Forecasting returns of coho and Chinook salmon in the northern California Current: a role for long-term observations

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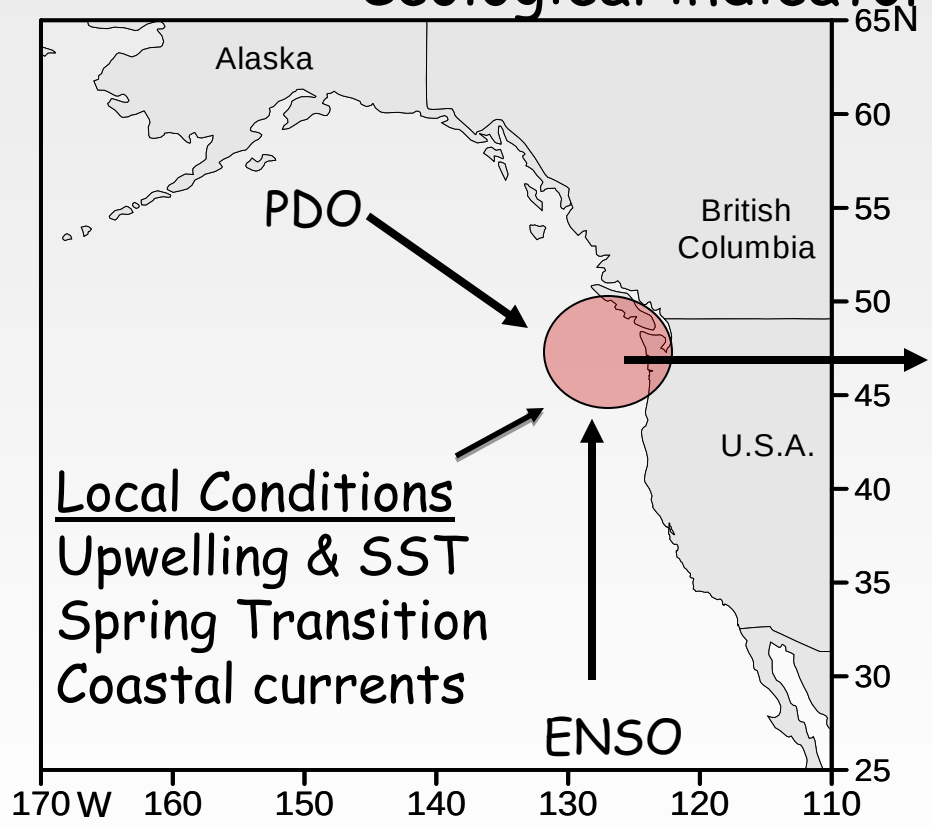
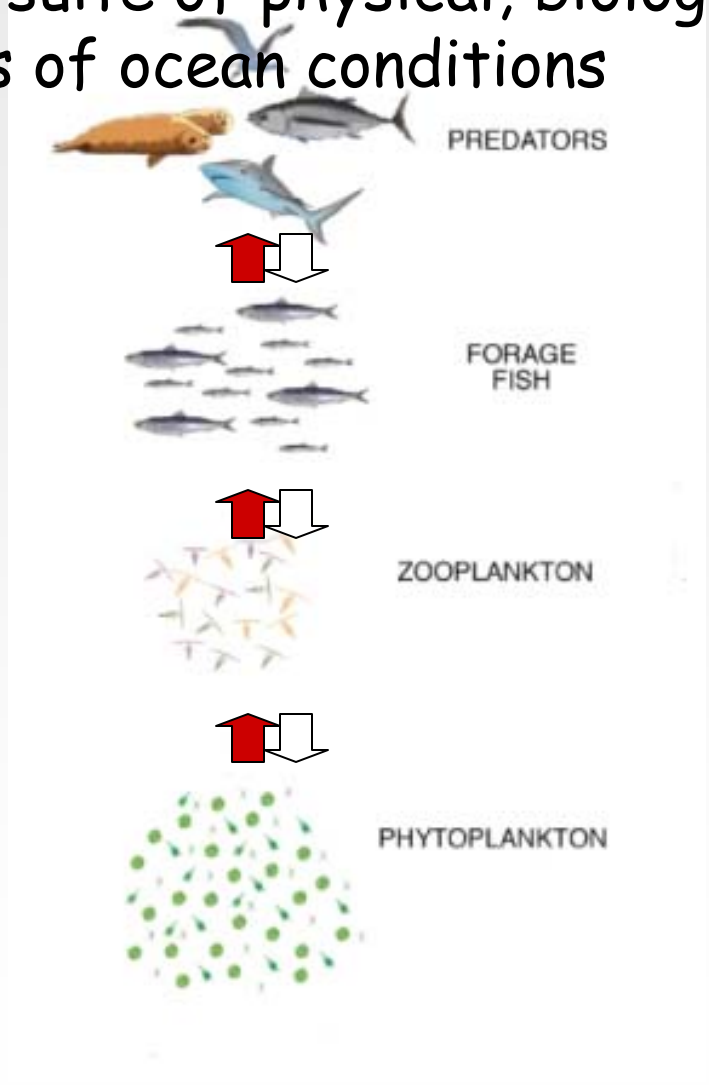
We are contributing to salmon management by studying the early ocean phase of their life history and by developing management advice based on a suite of physical, biological and ecological indicators of ocean conditions

Large scale forces acting at the local scale can influence biological process important for salmon





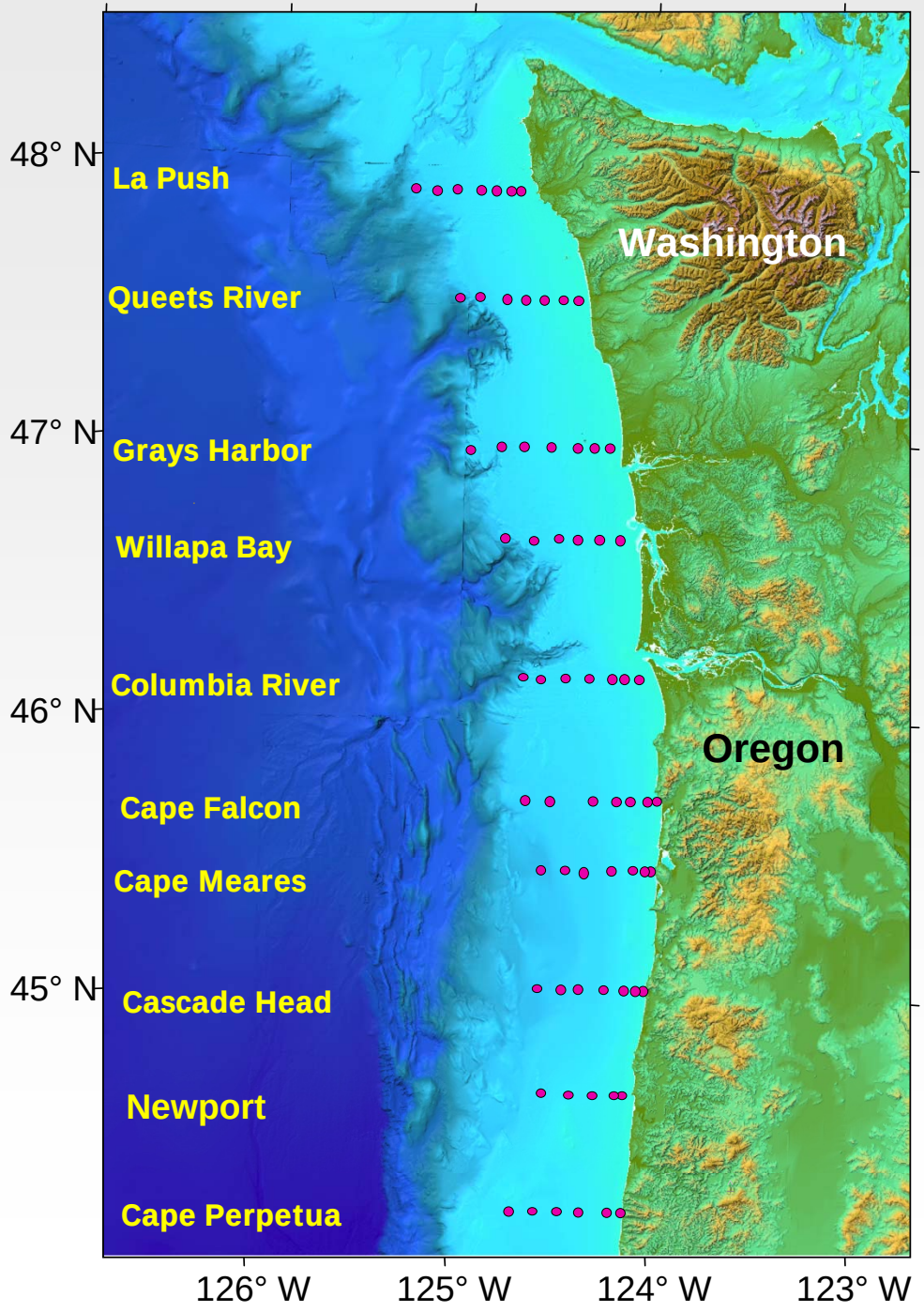
Local Biological Conditions

The source of the ideas which will be presented today

- Francis and Hare (1994) and Mantua et al. (1997)

  These studies showed that the North Pacific Index and Pacific Decadal Oscillation were correlated with salmon returns, particularly in the Pacific Northwest
- Nickelson (1987) and Pearcy (1992) suggested a role for coastal upwelling
- I wanted to work out the mechanism for these correlations ➔ how do changes in sign of the PDO (a basin scale indicator) and upwelling translate into changes in salmon returns (a local response)?

The answer is related to changes in food chain structure as indexed by copepod species composition



Observations

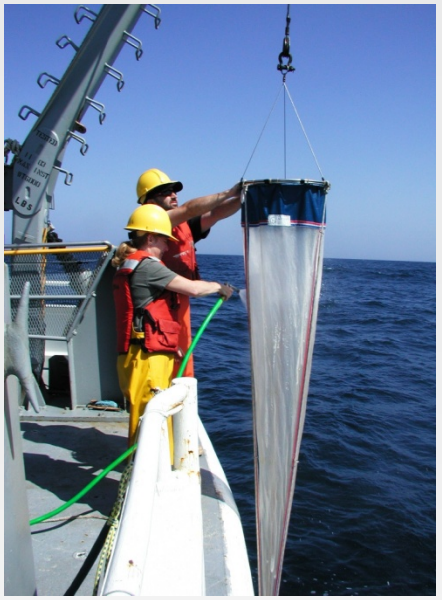
- Juvenile salmon sampled in May, June and September since 1998 (13th year) with NORDIC 264 rope trawl at stations shown on the left.

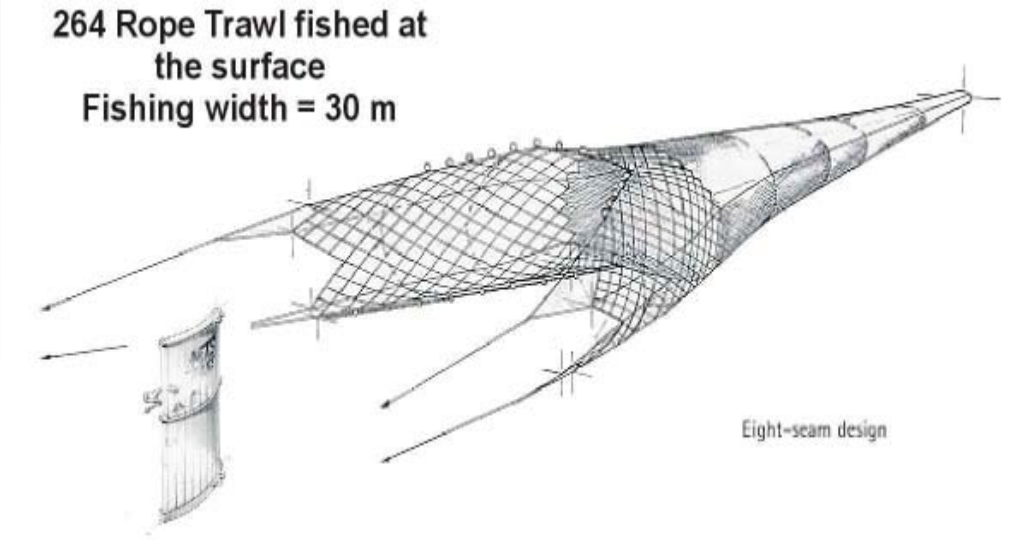
- Ocean conditions sampled biweekly off Newport on oceanographic cruises (temperature, salinity, nutrients, phytoplankton, zooplankton, krill, fish larvae)

- Web-based data = PDO, MEI, SST from NOAA Buoys

Sampling methods

- Copepods with ½ m diameter 200 µm mesh net towed vertically from 100 m
- Salmon with pelagic rope trawl, Nordic 264 from NET Systems: 20 m high x 30 m wide x 100 m in length



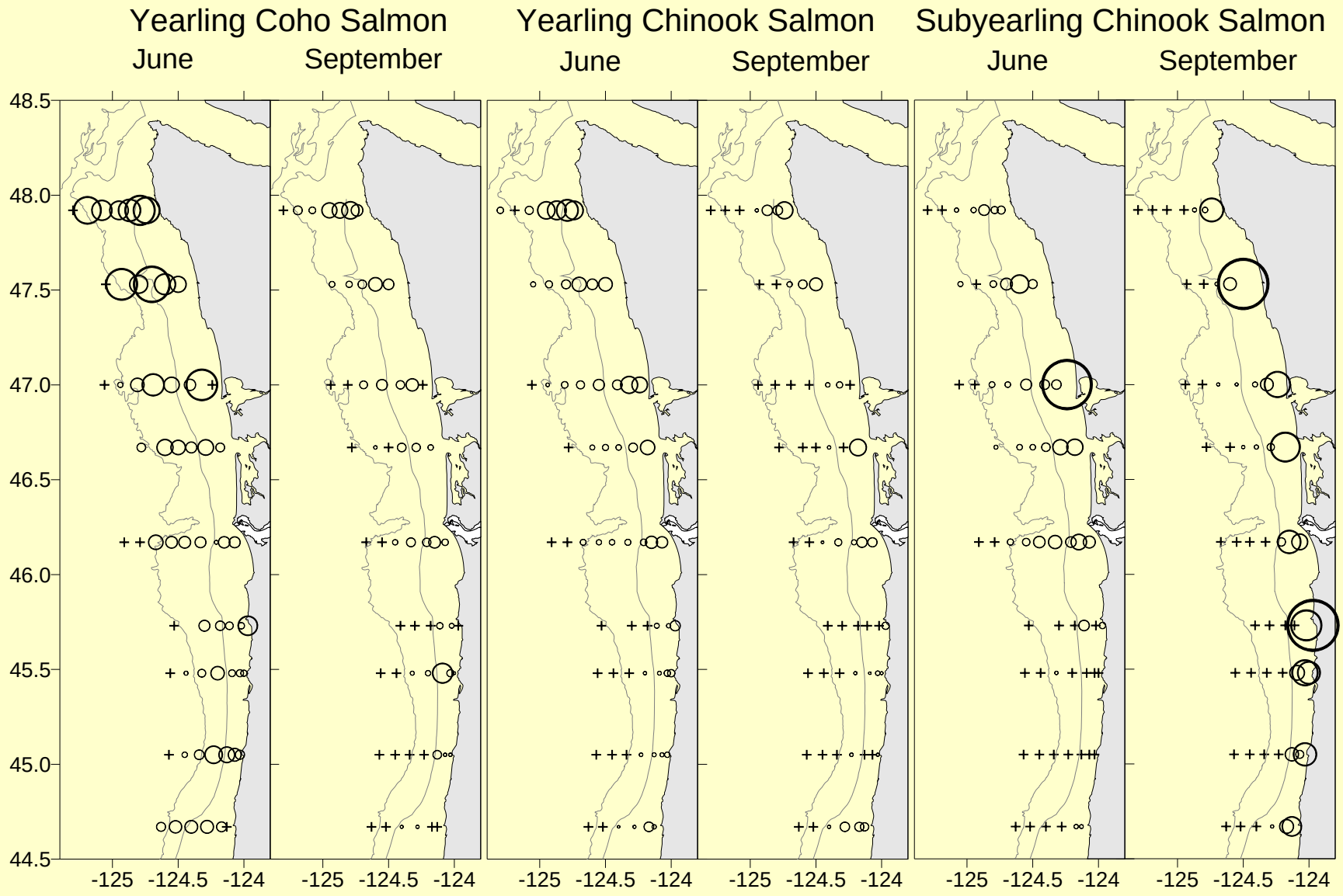


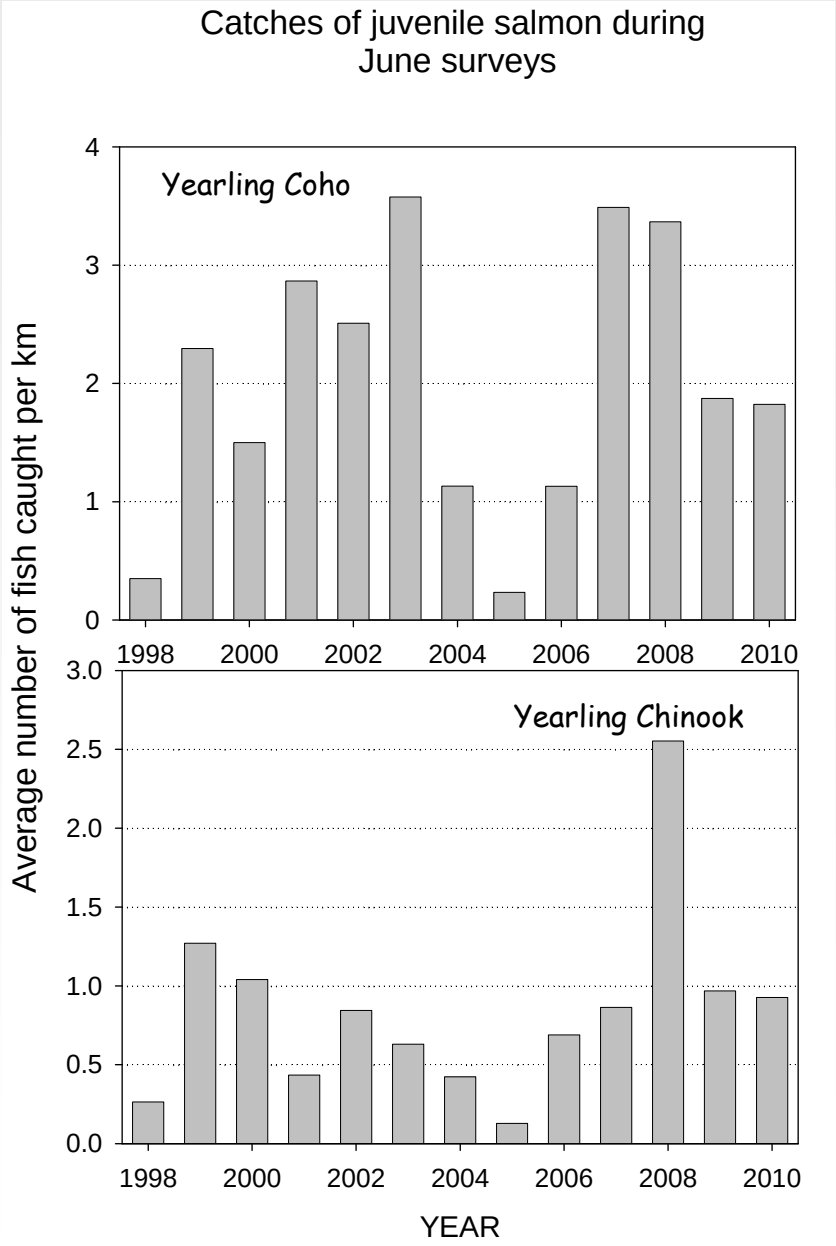
Salmon Habitats and Forecasting

- In order to forecast returns of salmon to rivers of the Pacific Northwest, we must first establish where they live in the ocean. This is true for recruitment, yield or catches of any species for which one might want to provide a forecast.

- We also assume that the rates of return are set for the most part during the first summer at sea

Climatology: 10 year average catches





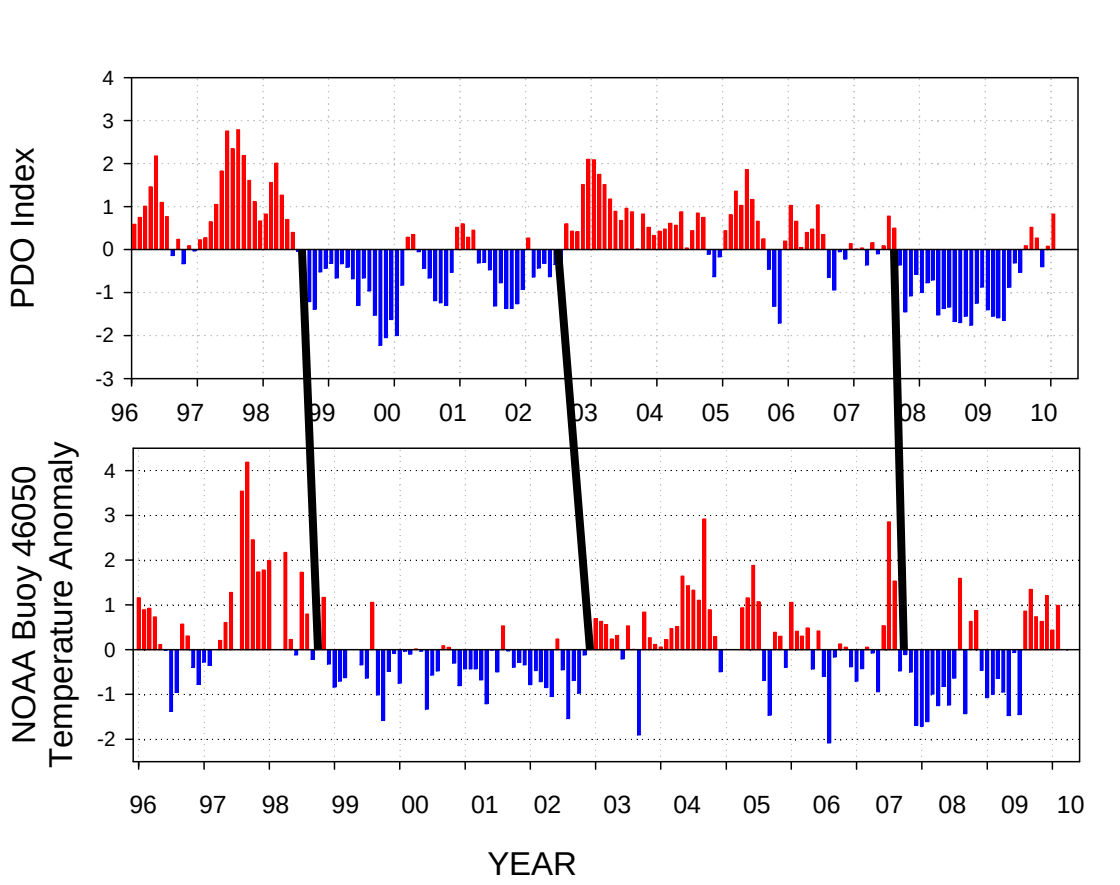
Catches of juvenile salmon in rope trawl surveys

- Catches range over one order of magnitude
- High catches of coho in 1999-2003 and again in 2007 and 2008; lowest in 2005
- Highest catches of spring Chinook in 2008, lowest in 2005
- High catches associated with negative phase of PDO and low catches with positive phase of the PDO. Examples are 2008 (negative) and 2005 (positive)

So……how do changes in sign of the PDO (a basin scale indicator) translate into changes in salmon returns (a local response)?

How does the PDO relate to changes in food chain structure as indexed by copepod species composition

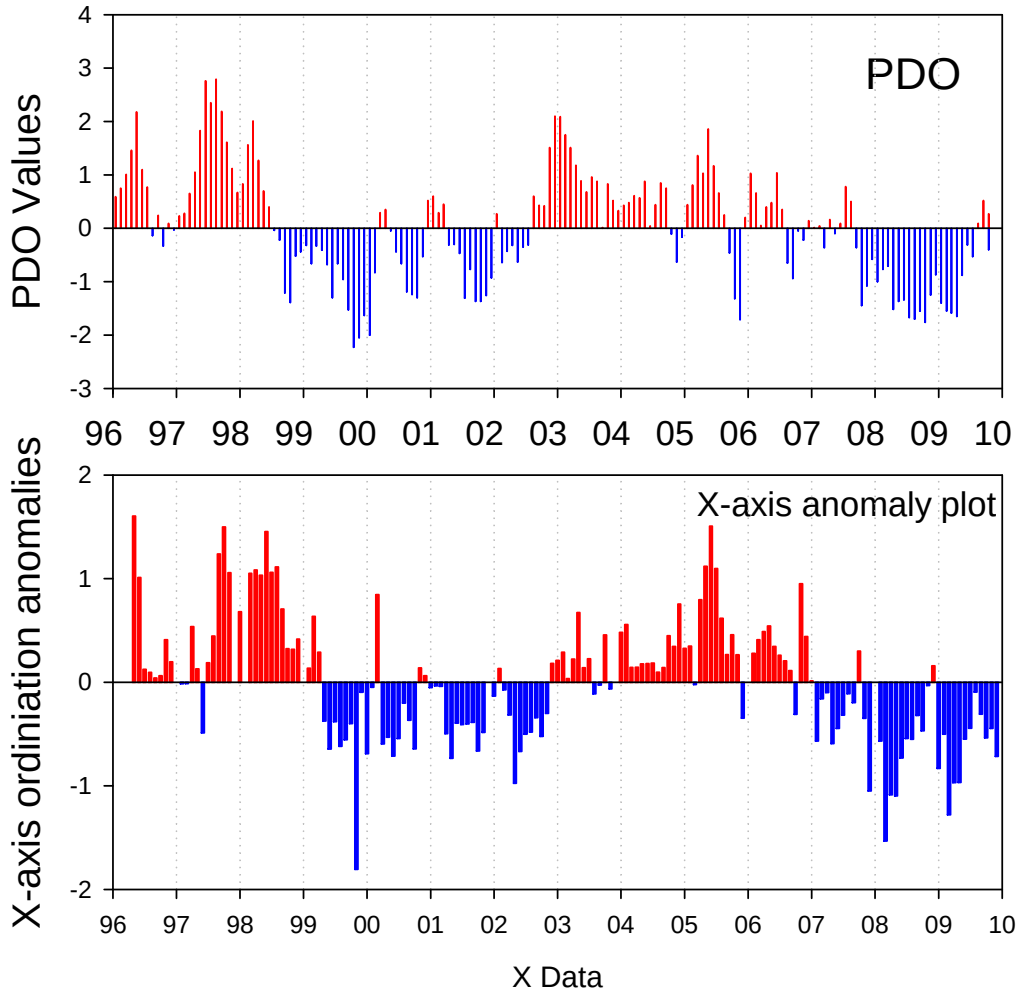
14 year time series of monthly averaged SST off Newport shows that PDO downscales to local SST



- PDO and SST correlated, as they should be.
- Note the three recent periods of persistent sign changes: mid-1999, mid-2003 and mid-2007
- However there are time lags between PDO sign change and SST response of ~ 3-5 months, suggesting perhaps that the PDO is an advective signal along the Oregon coast

Temperature differences usually ± 1° C

PDO and zooplankton: copepod community composition



The sign of the PDO is associated with warm (+) or cold (-) water in coastal waters of the northern California Current

As a consequence you get "warm" and "cold" water zooplankton communities in coastal waters with positive or negative phase of the PDO, but with a few months lag

← Warm water community

← Cold water community

Comparisons in size and biochemical composition/bioenergetics

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

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

Therefore, significantly different food chains result from PDO shifts;

What about coastal upwelling, a local factor?

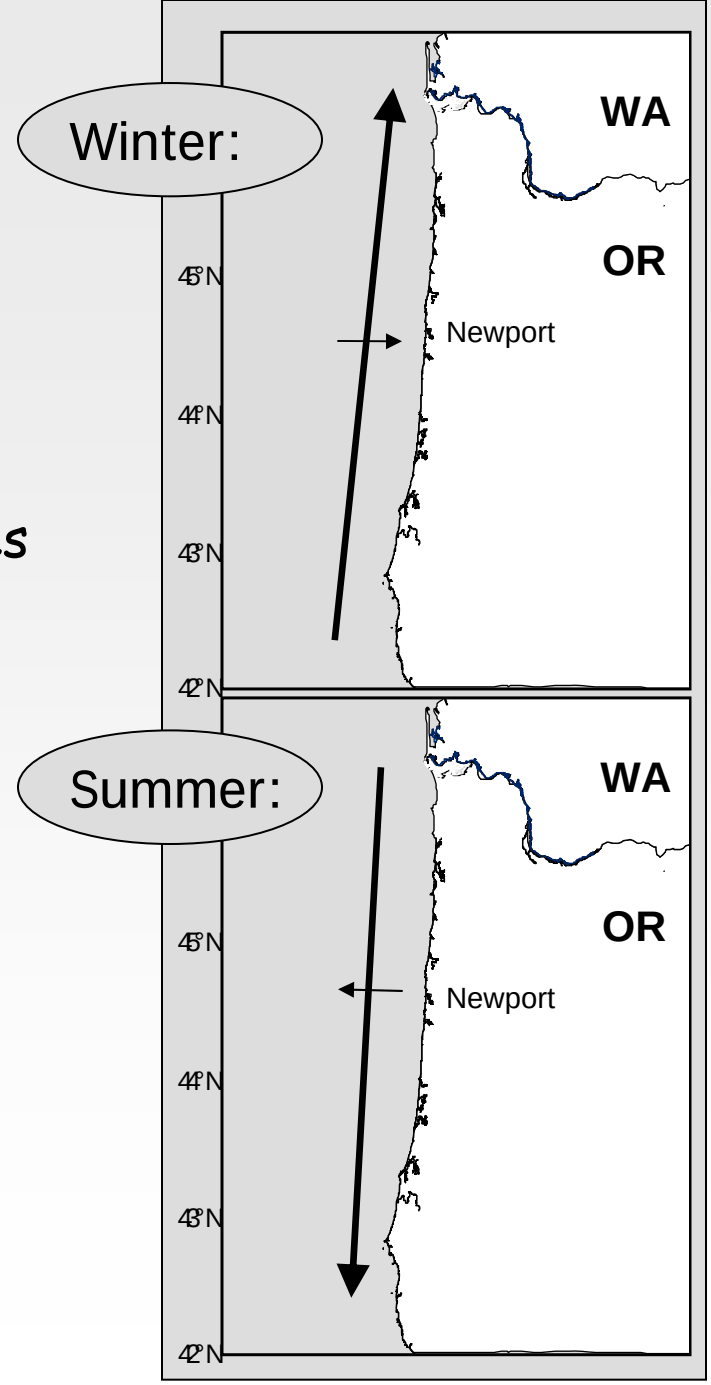
Winds and current structure off coastal Oregon:

- Winter:
  - Winds from the South
  - Downwelling
  - Poleward-flowing Davidson Current
  - Subtropical and southern plankton species transported northward & onshore
  - Many fish spawn at this time

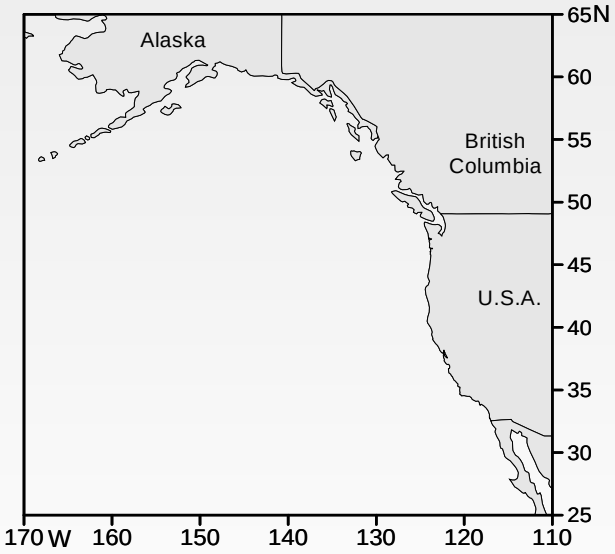
- **Spring Transition in April/May**

- Summer:
  - Strong winds from the North
  - Coastal upwelling
  - Equatorward alongshore transport
  - Boreal/northern species transported southward

- **Fall Transition in October**



Forecasting -- we use the following variables….



- Basin scale physical indicators
  - PDO
  - MEI
- Local scale physical indicators
  - SST
  - Upwelling
  - Date of physical spring transition
  - Length of upwelling season
- Biological indicators
  - Copepod biodiversity
  - N. copepod biomass anomaly
  - Copepod Community Structure
  - Biological spring transition
  - Catches of spring Chinook in June
  - Catches of coho in September

1. Data presented in a "stoplight" table as a visual representation of "ocean conditions" in each year, since 1998

2. Each of the individual data sets used in the forecasts are correlated to varying degrees with salmon survival.

3. We show two approaches to forming a simple **composite** index that combines the 16 time series to form a prediction:
    - Sum of ranks of the 16 variables vs. salmon survival
    - Maximum covariance analysis

Indicator Values

		1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PDO (December-March)		5.07	-1.75	-4.17	1.86	-1.73	7.45	1.85	2.44	1.94	-0.17	-3.06	-5.41
PDO (Sum May-September)		0.9	-5.54	-3.23	-2.95	-0.47	3.42	2.21	3.94	0.28	0.18	-6.08	-1.11
MEI Annual		0.87	-0.85	-0.51	-0.18	0.59	0.46	0.38	0.40	0.22	-0.20	-0.65	0.32
MEI Jan-June		2.28	-0.80	-0.63	-0.28	0.32	0.55	0.27	0.65	-0.42	0.49	-0.84	-0.23
SST 46050	deg C	13.70	13.14	12.54	12.56	12.30	12.92	14.59	13.43	12.60	13.88	12.5	13.02
SST NH 05 Summer	deg C	11.34	10.89	10.62	10.91	11.14	11.2	12.99	12.24	11.02	11.55	10.9	12.00
SST NH 05 Winter Before	deg C	12.11	10.52	10.26	10.31	10.01	10.81	11.32	11.07	10.92	9.96	9.03	9.63
SST NH 05 Winter After E	deg C	10.52	10.26	10.31	10.01	10.81	11.32	11.07	10.92	9.96	9.03	9.63	
Physical Spring Trans Log	Day of Year	105	91	72	61	80	112	110	145	112	74	89	82
Upwelling Anomaly (April-May)		-14	19	-36	2	-12	-34	-27	-55	-14	9	0	-5
NH 05 Deep T	deg C	8.58	7.51	7.52	7.50	7.39	7.75	7.88	7.91	7.92	7.55	7.46	7.83
NH 05 Deep S		33.51	33.87	33.83	33.87	33.87	33.7	33.66	33.79	33.82	33.88	33.9	33.68
Length of upwelling seasc	days	191	205	208	173	218	168	178	132	194	200	180	201
Copepod richness	no. of speci	5.49	-2.46	-3.03	-0.41	-0.72	1.52	0.57	5.02	3.67	-0.39	-0.53	-0.35
Northern Copepod Bioma	log biomass	-1.97	0.084	0.717	0.486	0.834	-0.08	0.262	-1.74	0.163	0.617	0.87	0.662
Biological Transition	Day of Year	187	119	96	129	120	156	131	206	150	81	63	83
Copepod Community stru	X-axis ordir	0.726	-0.82	-0.82	-0.78	-0.98	-0.18	-0.14	0.541	0.15	-0.66	-0.96	-0.8
June-Chinook Catches	fish per km	0.26	1.27	1.04	0.44	0.85	0.63	0.42	0.13	0.69	0.86	2.55	1.00
Sept-Coho Catches	fish per km	0.11	1.12	1.27	0.47	0.98	0.29	0.07	0.03	0.16	0.15	0.27	0.01

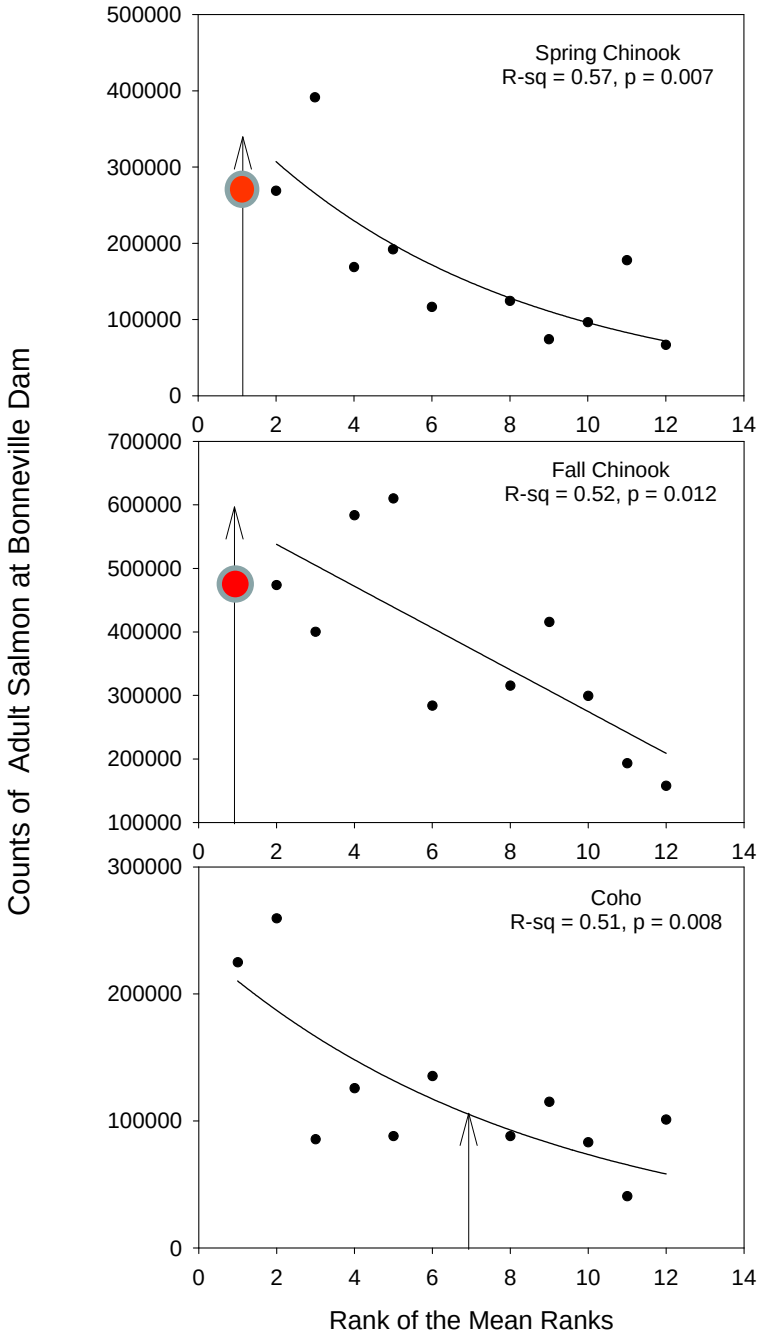
Stoplight Chart showing ocean conditions among years: 1998-2009

1998, 2003-2005 = warm & unproductive; poor salmon returns

1999-2002 and 2008 = cold & productive; record returns

Environmental Variables	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PDO (December-March)	11	5	2	8	4	12	7	10	9	6	3	1
PDO (May-September)	9	2	3	4	6	11	10	12	8	7	1	5
MEI Annual	12	1	3	5	11	10	8	9	6	4	2	7
MEI Jan-June	12	2	3	5	8	10	7	11	4	9	1	6
SST at 46050 (May-Sept)	10	8	4	5	1	6	12	9	2	11	3	7
SST at NH 05 (May-Sept)	8	2	1	4	6	7	12	11	5	9	3	10
SST winter before going to sea	12	7	5	6	4	8	11	10	9	3	1	2
Physical Spring Trans (Logerwell)	8	7	2	1	4	10	9	12	10	3	6	5
Upwelling (Apr-May)	7	1	11	3	6	10	9	12	7	2	4	5
Deep Temperature at NH 05	12	4	5	3	1	7	9	10	11	6	2	8
Deep Salinity at NH05	12	3	6	2	5	9	11	8	7	1	4	10
Length of upwelling season	7	3	2	10	1	11	9	12	6	5	8	4
Copepod richness	12	2	1	5	3	9	8	11	10	6	4	7
N.Copepod Anomaly	12	9	3	6	2	10	7	11	8	5	1	4
Biological Transition	11	5	4	7	6	10	8	12	9	2	1	3
Copepod Community structure	12	3	4	6	1	8	9	11	10	7	2	5
Catches of salmon in surveys												
June-Chinook Catches	11	2	3	9	6	8	10	12	7	5	1	4
Sept-Coho Catches	9	2	1	4	3	5	10	11	7	8	6	12
Mean of Ranks of Environmental Da	10.4	3.8	3.5	5.2	4.3	8.9	9.2	10.8	7.5	5.5	2.9	5.8
RANK of the mean rank	11	3	2	5	4	9	10	12	8	6	1	7

See our Center's website: http://www.nwfsc.noaa.gov and click on "Ocean conditions…"

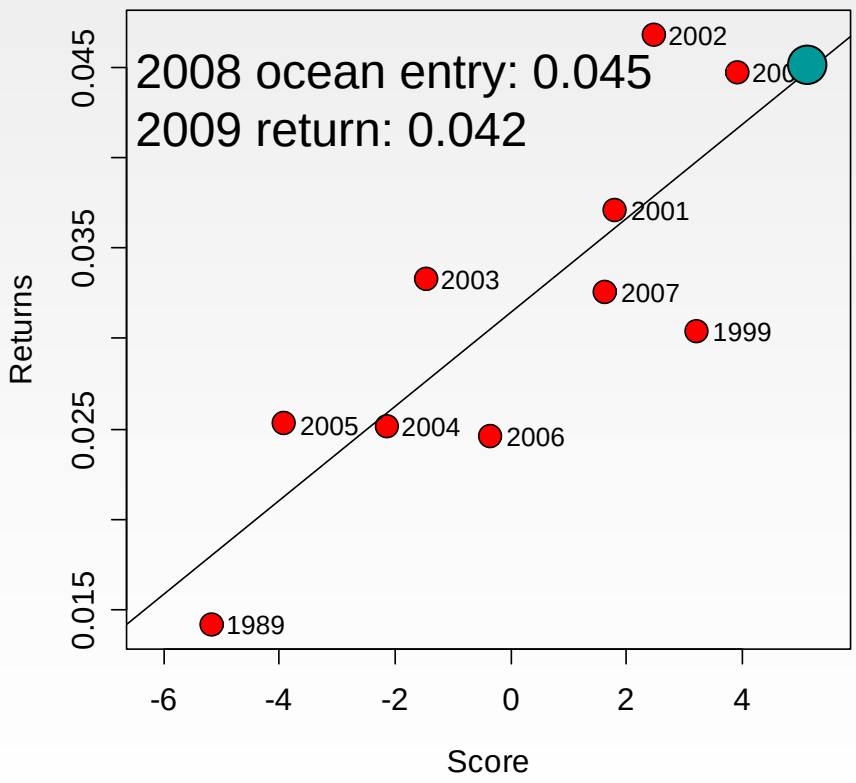


A simple approach to forecasting

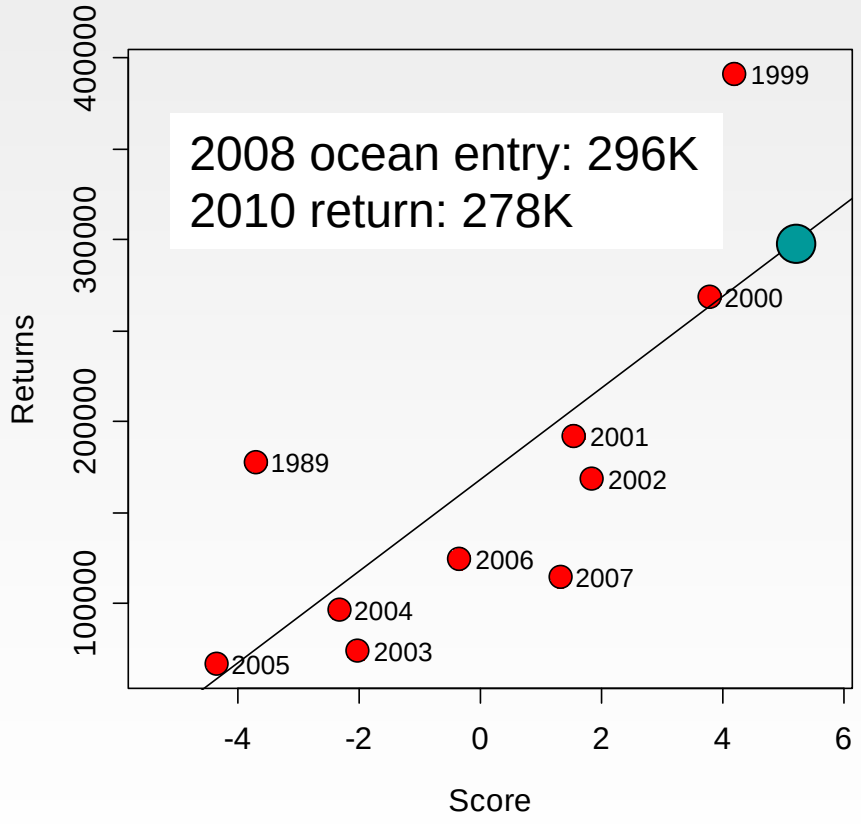
- Regression of salmon counts at Bonneville Dam with the rank of all variables.
- Spring Chinook (2008 ocean entry) returned in 2010 at 3rd highest in history (278K)
- Fall Chinook (2008 ocean entry) returned in 2010 at 3rd highest numbers; 466K (record was 604,200 in 2003).
- Of the Coho that went to sea in 2008, 224,592 passed Bonneville Dam in 2009 (2nd highest on record); Coho that went to sea in 2009 are just now returning; forecast to only reach about half that value.

Maximum Covariance Analysis (Brian Burke)

Coho salmon



Spring Chinook salmon



A chain of events (in a perfect year)

	Negative	Positive
• Changes in basin-scale winds lead to sign changes in PDO		
• 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!

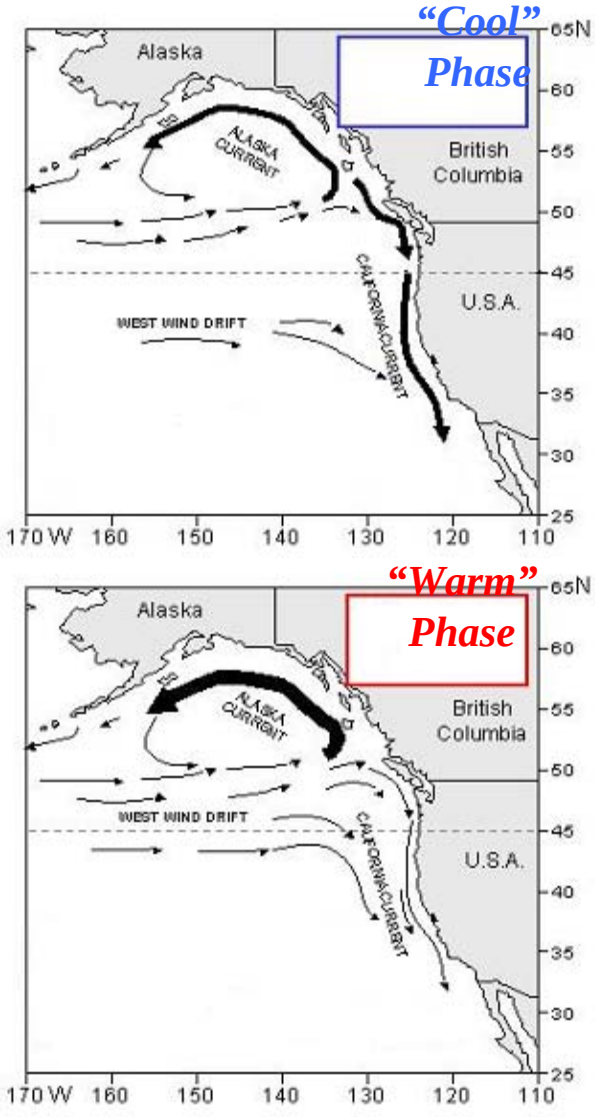
The PDO affects food chain structure through source waters…

Cool Phase ➔

Transport of boreal coastal copepods into NCC from Gulf of Alaska

Warm Phase ➔

Transport of sub-tropical copepods into NCC from Transition Zone offshore



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- See www.nwfsc.noaa.gov, "Ocean Conditions and Salmon Forecasting"