Dominant zooplankton shift in the Strait of Georgia: An educated guess on the trophic implications and the probable biophysical context

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Study area: Strait of Georgia

Sampling locations

- Spring/summer, 1990 & 1991
- Monthly, 1997
Dominant species

(Re drawn from Harrison et al., 1983)
Objectives

• Trophic ecology of dominant zooplankton
  - Stomach contents

• Zooplankton community structure
  - Potential food - prey
Material & Methods

- Bongo net 202-µm mesh
- Chlorophyll a, and zooplankton biomass
- Daylight sampling 10 AM – 14 PM; 0 – 400 M depth
- Zooplankton taxonomy to lowest possible level
- Community composition and dominance analyzed by principal component analysis (PCA)
- Similarity analysis between stomach contents and prey
RESULTS

Zooplankton and Chlorophyll a from the Strait of Georgia during 1997

- Zooplankton biomass
- Chlorophyll a

mg / m³

Jan Feb Mar Apr May Jun Jul Ago Sep Oct Nov Dec
PCA Results: Dominant species in 1990 & 1991

MAY 29 – JUNE 6 1990 (Estuarine plume 34%)
Oithona spinirostris, Cyphocaris challengeri, Parathemisto pacifica,
Metridia okhotensis, Pseudocalanus minutus, Oithona similis,
Metridia pacifica, Oncaea borealis

APRIL 7 - 16 1991 (Estuarine plume 37%)
Pseudocalanus minutus, Euphausia pacifica, Neocalanus plumchrus,
Calanus marshallae, Cyphocaris challengeri, Metridia pacifica,
Eucalanus bungii, Oithona spinirostris

JUNE 11 – 14 1991 (Estuarine plume and Central Strait 39%)
Pseudocalanus minutus, Euphausia pacifica, Parathemisto pacifica,
Cyphocaris challengeri, Metridia pacifica, Paracalanus parvus,
Oithona similis, Acartia longiremis
PCA Results: Dominant species during 1997

Late spring – summer (54%)

*Cyphocaris challenger*, *Parathemisto pacifica*, *Metridia pacifica*, *Pseudocalanus minutus*, *Oithona similis*, *Conchoecia alata minor*

Fall – winter (9%)

*Parathemisto pacifica*, *Oncaea borealis*, *Oithona similis*, *Pseudocalanus minutus*, *Conchoecia spinirostris*, *Cyphocaris challenger*

Late winter – spring (5%)  

*Oithona similis*, *Pseudocalanus minutus*, *Metridia pacifica*, *Conchoecia spinirostris*, *Limacina helicina*, *Parathemisto pacifica*, *Cyphocaris challenger*. 
### Peak abundance of main species in the Strait of Georgia

<table>
<thead>
<tr>
<th>Species and size in mm</th>
<th>season</th>
<th>author</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Neocalanus plumchrus</em>, 5</td>
<td>Spring</td>
<td>Fulton, 1973</td>
</tr>
<tr>
<td><em>Calanus marsallae</em>, 4</td>
<td>Summer</td>
<td>Stephens et al., 1969</td>
</tr>
<tr>
<td><em>Calanus pacificus</em>, 3</td>
<td>Summer</td>
<td>Stephens et al., 1969</td>
</tr>
<tr>
<td><em>Metridia pacifica</em>, 3</td>
<td>Fall</td>
<td>Stephens et al., 1969</td>
</tr>
<tr>
<td><em>Pseudocalanus minutus</em>, 1</td>
<td>Spring &amp; fall</td>
<td>Harrison et al., 1983</td>
</tr>
<tr>
<td><em>Oithona similis</em>, 0.7</td>
<td>Late fall &amp; winter</td>
<td>(LeBrasseur, 1965)</td>
</tr>
<tr>
<td><em>Oithona spinirostris</em>, 1.4</td>
<td>Fall</td>
<td>Haro, 2001</td>
</tr>
<tr>
<td><em>Oncaea boralis</em>, 0.7</td>
<td>Spring &amp; fall</td>
<td>Haro, 2001</td>
</tr>
<tr>
<td><em>Euphausia pacifica</em>, 25</td>
<td>Fall &amp; winter</td>
<td>Harrison et al., 1983</td>
</tr>
<tr>
<td><em>Parathemisto pacifica</em>, 16</td>
<td>Summer &amp; Fall</td>
<td>Haro 2001</td>
</tr>
</tbody>
</table>
Stomach contents
Parathemisto pacifica

Pseudocalanus minutus
Conchoecia spinostris
Copepods
Stomach contents

*Cyphocaris challenger*i

*Oithona sp. male*
Number of prey items (numerator) identified per number of stomachs analyzed (denominator) for samples collected during three years from the Strait of Georgia.

<table>
<thead>
<tr>
<th>Year</th>
<th>1990</th>
<th>1991</th>
<th>1997</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parathemisto pacifica</td>
<td>48 / 116</td>
<td>47 / 114</td>
<td>45 / 77</td>
<td>140 / 307</td>
</tr>
<tr>
<td>Cyphocaris challengeri</td>
<td>40 / 99</td>
<td>38 / 79</td>
<td>38 / 80</td>
<td>116 / 258</td>
</tr>
<tr>
<td>Total</td>
<td>88 / 215</td>
<td>85 / 193</td>
<td>83 / 157</td>
<td>256 / 565</td>
</tr>
</tbody>
</table>
# Stomach contents

**Parathemisto Pacifica**

<table>
<thead>
<tr>
<th>Copepods 44%</th>
<th>Amphipods 31%</th>
<th>Cladocerans 7%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corycaeus anglicus</td>
<td>Parathemisto pacifica</td>
<td>cladocerans</td>
</tr>
<tr>
<td>Metridia pacifica</td>
<td>Cyphocaris challengeri</td>
<td></td>
</tr>
<tr>
<td>Oncaea borealis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paracalanus parvus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pseudocalanus minutus</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Cyphocaris challengeri**

<table>
<thead>
<tr>
<th>Copepods 32%</th>
<th>Amphipods 32%</th>
<th>Bryozoans 8%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corycaeus anglicus</td>
<td>Parathemisto pacifica</td>
<td>Cyphonutes larva</td>
</tr>
<tr>
<td>Oithona similis</td>
<td>Cyphocaris challengeri</td>
<td></td>
</tr>
<tr>
<td>Paracalanus parvus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pseudocalanus minutus</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Diet of main zooplankton species

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<thead>
<tr>
<th>Species and size in mm</th>
<th>Food</th>
<th>Author</th>
</tr>
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<tbody>
<tr>
<td><em>Calanus marsallae</em>, 4</td>
<td>Hervibore</td>
<td>Parsons et al., 1969</td>
</tr>
<tr>
<td><em>Calanus pacificus</em>, 3</td>
<td>Omnivore</td>
<td>Raymont 1983</td>
</tr>
<tr>
<td><em>Metridia pacifica</em>, 3</td>
<td>Omnivore-fac.pred</td>
<td>Corkett &amp; McLaren´s 1978</td>
</tr>
<tr>
<td><em>Pseudocalanus minutus</em>, 1</td>
<td>Nannoplankton</td>
<td>Parsons &amp; Lalli 1988</td>
</tr>
<tr>
<td><em>Oithona similis</em>, 0.7</td>
<td>Nannoplankton</td>
<td>Parsons &amp; Lalli 1988</td>
</tr>
<tr>
<td><em>Oithona spinirostris</em>, 1.4</td>
<td>Nannoplankton</td>
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<td>Parsons &amp; Lalli 1988</td>
</tr>
<tr>
<td><em>Euphausia pacifica</em>, 25</td>
<td>Omnivore</td>
<td>Lasker 1966</td>
</tr>
<tr>
<td><em>Parathemisto pacifica</em>, 15</td>
<td>Microphage-carnivore</td>
<td>Haro, 2004</td>
</tr>
<tr>
<td><em>Cyphocaris challenger</em>, 16</td>
<td>Carnivore</td>
<td>Haro, 2004</td>
</tr>
</tbody>
</table>
## Herring and juvenile salmon diet in the Strait

<table>
<thead>
<tr>
<th></th>
<th>Food</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pink Sockeye</td>
<td><em>Neocalanus plumchrus</em>, <em>Parathemisto pacifica</em>&lt;br&gt;<em>Parathemisto pacifica</em>&lt;br&gt;Herring&lt;br&gt;Herring&lt;br&gt;Herring</td>
<td>LeBrasseur et al., 1969&lt;br&gt;Beacham, 1986&lt;br&gt;Parker and Kask, 1972a,b&lt;br&gt;Parker and Kask, 1972a,b&lt;br&gt;Parker and Kask, 1972a,b</td>
</tr>
<tr>
<td>Chinook, Coho</td>
<td><em>Neocalanus plumchrus</em>, <em>Parathemisto pacifica</em>&lt;br&gt;<em>Parathemisto pacifica</em>&lt;br&gt;Herring&lt;br&gt;Herring&lt;br&gt;Herring</td>
<td>LeBrasseur et al., 1969&lt;br&gt;Beacham, 1986&lt;br&gt;Parker and Kask, 1972a,b&lt;br&gt;Parker and Kask, 1972a,b&lt;br&gt;Parker and Kask, 1972a,b</td>
</tr>
<tr>
<td>Steelhead</td>
<td><em>Neocalanus plumchrus</em>, <em>Parathemisto pacifica</em>&lt;br&gt;<em>Parathemisto pacifica</em>&lt;br&gt;Herring&lt;br&gt;Herring&lt;br&gt;Herring</td>
<td>LeBrasseur et al., 1969&lt;br&gt;Beacham, 1986&lt;br&gt;Parker and Kask, 1972a,b&lt;br&gt;Parker and Kask, 1972a,b&lt;br&gt;Parker and Kask, 1972a,b</td>
</tr>
<tr>
<td>Herring, juv</td>
<td><em>Pseudocalanus minutus</em>&lt;br&gt;Copepods and&lt;br&gt;<em>Parathemisto pacifica</em></td>
<td>Raymont, 1983&lt;br&gt;Raymont, 1983</td>
</tr>
<tr>
<td>Herring, adult</td>
<td><em>Pseudocalanus minutus</em>&lt;br&gt;Copepods and&lt;br&gt;<em>Parathemisto pacifica</em></td>
<td>Raymont, 1983&lt;br&gt;Raymont, 1983</td>
</tr>
</tbody>
</table>
Discussion

- Typical dominant species were scarce during 1997, therefore a change in functional groups occurred
- Change in food web structure and trophic pathways
- Different nutritional value and size of zooplankton available as food for consumers
Size of main functional groups

Neocalanus plumchrus 5 mm

Oncaea borealis 0.7 mm

Oithona similis 0.7 mm

Pseudocalanus minutus 1.5 mm

Parathemisto pacifica 9 mm
Established spring trophic pathway in the Strait of Georgia

- Neocalanus plumchrus
- Calanus marshallae
- Centric diatoms
- Salmon
- Herring
- Larval fish
- Microzooplankton
- Nanoflagellates
- Bacteria

(Harrison et al., 1983)
Proposed spring trophic pathway in the Strait of Georgia during 1997

- **Salmon**
- **Herring**
  - **Parathemisto pacifica**
  - **Neocalanus plumchrus**
  - **Calanus marshallae**

- **Larval fish, herring larvae**
  - **Pseudocalanus minutus**, **Paracalanus parvis**, **Corycaeus anglicus**, **Metridia pacifica**, **Oncaea borealis**

- **Microzooplankton**
- **Nanoflagellates**
- **Bacteria**

- **Centric diatoms**
Established autumn trophic pathway in the Strait of Georgia

Euphausia pacifica

Centric diatoms
Dinoflagellates

Microzooplankton

Nanoflagellates
Bacteria

(Harrison et al., 1983)
Proposed autumn trophic pathway in the Strait of Georgia during 1997

- Euphausia pacifica
- Cyphocaris challenger
- Corycaeus anglicus, Oithona similis, Pseudocalanus minutus, Paracalanus parvus
- Microzooplankton
- Nanoflagellates
- Bacteria
- Centric diatoms
- Dinoflagellates
Earlier phytoplankton bloom coincided with low Fraser River flow.

Change in Timing of One-third of Fraser River Annual Flow, 1912-1998

SOURCE: Data from the Water Survey of Canada, Environment Canada. Analysis by John Morrison, Institute of Ocean Sciences, 2001, for Ministry of Water, Land and Air Protection. NOTES: All values are statistically significant. ($R^2 = 0.1216$, $p = 0.001$).
Properties of climate that have changed during the 20th century, affecting marine, freshwater, and terrestrial ecosystems in British Columbia.

- Average annual temperature increased by 0.6°C on the coast, 1.1°C in the interior, and 1.7°C in northern BC
- Night-time temperatures higher across most of BC in spring and summer
- Precipitation increased in southern BC by 2 to 4% per decade.
- Lakes and rivers become free of ice earlier in the spring
- Sea surface temperatures increased by 0.9°C to 1.8°C along the BC coast
- Two large BC glaciers retreated by more than a kilometre each
- The Fraser River discharges more of its total annual flow earlier in the year.
- Water in the Fraser River is warmer in summer

http://www.gov.bc.ca/wlap
Consequences of changes in climate in the estuarine environment

• Changes in freshwater inflow, air temperatures, and precipitation patterns affect water residence time, nutrient delivery, dilution, vertical stratification, which control phytoplankton growth rates

• Decreased freshwater runoff will increase estuarine water residence time.
• Whereas increased runoff will decrease residence time
• Increased air temperature may also lead to earlier snowmelt and the resulting peak in freshwater inflow.
  – Summer flows may be reduced as a result of greater evapotranspiration.
  – Therefore increase in estuarine salinity modifies stratification and mixing, thus influencing biotic distributions, life histories, and biogeochemistry

Conclusions

– Earlier phytoplankton bloom observed most probably caused by combined effect of warm water, premature entrainment and/or wind events [River flow during 1997 was lower, earlier and warmer (www.gov.bc.ca/wlap)]

– Mismatch of *N. plumchrus* with spring bloom

– Altered feeding window for migrating juvenile salmon, and other fish

– Also change in zooplankton community structure, and different nutritional value of zooplankton for zooplanktivores

– Change in attributes of functional groups (number, size, schedule, biochemical composition) that link to upper levels as food, therefore:

– Trophic pathways not as previously reported
Therefore:
consequences of trophic changes for consumer fish

- Smaller body size
- Lower survival
- Decreased adult fecundity
- Fishery and economics
Areas of research that need further studies or development

- Microzooplankton
- Bioenergetic and trophodynamic modelling of key species
- Field and modelling analysis combined to explore plankton dynamics and its propagating effects to upper trophic levels
• Beacham, T. D., 1986. Type, quantity, and size of food of pacific salmon (*Oncorhynchus*) in the Strait of Juan de Fuca, British Columbia. Fish. Bull. 84: 77-89.


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(www. VirtualTourist.com)