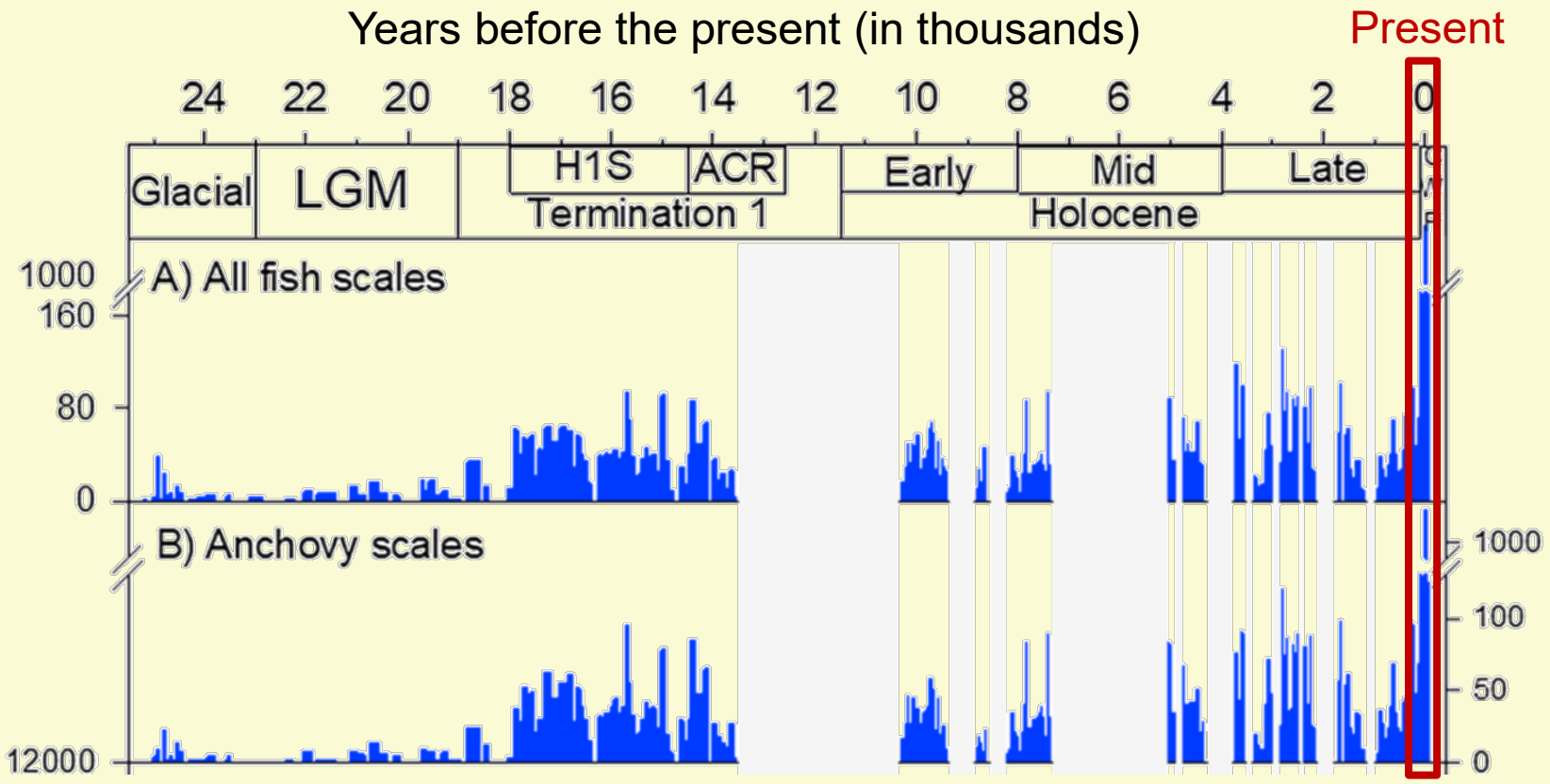
The NHCS, the most productive in terms of fish

The northern Humboldt Current system (NHCS): the world most productive system in terms of fish

→ ~10 times more than comparable systems



The NHCS, currently the most productive in terms of fish



Salvatteci et al. (2019, PinO), see also *Salvetteci et al. (2022, Science)*

→ Current extreme productivity is **not typical**: there is presently an unusual set of conditions

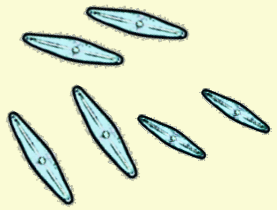
→ Our historical vision and the conclusions we derive correspond to an **exceptional ecosystem state**

→ Industrial fisheries developed during a period of extraordinary productivity in relation to that of the last 25 kyr or 130 kyr

→ This golden age is bound to collapse

Short to long food-web

During decades: Peruvian anchovy considered to forage directly on primary producers (e.g., *Ryther, 1969*)
→ short efficient food-chain - same for Cape anchovy (e.g. *Robinson, 1966*)



Trophic level~2.2

Revisiting the trophodynamics

(*Espinoza et al., 2009, 2017; Espinoza and Bertrand, 2008, 2014* – see also *Pizarro et al., 2019* for Chile and *van der Lingen 2002* for the Benguela)

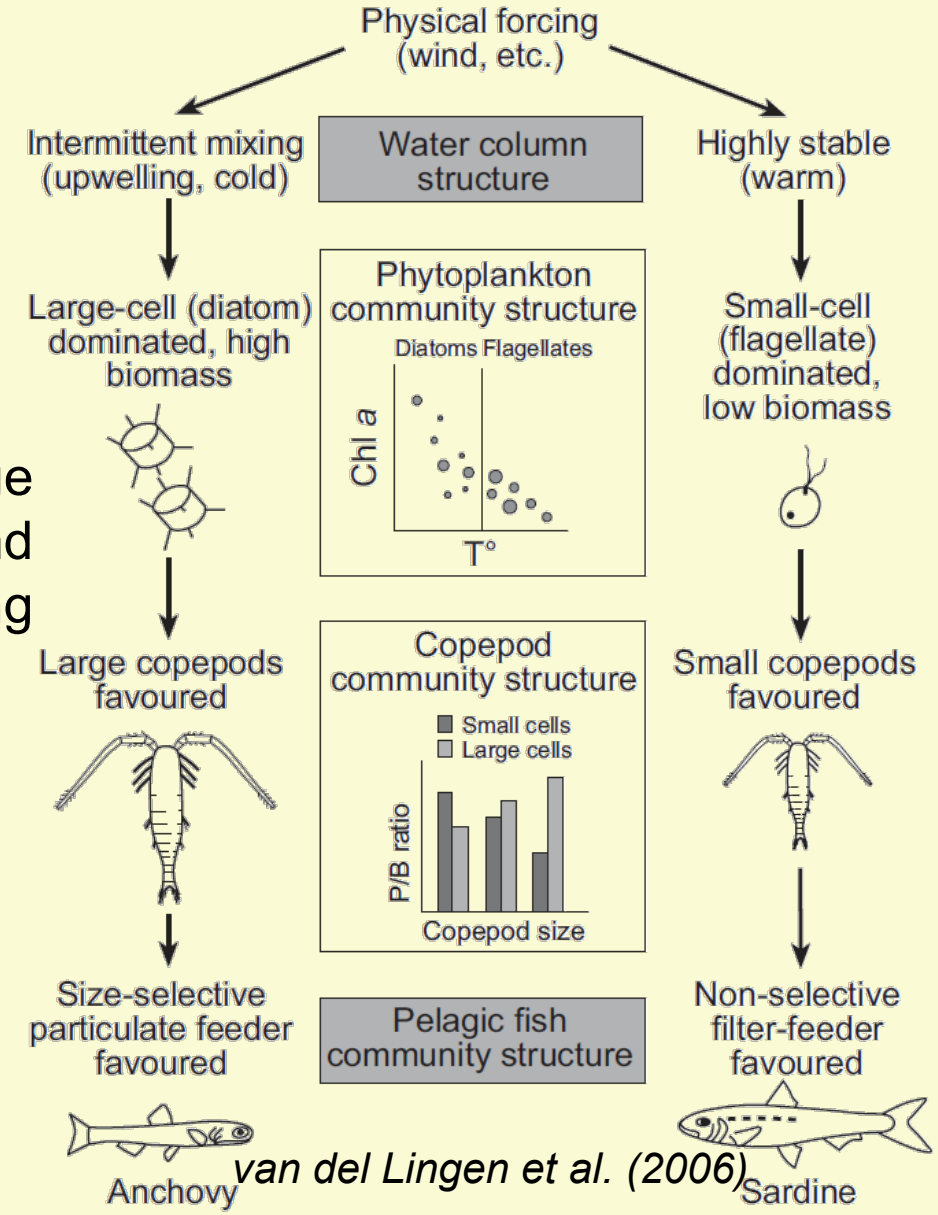
Trophic level ~3.5

→ More than one order of magnitude of change in terms of energy fluxes
→ May still need to be adjusted in some systems
→ Still not fully considered in the literature and models

Drivers of fish variability

Temperature and trophic food web structure as main drivers

Schwartzlose et al. (1999):
Two mechanisms may sustain large shifts in abundance of sardine and anchovy populations over long periods: food and temperature.



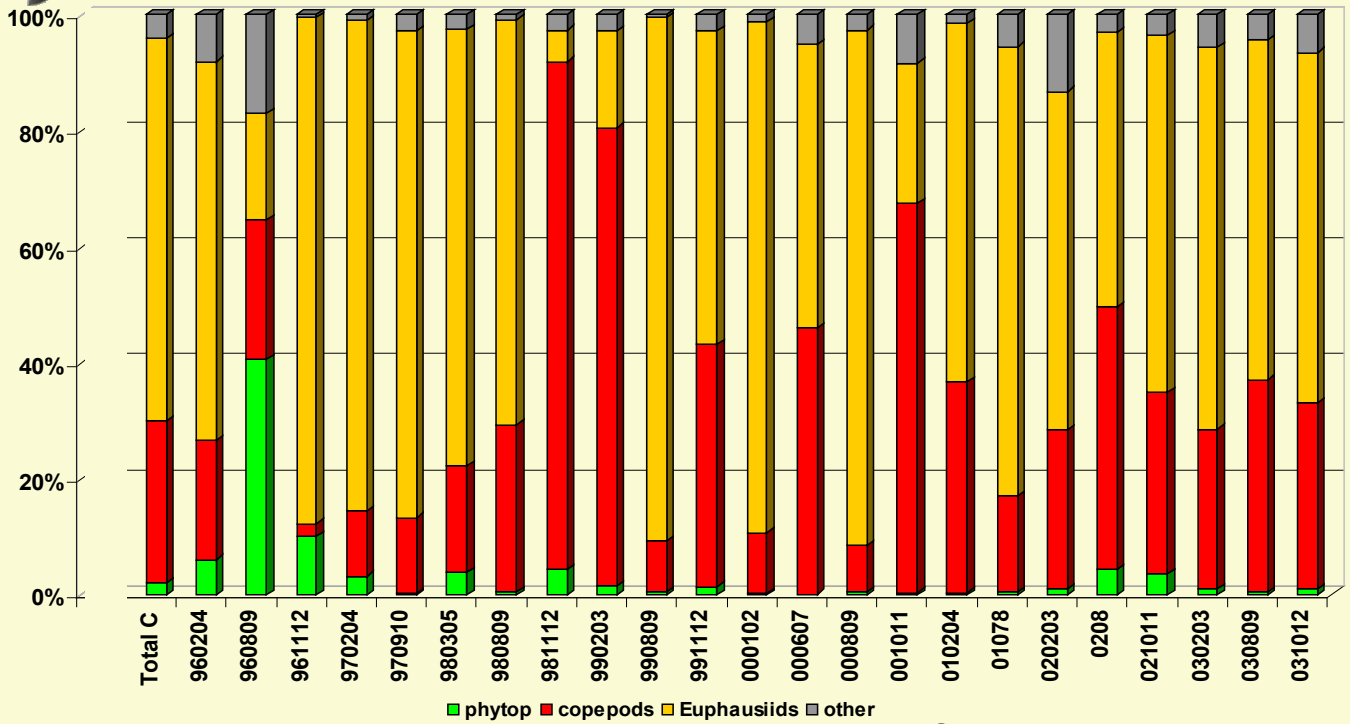
van del Lingen et al. (2006)

Density-dependent factors not addressed here

Drivers of fish variability

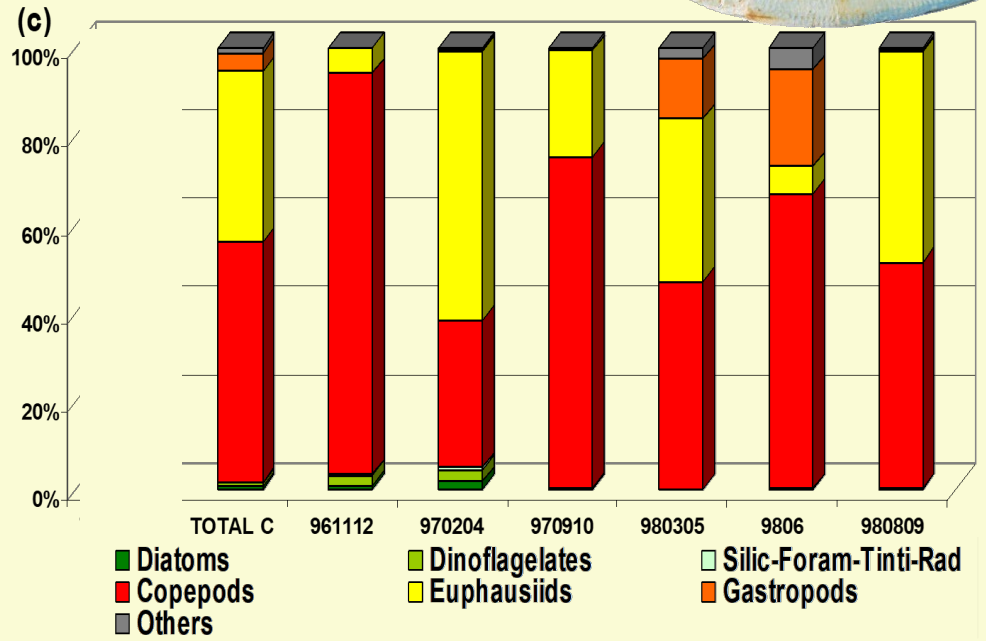
Food size structure

Anchovy diet (carbon content)



Espinoza and Bertrand (2008, PinO)

Sardine diet (carbon content)

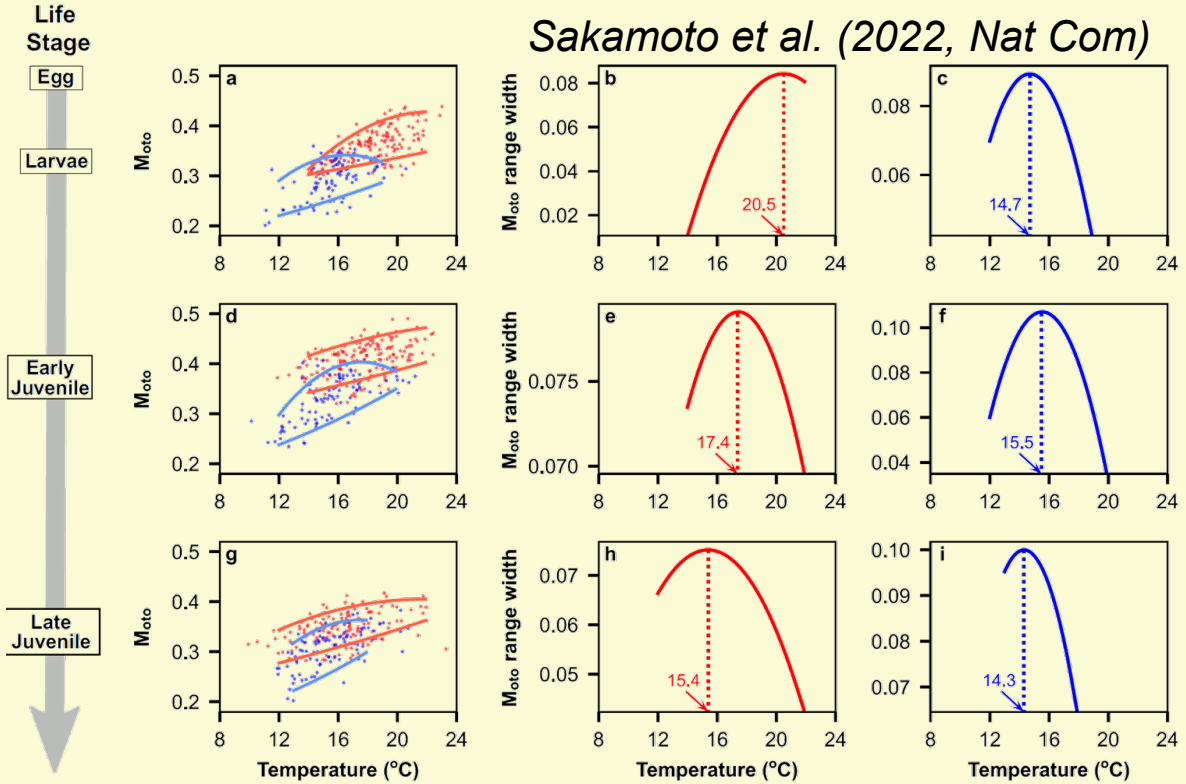


Espinoza et al. (2009, PinO)

Anchovy and sardine can forage over a large variety of prey with strong overlap among species

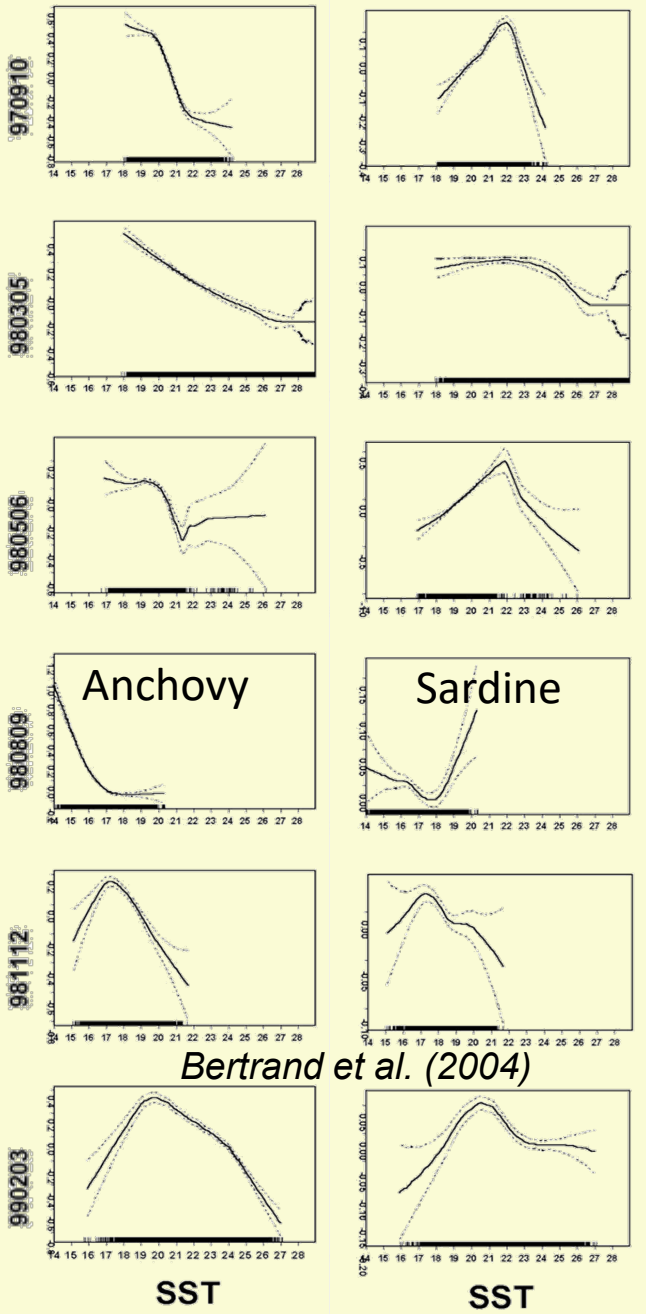
Drivers of fish variability

Temperature as a driver

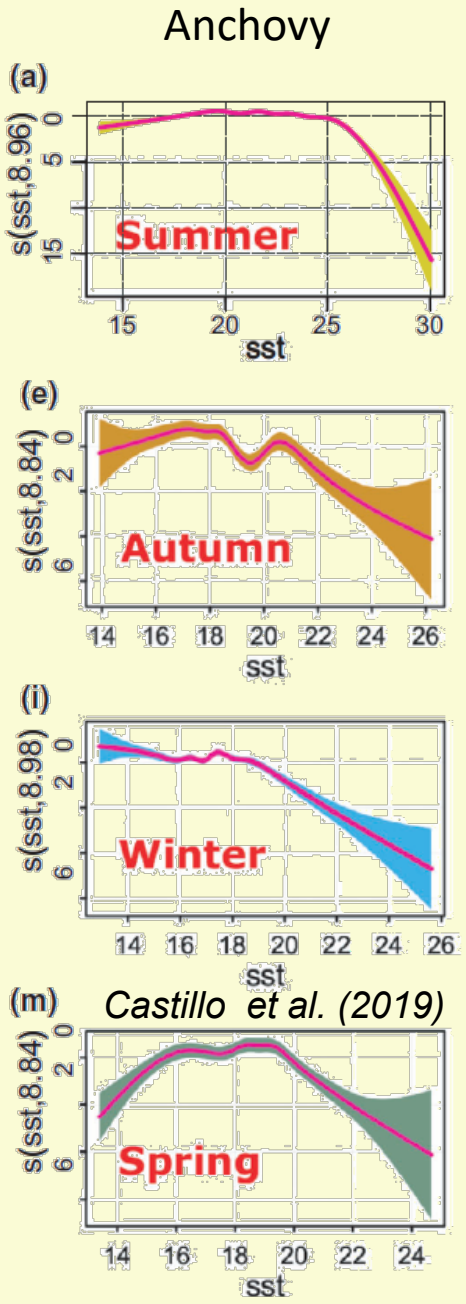


Strong placticity towards temperature

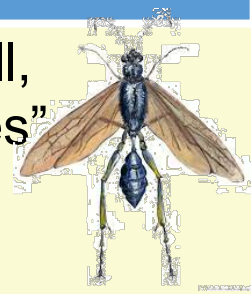
Temperature alone, not a key parameter: interaction with a variety of factors → difficult to decipher



Bertrand et al. (2004)

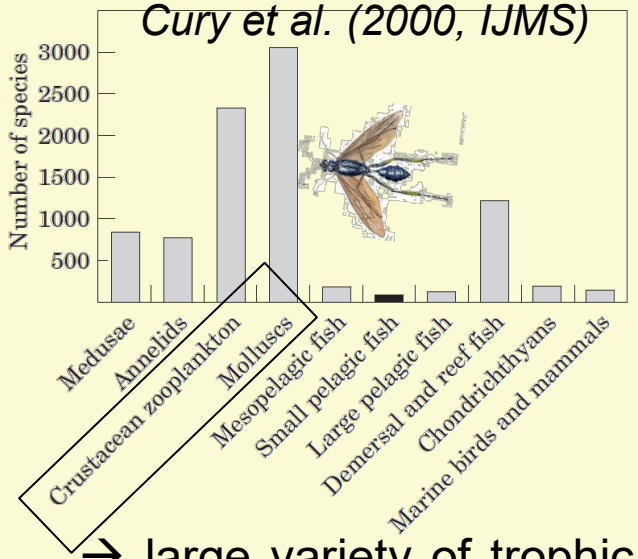


EBUS as wasp-waist systems

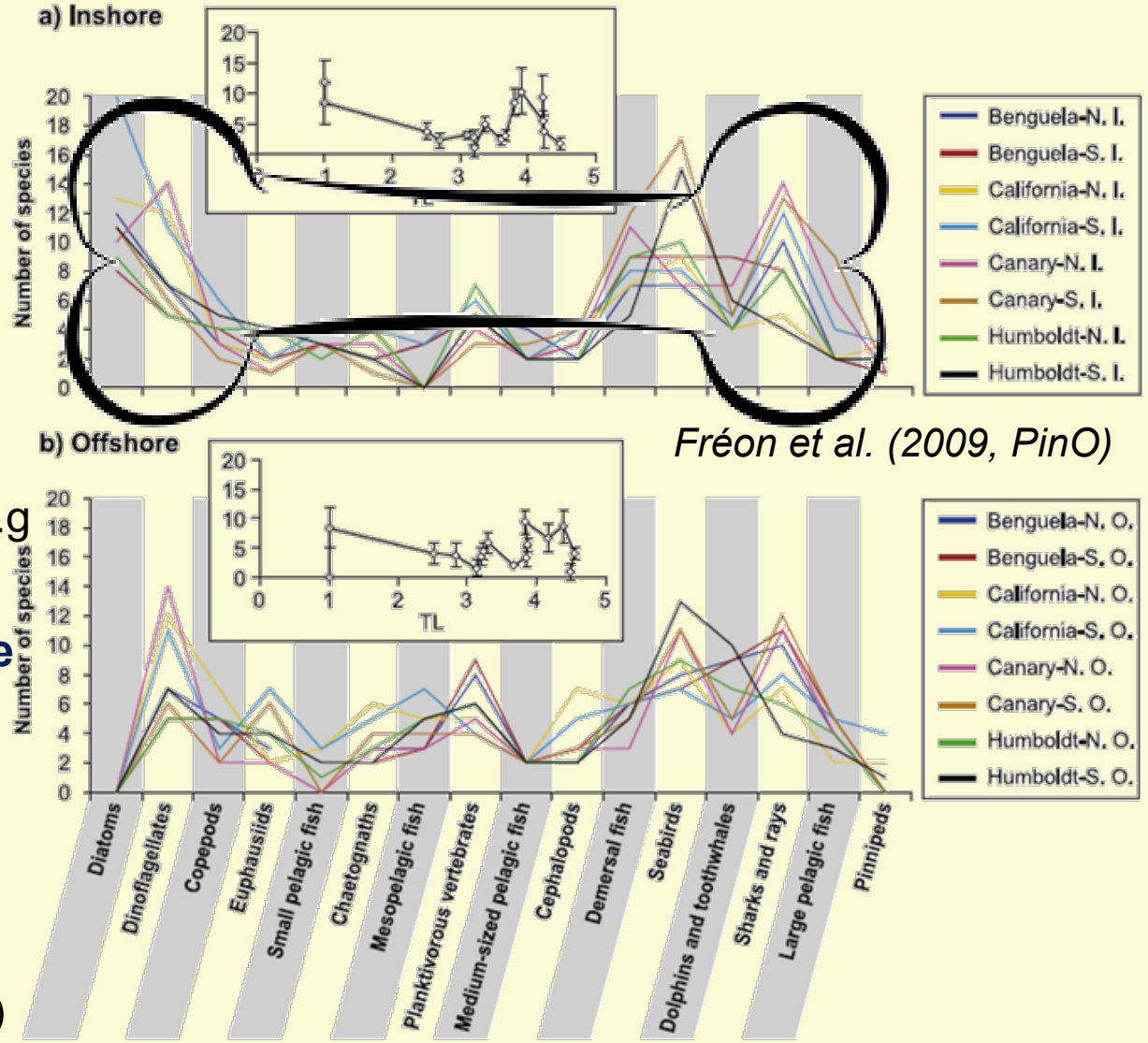


Wasp-waist structure (Bakun, 1996): "there is often a crucial intermediate TL, occupied by small, plankton feeding pelagic fishes, that is typically dominated by only one, or at most several, species"
→ primarily channelling the energy flow from lower to higher TL

Cury et al. (2000, IJMS)

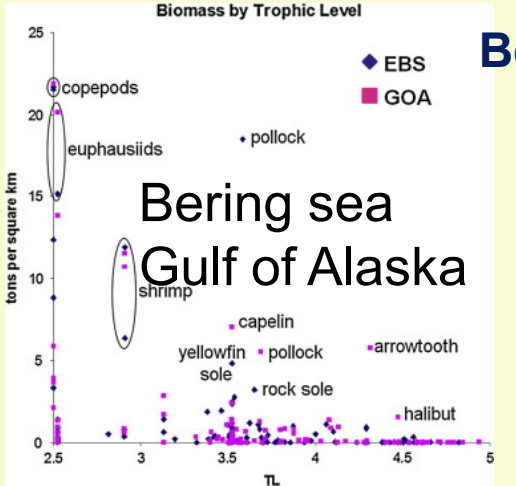


→ large variety of trophic levels, e.g small copepods vs. chaetognaths



Fréon et al. (2009, PinO)

Bone-shaped?

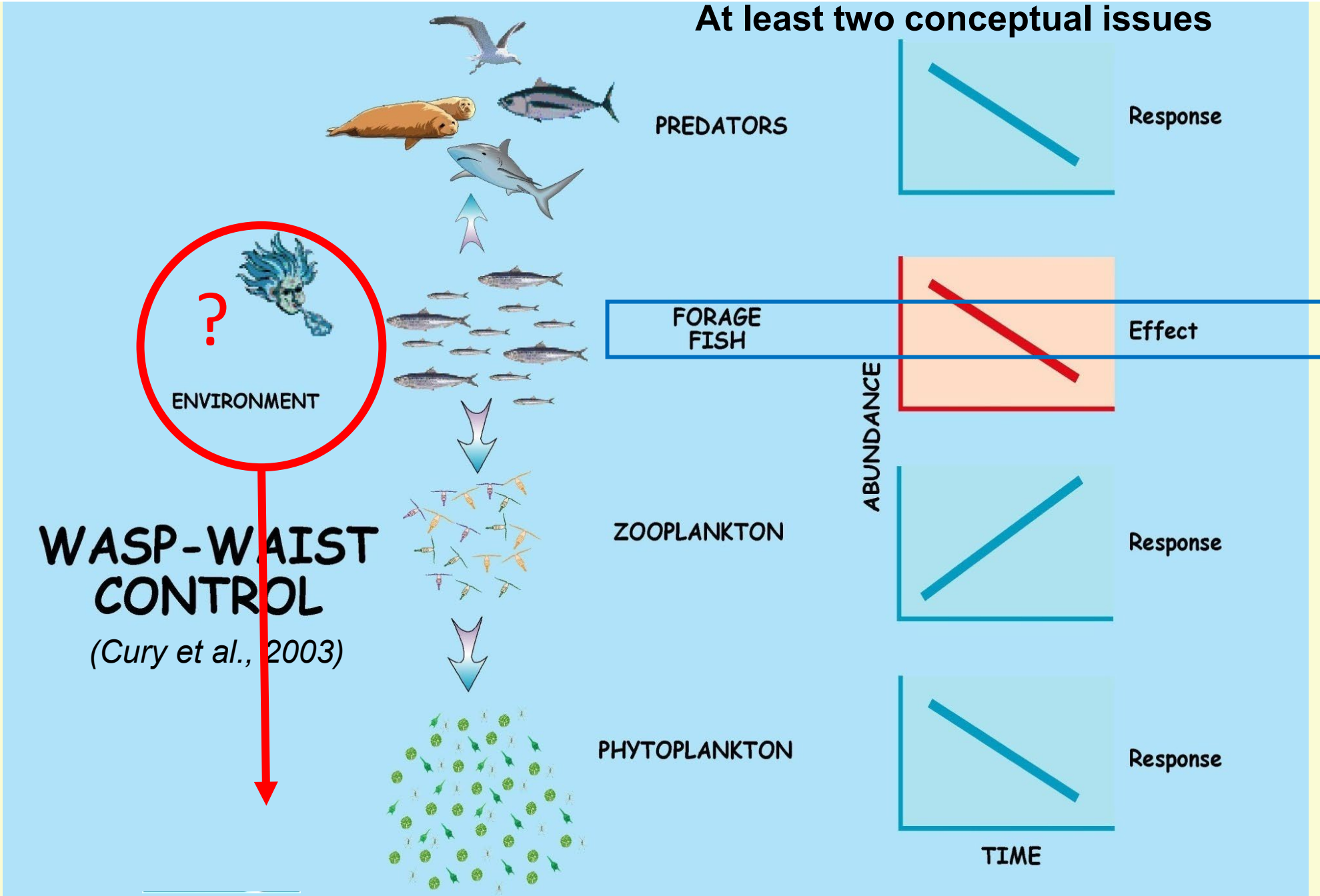


Bering sea
Gulf of Alaska

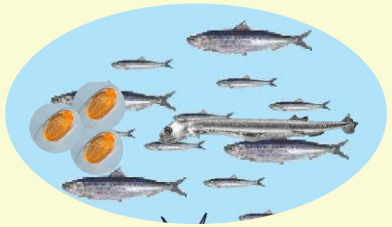
Beer belly structure

Gaichas et al. (2015)

EBUS as wasp-waist systems

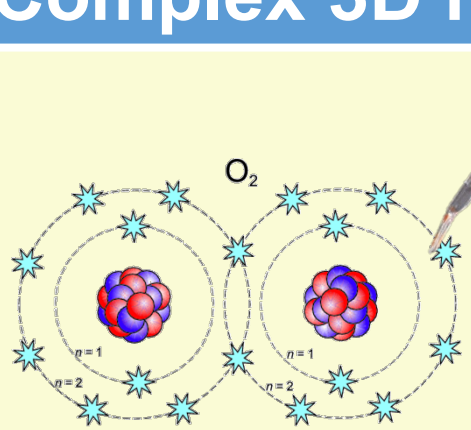


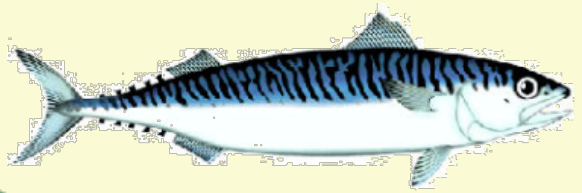
Encompasses all stages including eggs and larvae…



May explain why we lack of observational evidences…

Complex 3D habitat

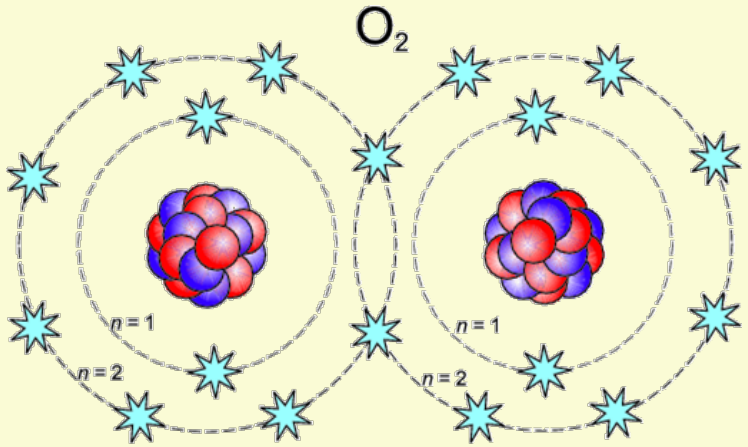


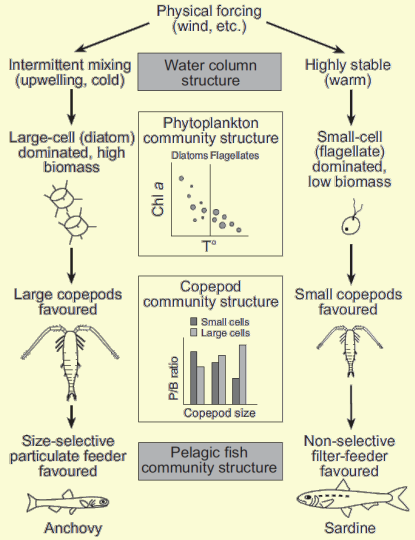


+ density dependence, etc…

Example of anchovy 3D habitat during an acoustic survey

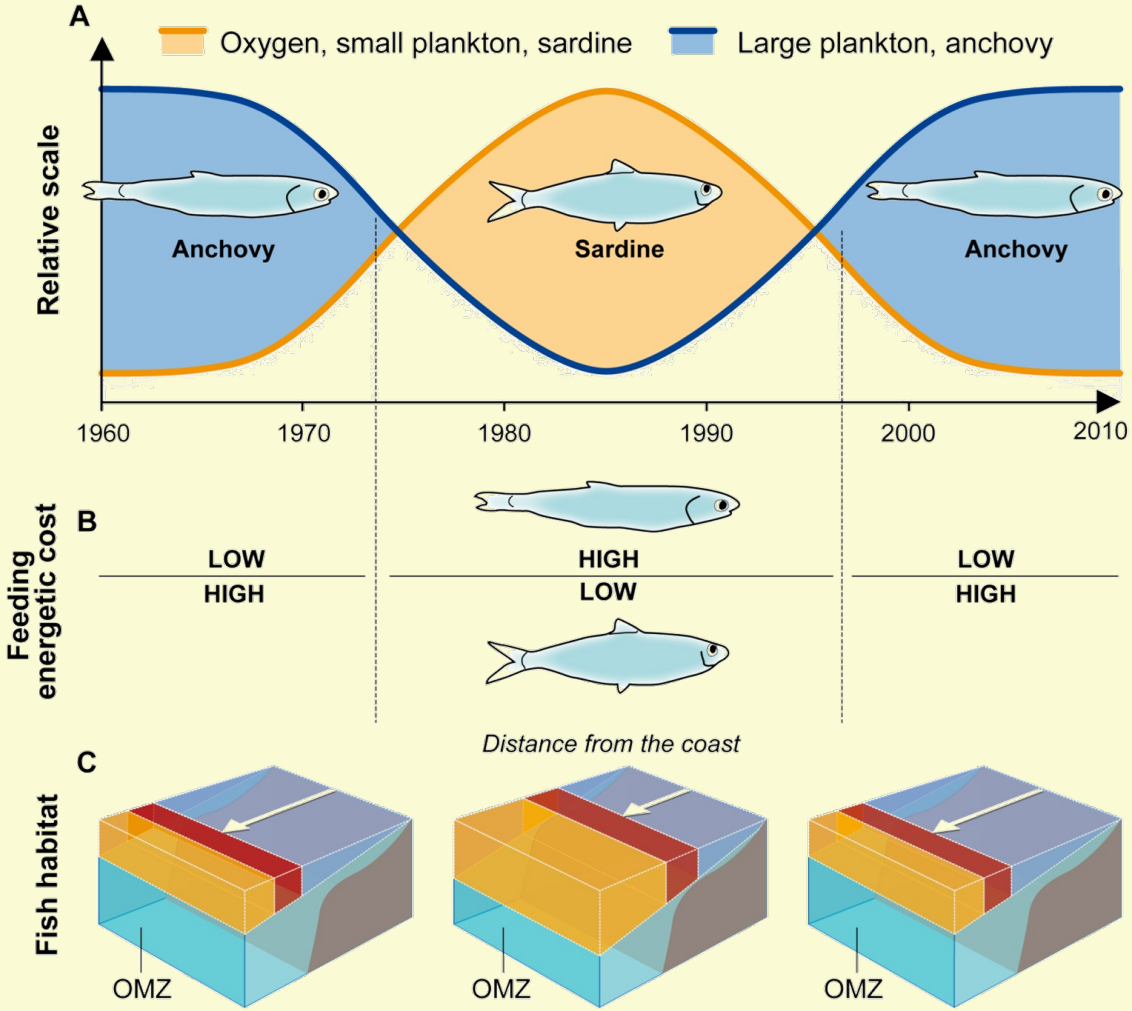
Complex 3D habitat





Completing the approach

Oxygen does matter: Fish need both food and oxygen, in some situations the latter might be more difficult to obtain than the former (Pauly, 2010)



At local to decadal scale, oxygen content is a key factor modulating SPF population in systems such as the Northern HCS

Bertrand et al. (2011, PLoS ONE)

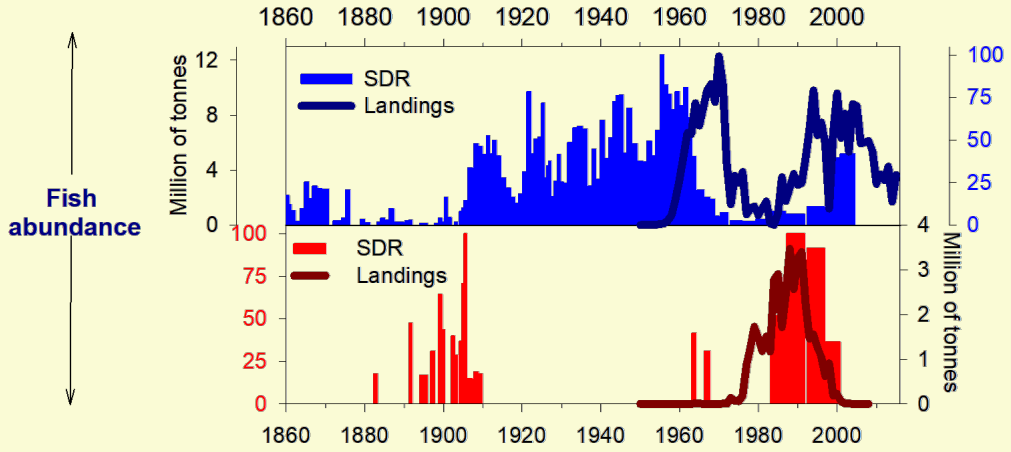
Fish variability

At larger centennial to millennial-scale, both productivity and OMZ intensity show large changes

→ Productivity main factor controlling small pelagic fish abundance

→ Sub-surface oxygenation seems to play a role in a species-dependent way

Anchovy present in large abundance since at least 18 000 years ago (see also *Bearez and Miranda, 2000*), while sardine flourish in specific conditions, only



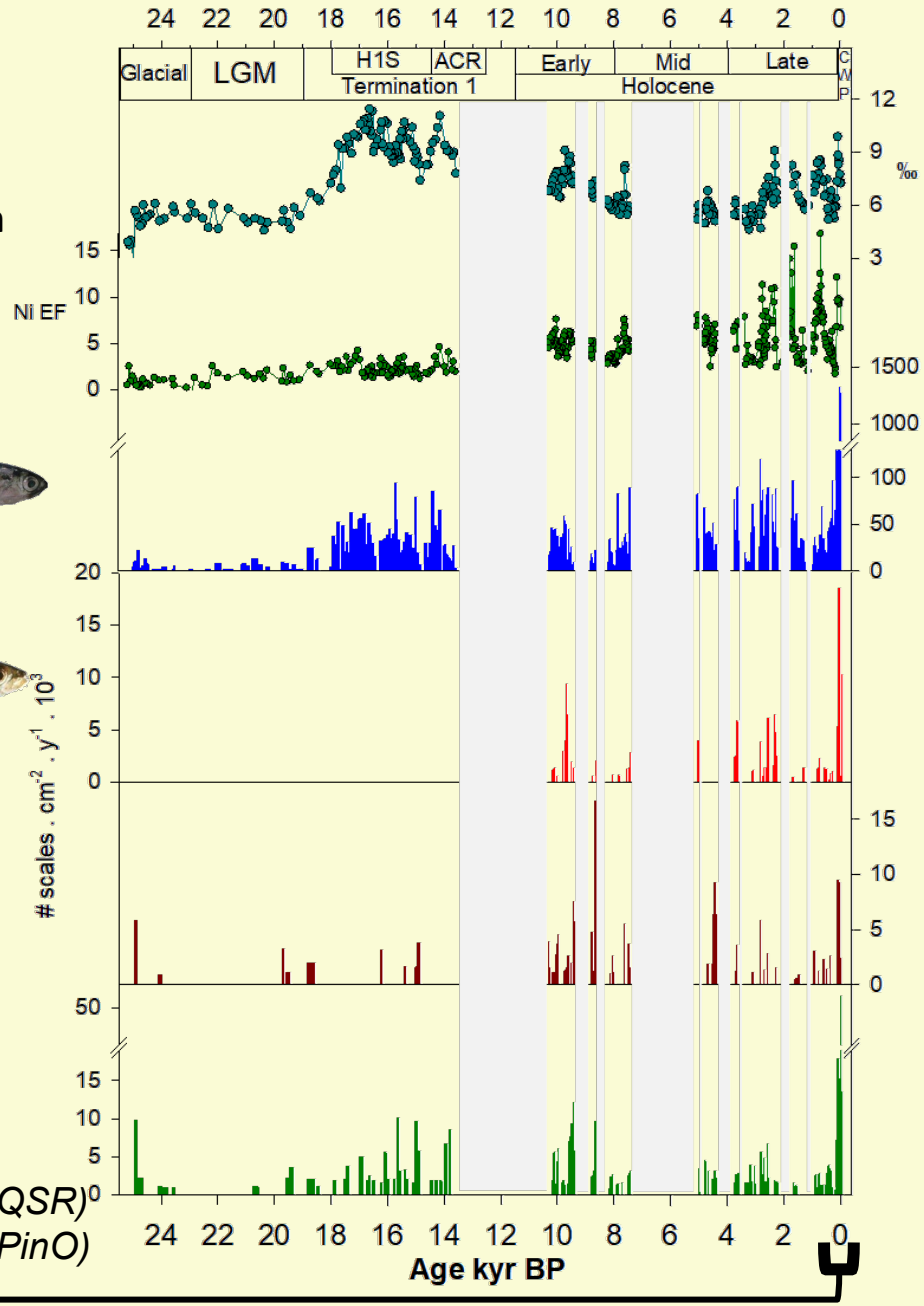
Salvatteci et al. (2018, GCB)

Anchovy

Sardine

Jack mackerel

Mesopelagic fishes

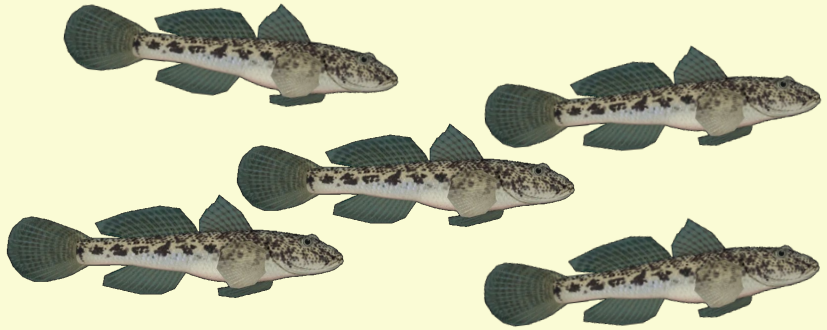


Salvatteci et al. (2016, QSR)
Salvatteci et al. (2019, PinO)

The ultimate metamorphosis?

In a warmer and less oxygenated HCS, small pelagic fish may turn into…

… gobies



For more information about the Goby World, see *Salvatteci et al. (2022, Science)* and the talk by Renato Salvatteci on Thursday at 9:30 - Session 4 Plenary

(Trivial) Conclusions

We need to be modest on what we (think to) know and doubt every day

All hypotheses or paradigms, even if eventually refuted, are crucial to make science advance

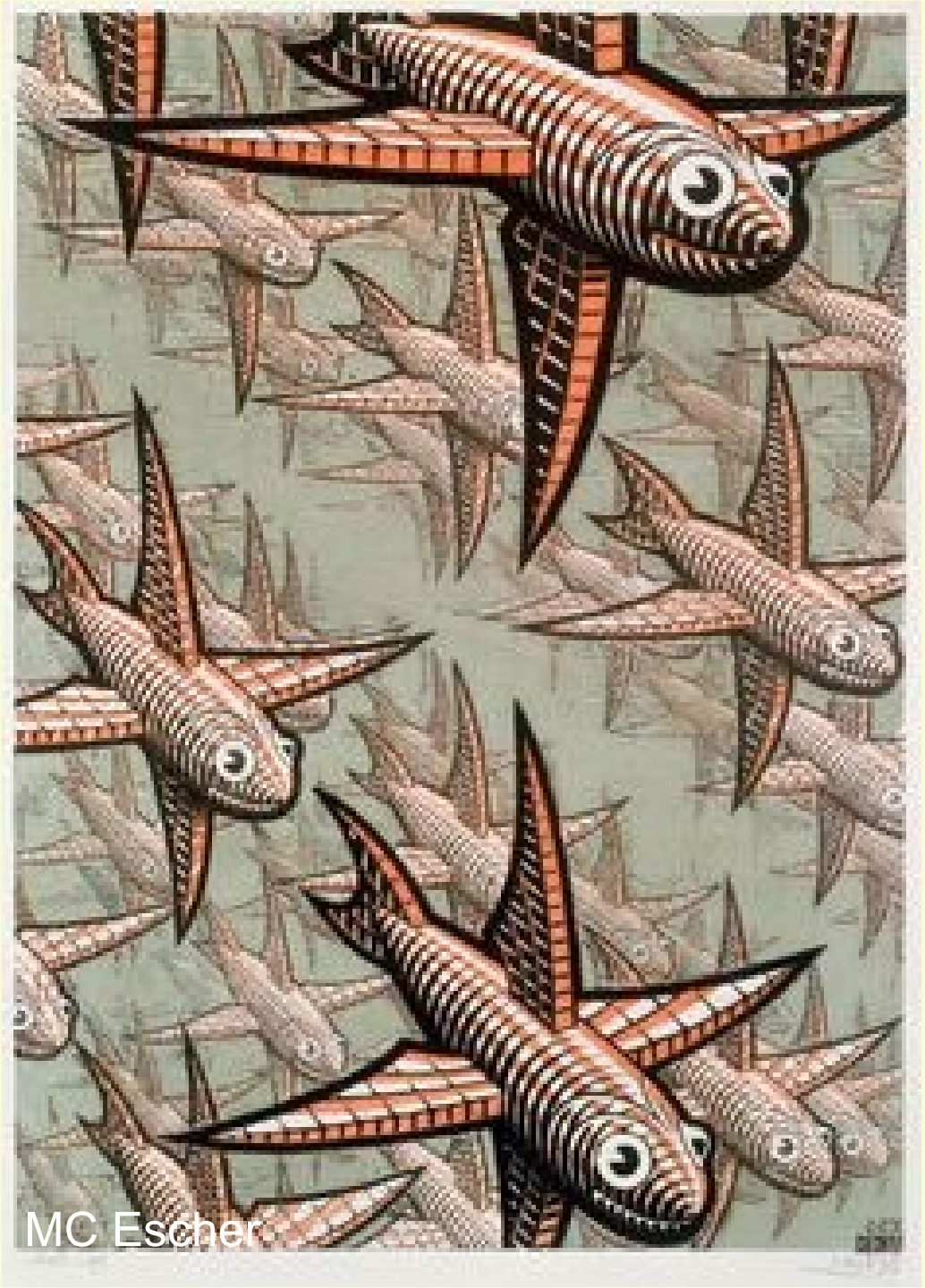
Be very cautious on the conclusion we draw from (short) time series

In dynamical systems be prepared to see and accept changes in relationships, paradigms…

Be aware that future warmer oceans can be totally different from what we saw

→ Not predictable with historical data and current models !!!! (see R. Salvatteci)

Just like SPF, we need to be plastic in our thinking



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The metamorphosis of small pelagic fish

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