Upwelling conditions and cohort analysis of the euphausiid *Euphausia pacifica* off Newport, OR, USA

C. Tracy Shaw, Leah R. Feinberg, Hongsheng Bi, and William T. Peterson
Background & Objectives

- *Euphausia pacifica* have a period of intense spawning activity July-August in our study area. Using biweekly samples, could we:
  - Identify a cohort attributable to this intense summer spawning activity
  - Track a cohort over time
  - See interannual variability in cohorts in relation to upwelling conditions
  - Compare cohort growth rates to growth rates measured in live animal experiments
  - Create survivorship curves
Time series off Newport, OR (NH line)

- Sampled twice per month by the Peterson lab since 1996
- Adult euphausiids sampled with night bongo tows starting in 2001
- Cohort data from station NH25 (★) at the shelf break (~300m)
- Instantaneous growth rate (IGR) experiments on live animals since 2001
Methods

- Counted euphausiid eggs from 1/2m vertical net samples to determine timing of high egg density (“egg peak”)
- Counted and measured juvenile and adult *E. pacifica* from nighttime bongo nets
- Identified cohorts using maximum likelihood method in Matlab
- Characterized upwelling conditions for each year based on timing and intensity
Cohort Identification

- Cohorts are based on juveniles and adults since larvae are rarely present in sufficient numbers to identify a cohort.
- *E. pacifica* develop from egg to juvenile in an average of 60 days (Feinberg et al. 2006).
- Therefore, a cohort that appears about two months after an egg peak could be attributable to those eggs.
E. pacifica spawning activity

Total eggs NH05+15+25

Date

2000 (n=14)
2001 (n=30)
2002 (n=29)
2003 (n=24)
2004 (n=26)
2005 (n=23)
## Upwelling and Euphausioid Eggs

<table>
<thead>
<tr>
<th>Year</th>
<th>Spring transition (ST)</th>
<th>Fall transition (FT)</th>
<th>Duration of upwelling (mo)</th>
<th>CUI</th>
<th>ST→egg peak (mo)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>2-Mar</td>
<td>12-Nov</td>
<td>8.5</td>
<td>6642</td>
<td>4.6</td>
</tr>
<tr>
<td>2002</td>
<td>21-Mar</td>
<td>6-Nov</td>
<td>7.7</td>
<td>7611</td>
<td>4.1</td>
</tr>
<tr>
<td>2003</td>
<td>22-Apr</td>
<td>15-Oct</td>
<td>5.9</td>
<td>7940</td>
<td>2.4</td>
</tr>
<tr>
<td>2004</td>
<td>20-Apr</td>
<td>7-Nov</td>
<td>6.7</td>
<td>4800</td>
<td>4.0</td>
</tr>
<tr>
<td>2005</td>
<td>25-May</td>
<td>29-Sep</td>
<td>4.2</td>
<td>5906</td>
<td>4.0</td>
</tr>
<tr>
<td>2006</td>
<td>22-Apr</td>
<td>31-Oct</td>
<td>6.4</td>
<td>9747</td>
<td>--</td>
</tr>
</tbody>
</table>

### Averages

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.7</td>
<td>7108</td>
<td>3.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
“Traditional” cohort analysis

- Adult and juvenile *Euphausia pacifica* counted and measured from biweekly samples
- Plotted for each sampling date in 1 mm length bins
- The next slide shows the cohort data from 2003
Cohort Data 2003

We can calculate growth rates from change in cohort mean length over time.

Traditional cohort analysis subjective with size modes identified by eye.
Cohorts from maximum likelihood method

- This technique identifies overlapping distributions.
- We calculated growth rates from change in mean length of each size mode from one sampling date to the next.
Cohort mean TL 2001-2006

- Cohort appears in Jan/Feb time frame in all years
- November spawning?
- Overwintering juveniles?
Cohort mean TL 2001-2006

Cohorts start approximately:
- February
- April
- July
- September
Can we track a cohort?

- Previous slide showed that a cohort appeared in February of each year.
- Attempted to track cohort through the year, using 2004 as an example.
- February 2004 cohort shown in green in the following graphs.
- New cohort appears in March (red bar).
- Another new cohort appears in May (blue bar).
24-Jan

NH25 012404

$\mu=7.69 \sigma_1=1.61$

Counts

Length (mm)
4-Feb
2-Mar

\[ \mu_1 = 6.30 \quad \sigma_1 = 0.90 \quad w_1 = 0.28 \]

\[ \mu_2 = 9.90 \quad \sigma_2 = 1.35 \quad w_2 = 0.72 \]
31-Mar

NH25 033104

\[ \mu_1 = 5.23, \sigma_1 = 0.57, \omega_1 = 0.15 \]

\[ \mu_2 = 12.19, \sigma_2 = 2.00, \omega_2 = 0.85 \]
28-Apr

\[ \mu_1 = 5.45 \quad \sigma_1 = 0.68 \quad w_1 = 0.26 \]
\[ \mu_2 = 9.92 \quad \sigma_2 = 2.76 \quad w_2 = 0.40 \]
\[ \mu_3 = 14.41 \quad \sigma_3 = 0.77 \quad w_3 = 0.34 \]
10-May

\[ \mu_1 = 4.59 \quad \sigma_1 = 0.50 \quad w_1 = 0.57 \]
\[ \mu_2 = 8.06 \quad \sigma_2 = 1.00 \quad w_2 = 0.35 \]
\[ \mu_3 = 14.10 \quad \sigma_3 = 0.99 \quad w_3 = 0.08 \]
25-May

\[
\begin{align*}
\mu_1 &= 6.17 \quad \sigma_1 = 1.04 \quad w_1 = 0.35 \\
\mu_2 &= 9.50 \quad \sigma_2 = 1.61 \quad w_2 = 0.15 \\
\mu_3 &= 14.78 \quad \sigma_3 = 0.68 \quad w_3 = 0.50
\end{align*}
\]
7-June

\[
\begin{align*}
\mu_1 &= 4.09 \quad \sigma_1 = 0.42 \quad w_1 = 0.09 \\
\mu_2 &= 9.32 \quad \sigma_2 = 1.89 \quad w_2 = 0.44 \\
\mu_3 &= 14.92 \quad \sigma_3 = 0.79 \quad w_3 = 0.46
\end{align*}
\]
19-July

\[ \mu_1 = 10.14 \quad \sigma_1 = 3.54 \quad w_1 = 0.26 \]

\[ \mu_2 = 15.62 \quad \sigma_2 = 0.77 \quad w_2 = 0.74 \]
8-Aug

\[ \mu_1 = 5.54 \quad \sigma_1 = 0.93 \quad w_1 = 0.35 \]

\[ \mu_2 = 12.91 \quad \sigma_2 = 1.54 \quad w_2 = 0.65 \]
NH25 081704

\[ \mu_1 = 5.74 \quad \sigma_1 = 1.04 \quad w_1 = 0.38 \]

\[ \mu_2 = 12.23 \quad \sigma_2 = 1.08 \quad w_2 = 0.41 \]

\[ \mu_3 = 16.29 \quad \sigma_3 = 0.70 \quad w_3 = 0.21 \]
30-Aug

NH25 083004

$\mu_1=5.73 \quad \sigma_1=0.60 \quad w_1=0.41$

$\mu_2=13.19 \quad \sigma_2=1.85 \quad w_2=0.39$

$\mu_3=16.67 \quad \sigma_3=0.83 \quad w_3=0.20$
6-Nov

\[\begin{align*}
\mu_1 &= 7.82, \quad \sigma_1 = 1.61, \quad w_1 = 0.24 \\
\mu_2 &= 10.35, \quad \sigma_2 = 0.62, \quad w_2 = 0.24 \\
\mu_3 &= 13.71, \quad \sigma_3 = 1.27, \quad w_3 = 0.52
\end{align*}\]
Biweekly sampling may allow us to track cohorts in our study area. Patchy distribution of euphausiids may account for disappearance & reappearance of particular size modes.
Do juveniles appear ~2 months after egg peak?

<table>
<thead>
<tr>
<th>Year</th>
<th>Date of egg peak</th>
<th>Date size mode appeared</th>
<th>Months btwn dates</th>
<th>Size mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>18-Jul</td>
<td>7-Nov</td>
<td>3.7</td>
<td>9.14</td>
</tr>
<tr>
<td>2001</td>
<td>18-Jul</td>
<td>27-Nov</td>
<td>4.4</td>
<td>5.13</td>
</tr>
<tr>
<td>2002</td>
<td>23-Jul</td>
<td>15-Oct</td>
<td>2.8</td>
<td>6.45</td>
</tr>
<tr>
<td>2002</td>
<td>1-Nov</td>
<td>6-Feb</td>
<td>3.2</td>
<td>6.95</td>
</tr>
<tr>
<td>2003</td>
<td>3-Jul</td>
<td>5-Sep</td>
<td>2.1</td>
<td>4.98</td>
</tr>
<tr>
<td>2004</td>
<td>17-Aug</td>
<td>28-Oct</td>
<td>2.4</td>
<td>7.95</td>
</tr>
<tr>
<td>2005</td>
<td>21-Sep</td>
<td>15-Nov</td>
<td>1.8</td>
<td>4.55</td>
</tr>
<tr>
<td>2006 ST: April 22</td>
<td>20-Oct</td>
<td>2.0</td>
<td>5.75</td>
<td></td>
</tr>
</tbody>
</table>

Test of this idea limited by sampling intervals. Longer intervals tend to have a higher size mode, consistent with the animals having had more time to grow.
Growth rates: cohorts & experiments

- Growth rate calculated from change in mean length of cohort between sampling dates
- Individual krill may grow, shrink, or remain the same size after molting
- Molt approximately every 7 days in our study area
- Two-week sampling interval probably covers at least two intermolt periods
- Individual animals could grow and shrink within one sampling interval
Interannual variability in cohort growth

- Growth rates usually 0.01-0.17 mm d\(^{-1}\)
- Growth rates above 0.4 mm d\(^{-1}\) only in 2001
- Growth rates usually positive, negative growth more common when animals ≥10 mm

Cohort growth rates consistent among years. Interannual variability minimal if at all.
• Cohort growth rates (red) show that growth tends to slow as animals reach maturity
• IGR growth rates (gray) show range of individual variability
We don’t have measured stage durations for juveniles and adults. The stage duration estimates that best fit these curves were:

- **Juveniles** - 6 months
- **Adults** - 2 years

2005: late upwelling, lots of eggs, few survivors
Summary & Conclusions

• Highest egg density occurred ~4 months after the spring transition (use for prediction?)

• Cohort analysis using maximum likelihood method and sufficiently short sampling interval can:
  – yield growth rates comparable to IGR experiments
  – identify some incidences of negative growth

• Biweekly sampling seems adequate to track cohorts

• Survivorship from egg to furcilia was similar among years except in 2005: delayed upwelling → delayed spawning → lower survivorship

• Survivorship curves suggest the juvenile stage lasts about 6 months and that adults live about 2 years
Acknowledgements


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- Thanks for help with experiments: Julie Keister, Mitch Vance, Rian Hooff, Jesse Lamb, Jaime Gómez-Gutiérrez, Jennifer Menkel, Jay Peterson.
Euphausiidi Live Work Protocol

Protocols for Measuring Molting Rate and Egg Production of Live Euphausiids

Everything you always wanted to know about working with live euphausiids!

Available on the PICES website! (www.pices.int) under the “Projects” heading

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Courtesy of the Peterson Lab at Hatfield Marine Science Center, Newport, Oregon, USA
# Experimental vs. cohort growth rates

<table>
<thead>
<tr>
<th>Experiment data</th>
<th>Cohort data</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Growth rate for each individual animal that molts</td>
<td>• Growth rate for each mode in the size frequency (1-3 growth rates for each pair of samples)</td>
</tr>
<tr>
<td>• Range of individual growth rates at one point in time (can’t compare dates)</td>
<td>• Average growth over time interval between samples (usually 2 weeks)</td>
</tr>
<tr>
<td>• Individual growth rates often zero or negative</td>
<td>• Difficult to measure negative or zero growth with cohort data</td>
</tr>
</tbody>
</table>
Average growth rates by size bin

- Average individual growth rates usually lower than cohort rates (more influence from negative growth)
- Growth rates positive for small animals (<5 mm) during upwelling and downwelling
Cumulative Upwelling Index 2001-2006

- Shortest upwelling seasons 2003 (5.9 mo., and 2005 (4.2 mo.).
- Average 6.7 months of upwelling

http://www.pfel.noaa.gov/products/PFEL/modeled/indices/upwelling/upwelling.html