Comparisons among North Pacific Zooplankton Time Series

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Table of Contents:

• Why long time series?
  Why zooplankton?
• Variables & methods
• North Pacific zooplankton time series:
  (Where & when)
• Results from “within-data-set” analyses
• Results from “comparisons”
Why do we need long time series?

“The world today just isn’t like it used to be!!”

- Former trademark opinion of ‘grumpy old men’
- Now a fair summary of scientific knowledge about environmental constancy
- Need an ongoing history of observations to characterize past changes and recognize future changes (sorry, but models can’t do it alone)
Why zooplankton?

- Key link between “physics” and “fish”
- Zooplankton sampling methods are (relatively):
  - simple,
  - intercomparable,
  - fishery-independent
- Time scale of population response (~1 year or less) gives very good tracking of climate forcing at interannual-decadal time scales
- Long zooplankton time series are now available from several different parts of the ocean
- Recent improvements in tools for data analysis & data exchange/management
Why compare zooplankton time series?

- Can improve statistics of “short” autocorrelated time series by ensemble averaging
- Apply/compare the same suite of analysis methods
- Explore type & sequence of alternative “regimes”
- Look for evidence of global “synchrony” of zooplankton regime changes (do zooplankton resemble fish)??
Modes of zooplankton variability

• “How much?” = total biomass or biovolume
• “What kinds?” = partitioning of total based on species composition (allows broader interpretation of cause & consequence)
• “Timing window?” = seasonal phenology, (allows interpretation of match-mismatch) usually indexed as date of annual peak
• “Fat & happy?” = body size & condition indices
Interannual zooplankton variability is BIG!
But to see it clearly, need to isolate it from three other 'big' components of variance

(1) Local seasonal cycle

(2) Persistent 'regional' patchiness

(3) Transient 'small-scale' patchiness
Zooplankton sampling & analysis strategy: Separate components of total variance at different spatial and temporal scales

<table>
<thead>
<tr>
<th>Source &amp; scale of variability</th>
<th>How dealt with</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unresolved small-scale patchiness plus sampling error</td>
<td>Minimized by averaging of ‘replicates’ at all levels</td>
</tr>
<tr>
<td>Persistent mesoscale spatial structure</td>
<td>Stratification into ‘regions’ based on proximity, statistical similarity, &amp;/or oceanographic processes</td>
</tr>
<tr>
<td>Annual seasonal cycle (‘Climatology’)</td>
<td>Block averaging within seasons and across years.</td>
</tr>
<tr>
<td>Interannual variability</td>
<td>WHAT’S LEFT: Anomalies from climatology averaged within years and regions.</td>
</tr>
</tbody>
</table>
Where are the North Pacific zooplankton time series??

Updated from PICES Scientific Report #18 (2001)
Many/most share the following traits:

- Densest coverage along continental margins
- Sampling gear fairly basic (OK!!)
- Best for mesozooplankton (~1mm - 1 cm) (smaller, larger, & fragile taxa under-sampled).
- Sampling interval monthly-to-annual (varies with distance to home port)
Historical review by Region:

1. Subtropical Oceanic
Oceanic Subtropical N. Pacific

- Huge and mostly under-sampled area, originally thought “stable & monotonous”
- Satellite & *in situ* time series are altering this view:

Shifting chlorophyll gradients: (Polovina et al. 2006)

HOTS zooplankton: (Sheridan & Landry 2004)
Historical review by Region:
2. Subarctic Oceanic

CPR

‘Oshoro Maru’

StnP / LineP
Oceanic Subarctic Pacific

- 50+ years of observations
- Multiple programs in various years and locations
Station P (50N 145W)  
"Weathership" time series

- Oldest detailed ‘open-ocean’ time series in the Pacific
- Very frequent vertical net tows (0-150m) from 1956-1981, processed for wet weight biomass + (rarely) for taxonomy
- Electronic archive (Waddell & McKinnell 1995), sampling gear re-calibrated during GLOBEC Canada (McKinnell & Mackas 2003)
- No remaining sample archive (discarded due to H&S concerns)
“Oshoro Maru” time series: 1953-present

- Annual summer cruises by Hokkaido University training ships (Oshoro Maru & Hokusei Maru)
Post 1981: Stn P/LineP

- Intensive field programs at Stn P in:
  - 1984, 1987 & 1988 (SUPER);
  - 1996 & 1997 (CJGOFS);
  - 2002 (SERIES)
- Annual Line P cruises (usually 3/year)
1997 and since 2000: North Pacific CPR Survey (S. Batten)

Fig. 1. The abundance of mesozooplankton (mean number of organisms per sample) for 1° latitude bands. All transects are plotted on the same scale. There was no sampling in the central section in June 00, the northern section of August 01, and the southern section of September 01.

(data in SAHFORS archive, some at IOS)
What have we learned from the Subarctic Pacific zooplankton data?

- Community composition
- Life history strategies
- Variability of total biomass
- Variability of individual size
- Variability of life cycle timing
Subarctic Pacific zooplankton biomass is dominated by large copepods with strongly seasonal life cycles.
‘Regime Shifts’ meet Zooplankton: Station P, Oshoro Maru, & NorPac data show 2-3x interdecadal variability of total zooplankton biomass.

Alaska Gyre - Brodeur & Ware (1992)
Strong biomass seasonality is related to Neocalanus life cycle

- “Dormant” much of year at >400m
- Onset of dormancy is locally ~synchronous but varies with latitude and proximity to coast
- Also large interannual timing fluctuations: complicates sampling but also a BIG ecological signal
Neocalanus timing variability is correlated with mixed layer temperature during the spring growing season.

$\Delta T = 6^\circ C$
Historical review by Region:

3. Western Margin

Korean Coastal Waters

Japan/East Sea (various)

Sakhalin/Okhotsk (Russia)

Kuroshio/Oyahi Project ODATE

‘Oshoro Maru’

CPR
Project ODATE: zooplankton in the Oyashio, Transition & Kuroshio areas

• Time series predates Stn P and CalCOFI
• Originally mostly biomass data
• Sample archive is intact & now being reanalyzed for many variables

(from K. Odate, 1994)
Example: Copepod size variability in Oyashio

- *Neocalanus* spp. all covary, (small in 1970s)

- Individual species size also covaried with population biomass, and with [PO$_4$]

Tadokoro et al. 2005
Korean coastal regions
(25+ years, 3 very distinct seas)

At decadal time scale, all 3 regions and several taxa share similar timing of highs and lows

Rebstock and Kang, 2003
Historical review by Region:
4. Eastern Margin
Multiple time scales !!

- Trend (~5-8x decline)
- Decadal ‘regimes’ (~5x fluctuation)
- 1-2 year El Niño events (~5x decline)

Strong alongshore coherence

CalCOFI
55+ years of the California Current (longest EBC time series)

M. Ohman, updated from Laveniegos & Ohman 2003
Species-level responses to “regime shifts” can be very strong (20-100x)

Results (to follow) from the Pacific Northwest are very similar
Main results:

- Moderate biomass anomalies
- Bigger species composition anomalies
- Many environmental correlates
- Strong alongshore spatial autocorrelation (to 1000 km separation)
Anomalies of total biomass: N to S

Alongshore similarity:
• HIGH 1970s-early 80s (followed by)
• LOW in 1990s (followed by)
• Brief upswing ~1999-2003 (followed by)
• LOW 2004-2005

Range of biomass variation decreases with latitude:
• ~8x off Southern Calif.
• ~3x off Oregon
• ~2x off Vancouver Island

Mackas, Peterson, Ohman & Laveniagos, 2006
Anomalies of community composition

Off Canada:
~2x larger than anomalies of total biomass

Strongly correlated
• Among adjoining regions (alongshore scale ~1000 km)
• Within “species groups” sharing zoogeography & habitat preferences
Species groups (and individual taxa) are correlated with multiple environmental indices, and vice versa

<table>
<thead>
<tr>
<th>Environmental index</th>
<th>Euphausiids</th>
<th>Boreal copepods</th>
<th>Southern copepods</th>
<th>Subarctic copepods</th>
<th>Sagitta spp.</th>
<th>Eukrohnia</th>
<th>Jellies</th>
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<tbody>
<tr>
<td><strong>Local Currents:</strong></td>
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<td>Alongshore - 35m</td>
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<td>-0.5</td>
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<td>Alongshore - 100m</td>
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<td>0.6</td>
<td>0.6</td>
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<tr>
<td>Cross-shore - 35m</td>
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<td>-0.8</td>
<td>-0.6</td>
<td>0.4</td>
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<tr>
<td>Cross-shore - 100m</td>
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<td><strong>Climate indices:</strong></td>
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<td>0.6</td>
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<td>SOI</td>
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<td>0.6</td>
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<td>NOIx</td>
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<td>NPI</td>
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<td>PDO</td>
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<td>Bakun anom. (winter)</td>
<td></td>
<td>-0.6</td>
<td>-0.5</td>
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<tr>
<td>Winter shear index</td>
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<tr>
<td>Bakun anom. (summer)</td>
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<tr>
<td>Summer shear index</td>
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<td><strong>Temperature:</strong></td>
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<td>Winter 5m</td>
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<td>0.9</td>
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<tr>
<td>Summer 5m</td>
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<tr>
<td>Winter 75m</td>
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<td>-0.7</td>
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<td>Summer 75m</td>
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<td>0.6</td>
<td>-0.7</td>
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<tr>
<td>Amphitrite summer</td>
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<td>-0.6</td>
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<tr>
<td><strong>Salinity:</strong></td>
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<td></td>
<td>0.7</td>
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<tr>
<td>Winter 5m</td>
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<td></td>
<td>0.7</td>
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<tr>
<td>Summer 5m</td>
<td></td>
<td>0.5</td>
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<td>-0.6</td>
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<tr>
<td>Summer 75m</td>
<td></td>
<td></td>
<td>-0.5</td>
<td>-0.6</td>
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</tr>
</tbody>
</table>

Shown: product moment; shading indicates most useful predictors from stepwise regression
Anomalies of species composition: N to S

‘Resident’ & ‘Northern’ species do well when:
- $T(°C)$ cool,
- stratification weak,
- upwelling strong, &
- total biomass high

‘Southern’ species increase when
- $T(°C)$ warm,
- stratification strong,
- poleward flow,
- upwelling weak, &
- total biomass low

Mackas 2006 & PICES 2004, (based on data from McGowan, Rebstock, Ohman & Lavaniegos, Mackas, Peterson, Zamon)
Comparison of zooplankton time series with ‘climate’ & ‘predator’ time series

Can we get from here:

To here:

To here:
Short answer: YES

- EVERYTHING covaries in the NE Pacific

**BUT**

- Zooplankton and “fish” share amplification of low-frequency physical variability & rejection of high-frequency “noise”

- Zooplankton reveal their story sooner than “fish”

(Watch for low-frequency synchrony in the following)
Upper-ocean Temperature (& proxy for much else)

Top: Global (trend + fluctuations)

Middle: Regional (~same trend + bigger fluctuations)

Bottom pair: N Pacific EOFs of detrended SST (trend discarded, fluctuations partitioned based on spatial covariance)

Zooplankton anomalies of timing & composition
Indices of “Predator success”

- Coho salmon survival & growth
- Sablefish recruitment
- Seabird reproduction (planktivore & piscivore)
Strong shared message: PCA of SST, zooplankton & ‘predator’ correlations

- Lead EOF (56% of variance) corresponds qualitatively to a “cool & productive” vs. “warm & unproductive” gradient
- “Biological” variables all weight/respond more strongly than all SST indices

Performance:
- Average pairwise $|r|$ among variables = 0.48
- Average $|r|$ with PC1=0.72
- $r$ vs. reconstructed time series 0.8-0.95
The next step: SCOR WG125
“Global Comparison of Zooplankton Time Series”

- Formed in 2005
- http://scor.e-plankton.net/
- Develop a suite of analysis methods, and apply to available “long zooplankton time series”
- Quantify amplitudes, time scales, and ‘synchrony’
Regional time series (so far)
Winter Pacific Decadal Oscillation (PDO)

CaCOFI copepods
BC & Oregon copepods
Kuroshio copepods
Korea zooplankton
*Neocalanus* peak timing (NE Pacific)
North Sea plankton & cod
NE Atlantic plankton
NW Atlantic copepods

Winter North Atlantic Oscillation (NAO)

Perry et al. 04
My own very preliminary “synthesis” of WG125 (will evolve):

1. Scale of zooplankton spatial correlation (distance over which a similar ‘change’ occurs at a similar time) is proportional to event duration
2. For 5-20 year time scale the correlation length is ~1000 km
3. ‘Synchrony’ scale (‘change’ of differing variables, but similar duration and onset timing) may be trans Pacific, but probably not global
Zooplankton (and fish) have a stronger response to low frequency variation. WHY?

<table>
<thead>
<tr>
<th>Mode of variation</th>
<th>Physics (e.g. SST)</th>
<th>Zooplankton (e.g. species abundance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seasonal cycle</td>
<td>(~ 10^\circ\text{C})</td>
<td>(~ \text{factor of 3-10})</td>
</tr>
<tr>
<td>Latitudinal gradient</td>
<td>(~ 20^\circ\text{C})</td>
<td>(~ \text{factor of 5})</td>
</tr>
<tr>
<td>ENSO anomaly</td>
<td>(~ 1-3^\circ\text{C})</td>
<td>(~ \text{factor of 5})</td>
</tr>
<tr>
<td>Decadal anomaly</td>
<td>(~ 1-3^\circ\text{C})</td>
<td>(~ \text{factor of 5-10})</td>
</tr>
<tr>
<td>Climate trend</td>
<td>(~ 4-5^\circ\text{C})??</td>
<td>(\infty)? (extinction?)</td>
</tr>
</tbody>
</table>

‘Physics’ & ‘Zooplankton’ share time scales of variability but amplitudes differ!!
Why small interannual changes in physics produce large changes in ecosystem structure

- Steady or predictably-varying conditions (mean, tidal, seasonal = the ‘first order’ physics) are already ‘discounted’ by prior evolutionary adaptation
- Differential advantage is ability to respond to ‘unpredictable’ change (‘second order' physics: aperiodic & weak precursor signals)
- We need to understand more about what cues make a change ‘predictable’, and also how and when cues are ‘misinformation’
Spare slides to answer questions
**Within-species body size variation**

- Interannual: 10-20% in length, ~30-70% in weight
- Correlated among species and across latitudes
- Overlaid on persistent large-scale spatial gradient

![Graph showing mean prosome length for N. plumchrus, N. plumchrus, and N. flemingeri females over years 1978 to 1982.](image)

**Kobari & Ikeda (2001)**

Along 180°
**ODATE workup is nearing completion for Oyashio samples, shows:**

- **2-5x changes in biomass**
- **Changes in diversity & copepod abundance**
- **Changes in ranking of dominant species**

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**H. Sugisaki 2005**
Seasonal timing variability in Oyashio waters:

- Differing responses of ‘spring’ vs. ‘summer’ zooplankton species
- Best indexed by seasonal (not annual) temperature anomalies
- Seasonal peaks of individual species narrower than in eastern subarctic?
Average Seasonal Cycles ⇒ Anomalies

Within cruise spatial averaging of regional “replicates”

- Time averaging across years within regions to produce *seasonal climatology for each species* (summarized at right -note differences in species dominance and timing between adjoining regions)
- Produce time series of *annual anomalies* for total biomass and for individual species (and species groups) by within-year averaging of:
  \[
  \log(\text{observed}) - \log(\text{multiyear average for that season and region})
  \]
- Annual anomaly of +1.0 means 10x more than long term average
- NO smoothing of anomalies across years
Zooplankton Sampling:
1) Off Vancouver Island

Vertically-integrated bongo net tows (black net, 0.23 mm mesh)

Sample 3-6 time periods each year
- since 1979 off southern Vancouver Island (red dots are standardized grid used since 1985)
- since early 90s off central and northern Vancouver Island (blue)

Spatial stratification (areas defined by orange lines) based on bathymetry and current patterns

Identify and count zooplankton to species and stage, multiply by individual size and sum to estimate dryweight biomass m$^{-2}$ for each species at each site
Zooplankton Sampling: 2) Off Oregon

Five USGLOBEC LTOP lines (●) sampled 4-5 times per year since 1997:
- vertically-integrated bongo net tows.
- CTD and water chemistry

For the inner Newport Line ( ), a longer and higher resolution zooplankton time series:
  - vertical net hauls with a mix of net types
  - sampling biweekly to monthly spring-autumn
Anomaly time series also very similar between BC and Oregon

- (Mackas, Peterson & Zamon, 2004)
- $r = 0.3 – 0.95$
- Amplitude of anomalies declines from south to north
Example:
Example: Big fluctuation in euphausiids (up at end of 80s, down in mid-late 90s):
_Euphausia pacifica, Thysanoessa spinifera_
Standardization & intercalibration of sampling methods

Any method change risks loss of time continuity (a serious concern)

Net intercalibrations are feasible (e.g. McKinnell & Mackas 2003):
- Mesh size, flow metering, tow depth all matter, **but**
- Modern nets (if flow-metered) perform similarly
- Correction factors often small compared to real signal