Modelers: know they fish

in other words, it will be difficult to forecast fisheries yields without knowledge of (a) basic life history parameters,(b) where fish live in the ocean and (c) when/where recruitment is set

Need to know the mechanisms

Bill Peterson, Senior Scientist

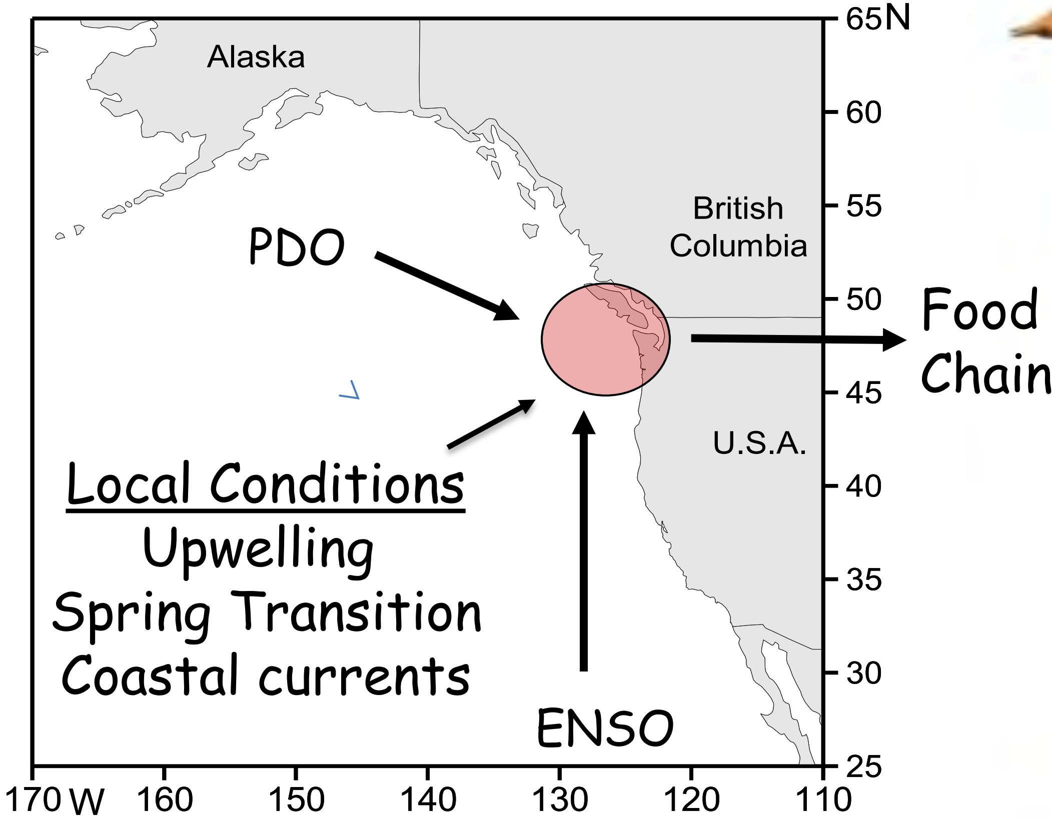
NOAA-Northwest Fisheries Science Center

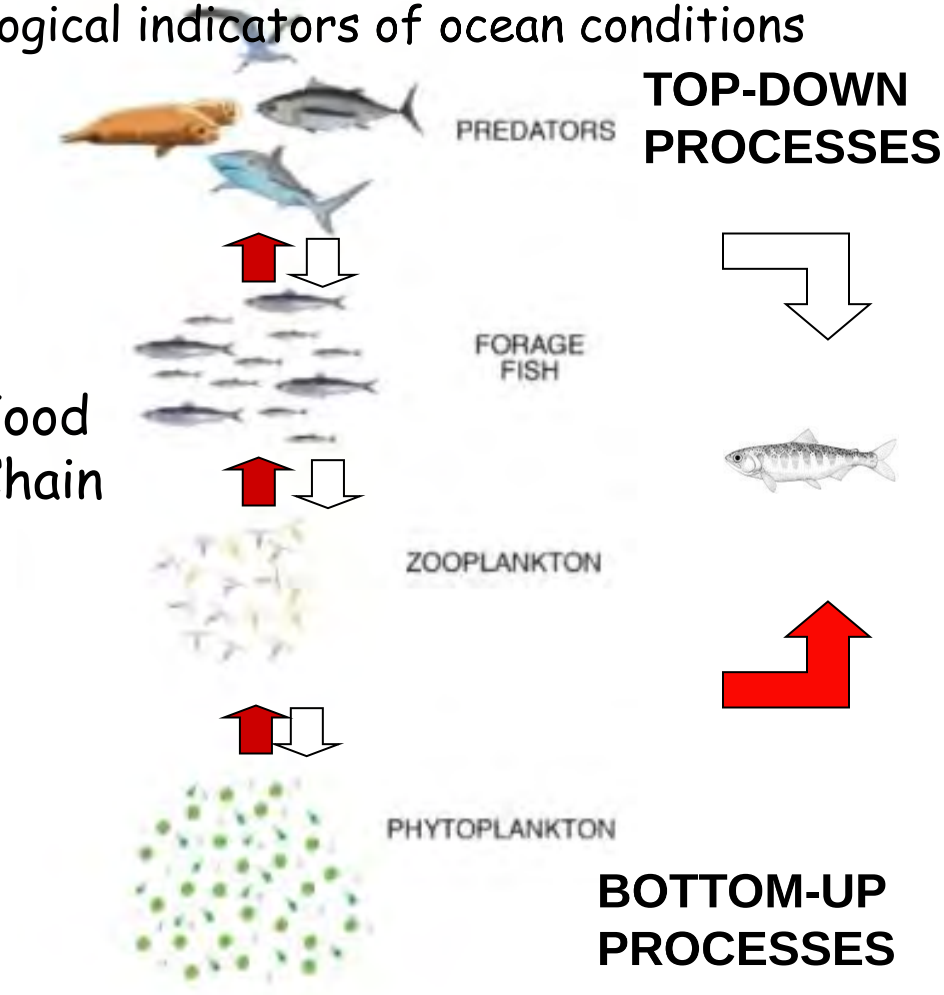
Hatfield Marine Science Center

Newport Oregon

We are contributing to a general understanding of the pelagic ecosystem of the northern California Current through our long-term ocean observations program which is resulting in "outlooks" and "management advice" for fisheries, 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 fishes such as salmon





How does climate variability affect our outlooks for the future? And what about climate change?

Local Biological Conditions: The Food Chain

The three most abundant salmon

	SPRING CHINOOK	FALL CHINOOK	COHO
Adults migrate to natal stream	Spring (March-April)	Autumn (after first heavy rains)	Autumn (after first heavy rains)
Spawning location	High elevation snow-fed streams	Main stem Columbia River; rain-fed tributaries	Rain-fed tributaries; Coast Range rivers along the Oregon coast
Time in freshwater	1+ years	6 months	1+ years
Migration downstream	Spring as a yearling	Spring as a sub-yearling	Spring as yearling
Residence in estuaries	No	Yes, for many months	No
Residence in local ocean waters	For a few weeks as they migrate slowly towards the coastal Gulf of Alaska	Likely for the entire time that they spend at sea	Most remain locally but some migrate north to the Gulf of Alaska
Age at Return	2-ocean	3-ocean	1.5-ocean

Several lines of evidence that suggest that year-class strength is set during the first summer at sea:

(a) jack salmon correlate with adults one year later and

(b) correlations of adult returns with environmental data are always significant with 1, 2 or 3 year lags depending on species and life history type.

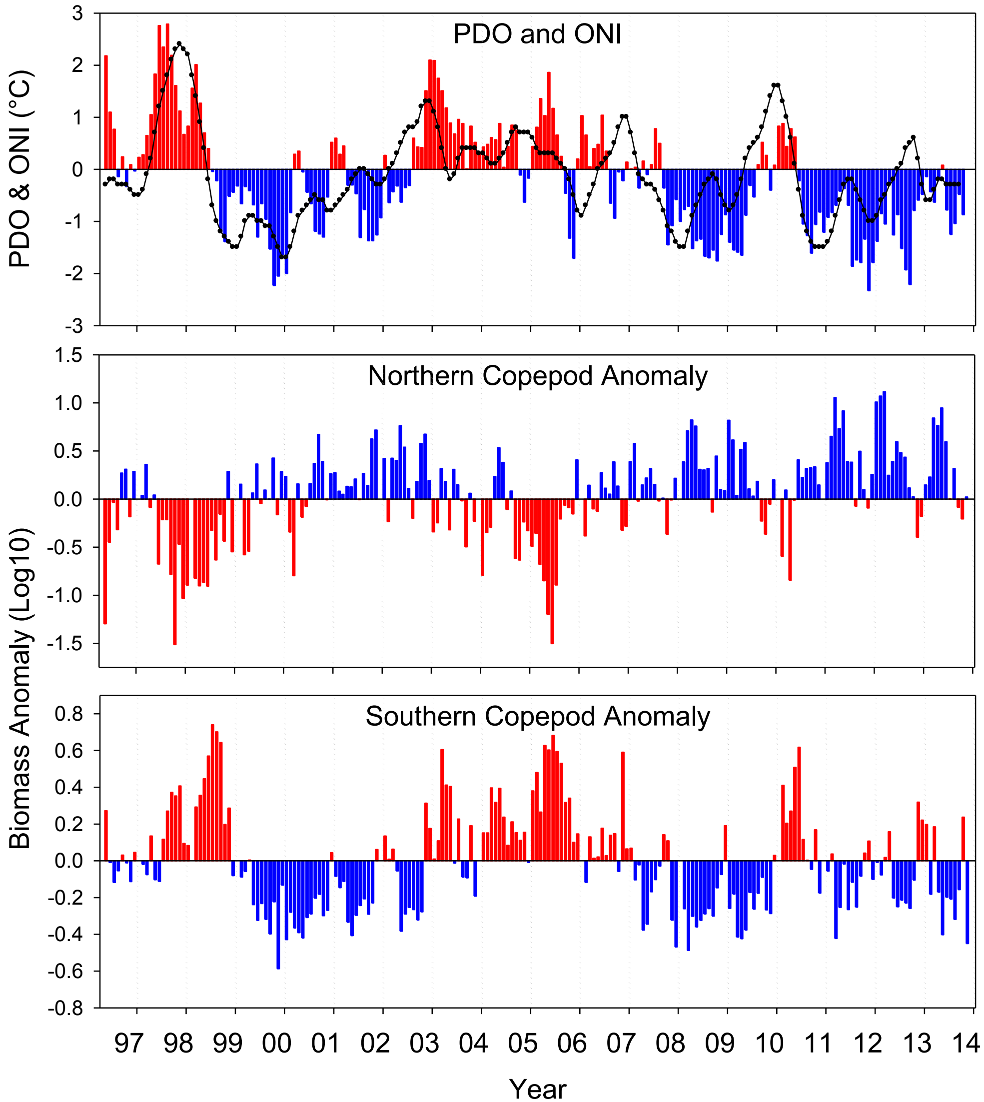
We also know where these fish live in the ocean as juveniles thus know some of their habitat parameters (temperature, salinity, chlorophyll, copepods

We know from past research (in part by Mantua and others) that changes in the sign of the PDO (a basin scale indicator) translate into changes in salmon returns (a local response) throughout the North Pacific

But what mechanism(s) link the forces that give us the PDO with salmon production?

I will show that the PDO seems to control pelagic food chain structure as indexed by copepod species composition

PDO and Copepod Groups



- PDO and ONI often track each other most of the time
- Anomalously high biomass of "northern" copepod species when the PDO is in negative phase
- Anomalously high biomass of "southern copepod species" under three conditions:
  - when PDO is in positive phase;
  - During strong El Niño events:1997-1998 and 2009-10
  - During weak El Niño events of 03-06
  - During the non-event in 2012
  - But NOT during the 2006-07 El Niño event

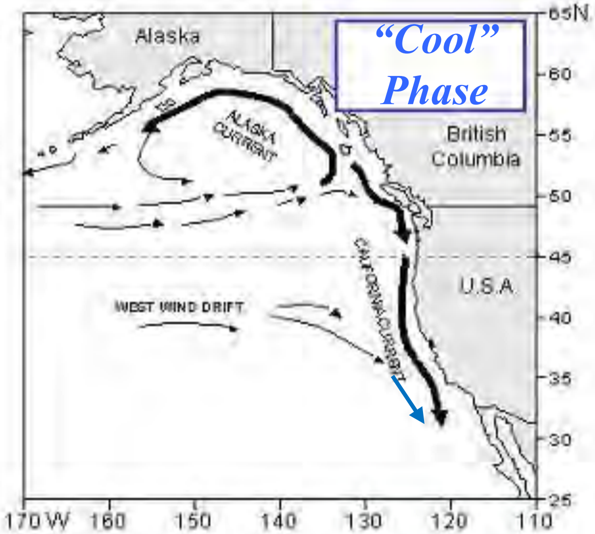
Comparisons of copepods by size and chemical composition

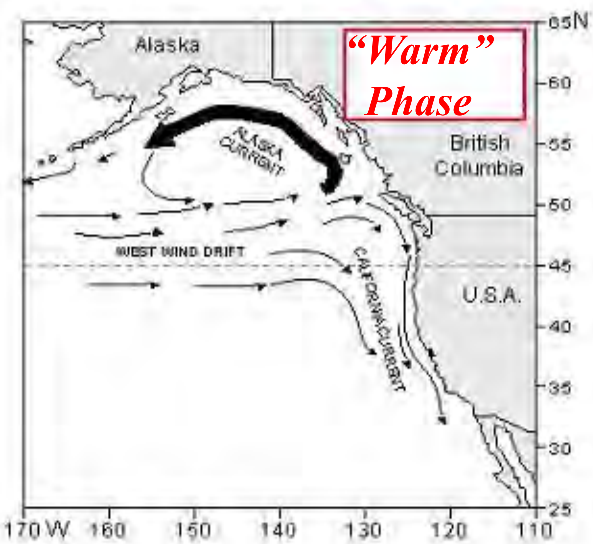
- **Warm-water subtropical taxa** - (from offshore OR and S. California) are **small** in size and have minimal high energy wax ester lipid depots
- **Cold-water taxa** – (boreal coastal species) are **large** and store high-energy **wax esters** as an over-wintering strategy

Therefore, significantly different food chains result from climate shifts

A fat salmon is a happy salmon

Dramatic changes in pelagic food webs occur with changes in phase of the PDO





1. "Cool Phase". Strong subarctic coastal currents bring cold water and large **lipid-rich copepod** species to the N. Calif. Current (NCC);

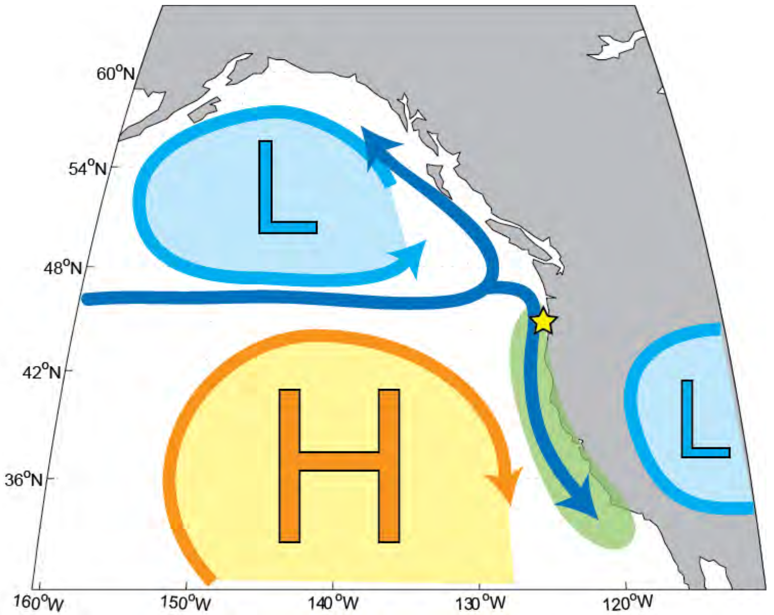
2. "Warm Phase". The West Wind Drift and seasonal reversals in coastal currents bring subtropical water and **small lipid-poor subtropical copepod** species to the NCC

3. Therefore, bioenergetic content of the food chain is controlled by the source waters which feed the NCC.

Cartoon from Ryan Rykaczewski

Cool Coastal Phase:

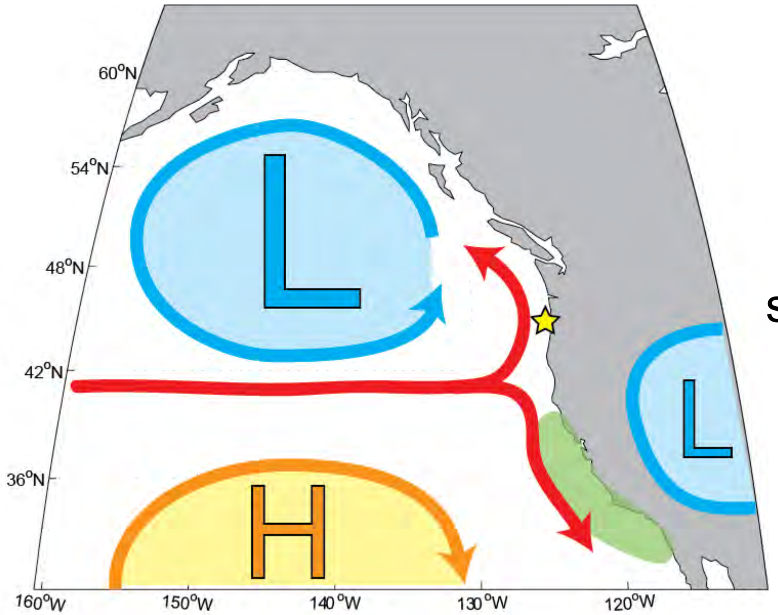
Weaker low pressure; but **more southerly flow** along the coast; rich, boreal zooplankton at Newport



Smaller subpolar gyre; Larger subtropical gyre

Warm Coastal Phase:

Stronger low pressure; but **more northerly flow** along the coast; smaller, subtropical zooplankton at Newport



Larger subpolar gyre; Smaller subtropical gyre

In constructing “outlooks” or “forecasts” we use the following variables because each individually is significantly correlated with salmon returns

- Basin scale physical indicators
  - PDO, ONI
- Local scale physical indicators
  - SST, T of upper 20 m in shelf waters, temperature and salinity of deep water which will upwell
- Local biological indicators
  - Copepod biodiversity
  - Northern copepod biomass
  - Copepod community structure (from ordinations)
  - Date of biological spring transition
  - Composition of fish larvae in winter before salmon enter the sea (as an index of fish available when juv. salmon enter the sea in April/May)
  - Catches of spring Chinook in June
  - Catches of coho in September
- Not used because of low information content
  - Upwelling, date of physical spring transition, length of upwelling season

DATA MATRIX

INDICATORS 1998 ← YEAR → 2013

Ecosystem Indicators	*units*	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
PDO (Sum Dec-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	2.17	-3.65	-5.07	-1.67
PDO (Sum May-September)		-0.37	-5.13	-3.58	-4.22	-0.26	3.42	2.96	3.48	0.28	0.91	-7.63	-1.11	-3.53	-6.45	-7.79	-3.47
ONI Jan-June (Average)		1.08	-1.10	-1.13	-0.42	0.23	0.33	0.20	0.37	-0.38	0.02	-1.05	-0.27	0.70	-0.77	-0.42	-0.38
46050 SST (May-Sept)	deg C	13.66	13.00	12.54	12.56	12.30	12.92	14.59	13.56	12.77	13.87	12.39	13.02	12.92	13.06	13.26	13.37
NH 05 Upper 20 m T winter prior (Nov-Mar)	deg C	12.27	10.31	10.12	10.22	10.08	10.70	10.85	10.60	10.61	10.04	9.33	10.19	11.01	10.02	9.62	10.09
NH 05 Upper 20 m T (May-Sept)	deg C	10.38	10.13	10.19	9.77	8.98	9.62	11.39	10.73	9.97	9.99	9.30	9.90	10.14	10.05	9.95	10.63
NH 05 Deep Temperature	deg C	8.61	7.63	7.74	7.56	7.45	7.81	7.89	7.97	7.83	7.58	7.48	7.73	7.89	7.86	7.56	8.30
NH 05 Deep Salinity		33.54	33.86	33.78	33.86	33.85	33.68	33.66	33.77	33.85	33.88	33.87	33.72	33.61	33.74	33.75	33.70
Copepod Richness Anomaly (May-Sept)	no. of species	4.37	-2.83	-3.61	-1.28	-1.35	1.67	1.24	4.14	2.47	-0.88	-1.01	-0.89	2.87	-2.38	-1.53	-3.16
N. Copepod Biomass Anomaly (May-Sept)	log mg C m^{-3}	-0.58	0.09	0.19	0.15	0.28	-0.08	0.05	-0.77	0.14	0.14	0.31	0.14	0.25	0.42	0.40	0.35
S. Copepod Biomass Anomaly (May-Sept)	log mg C m^{-3}	0.62	-0.30	-0.28	-0.29	-0.30	0.09	0.22	0.55	0.10	-0.10	-0.31	-0.22	0.24	-0.15	-0.23	-0.26
Biological Transition	day of year	263	134	97	79	108	156	132	238	180	81	64	65	169	82	125	91
Winter Ichthyoplankton	log mg C 1000 m^{-3}	0.12	0.90	1.80	1.25	1.05	0.53	0.58	0.83	0.59	0.60	1.84	0.89	1.65	0.61	0.99	1.16
Chinook Juv Catches (June)	fish per km	0.26	1.27	1.04	0.44	0.85	0.63	0.42	0.13	0.69	0.86	2.56	0.97	0.89	0.46	1.32	1.38
Coho Juv Catches (Sept)	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	0.03	0.30	0.13	NA
Ecosystem Indicators not included in the mean of ranks or statistical analyses																	
Physical Spring Trans UI Based	day of year	83	88	134	120	84	109	113	142	109	70	87	82	95	105	123	97
Upwelling Anomaly (April-May)		-14	19	-36	2	-12	-34	-27	-55	-14	9	0	-5	-35	-36	-35	-21
Length of Upwelling Season (UI Based)	days	191	205	151	173	218	168	177	129	195	201	179	201	161	153	161	164
NH 05 SST (May-Sept)	deg C	11.39	11.09	11.06	11.03	10.12	10.78	13.23	12.11	11.26	11.90	10.78	12.14	11.32	11.15	11.73	11.95
Copepod Community structure	x-axis ordination	0.71	-0.76	-0.75	-0.73	-0.91	-0.17	-0.14	0.53	0.01	-0.62	-0.83	-0.73	-0.19	-0.64	-0.72	-0.79

Seven Physical Indicators

- PDO (Dec-March
- PDO (May-Sept
- ONI (Jan-June)
- SST (NOAA Buoy, 22 miles offshore
- SST (upper 20 m average, mid-shelf
- T of deep water on the shelf that will upwell
- S of deep water on the shelf that will upwell

Seven Biological Indicators

- Copepod species richness
- Northern (cold water) copepod anomaly
- Southern (warm water) copepod anomaly
- Biological transition
- Winter ichthyoplankton biomass
- Catch of juv. chinook salmon in June
- Catch of juv. coho salmon salmon in Sep

Ecosystem Indicators	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
PDO (December-March)	15	6	3	11	7	16	10	14	12	9	5	1	13	4	2	8
PDO (May-September)	10	4	6	5	11	15	14	16	12	13	2	9	7	3	1	8
ONI Jan-June	16	2	1	5	12	13	11	14	7	10	3	9	15	4	5	7
46050 SST (May-Sept)	14	8	3	4	1	7	16	13	5	15	2	9	6	10	11	12
NH 05 Upper 20 m T winter prior (Nov-Mar)	16	10	7	9	5	13	14	11	12	4	1	8	15	3	2	6
NH 05 Upper 20 m T (May-Sept)	13	10	12	4	1	3	16	15	7	8	2	5	11	9	6	14
NH 05 Deep Temperature	16	6	8	4	1	9	12	14	10	5	2	7	13	11	3	15
NH 05 Deep Salinity	16	3	7	4	5	13	14	8	6	1	2	11	15	10	9	12
Copepod Richness Anomaly	16	3	1	7	6	12	11	15	13	10	8	9	14	4	5	2
N. Copepod Biomass Anomaly	15	12	7	8	5	14	13	16	9	11	4	10	6	1	2	3
S. Copepod Biomass Anomaly	16	3	5	4	2	11	13	15	12	10	1	8	14	9	7	6
Biological Transition	16	11	7	3	8	12	10	15	14	4	1	2	13	5	9	6
Winter Ichthyoplankton	16	8	2	4	6	15	14	10	13	12	1	9	3	11	7	5
Chinook Juv Catches (June)	15	4	5	13	9	11	14	16	10	8	1	6	7	12	3	2
Coho Juv Catches (Sept)	11	2	1	4	3	6	12	14	8	9	7	15	13	5	10	NA
Mean of Ranks	14.7	6.1	5.0	5.9	5.5	11.3	12.9	13.7	10.0	8.6	2.8	7.9	11.0	6.7	5.5	7.6
RANK of the Mean Rank	16	6	2	5	3	13	14	15	11	10	1	9	12	7	3	8
Principle Component Scores (PC1)	6.58	-2.18	-2.93	-1.56	-2.07	2.19	3.11	4.28	1.00	-0.24	-4.41	-0.96	1.67	-1.40	-2.07	-1.01
Principle Component Scores (PC2)	0.04	0.21	0.42	-1.04	-2.20	-1.73	2.24	-0.73	-1.18	0.15	-0.78	0.58	-0.35	1.24	0.96	2.16
Ecosystem Indicators not included in the mean of ranks or statistical analyses																
Physical Spring Trans (UI Based)	3	6	15	13	4	10	12	16	10	1	5	2	7	9	14	8
Upwelling Anomaly (Apr-May)	7	1	14	3	6	11	10	16	7	2	4	5	12	14	12	9
Length of Upwelling Season (UI Based)	6	2	15	9	1	10	8	16	5	3	7	3	12	14	12	11
NH 05 SST (May-Sept)	10	6	5	4	1	3	16	14	8	12	2	15	9	7	11	13
Copepod Community Structure	16	4	5	7	1	12	13	15	14	10	2	6	11	9	8	3

PHYSICS SUGGESTS AN AVERAGE YEAR

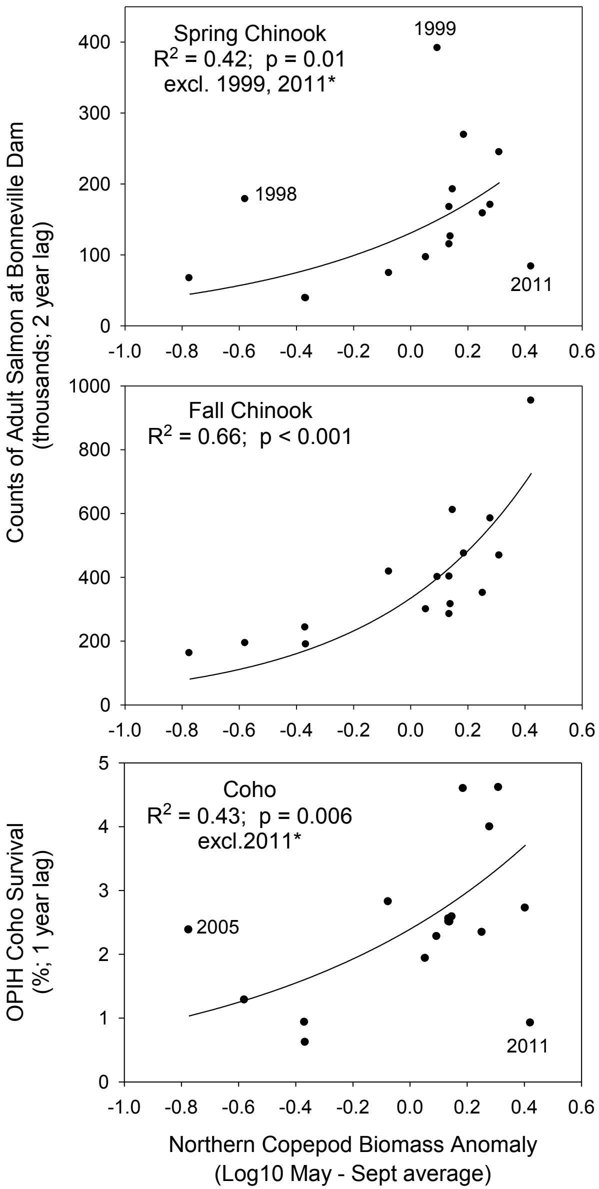
PDO 8th rank both winter and summer
Winter SST 6nd coldest
Spring Transition 8th
Length of upwelling season 11th

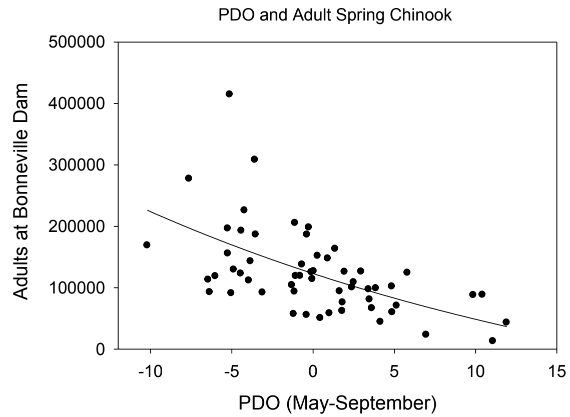
BIOLOGY SUGGESTS A VERY GOOD YEAR

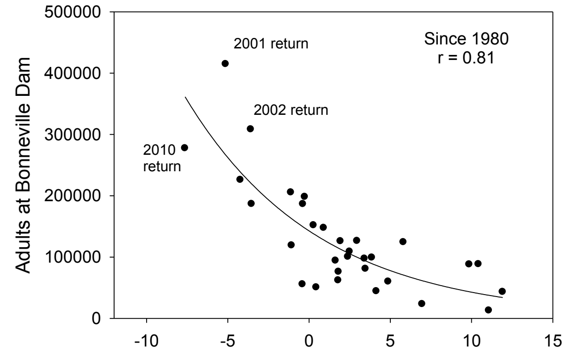
Northern Copepods 3rd highest
Copepod Community Index 3rd highest
Winter Ichthyoplankton 5th ranked
Catches of spring Chinook in June 2nd highest

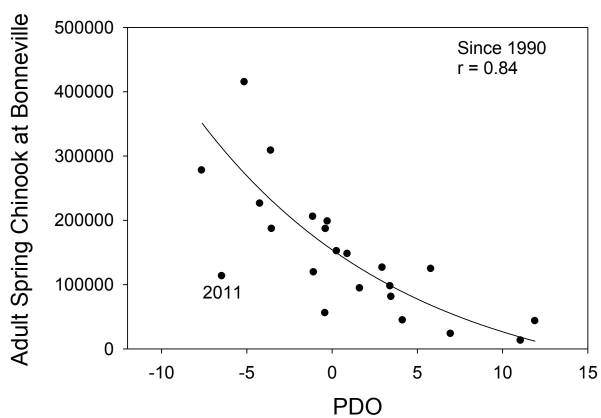
PC 1 = -1.01, 8th ranked

Northern Copepods, PDO and salmon returns to Bonneville Dam



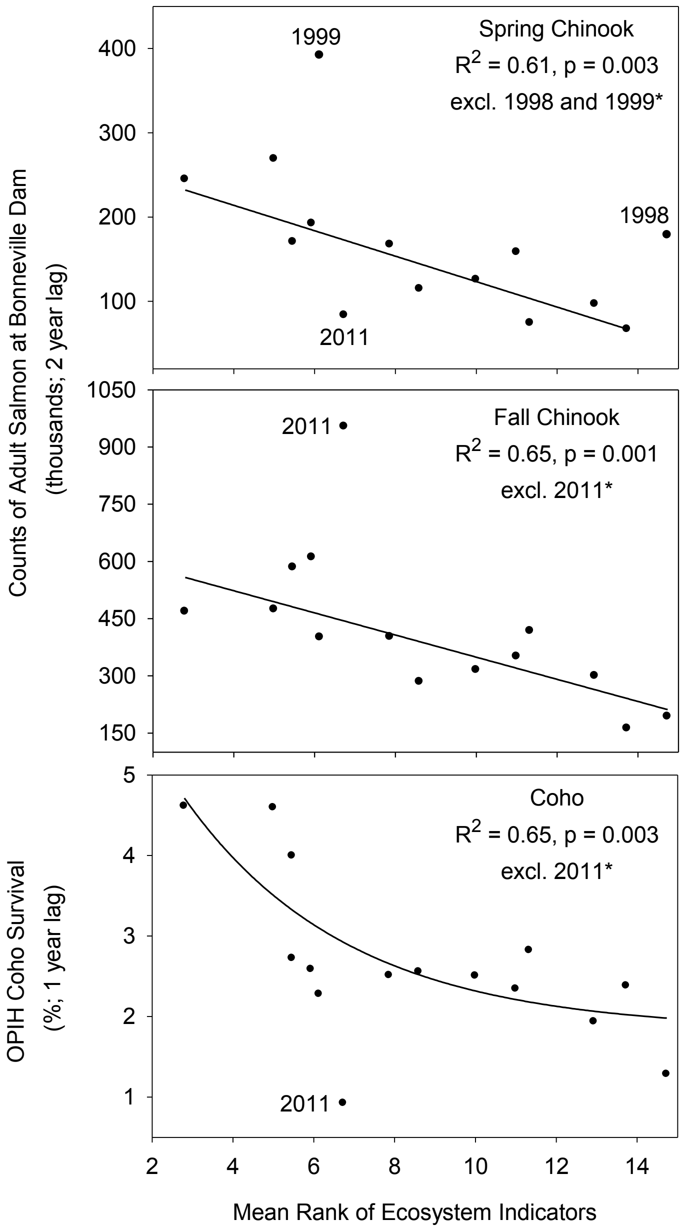




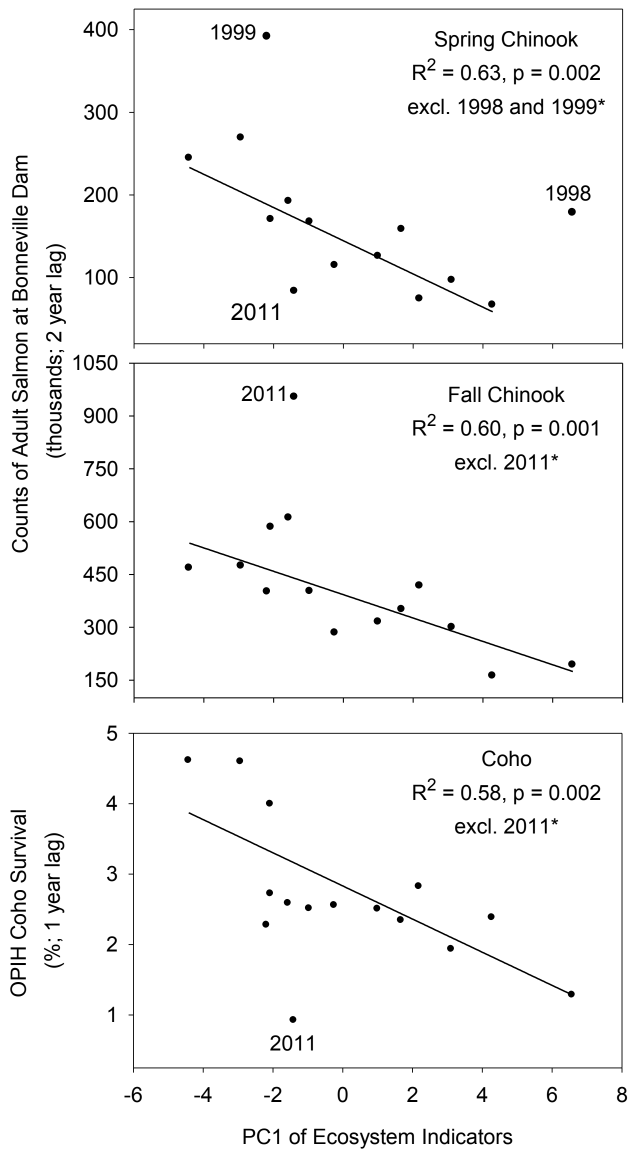


- Copepods work well for fall Chinook and for spring Chinook in most years.
- PDO and Spring chinook correlations are improving!
  - Top: since 1955
  - Middle: since 1980
  - Bottom: since 1990

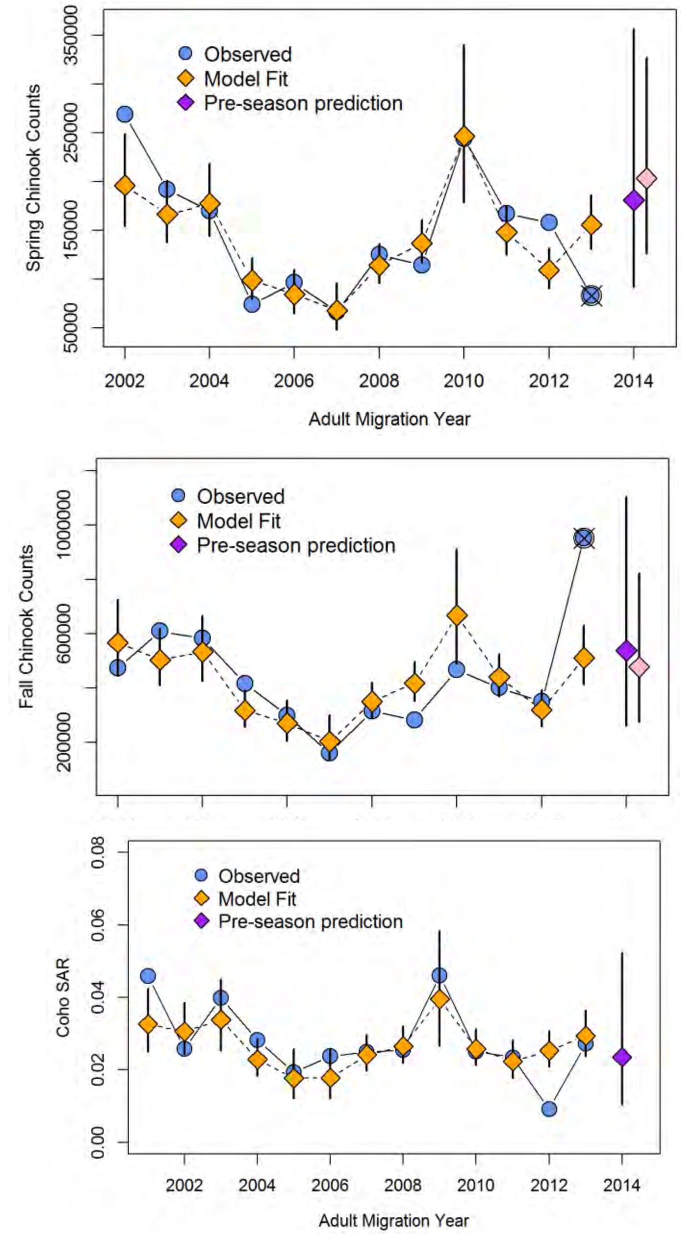
Using only the rank of the mean ranks (non-parametric)



Principal Components Analysis



Maximum Covariance Analysis



Outlooks based on single predictor variables. The advantage is that we can include predictor variables that are less than the full time series in length (e.g., Bongos, IGF, others)

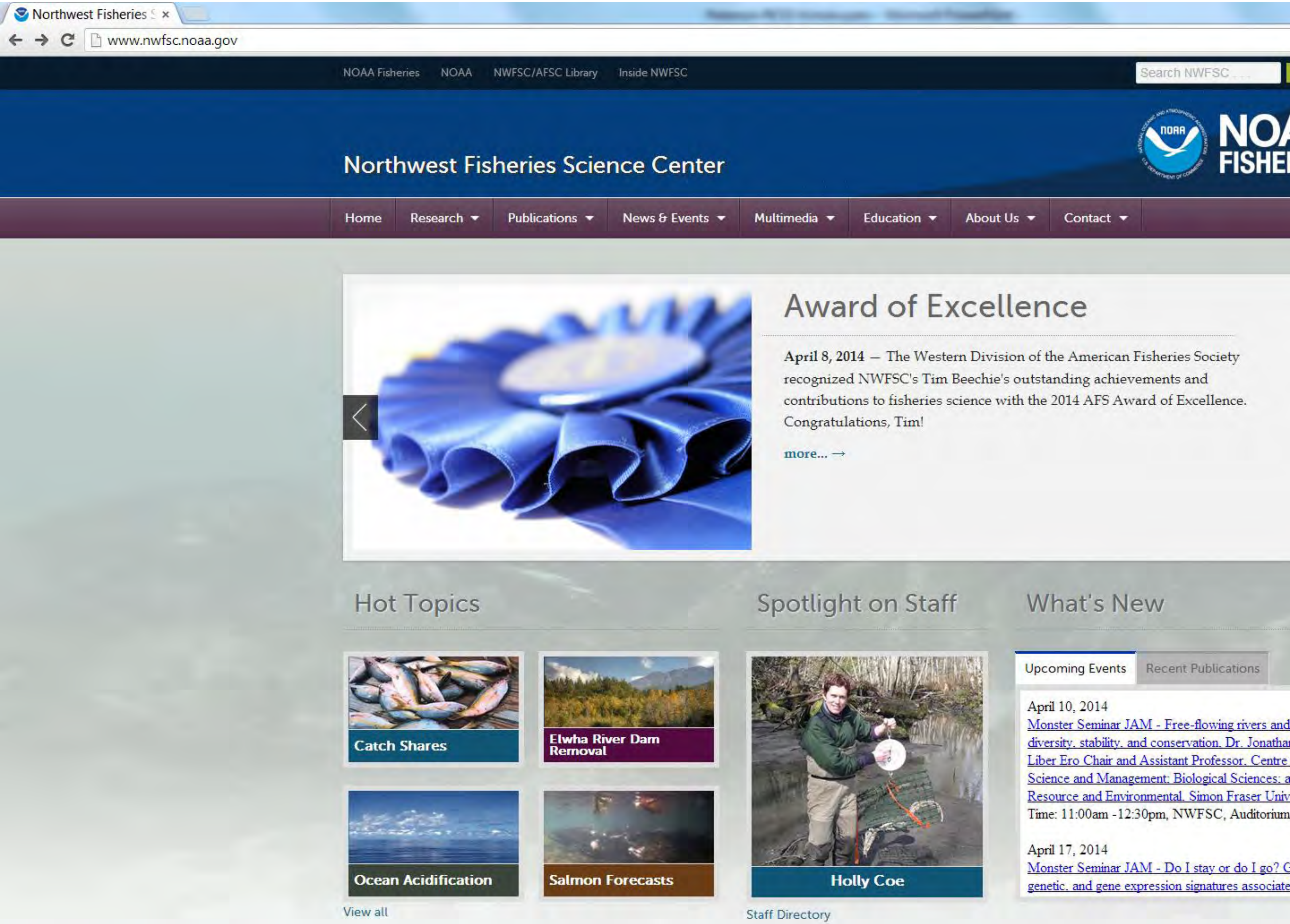
	Outlook for 2014 Adult Salmon Returns		
	coho	Spring Chinook	Fall Chinook
Metric	(SAR, %)	(Adults at BON)	(Adults at BON)
Multivariate			
MCA	2.82	199,993	461,381
PCA	3.07	186,094	461,259
Rank	2.71	191,295	479,592
Single factor			
Northern Copepods	3.52	230,014	702,386
Prey (Bongo Nets)	3.06	270,999	682,970
CCI	3.02	173,844	453,186
IGF	NA	300,211	NA
Jacks	NA	317,673	402,609
Winter Ichthyo.	2.99	152,749	384,287

Our forecasts were completely wrong for salmon that went to sea in 2011 and returned in 2012 (coho) and 2013 (spring Chinook)

- Spring Chinook counts were 83K whereas we had forecasted 200K
- Coho were < 1% but we expected 3%
- Biological ccean conditions were very good (PDO and copepods) but physical indicators were not (upwelling was delayed and weak)
- Convened a workshop in June 2013 and learned from our Alaskan colleagues that the Gulf of Alaska was not productive in summer 2011 (Zador talk this afternoon)
- Failure is a good thing because it gives one a chance to hopefully determine why the failure occurred. Working out "why" may reveal the need to add a "missing explanatory variable" or perhaps delete long-standing "explanatory variables".
  - coastal upwelling once "explained everything" but correlations with salmon returns are no longer significant
  - spring transition has since failed
  - PDO is now showing signs of failing

Engagement

- Website is very popular
- But, direct use of data by managers is a problem!
  - Managers are reluctant to make rigorous use of our data because there is no guarantee that they will be available next year.
  - All of our work is based on “research dollars” generated through the “proposal process”. It could all end tomorrow!
- Regardless, we are planning to add a blog to our website within the next few weeks with biweekly updates on “ocean conditions”; should be especially interesting due to a major El Niño brewing at the equator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April 8, 2014 — The Western Division of the American Fisheries Society recognized NWFSC's Tim Beechie's outstanding achievements and contributions to fisheries science with the 2014 AFS Award of Excellence. Congratulations, Tim!
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Ocean Indicators and Salmon Forecasting

Since 1996, the Center has been monitoring the ocean environment off the Washington and Oregon coasts, its interaction with the California Current, and how ocean conditions affect salmon. This ongoing research is helping us better understand some key relationships between climate, oceanography, and biology that largely determine the fate of salmon entering the ocean during specific years.

What is the ocean index?

NWFSC scientists have developed a novel ocean index tool that combines a suite of oceanographic data, such as sea surface temperature, with biological indicators, such as the amount of salmon prey. Together, these indicators can capture the dynamics of a changing ecosystem and allow us to predict the relative abundance of Chinook and coho harvests far enough in advance for decision makers to plan for good, average, or poor-yield years. The accuracy of such predictions is invaluable to state and federal fishery managers in setting harvest limits and allocations and for tracking recovery of endangered or threatened salmon runs.

Recent salmon forecasts

In 2008, scientists tracked one of the highest levels of ocean productivity observed on record, with a negative Pacific Decadal Oscillation (PDO)

Research

Themes
- Habitats
- Species
- Ecosystem Science
- Seafood Safety

Research Divisions
- Conservation Biology
- Environmental and Fisheries Sciences
- Fish Ecology
- Fishery Resource Analysis and Monitoring

Other Projects

Data & Technololgies

Explore More

Annual salmon

Learn more abo indicators

NWFSC top stor Predicting salm (2008)

Forecast of Adult Returns for coho salmon Chinook Salmon

2013 was another year of mixed ocean conditions. The climate-indicators, such as PDO and El Niño, were 'neutral', sea surface temperatures were warmer than usual, and the majority of the upwelling occurred over a short period of time (July) with the upwelling 'season' ultimately ending much earlier than usual. The biological indicators pointed to good ocean conditions, with a high abundance of large, lipid-rich zooplankton, a moderate abundance of winter fish larvae that develop into salmon prey in the spring, and catches of juvenile spring Chinook salmon during the June survey off Washington and Oregon that were the second highest in 16 years. Overall, juvenile salmon entering the ocean in 2013 encountered average to above average ocean conditions off Oregon and Washington.

Our annual summary of ecosystem indicators during 2013 is here, and our "stoplight" rankings and predictions are shown below in Table 1, Table 2, and Figure SF-01.

Table 1. Ocean ecosystem indicators of the Northern California Current. Colored squares indicate positive (green), neutral (yellow), or negative (red) conditions for salmon entering the ocean each year. In the two columns to the far right, colored dots indicate the forecast of adult returns based on ocean conditions in 2013 (coho salmon) and 2012 (Chinook salmon).

	Juvenile Migration Year				Adult Return Outlook	
	2010	2011	2012	2013	Coho 2014	Chinook 2014
Large- scale ocean and atmospheric indicators						
PDO (May – Sept)	yellow	green	green	yellow	yellow	green
ONI (Jan-Jun)	red	green	green	yellow	yellow	green
Local and regional physical indicators						

Why produce outlooks for salmon returning to the Columbia River

- **Habitat Restoration and Dam Passage**. Need to interpret freshwater actions in light of variable ocean conditions.
- **Early Warning Indicators** from ocean data
  - El Niño forecast – what might be the outcome
  - PDO changing sign frequently
  - Delayed upwelling
  - Water column stratification
  - Hypoxia and ocean acidification
- **In season prediction of future ocean conditions**. Useful for knowing when to release hatchery fish to the ocean?
- **Why settle for an upwelling index or a PDO value for your forecasting attempts when you have a long time series of rich ecological measurements?**

My Friends

FATE
FISHERIES AND THE ENVIRONMENT

GLOBEC
Global Ocean Ecosystem Dynamics

BONNEVILLE
POWER ADMINISTRATION

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
U.S. DEPARTMENT OF COMMERCE

NSF

U.S. GLOBEC
Northeast Pacific Program

Pacific Ocean Boundaries
POBEX
Ecosystem and Climate Study

CAMEO
COMPARATIVE ANALYSIS OF MARINE ECOSYSTEM ORGANIZATION

NASA

What about recruitment in other fishes in the California Current

- Sablefish and copepods match-up well
- Sardines and warm water copepods match-up well
- Juv. Rockfish show some promise
- Hake recruit

Sardines and Rockfish