Tracking ecosystem change in the northern California Current: a role for long-term shipboard observations

Bill Peterson
Senior Scientist, NOAA Fisheries
Hatfield Marine Science Center, Newport Oregon
And
Jay Peterson[2], Cheryl Morgan[2] and Jennifer Fisher[2]
[2] Oregon State University, Cooperative Institute for Marine Resource Studies

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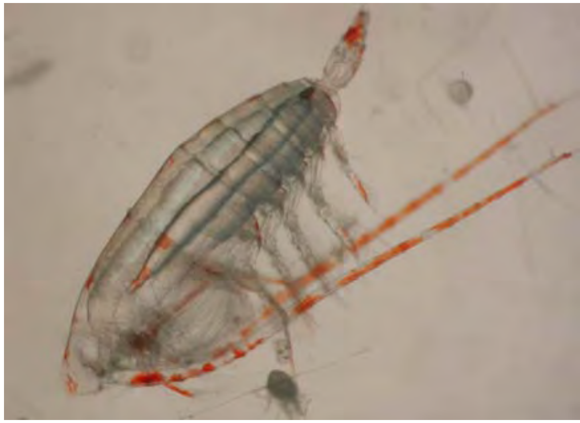
<www.nwfsc.noaa.gov> "Ocean Conditions and Salmon Forecasting"



We provide forecasts of returns of three types of salmon to rivers of the Pacific Northwest. Others have tried with limited success, using the following:

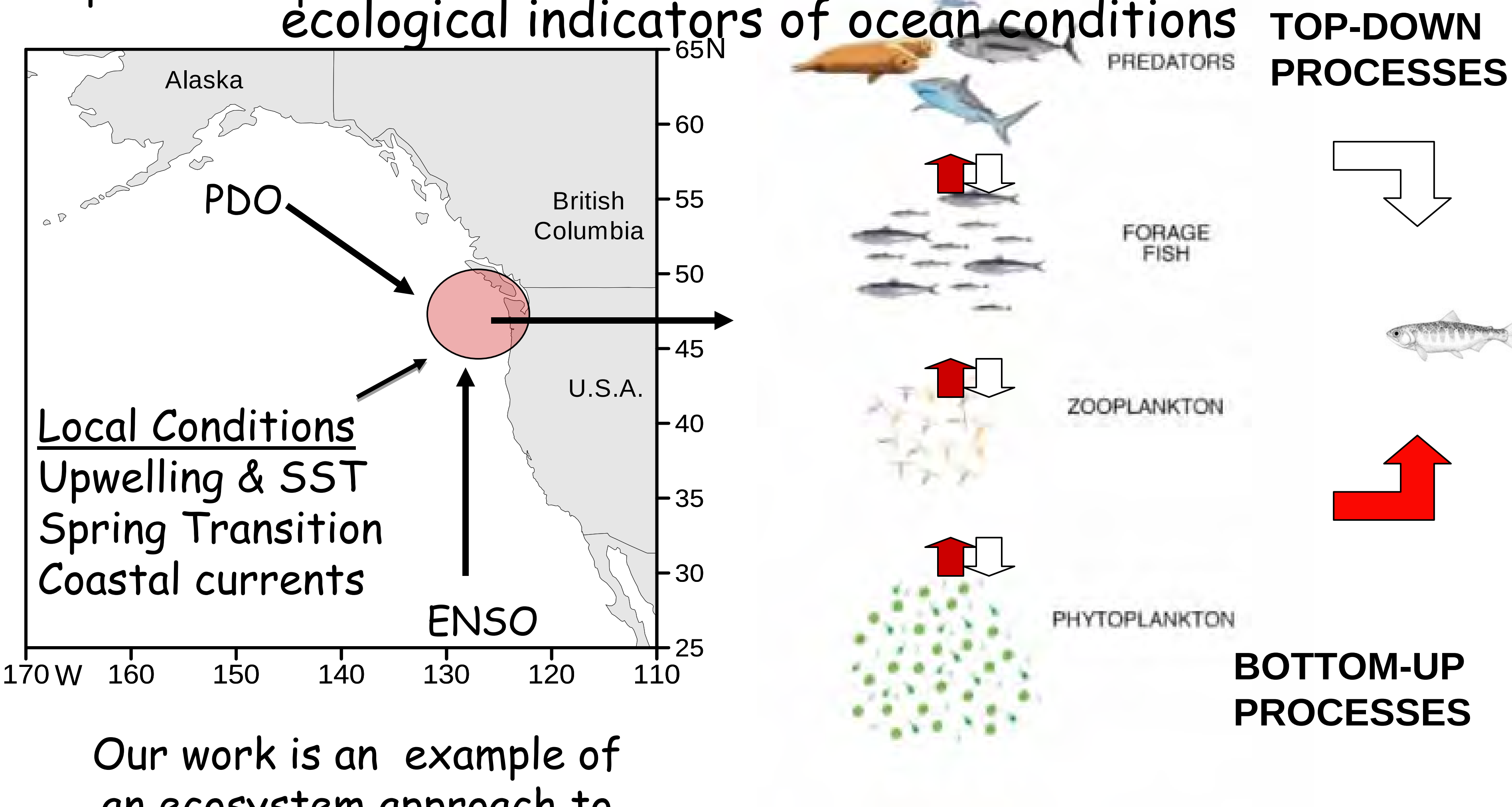
- coastal upwelling index
- date of transition to upwelling in spring from winter downwelling conditions.
- SST during the winter before salmon go to sea
- Pacific Decadal Oscillation

Data for each of these indices can be provided by physical oceanographic observing systems, but are physical observations sufficient?

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 of ocean conditions

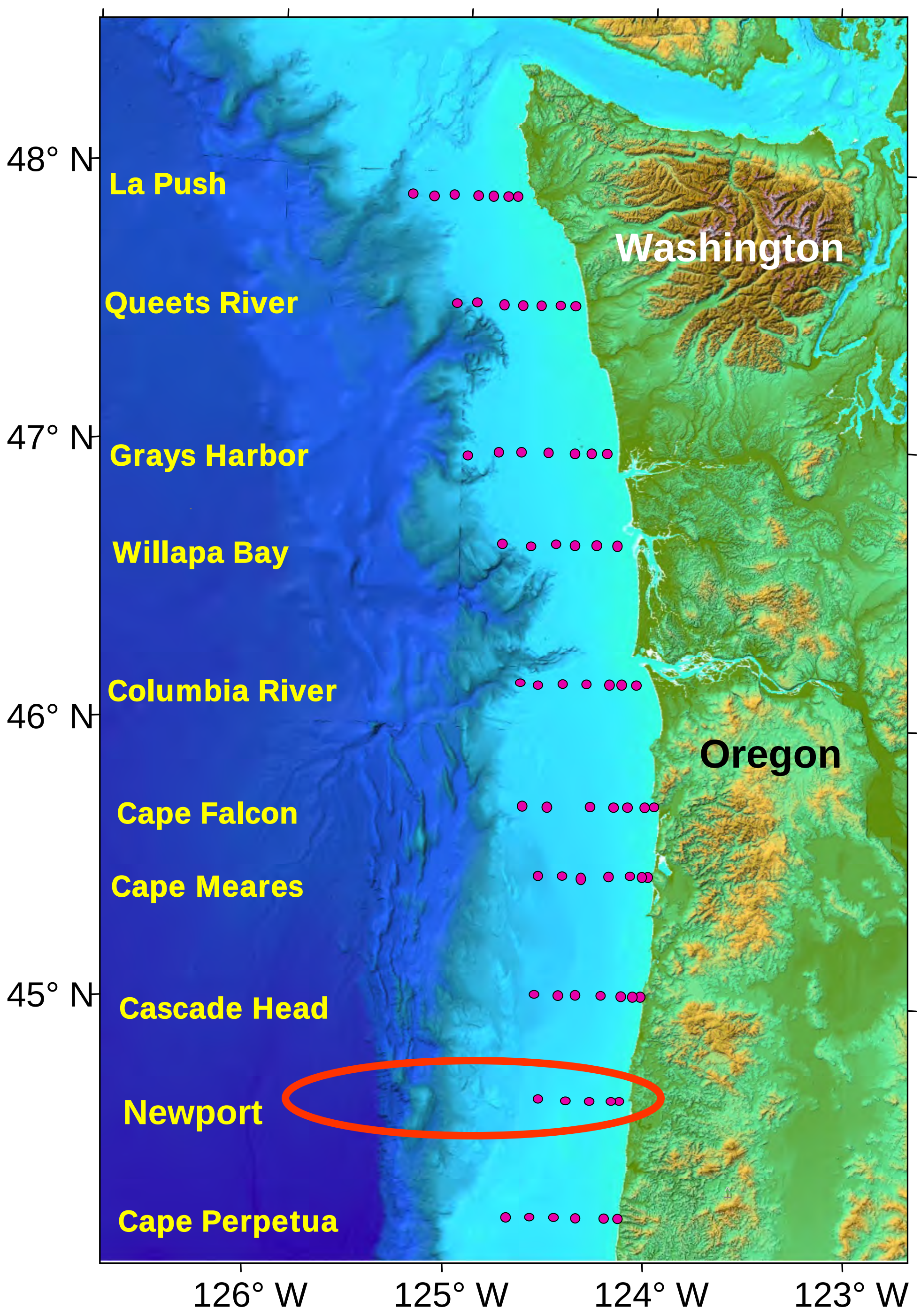
Today I will speak about some of these aspects of "ocean conditions"

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



Our work is an example of an ecosystem approach to management

Local Biological Conditions



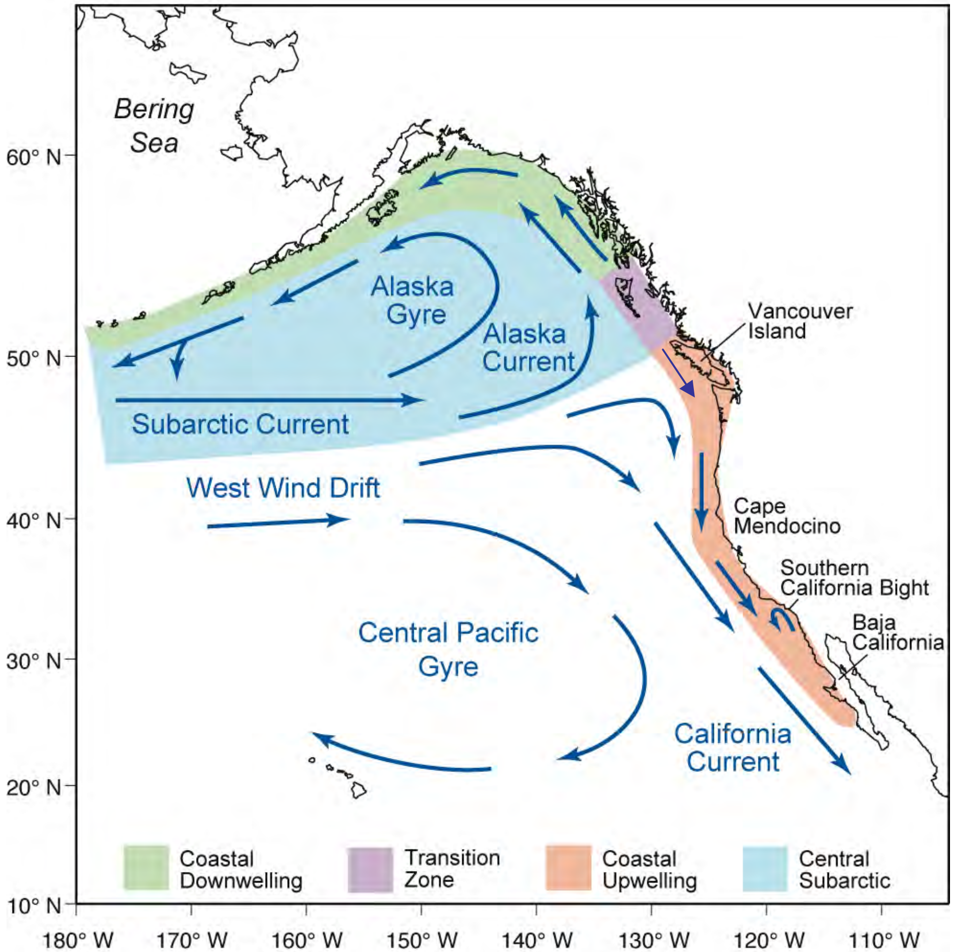
Observations

- Newport Line biweekly sampling since 1996 (17th year). Speak mostly about the zooplankton today.

- Juvenile salmon sampling in June and September since 1998 (15th year)

- Historical data:
  - hydrography, 1960s;
  - zooplankton, 1969-1973; 1983, 1990-1992
  - juvenile salmon, 1981-1985

Circulation off the Pacific Northwest



Transport is a key part of our results and is important for three reasons:

1. Subarctic Current brings cold water and northern species to the N. California Current;

2. The West Wind Drift brings subtropical water and subtropical species to the N. California Current

3. Therefore, ecosystem structure is affected by the source waters which feed the California Current.

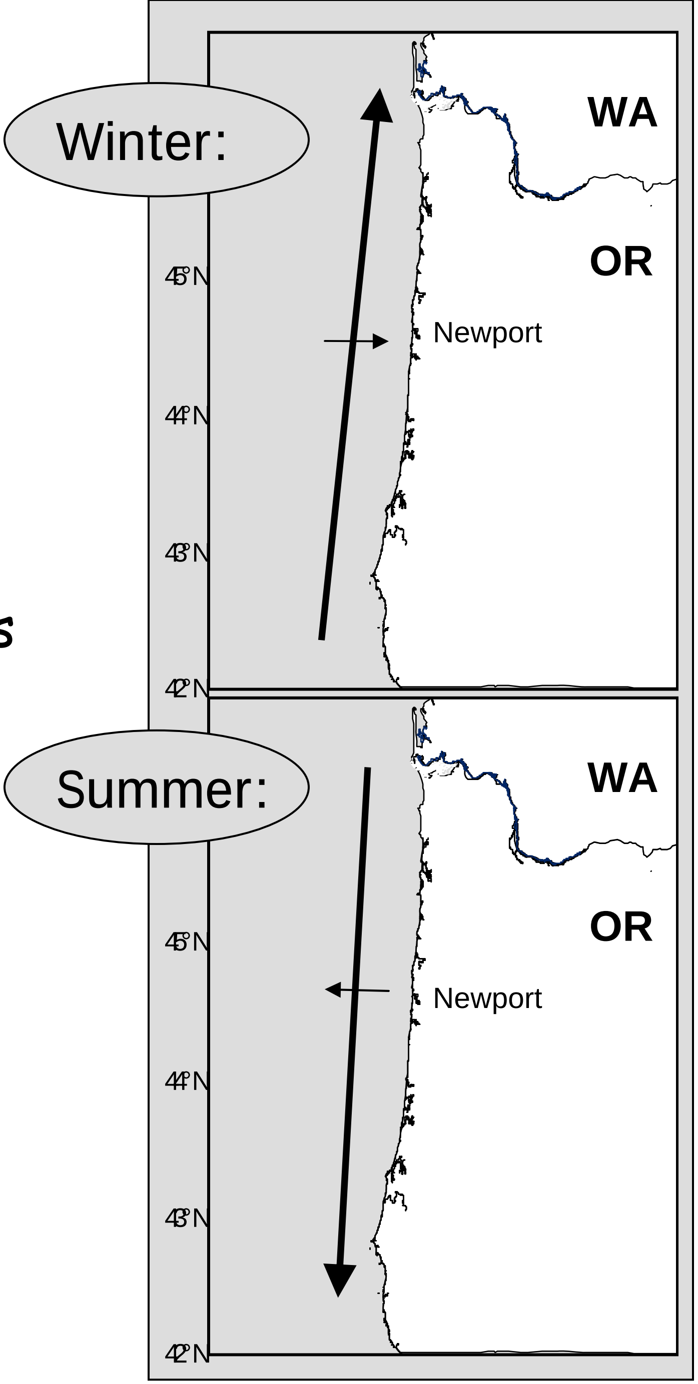
Winds and current structure off coastal Oregon have pronounced seasonality:

- Winter:
  - Winds from the South
  - Downwelling
  - Poleward-flowing Davidson Current
  - Subtropical and southern plankton species transported northward & onshore
  -

•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



Results

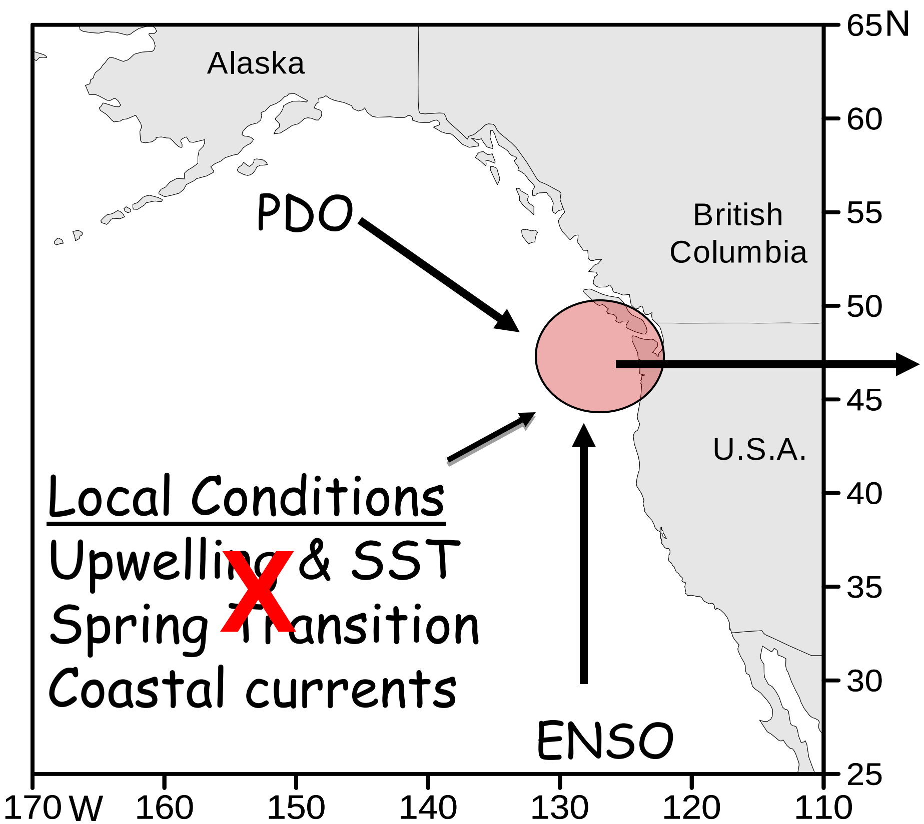
Are some of the more traditional indices correlated with returns of salmon?

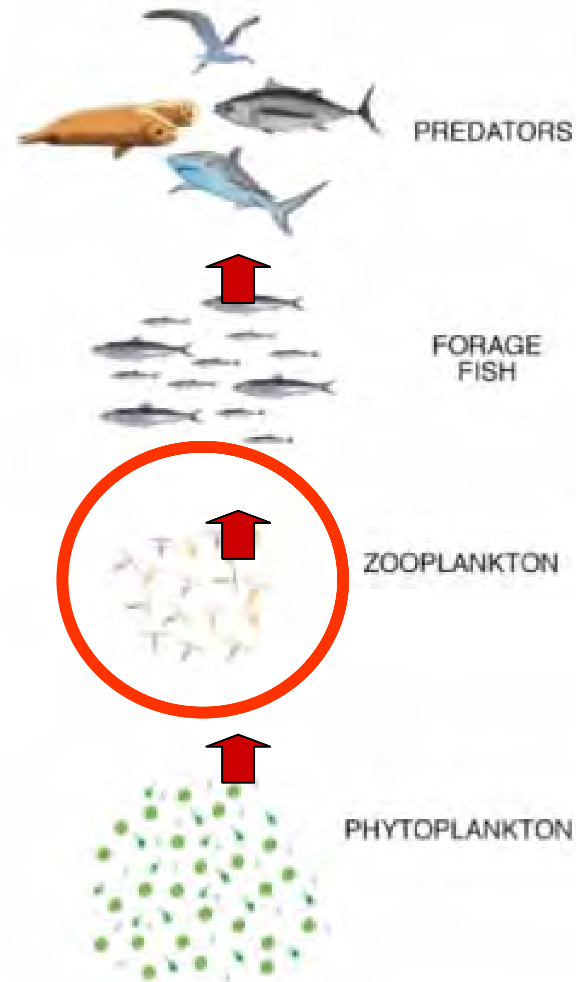
(1) Upwelling
(2) Spring transition

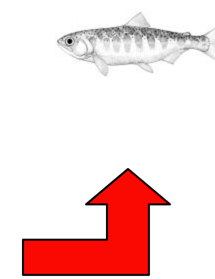
Four Physical Indicators

	Coho		Spring Chinook		Fall Chinook	
	r	p	r	p	r	p
Upwelling Apr-June	0.22	0.42	**0.53**	**0.05**	0.33	0.25
Upwelling May-Sep	0.16	0.58	0.28	0.34	0.18	0.55
Physical Spring Transition from UI	0.02	0.96	0.30	0.32	0.13	0.68
Hydrographic Spring transition	**0.65**	**0.013**	**0.57**	**0.04**	**0.76**	**0.003**

PDO and local biological indicators are more useful for forecasting returns of salmon to the Columbia River

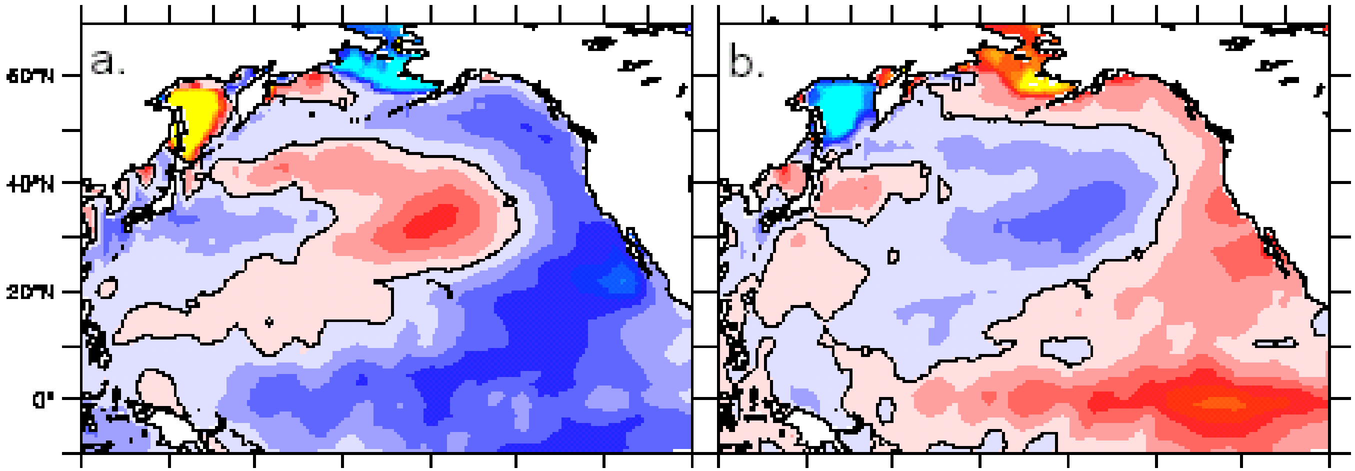






Local Biological Conditions

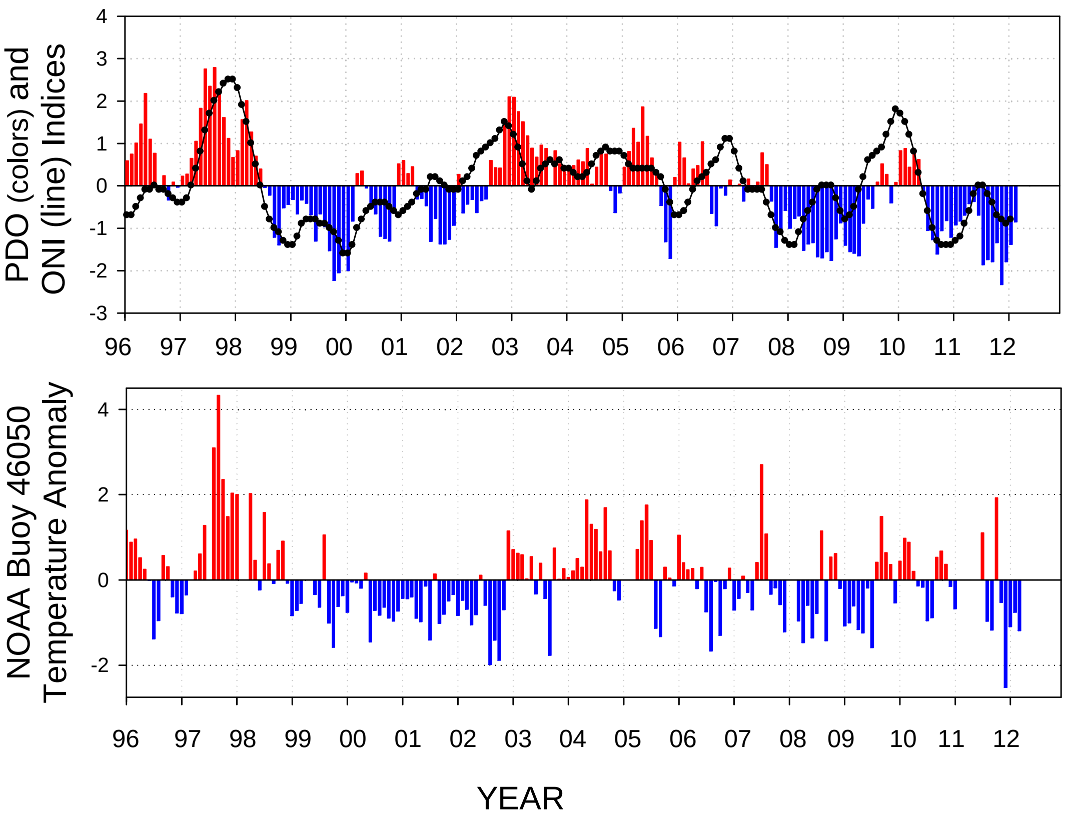
North Pacific SST patterns and the Pacific Decadal Oscillation



Blue is anomalously cold
Red is anomalously warm

The PDO has two phases, negative and positive: SST anomaly patterns result from basin scale winds: W'ly and NW'ly [negative phase] and SW'ly [positive phase].

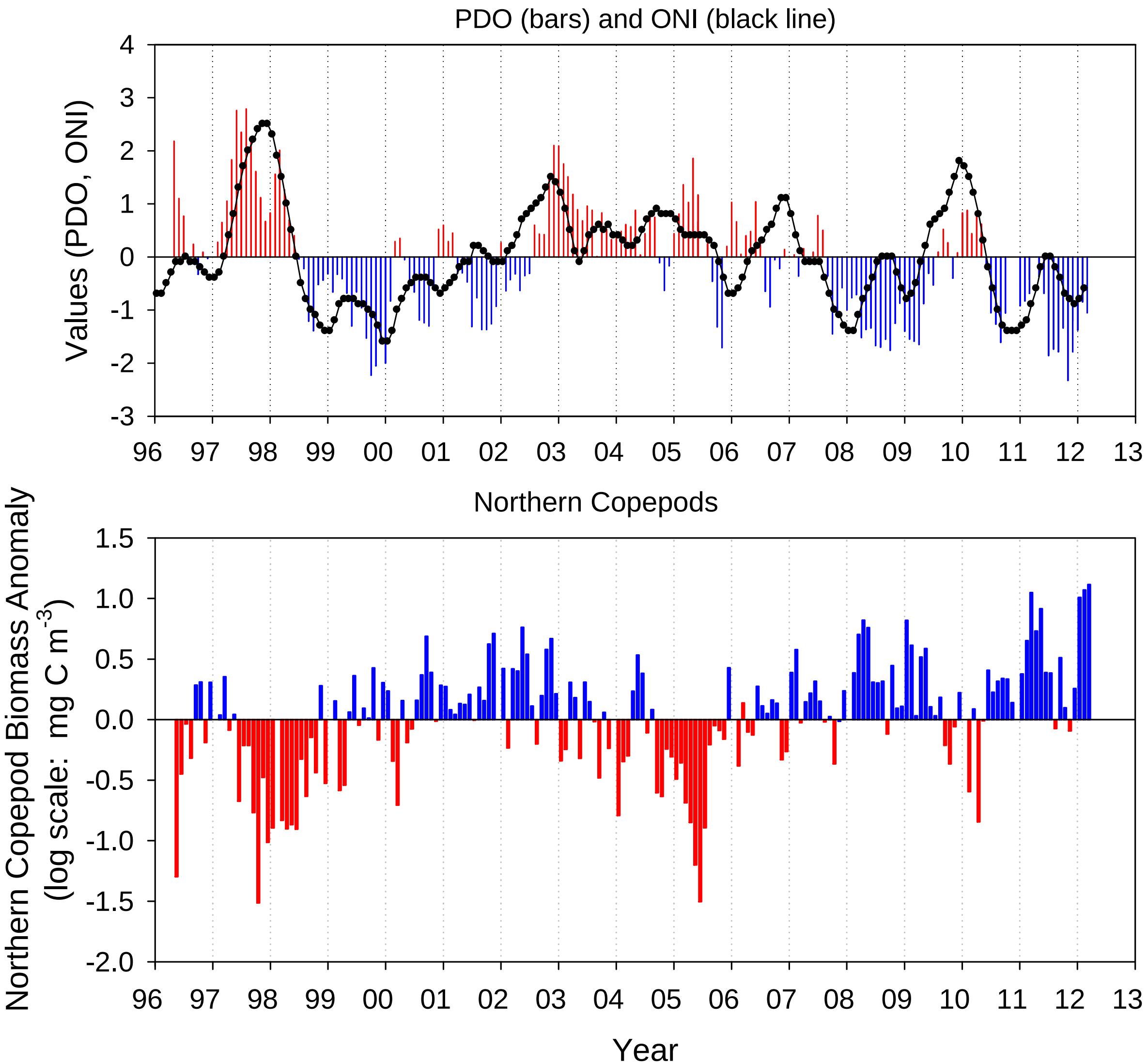
16 year time series of SST anomalies off Newport shows that PDO downscales to local SST



- PDO and SST correlated, (as they should be).
- Note the four recent shifts in the PDO: 1998, 2002, 2007 & 2010
- Note also the time lags between PDO sign change and SST, ~ 3-5 months, suggesting perhaps that the PDO is an advective signal along the Oregon coast

RED = positive and warm; **BLUE = negative and cold**

Time series of PDO, ENSO and Biomass of Northern Copepods



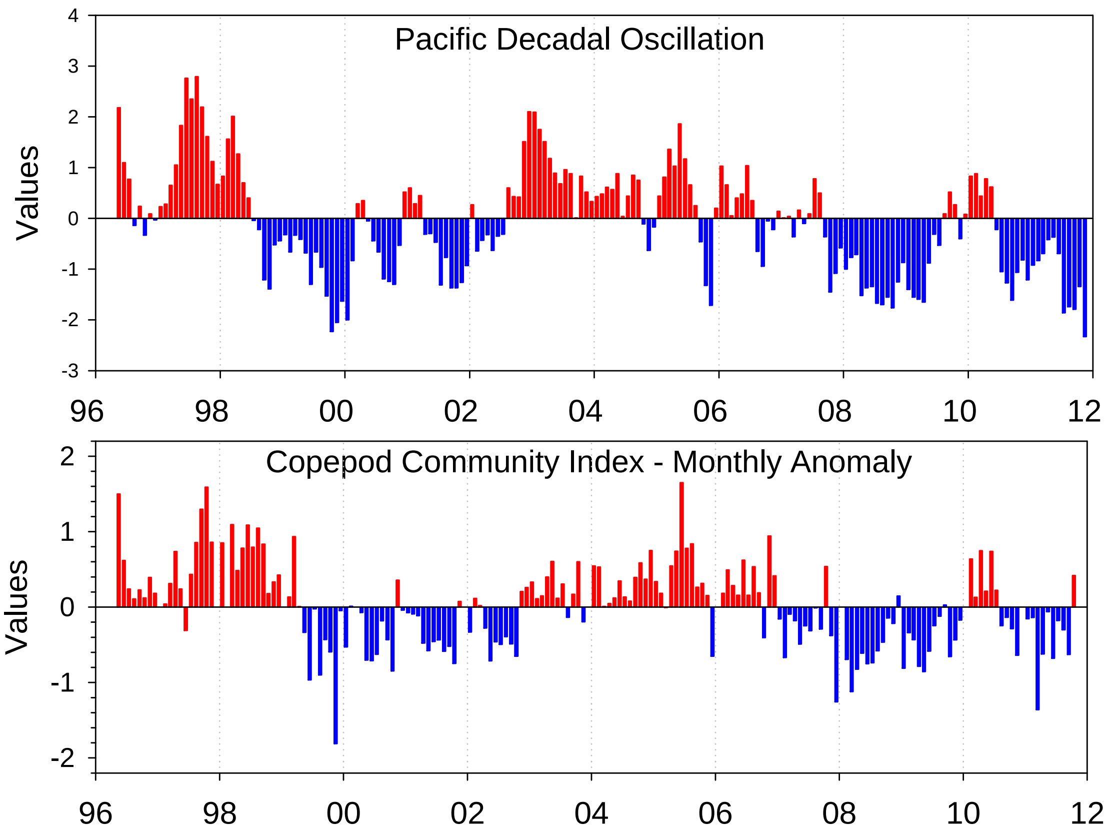
RED BARS = positive PDO & ONI, warm water and sub-tropical copepods from the south and offshore

BLUE BARS = negative PDO & ONI, cold water, and northern copepods from the north

PDO and zooplankton: copepod community composition based on non-metric multidimensional scaling (NMDS -Ordination)

The sign of the PDO is associated with either warm or cold water being advected to the coast

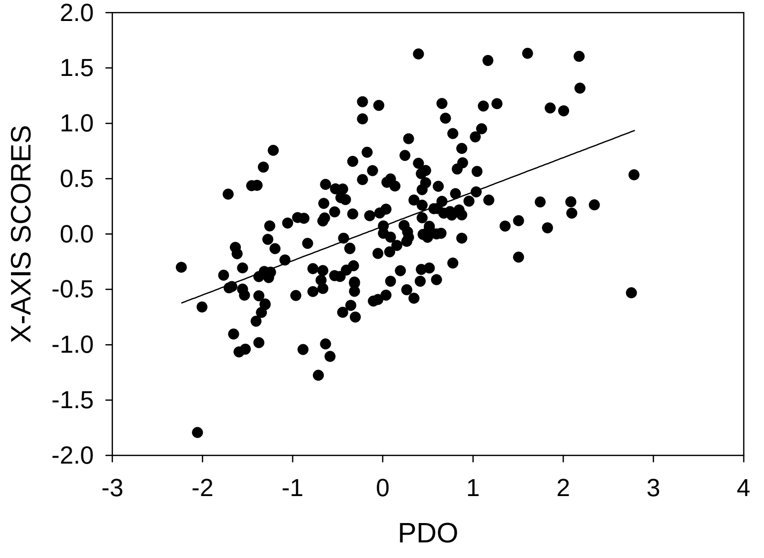
As a consequence you get "warm" and "cold" water zooplankton communities in coastal waters in association with positive or negative phase of the PDO, but with a few months lag.



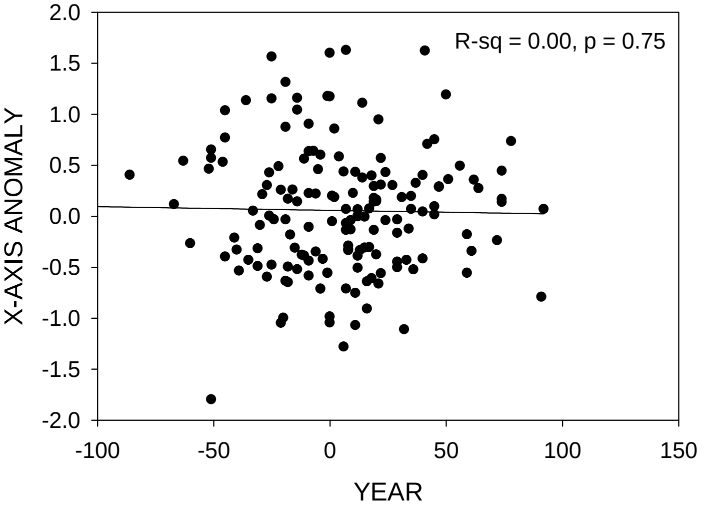
Warm water community

Cold water community

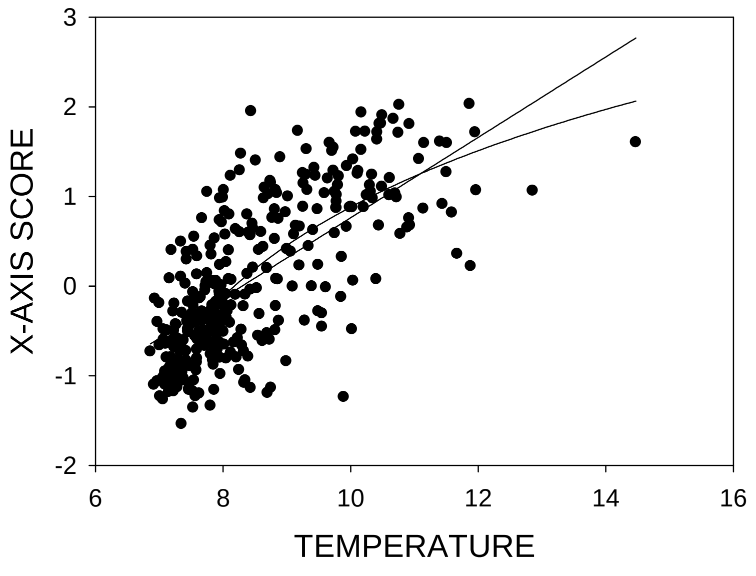
X-axis anomaly vs PDO



X-axis anomaly vs Upwelling Index

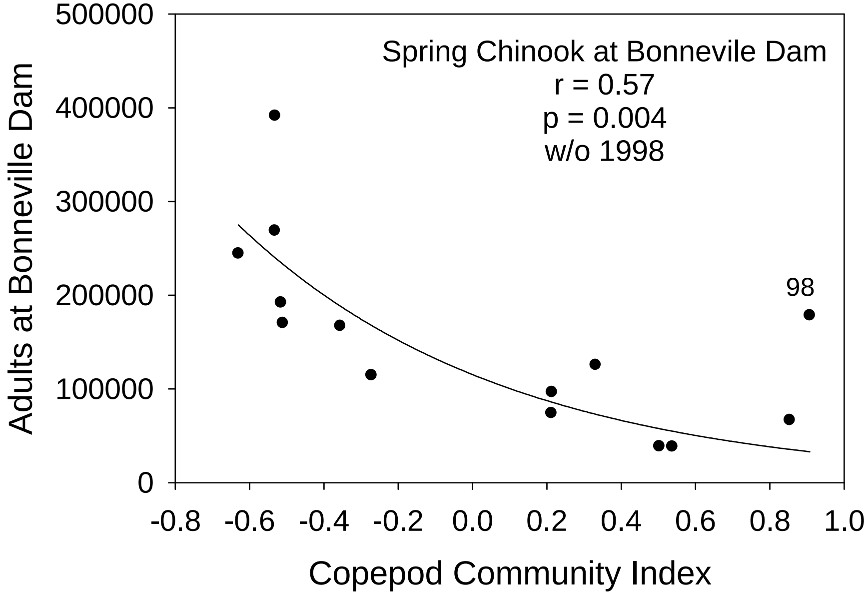


X-axis anomaly vs temperature

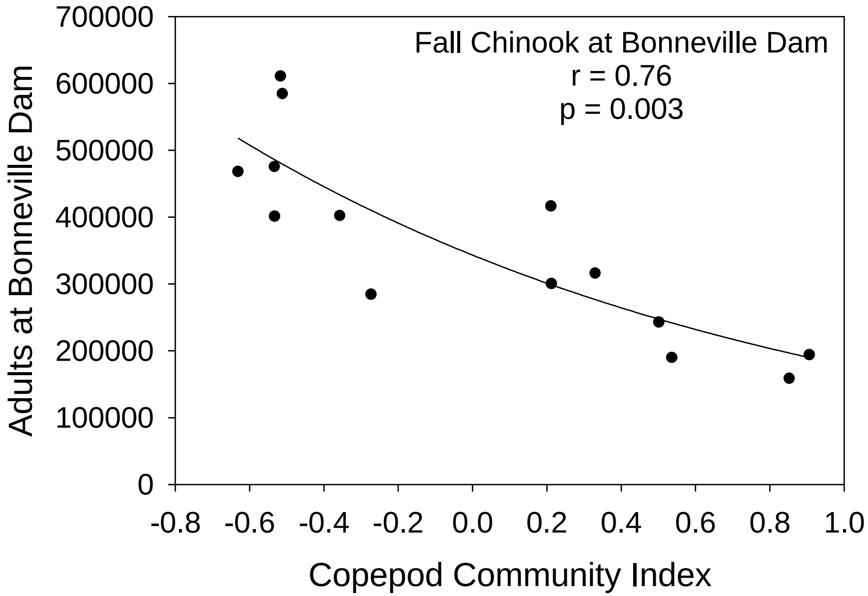


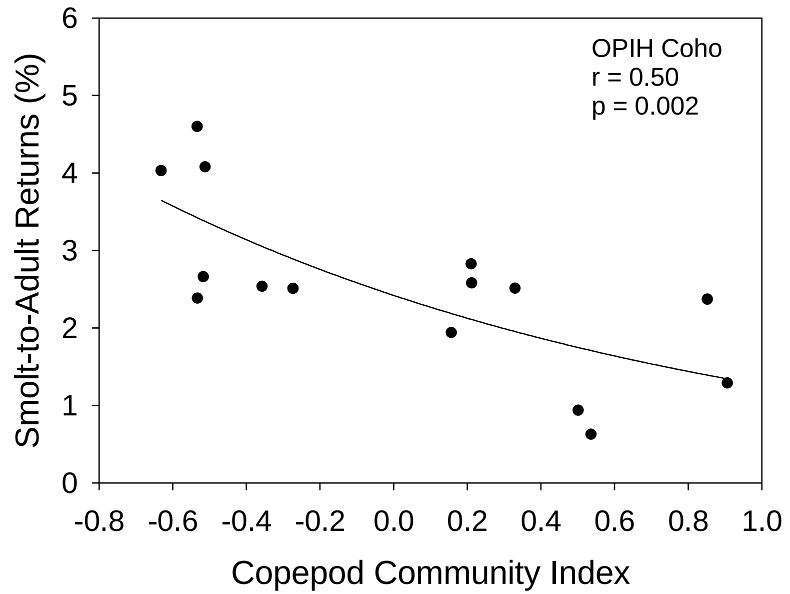
The PDO and Biological Indicators

	Coho		Spring Chinook		Fall Chinook	
	r	p	r	p	r	p
PDO (Dec-Mar)	**0.56**	**0.03**	**0.58**	**0.03**	**0.42**	**0.13**
PDO (May-Sep)	0.46	0.10	**0.87**	**>0.001**	**0.62**	**0.025**
Northern Copepod Biomass Anomaly	**0.60**	**>0.001**	**0.85**	**>0.001**	**0.82**	**>0.001**
Copepod Community Composition	**0.65**	**0.013**	**0.57**	**0.004**	**0.76**	**0.003**



Adult Spring and Fall Chinook salmon counted at Bonneville Dam and survival of coho salmon returning to hatcheries to spawn, as a function of copepod community structure





Comparisons of copepods by size and chemical composition

- **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

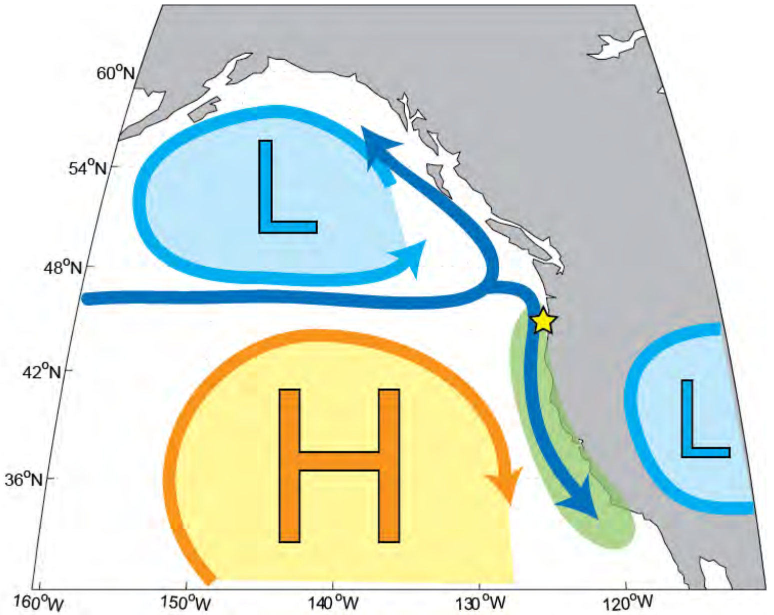
Therefore, significantly different food chains may result from climate shifts

A fat salmon is a happy salmon

Cartoon from Ryan Rykaczewski

Cool Coastal Phase ➔

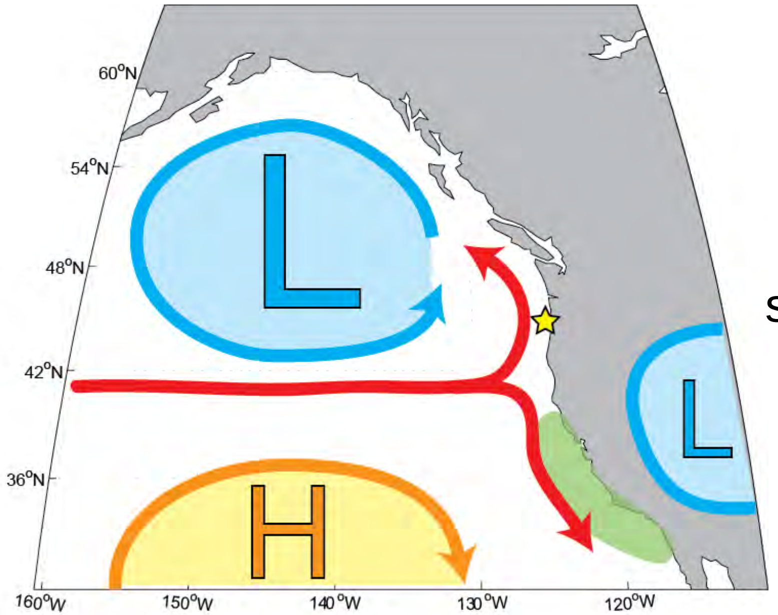
Weaker low pressure; but more southerly flow along the coast; rich, boreal zooplankton at Newport



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

What do we need from models and from the "ocean observing systems" to forecast better the returns of coho and Chinook salmon to the Columbia and other rivers?

- Transport in the coastal California Current both (a) in real time, from moorings, CODAR, altimeters and data assimilation models, and (b) in forecast mode, one year in advance. Possible some day?
- A prognosis of the future state of the PDO from climate models because the PDO seems to drive the composition of the food chain upon which salmon feed
- A better understanding of the bifurcation, from ARGO and data assimilation models

We also need to keep going to sea because the zooplankton data provide our best indicators for salmon and may do as well for other fishes

What problems lie ahead for salmon and other fishes off the Pacific Northwest?

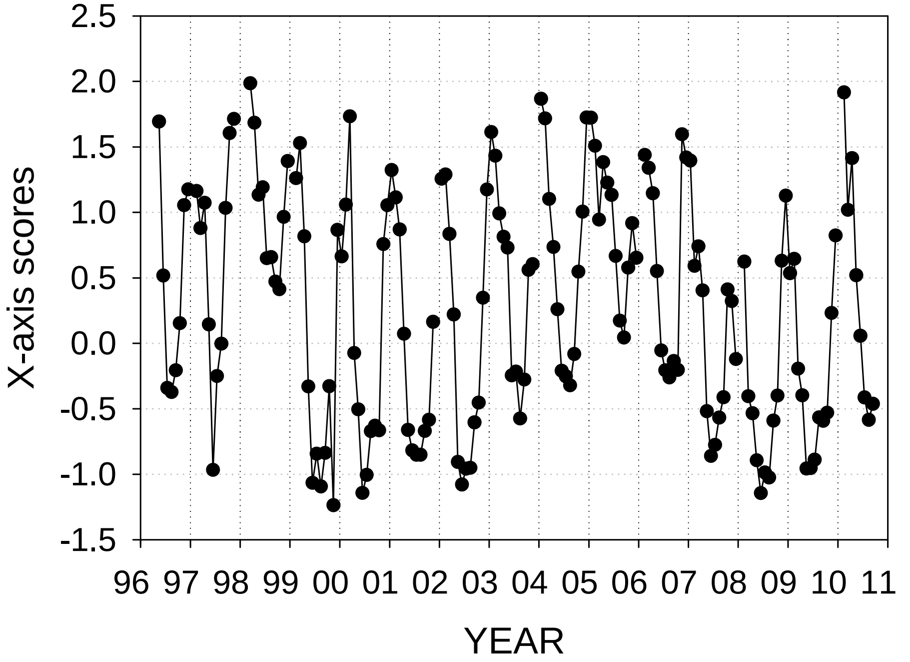
- Will coastal upwelling become weaker, stronger or stay the same? Do salmon care? At some point "yes" but unclear.
- Will warming of the ocean lead to greater stratification thus reducing the effectiveness of coastal upwelling? Do we care?
- Will the Pacific "Decadal" Oscillation return to "Decadal"?
- Will the central North Pacific Gyre expand northward and make the waters off Oregon more subtropical?
- Alternatively, will expansion of the gyre make coastal upwelling more productive? Rykaczewski.
- Of great concern in coastal upwelling systems is the trend toward decreased oxygen concentration and of decreased pH in waters which upwell at the coast.

Acknowledgements

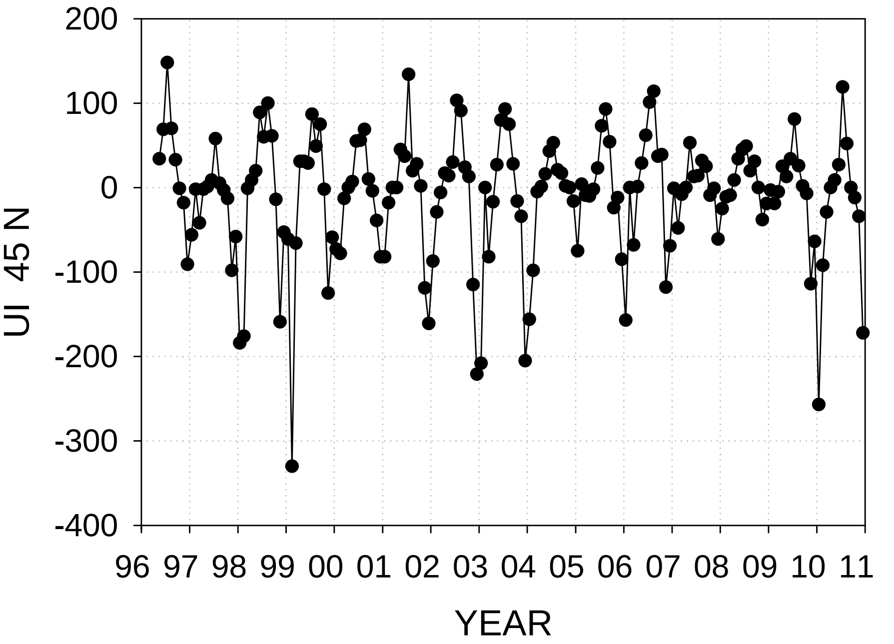
- Bonneville Power Administration
- U.S.GLOBEC Program (NOAA/NSF)
- NOAA Stock Assessment Improvement Program (SAIP)
- Fisheries and the Environment (FATE-NOAA)
- National Science Foundation
- Office of Naval Research
- NASA

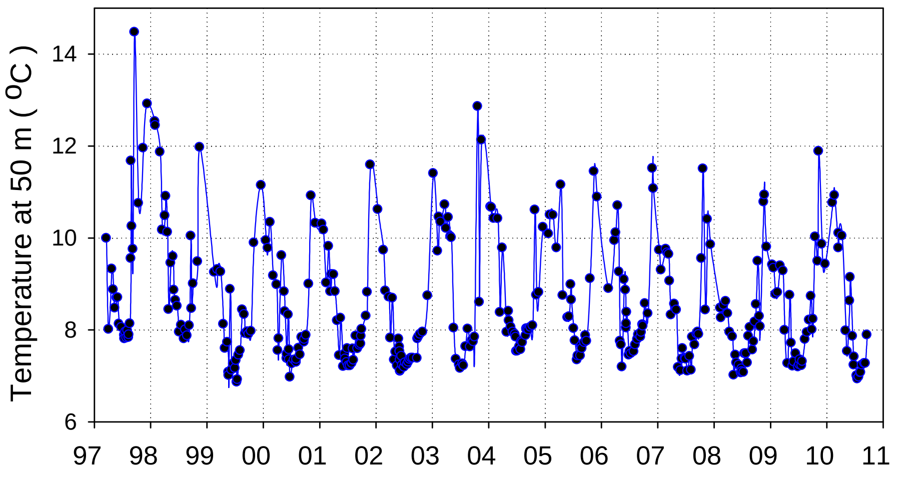
- See www.nwfsc.noaa.gov, “Ocean Conditions and Salmon Forecasting”

X-axis Ordination Scores

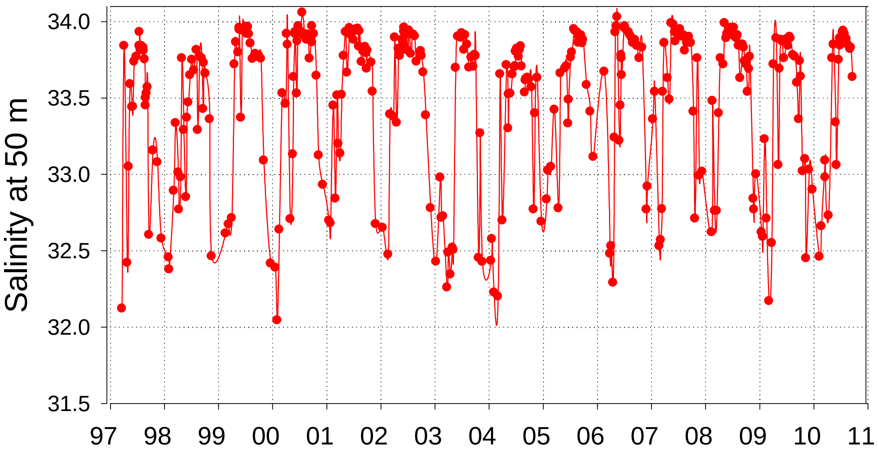


UPWELLING INDEX AT 45 N



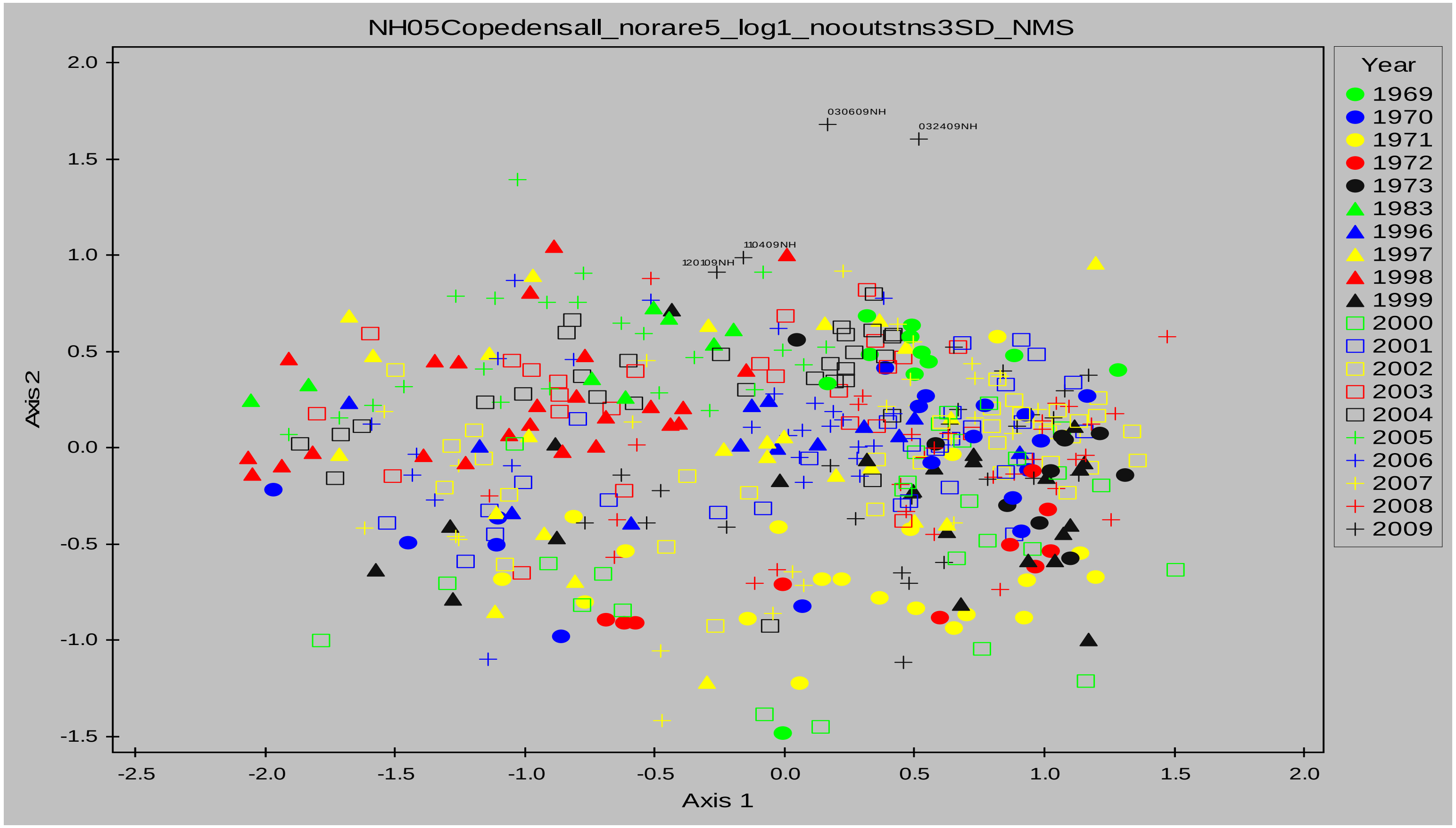


TEMPERATURE AT NH 05 at 50 m



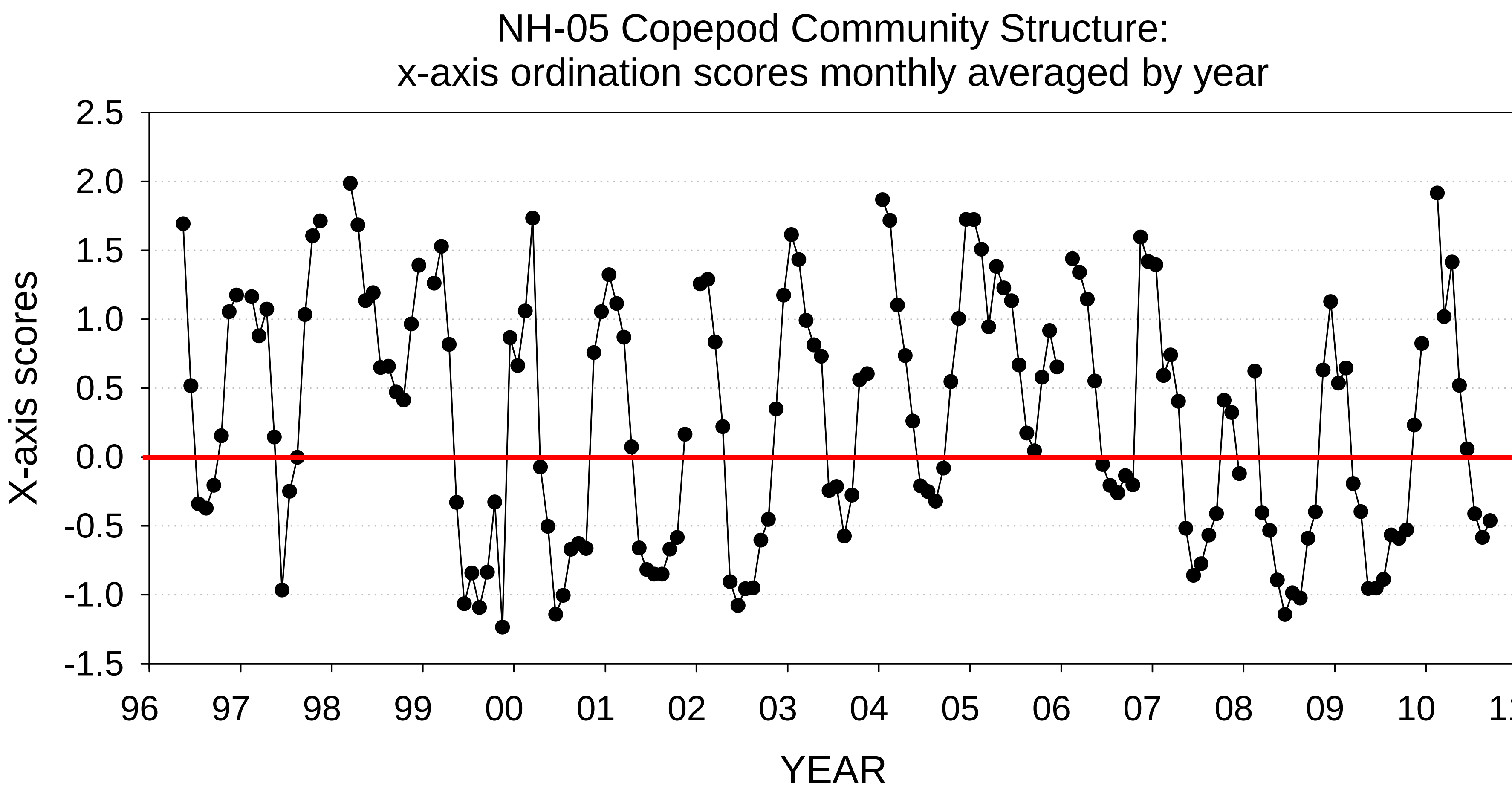
SALINITY AT NH 05 at 50 m

NMDS (Non-Metric Multidimensional Scaling) Plot of Copepod Community Structure



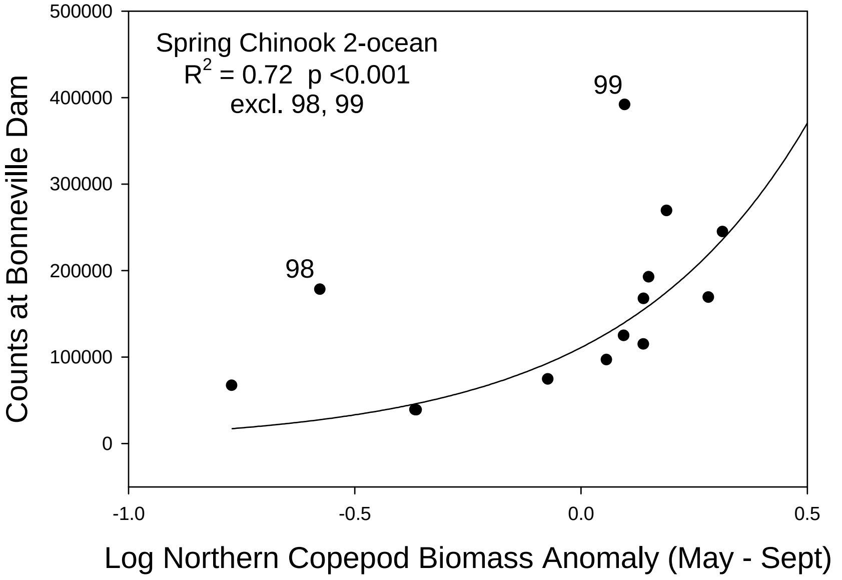
X-axis explains about 70% of the variance

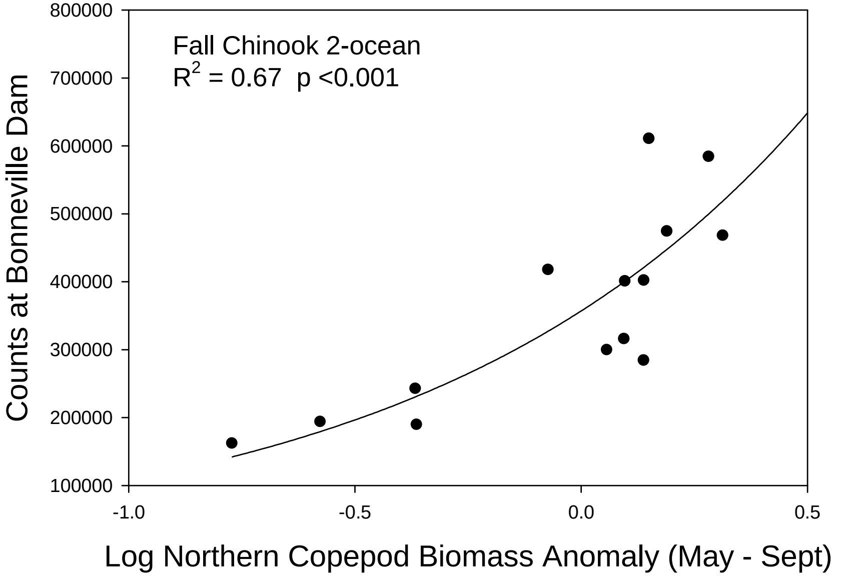
Interannual Variability in Copepod Community Structure

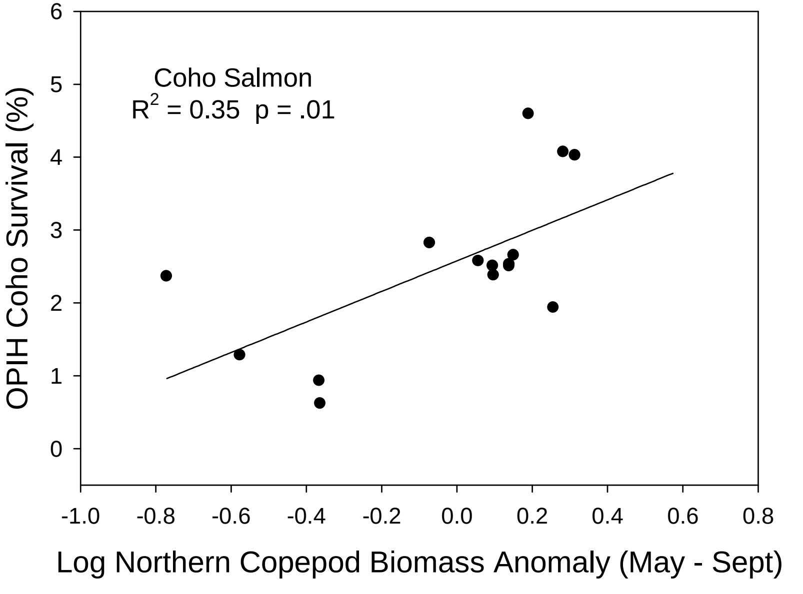


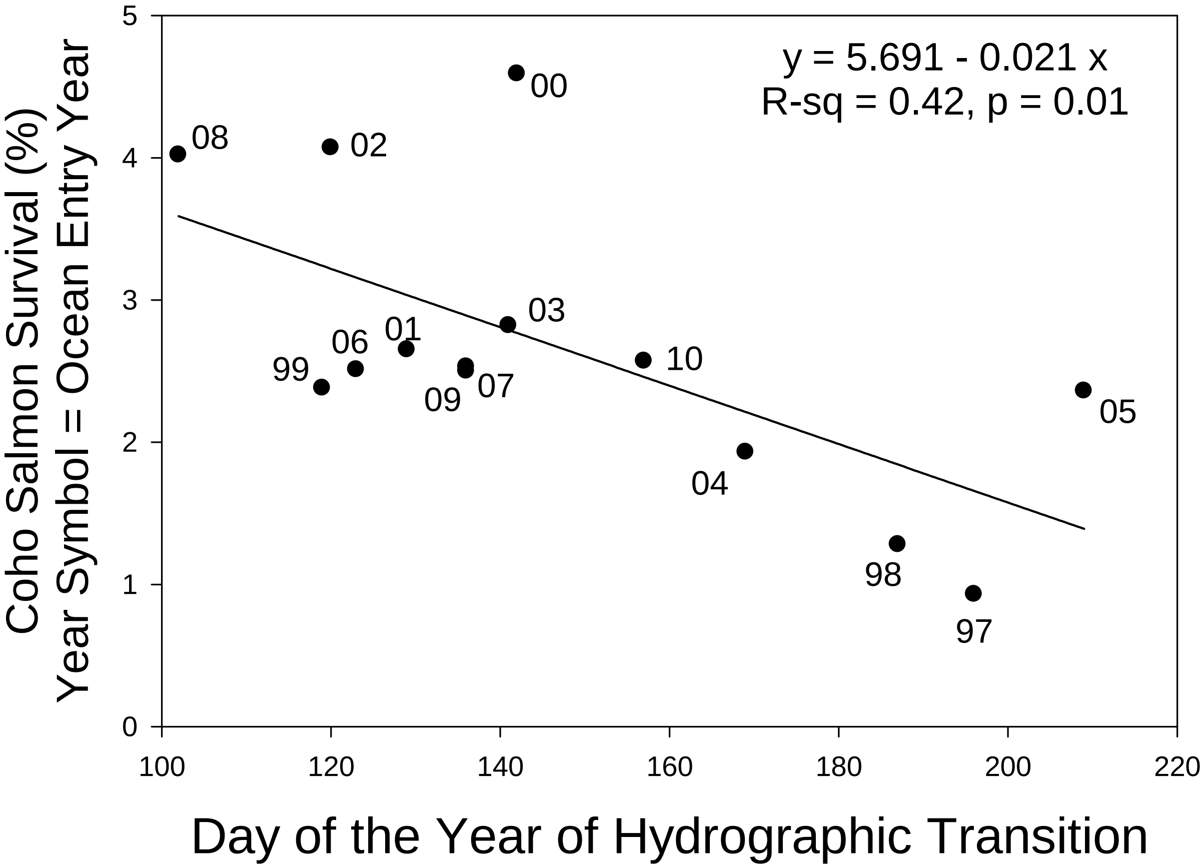
Positive scores = warm water community; usually in winter
Negative scores = cold water community; usually in summer
Exceptions: El Nino 1998 and summer 2005

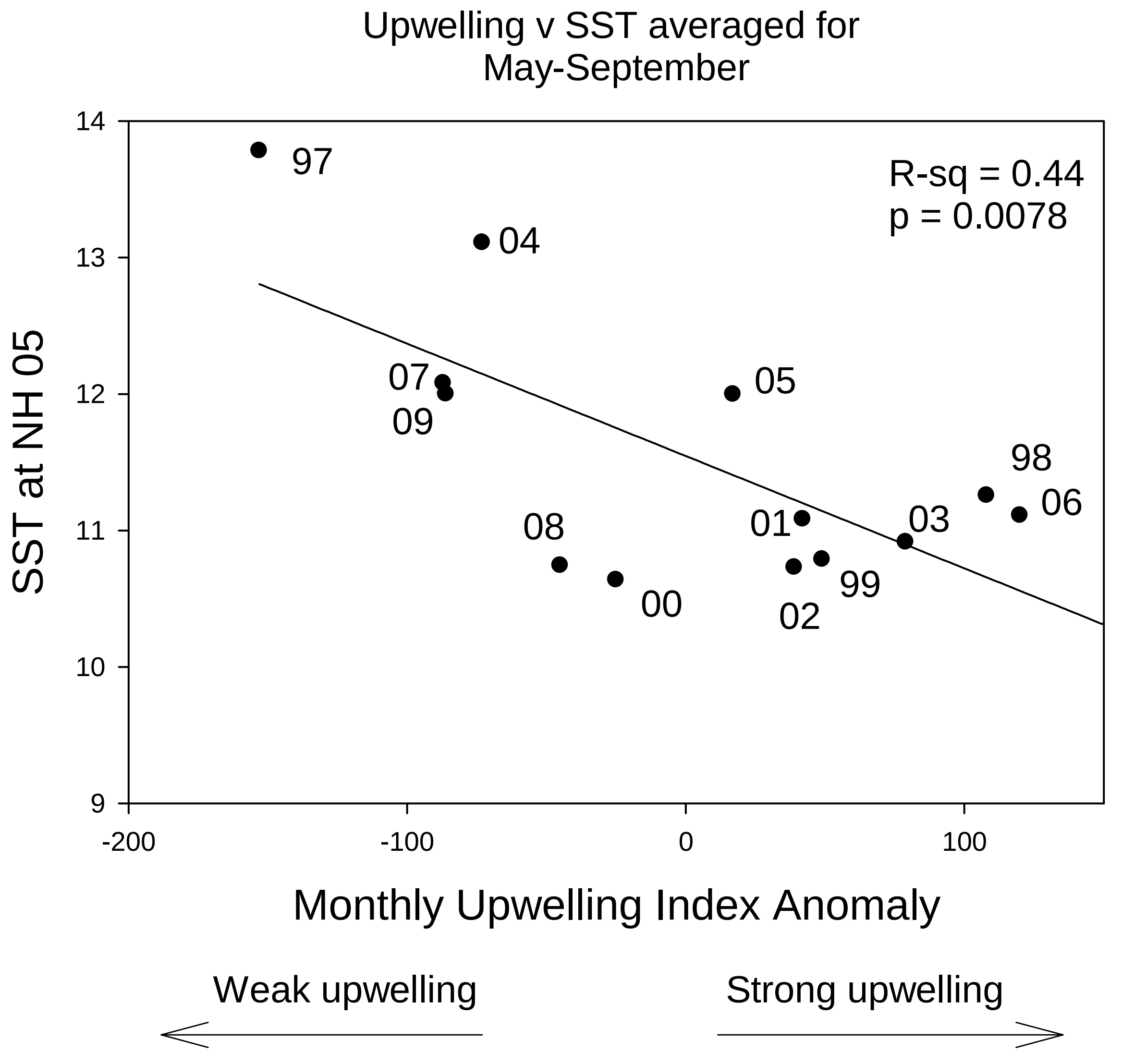
Adult Spring and Fall Chinook salmon at counted Bonneville Dam and survival of coho salmon returning to hatcheries to spawn as a function of northern copepod biomass



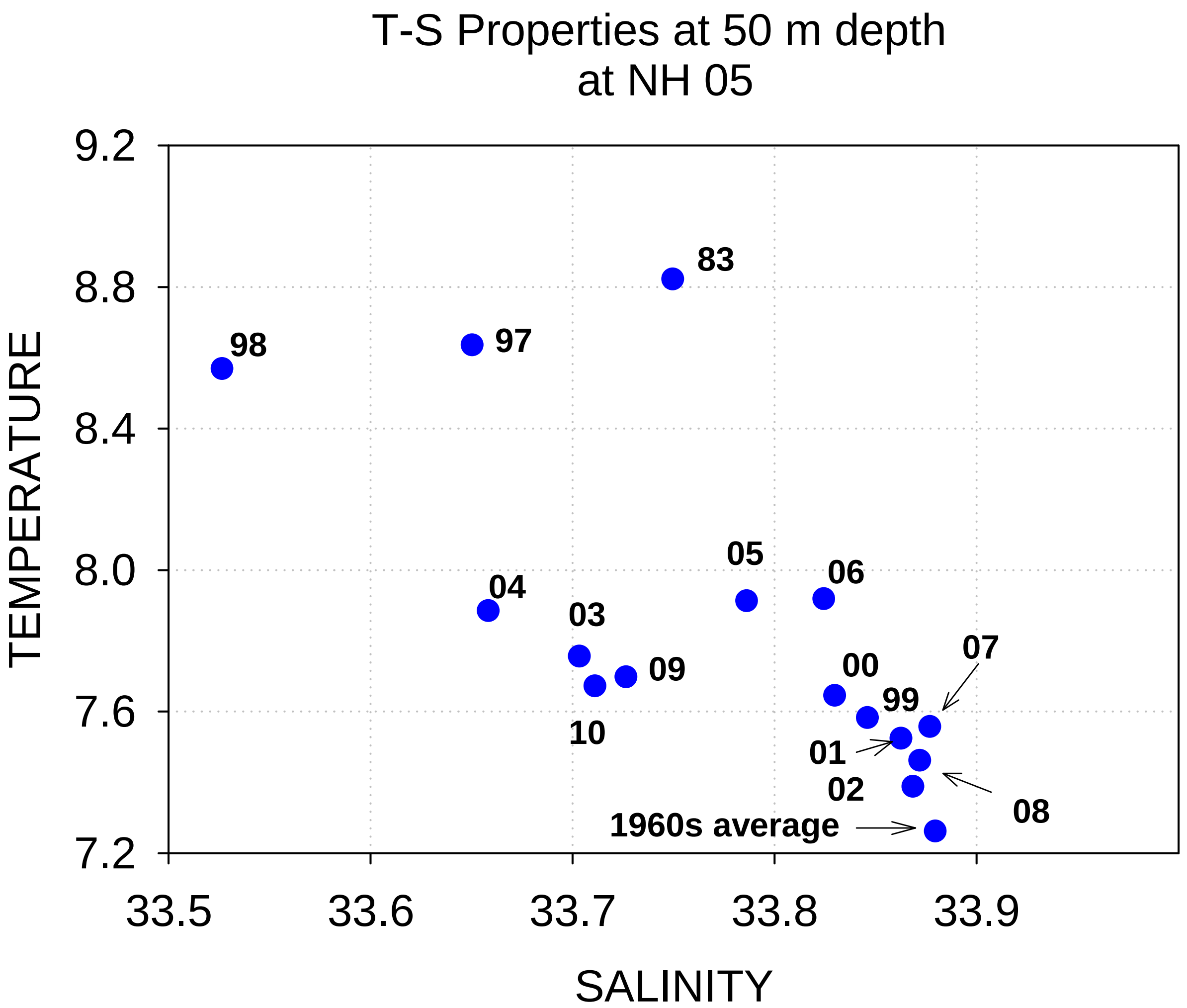





y = 5.691 - 0.021 x
R-sq = 0.42, p = 0.01
08
02
00
03
01
06
99
09
07
10
05
04
98
97
0
1
2
3
4
5
100
120
140
160
180
200
220
Coho Salmon Survival (%)
Year Symbol = Ocean Entry Year
Day of the Year of Hydrographic Transition


Upwelling v SST averaged for
May-September
R-sq = 0.44
p = 0.0078
97
04
07
09
05
98
06
08
01
03
99
00
02
SST at NH 05
14
13
12
11
10
9
-200
-100
0
100
Monthly Upwelling Index Anomaly
Weak upwelling
Strong upwelling

T-S at 50 m at NH 05, 62 m depth



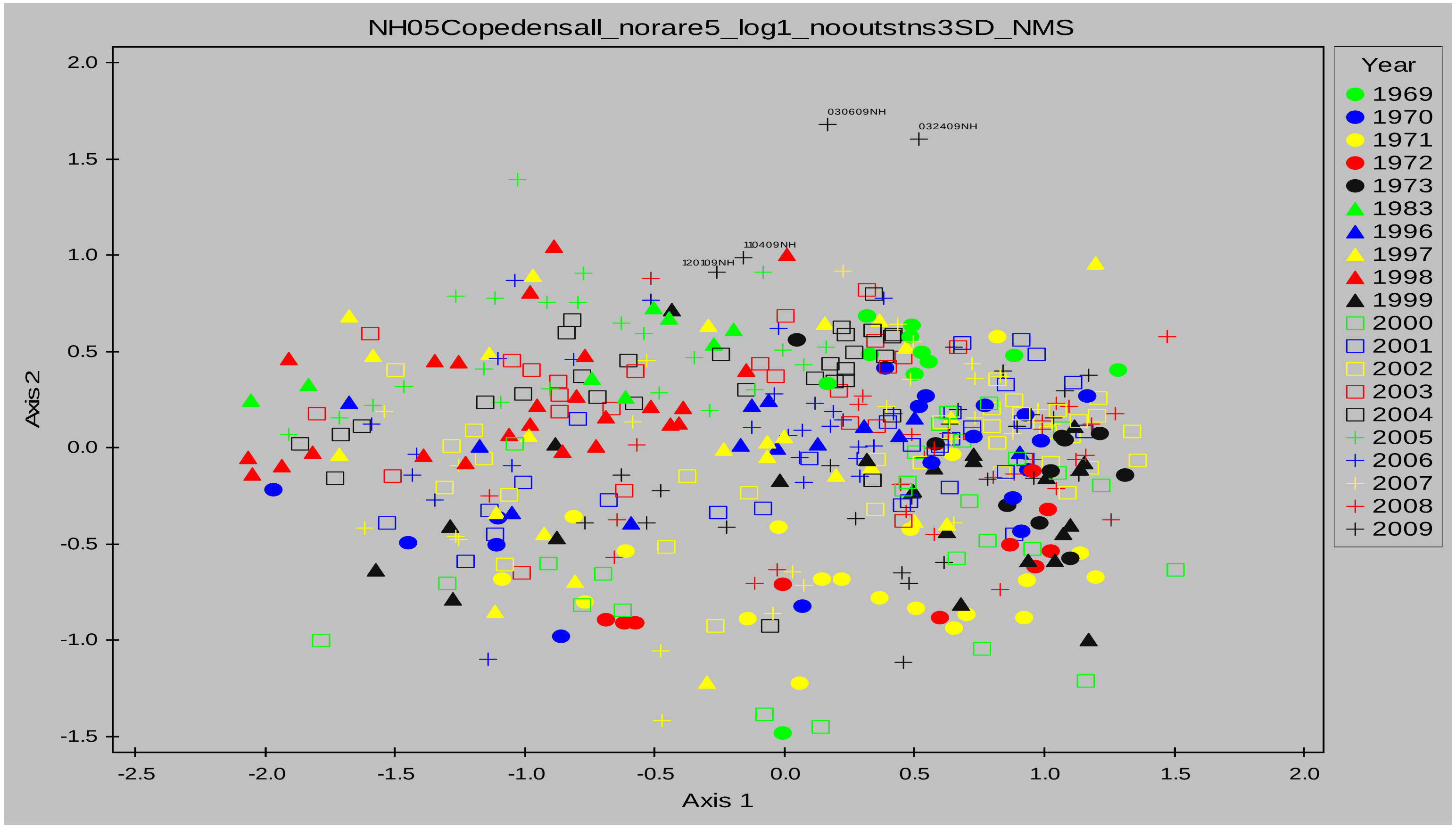
ENSO: 83, 97, 98

+ PDO: 03-06

Weak PDO: 09-10

- PDO: 99-02, 07-08
1960s

NMDS (Non-Metric Multidimensional Scaling) Plot of Copepod Community Structure



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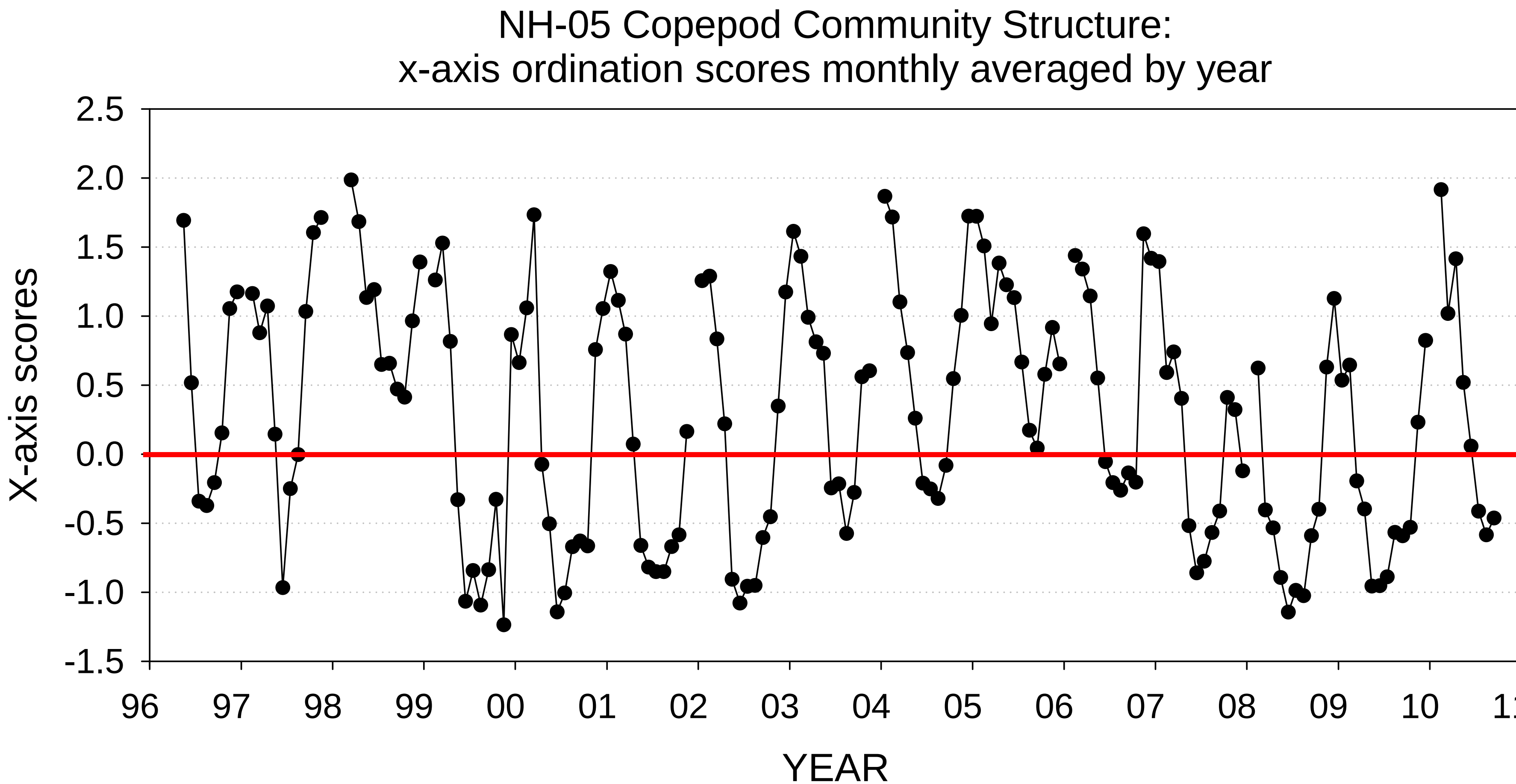

Positive scores = warm water community; usually in winter
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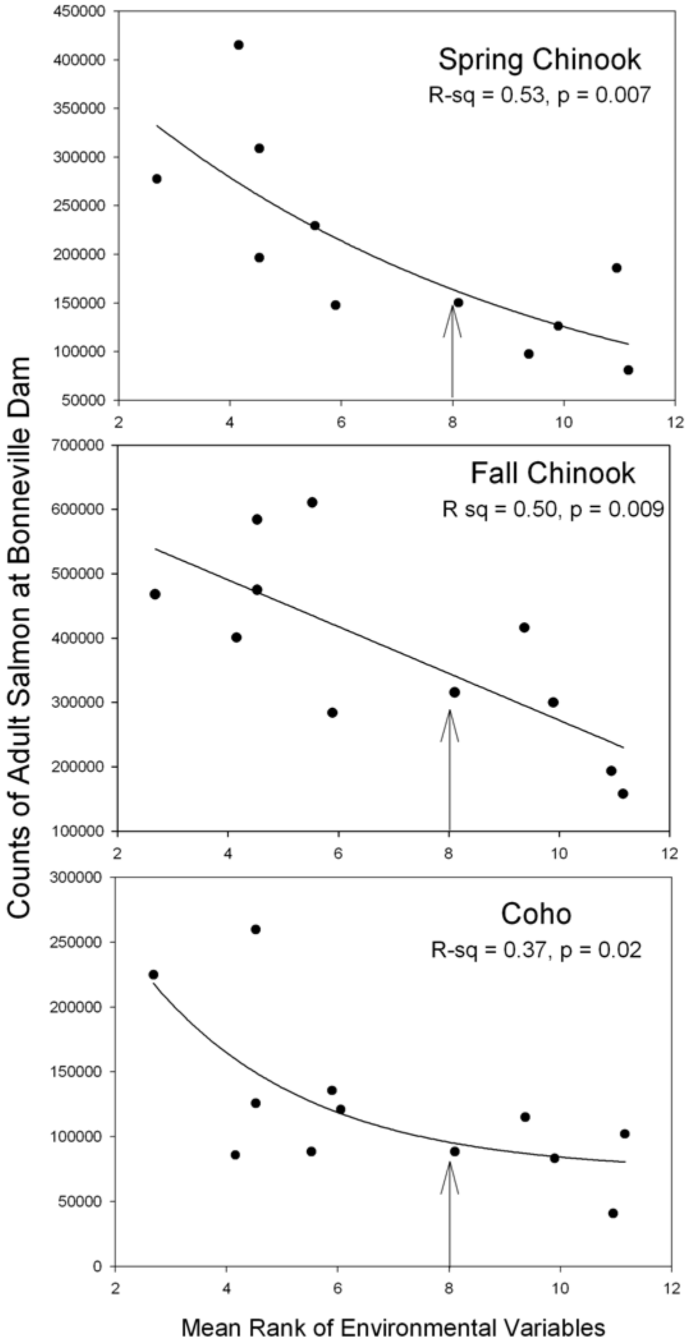
Exceptions: El Nino 1998 and summer 2005

1998, 2003-2005 = warm & unproductive; poor salmon returns
1999-2002 and 2008 = cold & productive; record returns
2010 = a mixed bag—poor early, great late!

Environmental Variables	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
PDO (December-March)	12	4	2	8	5	13	7	11	9	6	3	1	10
PDO (May-September)	7	2	4	3	8	12	11	13	9	10	1	6	5
MEI Annual	13	1	3	6	12	11	10	7	8	5	2	9	4
MEI Jan-June	13	1	3	4	9	10	8	11	5	7	2	6	12
SST at 46050 (May-Sept)	11	8	3	4	1	7	13	10	5	12	2	9	6
SST at NH 05 (May-Sept)	8	4	1	6	2	5	13	10	7	12	3	11	9
SST winter before (Nov-Mar)	13	10	3	5	6	9	11	8	7	2	1	4	12
Physical Spring Trans (UI Based)	3	6	12	11	4	8	10	13	8	1	5	2	7
Upwelling Anomaly (Apr-May)	7	1	12	3	6	10	9	13	7	2	4	5	11
Length of upwelling season (UI Bas	6	2	12	9	1	10	8	13	5	3	7	3	11
Deep Temperature at NH 05	13	4	6	3	1	9	10	11	12	5	2	8	7
Deep Salinity at NH05	13	3	6	2	5	11	12	8	7	1	4	9	10
Copepod Richness Anomaly	13	2	1	5	3	9	8	12	10	6	4	7	11
N.Copepod Anomaly	13	10	3	7	2	11	8	12	9	6	1	5	4
Biological Transition	13	7	5	3	6	11	9	12	10	4	1	2	8
Copepod Community structure	13	3	4	6	1	9	10	12	11	7	2	5	8
Winter Ichthyoplankton	13	6	2	4	5	9	12	8	11	10	1	7	3
Catches of salmon in surveys													
June-Chinook Catches	12	2	3	10	7	9	11	13	8	6	1	4	5
Sept-Coho Catches	9	2	1	4	3	5	10	12	7	8	6	13	11
Mean of Ranks of Environmental Da	10.8	4.1	4.5	5.4	4.6	9.4	10.0	11.0	8.2	5.9	2.7	6.1	8.1
RANK of the mean rank	12	2	3	5	4	10	11	13	9	6	1	7	8

2010 Ocean Entry



Salmon counts at Bonneville vs. mean rank of environmental variables

- Expect ~ 100,000 coho in fall 2011
- Expect ~ 2.6% OPIH
- Expect ~ 310,000 fall Chinook in fall 2012
- Expect 150,000 spring Chinook in spring 2012