Characterizing spatial coherence of copepods in the Northern California Current

OR From Dr. Otto's plenary talk:
How "spatially universal" are the indicators from a sentinel station of the Newport Hydrographic Line?

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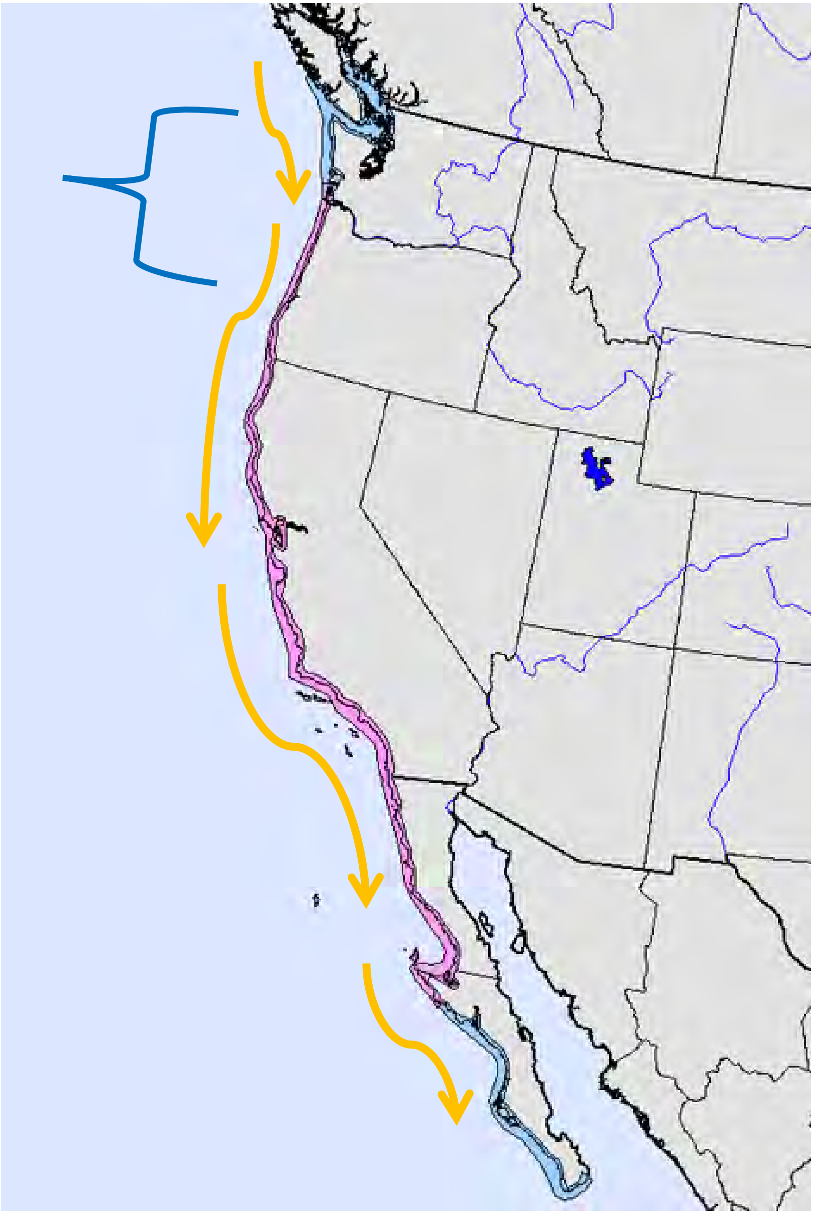
Outline

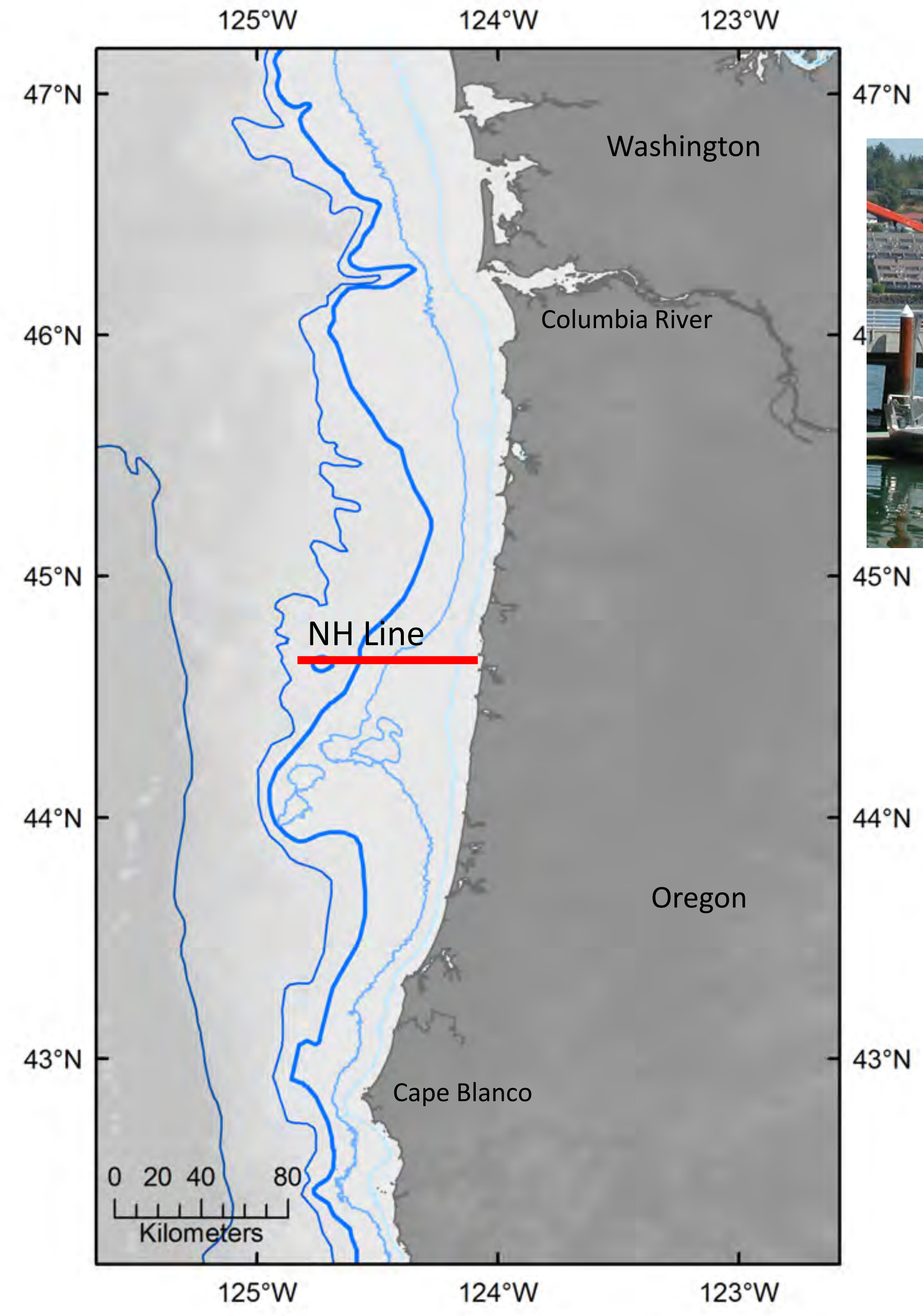
- Acknowledge the knowledge base from previous work of Drs. Mackas, Peterson, Keister, and the rest of the Peterson Zooplankton Lab
- Background on sampling region
- Why and how copepod biomass used as indicators
- Our objective
- Methods
- Results
- Etc…

The Northern California Current

Study area



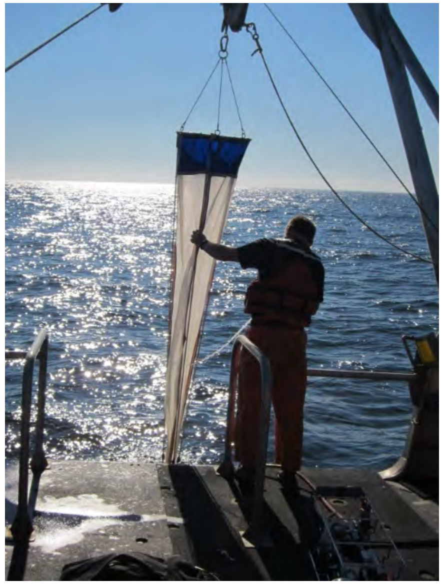
- Productive ecosystem dominated by strong seasonal upwelling periods
- Provides early marine residence to approximately 145 million hatchery salmon produced in the Columbia River Basin



Newport Hydrographic Line

- Sampled biweekly for 23 years
  - 1996 - present
  - 7 stations (1 – 25 nm)

- Ichthyoplankton, zooplankton, krill, CTD, nutrients, HABs, chl-*a*

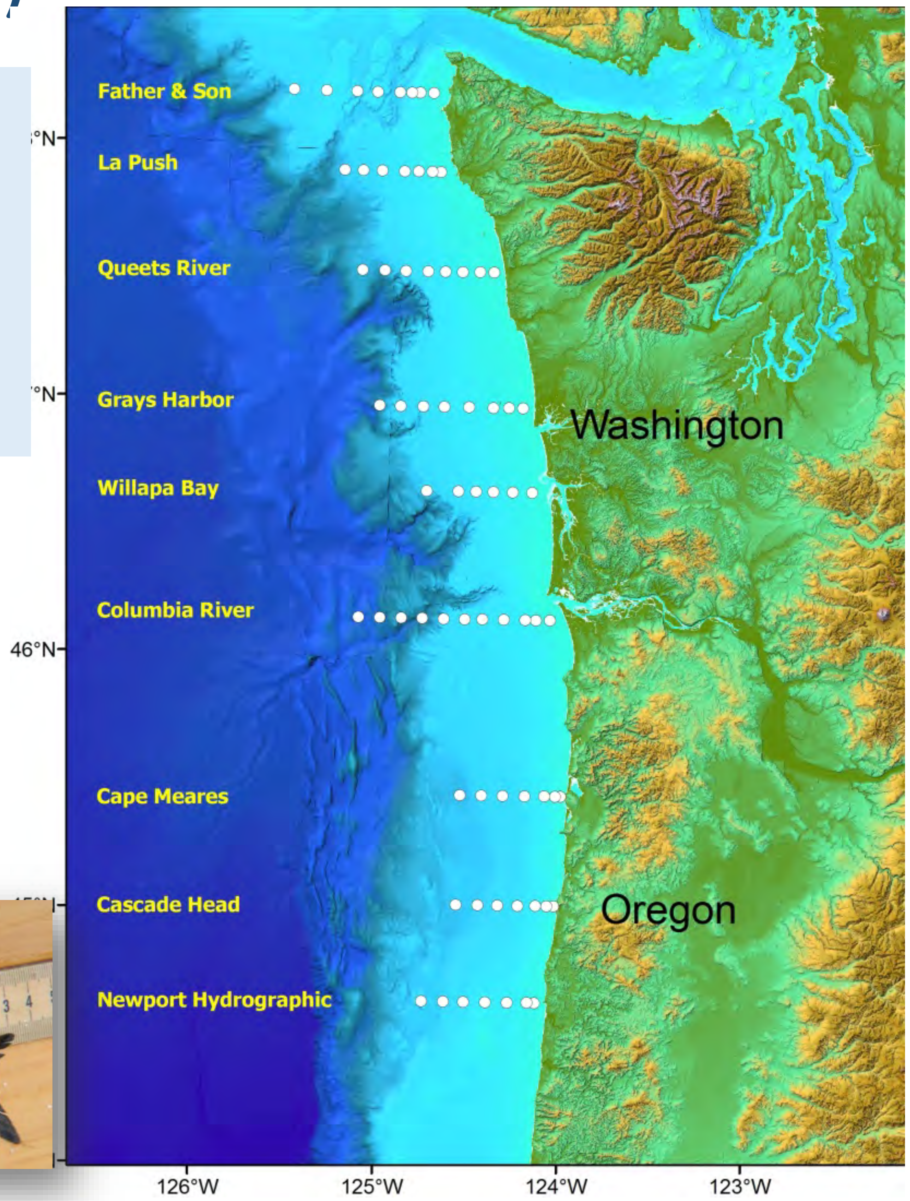


- **Copepod collection methods**
  - **0.5 m vertical net; 202 µm mesh**
  - **Towed vertically from 2 m off the bottom**
  - **Upper 100 m**

- **NH-5 (9 km) 60 m water depth**

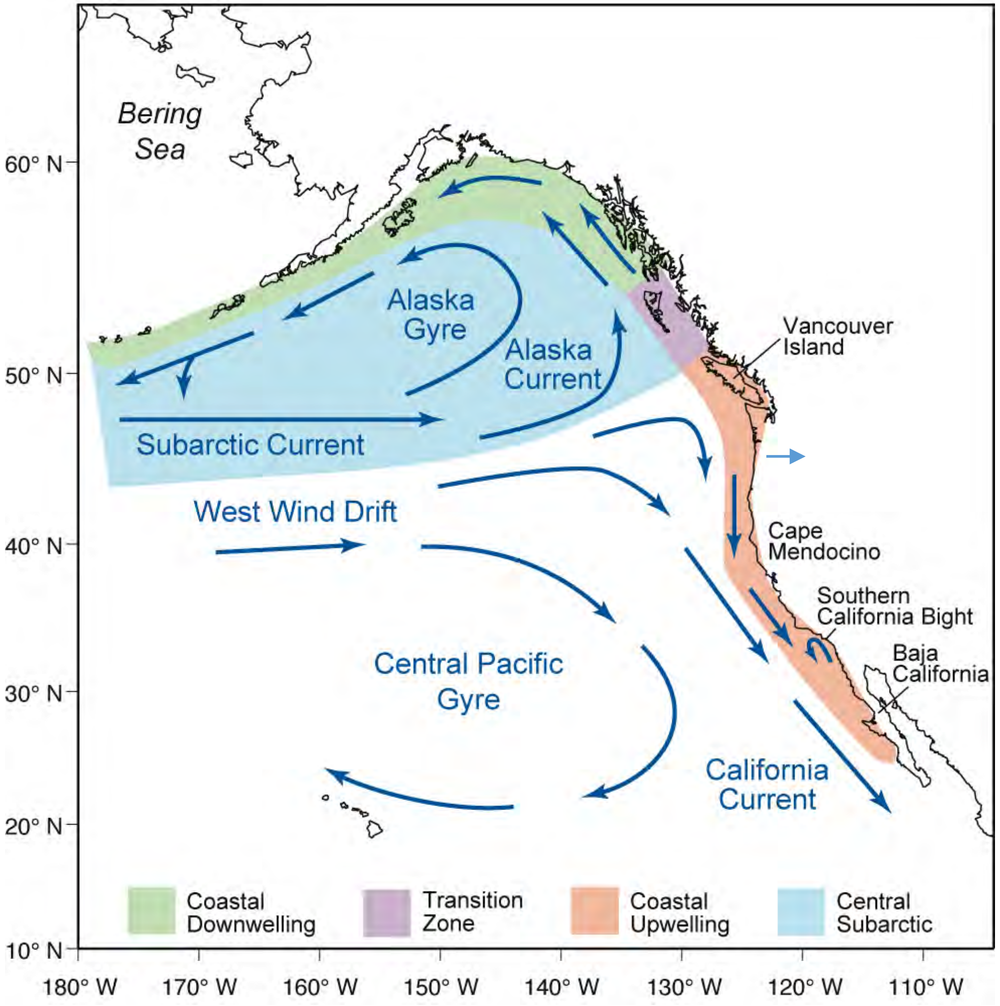
Juvenile Salmon and Ocean Ecosystem Survey (JSOES)

- May and **June** (1998 – present)
- Daytime surface trawls for salmon
- CTD, nutrients, chl-*a*, zooplankton, ichthyoplankton
- Vertical nets all stations 1998-2011



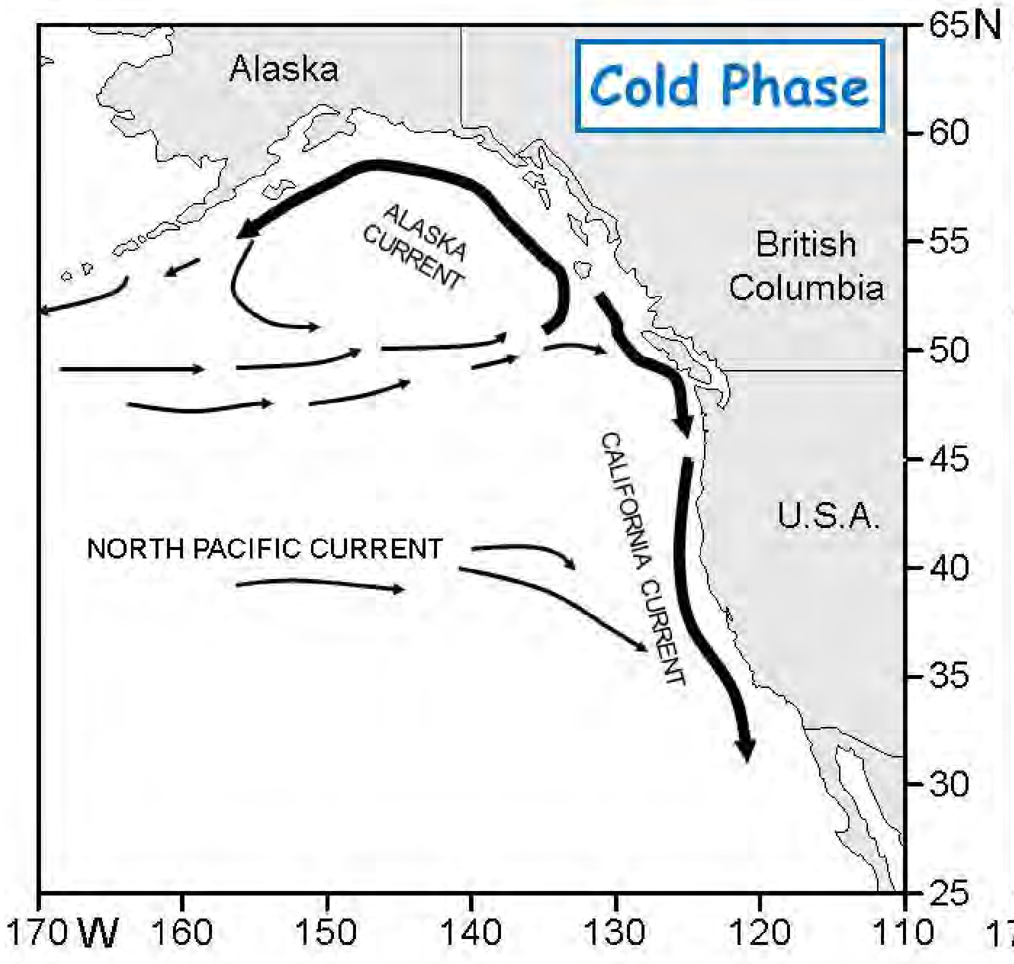
Circulation off the Pacific Northwest

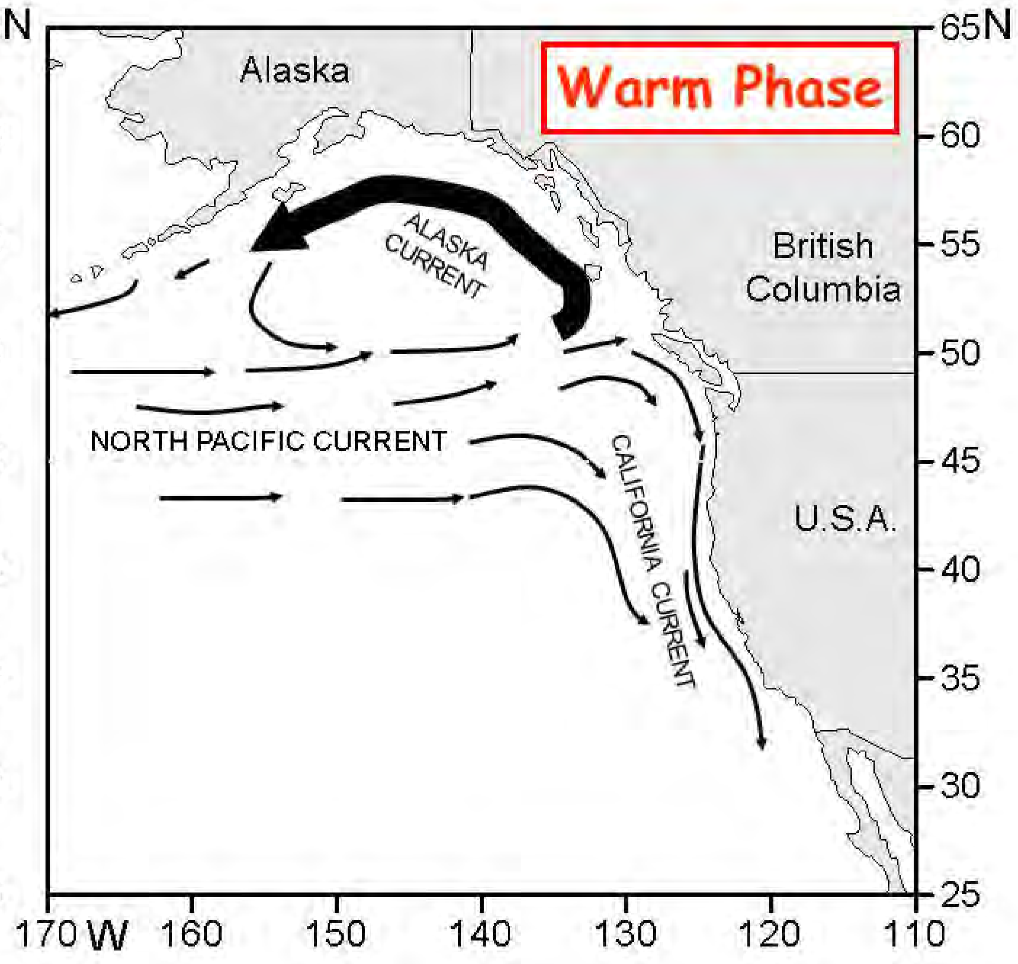
- California Current (CC) begins at ~northern end of Vancouver Island and is primarily along the shelf break and offshore
- Currents over the shelf are largely dominated by local winds
- Phases of the Pacific Decadal Oscillation affects currents and regional biology



from Barth, 2007

The different phases of the PDO influence our ocean currents and also transport different copepod taxa on to the shelf





Different source waters bring different copepod taxa to the shelf waters off Washington and Oregon

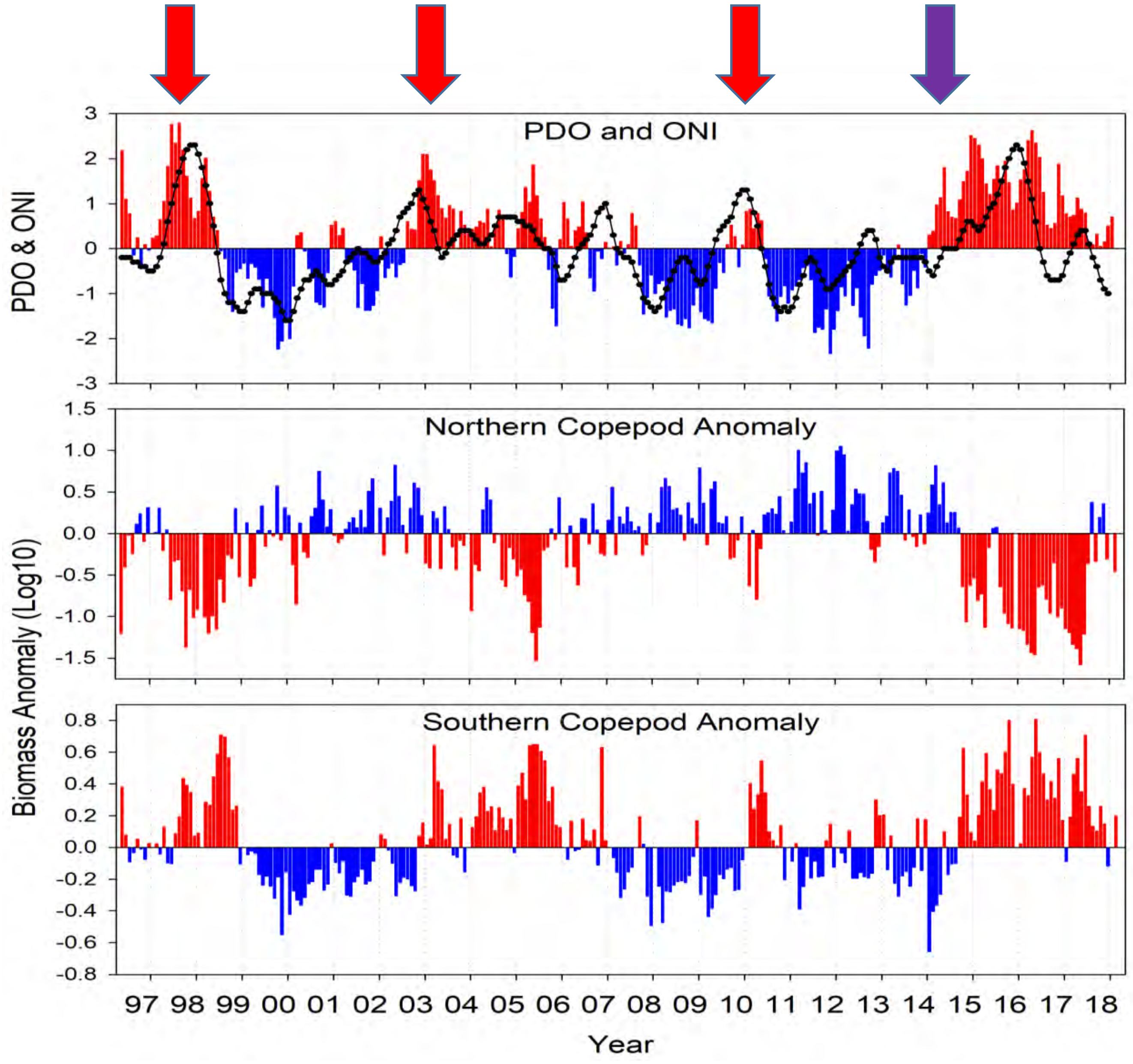
Boreal Cold Water Taxa

Acartia longiremis
Calanus marshallae
Pseudocalanus spp.

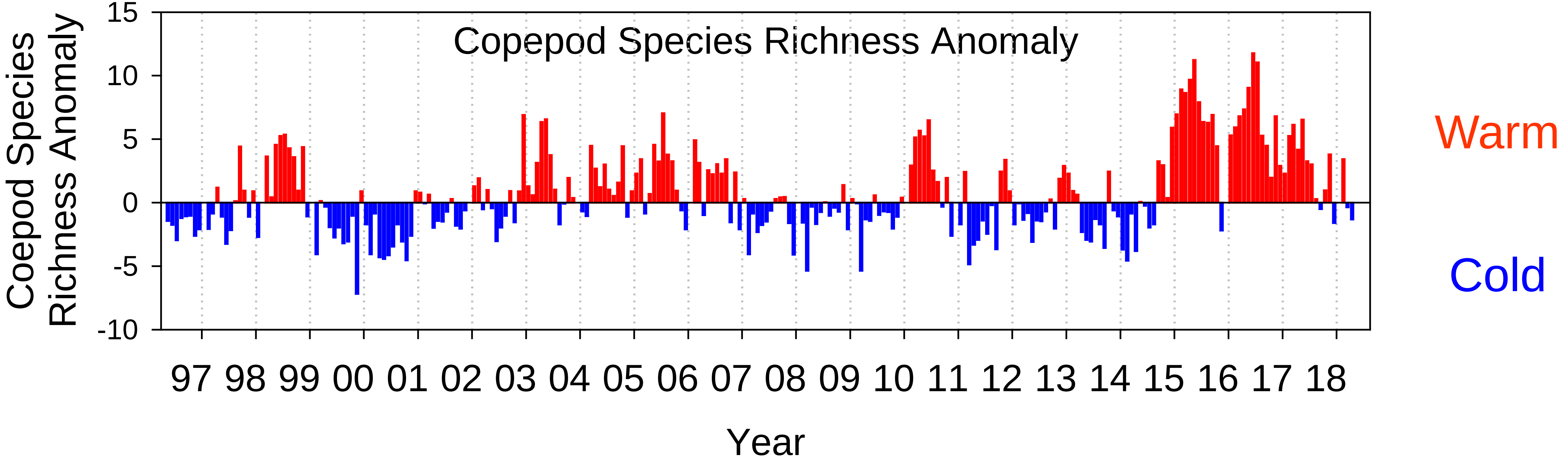
Offshore and Southern Warm Water Taxa

Acartia tonsa
Calanus pacificus
Calocalanus spp.
Clausocalanus spp.
Ctenocalanus vanus
Mesocalanus tenuicornus
Paracalanus parvus

The anomalies of northern and southern copepod taxa at NH05 track the phases of the PDO and Oceanic Niño Index

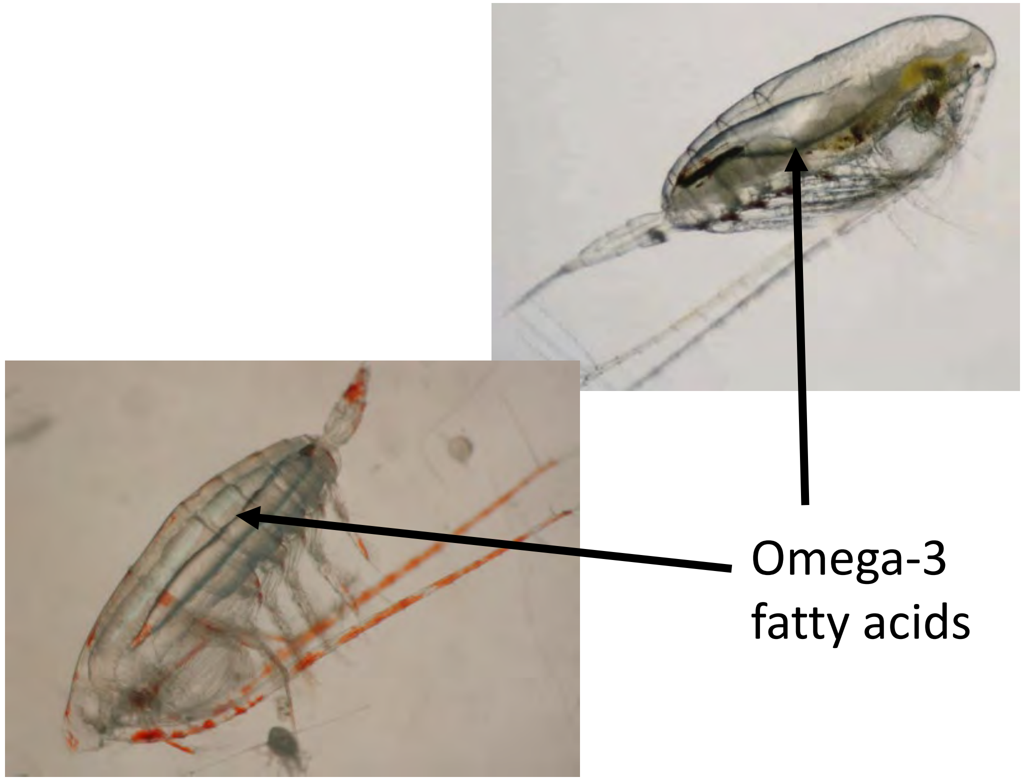


Copepod biodiversity (the more diverse warm water taxa) was even greater the recent marine heat wave



These copepods vary in size and chemical composition affecting the local food web: significantly different food chains result from climate shifts

- **Warm-water taxa** - (southern species) are **small** in size and have minimal high energy wax ester lipid depots
- **Cold-water taxa** – (northern species) are **large** and store high-energy **wax esters** as an over-wintering strategy



Four of the biological metrics in our stop-light chart of indicators of ocean conditions for juvenile salmon are copepod metrics from NH05

- State of the California Current report
- Coastal Pelagics Species' Stock Assessment and Fisheries Ecosystem report
- California Current Integrated Ecosystem Assessment

	Year																				
Ecosystem Indicators	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
PDO (Sum Dec-March)	18	6	3	13	7	20	12	16	14	9	5	1	15	4	2	8	10	21	19	17	11
PDO (Sum May-Sept)	10	4	6	5	11	17	16	18	12	14	2	9	7	3	1	8	19	21	20	15	13
ONI	20	1	1	7	14	16	15	17	9	12	3	11	18	4	6	8	10	19	21	13	5
Copepod richness anom. (no. species; May-Sept)	19	2	1	7	6	14	13	18	15	10	8	9	17	4	5	3	11	20	21	16	12
N. copepod biomass anom. (mg C m^{-3}; May-Sept)	19	14	10	11	3	16	13	20	15	12	6	9	8	1	2	4	5	17	21	18	7
S. copepod biomass anom. (mg C m^{-3}; May-Sept)	21	2	5	4	3	14	15	20	13	10	1	7	16	9	8	6	11	18	19	17	12
Biological transition (day of year)	18	8	5	7	9	14	13	19	12	2	1	3	16	6	10	4	11	21	21	17	15
Ichthyoplankton biomass (mg C 1,000 m^{-3}; Jan-Mar)	21	12	3	8	10	19	18	15	17	16	2	13	5	14	11	9	20	6	7	1	4
Ichthyoplankton community index (PCO axis 1 scores; Jan-Mar)	10	13	2	7	5	11	20	18	3	12	1	14	15	8	4	6	9	19	21	17	16
Chinook salmon juvenile catches (no. km^{-1}; June)	19	4	5	16	8	12	17	20	11	9	1	6	7	15	3	2	10	13	18	21	14
Coho salmon juvenile catches (no. km^{-1}; June)	19	8	13	6	7	3	16	20	17	5	4	10	11	15	18	1	12	9	14	21	2
Mean of ranks	17.9	7.2	6.0	7.3	6.1	13.0	15.9	17.1	11.3	9.2	2.7	8.6	12.8	8.1	6.6	7.7	12.8	16.7	17.2	14.5	11.6
Rank of the mean rank	21	5	2	6	3	15	17	19	11	10	1	9	13	8	4	7	13	18	20	16	12

https://www.nwfsc.noaa.gov/oceanconditions

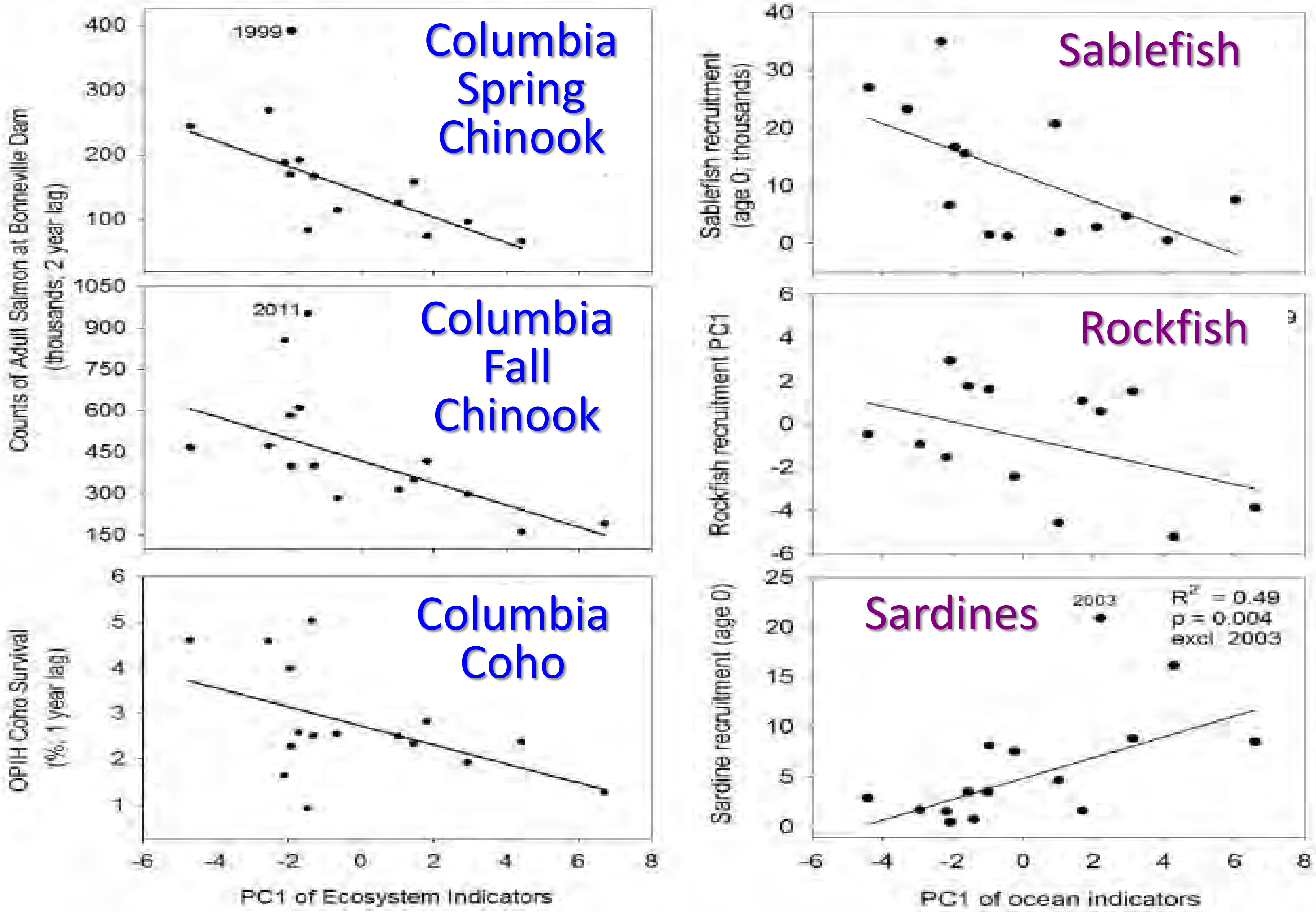
Metric of combined environmental indices relates well with salmon returns to the Columbia River

and to recruitment:

Sablefish in the NCC

Rockfish in the CCC

Sardine in the SCC

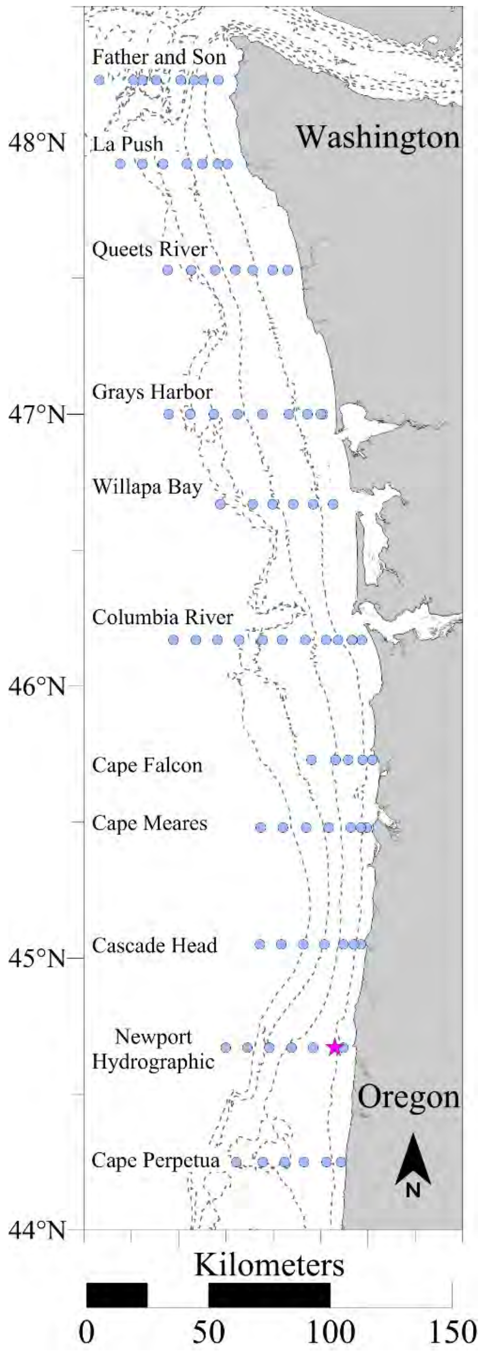


Peterson et al. 2014, Oceanography

Goal of this study

NH05 serves a sentinel station or indicator for NCC ocean conditions, but how well does it represent the rest of the region where Pacific northwest salmon reside during early marine residence?

Do we need to continue to sample northern transects?



METHODS

We applied statistical models to the data to:

- quantify the spatial coherence of cold water and warm water copepod biomass throughout the central Oregon and Washington shelf

- identify the regional and basin-scale environmental drivers that may influence the biomass distributions

METHODS

Correlations with NH05

- To understand how well NH05 represents cold-water copepod biomass across the broader region, we calculated Pearson's correlation coefficients between NH05 and all other stations.
  - Only included stations sampled during 10 years, excluded 4 transects
  - 365 km or 3.25 degrees of latitude from NH Line to La Push, Washington

- There were many zero counts for warm water copepod biomass so calculated the non-parametric Spearman’s correlation for those comparisons

- We used the Benjamini-Hochberg *p*-value correction to adjust for multiple, positively dependent comparisons within each copepod group.

METHODS

Environmental variables:

We used two different approaches to assess the strength of the relationships between a suite of environmental variables:

- For cold-water copepods we used a linear mixed effects model.

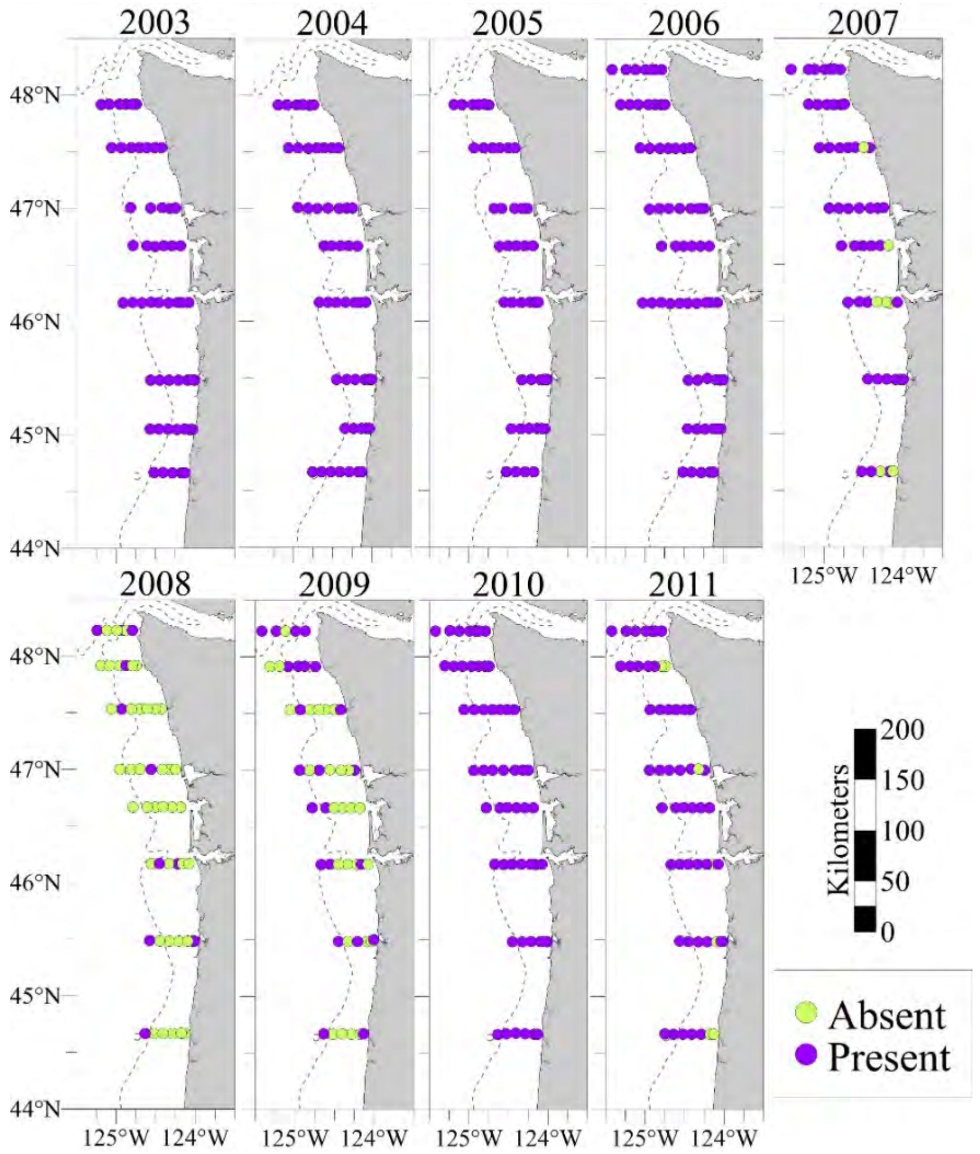
But…

Environmental Variables

- For warm-water copepods, because many of the biomass values were zero, we modeled two separate biological processes:

  1. the probability of copepod presence was modeled with logistic mixed effects regression

  2. non-zero values modeled with linear mixed effects regression.



Not showing all of the years so that you can see the stations…

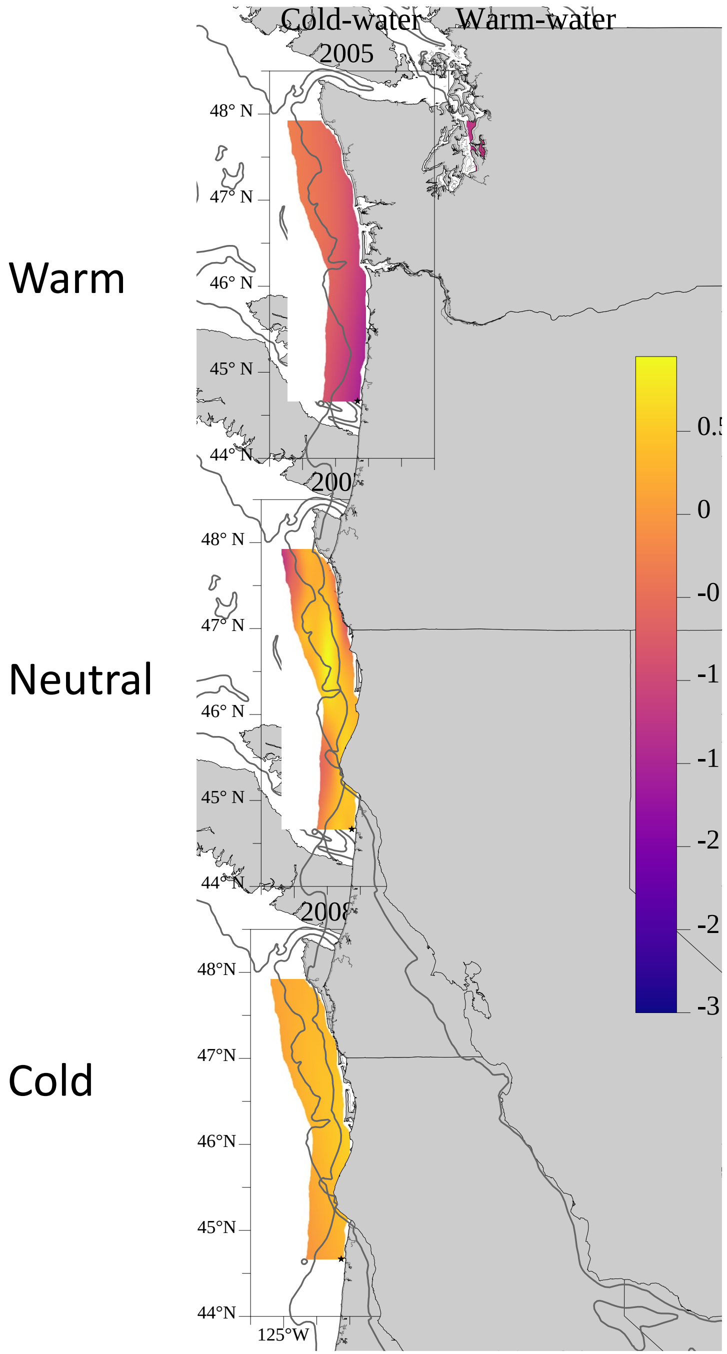
The 200 meter depth contour is indicated by the dotted line

RESULTS

Spatial biomass estimates (logged and smoothed) of copepod taxa in a <u>typical</u> warm, neutral, and cold year:

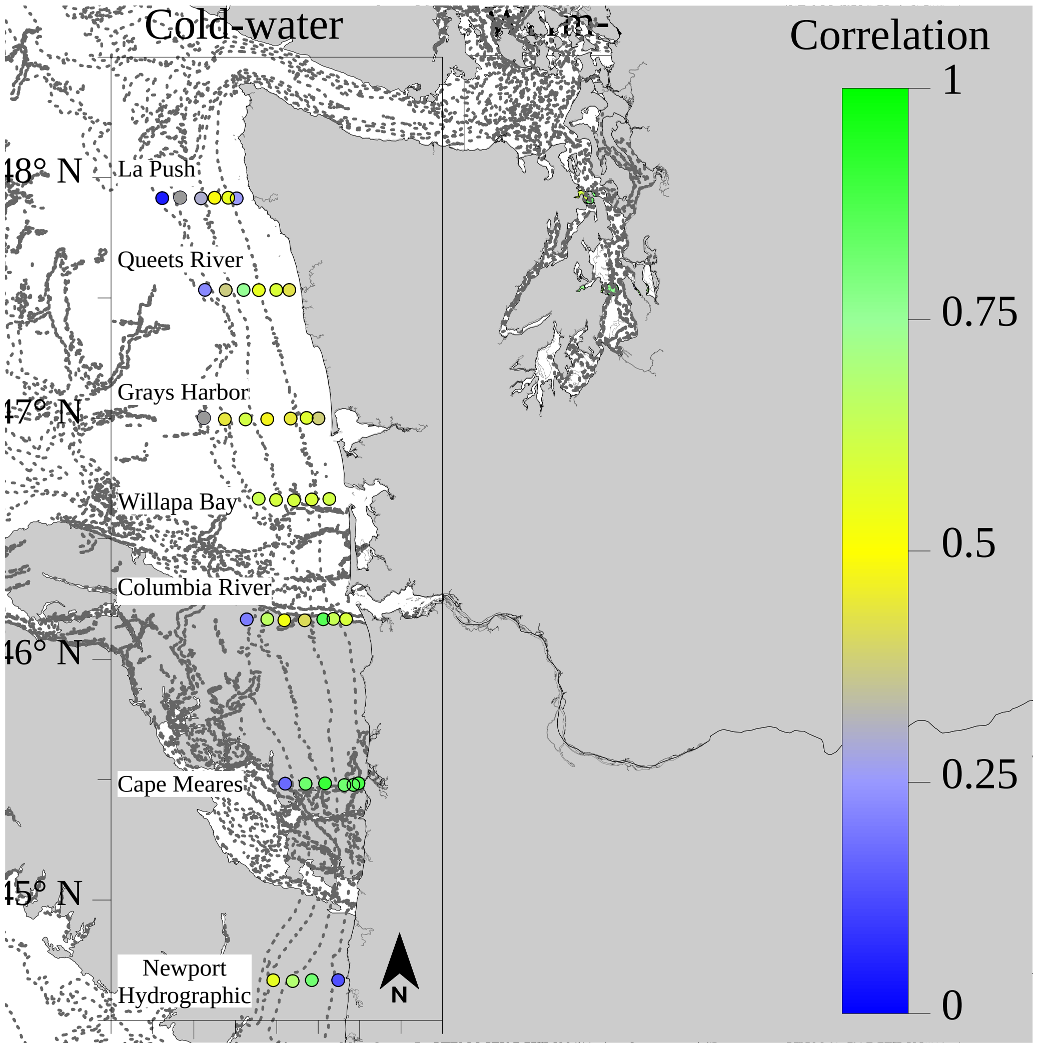
Biomass of warm copepod taxa is less than cold due to their small size. They are less variable spatially when present compared to cold water taxa.

Can see some spatial variability in warm and neutral year for cold water taxa biomass



RESULTS

- High correlations of cold-water copepod biomass with NH05 were observed at stations of similar depths: mid-shelf
- Least correlations with stations on shelf break and off La Push, WA
- Greater number of correlations with NH05 for warm-water taxa.



Correlation coefficient estimates for cold-water copepod (Pearson's) and warm-water copepod (Spearman's) biomass at NH05 and other JSOES stations

Environmental Variables Tested:

Station Level:

- Latitude
- Station depth (m)
- Surface temperature (1 m depth)
- Deep temperature (50 m or 5 m above ocean floor)
- Chlorophyll *a* (3 m depth)
- Longitude
- Distance off shore
- Surface and deep salinity

Basin Level:

- Annual Pacific Decadal Oscillation (PDO) index
- June Coastal Upwelling Index (Bakun) at 45°N

Two-way interactions between latitude and other variables

Significant Effects from Environmental Models:

Cold-water Copepod Biomass

VARIABLE	RELATIONSHIP
Station depth	-
Temperature 5 m	-
Deep temperature (50 m)	-
Latitude * Temperature 5 m	+
Latitude * Deep temperature	+

Indicating:

- A decrease in cold water copepod biomass as station depth and deep water temperature increases
- Interaction effect indicates less of a negative effect on biomass with temperature in more northern transects

Significant Effects from Environmental Models:

Warm-water Copepod Presence

VARIABLE	EFFECT
Latitude	-
Station depth	+
Deep temperature (50 m)	+
PDO	+
Latitude * Surface temp	-
Latitude * Station depth	-
Latitude * Deep temp	-
Latitude * Upwelling	-

Indicating:

- Warm-water copepods more likely to occur during a positive PDO, at deeper stations, as deep water temperature increases, and in southern stations
- Interaction effect indicates these factors have less of an effect as you move up in latitude.
- Transport of these copepods into our region is from offshore and the south (Keister, Hooff, Peterson).

Significant Effects from Environmental Models:

Warm-water Copepod Biomass

VARIABLE	EFFECT
Latitude	-
Surface temperature (1 m)	-
PDO	+
Latitude * Temp 5 m above ocean floor	Weakly +

Indicating:

- When warm-water copepods occur, biomass lower at higher latitudes
- Greater biomass during a positive PDO and with higher surface temperatures
- Interaction effect indicates the effect of deep temperature was somewhat greater at higher latitudes (+ for presence).

Effective Spatial Range Estimates

- Cold water copepods biomass is spatially autocorrelated up to a distance of approximately 45 km, warm water taxa up to 75 km.

- Mackas et al. 1984 reported total zooplankton biomass became uncorrelated around 10-25 km cross-shelf and alongshore, whereas spatial variation of community composition reached up to 100 km.

- Comparisons of interannual biomass anomalies of zooplankton communities between Vancouver Island and the NH Line has shown considerable alongshore similarity and synchrony in anomalies (Mackas et al. 2004; 2006; Tucker et al. 2015).

Summary

- Correlations showed evidence of a strong similarity between the biomass of cold-water copepods at NH05 and other sampling stations of similar bathymetry.

- This similarity was even stronger for the warm-water copepod taxa. These taxa usually present during downwelling when less advective processes and more consistent conditions exist across the shelf (Keister and Peterson 2003, Keister et al. 2011).

- Environmental models revealed no surprises: deep temperature, station depth, and the PDO as the main drivers of the distribution of copepod biomass along the Oregon and Washington shelf.

- Copepods off very northern area of Washington potentially influenced by the Strait of Juan de Fuca, canyons, and Juan de Fuca Eddy. We continue to sample this transect every June.

Thanks to juvenile salmon team and current NHL team…

Brian Beckman
Paul Bentley
Ric Brodeur
Cindy Bucher
Brian Burke
Ed Casillas
Andrew Claiborne
Elizabeth Daly
Bob Emmett
Joe Fisher
Kurt Fresh
Troy Guy
Susan Hinton
Meredith Journey

Greg Krutzikowsky
Marisa Litz
James Losee
Jessica Miller
Thomas Murphy
Jay Peterson
Elizabeth Phillips
Mary Beth Rew
Jim Ruzicka
Todd Sandell
Tom Wainwright
Laurie Weitkamp
Jen Zamon
Captain & Crew FV *Frosti*

Happy Birthday Moira!

Jennifer Fisher
Sam Zeman

OSU Oregon State University
Cooperative Institute for Marine Resources Studies CIMRS
NWFSC Northwest Fisheries Science Center
Bonneville Power Administration