Overview of Artificial Cohort Method for Estimating Zooplankton Production in the Ocean

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Outline

- Classical methods for measuring zooplankton production
- Artificial Cohort (AC) methods and Caveats
- Utility and practicality of AC methods
- Status of AC research in the USA
Zooplankton Production

- Limited spatial-temporal resolution of zooplankton production
- A bottleneck for estimating zooplankton production

\[ P_{2nd} = \sum_{i=1}^{n} G_i \times B_i \]

Methodological Challenge

Natural cohort method

Assumptions:
- Same population to be sampled over time
- Highly synchronized spawning
- High frequency sampling
Egg production rate

Assumptions

- SEP not influenced by incubation
- Somatic growth of all preceding stages is equivalent to female SEP
- Female remains in steady-state

Courtesy of Ohman et al. 1998
Artificial Cohort Method (Kimmerer & McKinnon 1987)

- uses sieves of varying mesh sizes to separate the copepod community into different size classes (size-fractioned cohorts)
- also can be done by manually picking specific stages (cleaned and sorted cohorts)

Screens restrict sizes/stages into 3 classes more easily followed over time
Caveats of AC methods

Assumptions

- Close coupling between moulting and growth (Hart 1990, Peterson et al. 1991)
- Handing does not stimulate moulting, “moulting burst” (Miller et al. 1991)

Limitations

- No control over number and kinds of species
- Differential growth among stages and species
- Different developmental stage isolated for different species. Incubation times to be appropriate for species and stages of interest
Methodological considerations of AC

- Age structure within stages
  Ideally uniform age structure within stages assumed (Hirst et al. 2005). In practice growth often labeled by stage, not age

- Biomass increment of growth
  Direct measurement of biomass (Kimmerer et al. 2007), or using a length-weight relationship (Liu & Hopcroft 2006a&b,&07&08)

Liu & Hopcroft (2007)
### Applications of AC

By 2008, 18 studies, 14 regions, 31 species and 4 copepod guilds

Kimmerer et al. (2007)

<table>
<thead>
<tr>
<th>Species</th>
<th>Location</th>
<th>Temp. (°C)</th>
<th>Weight method</th>
<th>Growth rate (cm d⁻¹)</th>
<th>Incubation period (d)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acartia clauseni</em></td>
<td>Australia</td>
<td>11–12</td>
<td>Mean weight of stage</td>
<td>0.025–0.26</td>
<td>26–59</td>
<td>Kimmerer &amp; McKinnon (1987)</td>
</tr>
<tr>
<td>Centropages typicus</td>
<td>Skagerrak</td>
<td>15–17</td>
<td>Length-weight regression</td>
<td>0.24–0.77</td>
<td>24</td>
<td>Peterson et al. (1991)</td>
</tr>
<tr>
<td><em>Flemingeria parallela</em></td>
<td>Norway</td>
<td>18</td>
<td>Length-weight regression</td>
<td>0.00–0.32</td>
<td>1 sample (24 h)</td>
<td>Hernandez-Leon et al. (2006)</td>
</tr>
<tr>
<td><em>Pseudocalanus maximus</em></td>
<td>Canary Islands</td>
<td>20</td>
<td>Mean weight of stage</td>
<td>0.10–0.14</td>
<td>24</td>
<td>Clain et al. (2005)</td>
</tr>
<tr>
<td><em>Acartia longispina</em></td>
<td>Japan</td>
<td>28</td>
<td>Length-weight regression</td>
<td>0.25–1.43</td>
<td>120</td>
<td>Hopcroft &amp; Roff (1999)</td>
</tr>
<tr>
<td><em>Paracalanus parvus</em></td>
<td>Japan</td>
<td>6–16</td>
<td>Mean weight of stage</td>
<td>0.70–1.00</td>
<td>120</td>
<td>Hopcroft &amp; Roff (1998b)</td>
</tr>
<tr>
<td><em>Paracalanus aculeatus</em></td>
<td>Plymouth</td>
<td>15</td>
<td>Mean weight of stage</td>
<td>0.21–1.26</td>
<td>40</td>
<td>Shively et al. (1998)</td>
</tr>
<tr>
<td><em>Calanus helgolandicus</em></td>
<td>North Sea</td>
<td>17</td>
<td>Volume-weight relationship</td>
<td>&lt;0.01–0.23</td>
<td>24–26</td>
<td>Calbet et al. (2000)</td>
</tr>
<tr>
<td><em>Calanus finmarchicus</em></td>
<td>Georges Bank</td>
<td>17–18</td>
<td>Mean weight of stage</td>
<td>0.19–0.46</td>
<td>24</td>
<td>Peterson &amp; Hutchings (1988)</td>
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<tr>
<td><em>Oithona similis</em></td>
<td>France</td>
<td>20</td>
<td>Length-weight regression</td>
<td>0.00–0.14</td>
<td>72</td>
<td>Inoue &amp; Costello (1995)</td>
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<tr>
<td><em>Oithona similis</em></td>
<td>North Sea</td>
<td>21–23</td>
<td>Volume-weight relationship</td>
<td>C: −0.09 to 0.011</td>
<td>43</td>
<td>McKinney et al. (2001a)</td>
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<td><em>Oithona similis</em></td>
<td>Atlantic Ocean</td>
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<td>Volume-weight relationship</td>
<td>N: −0.07 to 0.26</td>
<td>43</td>
<td>McKinney et al. (2001a)</td>
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<td><em>Oithona similis</em></td>
<td>Great Barrier Reef</td>
<td>22–30</td>
<td>Volume-weight relationship</td>
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<td>McKinney et al. (2005)</td>
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<td><em>Oithona similis</em></td>
<td>Gulf of Alaska</td>
<td>2–9</td>
<td>Length-weight regression</td>
<td>0.01–0.28</td>
<td>120</td>
<td>Liu &amp; Hopcroft (2006a)</td>
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<td><em>Oithona similis</em></td>
<td>Gulf of Alaska</td>
<td>5–14</td>
<td>Length-weight regression</td>
<td>0.01–0.30</td>
<td>96 or 120</td>
<td>Liu &amp; Hopcroft (2006b)</td>
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<td>96 or 120</td>
<td>H. Liu &amp; R. R. Hopcroft (unpubl.)</td>
</tr>
</tbody>
</table>
Deployment of the AC experiments
Size-fractionated vs. manually picked cohorts

### Comparison of Two Methods

<table>
<thead>
<tr>
<th>Single-Stage Method</th>
<th>Screen-Filter Method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pros:</strong></td>
<td><strong>Pros:</strong></td>
</tr>
<tr>
<td>1: known development</td>
<td>1: routinely deployed</td>
</tr>
<tr>
<td>stages for given</td>
<td>at sea</td>
</tr>
<tr>
<td>species</td>
<td>2: simultaneously</td>
</tr>
<tr>
<td>2: exact stage-specific</td>
<td>applicable to whole</td>
</tr>
<tr>
<td>growth data available</td>
<td>copepod community</td>
</tr>
<tr>
<td><strong>Cons:</strong></td>
<td><strong>Cons:</strong></td>
</tr>
<tr>
<td>1: apt for few large</td>
<td>1: mixed development</td>
</tr>
<tr>
<td>species</td>
<td>stages</td>
</tr>
<tr>
<td>2: labor intensive and</td>
<td>2: exact stage-specific</td>
</tr>
<tr>
<td>requires suitable</td>
<td>growth data unavailable</td>
</tr>
<tr>
<td>working condition at sea</td>
<td></td>
</tr>
</tbody>
</table>

### Stage Error in Screen-Filter Data
Forcing numerical values calculated from mixed stages to represent the single stage to facilitate comparison to the single-stage method

*Photos Courtesy of Russ Hopcroft*
Size-fractionated vs. manually picked cohorts

Fig. 6. Relationship between growth rate of *Neocalanus flemingeri/plumchrus* and the body weight (µg C individual$^{-1}$) within early copepodite stages estimated by artificial-cohort and single-stage methods in the northern Gulf of Alaska.

Liu & Hopcroft (2006)
Mixed stages in size-fractionated cohorts

\[
\bar{C} = \sum_{i=1}^{5} \frac{(fc)_i}{N}
\]

C: stage (1,2,3,4,5)
f: stage frequency
N: total observations of target species at each mesh size

Liu et al. (2013)
Stage errors estimated not significantly different from zero

The stages labeled with the practical technique in the screen-filter method not statistically different from that identified by manually picking
Uncertainty for using the L-W equations

\[ y = a + bx \]

\[ a + bx^* \pm t_{n-2,\alpha} \sqrt{S^2_{a+bx^*}} \]

\[ S_{a+bx^*} = S_e \sqrt{\frac{1}{n} + \frac{(x^* - \bar{x})^2}{S_{xx}}} \]
Inferences of a prediction value $a + \beta x^*$ using the L-W equations

- The estimated standard deviation of the statistic $a + \beta x^*$ is
  \[ S_{a+\beta x^*} = S_e \sqrt{\frac{1}{n} + \frac{(x^* - \bar{x})^2}{S_{xx}}} \]

- When the assumptions are met, the probability distribution of is t-distribution with df=($n$-2)
  \[ t = \frac{a + bx^* - (\alpha + \beta x^*)}{S_{a+\beta x^*}} \]

- Confidence interval for $a + \beta x^*$ has form:
  \[ a + bx^* \pm t_{n-2,\alpha} S_{a+bx^*} \]
Current AC research in the USA

- Field AC work ongoing in the Bering Sea and Chukchi Sea on *Calanus marshallae* and *Pseudocalanus spp.* (Hopcroft)

- Modeling research on AC (Liu)

- Others
Recap

- Size-based AC method is mostly practical for measuring growth rates of zooplankton with caveats.
- Sized-based method can be a substitute of the manually picked methods for measuring stage-specific growth rates.
- A potential way to tackle the uncertainty using L-W relationship for measuring biomass.
- Methods of theoretically perfect and practically operational.
Acknowledgements
Thank You