CAN TEMPERATURE-DEPENDENT GROWTH BE USED TO MEASURE SECONDARY PRODUCTION OF COPEPODS IN COASTAL UPWELLING SYSTEMS?

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PICES, Hiroshima 2012

Copepods as secondary producers

- They dominate virtually all marine systems
- They contribute significantly to zooplankton biomass (usually >60%)
- In the food web they capture and transfer C very fast (short life cycles)
- They are main prey of fish and other predators
- Many species.....many ecological capacities----many chances to occupy all kind of habitats

Copepods in upwelling systems: Humboldt Current as an example

- Low diversity high abundance and biomass
- Large sized copepods present, but usually medium size and even small copepods dominate (number and biomass)
- Large-sized herbivores are not the main pathway of C, but omnivore small-sized copepods seem the major channel for C in the food web
- They usually reproduce year round (continuous production)
- In the spring they feed on diatoms and in the winter the swicht to an heterotrophic diet.

If food is sufficient to sustain continuous growth, then we ask:

Can temperature control the dynamics of copepods in upwelling systems?

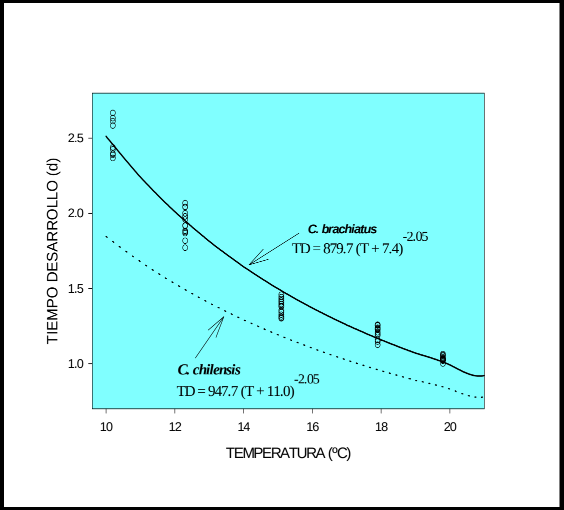
- Copepods are ectotherms

- Development rate is temperature dependent

- They show exponential growth, then g depends on DR, which is T° dependent
- DW/DT = Wo Exp (g t)

TEMPERATURE IS A KEY FACTOR FOR COPEPOD ECOLOGY

Temperature and development



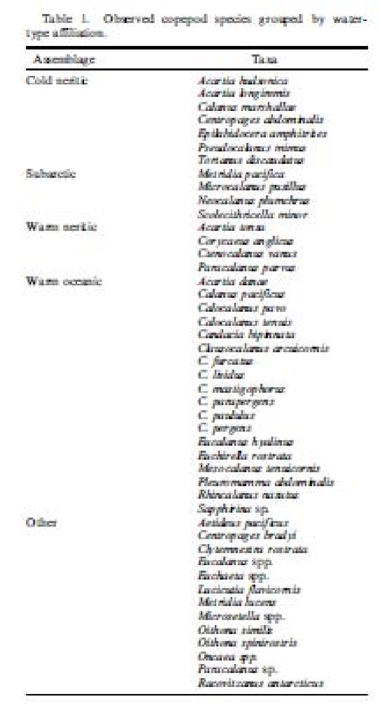
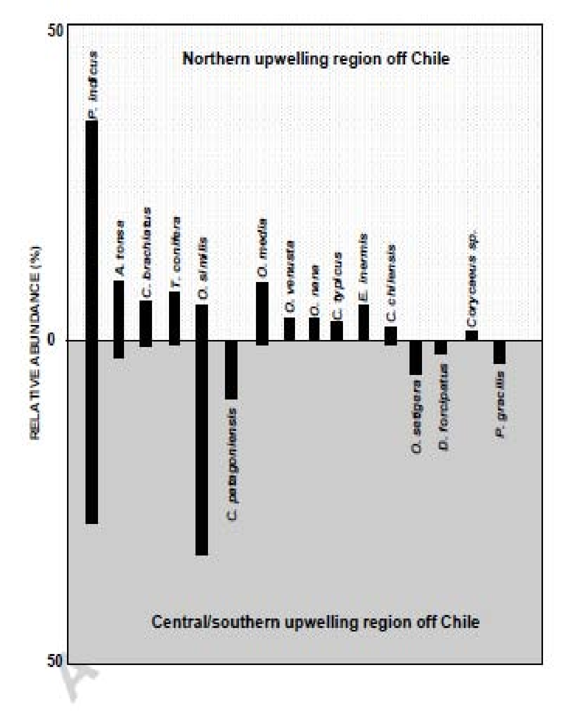


Table 1. Observed copepod species grouped by water-type affiliation.

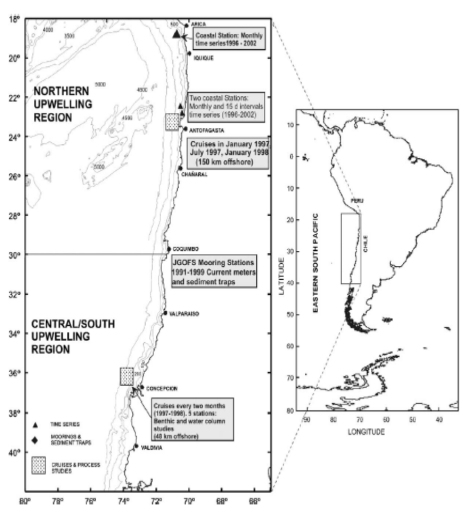
Assemblage	Taxa
Cold neritic	*Acartia hudsonica*
	Acartia longiremis
	Calanus marshallae
	Centropages abdominalis
	Epilabidocera amphitrites
	Pseudocalanus mimus
	Tortanus discaudatus
Subarctic	*Metridia pacifica*
	Microcalanus pusillus
	Neocalanus plumchrus
	Scolecithricella minor
Warm neritic	*Acartia tonsa*
	Corycaeus anglicus
	Ctenocalanus vanus
	Paracalanus parvus
Warm oceanic	*Acartia danae*
	Calanus pacificus
	Calocalanus pavo
	Calocalanus tenuis
	Candacia bipinnata
	Clausocalanus arcuicornis
	C. furcatus
	C. lividus
	C. mastigophorus
	C. parapergens
	C. paululus
	C. pergens
	Eucalanus hyalinus
	Euchirella rostrata
	Mesocalanus tenuicornis
	Pleuromamma abdominalis
	Rhincalanus nasutus
	Sapphirina sp.
Other	*Aetideus pacificus*
	Centropages bradyi
	Clytemnestra rostrata
	Eucalanus spp.
	Euchaeta spp.
	Lucicutia flavicornis
	Metridia lucens
	Microsetella spp.
	Oithona similis
	Oithona spinirostris
	Oncaea spp.
	Paracalanus sp.
	Racovitzanus antarcticus

WARM OR COLD ADAPTED COPEPODS SPECIES ARE EVERYWHERE

Norht Pacific (Hoofs & Peterson, 2006)



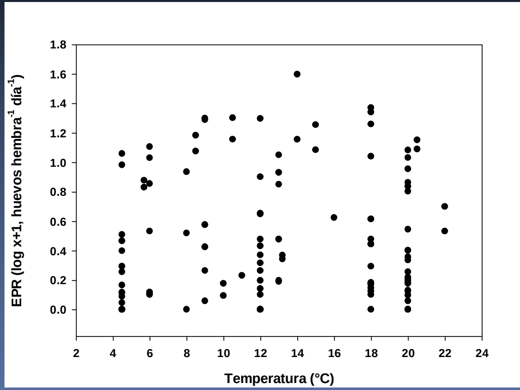
WARM OR COLD ADAPTED SPECIES



Hidalgo et al. (2010 DSR-II)

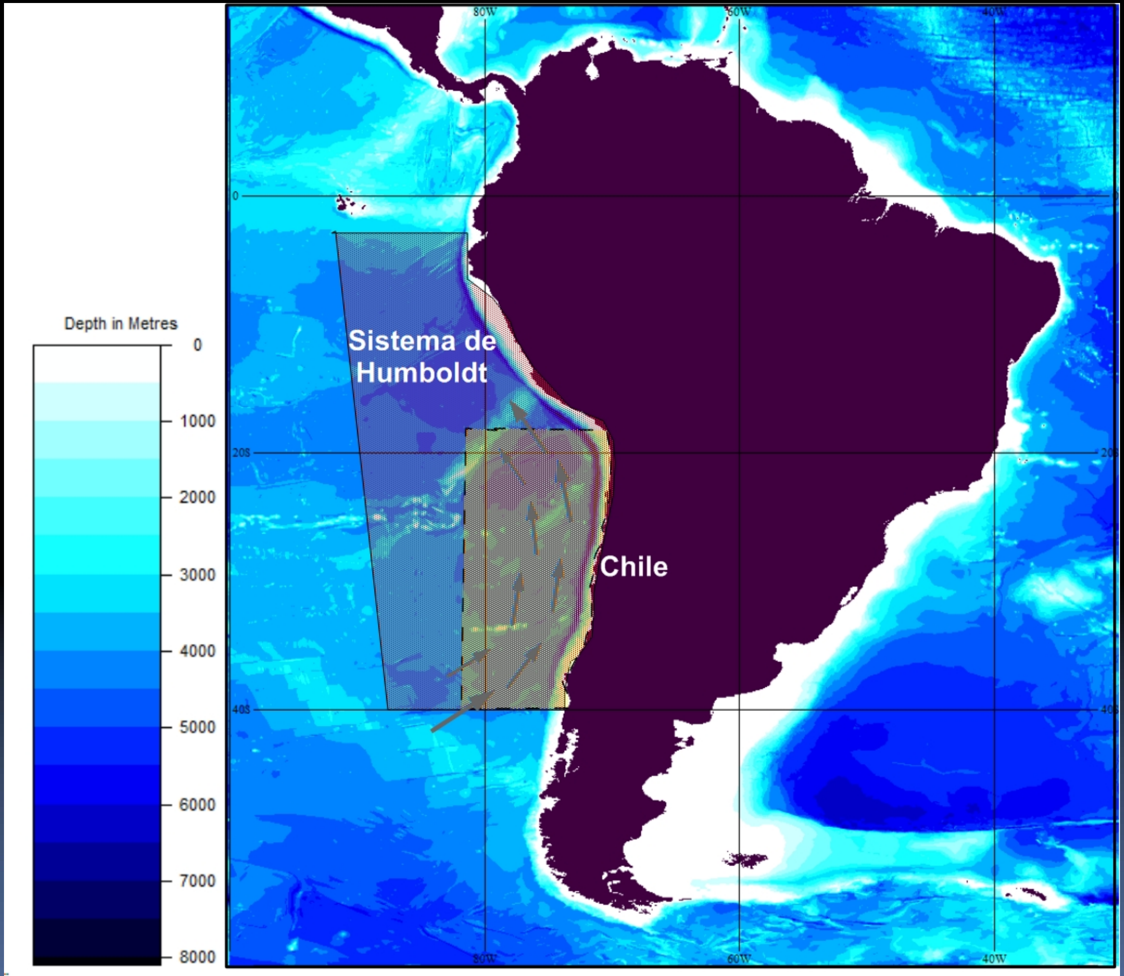
Rapid adjustment to highly variable temperature in upwelling systems

EPR vs Temperature
(*C. patagoniensis*
P. indicus, A. tonsa)



Fredericks & Escribano, in prep.

COPEPODS IN THE HUMBOLDT CURRENT

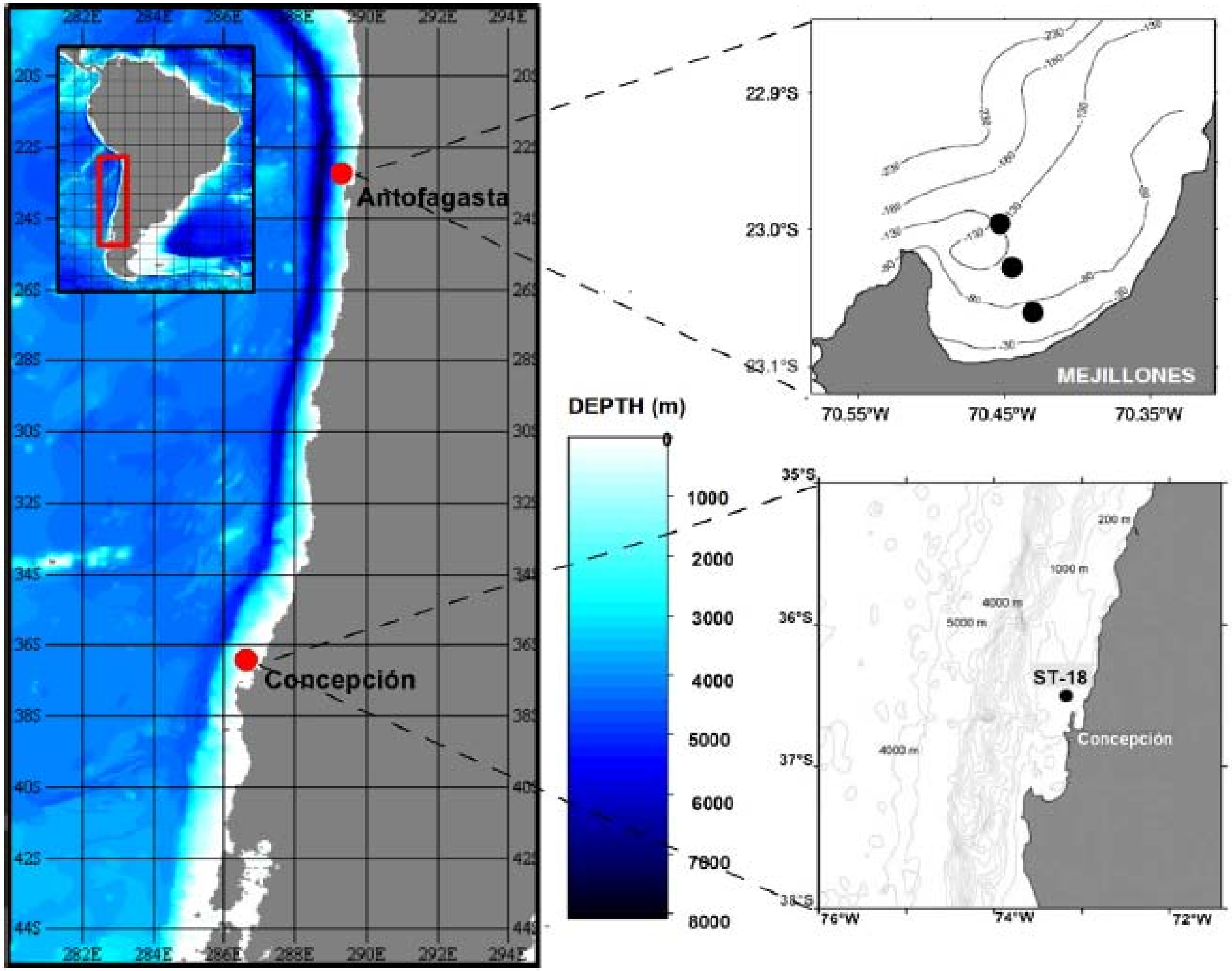


Paracalanus indicus
Calanus chilensis
Centropages brachiatus
Acartia tonsa
Calanoides patagoniensis
Eucalanus inermis
Rhincalanus nasutus

Most species distribute along a latitudinal gradient of ca 4500 km This is a temperature range of about 8 to 25 °C in the upper 50 m

Therefore, the HCS is a natural experiment to test T° effects on copepods dynamics

Study Area for experimental work



20 and 10 years of study on copepod dynamics

Data on oceanographic variability (time series studies)

Copepod biomass , abundance and diversity

In 2002-2003 and 2011 Live samples for experiments on development rate and temperature, using egg development approach

Egg development experiments (No food effect)

- Estimating species clutch size, hatching success and the embryonic development time at controlled temperatures..T° range in the upper 50 m layer
- Fitting an equation to egg development rate as a function of T°
- DR = a $(T + \alpha)^c$ (Belerhàdek equation)
- DR = a $(\exp^{bT})$ (Exponential model)
- Using DR as a proxy to estimate species generation time (GT)
- Finally, estimating the potential number of generations a year (NGY)

RESULTS FOR THREE DOMINANT SPECIES

CLUTCH SIZE AND DEVELOPMENT RATE

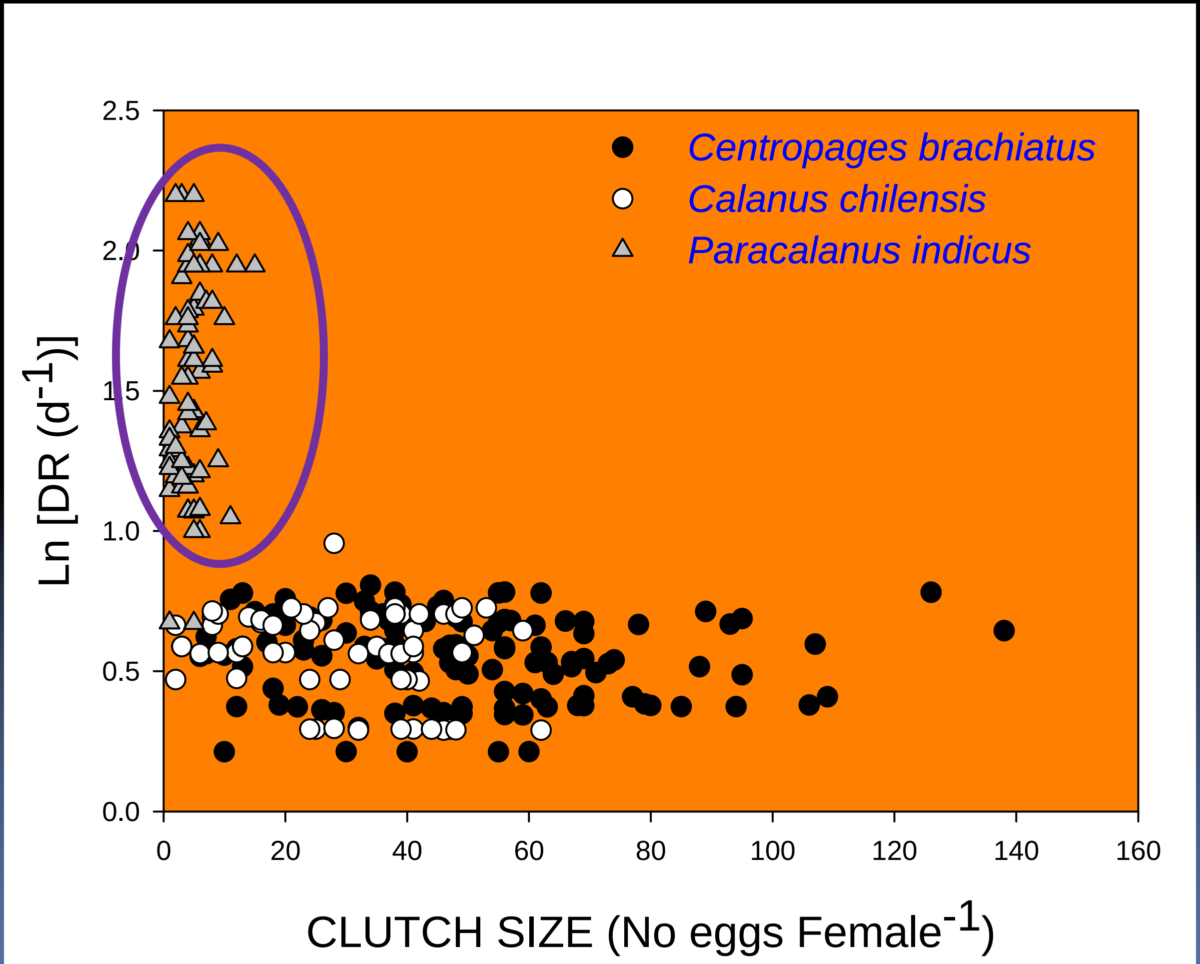
CLUTCH SIZE= No. of eggs spawned at once per female (within 2 h)

Species	Clutch size (eggs female-1) Mean ±SE	Hatching success (%) Mean ±SE	n1	DT (d) Mean ±SD	n2
C. chilensis	29.3 ± 1.97	32.0 ± 3.93	63	1.42 ± 0-074	79
C. brachiatus	43.3 ± 2.43	58.5 ± 4.93	141	1.60 ± 0-058	173
P. indicus	4.7 ± 0.31	51.9 ± 2.99	75	0.38 ± 0-019	100

Escribano et al. (submitted)

THE RELATIONSHIP BETWEEN CLUTCH SIZE AND DR

CLUTCH SIZE VS DEVELOPMENT RATE



C. brachiatus and *C. chilensis* similar DR, but larger CS in the former

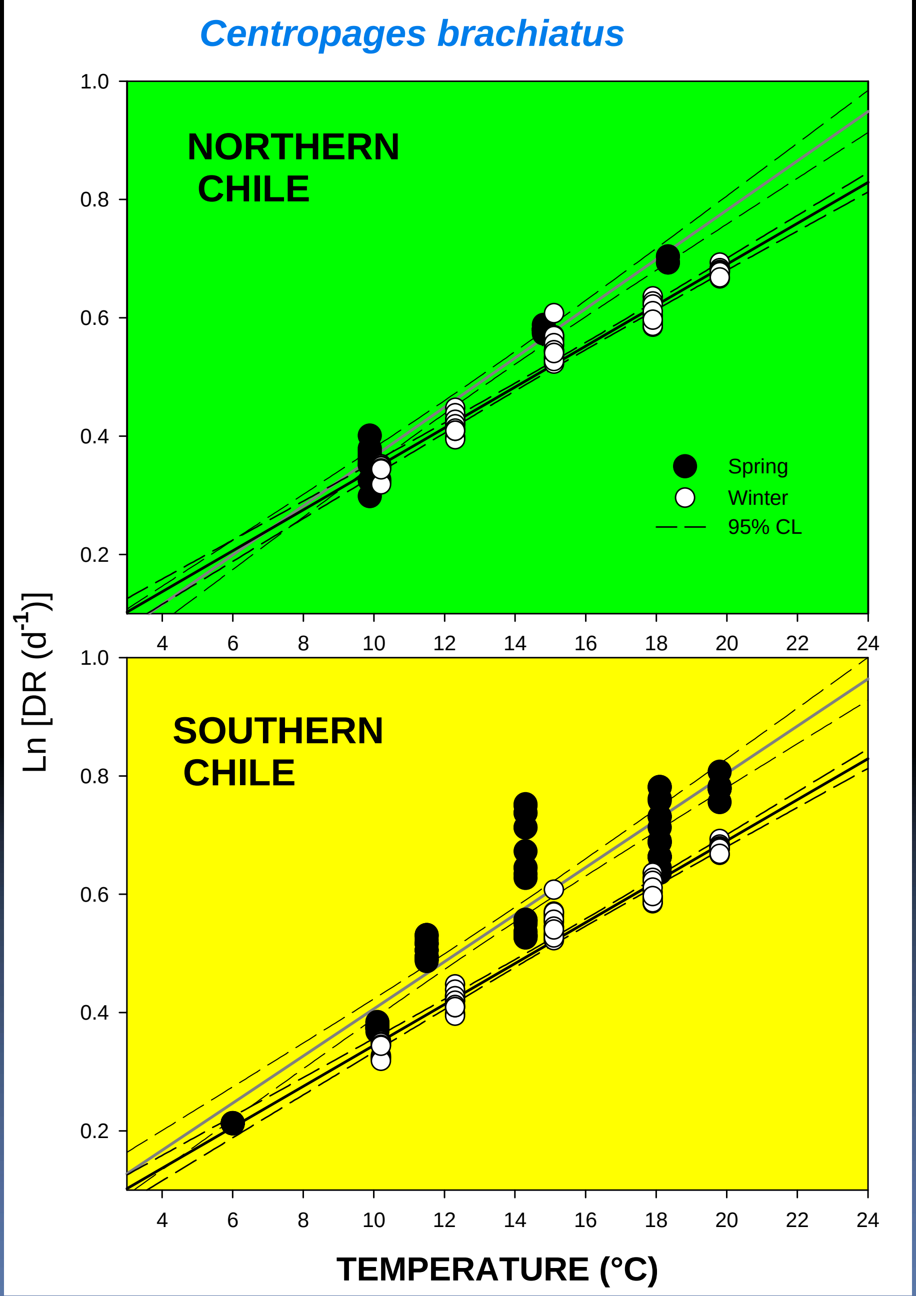
P. indicus extremely low CS, but very high DR

No seasonal effects on CS

No regional effects on CS

Escribano et al. (submitted)

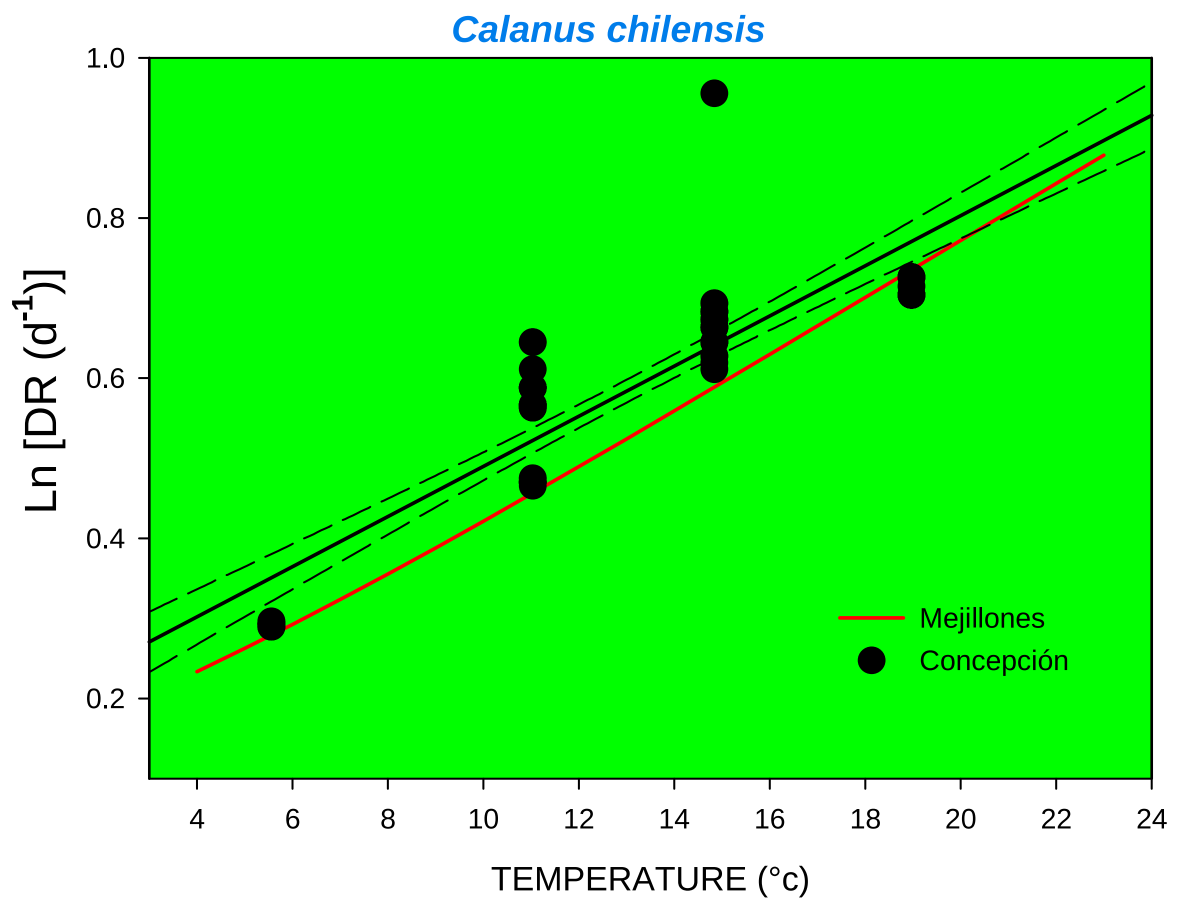
SEASONAL AND REGIONAL EFFECTS ON DR OF EGGS



1) DR is higher in the spring
2) DR is higher in northern Chile
3) warm adapted species

Escribano et al. (submitted)

SEASONAL AND REGIONAL EFFECTS ON DR OF EGGS



1) Only spring condition, hardly present in winter in southern Chile

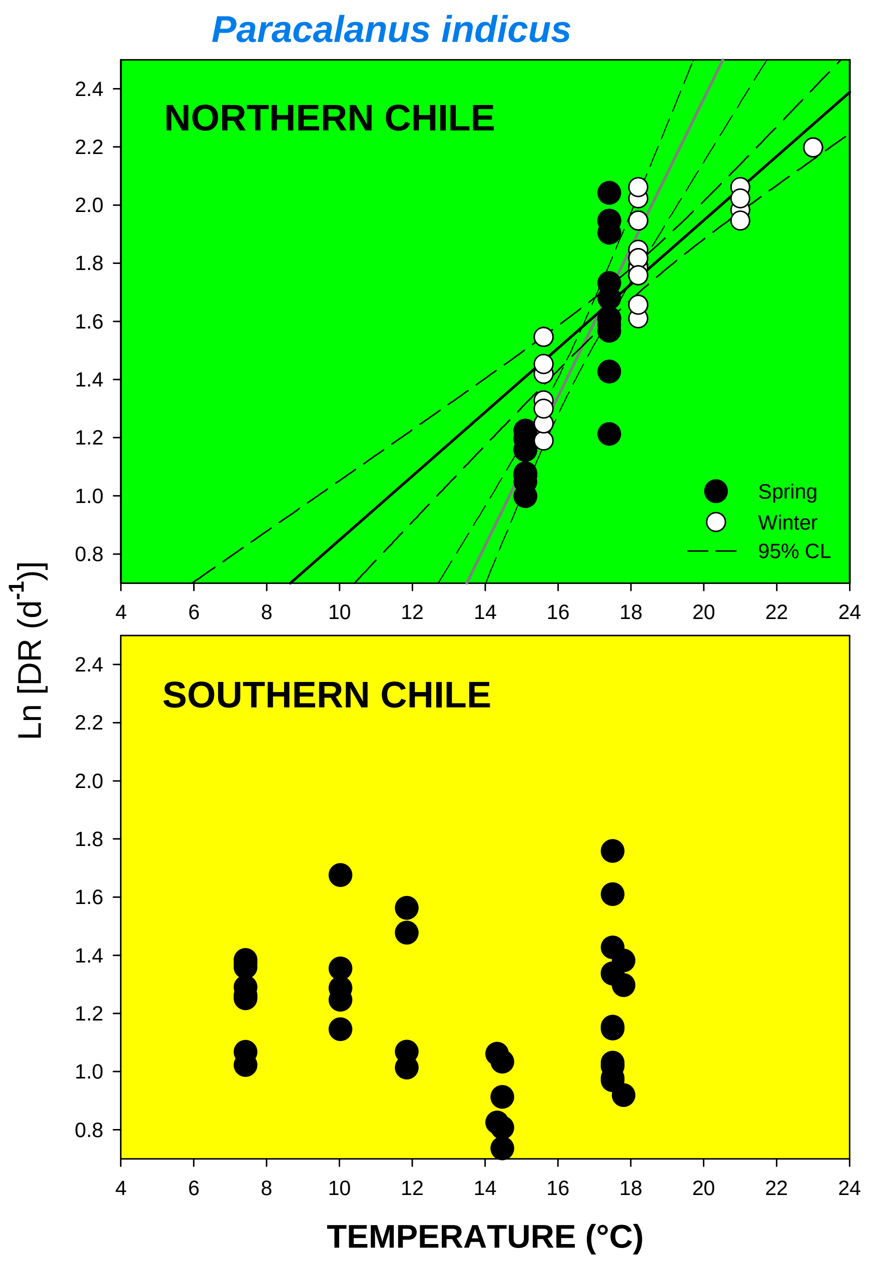
2) Fiited line for Mejillones is from Escribano et al. (1998)

3) DR is not differente between northern and southern Chile

3) warm adapted species (Escribano et al. 1998)

Escribano et al. (submitted)

SEASONAL AND REGIONAL EFFECTS ON DR OF EGGS



1) The response to T° depended on the temperature range

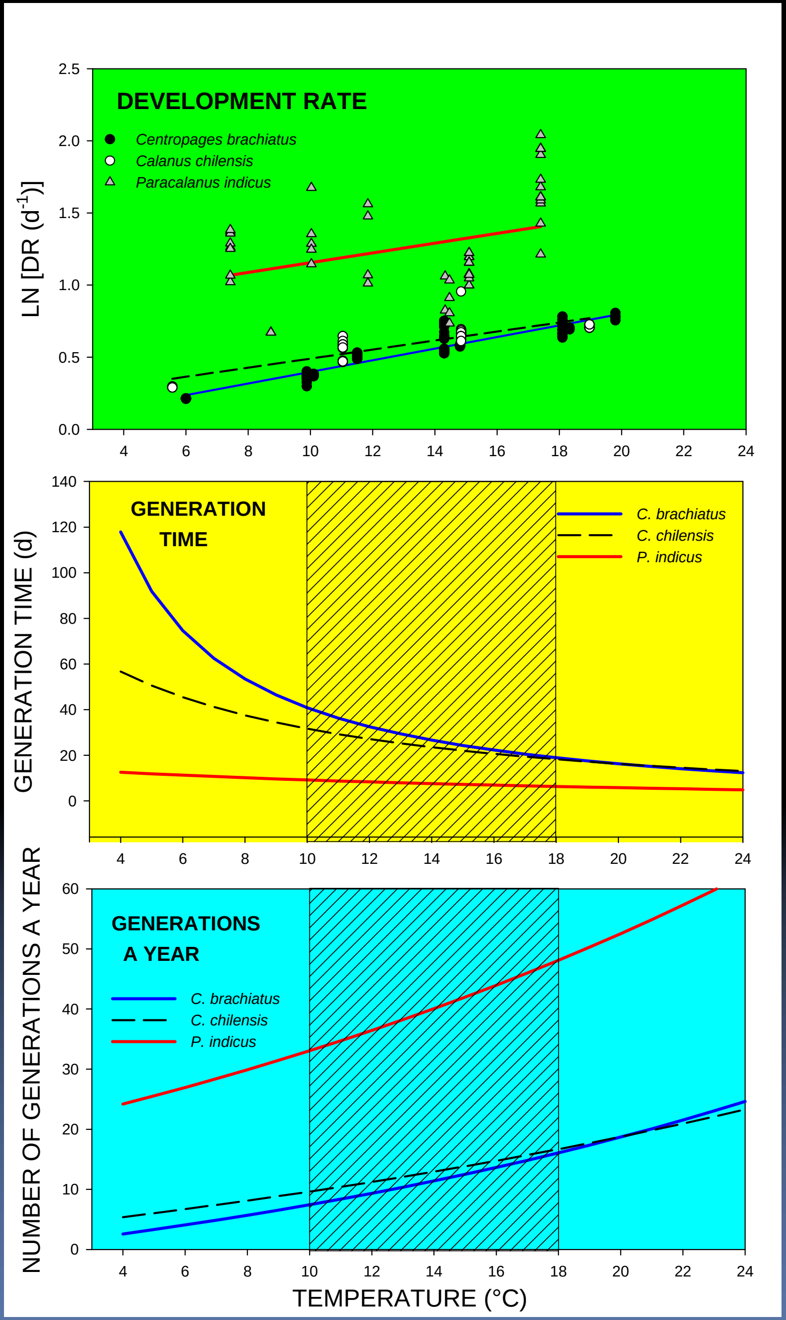
2) At low T° (<15 °C) eggs develop faster than expected (compensation?)

3) DR is not differente between northern and southern Chile

3) Cold adapted species. It shows similar DR’s at cold and warm conditions

Escribano et al. (submitted)

COMBINED DATA OF THE THREE SPECIES



1. The Small *P. indicus* is a ver fast developing species
2. *C. brachiatus* and *C. chilensis* are very similar
3. GT estimated assuming that egg development is 5% of GT (Escribano et al. 1998, also equiproportional rule from Corkett et al. 1986)
4. Potential NGY estimated assuming continuous reproduction and 10% of GT as a tiem lag to initiate spawning
5. Shaded area in the current observed range of T° in the upper 50 m
6. At any T° the small *P. indicus* will produce more generations a year
7. Low temperature clearly favours the small *P. indicus*

Escribano et al. (submitted)

IMPLICATIONS

PREDICTIONS FROM THE TEMPERATURE RESPONSE

Species	Location	Mean T°	Estimated GT	Potential NGY
C. brachiatus	Northern	15°C	24.3	**12.5**
C. chilensis	Northern	15°C	22.0	**13.8**
P. indicus	Northern	15°C	7.2	**41.9**

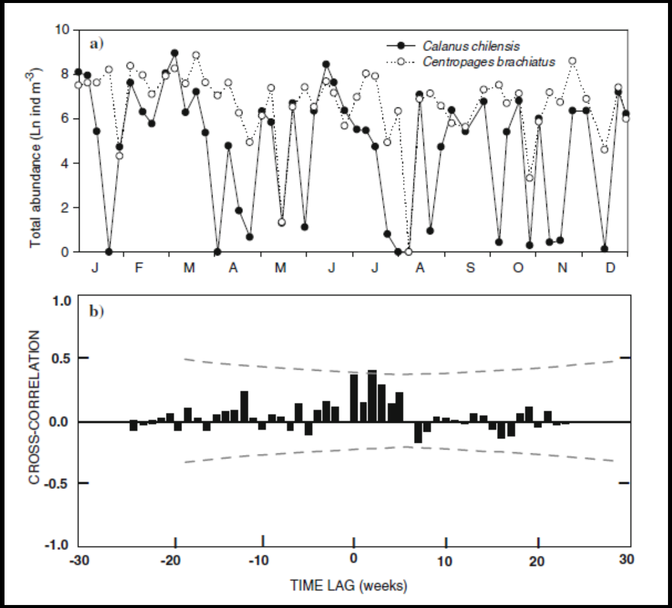
Species	Location	Mean T°	Estimated GT	Potential NGY
C. brachiatus	Southern	12°C	32.5	**9.3**
C. chilensis	Southern	12°C	27.1	**11.2**
P. indicus	Southern	12°C	8.3	**36.4**

FIELD OBSERVATIONS

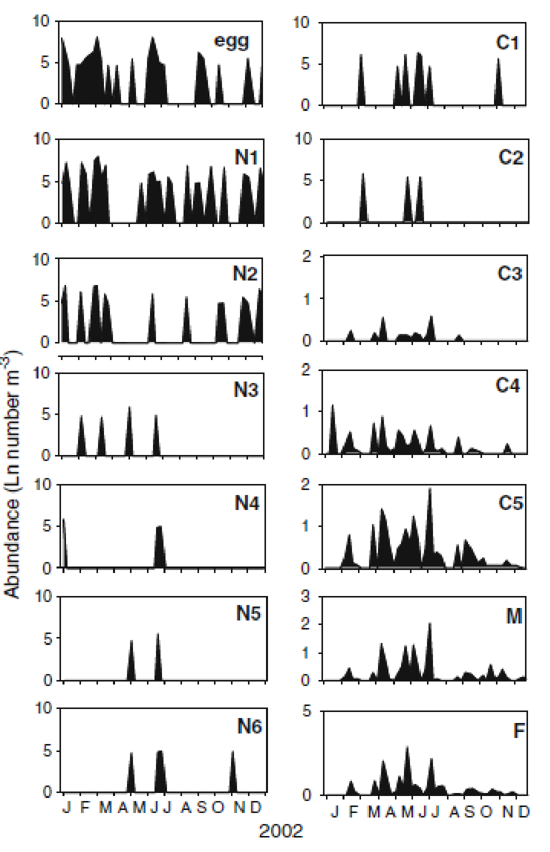
C. brachiatus **and** ***C. chilensis*** **at northern Chile**

2 years time series (15 d sampling interval)

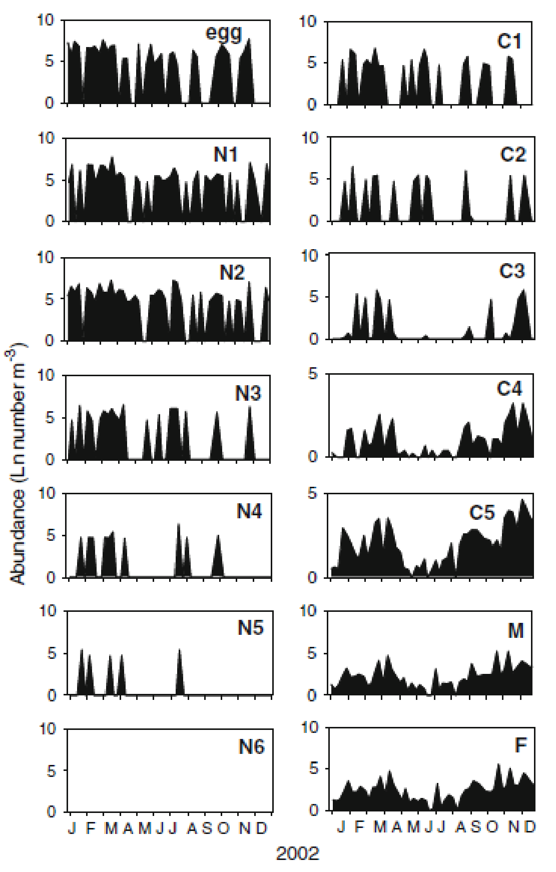
Both spp strongly associated with continuous reproduction and cohort development

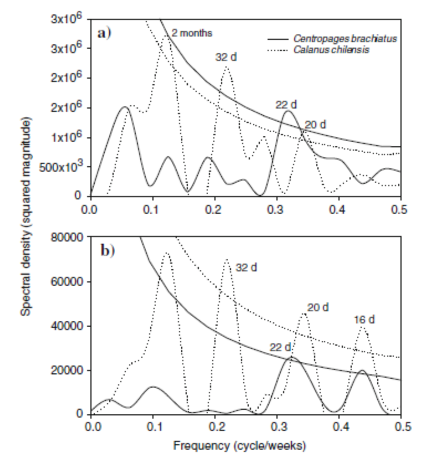


C. brachiatus



C. chilensis



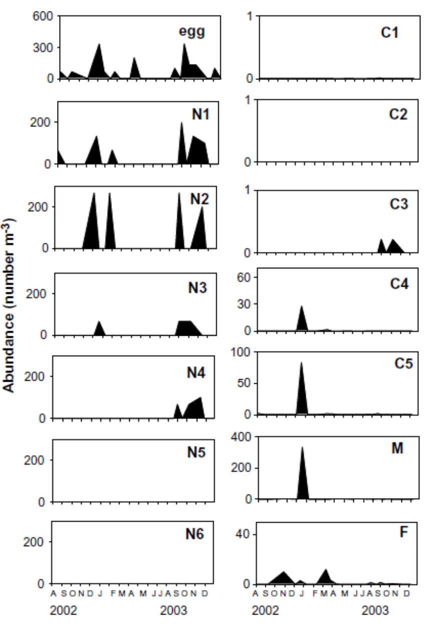


GT=22 d for *C. brachiatus* and 20 d for *C. chilensis*

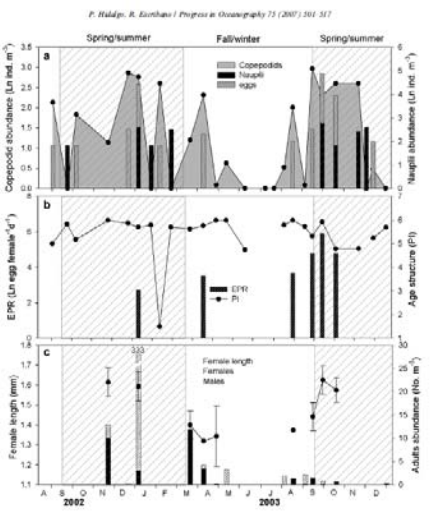
About 16 generations a year for both spp

Hidalgo & Escribano 2008

FIELD OBSERVATIONS



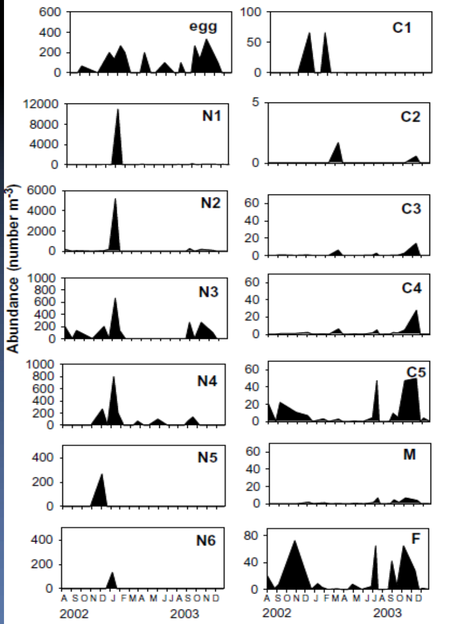
C. brachiatus



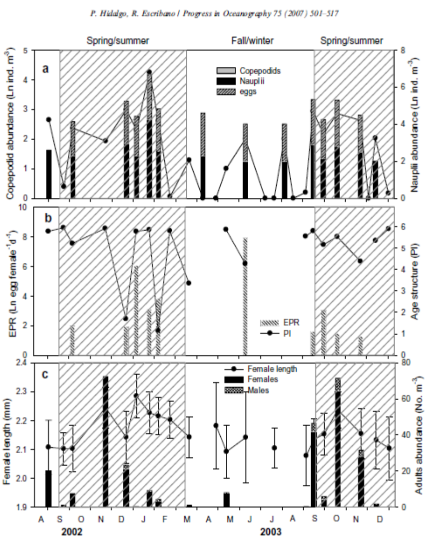
C. brachiatus and **C. chilensis** at southern Chile

2 years time series (15-30 d sampling interval)

Both spp also associated with continuous reproduction and cohort development



C. chilensis



No time series analysis

Tracking cohorts suggested:

GT= 30-35 d *C. brachiatus*
GT= 25-30 d *C. chilensis*

NGY = 10 *C. brachiatus*
12 *C. chilensis*

Hidalgo & Escribano 2007

PREDICTIONS VS OBSERVATIONS

NORTHERN CHILE

Species	T°	GT predicted	GT observed	NGY predicted	NGY Observed
C. brachiatus	15-16°C	22-24 d	22 d	**13 – 14**	**Ca. 16**
C. chilensis	15-16°C	20-22 d	20 d	**14- 15**	**Ca. 16**
P. indicus	15-16°C	7	NA	**42-44**	**NA**

SOUTHERN CHILE

Species	T°	GT predicted	GT observed	NGY predicted	NGY Observed
C. brachiatus	12-13°C	29- 33 d	30-35 d	**10**	**10**
C. chilensis	12-13°C	25-27 d	25 . 30 d	**11- 12**	**12**
P. indicus	12-13°C	8	NA	**36-38**	**NA**

PREDICTIONS FROM AN TEMPERATURE_DEPENDENT ESTIMATE OF THE NGY ARE SURPRINSINGLY CONSISTENT WITH INDEPENDT FIELD DATA

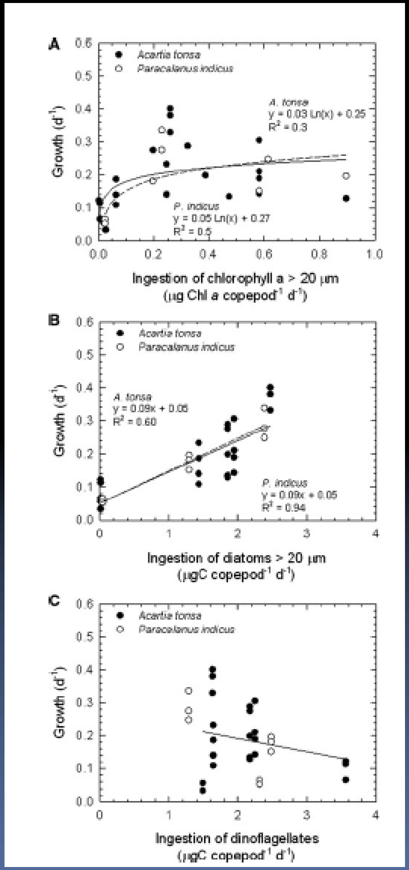
NO FIELD DATA AVAILABLE FOR *P. indicus*, but this is numerically dominant and persistent year-round at both places (Escribano et al. 2007)

Are the populations controlled by temperature?

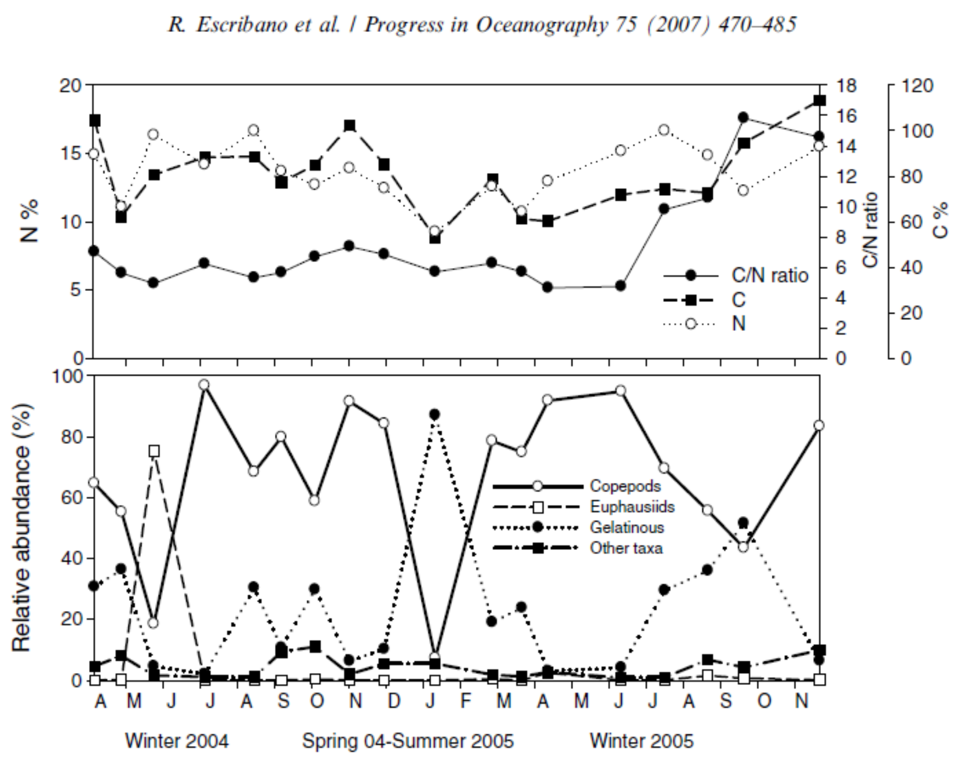
Is therefore growth temperature-dependent?

Food influences seasonal growth

However, greater growth in the spring implies more C from diatoms.. Copepods are overweighed. The C/N ratio increases in the spring (>C) while in winter is about 7

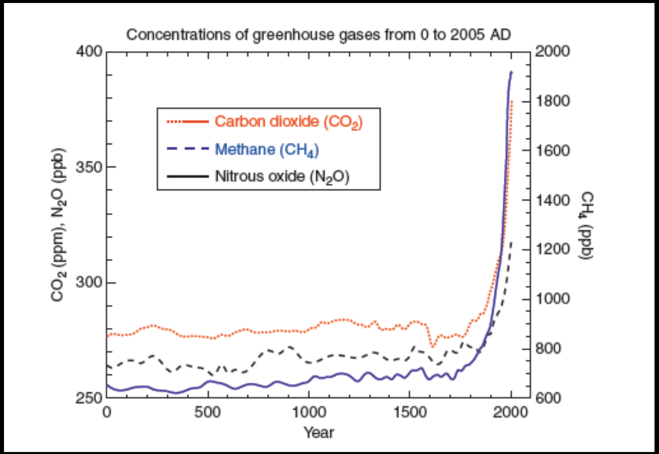


Vargas et al. 2010

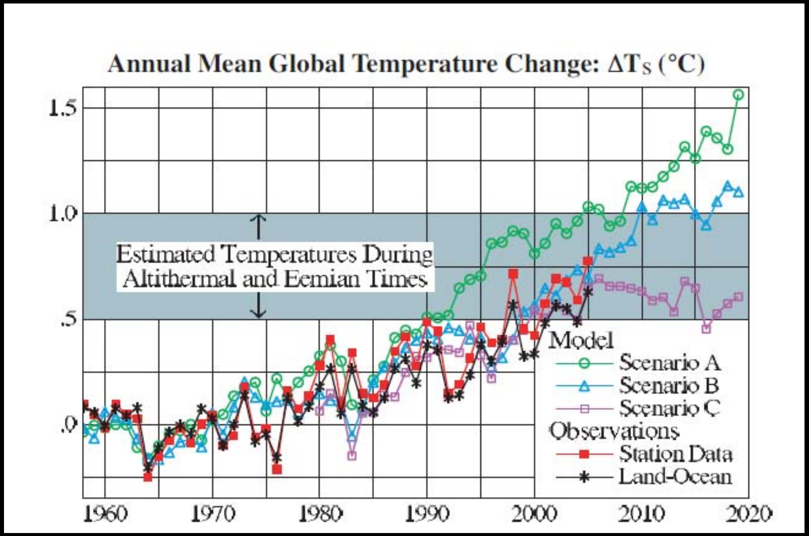


Escribano et al. 2007

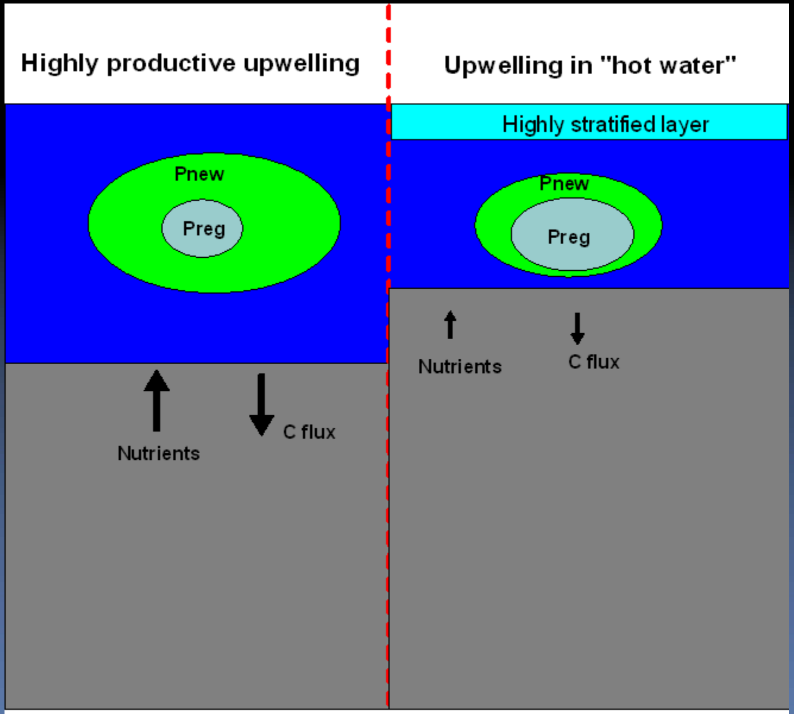
TEMPERATURE CONTROL OF COPEPOD DYNAMICS UPON GLOBAL WARMING



Reid et al. 2009 Adv. Mar. Ecol.



Hansen et al 2006 PNAS



Should we expect more copepods upon warmer conditions?

Ulloa et al. (2001) described an increase of *C. chilensis* population during the 1997-98 El Niño because of higher temperature

BUT, GLOBAL WARMING IS COOLING DOWN THE UPWELLING SYSTEMS

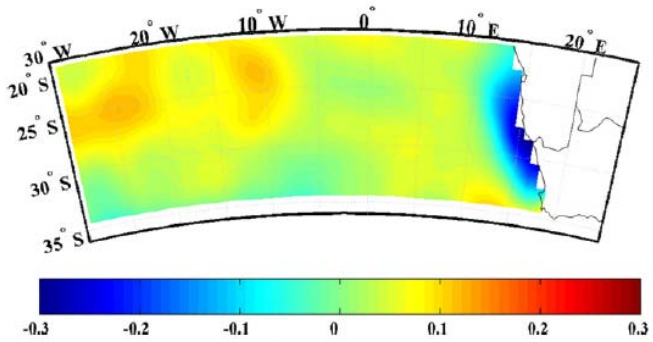
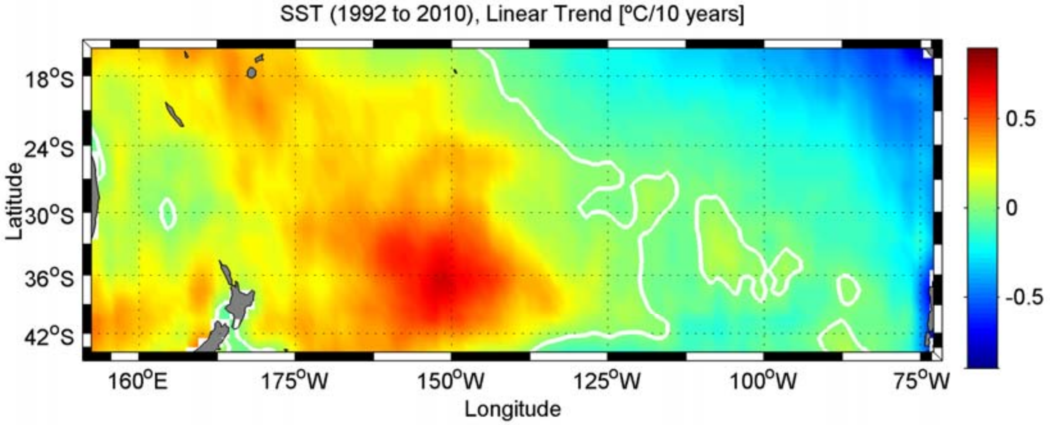


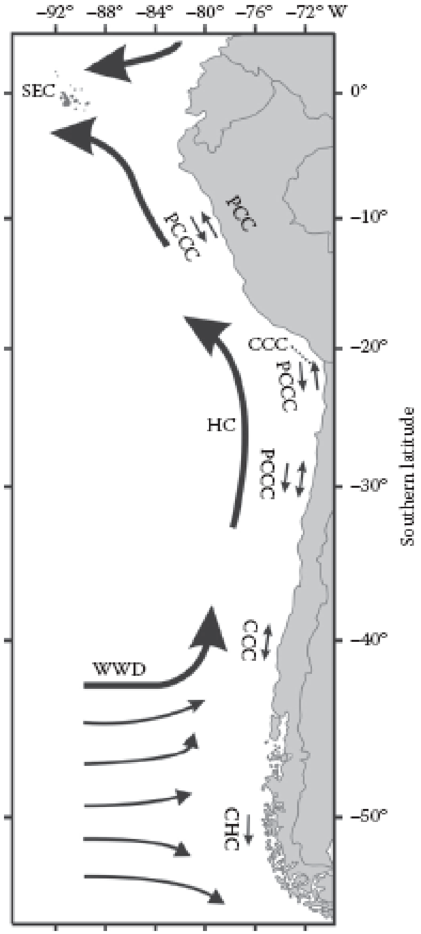
Fig. 3. Annual SST trend (°C dec^{-1}) for the area under study from 1970 to 2009.

Santos et al. 2012 CSR

Benguela current

Humboldt current



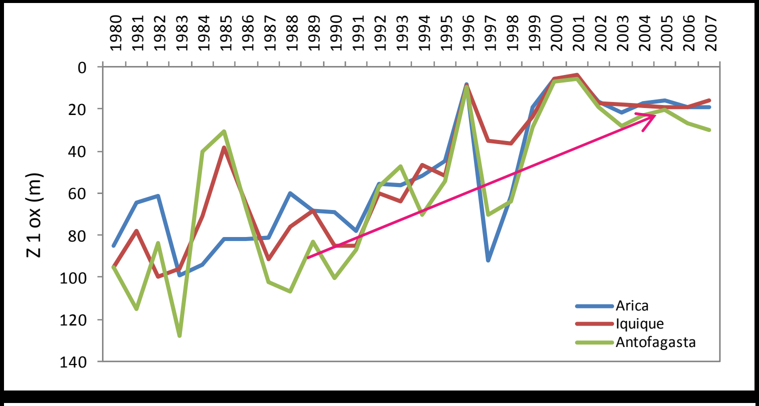


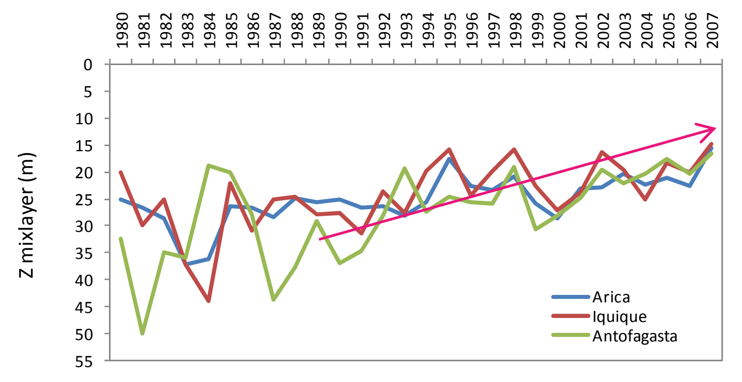
NEGATIVE TREND IN TEMPERATURE

THEN COLDER AND FRESHER IN THE LAST 20 YEARS

IN SITU DATA CLEARLY SHOW INCREASING UPWELLING

NORTHERN CHILE LAST 30 YEARS

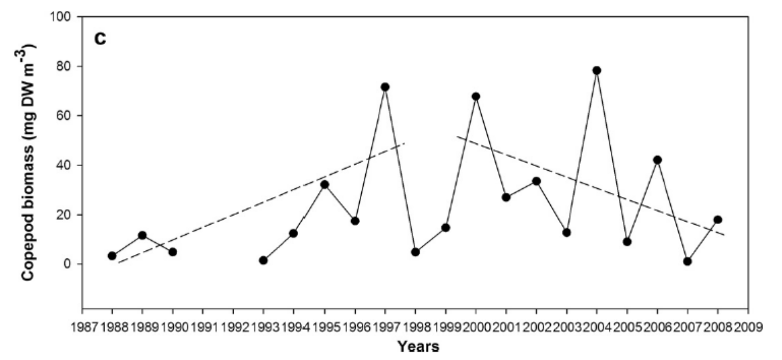


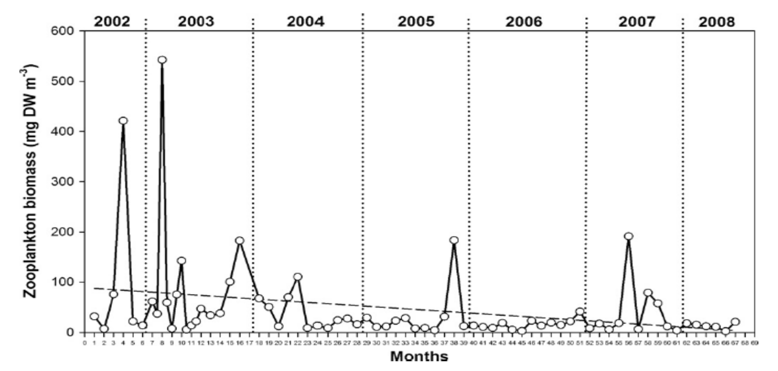


INCREASED UPWELLING MEANS A NARROW MIXING LAYER AND SHALLOWER OZM

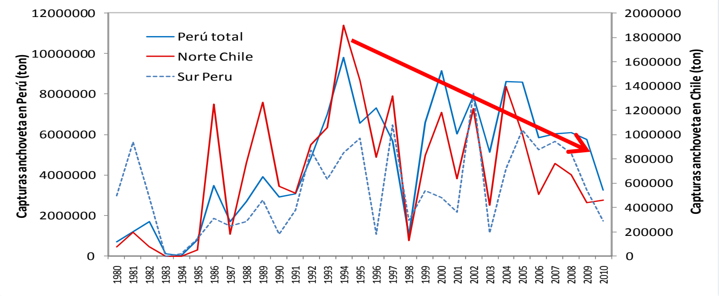
CONSEQUENCES ARE UNCERTAIN

MORE UPWELLING MAY NOT BE AS GOOD





Escribano et al (2012)



Escribano et al (unpublished)

SOME REMARKS

THE HUMBOLDT CURRENT IS JUST AN EXAMPLE ON HOW TEMPERATURE CAN CONTROL COPEPOD DYNAMICS. FINDINGS MAY APPLY TO SIMILAR UPWELLING SYSTEMS

HIGH-LATITUDE COPEPODS MAY NOT RESPOND TO TEMPERATURE SIMILARLY, BECAUSE OF FOOD LIMITATION, PRESENCE OF DIAPAUSE, ALSO BECAUSE T° REGIME IS MORE ESTABLE

TEMPERATURE-DEPENDENCE CANNOT BE SEEN OVER SHOR-TERM VARIABILITY (INTRASEASONAL, SEASONAL, LOCAL)

PRODUCTION DURING A YEAR CYCLE DEPEND ON HOW MANY GENERATIONS THE POPULATION CAN PRODUCE. THIS DEPEND ON THE GENERATION TIME, WHICH IS TEMPERATURE-DEPENDENT

HOPING THESE FINDINGS CAN HELP DEVELOP AN EMPIRICAL MODEL TO ESTIMATE COPEPOD PRODUCTION IN MARINE ECOSYSTEMS

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THANK YOU!