The paradox of fish abundance in the northern Humboldt Current System: why is it so productive?

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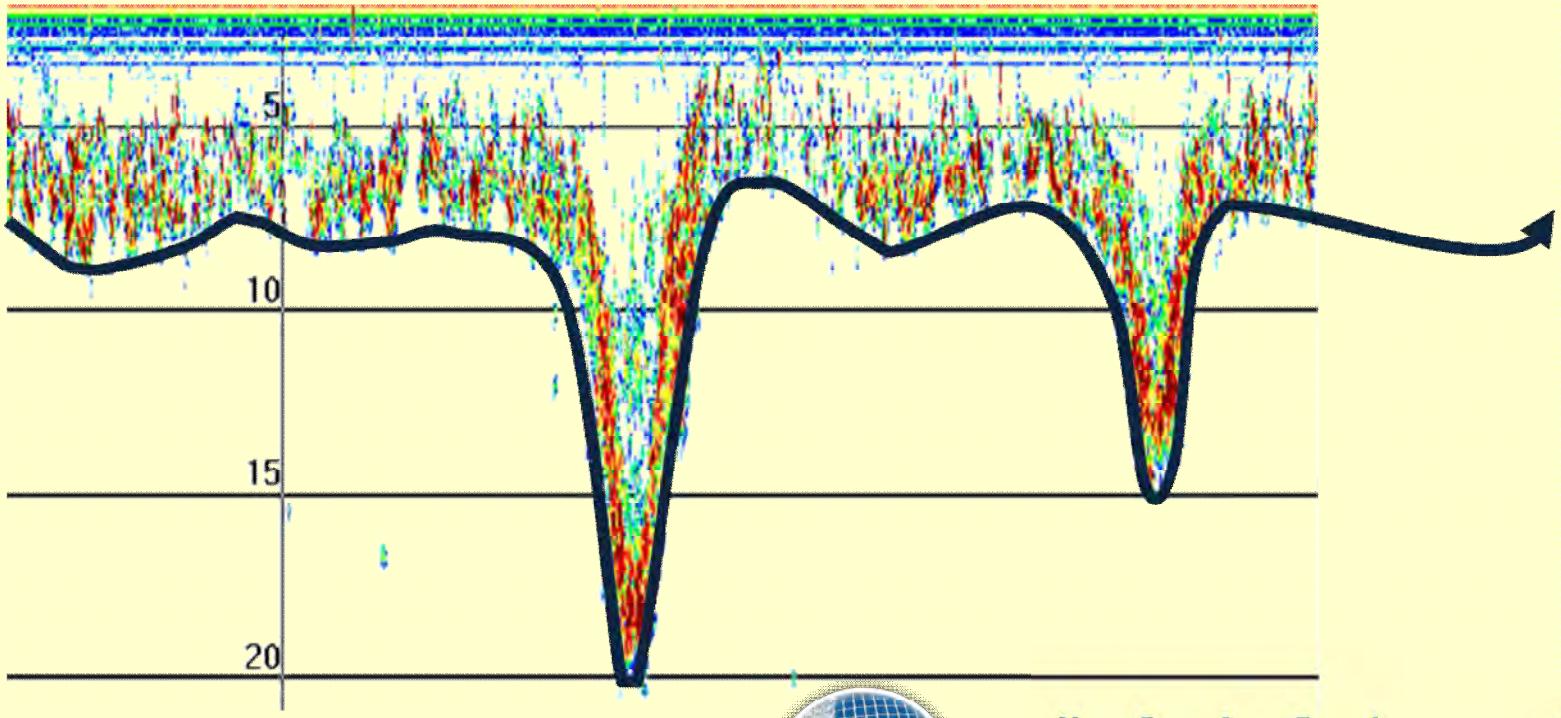

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Dynamics of the Humboldt Current system
DISCOH

M B A R I

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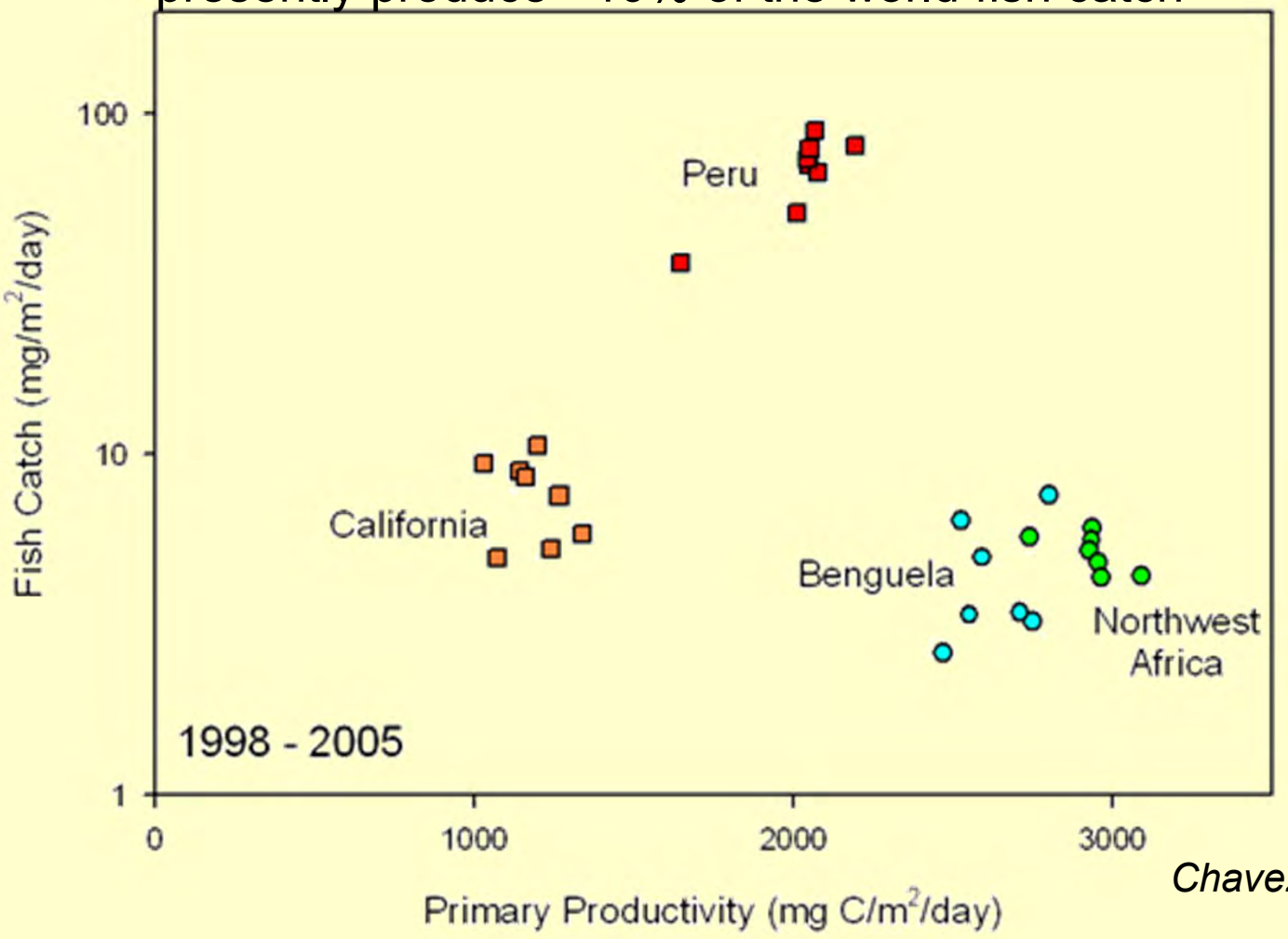
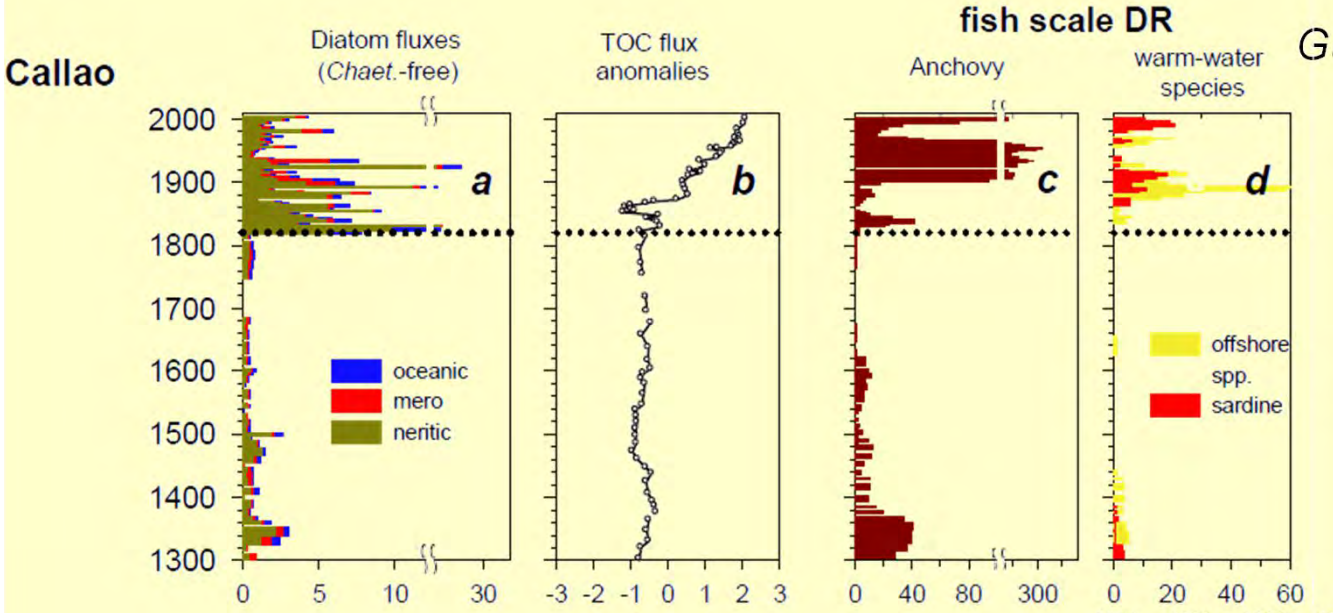
The northern Humboldt Current System (NHCS): an outlier

During the last decades the Northern HCS produced more fish per unit area than any other region in the world oceans: <0.1% of the ocean surface but presently produce ~10% of the world fish catch



Chavez et al. (2008)

The NHCS: not always highly productive

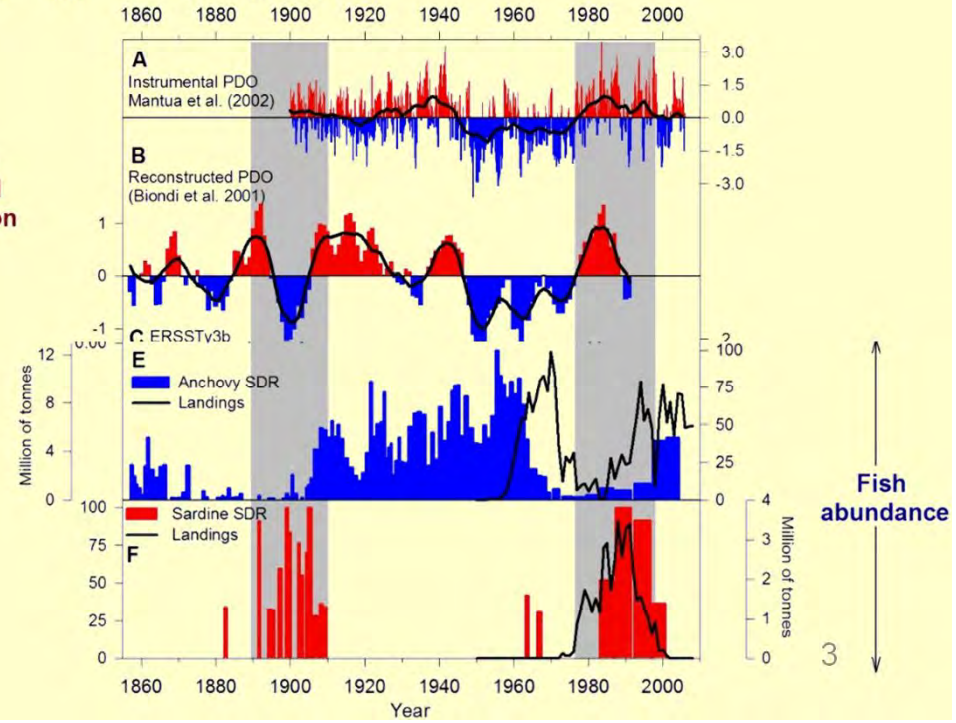


Gutiérrez et al. (2009)

Since the early 1900s: likely the most productive over the last 20 000 years

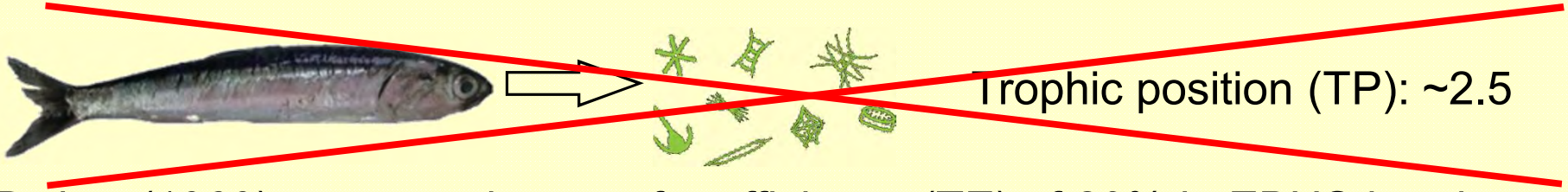
Pacific Decadal Oscillation

Processes are complex; PDO does not (always) drive Anchovy and Sardine fluctuations off Peru *Salvatteci et al. (this symp.)*



Contemporary NHCS high productivity: the first hypothesis

Ryther (1969): to account for the fish productivity in EBUS, and in particular Peru, you require a short food chain from phytoplankton to fish.



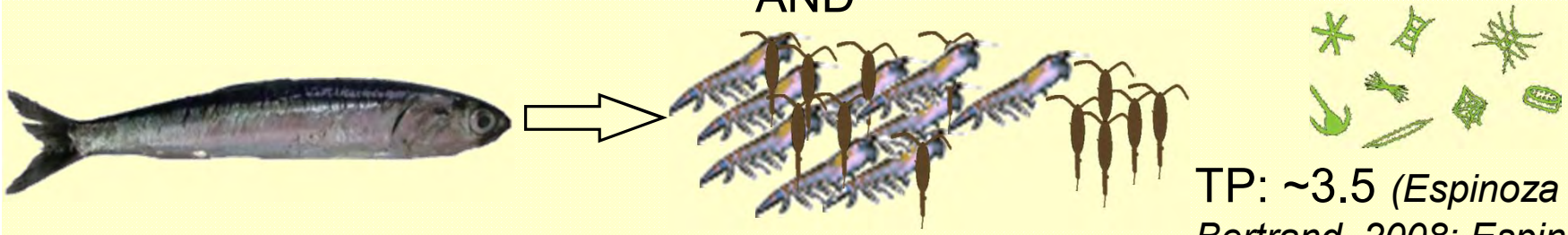
Trophic position (TP): ~2.5

Ryther (1969) suggested a transfer efficiency (TE) of 20% in EBUS but that "it is possible that the actual values are considerably lower".

BUT

Recent estimates report a TE of ~5% in EBUS (e.g. Chassot et al., 2010)

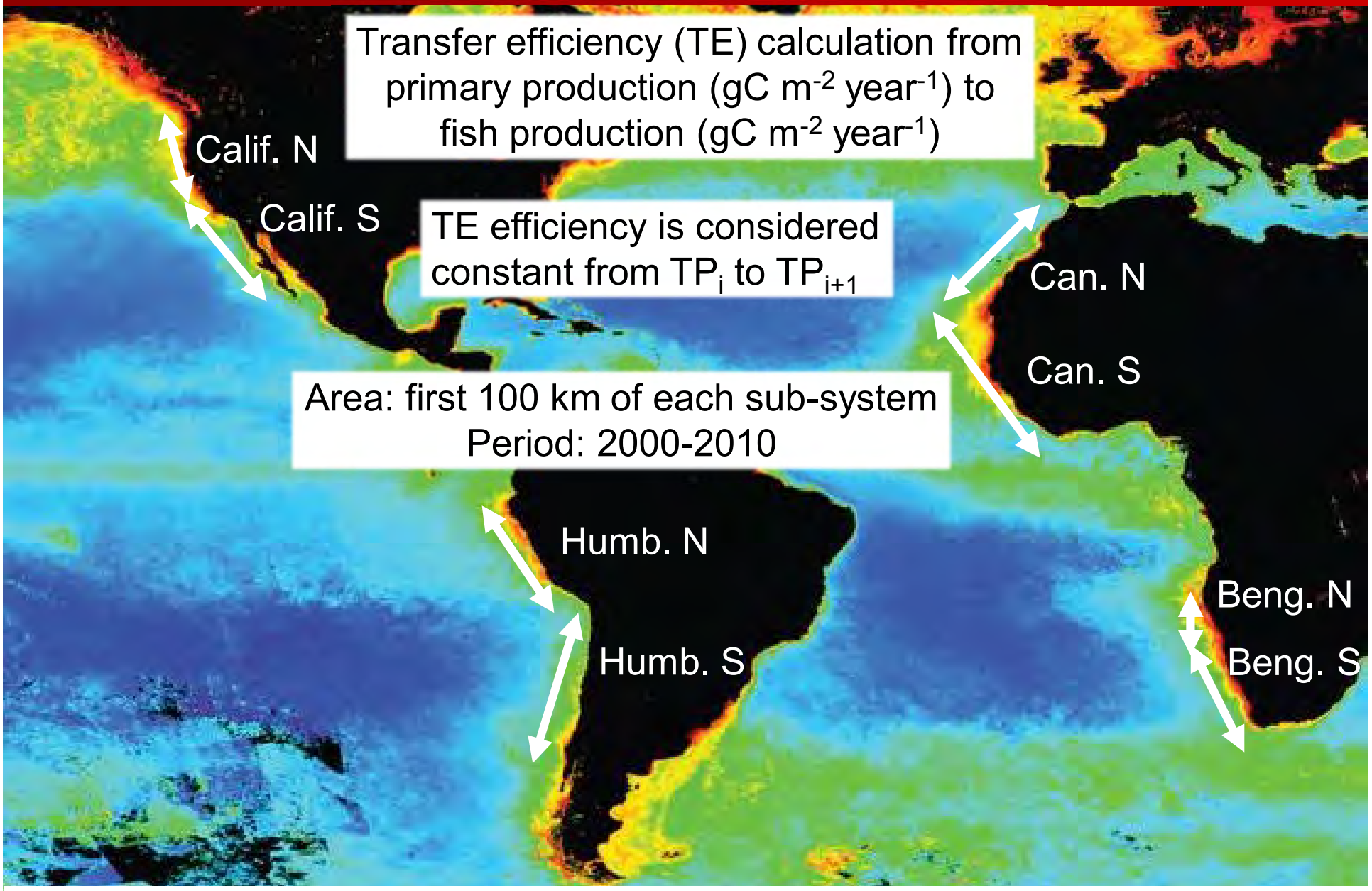
AND



TP: ~3.5 *(Espinoza & Bertrand, 2008; Espinoza et al. (in press)*

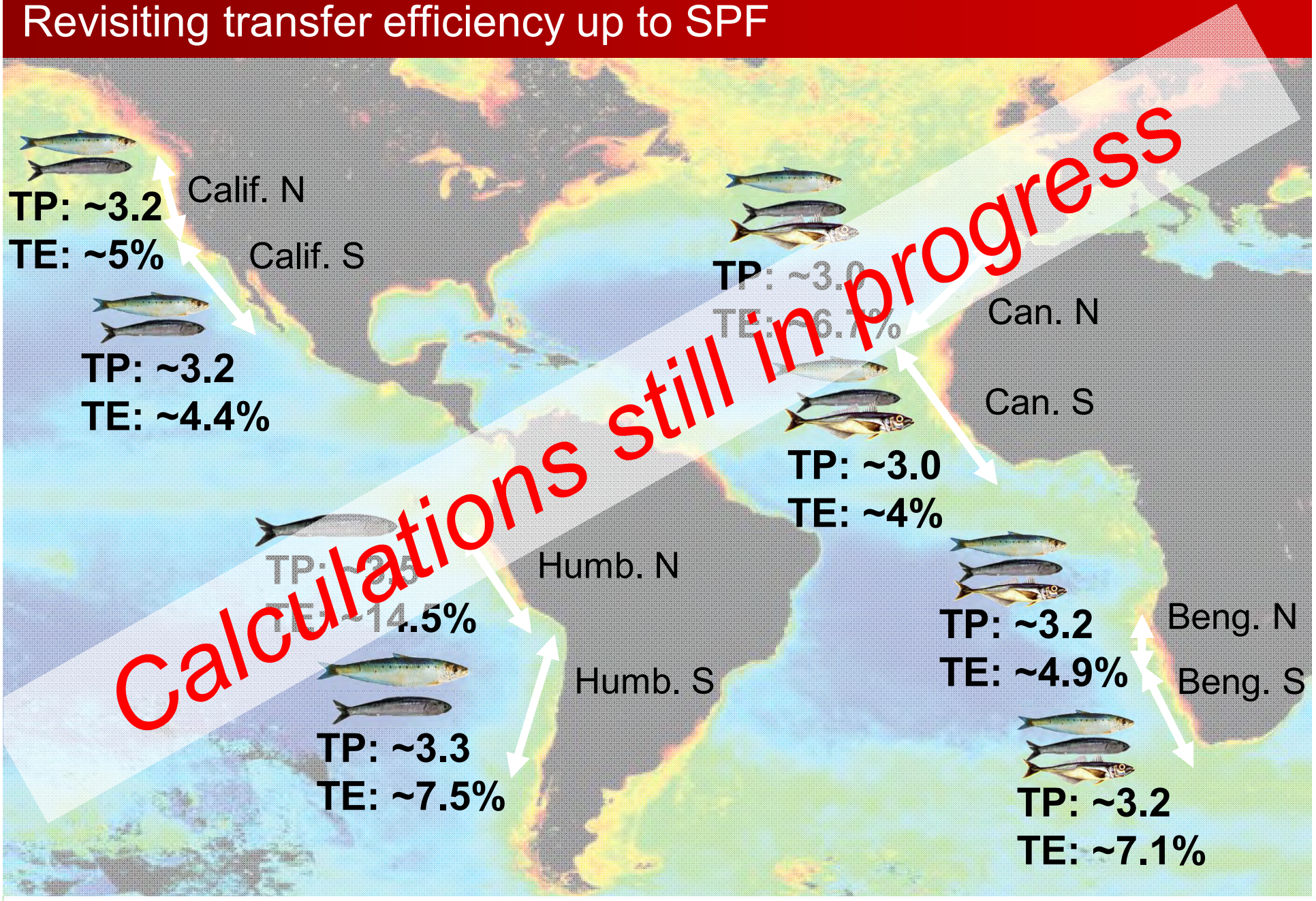
So how can the NHCS produce so much fish?

Revisiting transfer efficiency up to SPF



TP: Trophic Position *see van der Lingen et al. (2009)*, TE: Transfer Efficiency

Revisiting transfer efficiency up to SPF



TP: Trophic Position *see van der Lingen et al. (2009)*, TE: Transfer Efficiency

What explains such current high transfer efficiency in the NHCS?

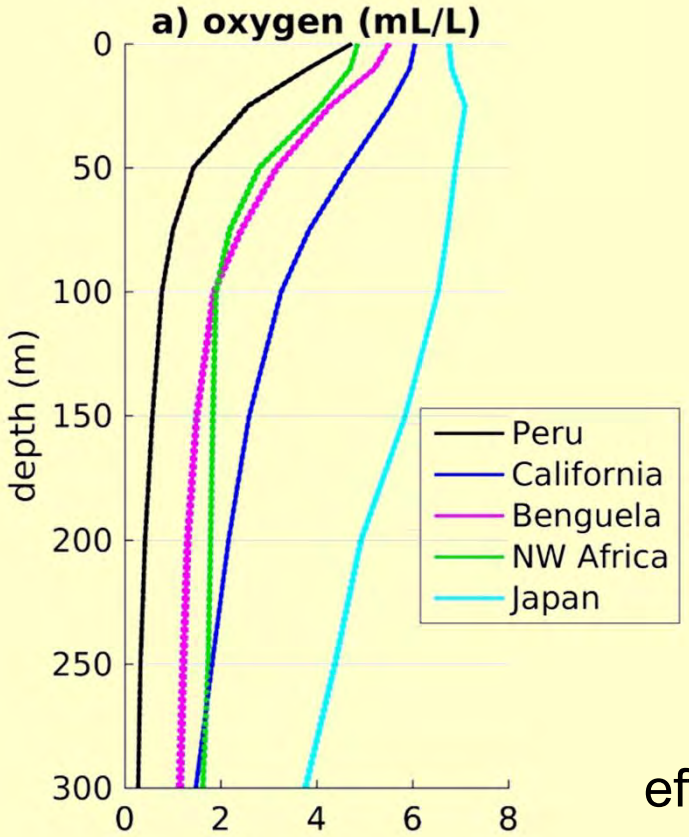
Some important factors:

- ✓ Proximity to the equator → strong upwelling-based nutrient enrichment with low wind-induced turbulence generation *(Bakun and Weeks, 2008)*
- ✓ Moderate but productive all year-long upwelling: Optimal Environmental Window conditions maximising recruitment success *(Cury and Roy, 1989)*
- ✓ Forage fish have access to highly energetic food: the euphausiids *(Espinoza and Bertrand, 2008, 2014)*
- ✓ El Niño effect: favouring fast growing fish like anchovy *(Chavez, 1987)* and preventing long lived ocean dwelling predators from getting established *(Bakun and Weeks, 2004)*. But top-down control really unlikely *(S. Bertrand, this symposium)*

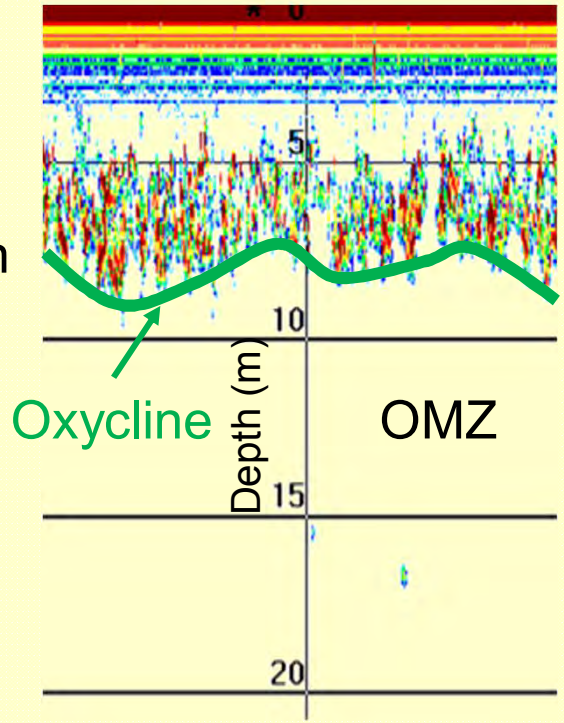
Important factors but likely not sufficient to explain such difference

What explains such current high transfer efficiency in the NHCS?

The oxygen minimum zone (OMZ) and habitat compression *(e.g. Prince and Goodyear, 2006)*



Off Peru the oxycline can be < 10 m concentrating marine life (night) in a thin surface layer *(Bertrand et al., 2010, 2011)*

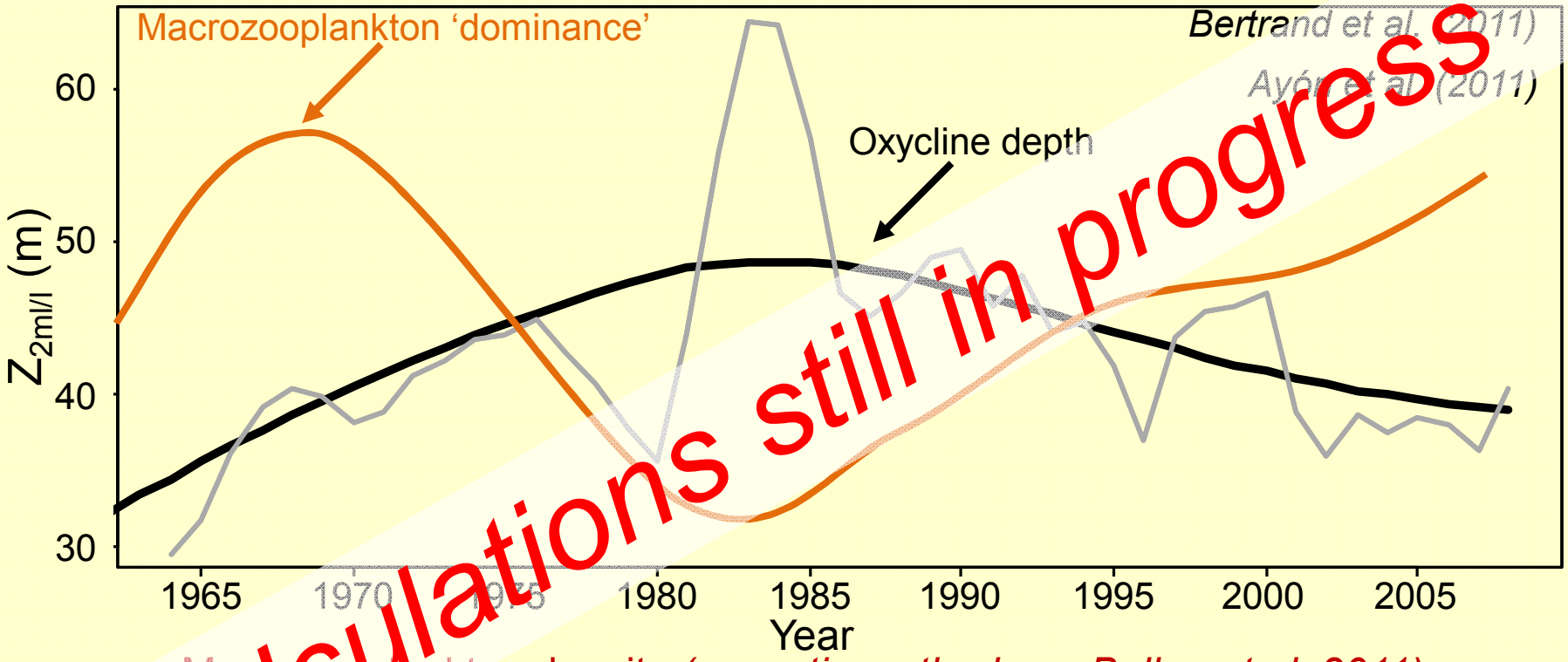


A shallow oxycline increases anchovy foraging efficiency *(Bertrand et al., 2008)* expulses fish that can compete/predate with/on anchovy (e.g. jack-mackerel; *Bertrand et al., 2016)* .

But favour the foraging efficiency of seabirds and fisherman *(Joo et al., 2015; Passunni et al., 2016; Brabraud et al., in press)*.

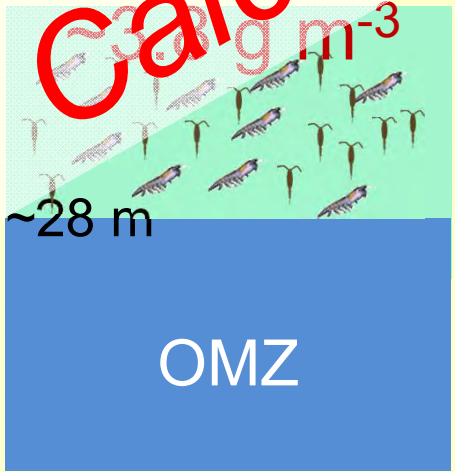
TE controlled by the productivity and the OMZ?

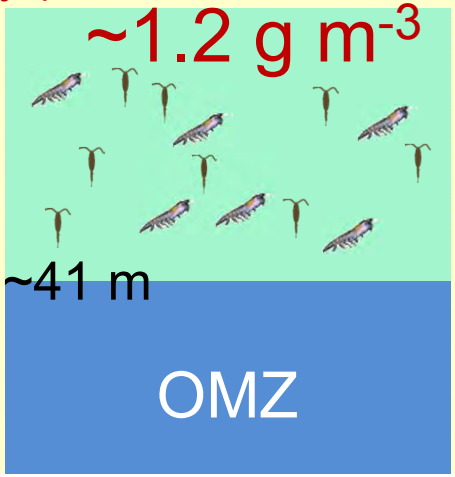
OMZ depth varies at a variety of scales *(e.g. Salvatteci, 2013)* consequences?

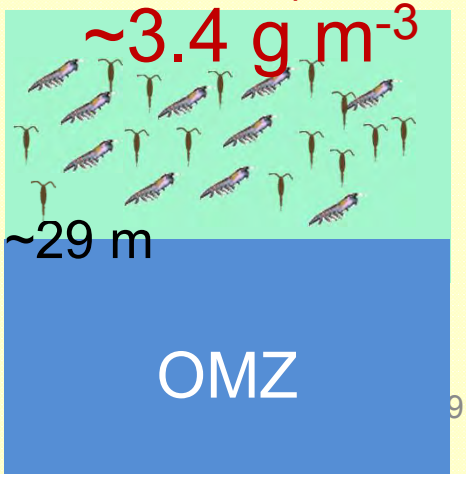


Calculations still in progress

Macrozooplankton density *(acoustic method see Ballon et al. 2011)*

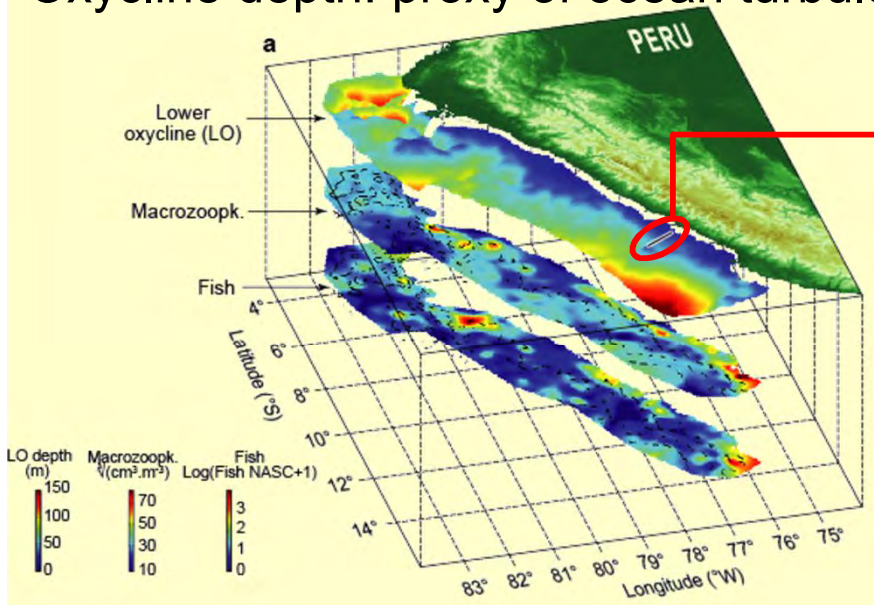


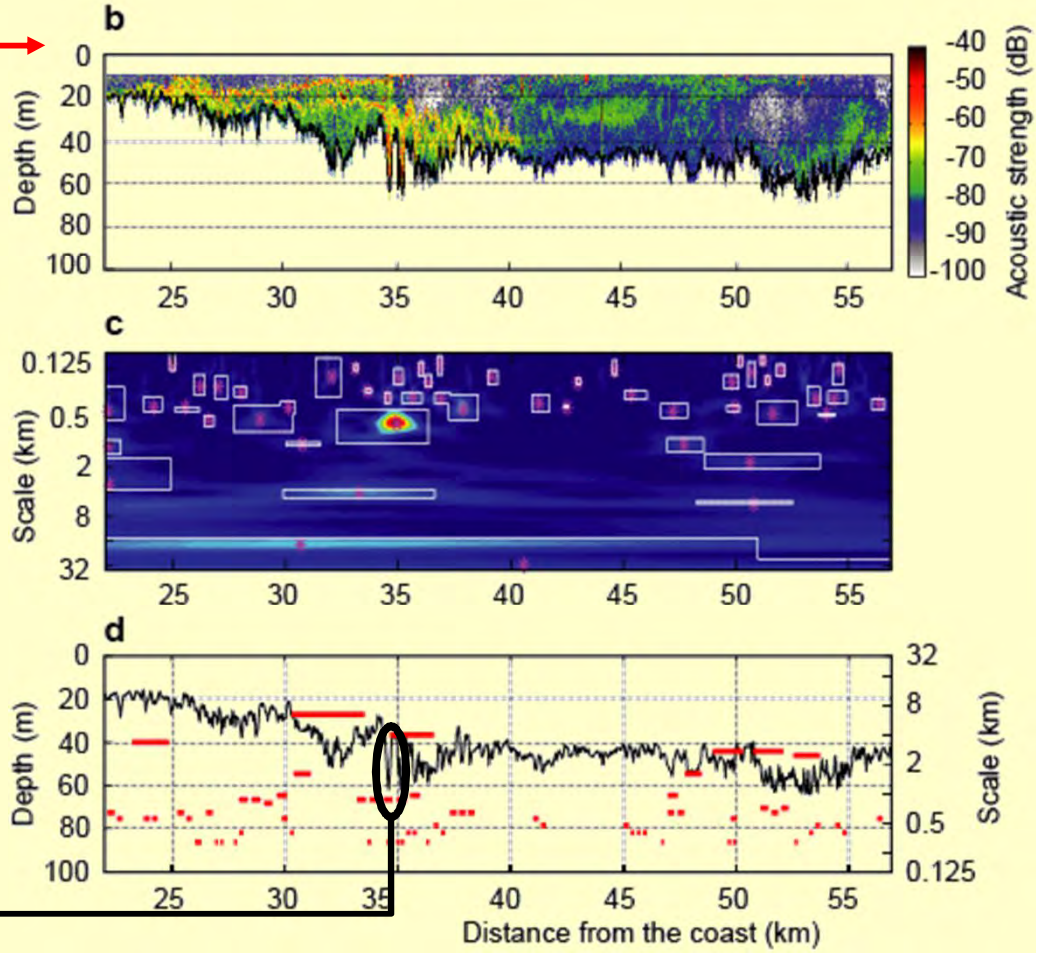




The role of ocean surface turbulence

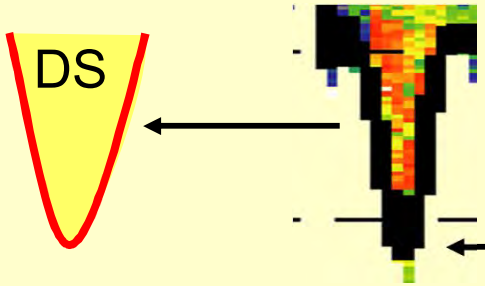
Oxycline depth: proxy of ocean turbulence → Extract physical structures along scales: wavelet-based method





Bertrand et al. (2014)
Grados et al. (2016, this symp)

Scale
Size
DS



DS: Downward Deformation Surface in m^2

Ocean dynamics at scales <10 km play the foremost role in shaping the seascape from zooplankton to seabirds *(Bertrand et al., 2014)*

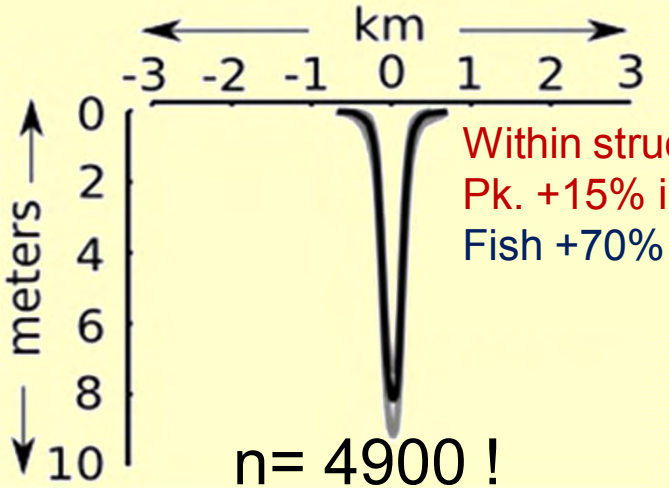
The role of ocean surface turbulence

Extraction of 35 000 structures

Grados et al. (2016; this symposium)

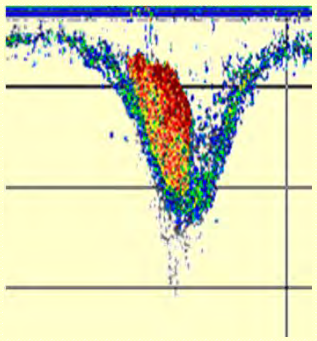
Typology

Cluster at the Internal Wave scale

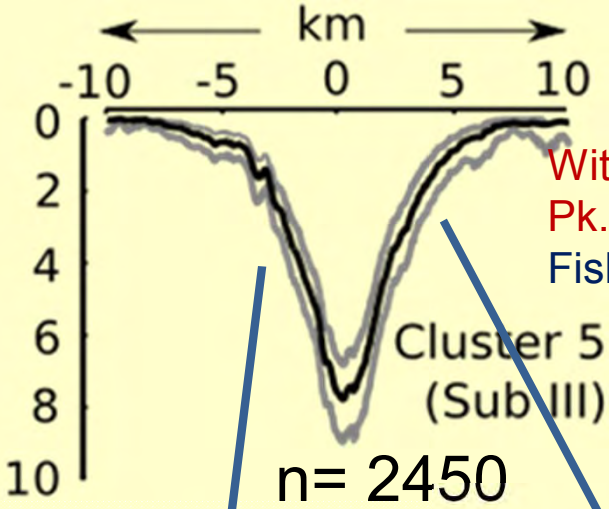


Within structures:
Pk. +15% in density
Fish +70% in density

n= 4900 !

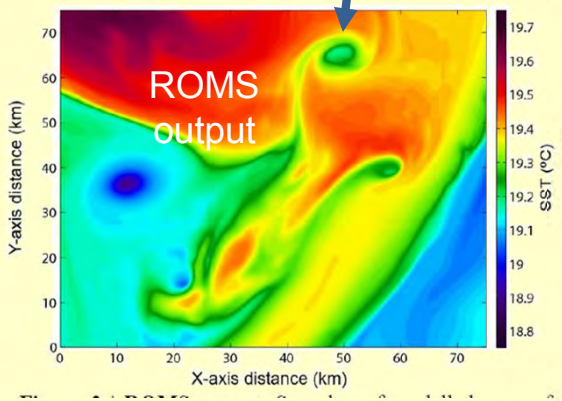


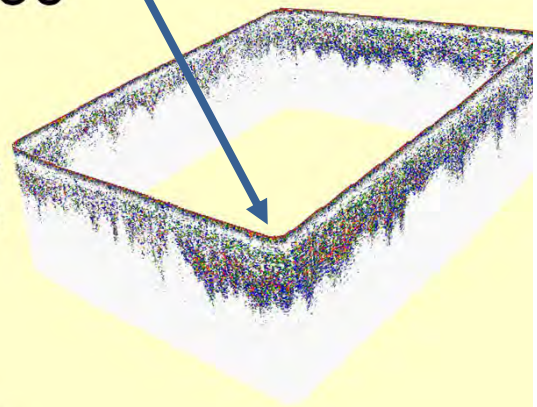
Cluster at the submeso-scale



Within structures:
Pk. +15% in density
Fish +100% in density

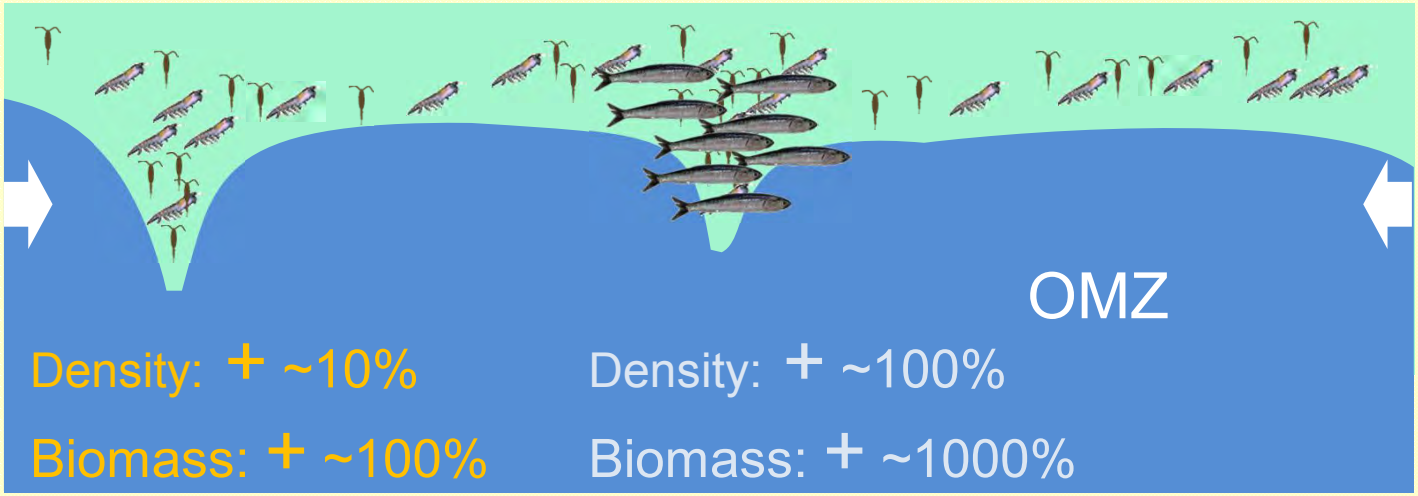
n= 2450

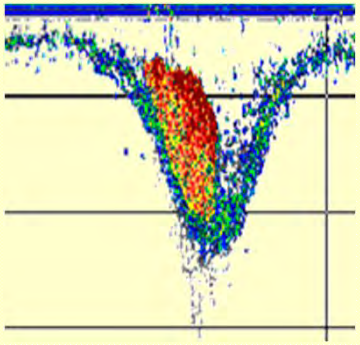




Ocean surface turbulence creates ephemeral oases which concentrate organisms ranging from zooplankton to seabirds *(Bertrand et al., 2014)*

Vertical and horizontal habitat compression



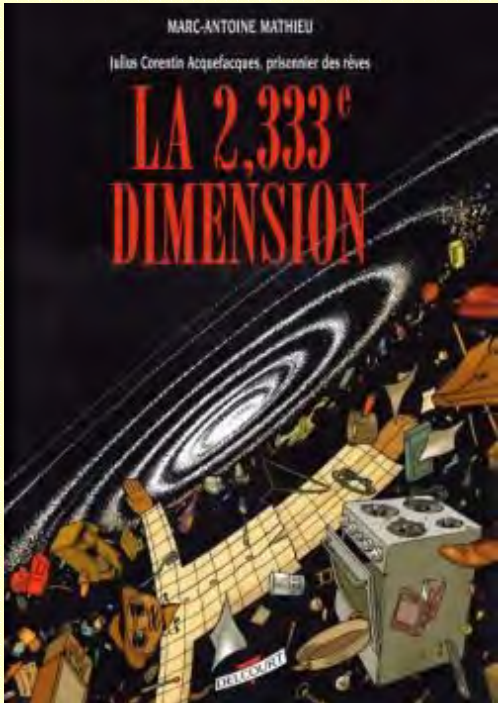


Behaviour, that is, schooling and the search for prey, magnify the physically induced spatial structuring (*Bertrand et al. 2014)*

Classically, higher TE in benthic environment likely due to their reduced dimensionality relative to pelagic environments *(see Stock et al., 2017)*.

In the NHCS, the vertical and horizontal compression reduce the dimensionality of the epipelagic habitat.

Welcome to the 2.333 dimension !



Summary

Reasons for the current (since ~1900) high fish productivity of the NHCS:

- ✓ Proximity to the equator
- ✓ Optimal Environmental Window conditions
- ✓ Forage fish have access to highly energetic food
- ✓ Much more efficient TE (~14.5%): 2-3 times higher than other EBUS

→ The vertical and horizontal habitat compression shapes a thin layer where ephemeral oases concentrate life and enhance trophic interactions

→ Trophic efficiency is modulated by productivity and the depth of the OMZ; both varying at a variety of spatiotemporal scales

Calculations still in progress

The 2.333 dimension !