DOES CLIMATE CHANGE MATTER FOR ZOOPLANKTON PRODUCTION IN UPWELLING SYSTEMS?

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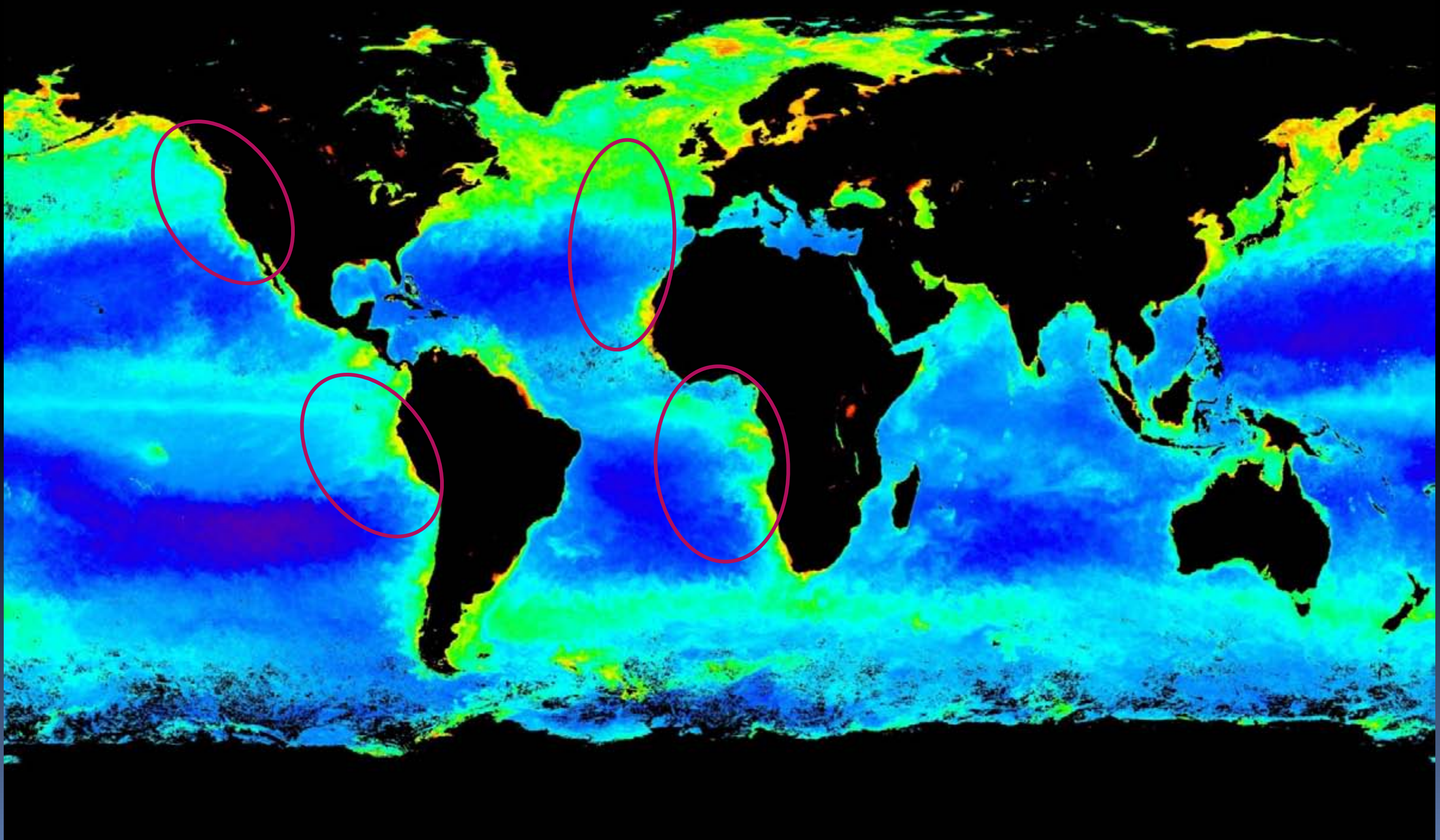
Outline

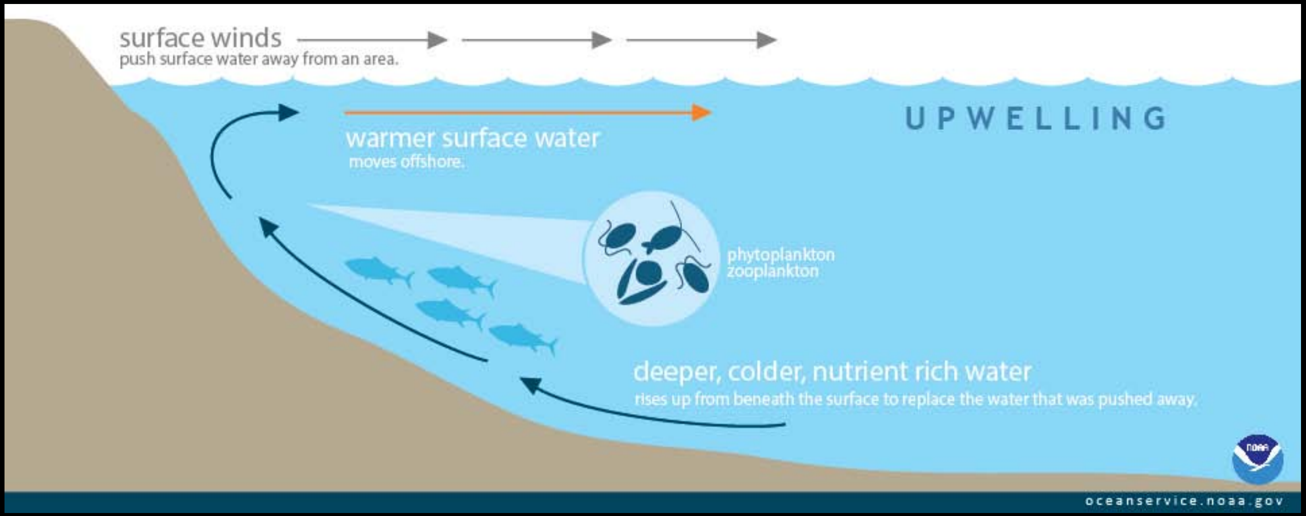
- Eastern Boundary Upwelling Ecosystems (EBUE)
- Climate change forcing EBUE variation
- Zooplankton in EBUE
- Measuring zooplankton biomass and production in an EBUE
- Remarks and thoughts

Eastern Boundary Upwelling Ecosystems (EBUE)

- Eastern boundary upwelling systems (EBUS) (<3% of the world ocean surface)
- A significant role in the climate system (Large and Danabasoglu, 2006)
- The largest contribution to ocean biological productivity: up to 40% of global fish catch (Pauly and Christiansen, 1995; Capone and Hutchins, 2013).



COASTAL UPWELLING: THE KEY PROCESS CONTROLLING BIOLOGICAL PRODUCTION IN EBUE



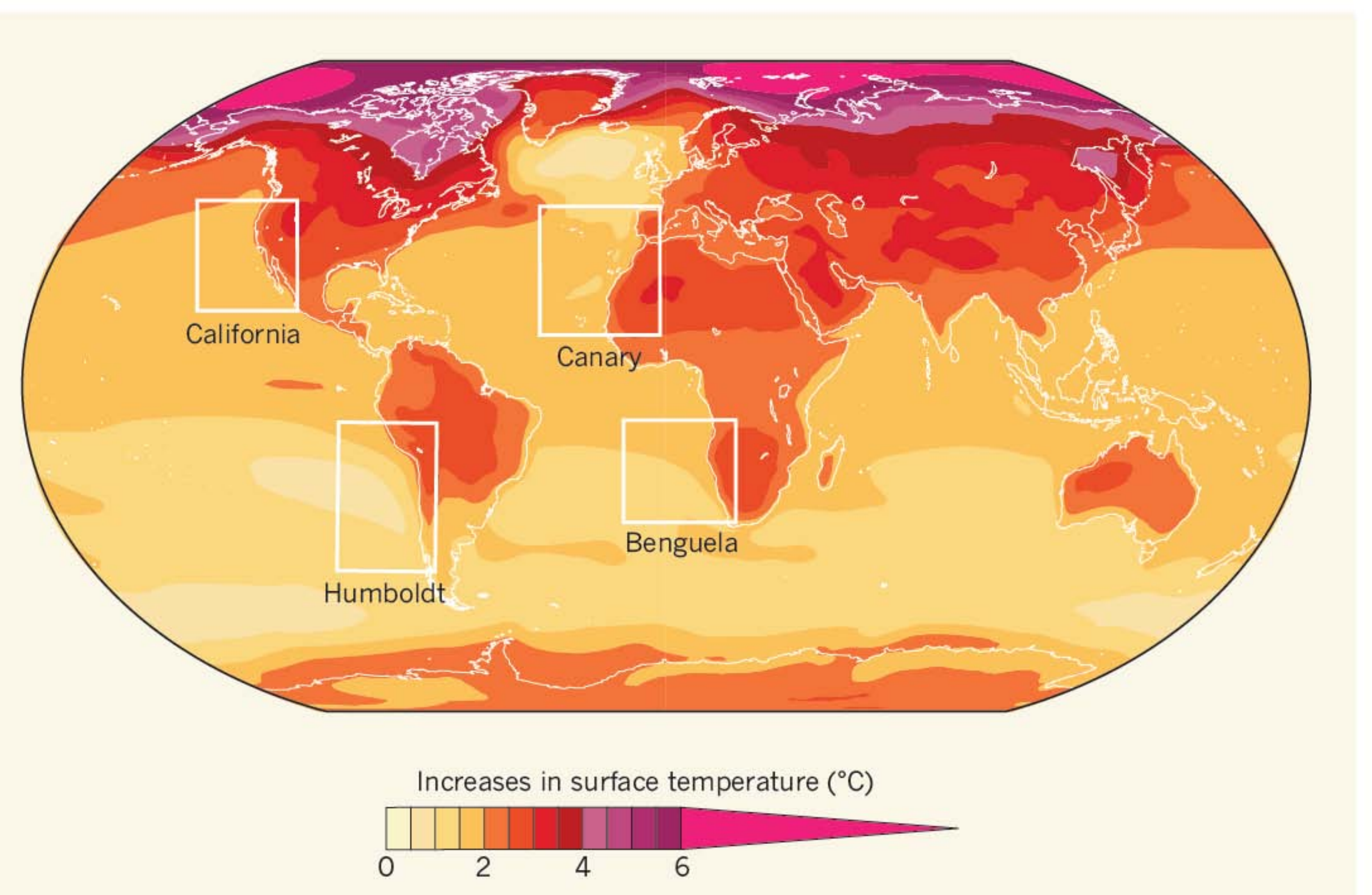
www.noaa.gov

Upwelling:

- Promotes primary production, secondary production and so on..
- But also has an important role in the cycling of marine nutrients microbially mediated.
- It also causes a strong natural variations in CO_2, pH, nutrient levels and SST

EBUE AND GLOBAL WARMING

Predicted changes in Earth's surface temperature

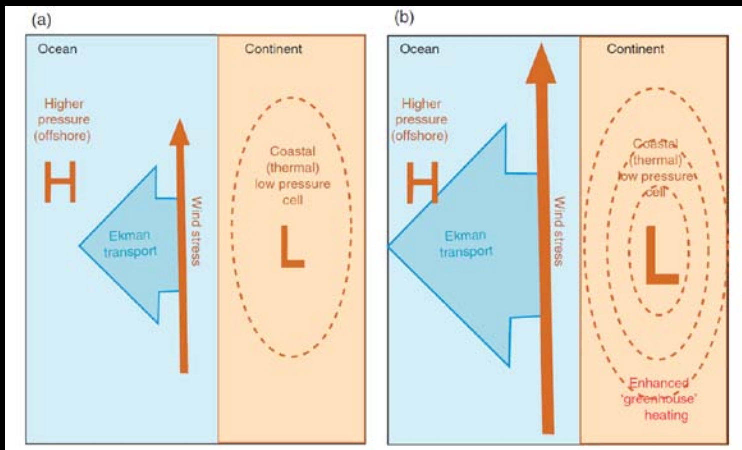


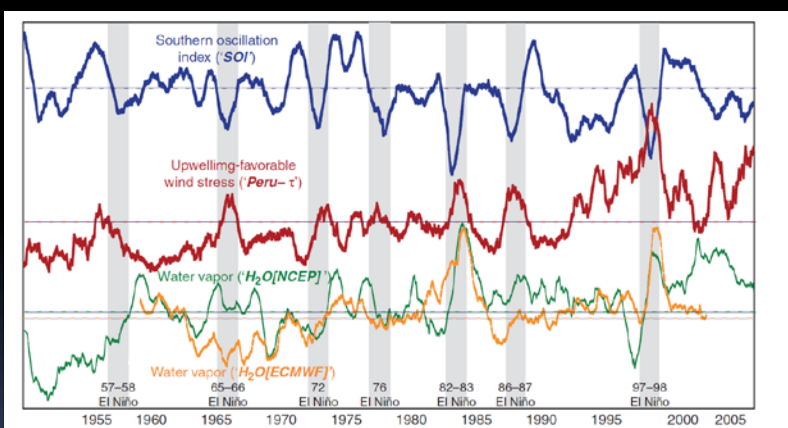
Differences in surface temperature between now and 2050, based on predictions from 27 climate models.

Di Lorenzo, 2015 Nature

THE FUTURE OF UPWELLING IS UNCERTAIN IN EBUE

BAKUN'S HYPOTHESIS





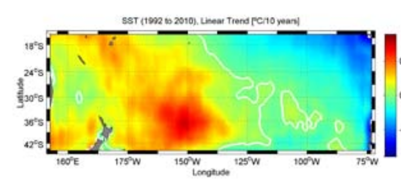
Bakun et al. 2010

✓INCREASED UPWELLING-FAVORABLE WINDS

✓MORE UPWELLING TAKING PLACE IN EBUEs

✓MORE UPWELLING IMPLIES COLDER NEAR-SURFACE WATER , MORE NUTRIENTS

Humboldt Current



Schneider et al. (unpublished)

Benguela Current

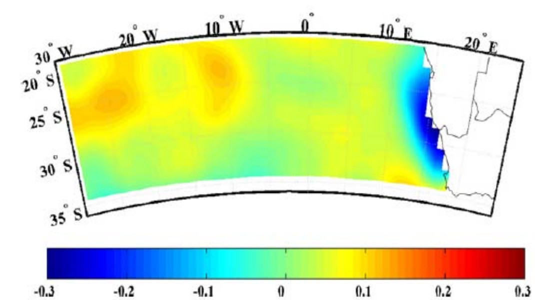


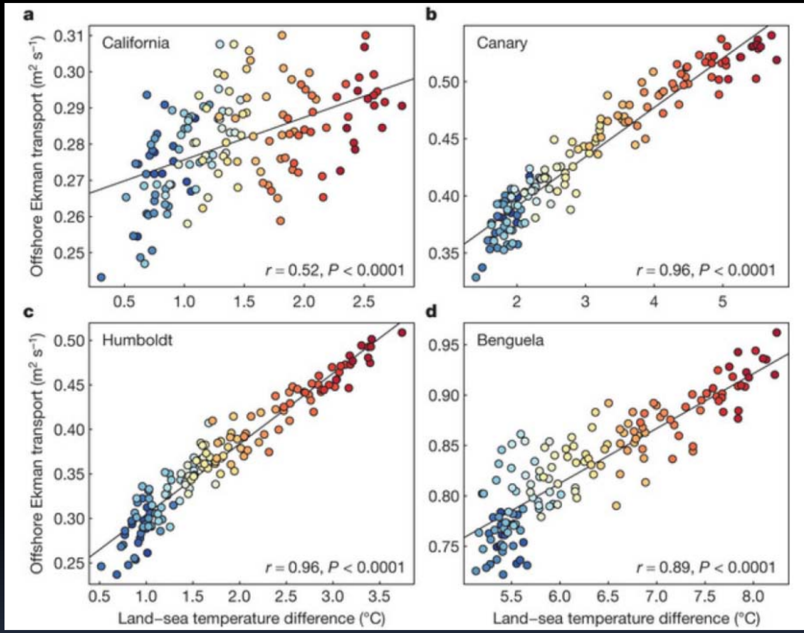
Fig. 3. Annual SST trend (°C dec^{-1}) for the area under study from 1970 to 2009.

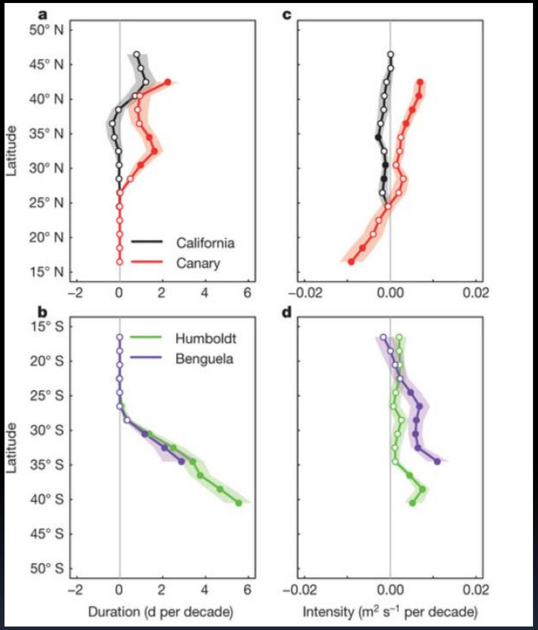
Santos et al. 2012 CSR

Upwellling intensity and upwelling regimes may change

Upwelling increases at mid and high latitudes

Also duration of upwelling increases in mid and high latitudes; potential spatial homogeneization

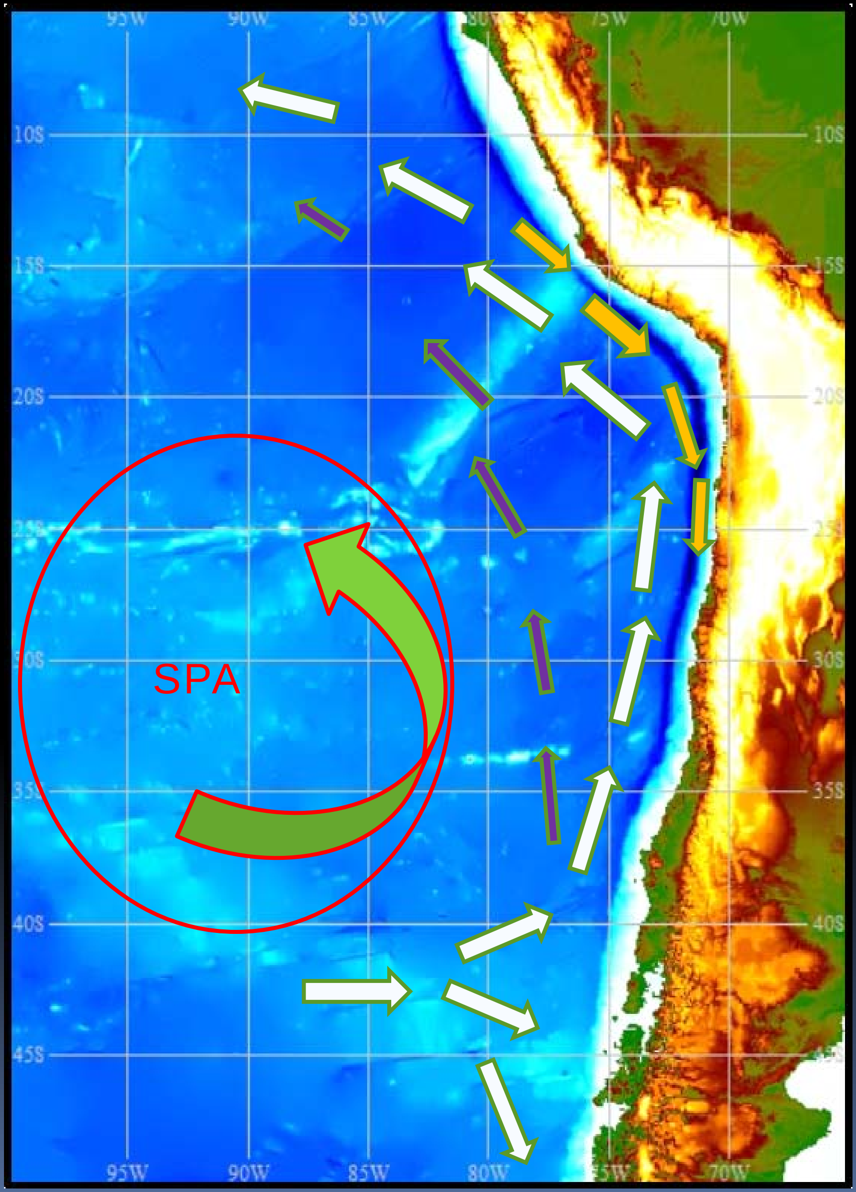




Not clear in California EBUE
Local variation?

Wang et al. 2015 Nature Lett.

IN THE ESP EBUE
HUMBOLDT CURRENT



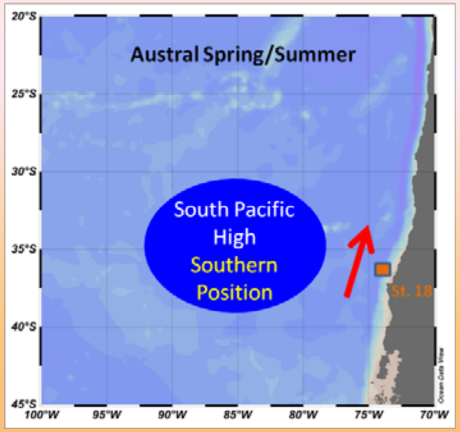
Escribano & Schneider 2016

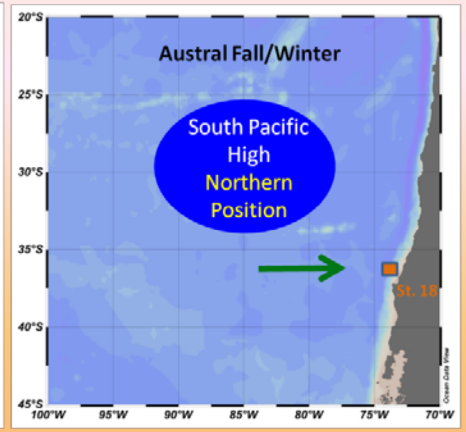
The Eastern Boundary Current strongly depending on the SPA dynamics

Also southerly upwelling-favorable winds

Both position and strengh of the SPA forced by climate variability (Time scale uncertain)

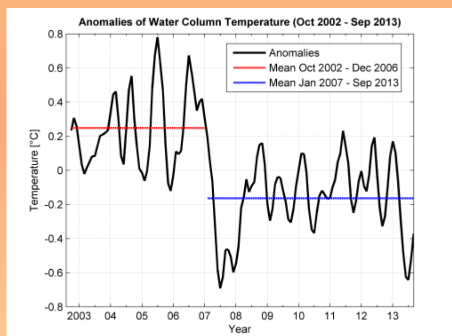
The South Pacific High and Winds at St. 18

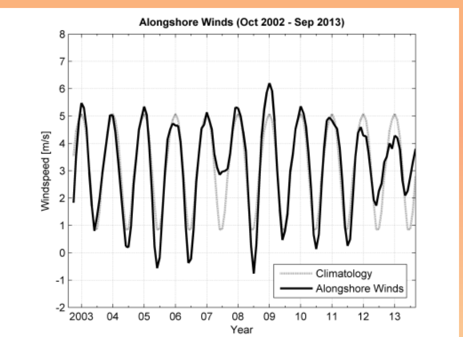


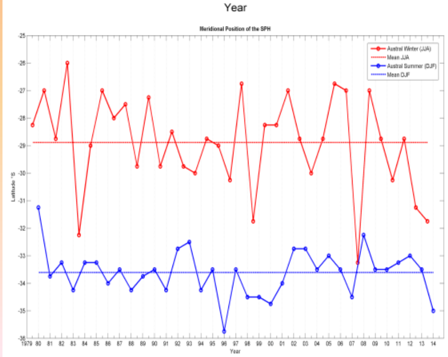


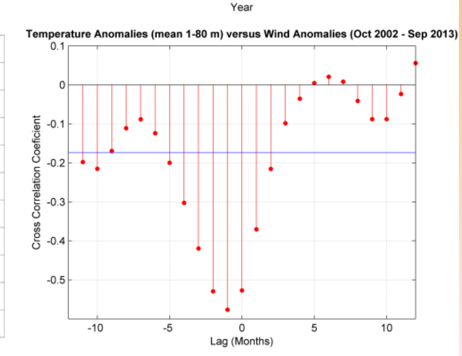
- Along-shore equatorward winds
- Coastal Upwelling
- As good as no rain fall
- Cooler shelf water column

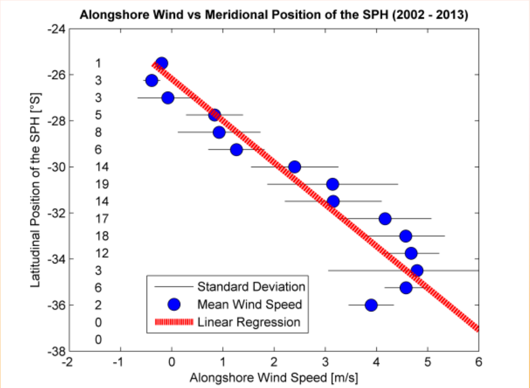
- No along-shore equatorward winds
- No coastal upwelling
- Rainy season
- Fresher surface waters

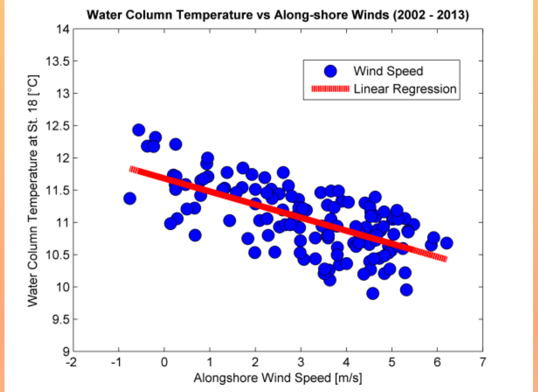


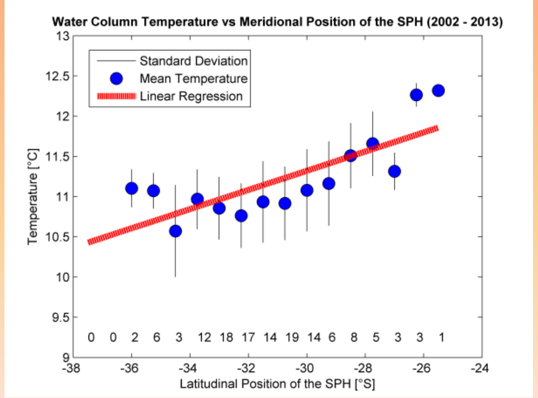












Schneider et al. (submitted)

Zooplankton in the ESP EBUE

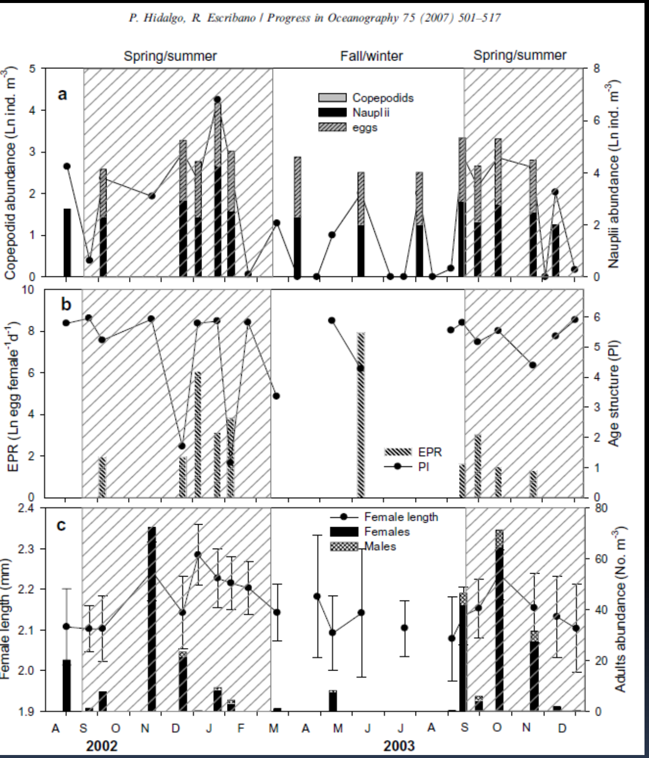
- Copepods dominate the bulk of biomass (though they are not the only ones)
- Life cycles of Copepod and euphausiids strongly linked to upwelling variation and regimes
- Seasonal and intra-seasonal variation, but mostly continuous reproduction year-round
- Growth and biomass production may not be limited by food resources (based on copepod models)

CONTINUOUS REPRODUCTION OF COPEPODS

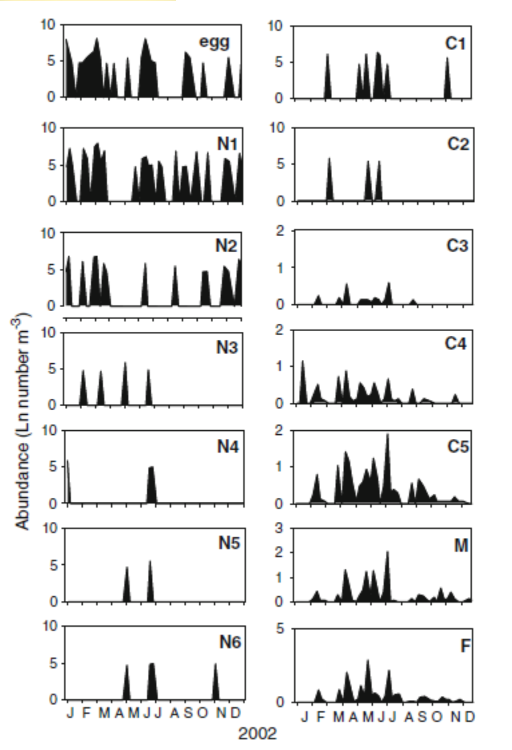
Eggs and nauplii present throughout the year !

Centropages brachiatus
Central/south Chile

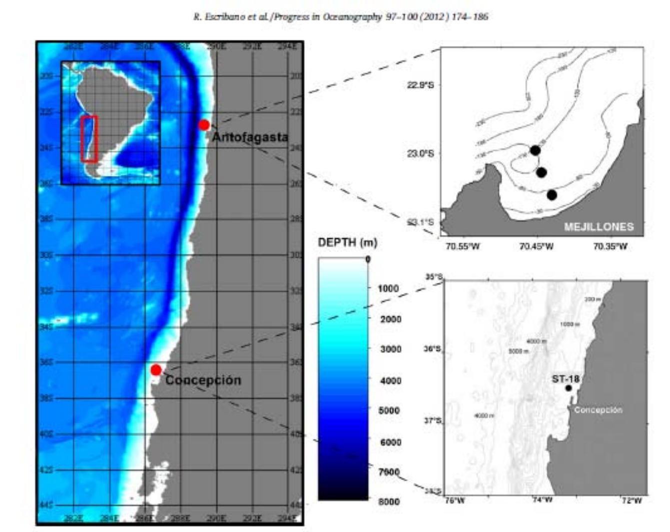
Calanus chilensis
Northern Chile



Hidalgo&Escribano (2007 Prog. Oceanogr.)



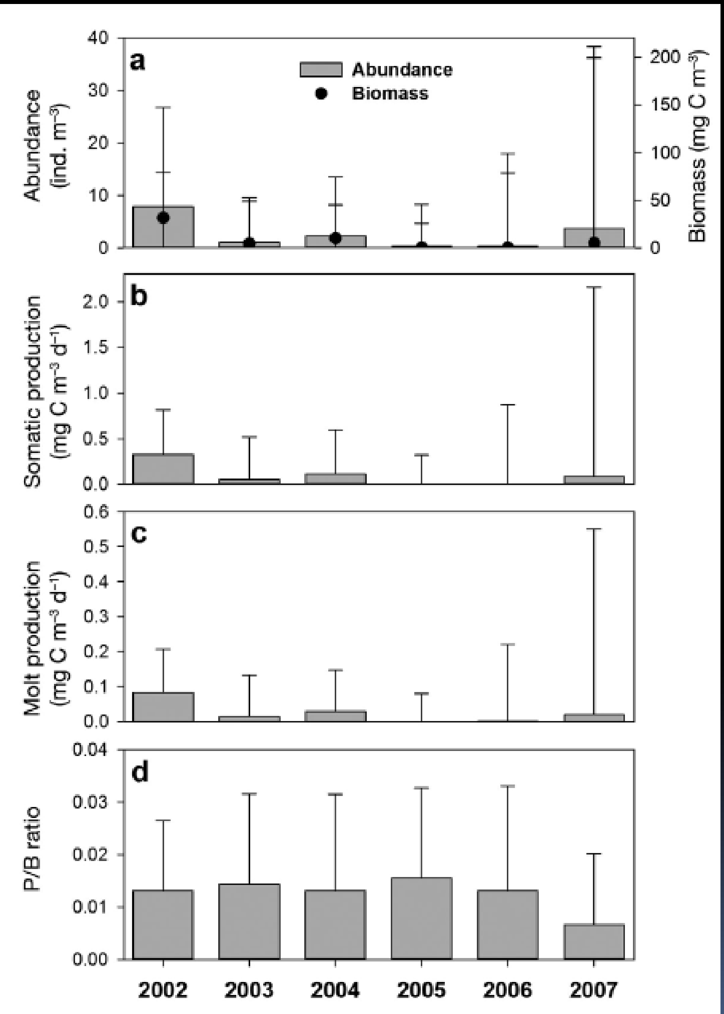
Hidalgo&Escribano (2008 Mar Biol.)

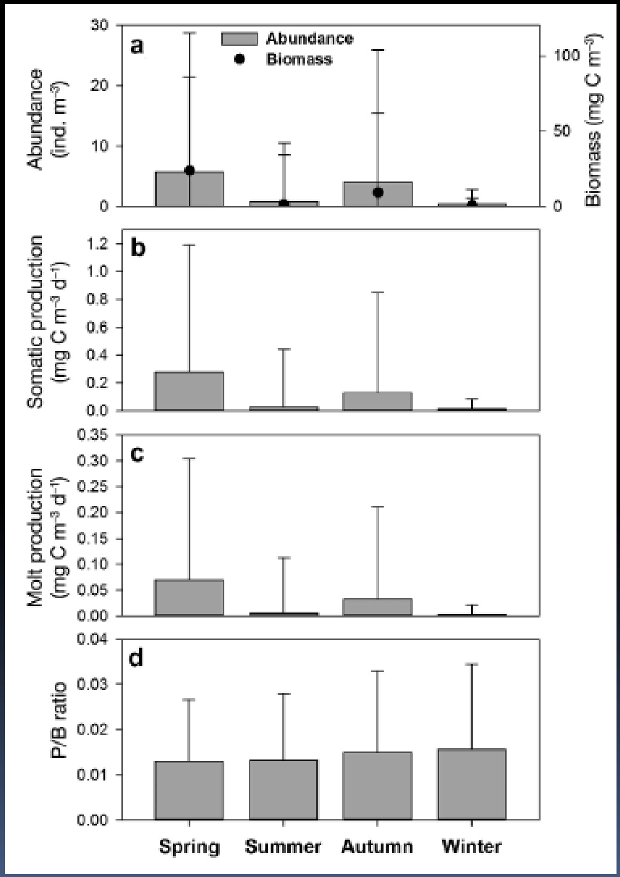


Escribano et al. (2012)

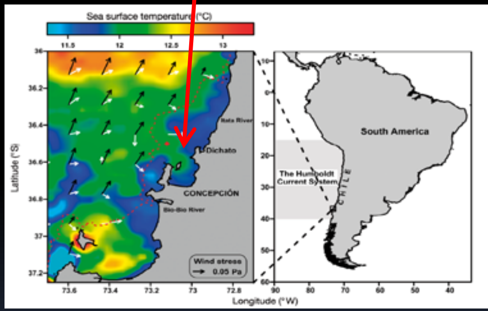
DOMINANT EUPHAUSIID SPECIES SIMILARLY TO COPEPODS

The Humboldt Current Krill *Euphausia mucronata*





STATION 18



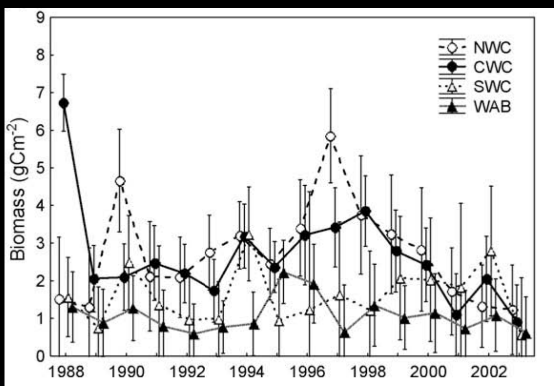
Riquelme-Bugueño et al. (2013 MEPS)

ZOOPLANKTON PRODUCTION IN EBUE

BIOMASS PRODUCTION (P)= *g* x *biomass*

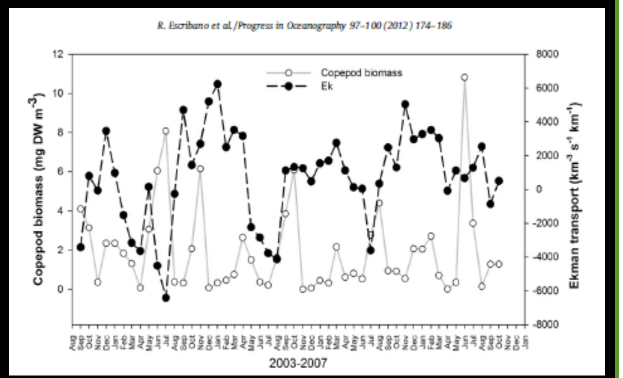
COPEPOD BIOMASS ESTIMATES:
Direct measures:
Dry weight, Wet Weight, C content, Biovolume,

Benguela EBUE

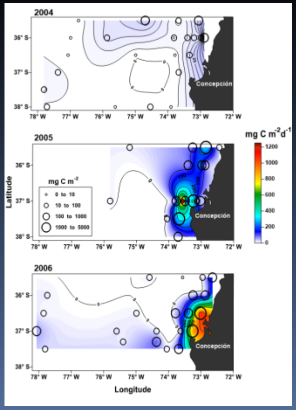


Hugget et al. (2009 Progr. Oceanogr.)

Central/south Chile



Escribano et al. (2009 Progr. Oceanogr.)



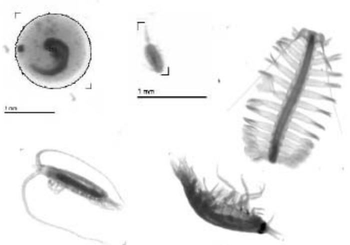
Estimates must account for both spatial and temporal variation

Using ZooImage or ZooProcess:

Application of RAPID approach

Benfield et al. 2007 Oceanograhy
McLeod et al. 2010 Nature

Automatic analysis of zooplankton: Taxonomic and biomass

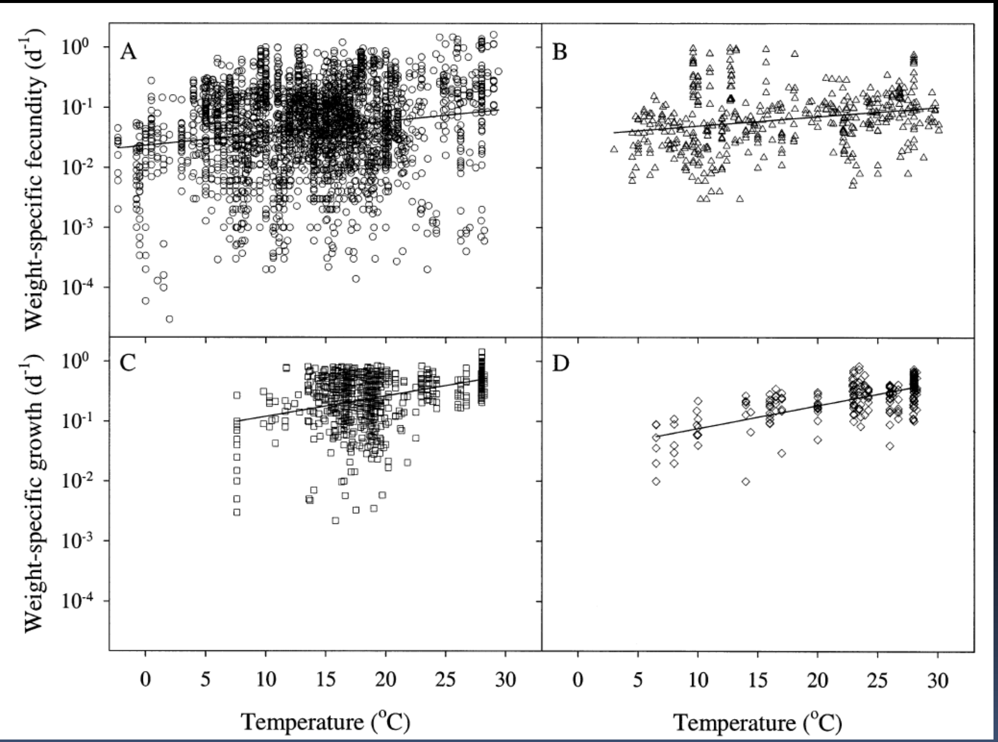


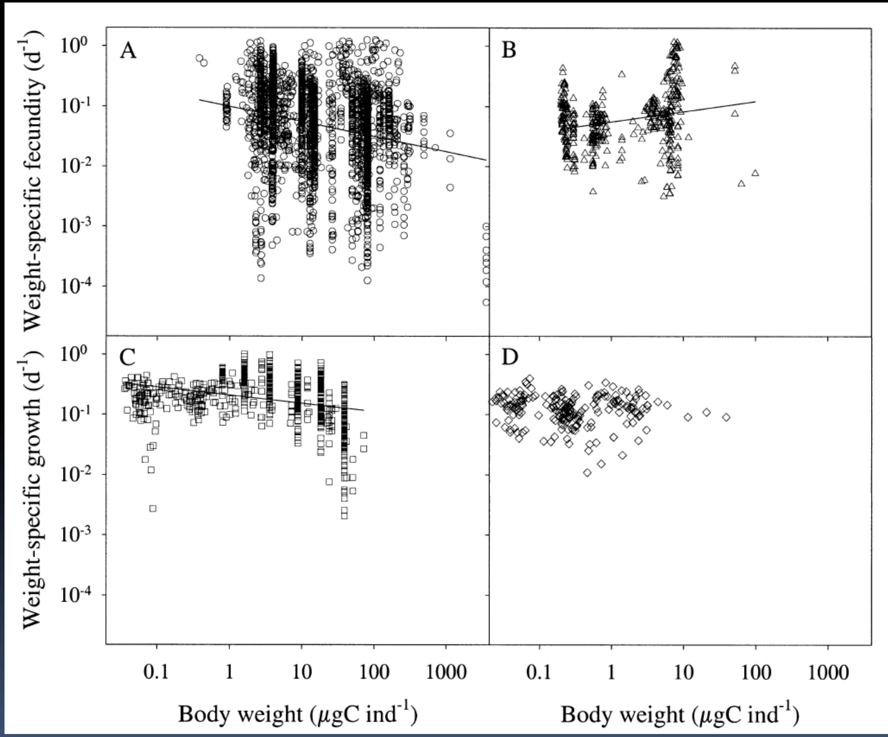
THE ISSUE OF GROWTH RATE (*g*)

Copepods as model: compiling data from a variety of conditions (Hirst & Bunker 2003 L&O)

g as a function of T° and size

In copepods *g* indeed correlates to both temperature and size



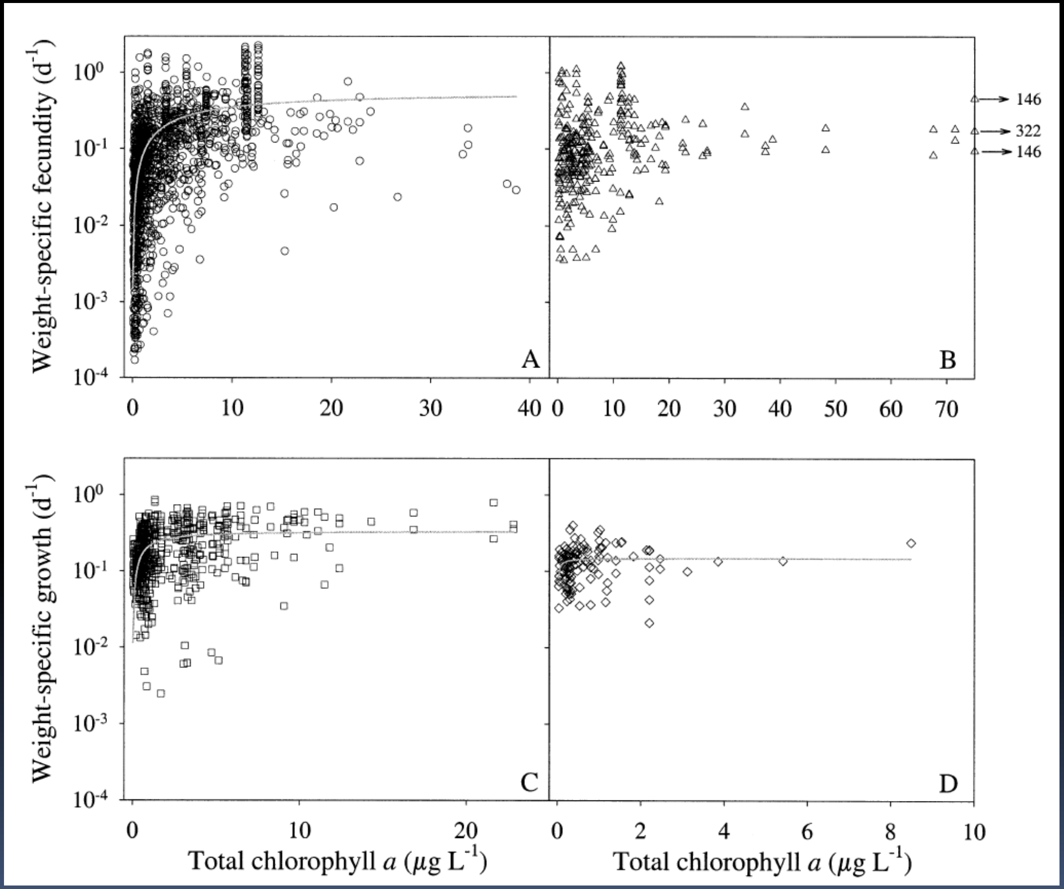


Hirst & Bunker (2003 L&O)

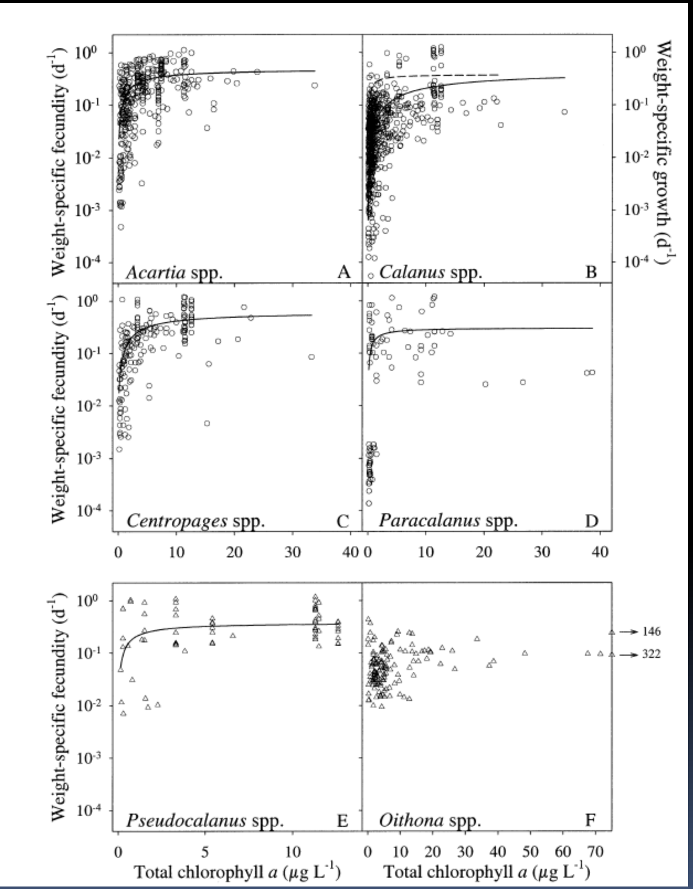
What about food effects?

g as a function of food (Chlorophyll-a)

Relationship not so clear, but a saturation model may fit



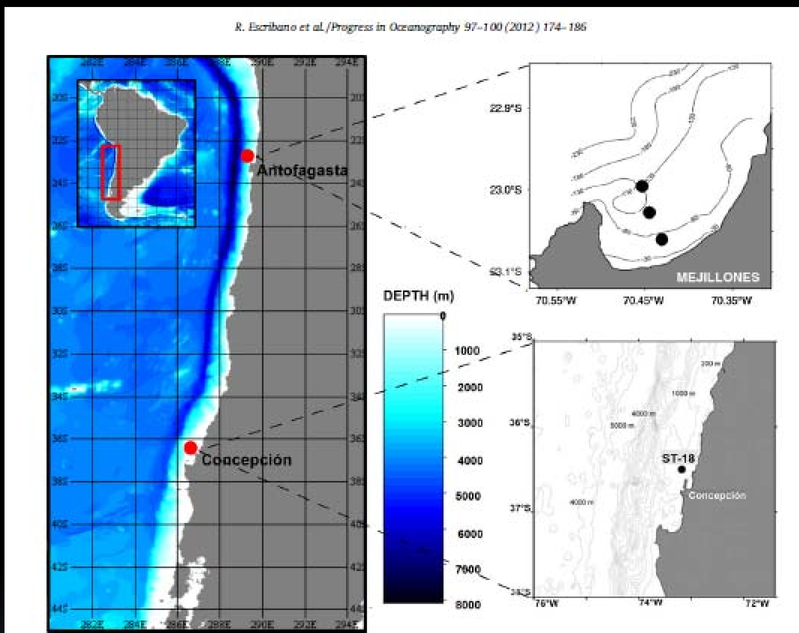
Michaelis-Menten equation



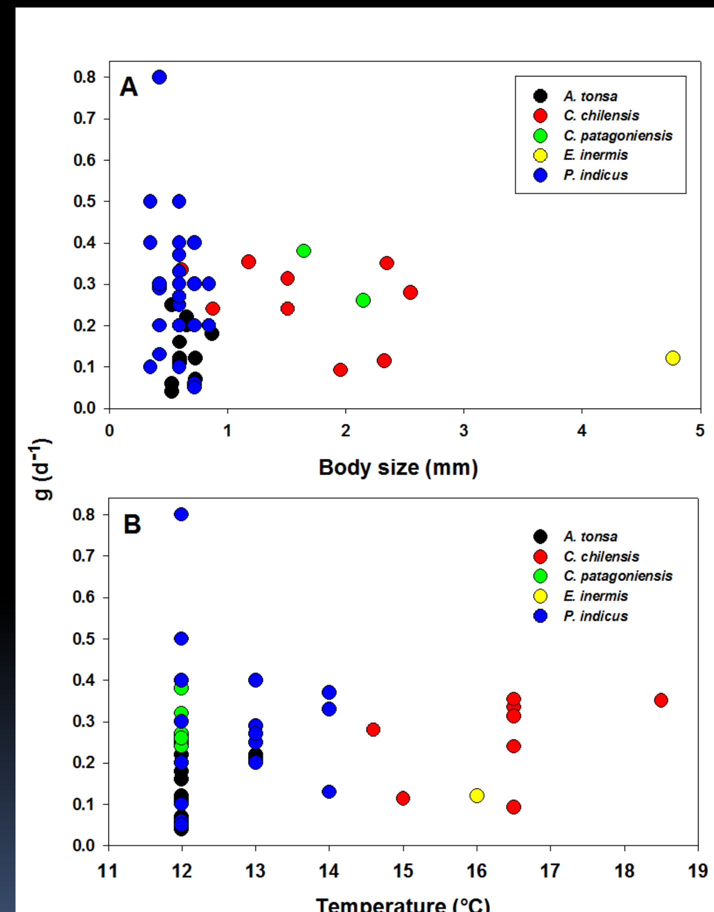
Hirst & Bunker (2003 L&O)

Testing *g* as function of T°, size and food in the ESP

Laboratory experiments: controlled conditions



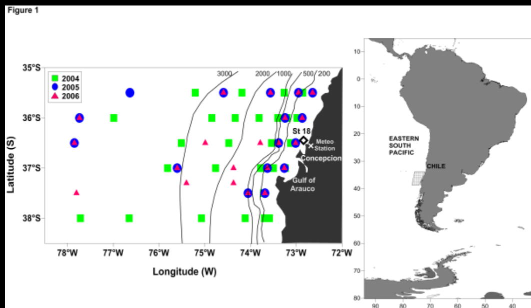
Direct estimates by moulting rate method under saturated food conditions

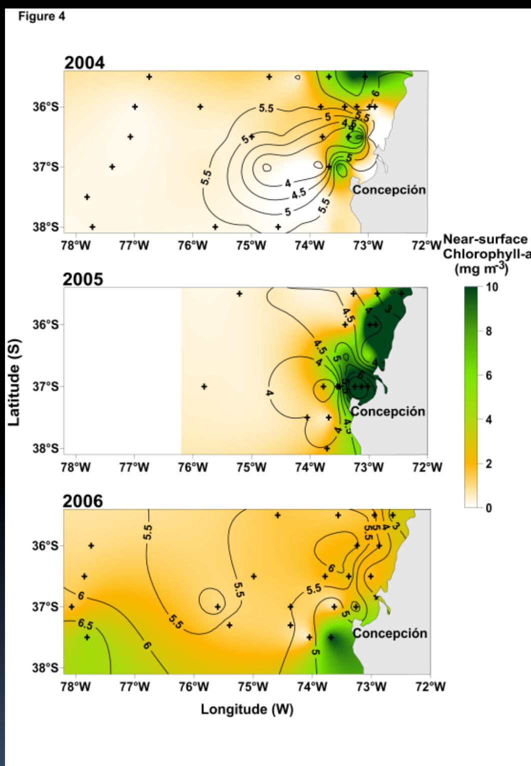


Escribano et al. 2013 Biogeoscience Discussion

Estimates of *g* are not sufficiently convincing to assess in situ growth and production

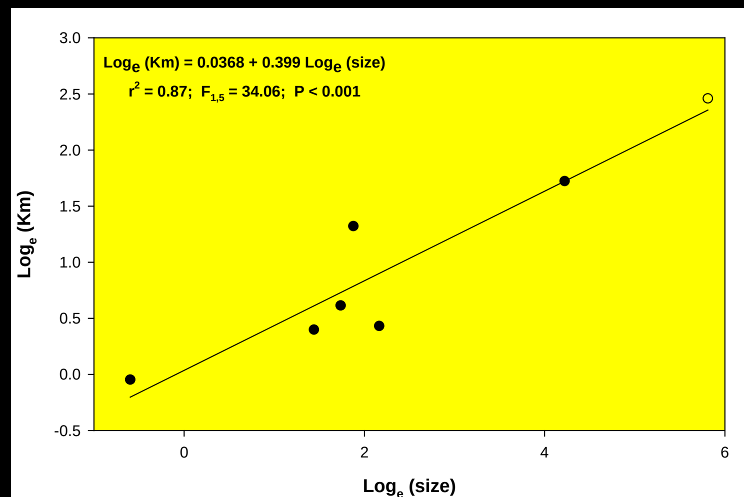
Testing food effects on growth rate





Michaelis-Menten Equation $g = g_{max}\left(\frac{Chl-a}{Chl-a+Km}\right)$

Saturation constant (Km) relates to copepod size



g_{max} from food-saturated conditions (e.g. Hirst & Bunker 2003) or assumed as only temperature/size-dependent

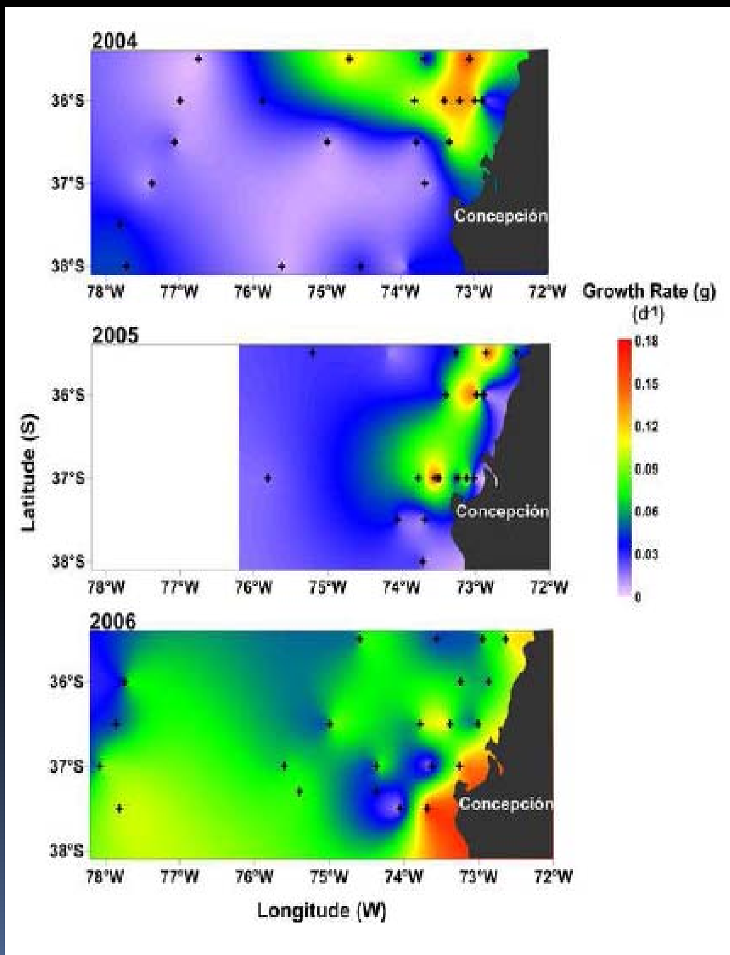
Thus a food-limited g can be estimated

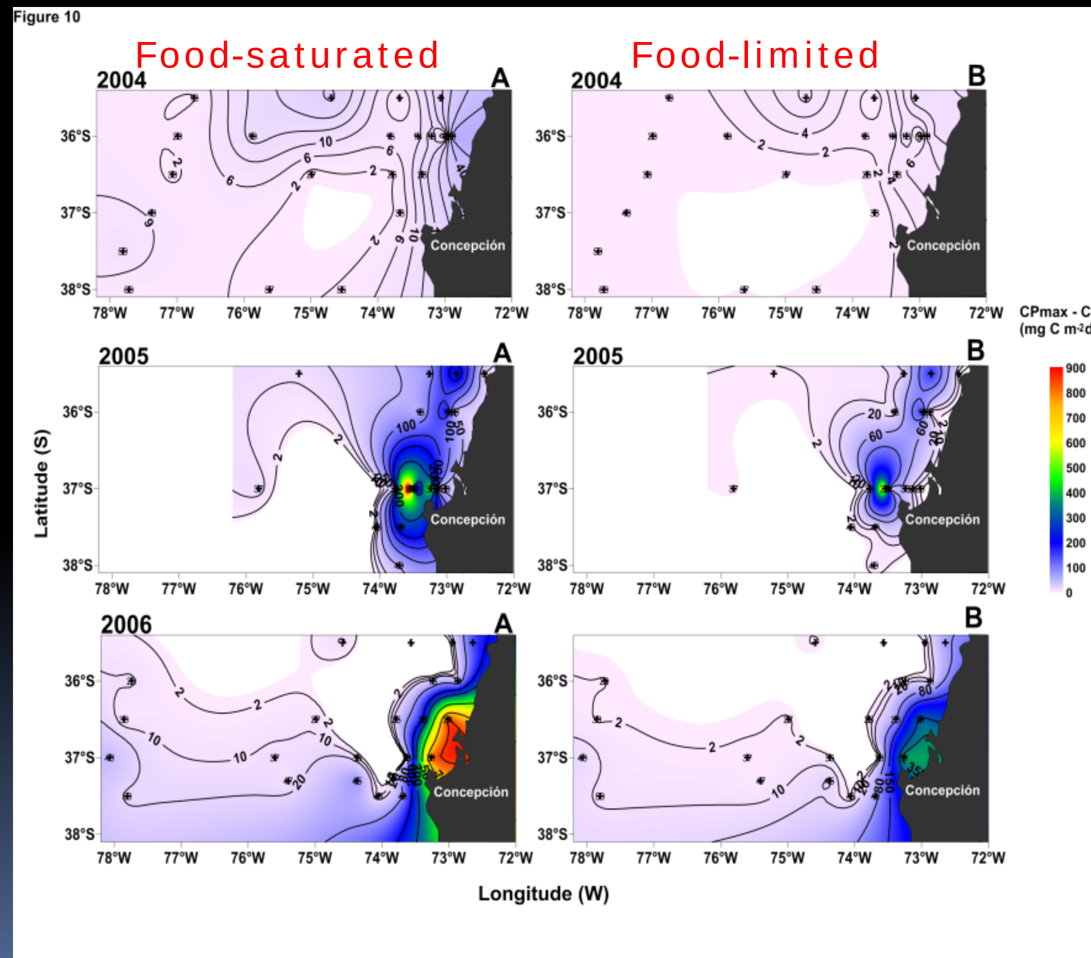
Escribano et al. (CSR submitted)

Copepod growth and production in the upwelling zone

Food-dependent *g*

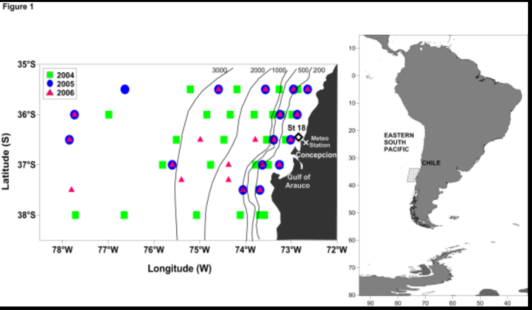
Copepod production (food limited and with food-saturate conditions)

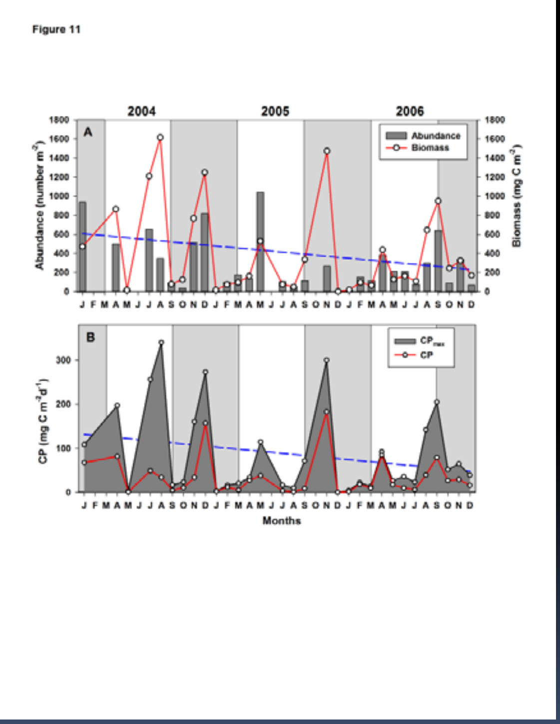




Escribano et al. (CSR submitted)

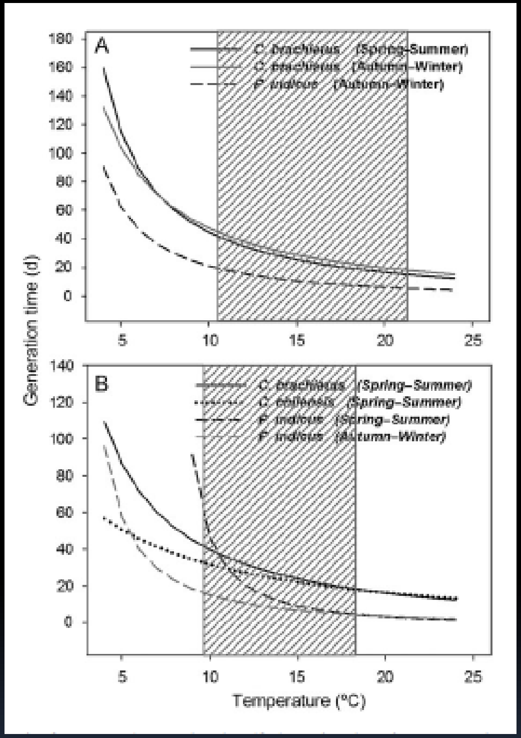
Food-limited or food saturated growth rates of copepods?



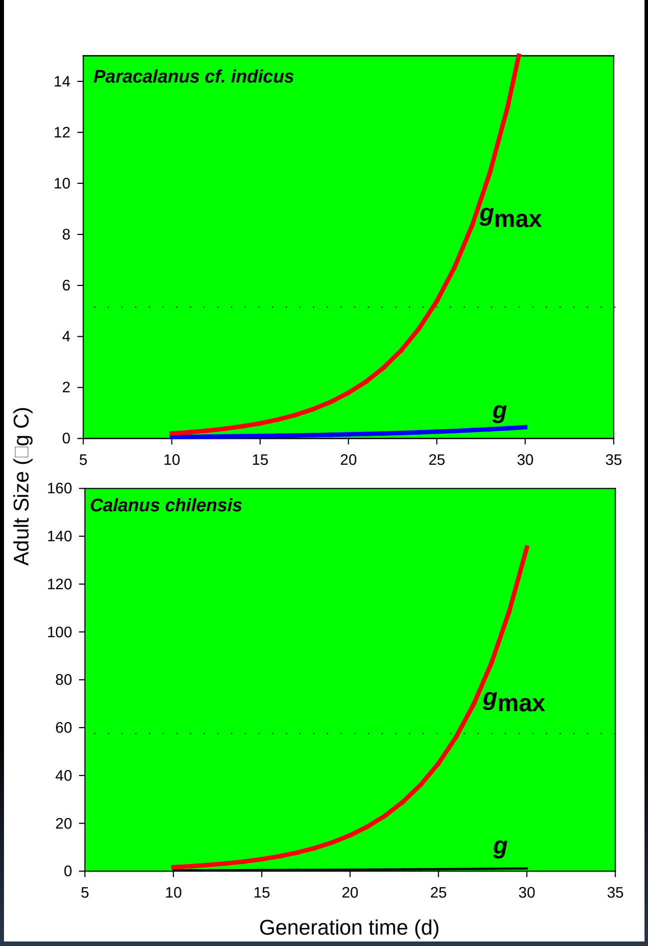


Escribano et al. (CSR submitted)

Temperature-dependent Generation times areconsistent with field data



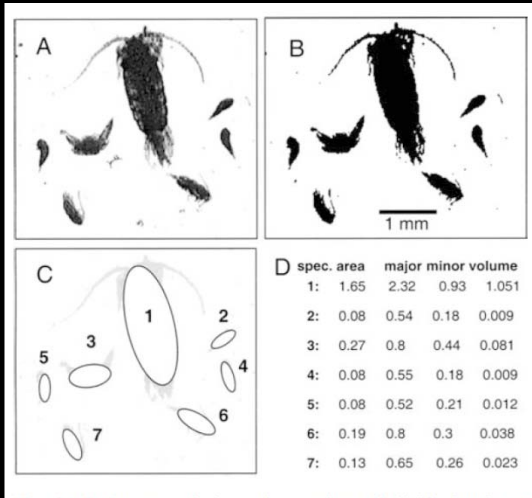
Escribano et al. (2014 JPR)



Food-limited growth cannot account for observed adult sizes andgeneration lenghts !

ESTIMATING PRODUCTION FOR THE WHOLE ZOOPLANKTON COMMUNITY

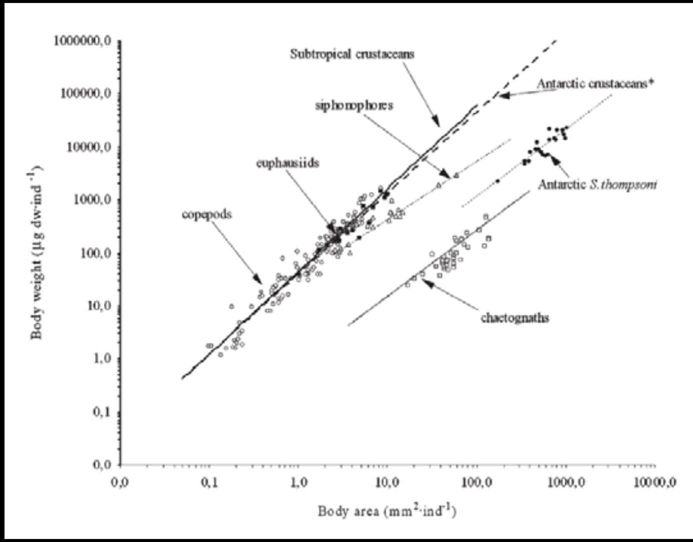
RAPID APROACH TO ESTIMATE BIOMASS BY TAXA OR SIZE CLASSES



spec.	area	major	minor	volume
1:	1.65	2.32	0.93	1.051
2:	0.08	0.54	0.18	0.009
3:	0.27	0.8	0.44	0.081
4:	0.08	0.55	0.18	0.009
5:	0.08	0.52	0.21	0.012
6:	0.19	0.8	0.3	0.038
7:	0.13	0.65	0.26	0.023

Fig. 4A–D Image analysis used to estimate individual volume.

Alcaraz et al. (2003 Mar- Biol.)



Lehette & Hernández-León (2009 L&O Methods)

$$\mathrm{BioV} = \frac{4}{3} \times \frac{Area}{\sqrt{Ratio}} \times \sqrt{\frac{Area}{\pi}}$$

Both ZooImage and ZooProcess provide organisms size (area) then convertible to biovolume

Biovolume to dry weight or C (e.g. Wiebe et al. 1975)

ESTIMATING PRODUCTION FOR THE WHOLE ZOOPLANKTON COMMUNITY

Production rate $= (N_i \times w_i) \times g_i$

Both N_i and w_i from ZooImage or ZooProcess

i = Taxonomic category (not species yet, but taxonomic group)

i = Size class (if don't like taxonomy)

g_i = f(T°, Size, food?)

We used g_i= f (T° & Size)
From Hirst et al. 2003 Adv. Mar. Ecol.

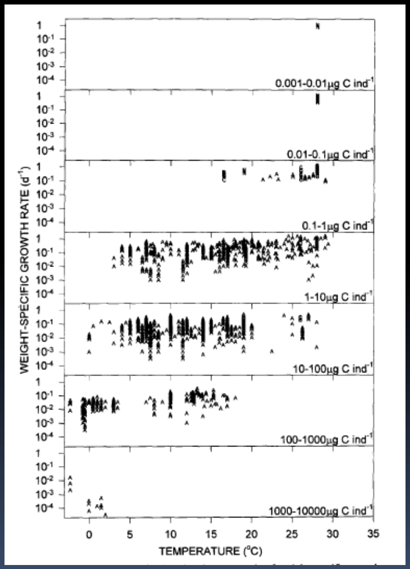
g estimated by either:

"Natural water approach"

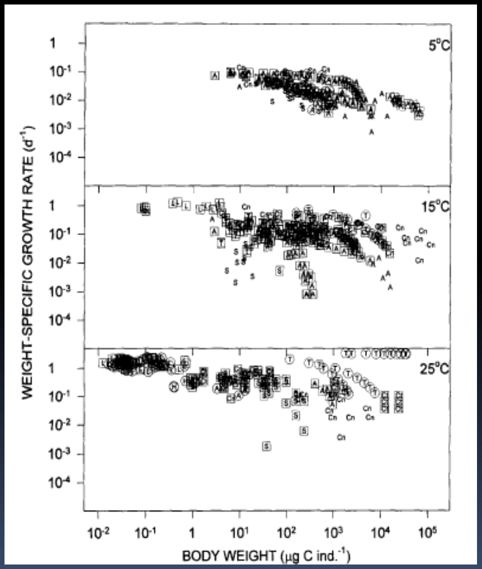
"Controlled approach"

Mostly representing field conditions

Copepods



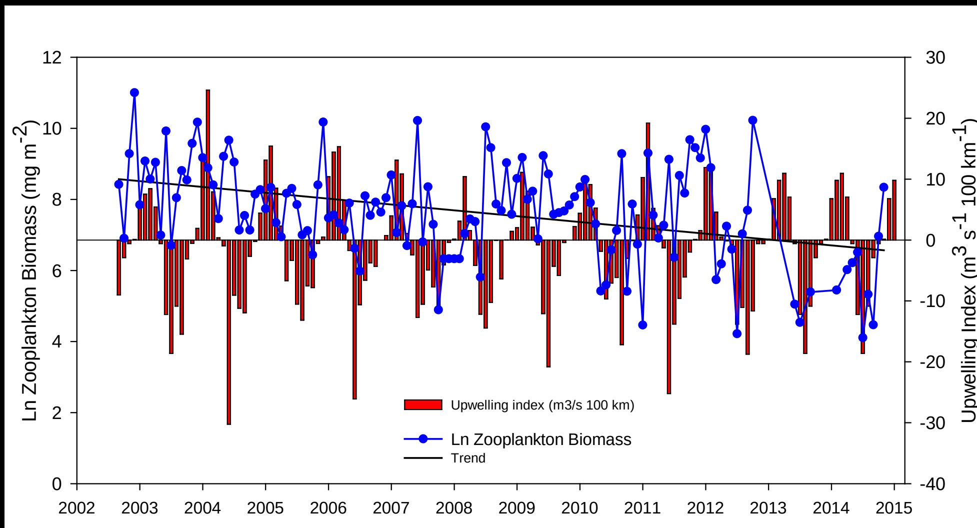
Other taxa



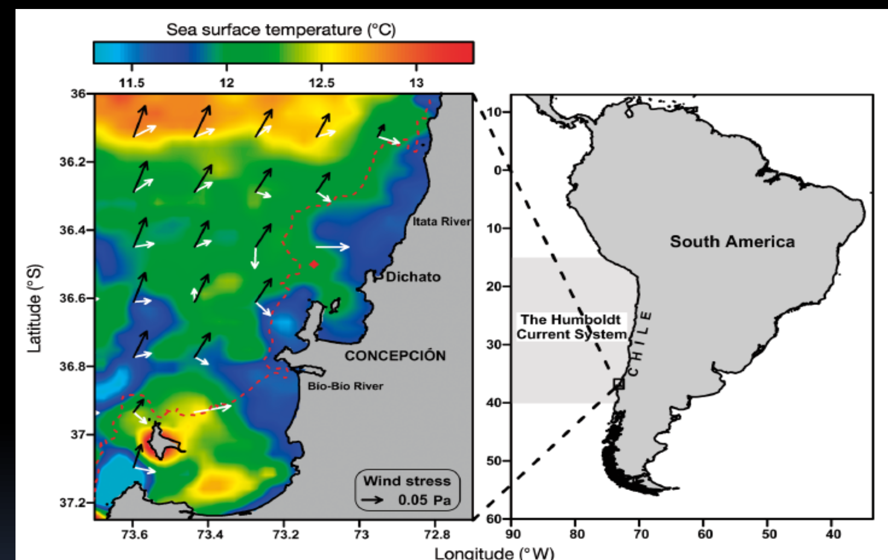
Hirst et al. (2003 Adv. Mr. Biol.)

Zooplankton biomass 2002-2014 Station 18

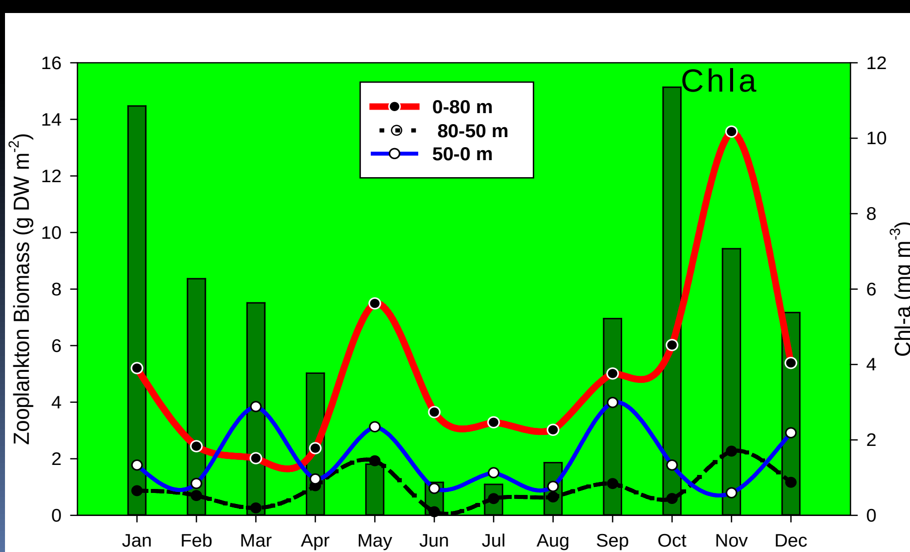
DIRECT MEASUREMENTS



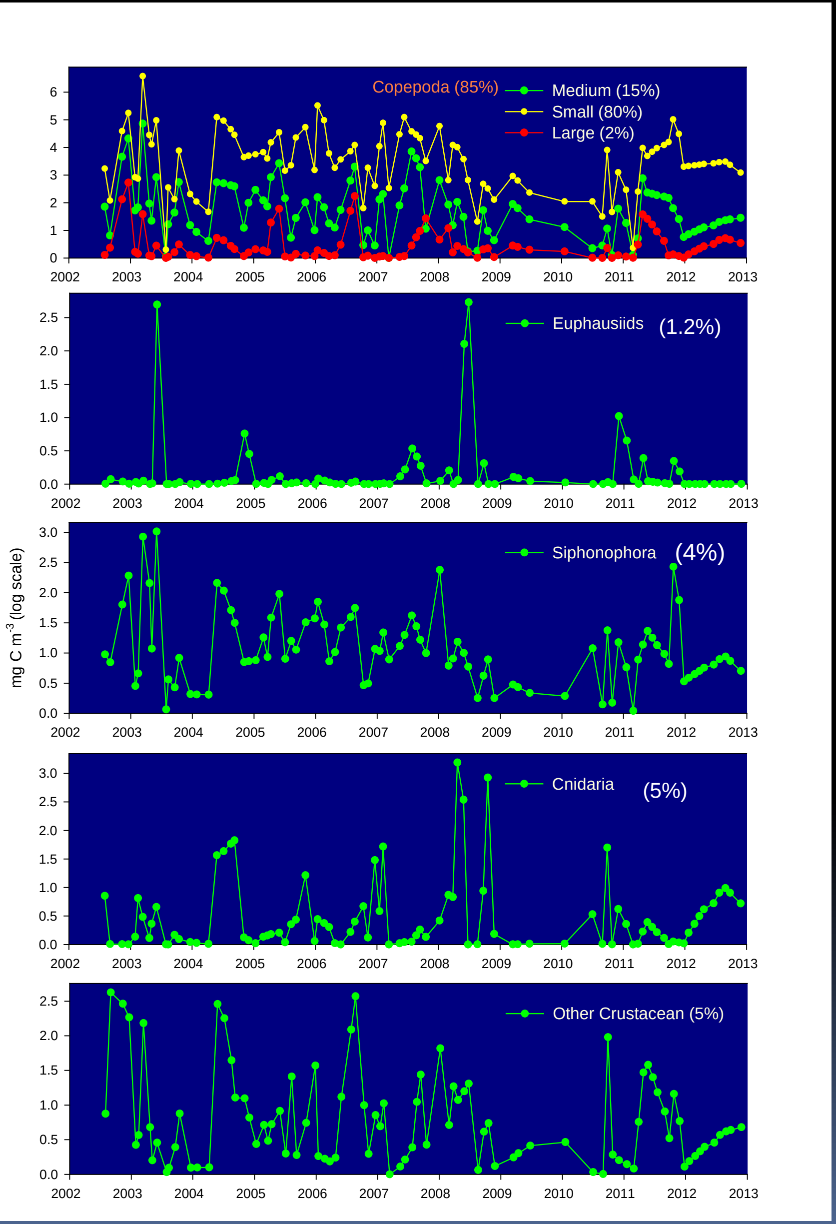
August 2002- 2014



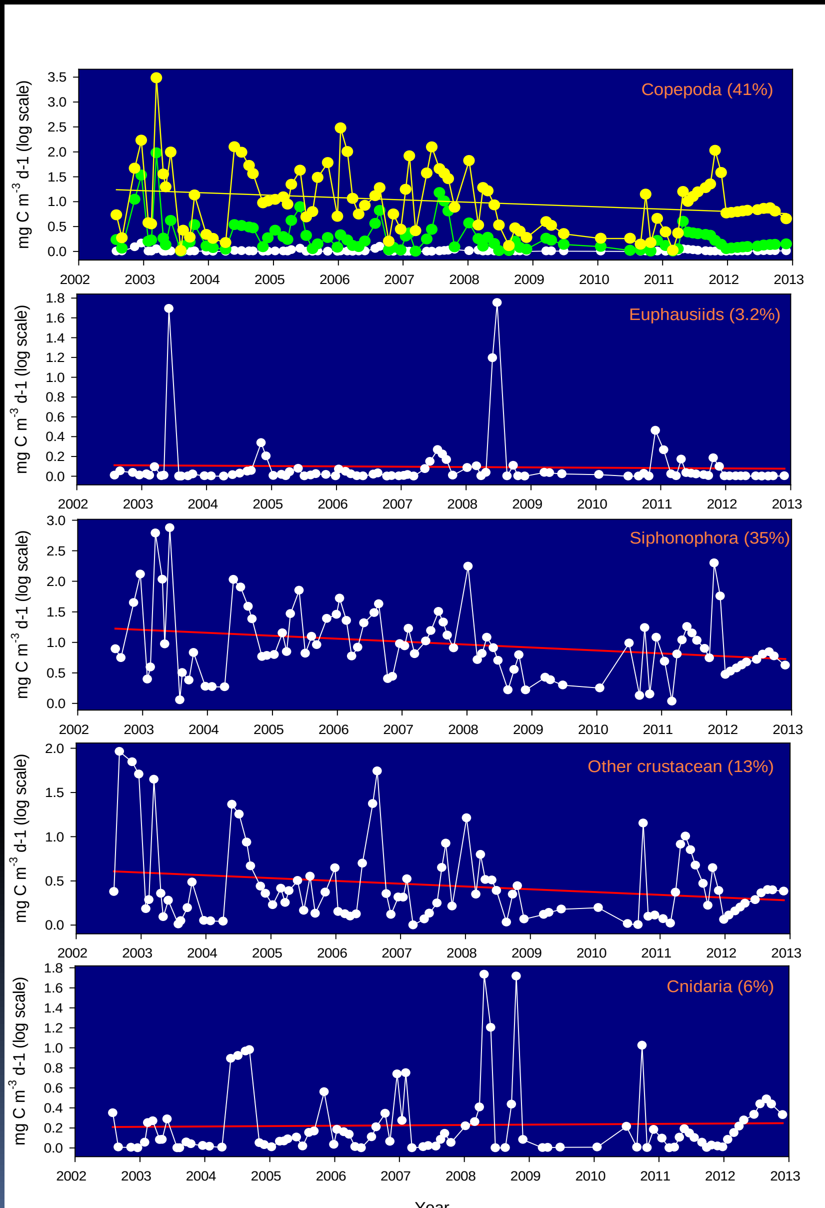
Seasonal climatology

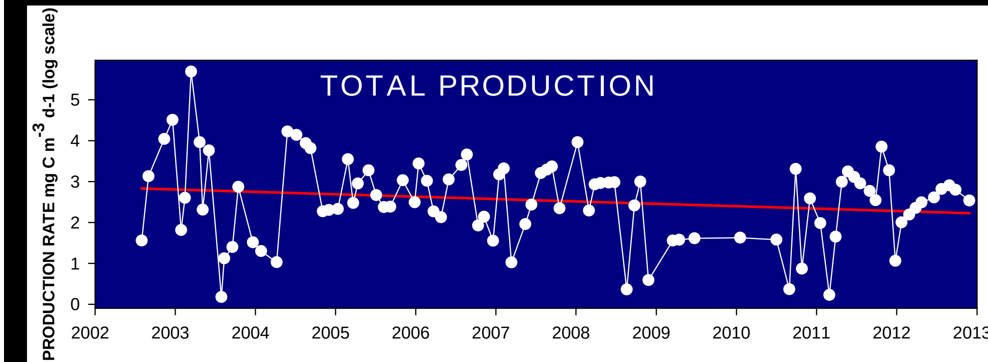


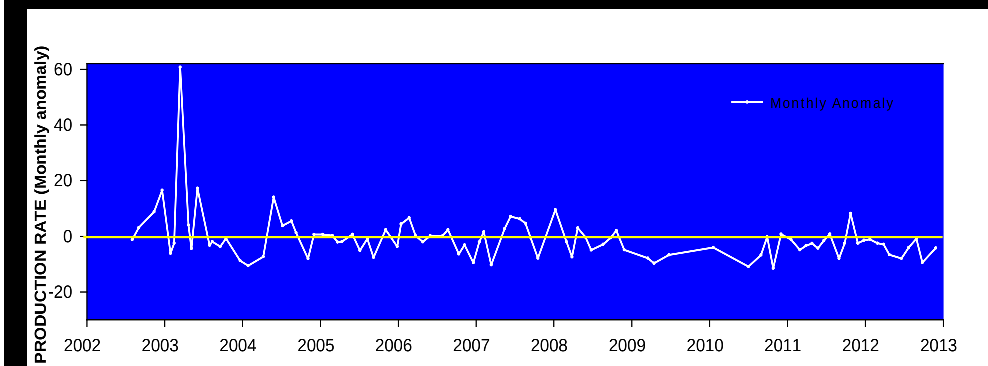
TAXONOMIC BIOMASS: ZOOIMAGE ANALYSIS

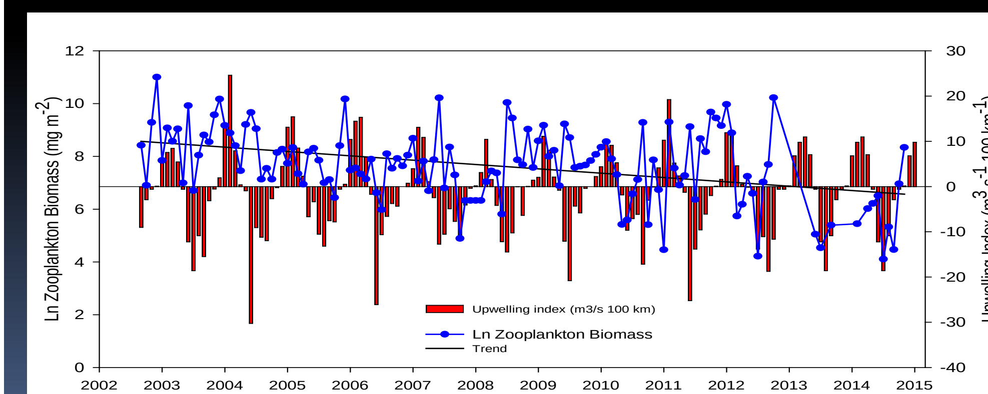


Zooplankton production 2002-2014 Station 18







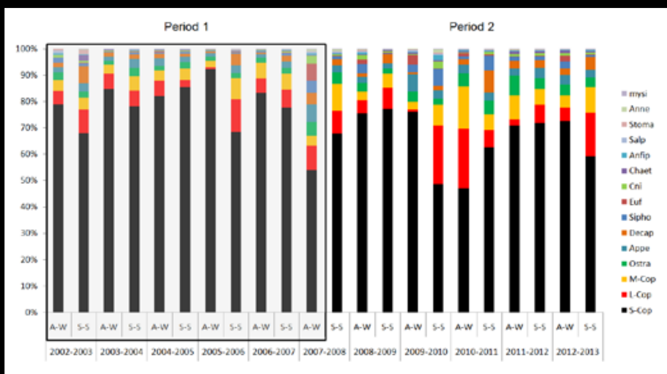


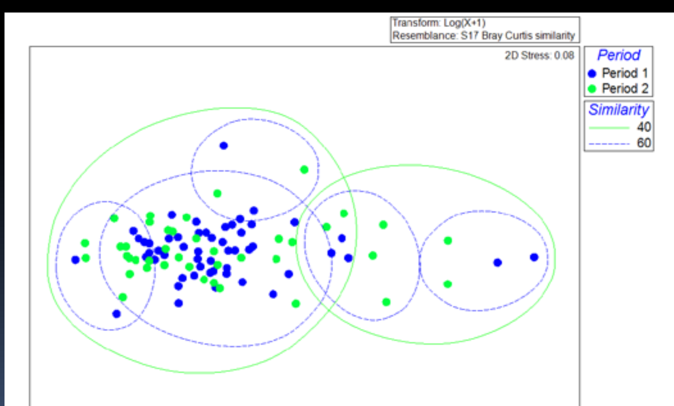
Medellin-Mora et al. (unpublished)

HOW CLIMATE CHANGE CAN AFFECT ZOOPLANKTON BIOMASS AND PRODUCTION

At Station 18 the commuity structure is showing some changes in the recent decades (2002-present)

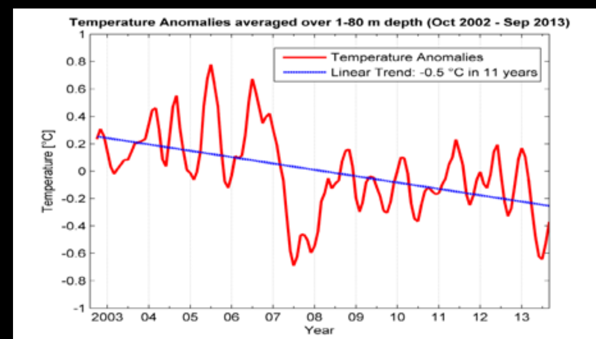
ZOOPLANKTON COMMUNITY STRUCTURE

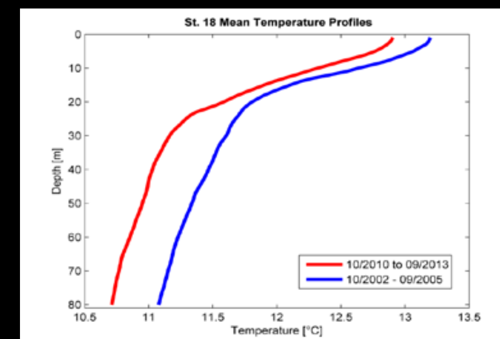




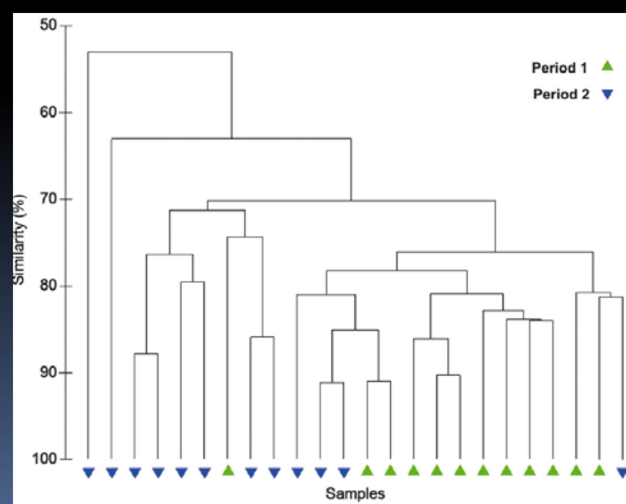
Medellin-Mora et al. (2016 Progr. Oceanogr.)

INCREASED UPWELLING





Schneider et al. submitted



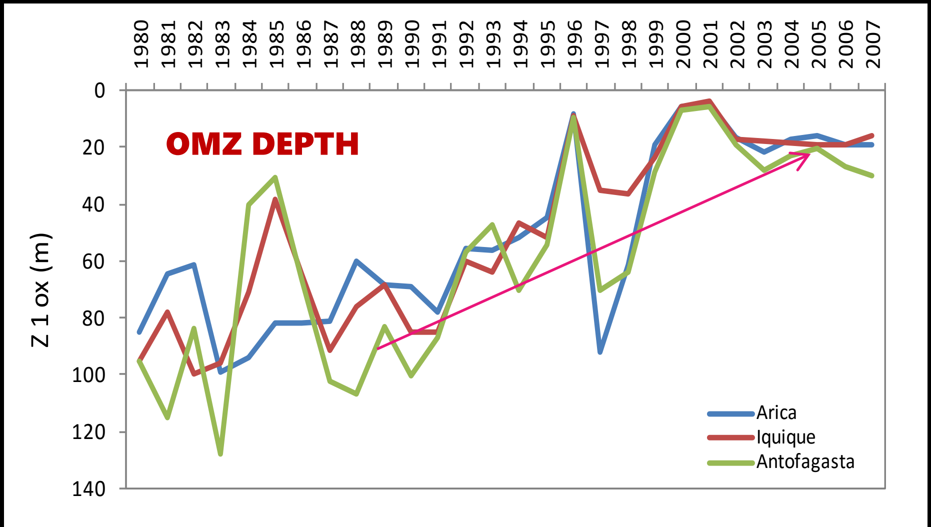
Pino-Pinuer et al. (2014 MEPS)

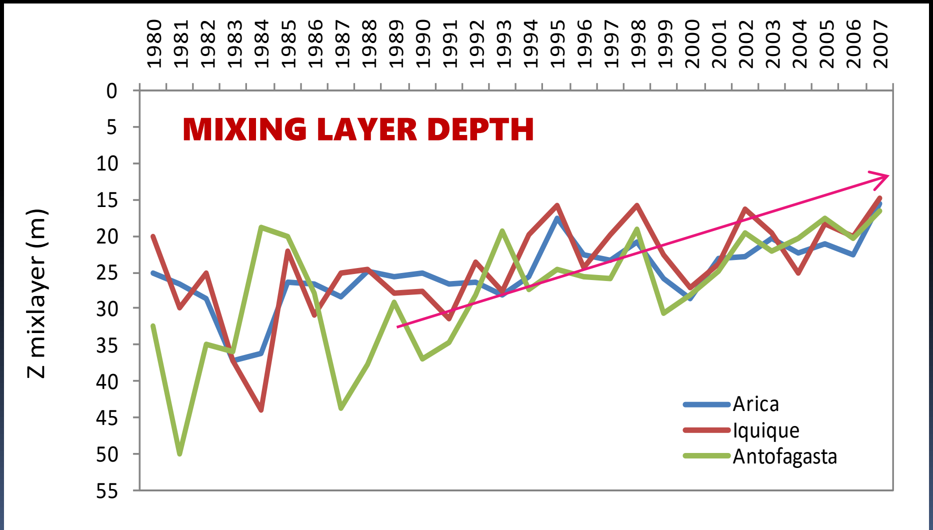
COPEPOD COMMUNITY STRUCTURE ALSO CHANGING

CONSEQUENCES OF INCREASED UPWELLING IN THE EBUE

- **Maybe enhanced primary production: not supporting evidence. Satellite Chla does not show that**
- **The ascent of the oxygen minimum zone. Low oxygen water closer to near surface**
- **More offshore transport: water masses and their properties get the offshore region (also plankton)**
- **More along shore transport: water from the southern region (also plankton)**
- **Plankton changes in abundance and composition**

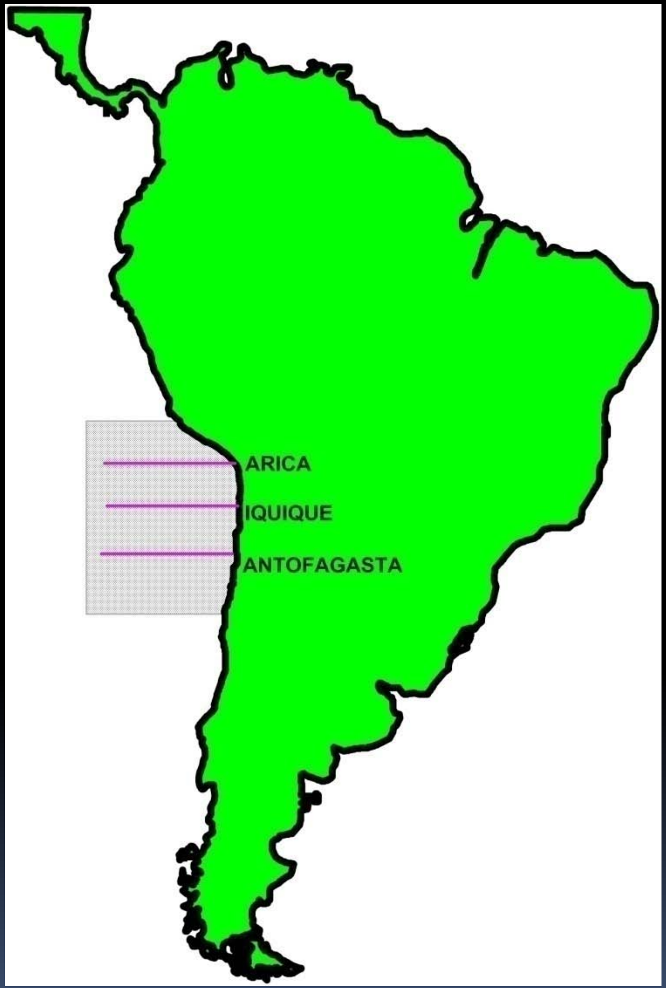
A SHALLOW OMZ AT NORTHERN CHILE





Escribano et al. (unpublished.)

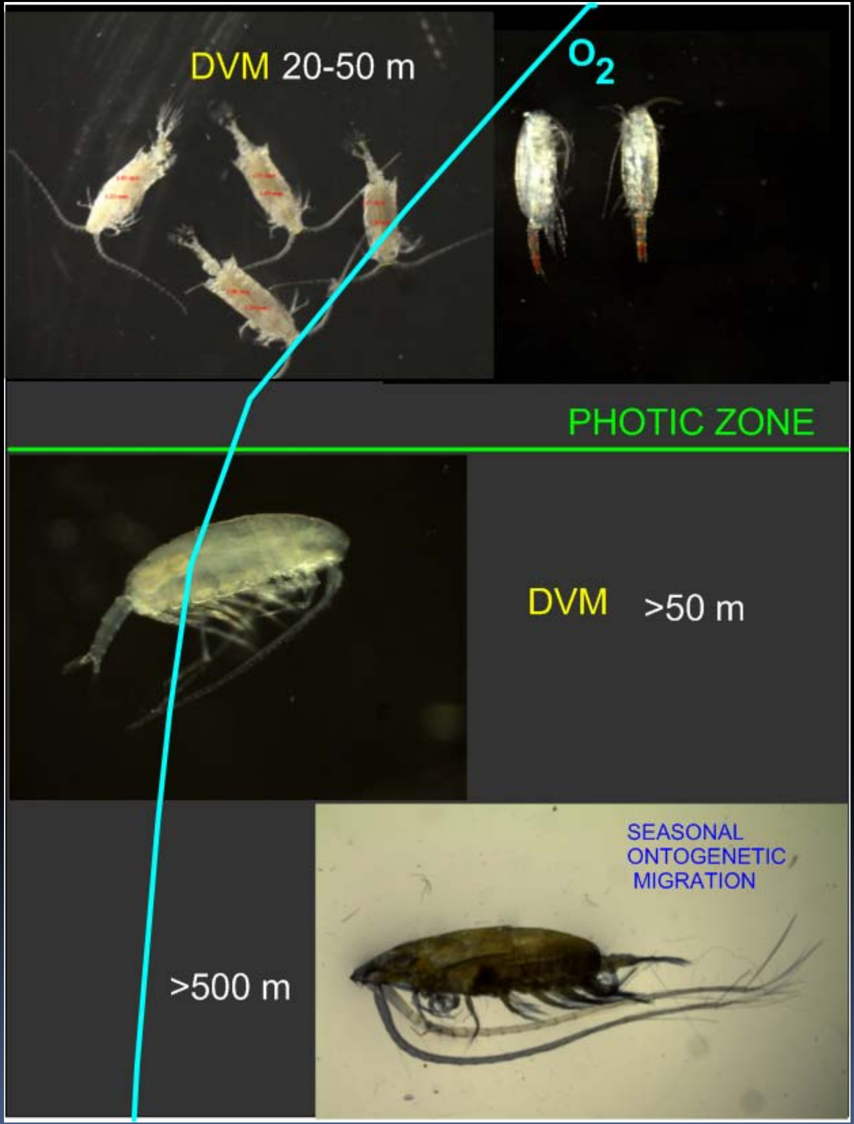
Seasonal hydrographic surveys



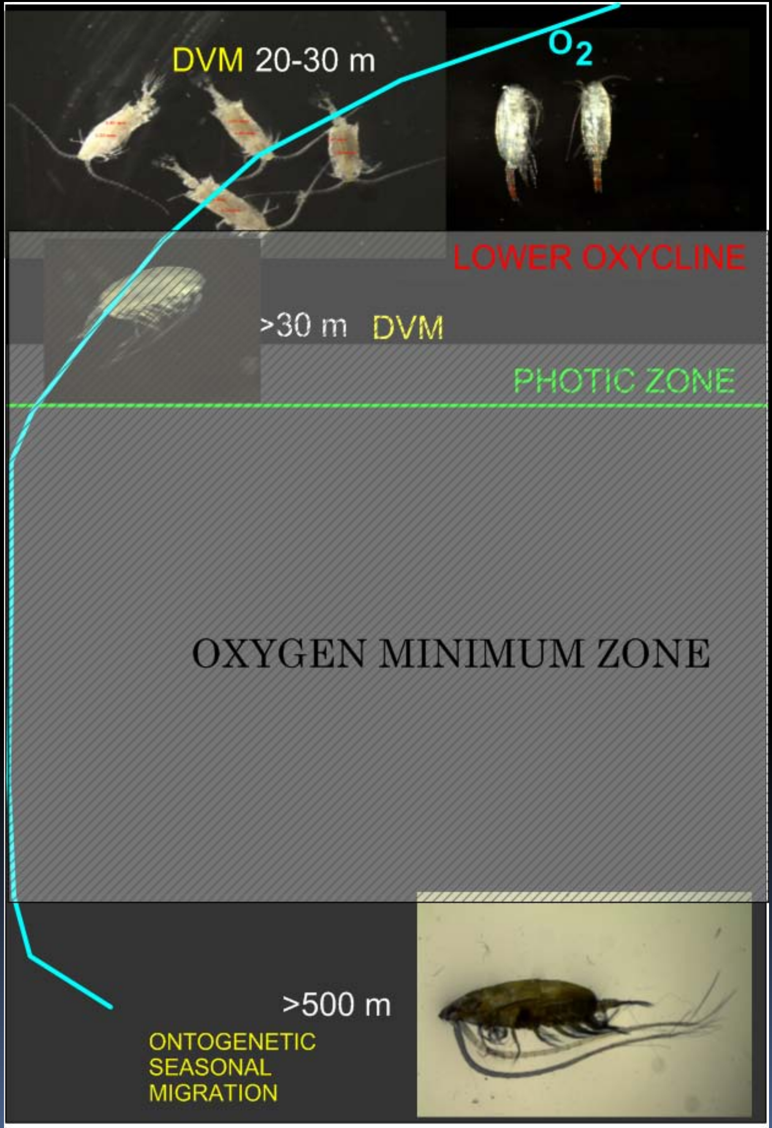
INCREASED UPWELLING IS RISING THE UPPER LIMIT OF THE OMZ AND SHOALING THE MIXING LAYER

IMPACT OF A SHALLOW OMZ

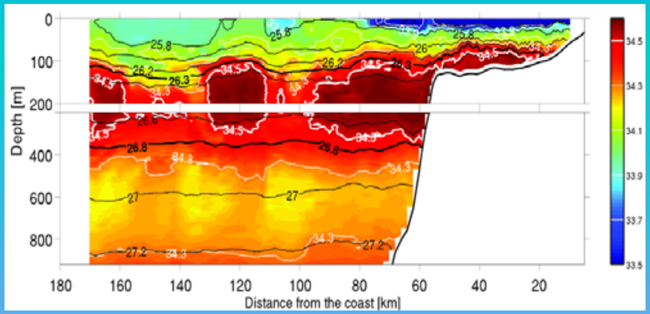
WEAK-MODERATE UPWELLING

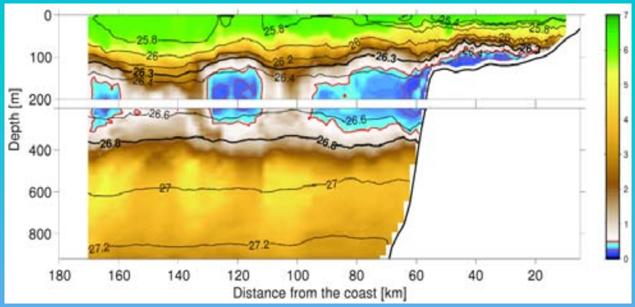


GREATLY INCREMENTED UPWELLING

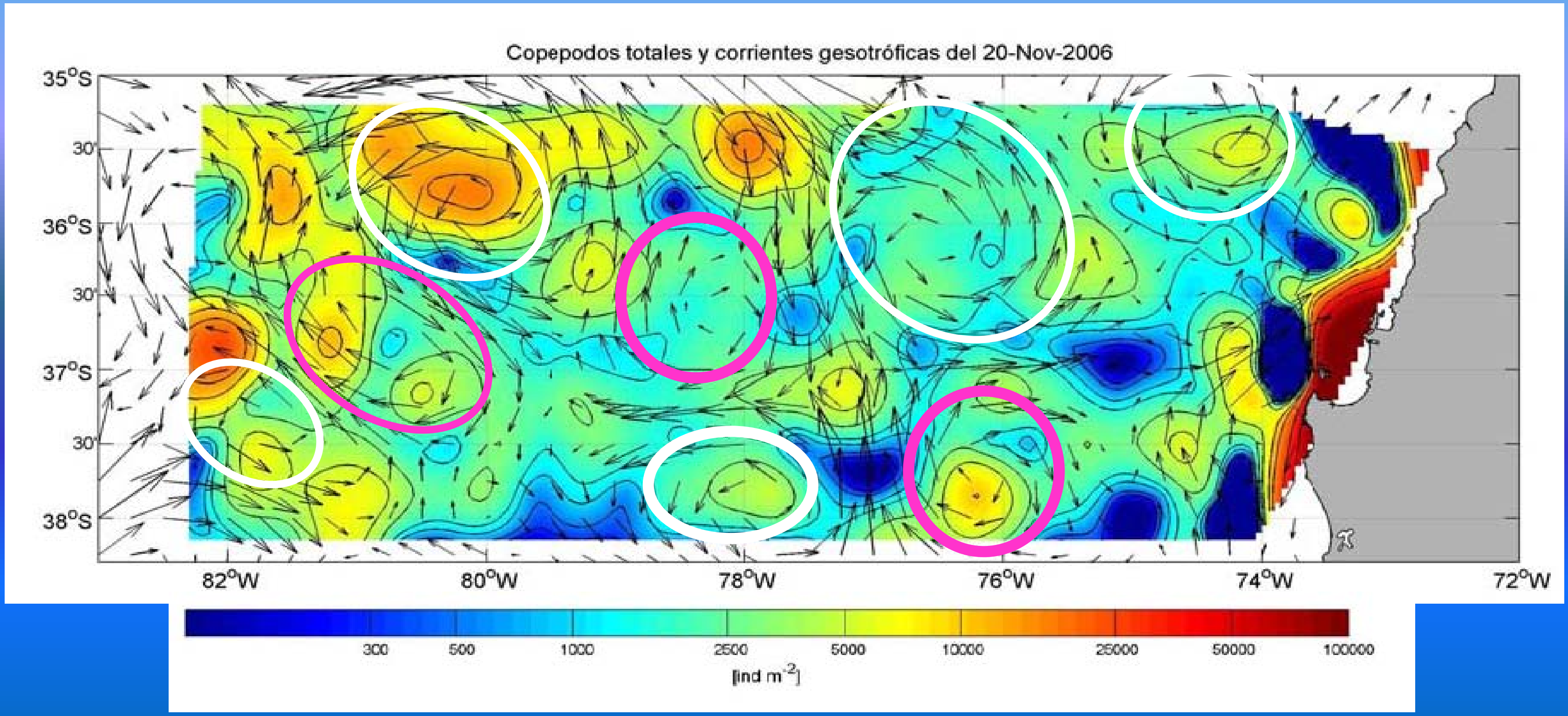


OFFSHORE ADVECTION UPON INCREASED UPWELLING





Morales et al. PiO (2012), Hormazábal et al. JGR (in press).



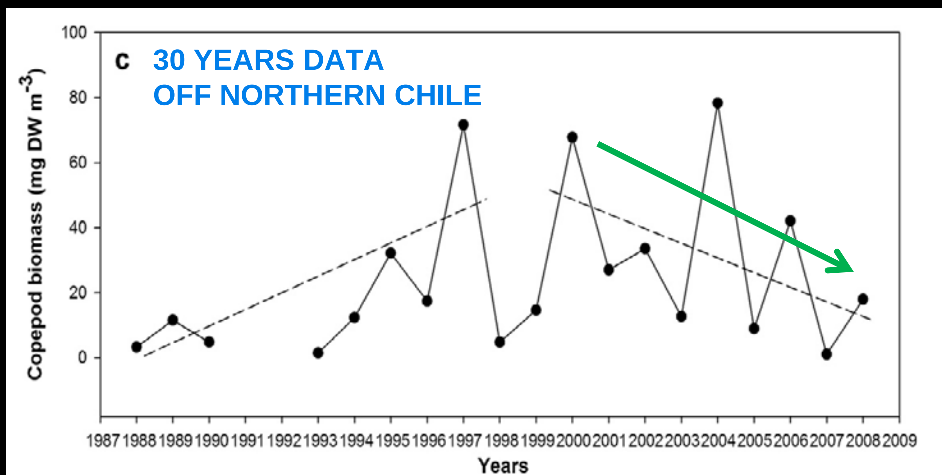
Anticyclonic eddy

Morales et al. (2010)

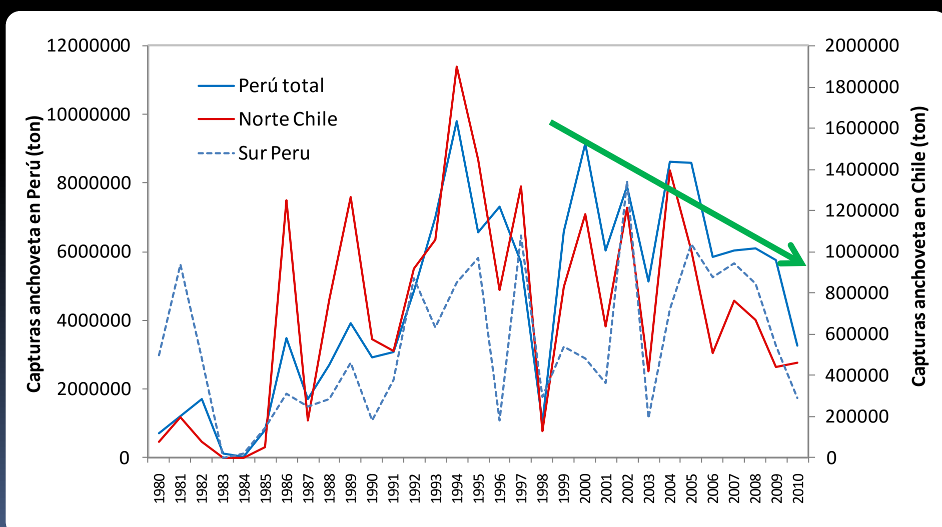
Cyclonic eddy

ZOOPLANKTON BIOMASS AND FISH

MOSTLY NEGATIVE TRENDS: RECENT DECADES



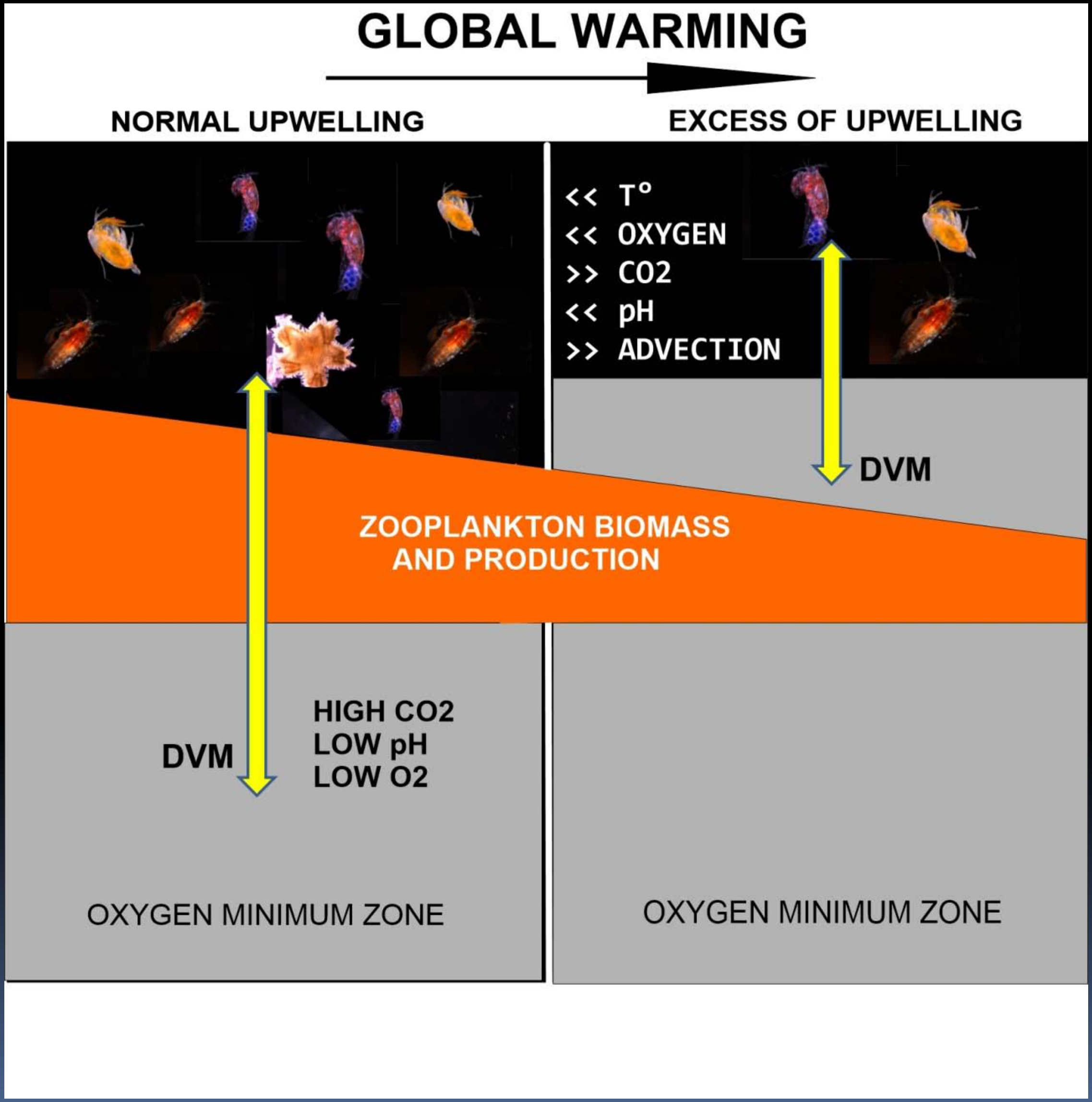
COPEPODS BIOMASS



FISH LANDINGS
Small pelagics fishes

Escribano et al. 2012

SUMMARY OF IMPACT ON ZOOPLANKTON



EFFECTS OF EXCESS OF UPWELLING ON ZOOPLANKTON

PRODUCTION DECREASES DUE TO:

LOWER BIOMASS

LOWER T°

OA AFFECTING YOUNG STAGES (LESS RECRUITMENT?)

REMARKS AND THOUGHTS

THE HUMBOLD CURRENT EBUE IS BECOMING A "COLD SPOT" UNDERLYING MECHANISMS ARE YET UNCLEAR

THERE IS MORE UPWELLING IN THE COASTAL SYSTEM: INCREASING HYPOXIA, PLANKTON MORE AGGREGATED AND POSSIBLY MORE EXPORT TO OFFSHORE. THIS CAN BE TRUE FOR ALL EBUEs

WHY LESS PRODUCTION AND BIOMASS?

Bottom-up effect unlikely

More advective losses from the upwelling zone?

Increased predation pressure? (strong aggregation near surface)

Small-sized zooplankton taking over: increased rates of metabolism and C cycling with lower biomass accumulation (faster turnover rates)

IMO
Instituto Milenio de Oceanografía

Automatic zooplankton analysis provides a tool to assess size-structured and taxonomic-structured zooplankton communities

Still alot of work ahead to get reliable estimates of zooplankton production: both biomass and g estimates need to be re-assessed

So far, we are getting indexes of zooplankton production: estimates and trends seem consistent

Secondary production is a key component of marine ecosystem functioning, but we do not see much work on the issue

UNIVERSIDAD DE CONCEPCION
CHILE