Forecasting returns of coho and Chinook salmon in the n. California Current: A role for high-frequency long term observations

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See www.nwfsc.noaa.gov, “Ocean Index Tools”
• Successful weather forecasting is based on a basic understanding of the underlying physics and physical mechanisms that determine the weather.

• Similarly, forecasting of ecological phenomena in ocean will require a basic understanding of the physical and ecological mechanisms that determine the outcomes which one hopes to predict.

• Through long-term observations of several trophic levels, we have now begun to attempt forecasts of salmon abundances based on analysis of basin-scale and local scale forcing and ecosystem response.
We are contributing to salmon management by studying the ocean phase of their life history and by developing management advice based on a suite of physical, biological and ecological indicators.

Today I will speak about changes in the food chain upon which salmon depend.
Here are some copepod and krill images...
Four factors affect plankton, food chains, pelagic fish and the growth and survival of salmon in the northern California Current

• Large-scale circulation patterns and the kinds of water that feed the California current
• Seasonal reversal of coastal currents: southward in summer – northward in winter
• Coastal Upwelling
• Phase of the Pacific Decadal Oscillation (PDO)

I will then briefly touch on our observations program, then present our forecast tools. Everything is on the web at http://www.nwfsc.noaa.gov under “Ocean Index tools”. 
Circulation off the Pacific Northwest

Continental shelf waters reverse direction with the seasons.

Winds drive currents and cause upwelling in summer and downwelling in winter.

Salmon like it cold thus they love upwelling.
The PDO has two phases, resulting from the direction from which winds blow in winter.

The SST anomaly patterns shown on the right results from basin scale winds: W'ly and NW'ly [negative phase] and SW'ly [positive phase] Westerlies dominated last winter (07-08) and now this winter so far.

PDO & SST

<table>
<thead>
<tr>
<th>Negative Phase</th>
<th>Positive Phase</th>
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<tr>
<td>1948-1976</td>
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<td>2006-</td>
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Blue is anomalously cold
Red is anomalously warm
• From 1925-1998, PDO shifted every 20-30 years. Some refer to these as “salmon” regimes (cool) and “sardine” regimes (warm).

• However, we have had two shifts of four years duration recently: 1999-2002 and 2003-2006, and another shift in late 2007, thus we have a natural experiment to test the affects of PDO on marine food chains and salmon populations.

• Note 2008: most negative PDO since 1950s!!
Observations

- Newport Line biweekly sampling since 1996 (13 years)
- Juvenile salmon sampling in June and September since 1998 (11 years)
13 year time series of SST at Buoy 46050 off Newport shows that PDO down scales to local SST

- PDO and SST correlated, as they should be.
- However there are time lags between PDO sign change and SST response of 3-5 months.
- PDO began to change in 2007 (neutral state) then turned strongly negative in 2008.
Copepod community structure vs. PDO (based on an ordination analysis)

- Positive values (red) indicate a “warm water community” and seen during PDO positive phase;
- Negative values (blue) indicate a “cold water community” and seen during PDO negative phase.
Contrasting Communities

• **Negative PDO = low diversity and “cold-water” copepod species.** These are dominants in Bering Sea, coastal GOA, coastal northern California Current
  – *Pseudocalanus mimus, Calanus marshallae, Acartia longiremis*

• **Positive PDO = high diversity and “warm-water” copepods.** These are common in the Southern California Current neritic and offshore NCC waters
  – *Clausocalanus spp., Ctenocalanus vanus, Paracalanus parvus, Mesocalanus tenuicornis, Calocalanus styliremis*

Based on Peterson and Keister (2003)
Comparisons in size and chemical composition

- **Warm-water taxa** - (from offshore OR) are **small** in size and have limited high energy wax ester lipid deposits

- **Cold-water taxa** – (boreal coastal species) are **large** and store **wax esters** as an overwintering strategy

Therefore, significantly different food chains may result from climate shifts;
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
1998 - 2004
Yearling Coho Salmon
Yearling Chinook Salmon
Subyearling Chinook Salmon
Forecasting -- since juvenile salmonids live in continental shelf waters, we use indices relevant to shelf waters

- **Basin scale indicators**
  - PDO
  - MEI

- **Local indicators**
  - SST
  - Upwelling
  - Date of spring transition
  - Length of upwelling season

- **Biological indicators**
  - Copepod biodiversity
  - N. copepod biomass anomaly
  - Copepod Community Structure
  - Catches of spring Chinook in June
  - Catches of coho in September
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A chain of events (in a perfect year)

- Changes in basin-scale winds lead to sign changes in PDO
  - Negative
  - Positive
- SST changes as do water types off Oregon
  - Cold/salty
  - Warm/fresh
- Spring transition
  - Early
  - Late
- Upwelling season
  - Long
  - Short
- Zooplankton species
  - Cold species
  - Warm species
- Food Chain
  - Lipid-rich
  - Lipid-deplete
- Forage Fish
  - Many
  - Few
- Juvenile salmonids
  - Many
  - Few

But time lags can complicate interpretations!
Acknowledgements

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• Office of Naval Research
• NASA

• See www.nwfsc.noaa.gov, “Ocean Index Tools”
Coho returns vs. rank of all variables

Proportion of smolts accounted for as adults

Mean rank of all predictor variables

Coho Returns
R-sq = 0.51, p = .02
Copepod indices: integrative measures

\[\begin{align*}
R^2 &= 0.75 \text{ W/O 1970, 1973} \\
&= 0.41 \text{ OTHERWISE}
\end{align*}\]

\[Y = 1.4817 + 0.0517 \exp (-4.92 X)\]

\[R^2 = 0.74, \ p < 0.0001\]
Spring Transition

- Upper chart is date based on change in sea level and start of upwelling season (Bakun upwelling index – Bograd POC and Logerwell et al. 2003)

When we look at the date when the copepods transitioned to a summer community, a somewhat different result is seen.
Copepods ➔ Anchovies ➔ Salmon

- Anchovy data from pelagic trawl surveys carried out by Bob Emmett
- Age-1 Anchovy catches lag cold water copepod anomalies by one year.
- Anchovy abundance may be the direct food chain link between copepods and salmon
Catches of juv. salmon vs. number of returning spring Chinook jacks and OPIH coho one year later