Bill Peterson’s warm-water/cold-water copepod story…

A working mechanistic hypothesis: source waters...

**Cool Phase**

Transport of boreal coastal copepods into NCC from Gulf of Alaska

**Warm Phase**

Transport of subtropical copepods into NCC from Transition Zone offshore

Verified in Keister et al. 2011 GCB and Bi et al. 2011 GRL
The climate-science community’s interest in interannual to interdecadal variability has been motivated by fisheries research in the Pacific.

**NPGO** on the salinity and nutrient distributions, its differing impacts on northern and southern portions of the Northeast Pacific, and its influence on ENSO development (Di Lorenzo)

**ENSO**
and its influence on anchovy and sardine of eastern boundary currents (noted since the 1890s; Kawasaki; Lluch-Belda; Schwartzlose)

**PDO**
(and its associated processes) on Pacific salmon stocks of North America (Beamish; Brown; Francis; Mantua; Hare; Hayward; Polovina)

**El Niño Southern Oscillation**

**Pacific Decadal Oscillation**
The Pacific Decadal Oscillation (PDO) describes the leading principal component of detrended SST anomalies in the North Pacific.

Temporal changes in this pattern are associated with strong transitions in the marine ecosystem (as popularized by Mantua et al., 1997).
Variability in copepod assemblages with PDO

Newport Hydrographic Line
- Hydrography, zooplankton, and ichthyoplankton sampling
- Biweekly intervals, 1996-present
- Coast to about 300 km offshore
Variability in copepod assemblages with PDO

<table>
<thead>
<tr>
<th>Cold-water “northern” taxa</th>
<th>Warm-water “southern” taxa</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pseudocalanus mimus</em>, <em>Calanus marshallae</em>, <em>Acartia longiremis</em></td>
<td><em>Clausocalanus</em> spp.*, <em>Ctenocalanus vanus</em>, <em>Paracalanus parvus</em>, <em>Mesocalanus tenuicornis</em>, <em>Calocalanus styliremis</em></td>
</tr>
</tbody>
</table>

Newport Hydrographic Line

- Hydrography, zooplankton, and ichthyoplankton sampling
- Biweekly intervals, 1996-present
- Coast to about 300 km offshore
## Variability in copepod assemblages with PDO

<table>
<thead>
<tr>
<th>Cold-water “northern” taxa</th>
<th>Warm-water “southern” taxa</th>
</tr>
</thead>
</table>
| *Pseudocalanus mimus,*  
*Calanus marshallae,*  
*Acartia longiremis* | *Clausocalanus* spp.,  
*Ctenocalanus vanus,*  
*Paracalanus parvus,*  
*Mesocalanus tenuicornis,*  
*Calocalanus styliremis* |

Data courtesy of Bill Peterson’s lab at NOAA NWFSC
Variability in copepod assemblages with PDO

data courtesy of Bill Peterson’s lab at NOAA NWFSC
Salmon returns are positively associated with biomass anomalies of cold-water copepods.

While this sequence of relationships is promising, the relationship between climate processes and the zooplankton remains vague.

data courtesy of Bill Peterson’s lab at NOAA NWFSC
Where does that leave us?

But, there need not be a single and/or a temporally invariant process that mediates the relationship between climate and ecological components of the system.
Where does that leave us?

1. Large-scale climate conditions → Population characteristics
2. Large-scale climate property → Influential ecosystem conditions → Population characteristics
3. Large-scale climate property (time variable?) → Influential ecosystem conditions (time variable?) → Population characteristics
We scientists have pursued a number of strategies for describing variability in marine fisheries and ecosystems (with varied levels of success).

**Strategies for understanding variability in fish populations**

<table>
<thead>
<tr>
<th>Manage commercial and recreational fisheries</th>
<th>Use a climate index as a proxy for marine survival</th>
<th>Understand bioenergetics and food-web processes</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Wishful thinking, but it can’t hurt!</em></td>
<td><em>Aha! It’s the ________!</em> (e.g. PDO)</td>
<td>It’s complicated…</td>
</tr>
<tr>
<td>Variability induced by climate processes is</td>
<td>Dynamics of the physical-biological interactions remain vague.</td>
<td>…but careful investigation of specific conditions can perform better than regional climate indices.</td>
</tr>
<tr>
<td>apparently quite influential.</td>
<td>Seems to work (some of the time).</td>
<td></td>
</tr>
</tbody>
</table>
Strategies for understanding variability in fish populations

We scientists have pursued a number of strategies for describing variability in marine fisheries and ecosystems (with varied levels of success).

<table>
<thead>
<tr>
<th>Manage commercial and recreational fisheries</th>
<th>Use a climate index as a proxy for marine survival</th>
<th>Understand bioenergetics and food-web processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wishful thinking, but it can’t hurt!</td>
<td>Aha! It’s the ________! (e.g. PDO)</td>
<td>It’s complicated…</td>
</tr>
<tr>
<td>Variability induced by climate processes is apparently quite influential.</td>
<td>Dynamics of the physical-biological interactions remain vague.</td>
<td>…but careful investigation of specific conditions can perform better than regional climate indices.</td>
</tr>
</tbody>
</table>

Can we continue to use these empirical, correlative relationships to guide us to real understanding?
What is attractive about an indicator based on the North Pacific Current?

Positioning and intensity of the NPC has received relatively little attention and is perhaps less vague in its relation to ecosystem processes.
What is attractive about an indicator based on the North Pacific Current?

Additionally, a poleward shift in the location of the NPC is one of the more robust projections of IPCC-style global climate models.
Why might we care about the NPC bifurcation?

Historical correlations suggest that NPC location is ecologically relevant:

Poleward bifurcation more zooplankton

The mechanism of this relationship is not clear. But the suggested reason is:

When the bifurcation is further north, there is an increased transport of “enriched” subarctic waters to the south.

Chelton and Davis (1982); Chelton et al., (1982).

Wickett (1967).
Why might we care about the NPC bifurcation?

Historical correlations suggest that NPC location is ecologically relevant:


Summary – A *poleward* shift in the bifurcation (or in the latitude of westerly winds) tends to increase zooplankton volume off California.
Why might we care about the NPC bifurcation?

Historical correlations suggest that NPC location is ecologically relevant:


2011 – *Geophysical Research Letters*. Does positioning of the North Pacific Current affect downstream ecosystem productivity?

William J. Sydeman, Sarah Ann Thompson, John C. Field, William T. Peterson, Ronald W. Tanasichuk, Howard J. Freeland, Steven J. Bograd, Ryan R. Rykaczewski
**Table 1. Biological Data Sets, Showing Sampling Location, Interval, and Length of Each Time Series**

<table>
<thead>
<tr>
<th>Biological Data Set</th>
<th>Location</th>
<th>Sampling Interval</th>
<th>Time Series Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern Copepod Abundance</td>
<td>Central Oregon</td>
<td>Biweekly</td>
<td>1996–2009</td>
</tr>
<tr>
<td>Copepod Species Richness</td>
<td>Central Oregon</td>
<td>Biweekly</td>
<td>1996–2009</td>
</tr>
<tr>
<td><em>E. pacifica</em> Abundance</td>
<td>Northern California</td>
<td>Annual</td>
<td>2002–2007</td>
</tr>
<tr>
<td>Juvenile Rockfish Abundance</td>
<td>Northern California</td>
<td>Annual</td>
<td>1983–2007</td>
</tr>
<tr>
<td>Auklet Productivity</td>
<td>Northern California</td>
<td>Annual</td>
<td>1971–2007</td>
</tr>
<tr>
<td>Auklet Phenology</td>
<td>Northern California</td>
<td>Annual</td>
<td>1972–2006</td>
</tr>
<tr>
<td>Murre Productivity</td>
<td>Northern California</td>
<td>Annual</td>
<td>1972–2007</td>
</tr>
<tr>
<td>Murre Phenology</td>
<td>Northern California</td>
<td>Annual</td>
<td>1972–2006</td>
</tr>
</tbody>
</table>
Why might we care about the NPC bifurcation?

Historical correlations suggest that NPC location is ecologically relevant:


Suggested mechanism: Increased transport of “rich” northern waters to the south

Assume that this large-scale, latitudinal gradient in surface nitrate concentration is constant and decoupled from the position of the currents.
Suggested mechanism: Increased transport of “rich” northern waters to the south

Assume that this large-scale, latitudinal gradient in surface nitrate concentration is constant and decoupled from the position of the currents.

A more **southerly** location of the current would transport **oligotrophic** waters along the coast.
Suggested mechanism: Increased transport of “rich” northern waters to the south

Assume that this large-scale, latitudinal gradient in surface nitrate concentration is constant and decoupled from the position of the currents.

A more southerly location of the current would transport oligotrophic waters along the coast.

A more northerly location of the current would transport eutrophic waters to the coast.

Is this really how it works? Can this mechanism be tested?

Does the position of the current affect nutrient transport along the coast?
1. Position of the North Pacific Current was examined in an ocean model coupled to a biogeochemistry model, forced at the surface by observed (gridded) atmospheric conditions.

2. Coherent anomalies in nutrient transport were then examined.

Atmosphere: **CORE v2** (Common Ocean-Ice Reference Experiment; Griffies *et al.*, 2009)

Ocean: **NOAA-GFDL MOM 4.1** (Modular Ocean Model; Pacanowski and Griffies, 1999)

Biology: **NOAA-GFDL TOPAZ** (Tracers of phytoplankton with Allometric Zooplankton) which includes N, P, Si and Fe cycles and three phytoplankton classes (Dunne *et al.*, 2007).
NP Current position: **SSH and streamfunction methods give similar estimates**

---

**Sea-Surface Height (CORE, 2007 JFM average)**

- Color scale indicates SSH (m) from -0.4 to 0.6
- Grid lines represent latitude and longitude

**0-100 m velocity streamfunction (CORE, 2007 JFM average)**

- Color scale indicates velocity streamfunction
- Grid lines represent latitude and longitude

---

**Chart: Latitude of bifurcation**

- Time series from 1950 to 2000
- Lines represent SSH and streamfunction values

---
NP Current position: SSH and streamfunction methods give similar estimates.
Northerly position correlates with NH Line zoopl.

NH Line copepods: A more northerly bifurcation is correlated with higher abundance of “cold-water,” lipid-rich copepods and low species diversity.
Current position related to large-scale climate

Latitudinal position of the North Pacific Current and its bifurcation appears to be another dynamic related to the PDO.

Remaining questions:
- Does the related SST fingerprint support this PDO relationship?
- What are the related anomalies of nutrient transport?
**SST and NO$_3$ variability correlated with position**

**SST:**

SST fingerprint definitely resembles the PDO pattern.
**SST and NO$_3$ variability correlated with position**

**SST:**
- SST fingerprint definitely resembles the PDO pattern.

**NO$_3$:**
- Increased coastal NO$_3$ concentrations present when the NP Current is in a **northerly** position.
**NO$_3$ transports also correlated with position**

**NO$_3$ flux (vertical):**

Increased vertical and horizontal advection of nutrients into the California Current correlated with a more **northerly** NP Current position.

**NO$_3$ flux (north):**
Incorporating position into the conceptual ‘PDO model’

More northerly current & bifurcation

More southerly current & bifurcation
Incorporating position into the conceptual ‘PDO model’

PDO phase: negative
Aleutian Low: weak

PDO phase: positive
Aleutian Low: strong
Incorporating position into the conceptual ‘PDO model’

PDO phase: negative  positive
Aleutian Low: weak     strong
Pacific High: north    south

More northerly current & bifurcation

More southerly current & bifurcation
Incorporating position into the conceptual ‘PDO model’

PDO phase: negative
Aleutian Low: weak
Pacific High: north
NP Current, CC: north, strong

PDO phase: positive
Aleutian Low: strong
Pacific High: south
NP Current, CC: south, weak
Incorporating position into the conceptual ‘PDO model’

PDO phase: **negative**
Aleutian Low: weak
Pacific High: north
NP Current, CC: north, strong
Coastal Upwelling: strong/extends poleward

PDO phase: **positive**
Aleutian Low: strong
Pacific High: south
NP Current, CC: south, weak
Coastal Upwelling: weak/restricted to south
Incorporating position into the conceptual ‘PDO model’

**PDO phase:** negative  positive

**Aleutian Low:** weak  strong

**Pacific High:** north  south

**NP Current, CC:** north, strong  south, weak

**Coastal Upwelling:** strong/extends poleward  weak/restricted to south

**Bio. Productivity:** high  low
Q: Does positioning of the North Pacific Current affect downstream ecosystem productivity?

A: In terms of nutrient supply and primary production:

Position of the current is certainly correlated with “downstream” production.

I don’t find this different than the suite of dynamics that have long been associated with the PDO and the strength of the Aleutian Low, e.g. changes in:

- coastal upwelling and wind stress
- strength of the California Current equatorward transport

However—Meso/macro zooplankton, with a longer residence time, may be more influenced by horizontal transport than vertical transport or local production.
Where does that leave us?

- Latitude of the North Pacific Current
- Intensity and position of the Aleutian Low (time variable?)
- Influential ecosystem conditions (time variable?)
- Population characteristics
Thanks!

Ryan Rykaczewski
University of South Carolina
ryk@sc.edu