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

Ruben Escribano
Pamela Hidalgo
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 \( T^\circ \) dependent
- \( \frac{DW}{DT} = W_0 \exp (g \ t) \)
TEMPERATURE IS A KEY FACTOR FOR COPEPOD ECOLOGY

Temperature and development

![Graph showing temperature vs development time for different species.](image)

**WARM OR COLD ADAPTED COPEPODS SPECIES ARE EVERYWHERE**

Norht Pacific (Hoofs & Peterson, 2006)

**Rapid adjustment to highly variable temperature in upwelling systems**

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

**Fredericks & Escribano, in prep.**

**Hidalgo et al. (2010 DSR-II)**

**Norht Pacific**

**WARM OR COLD ADAPTED SPECIES**
COPEPODS IN THE HUMBOLDT CURRENT

Paracalanus indicus
Calanus chilensis
Centropages brachiatu
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.
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. $T^\circ$ range in the upper 50 m layer
- Fitting an equation to egg development rate as a function of $T^\circ$
  - $DR = a (T + \alpha)^c$ (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)**

<table>
<thead>
<tr>
<th>Species</th>
<th>Clutch size (eggs female-1) Mean ±SE</th>
<th>Hatching success (%) Mean ±SE n1</th>
<th>DT (d) Mean ±SD n2</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. chilensis</em></td>
<td>29.3 ± 1.97</td>
<td>32.0 ± 3.93 n1</td>
<td>1.42 ± 0-074 n2</td>
</tr>
<tr>
<td><em>C. brachiatas</em></td>
<td>43.3 ± 2.43</td>
<td>58.5 ± 4.93 n1</td>
<td>1.60 ± 0-058 n2</td>
</tr>
<tr>
<td><em>P. indicus</em></td>
<td>4.7 ± 0.31</td>
<td>51.9 ± 2.99 n1</td>
<td>0.38 ± 0-019 n2</td>
</tr>
</tbody>
</table>

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

Centropages brachiatus

Escribano et al. (submitted)

1) DR is higher in the spring
2) DR is higher in northern Chile
3) warm adapted species
SEASONAL AND REGIONAL EFFECTS ON DR OF EGGS

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

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

3) DR is not different 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
1. The Small *P. indicus* is a very 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 time 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*
## IMPLICATIONS

### PREDICTIONS FROM THE TEMPERATURE RESPONSE

<table>
<thead>
<tr>
<th>Species</th>
<th>Location</th>
<th>Mean T°</th>
<th>Estimated GT</th>
<th>Potential NGY</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. brachiatatus</em></td>
<td>Northern</td>
<td>15°C</td>
<td>24.3</td>
<td><strong>12.5</strong></td>
</tr>
<tr>
<td><em>C. chilensis</em></td>
<td>Northern</td>
<td>15°C</td>
<td>22.0</td>
<td><strong>13.8</strong></td>
</tr>
<tr>
<td><em>P. indicus</em></td>
<td>Northern</td>
<td>15°C</td>
<td>7.2</td>
<td><strong>41.9</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Species</th>
<th>Location</th>
<th>Mean T°</th>
<th>Estimated GT</th>
<th>Potential NGY</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. brachiatatus</em></td>
<td>Southern</td>
<td>12°C</td>
<td>32.5</td>
<td><strong>9.3</strong></td>
</tr>
<tr>
<td><em>C. chilensis</em></td>
<td>Southern</td>
<td>12°C</td>
<td>27.1</td>
<td><strong>11.2</strong></td>
</tr>
<tr>
<td><em>P. indicus</em></td>
<td>Southern</td>
<td>12°C</td>
<td>8.3</td>
<td><strong>36.4</strong></td>
</tr>
</tbody>
</table>
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*

Abundance (L number m⁻²)

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. brachiatu**

*C. brachiatu* 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

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**C. chilensis**

No time series analysis

Tracking cohorts suggested:

GT= 30-35 d *C. brachiatu*

GT= 25-30 d *C. chilensis*

NGY = 10 *C. brachiatu*  
12 *C. chilensis*
### PREDICTIONS VS OBSERVATIONS

#### NORTHERN CHILE

<table>
<thead>
<tr>
<th>Species</th>
<th>$T^\circ$</th>
<th>GT predicted</th>
<th>GT observed</th>
<th>NGY predicted</th>
<th>NGY Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. brachiatu</td>
<td>15-16°C</td>
<td>22-24 d</td>
<td>22 d</td>
<td>13 – 14</td>
<td>Ca. 16</td>
</tr>
<tr>
<td>C. chilensis</td>
<td>15-16°C</td>
<td>20-22 d</td>
<td>20 d</td>
<td>14- 15</td>
<td>Ca. 16</td>
</tr>
<tr>
<td>P. indicus</td>
<td>15-16°C</td>
<td>7</td>
<td>NA</td>
<td>42-44</td>
<td>NA</td>
</tr>
</tbody>
</table>

#### SOUTHERN CHILE

<table>
<thead>
<tr>
<th>Species</th>
<th>$T^\circ$</th>
<th>GT predicted</th>
<th>GT observed</th>
<th>NGY predicted</th>
<th>NGY Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. brachiatus</td>
<td>12-13°C</td>
<td>29- 33 d</td>
<td>30-35 d</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>C. chilensis</td>
<td>12-13°C</td>
<td>25-27 d</td>
<td>25 . 30 d</td>
<td>11- 12</td>
<td>12</td>
</tr>
<tr>
<td>P. indicus</td>
<td>12-13°C</td>
<td>8</td>
<td>NA</td>
<td>36-38</td>
<td>NA</td>
</tr>
</tbody>
</table>

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
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

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 (unpublished)

Escribano et al (2012)
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 SHORT-TERM VARIABILITY (INTRA SEASONAL, 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
Acknowledgements

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THANK YOU!