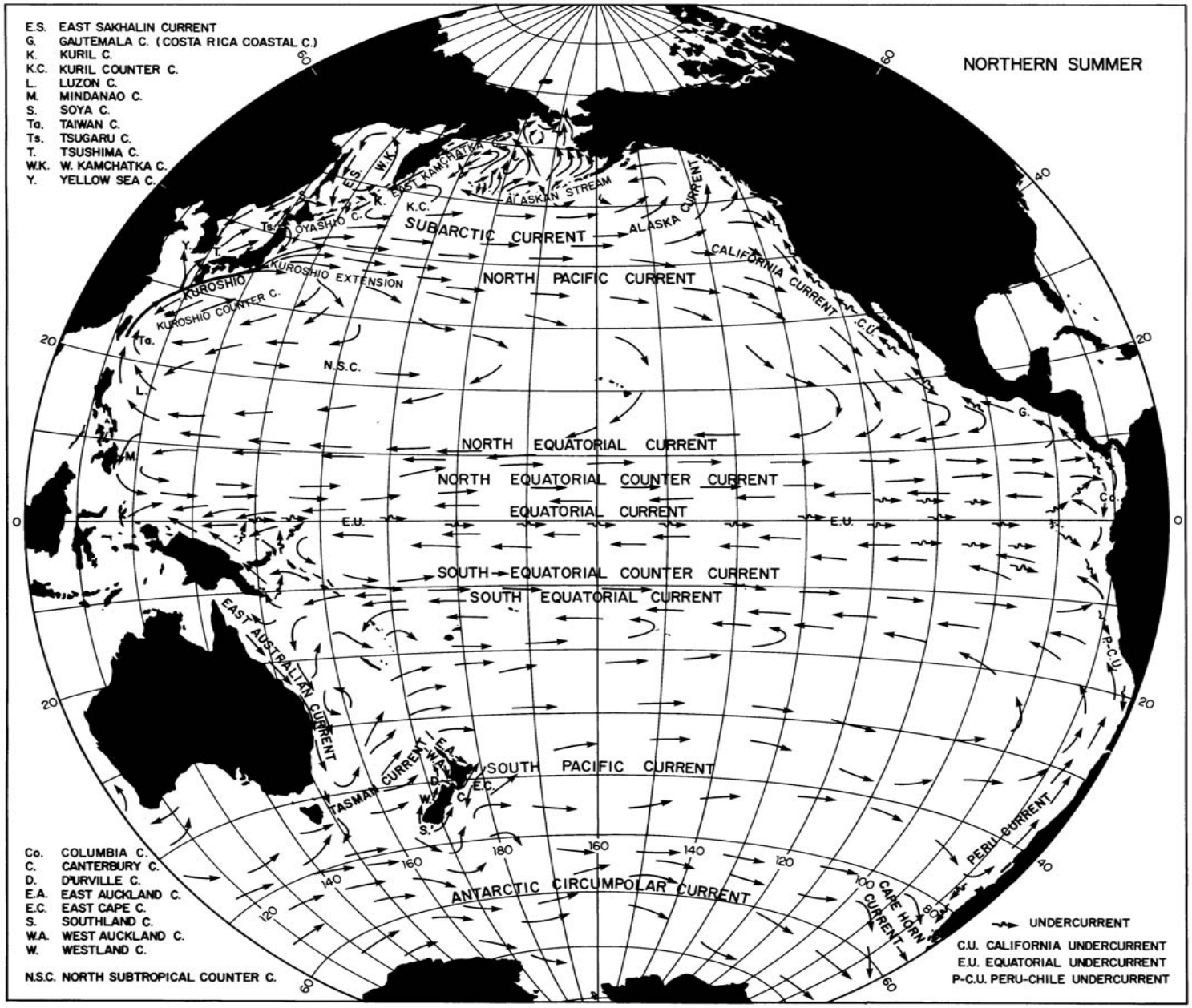
Climate change and ocean conditions in Oregon's coastal waters

Bill Peterson
N OAA-Fisheries
Northwest Fisheries Science Center
Hatfield Marine Science Center
NAL 153 867-0201

- McGowan, Cayan and Dorman (1998) commented that "…the biological consequences of climate variability are not well understood, largely because of the mismatch between time scales of important atmospheric and oceanographic processes and biological research programs".

We have had the good fortune of being able to assemble a hydrographic and plankton time series based on biweekly sampling off Newport OR (44°40'N), now in its 12th year, and historical plankton and hydrographic data collected off Newport from 1969-1973, and 1983.


NORTHERN SUMMER
E.S. EAST SAKHALIN CURRENT
G. GAUTEMALA C. (COSTA RICA COASTAL C.)
K. KURIL C.
K.C. KURIL COUNTER C.
L. LUZON C.
M. MINDANAO C.
S. SOYA C.
Ta. TAIWAN C.
Ts. TSUGARU C.
T. TSUSHIMA C.
W.K. W. KAMCHATKA C.
Y. YELLOW SEA C.
EAST KAMCHATKA
ALASKAN STREAM
ALASKA CURRENT
SUBARCTIC CURRENT
OYASHIO C.
KUROSHIO
KUROSHIO EXTENSION
KUROSHIO COUNTER C.
NORTH PACIFIC CURRENT
CALIFORNIA CURRENT
C.U.
N.S.C.
NORTH EQUATORIAL CURRENT
NORTH EQUATORIAL COUNTER CURRENT
EQUATORIAL CURRENT
E.U.
SOUTH EQUATORIAL COUNTER CURRENT
SOUTH EQUATORIAL CURRENT
EAST AUSTRALIAN CURRENT
TASMAN CURRENT
SOUTH PACIFIC CURRENT
ANTARCTIC CIRCUMPOLAR CURRENT
CAPE HORN CURRENT
PERU CURRENT
P-C.U.
Co. COLUMBIA C.
C. CANTERBURY C.
D. D'URVILLE C.
E.A. EAST AUCKLAND C.
E.C. EAST CAPE C.
S. SOUTHLAND C.
W.A. WEST AUCKLAND C.
W. WESTLAND C.
N.S.C. NORTH SUBTROPICAL COUNTER C.
UNDERCURRENT
C.U. CALIFORNIA UNDERCURRENT
E.U. EQUATORIAL UNDERCURRENT
P-C.U. PERU-CHILE UNDERCURRENT

Tabata (1975)

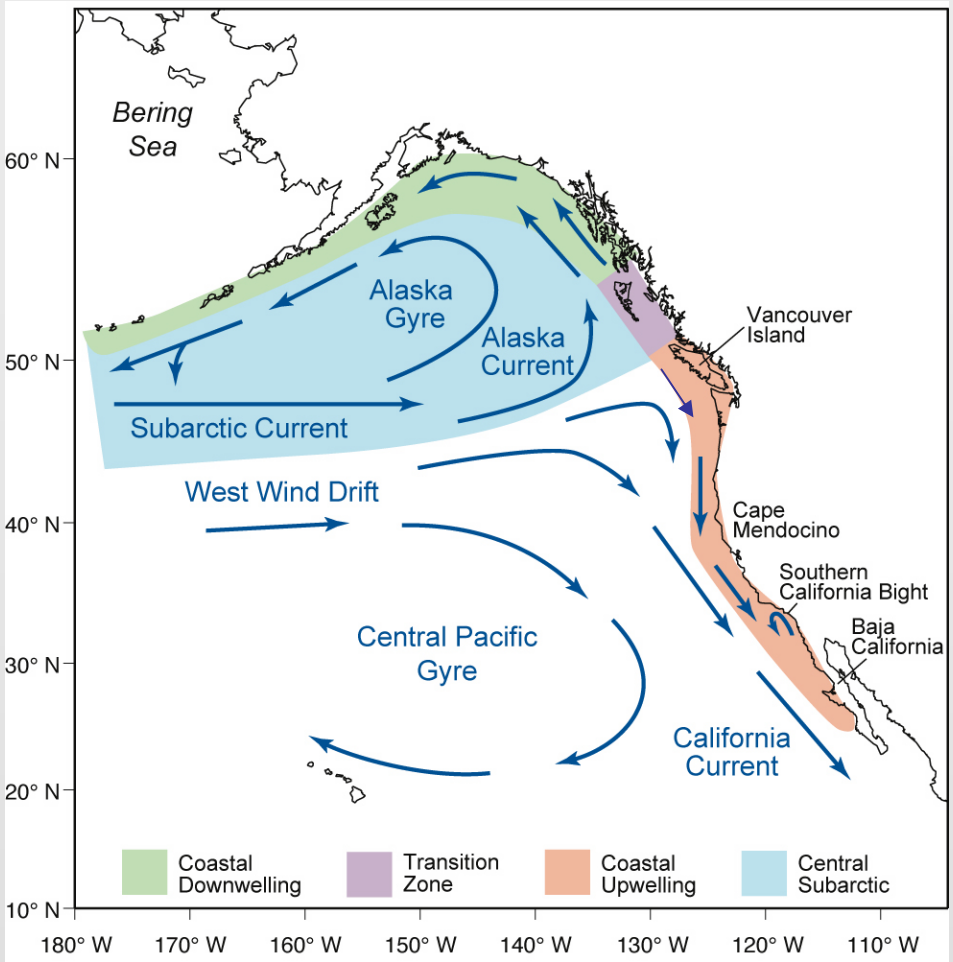
Three key factors affect ocean conditions, zooplankton and fish in the northern California Current off Oregon

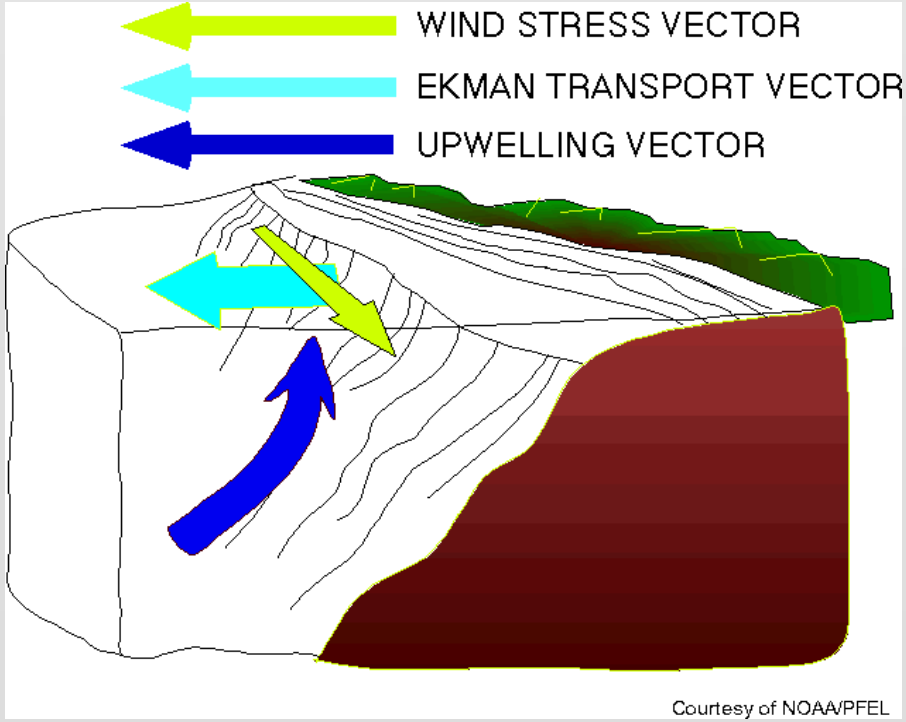
- Strength of coastal upwelling
- Seasonal reversal of coastal currents: southward in summer – northward in winter
- Phase of the Pacific Decadal Oscillation (PDO)

Climate change is going to affect each of these factors but we do not yet know in which direction

Circulation off the Pacific Northwest

Note: CC begins at ~ N end of Vancouver Island





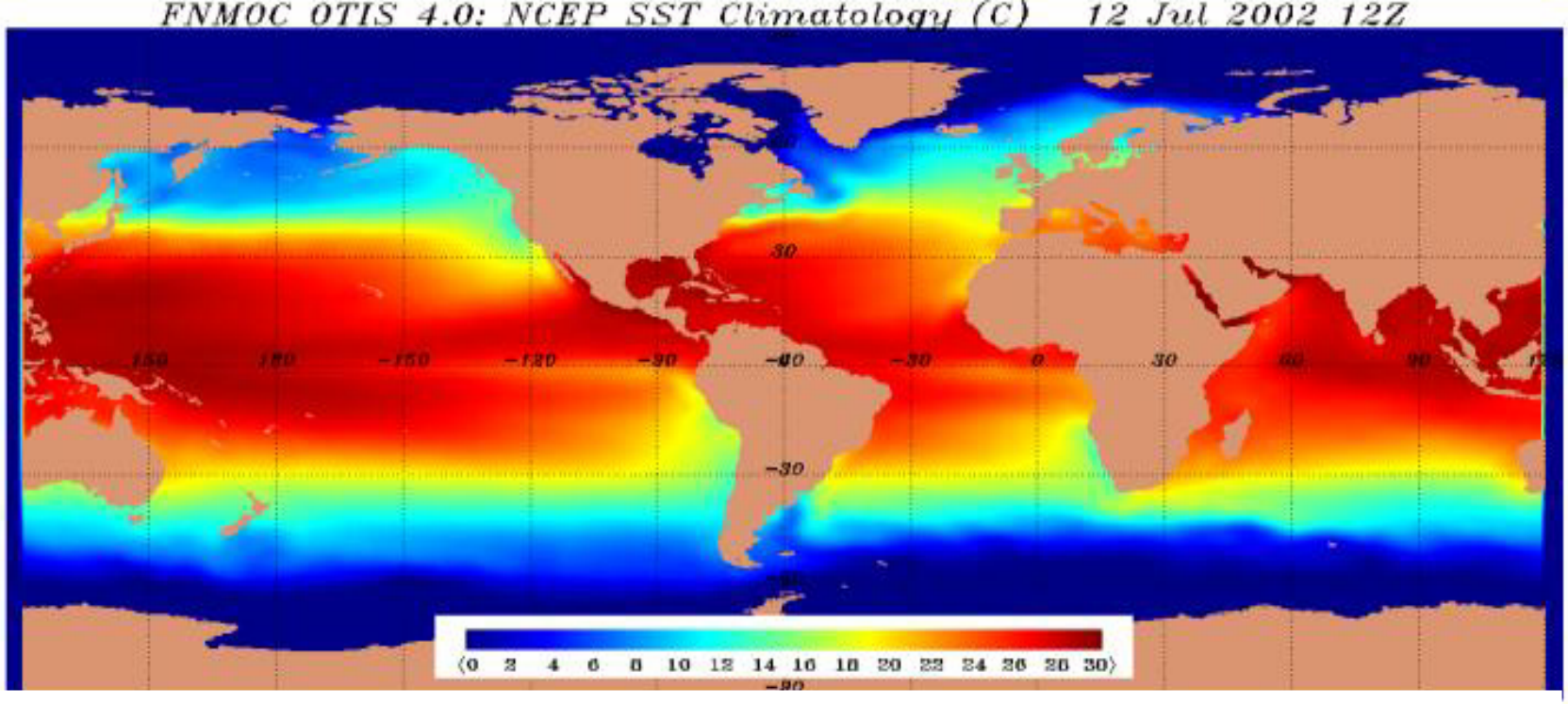
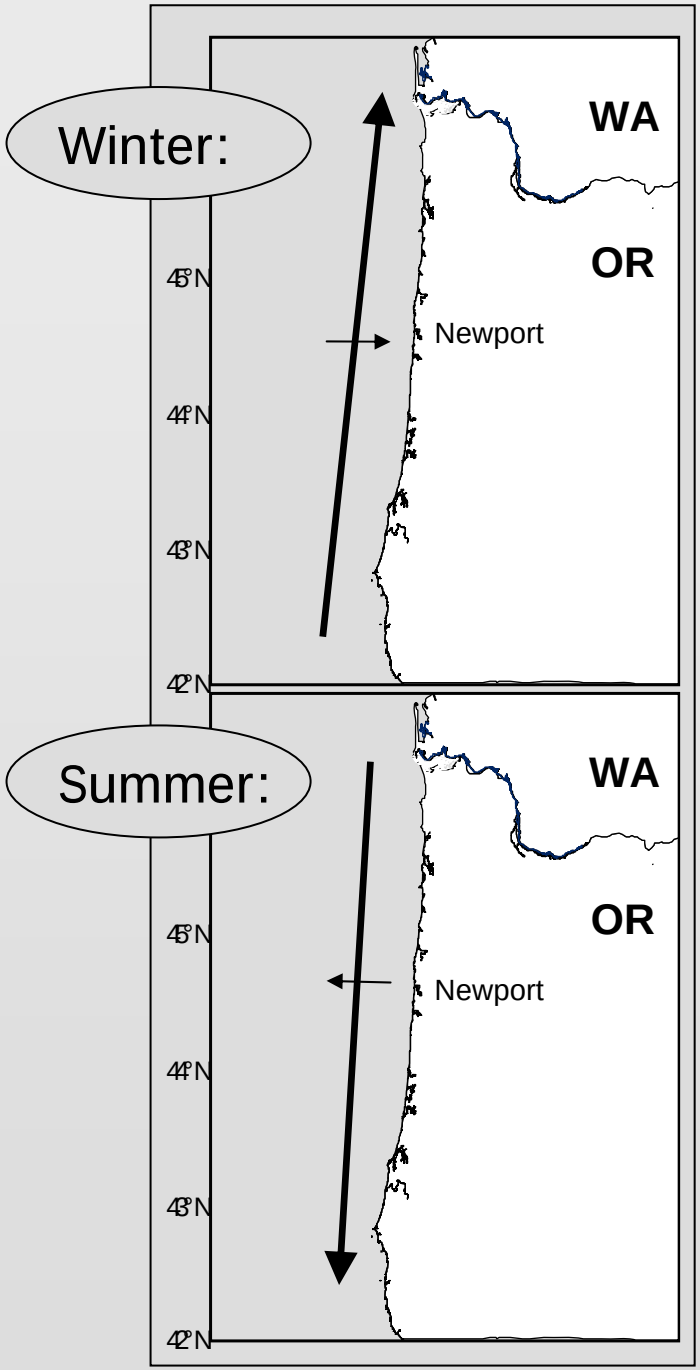


CHART OF SEA SURFACE TEMPERATURE

- Note: warm water between the equator and ~ 30 N
- Because of upwelling off North America, S. America N. Africa and S. Africa, cool water is found at the coast. Without upwelling, the coasts would be ~ 5-10☜C warmer during summer because offshore waters would move shoreward.
- Without upwelling we would have no salmon off PNW

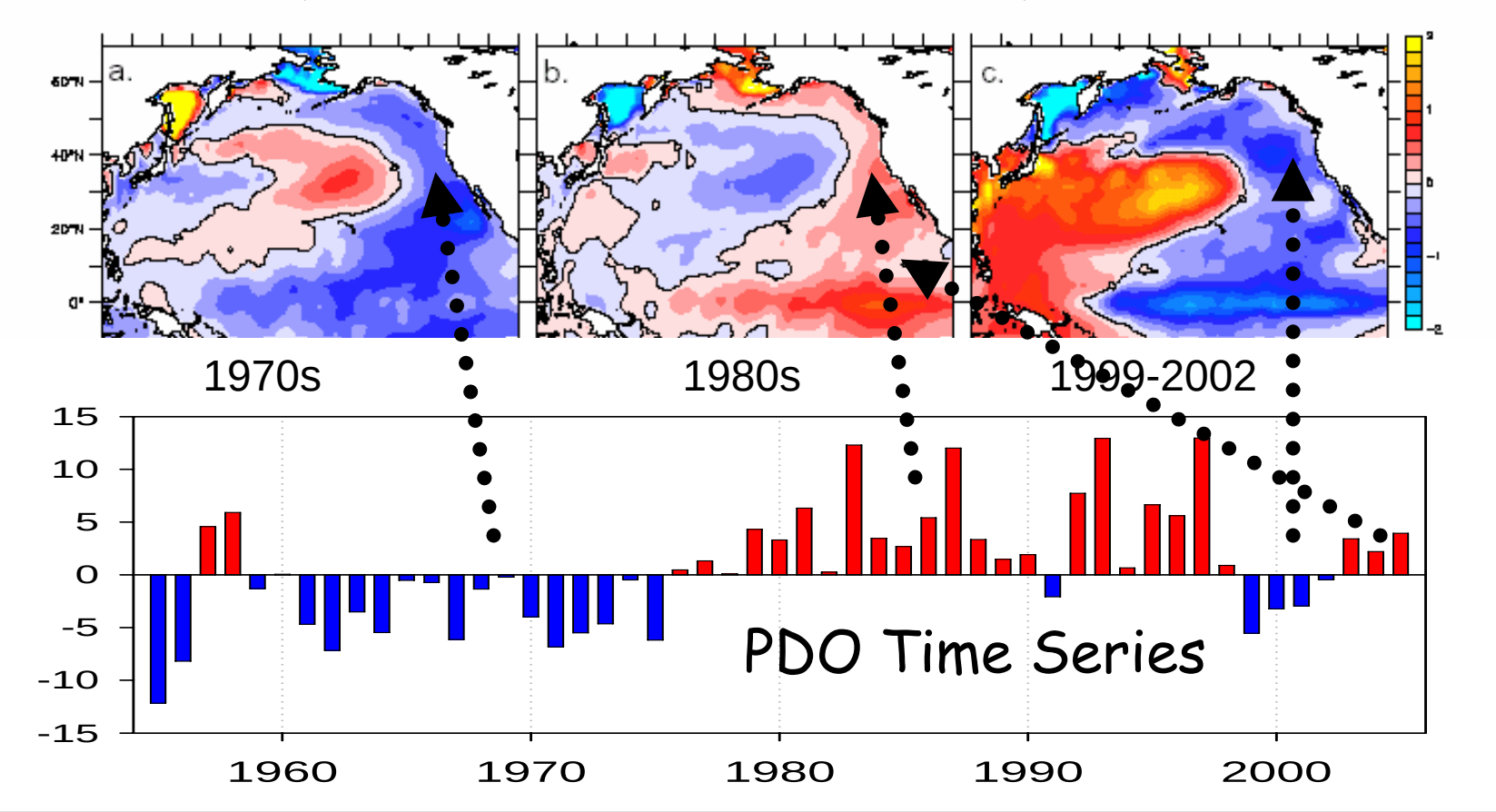
Winds and current structure off coastal Oregon:

- Winter:
  - Winds from the South
  - Downwelling
  - Poleward-flowing Davidson Current
  - Subtropical/southern 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**



Phase shifts are tracked by the Pacific Decadal Oscillation (PDO): negative values = cool phase; positive values = warm phase.

NORTH PACIFIC SST and PHASE SHIFTS

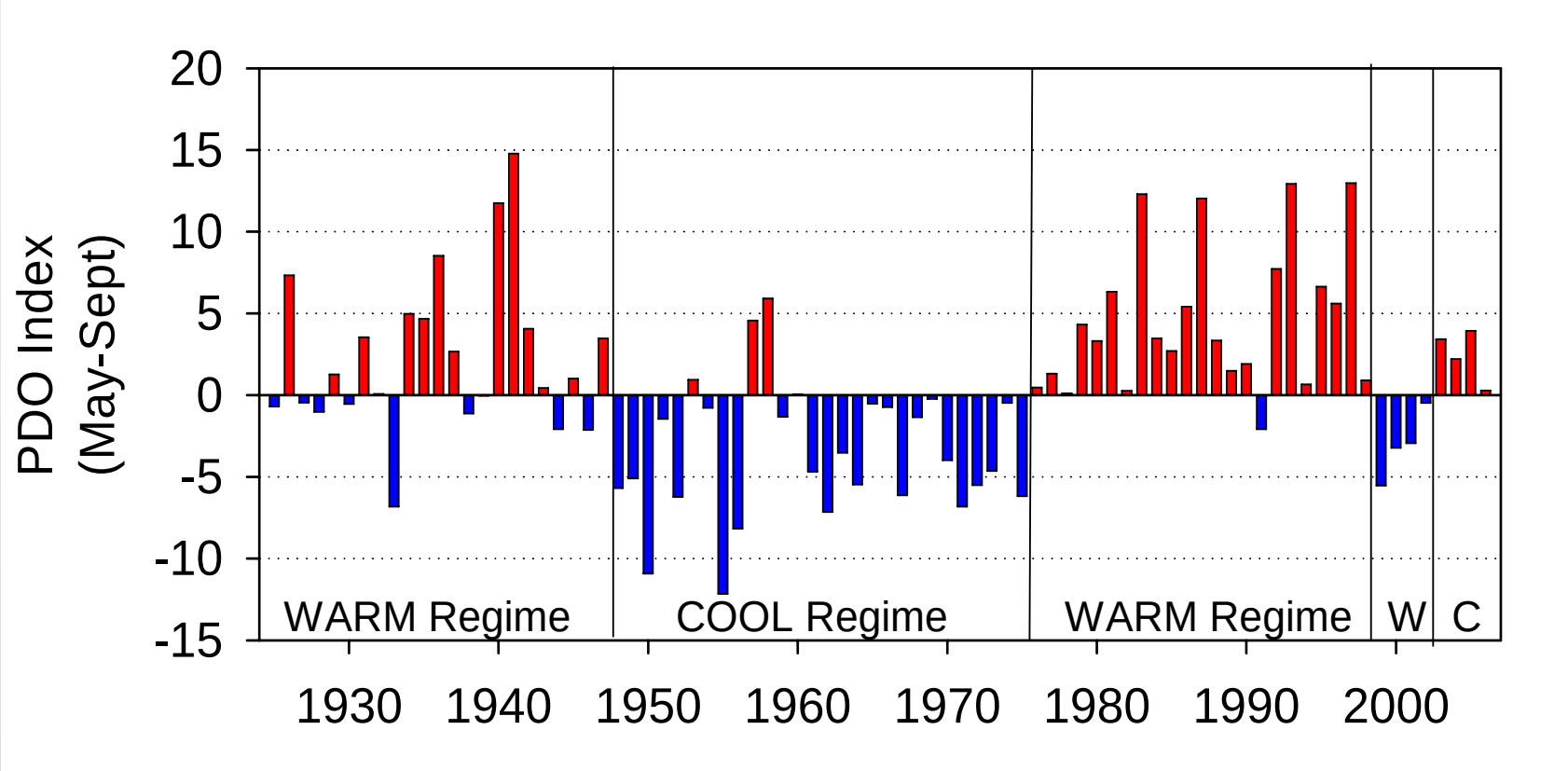


- Cool phase 1947-1976
- Cool phase 1999-2002
- Cool phase 2007 (?) -

- Warm phase 1977-1998
- Warm phase 2002-2006

Phase shifts caused by changes in winds during winter

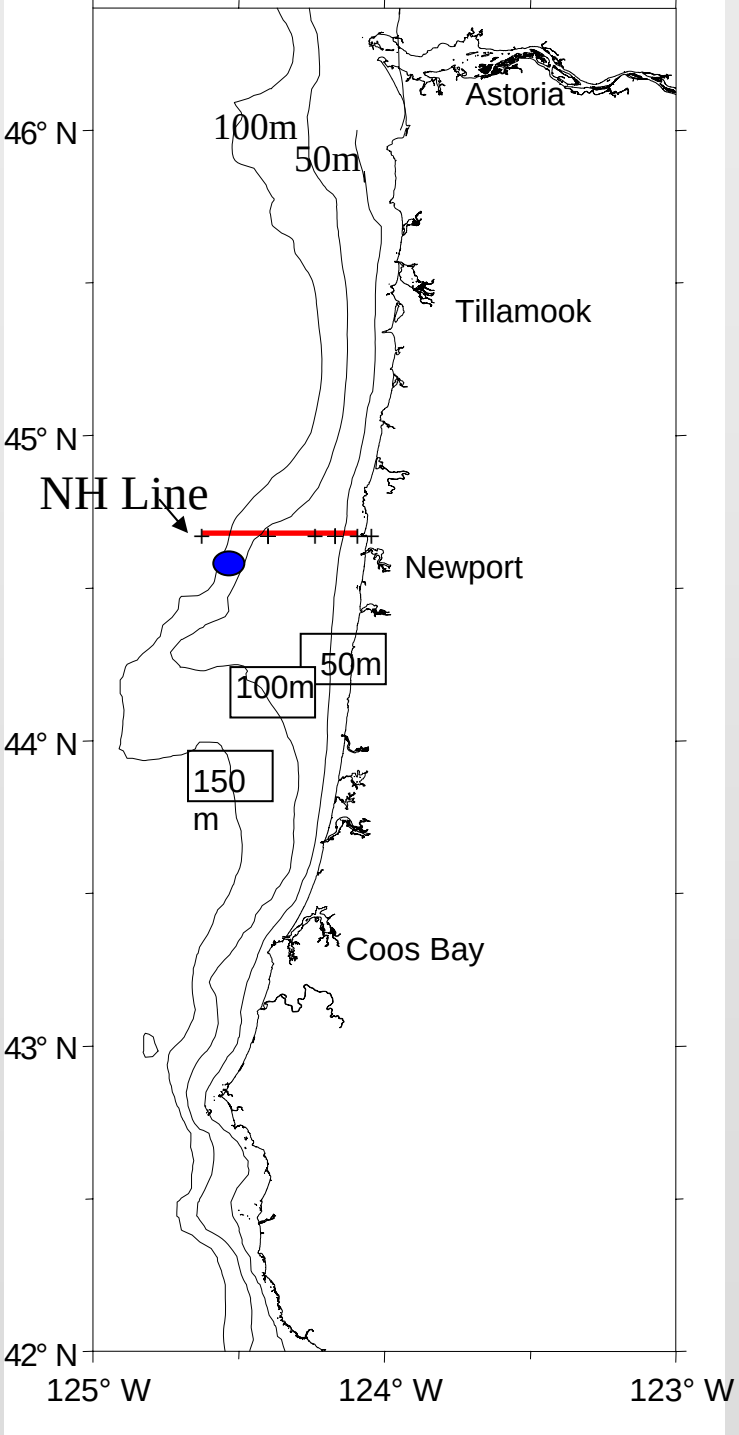
The PDO has been with us for quite some time, at least 80 years, but perhaps since 17th century



- Historical record does not contain a 4 X 4 shift

The recent 4-year cycling of the PDO has given us an "experiment"

- Is the ecosystem different during the warm and cool phases of the PDO?
- How quickly does the ecosystem respond to phases shifts?
- 1996-1998 Warm
- 1999-2002 Cold
- 2003-2006 Warm
- 2007 - Cold (in spring, but summer?)



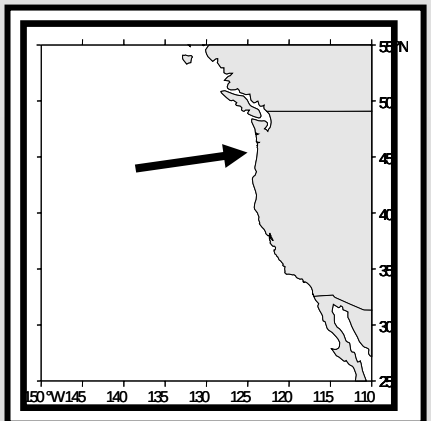
NH-Line Hydrographic and Zooplankton Time Series

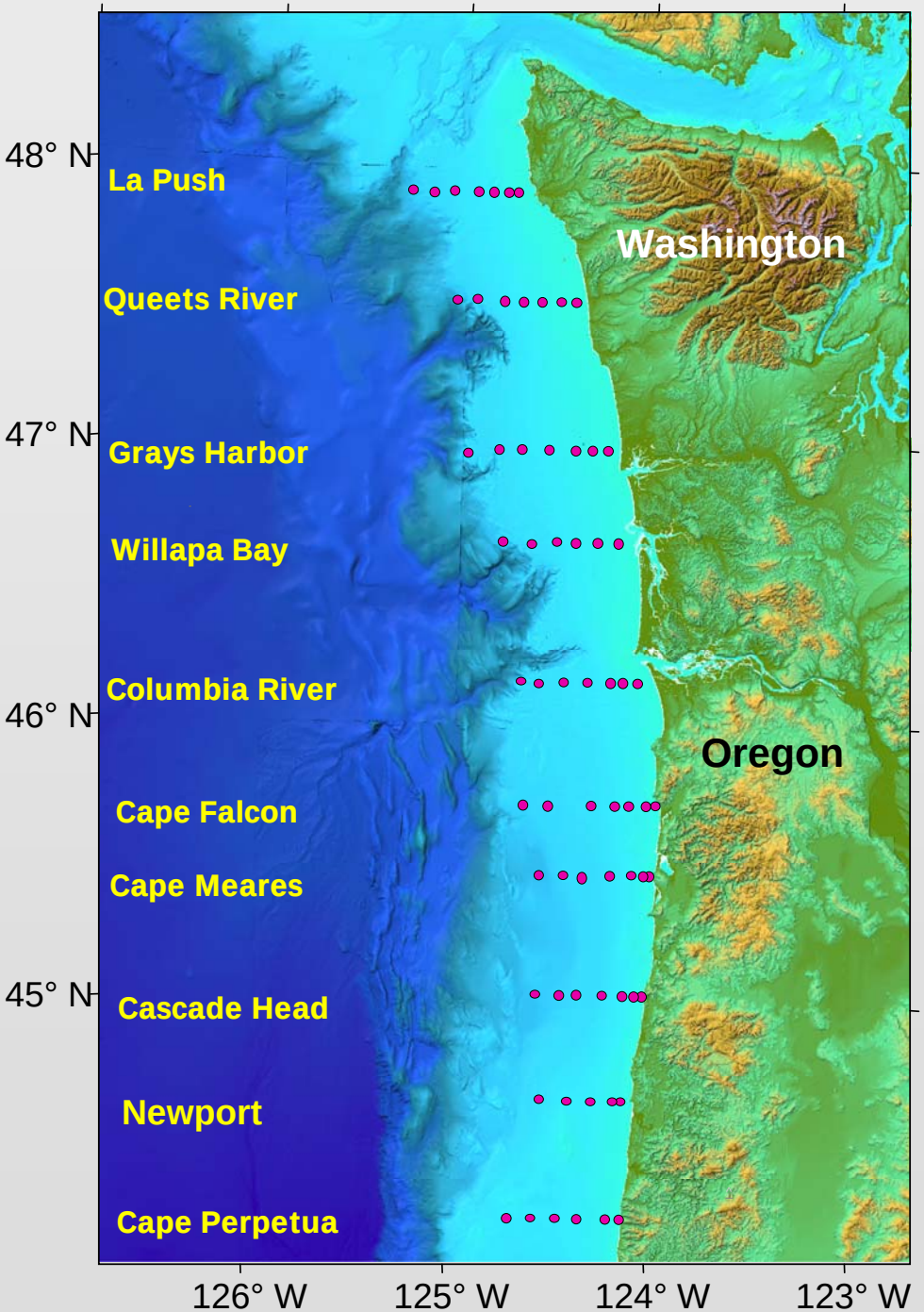
Bi-weekly Sampling:

- **1969 – 1973** (Miller, Pearcy, Peterson)
- **1977, 1978** (Miller, Peterson)
- **1983** (Miller, Batchelder, Pearcy, Brodeur)
- **1990-1992** (Fessenden and Cowles)
- **1996 – present** (Peterson et al.)

N = 401 visits to NH 05

= NOAA Weather Buoy



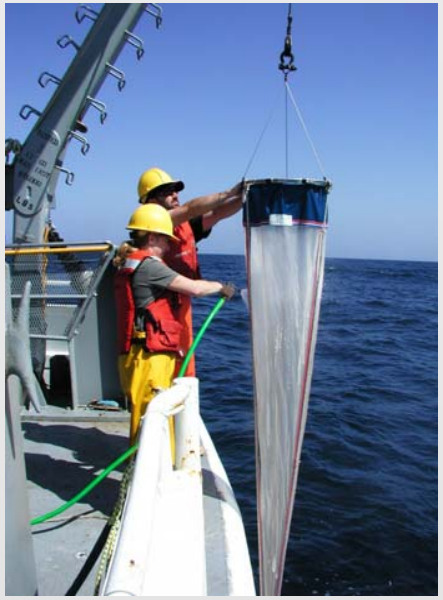


Salmon and Pelagic Fish Sampling

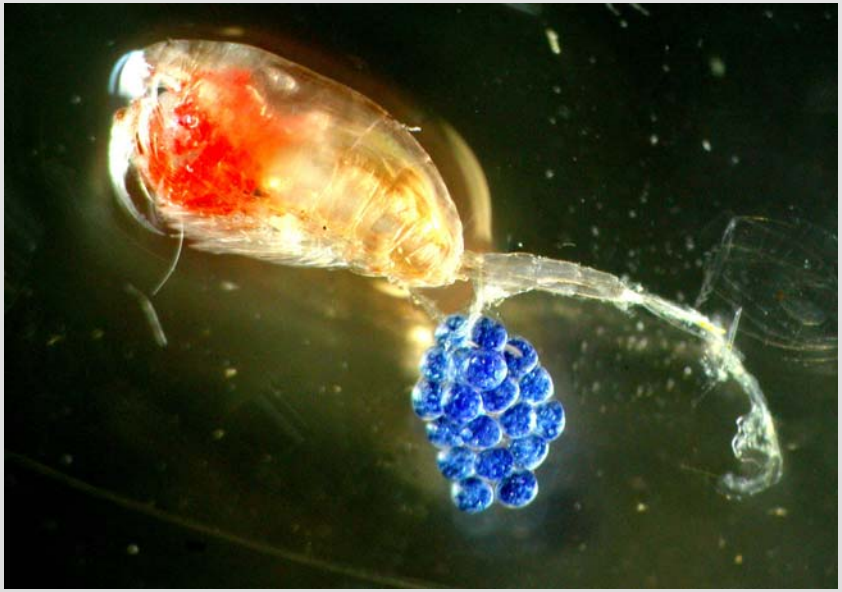
- Sample in May, June and September (DURING THE DAYTIME) at ~ 50 stations since 1998
- Sample Columbia River and Willapa every 10 days from April through July (AT NIGHT) at ~ 10 stations since 1998 (Bob Emmett)

Sampling methods

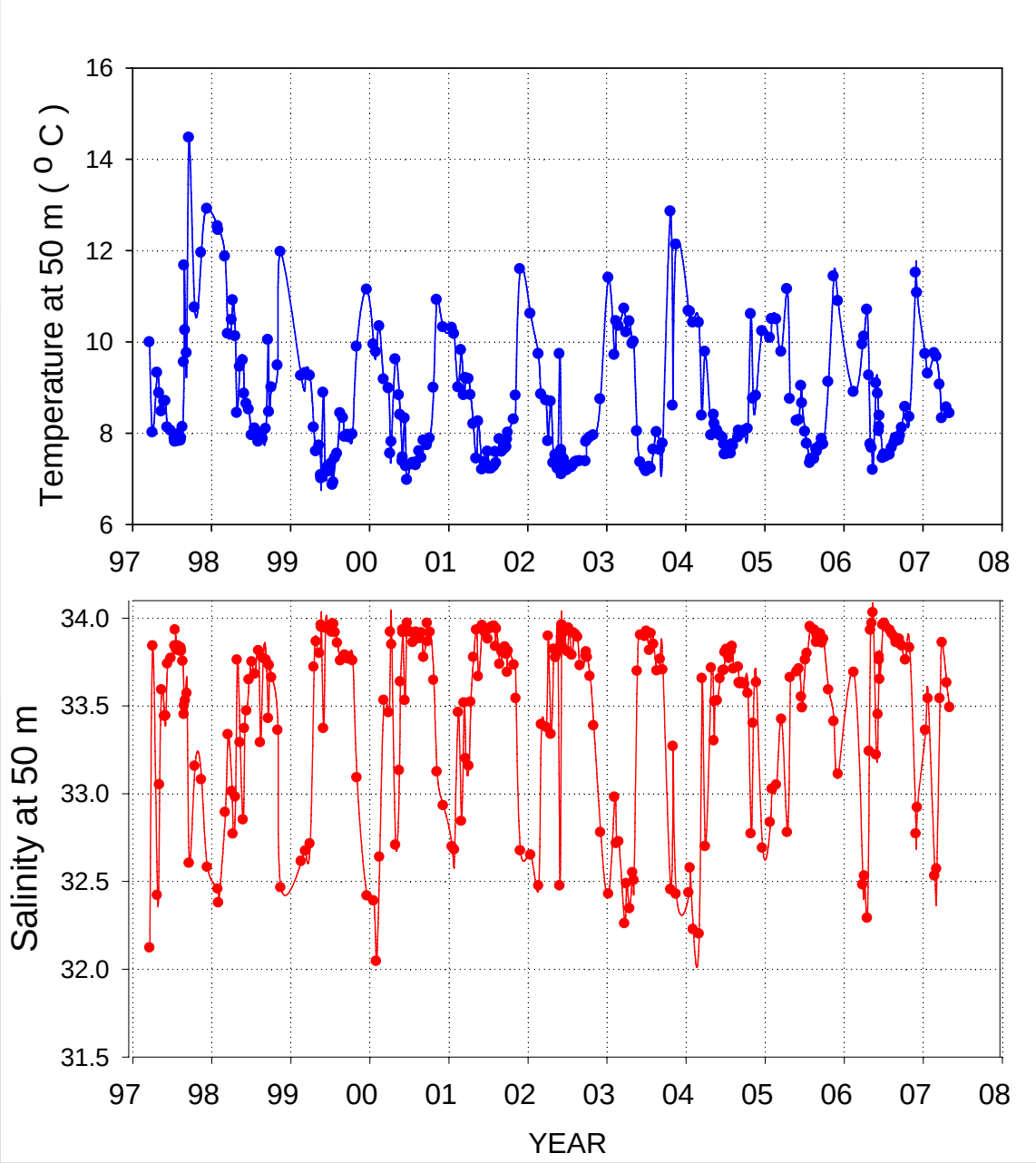
- Copepods with $\frac{1}{2}$ m diameter 200 μm mesh net towed vertically from 100 m
- Krill with 70 cm 333 μm mesh net towed obliquely



Here are some copepod images…



BTP1



Temperature and salinity at NH 05 at 50 m

- Note abrupt shift in <u>bottom water</u> T & S during summer of 1999

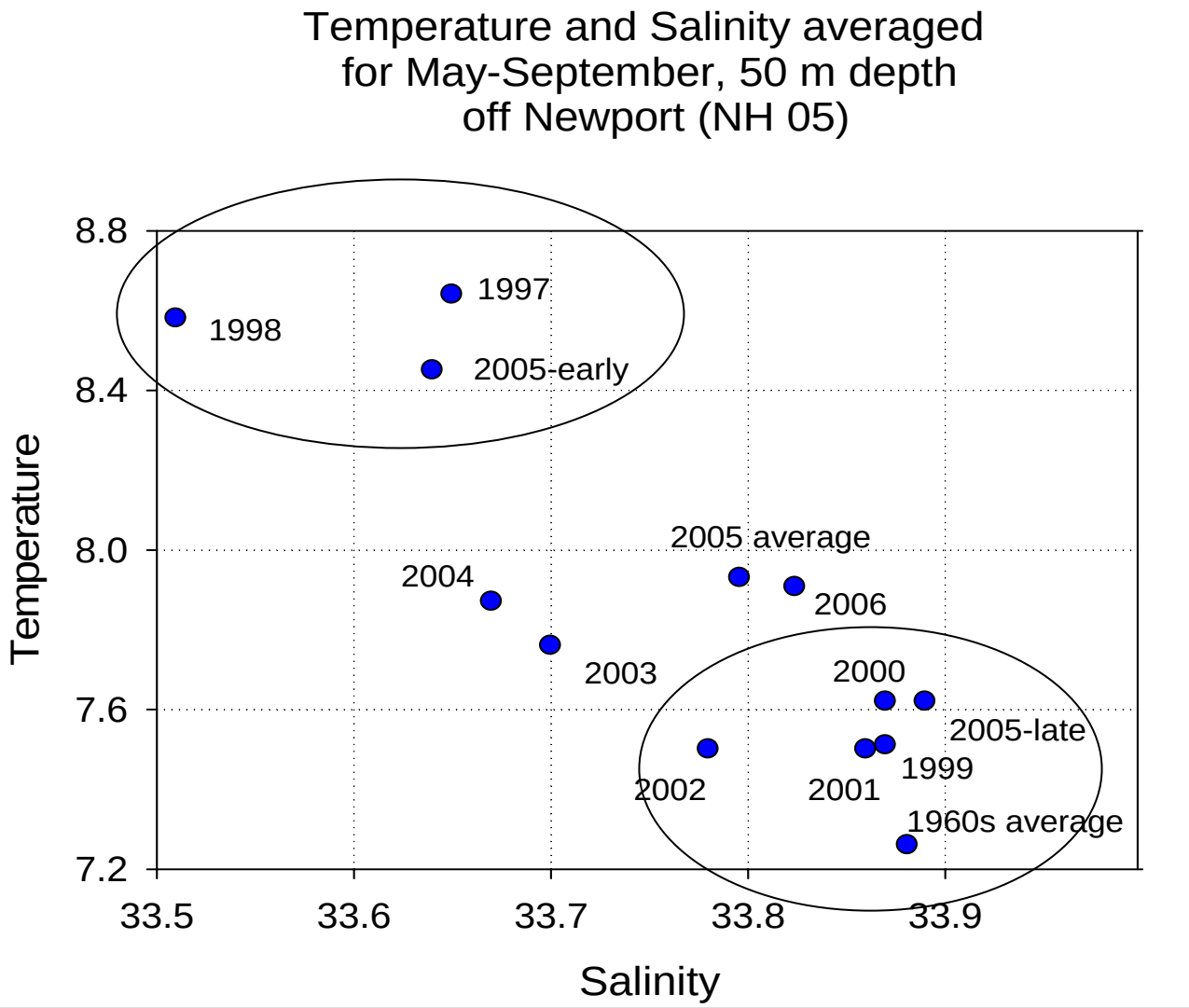
Fresher and warmer in summers 2004-2006

This tells us that there are different types of water off the coast with season and year.

BTP1 Note 0.5 deg increase in temperature in summer occurred on 5 Aug 2003.

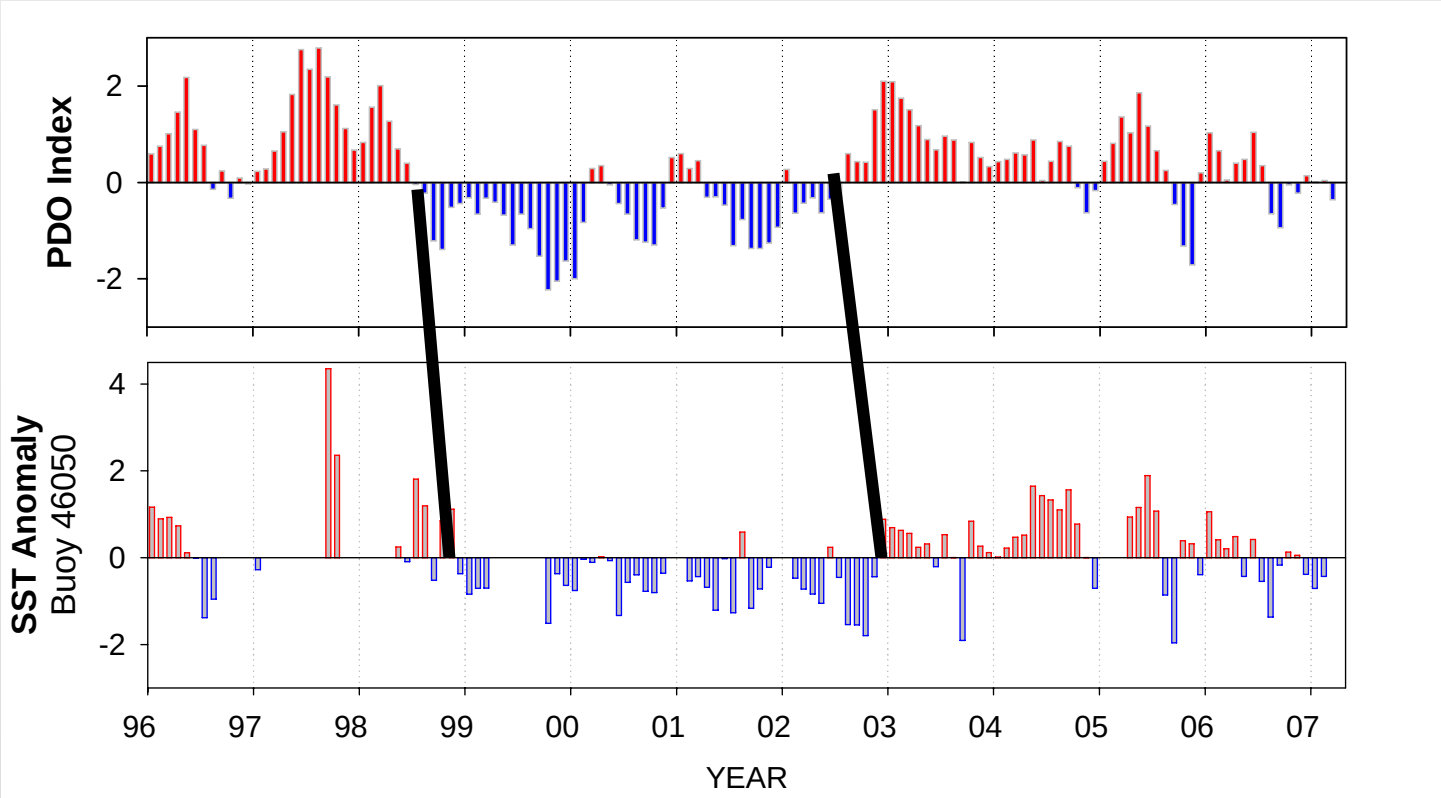
Bill T Peterson, 9/19/2005

T-S Properties at 50 m depth; mid-shelf off Newport



- years = 0.006 yr^{-1} Cold and salty during negative PDO (99-02), and 60s!
- Warm and fresh water during El Niño events (97-98) as well as early last summer (May-July 2005)
- Average for 1960s ~ 0.24 cooler in 40

Sea surface temperature (SST) data from weather buoy off Newport shows similar patterns & shows that SST off Newport is related to the PDO = downscaling



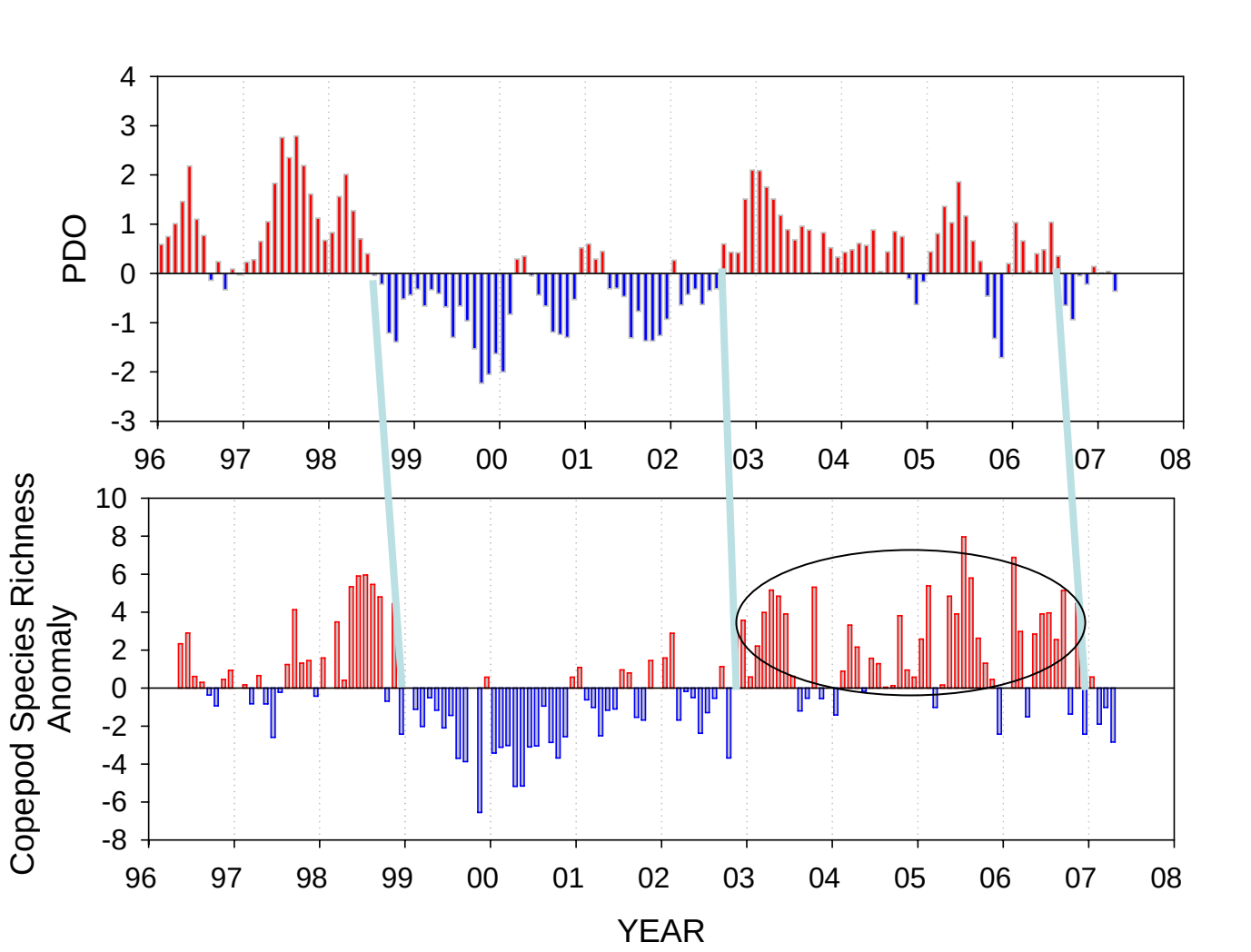
Cooler water in late 1998 associated with PDO change.

Warmer water in late 2002 associated with PDO change.

Most months cooler since late 2005

Note: time lags between PDO and SST change, associated with advection of different water types to Oregon.

Copepod species richness anomaly and the PDO



Species richness reflects origins of the animals. Low = subarctic; high = subtropical

Species richness declined in fall 1998 but began to increase in Nov 02 due to phase shift of PDO

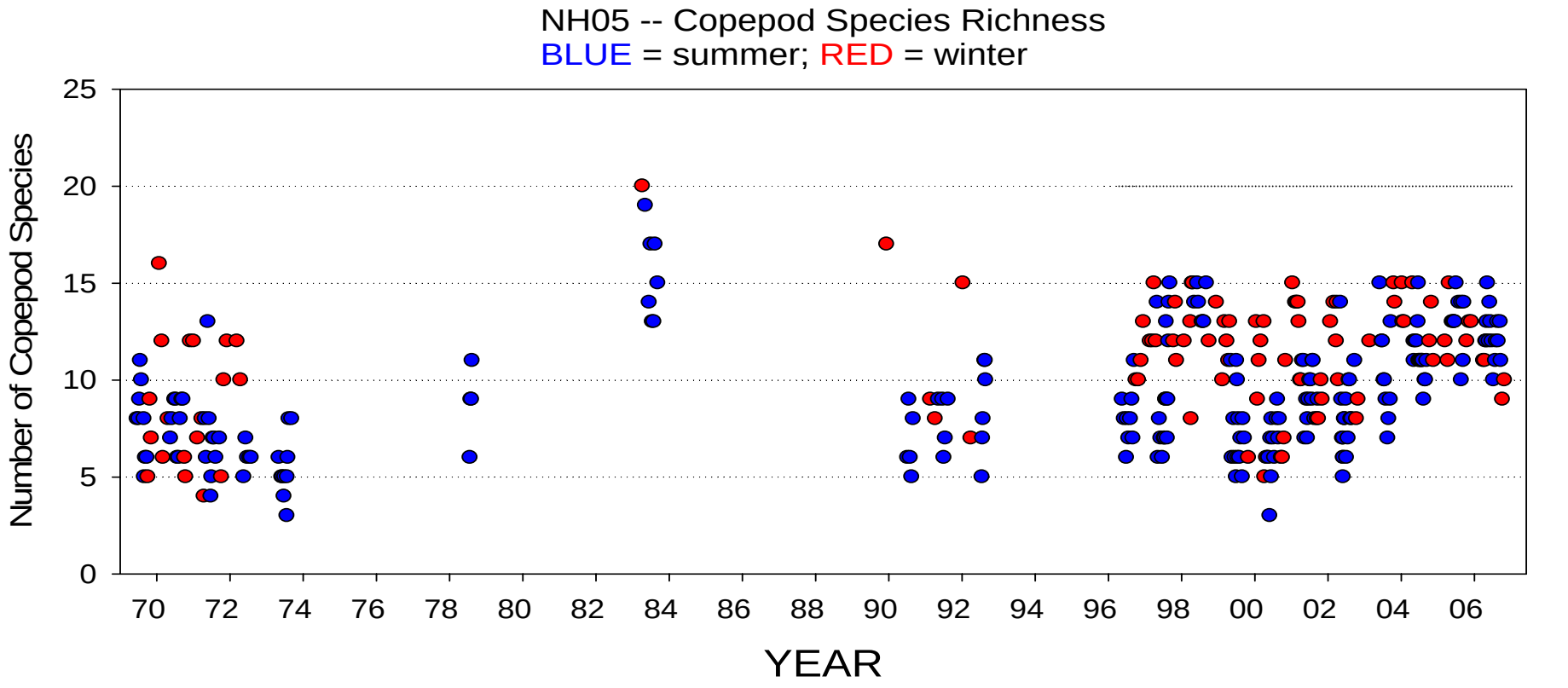
Richness in 2003-2006 similar to the 1997-98 El Niño event

As with SST, 3-5 months following PDO change, copepod species richness switches.

- Suggests different water types appear off Oregon with persistent changes in PDO.
- Now, changing again,

Copepod Biodiversity since 1969

Copepod Biodiversity is much higher now than in 1970s



Winter usually more diverse due to northward transport of sub-tropical species in the Davidson Current. Summers usually less diverse due to southward transport of boreal species from the coastal Gulf of Alaska. Diversity usually higher during El Niño (e.g.,1983, 1998)

Is increased biodiversity a problem?

- Perhaps….
  - Lesser volumes of sub-arctic waters may be transported into the Oregon coastal zone in summer and more water seems to be moving onshore from offshore.
  - Different water types bring different species of plankton.
  - Are there implications for existence of a very different mix of copepods dominating during cold vs warm water conditions?

Comparisons in size and chemical composition

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

- **Cold-water species** – (from Gulf of Alaska) are **large** and store **wax esters** (a kind of fat) to get them through the winter hibernation period.

Therefore, it is possible that significantly different food chains may result from climate shifts

Might food chains of differing bioenergetic content be important to species such as salmon?

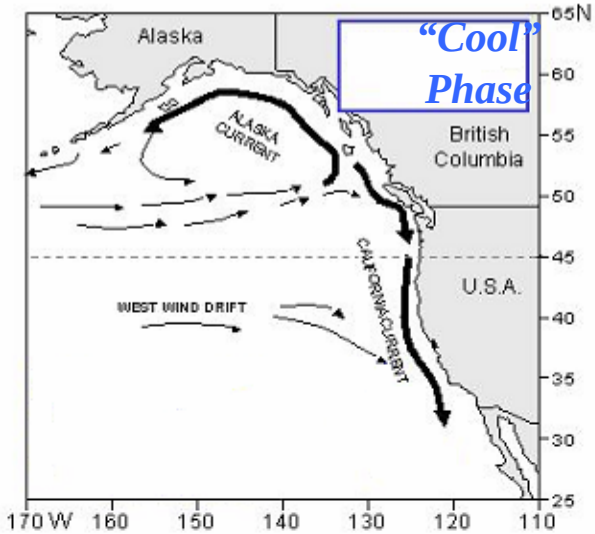
***A working mechanistic hypothesis*: source waters. . .**

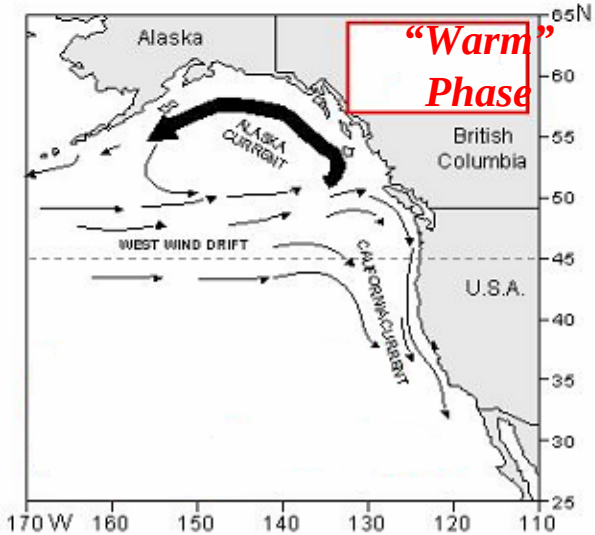
Cool Phase ➔

Transport of boreal coastal copepods into NCC from Gulf of Alaska

Warm Phase ➔

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



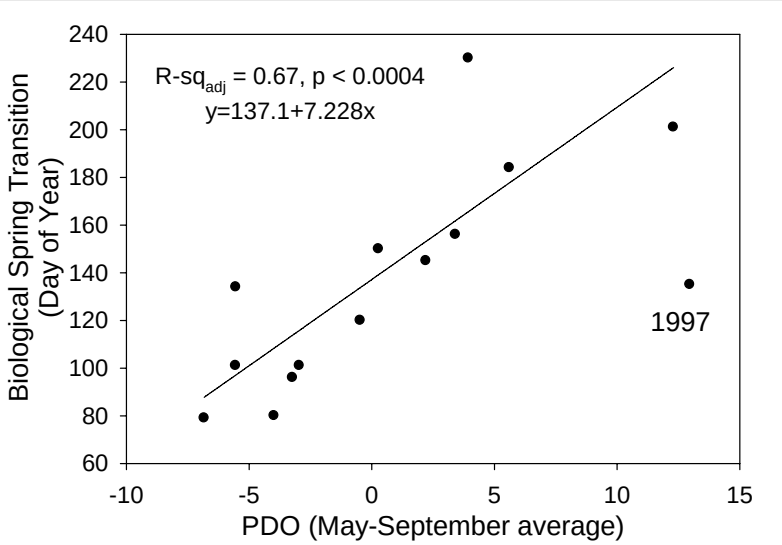


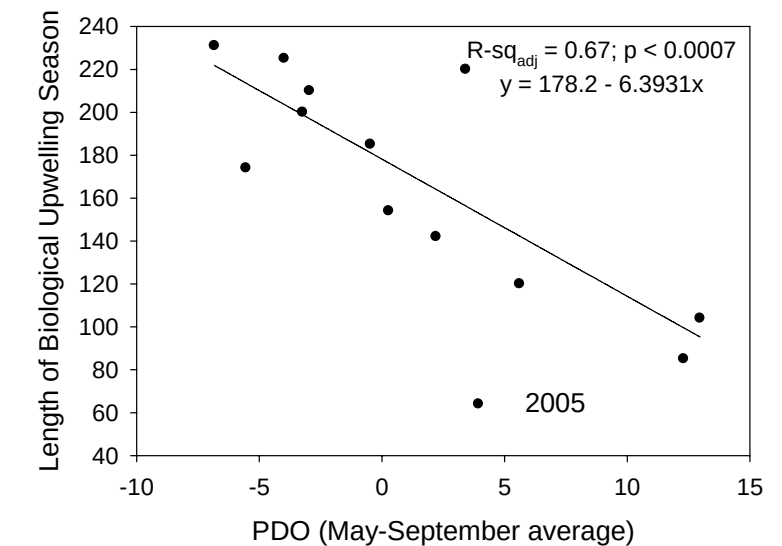
What's up with 2007? Very early transition

- Date of first appearance of summer community
- Length of upwelling season = 174-231 d if PDO neg
  64-154 d if PDO pos

	Upwelling Season		Length of the upwelling season	
	Start Date	End Date	Days	PDO
1970	~ 20 Mar	20 Oct	225	neg
1971	20 Mar	6 Nov	231	neg
1983	20 Jun	13 Sep	85	pos
1996	3 Jul	31 Oct	120	pos
1997	15 May	27 Aug	104	pos
1998	never	never	0	pos
1999	14 May	4 Nov	174	neg
2000	6 Apr	23 Oct	200	neg
2001	11 Apr	7 Nov	210	neg
2002	30 Apr	1 Nov	185	neg
2003	5 June	3 Oct	220	pos
2004	25 May	14 Oct	142	pos
2005	18 Aug	21 Oct	64	pos
2006	30 May	31 Oct	154	pos
2007	22 Mar			neg

PDO vs date of 'biological spring transition (UPPER) and number of days that a cold water community persisted in a given year (LOWER)





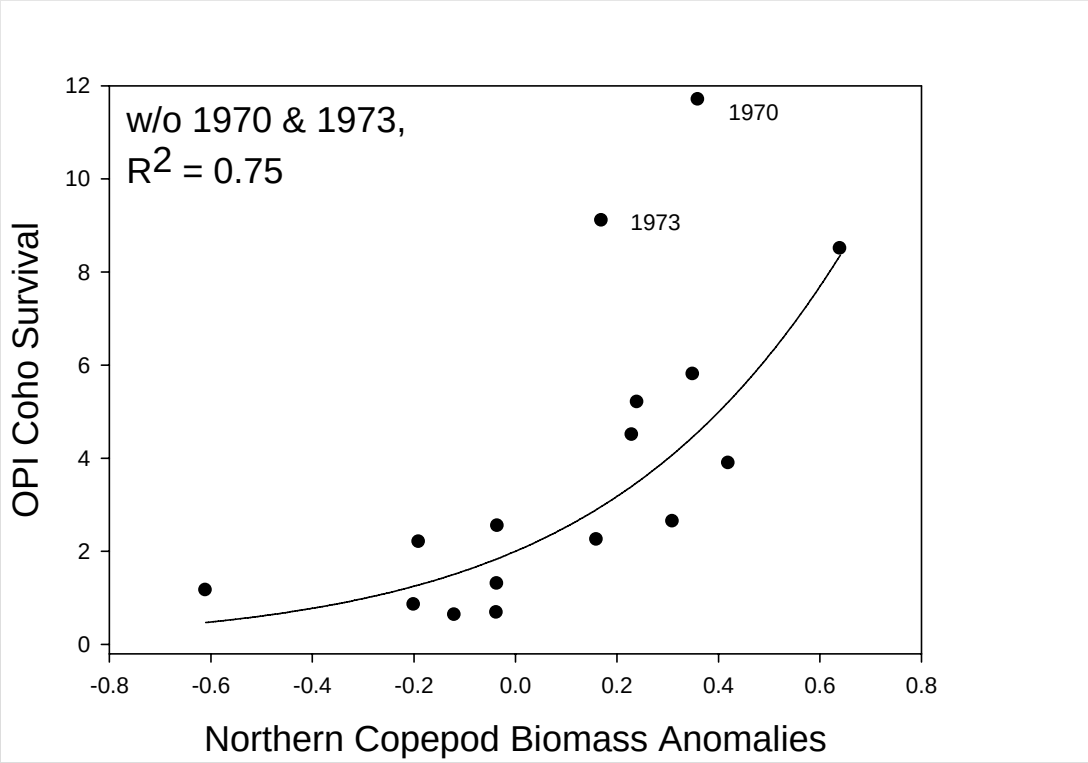
- The more negative the PDO, the **earlier** the date of "biological spring"
  - 'Zero' point is day 10 April
- The more negative the PDO the **longer** a cold water community persists.
  - 64-154 d when PDO positive
  - 174-231 d when PDO negative

	Juvenile migration year				Forecast of adult returns	
	2000	2004	2005	2006 (to June)	Coho 2006	Chinook 2007
Large-scale ocean and atmospheric indicators						
PDO	🟩	🟥	🟥	🟨	🔴	🔴
MEI	🟩	🟥	🟥	🟨	🔴	🔴
Local and regional physical indicators						
Sea surface temperature	🟩	🟥	🟥	🟩	🔴	🔴
Coastal upwelling	🟩	🟥	🟥	🟩	🔴	🔴
Physical spring transition	🟩	🟥	🟥	🟩	🔴	🔴
Deep water temp. & salinity	🟩	🟥	🟥	🟩		
Local biological indicators						
Copepod biodiversity	🟩	🟥	🟥	🟥	🔴	🔴
Northern copepod anomalies	🟩	🟩	🟥	🟩	🔴	🔴
Biological spring transition	🟩	🟥	🟥	🟨	🔴	🔴
Spring Chinook--June	🟩	🟨	🟥	🟨	🔴	🔴
Coho--September	🟩	🟨	🟥	🟥	🔴	🔴

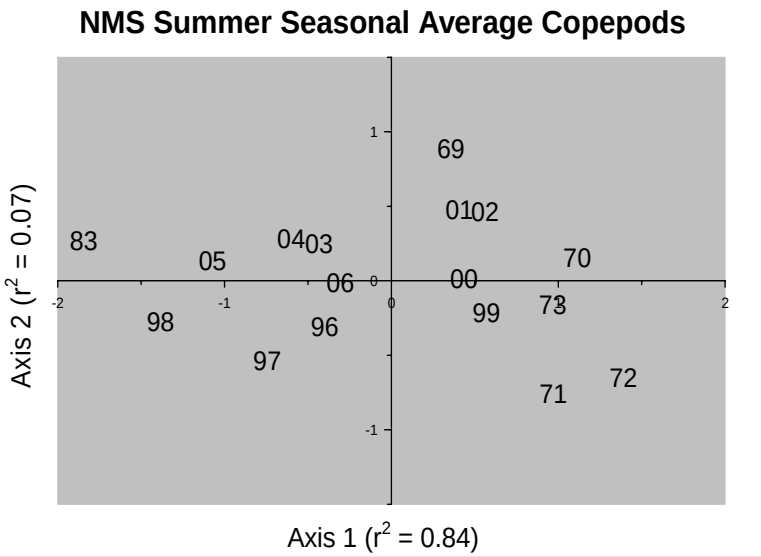
Key

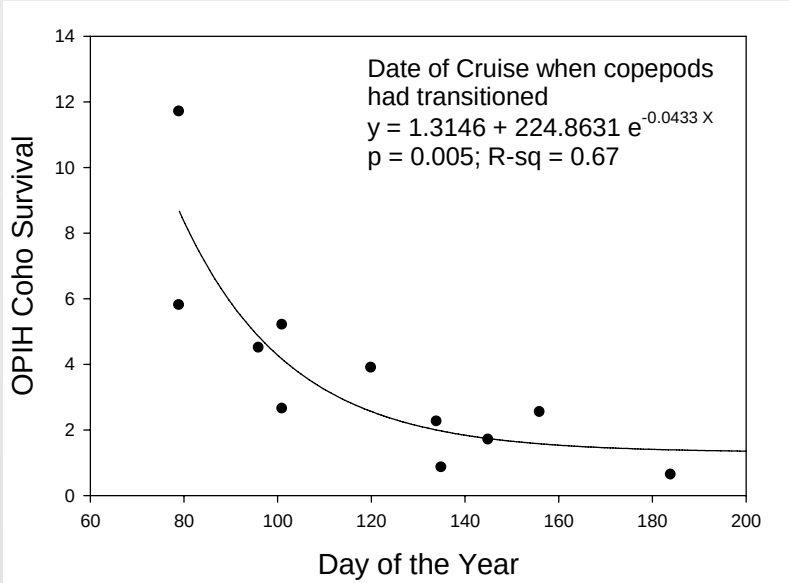
- 🟩 good conditions for salmon marine survival
- 🟨 intermediate conditions for salmon marine survival
- 🟥 poor conditions for salmon marine survival
- 🟢 good returns expected
- 🔴 poor returns expected

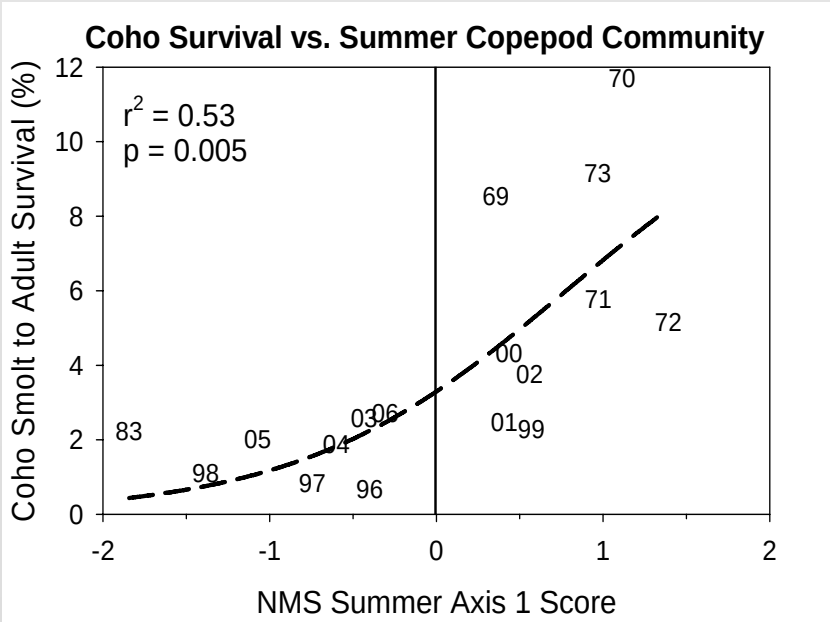
The biomass anomalies of northern cold water (fatty) copepods predict coho salmon returns

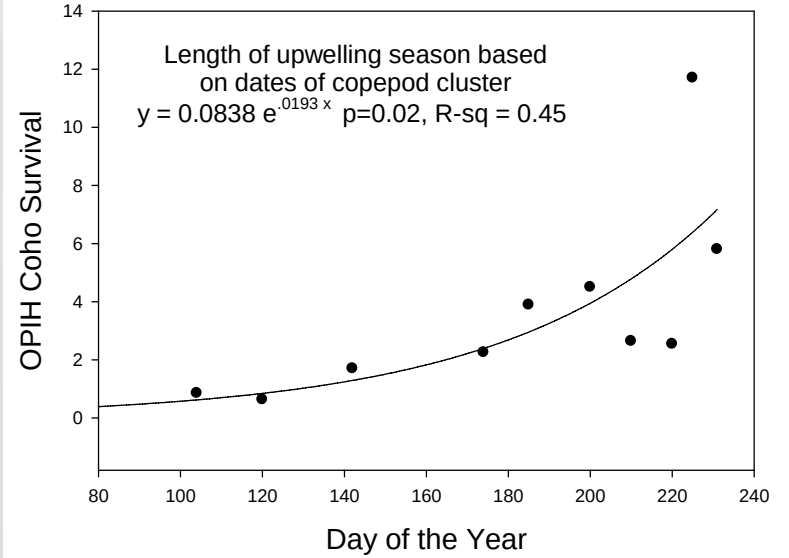


Assuming that a fat salmon is a happy salmon, we might just have found a link between changes in the PDO and changes in salmon production noted by Mantua et al. (1997)

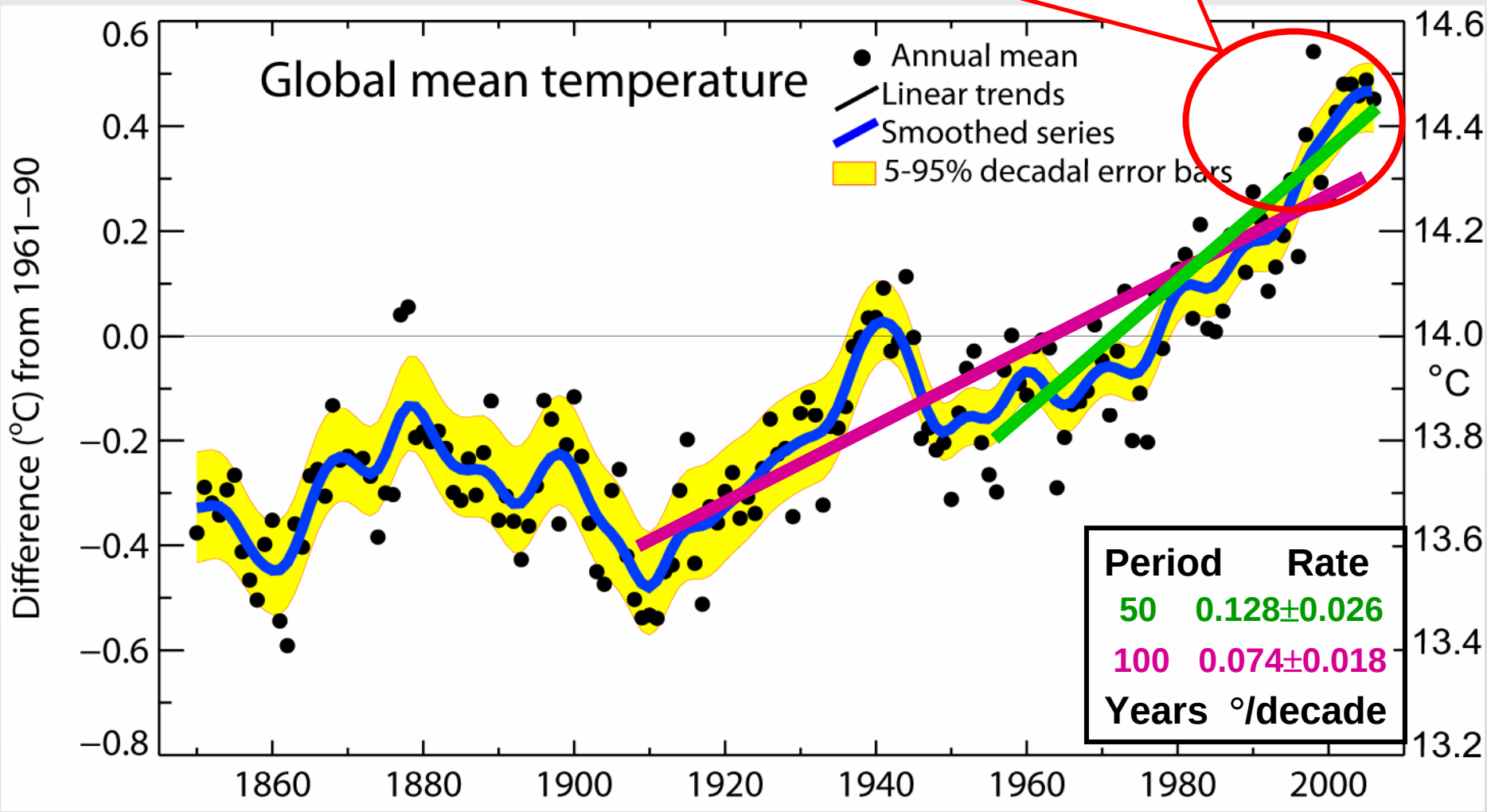

NMS Summer Seasonal Average Copepods
Axis 2 (r^2 = 0.07)
Axis 1 (r^2 = 0.84)
83
05
04
03
06
98
96
97
69
01
02
00
99
73
70
71
72


Date of Cruise when copepods had transitioned
y = 1.3146 + 224.8631 $e^{-0.0433 X}$
p = 0.005; R-sq = 0.67
OPIH Coho Survival
Day of the Year


Coho Survival vs. Summer Copepod Community
r^2 = 0.53
p = 0.005
Coho Smolt to Adult Survival (%)
NMS Summer Axis 1 Score
83
05
04
03
06
98
97
96
69
01
99
00
02
73
70
71
72


Length of upwelling season based on dates of copepod cluster
y = 0.0838 $e^{.0193 x}$ p=0.02, R-sq = 0.45
OPIH Coho Survival
Day of the Year

Global mean temperat[illegible]ith time



Wrap up

- PDO **downscales** to coastal waters of the NC C
- **Time lags** between PDO sign change and change in SST and copepod biodiversity is 3-5 months
- Changes in zooplankton species follow the PDO, with cold water lipid-rich copepods during negative phase and warm water lipid-poor animals in positive phase.
- Therefore if we can track the **behavior** of the PDO with climate models then we may be able to forecast food chain structure and in turn fisheries response, including returns of salmon to Columbia River.
- If climate change result in more water coming at the coast from offshore, and with it a "warm water" copepod community, higher level organisms may be in trouble because bioenergetic content of the food chain may be lower.
- Will it be salmon or tuna in the shops in Newport?

Acknowledgements

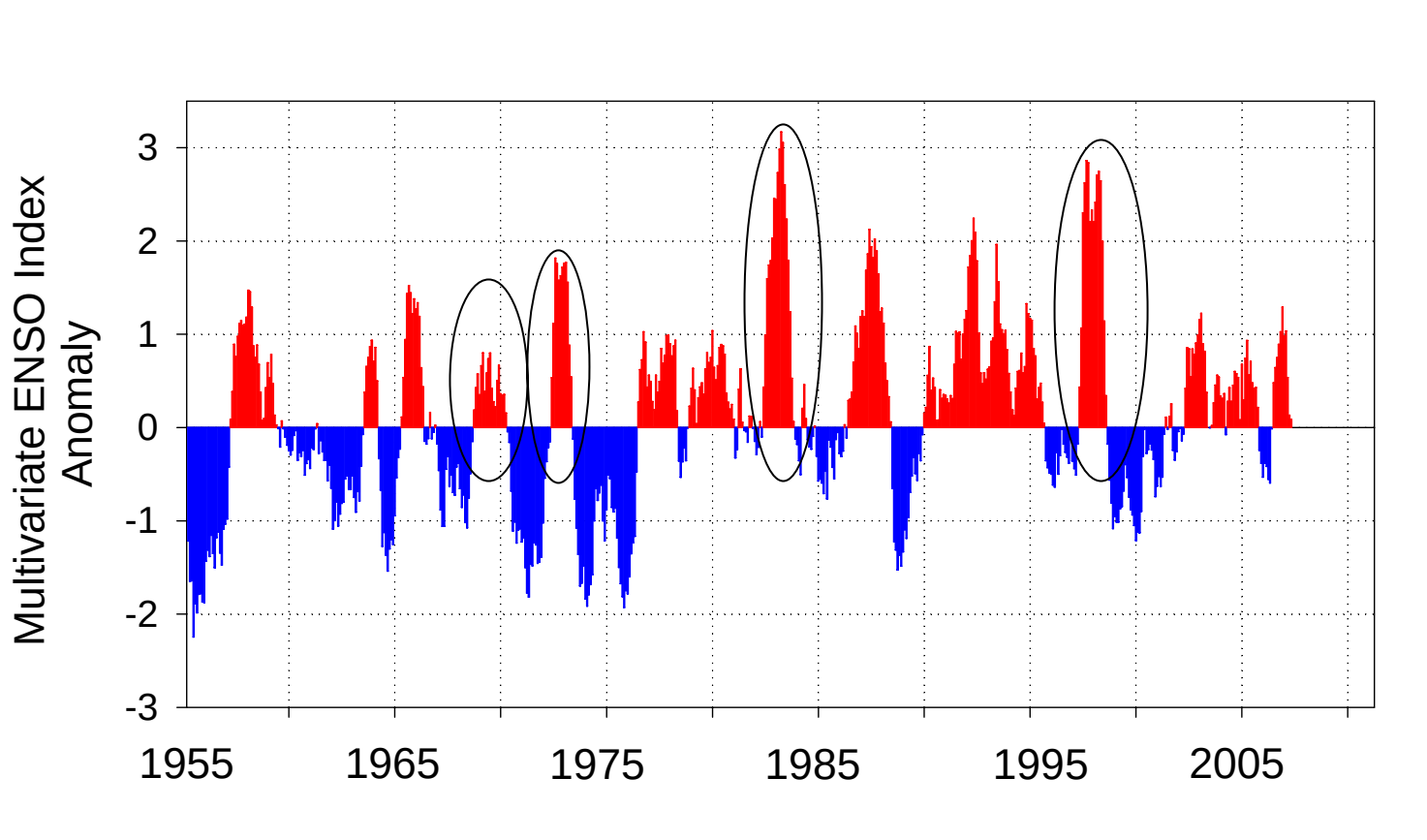
- U.S.GLOBEC Program (NOAA/NSF)
- PaCOOS Program (NOAA)
- NSF CoOP Programs (COAST, RISE)
- ONR-NOPP

- Lots of people have contributed to the success of 401 cruises:
  - since 1997: Leah Feinberg, Tracy Shaw, Jen Menkel, Jay Peterson, Jesse Lamb, Julie Keister, Linda & Tim O'Higgins + lots of lucky volunteers
  - in the 1970s and 1980s: Peter Rothlisberg, Greg Lough, Charlie Miller, Hal Batchelder + lots of lucky volunteers

- Check out our forecasts of ocean conditions at www.nwfsc.noaa.gov, and click on "What's New"

ENSO Index

negative = El Niño; positive = La Niña



- El Niño: 1969 1972 1983,1997-1998
  Weak Stronger Strongest

Other factors that matter to plankton (& salmon, Dungeness crabs, rockfish, anchovies, sardines, etc…) include:

- Water column stratification (from increased runoff and snowmelt)
- Seasonal cycles of production
- Phytoplankton species composition
- Zooplankton species composition
- Northward shifts in distribution (hake, halibut, pollock)

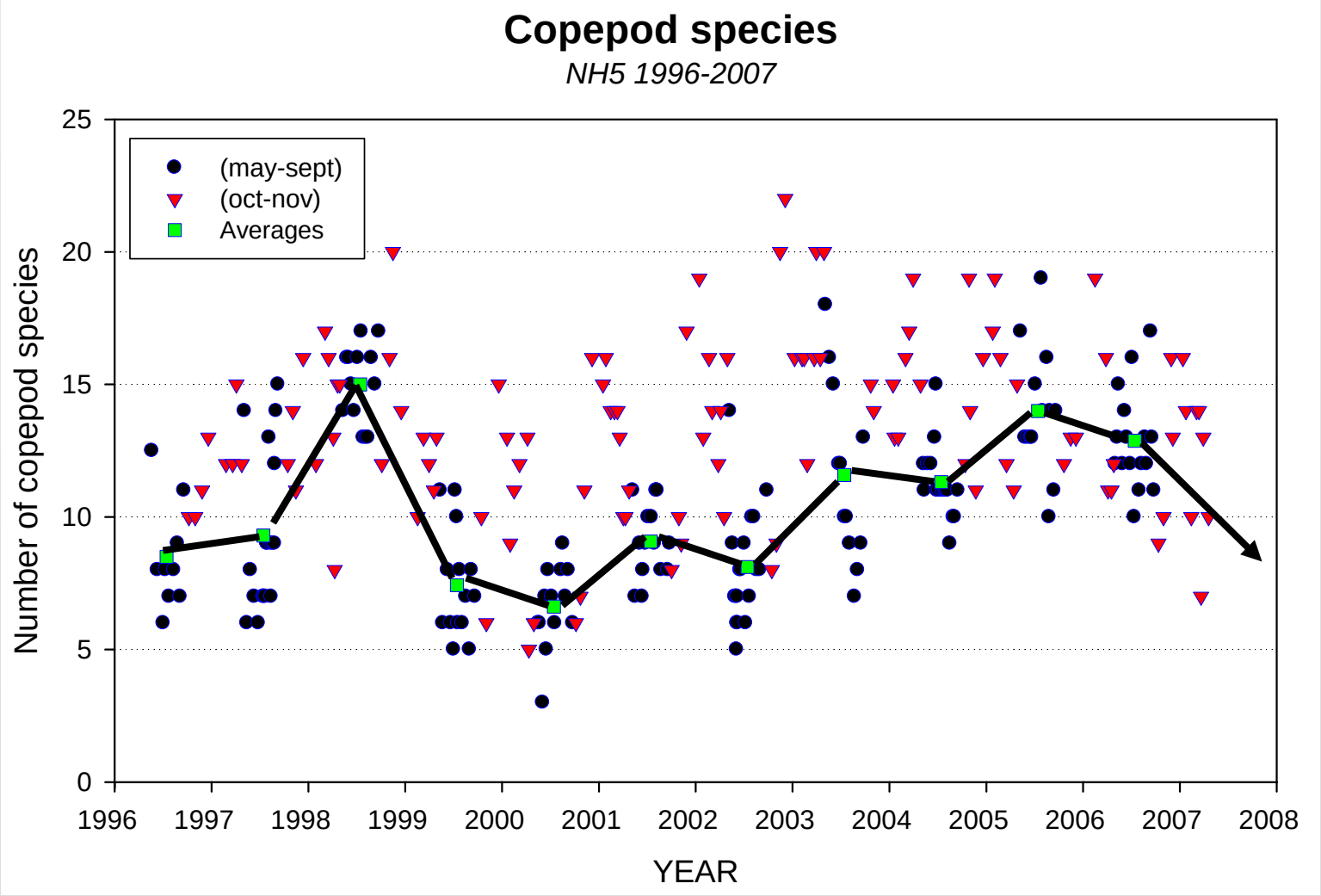
- Surprises have been the norm lately!

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)

Summer Averages in heavy black line

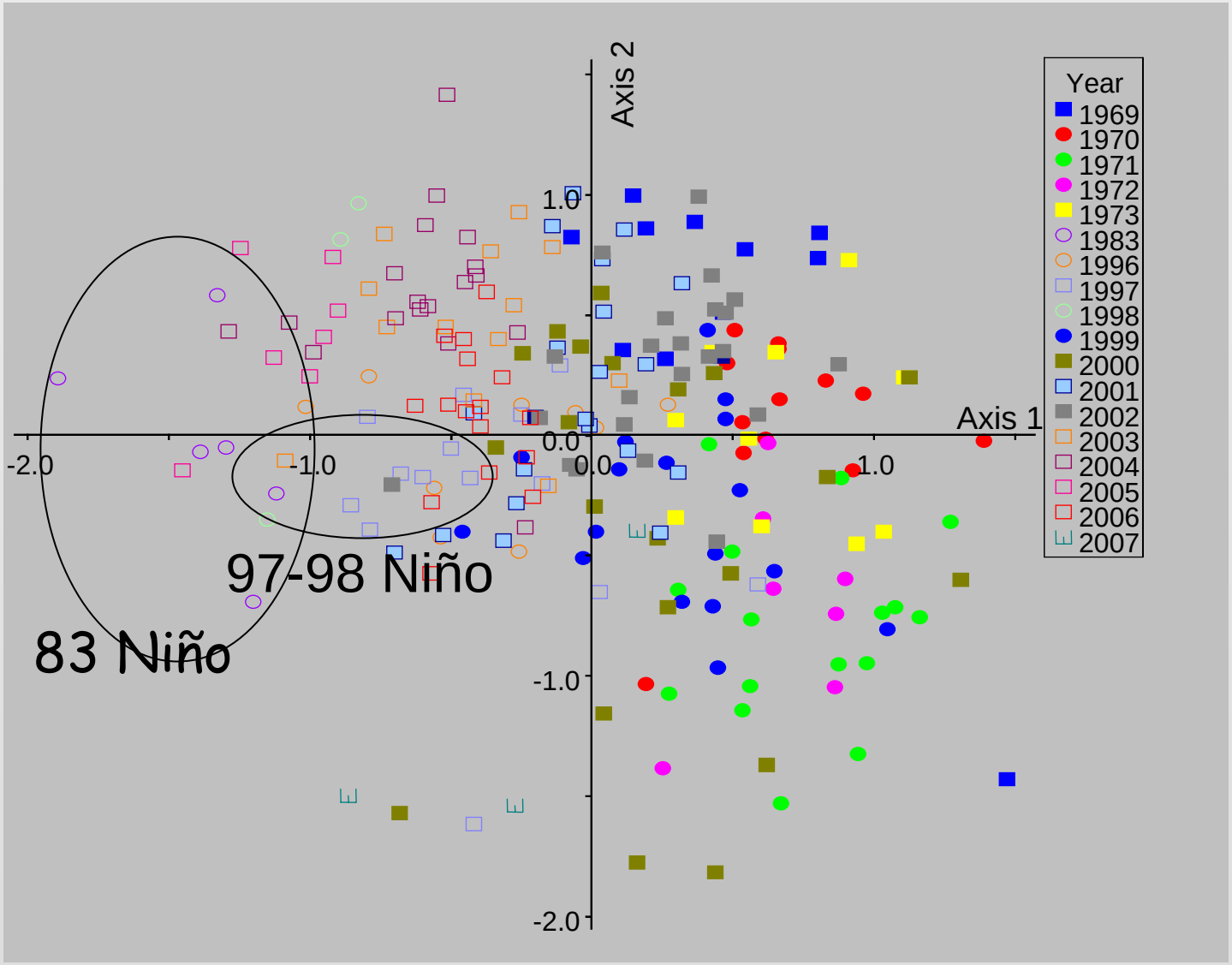


Community Composition:
Cold vs. warm water communities

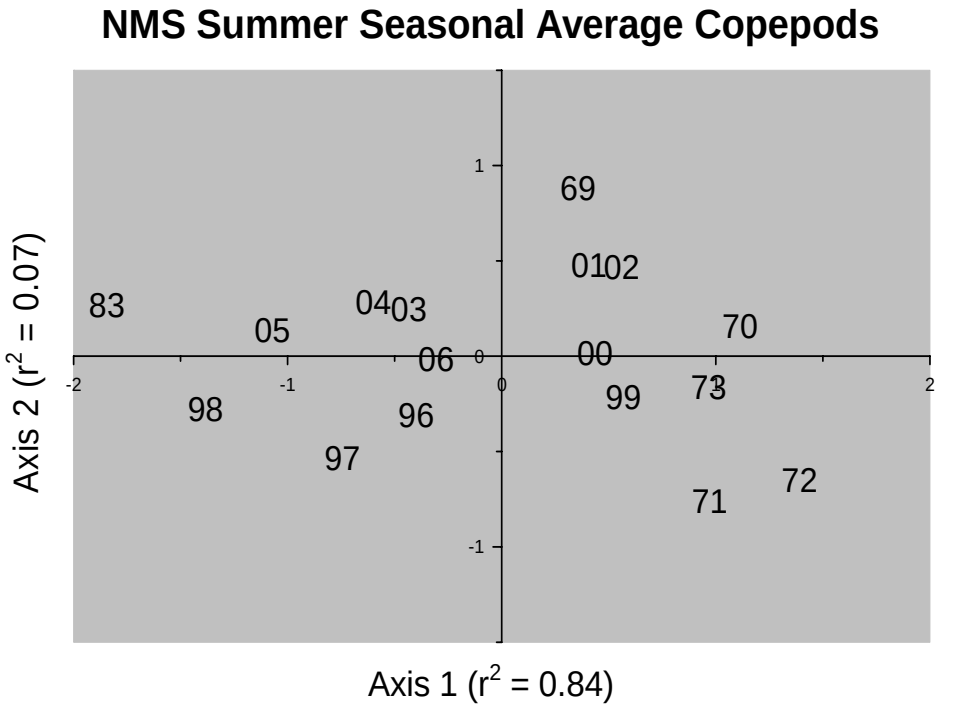
- Non-parametric multidimensional scaling (ordinations) groups stations using a similarity index; stations near to each other in MDS space have similar community structure

- Cluster Analysis: arranges similar community types into a dendogram structure

Ordination of 18 years of Summer Cruises)



Open Symbols = warm ocean conditions
Closed Symbols = cold ocean conditions



When we average the ordination scores by summers, we find similar communities in years with common patterns of PDO and SST:

- **Cold Water** Copepod Community in 1969-1973, 1999-2002
- **Warm Water** Copepod Community in 1983, 1996-1998, 2003-2006.

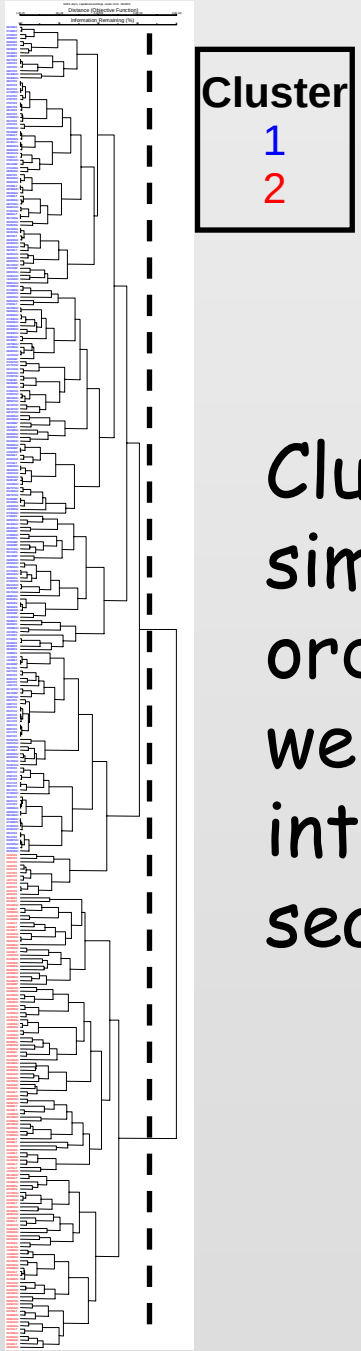
Cluster analysis

Results of processing of 368 samples not easy to illustrate.

Two patterns:

- Clusters 1 and 2 capture seasonal variations.

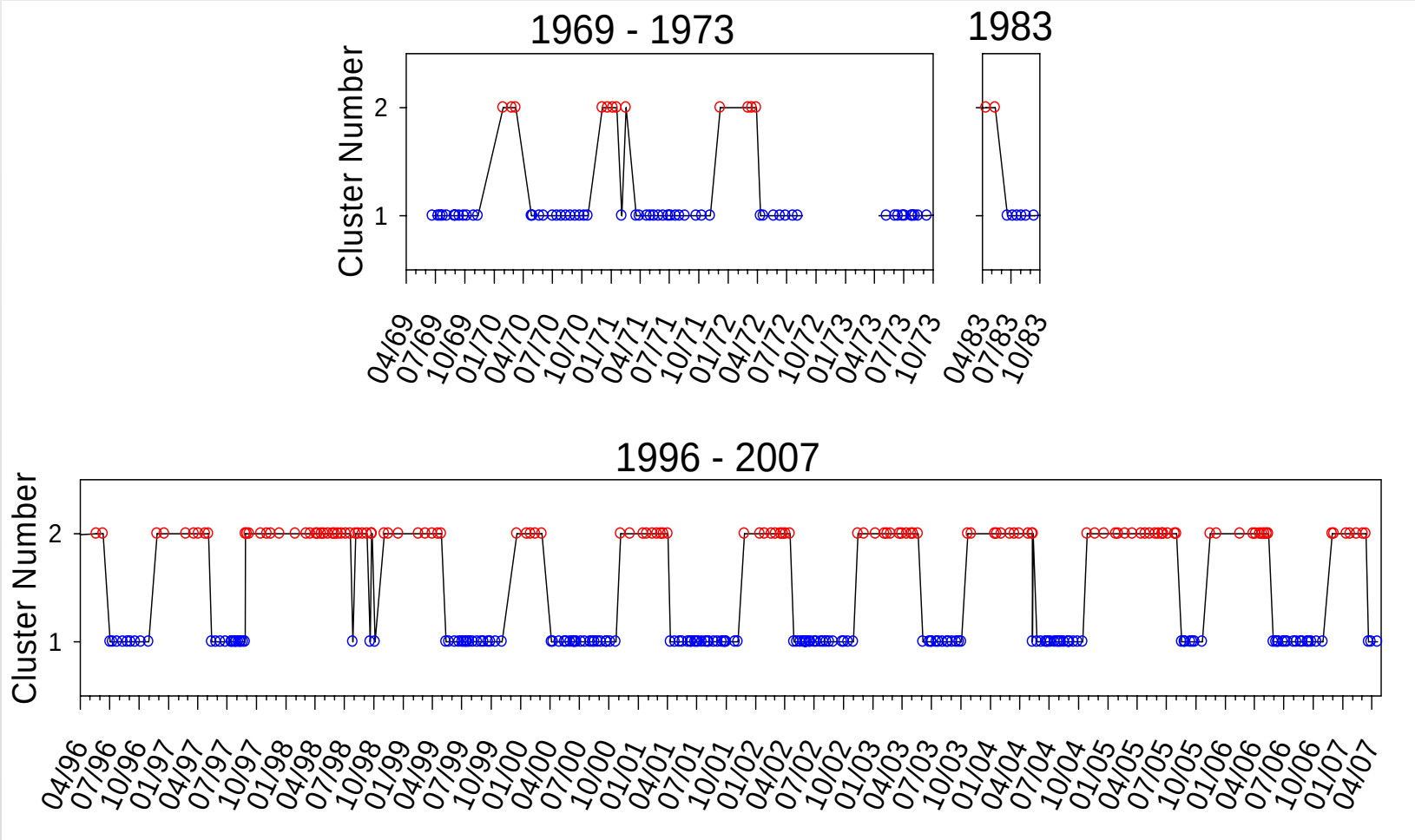
- Clusters 3-5 capture warm vs. cold ocean and El Niño events.



Cluster
1
2

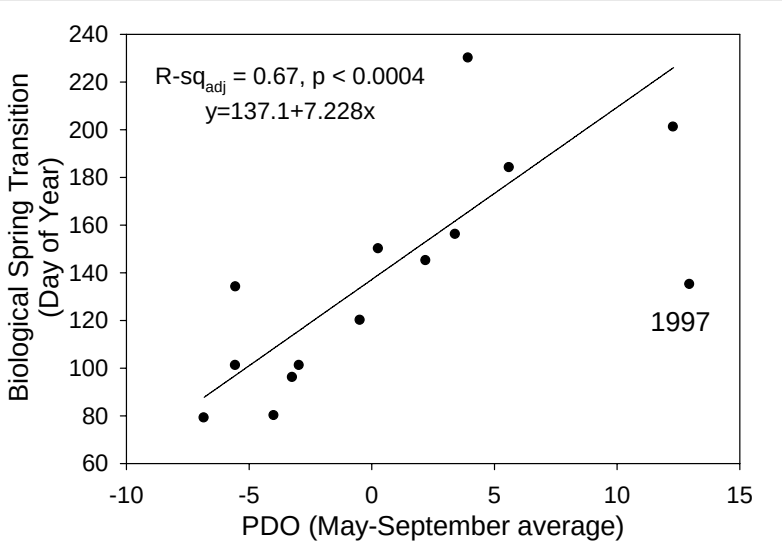
Cluster analysis shows similar results as the ordinations….but what we found most interesting were the seasonal changes

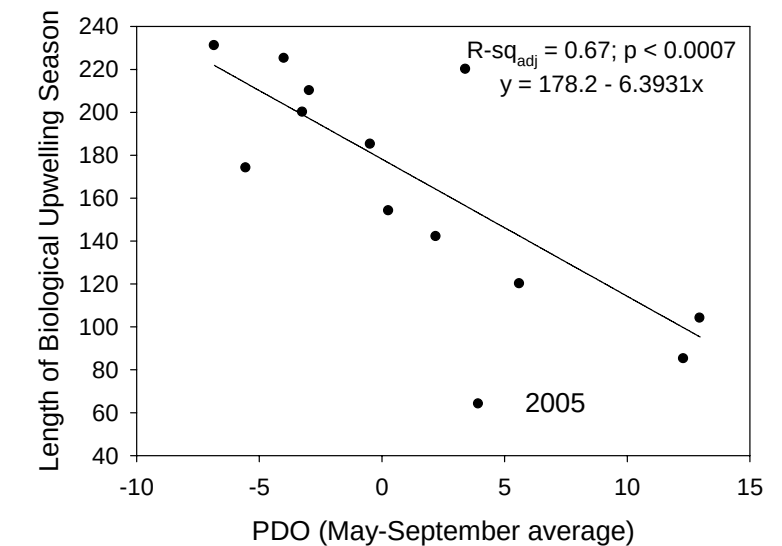
Summer and Winter Clusters



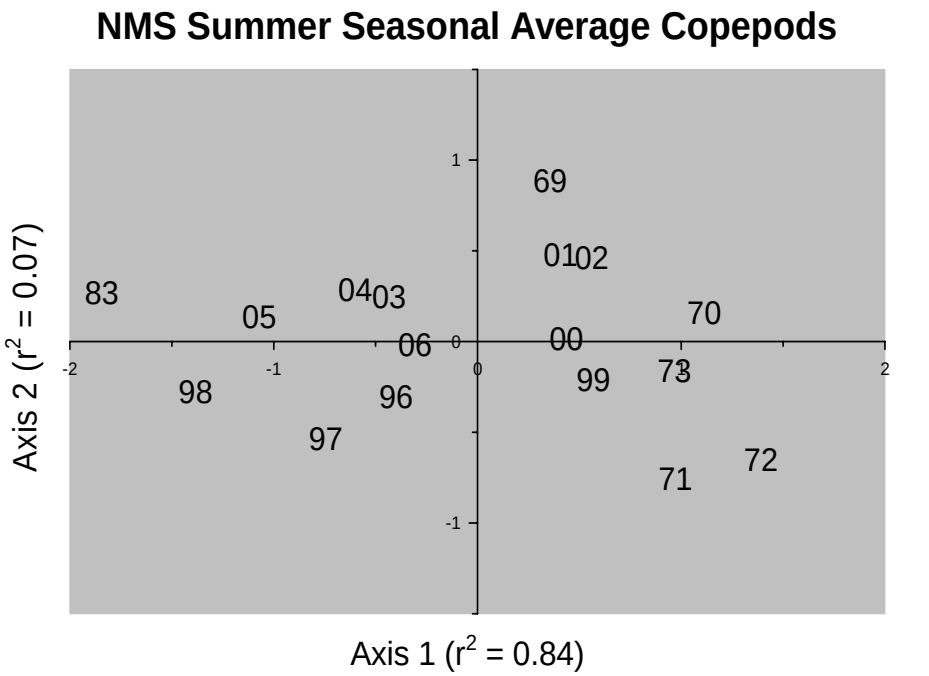
Apart from the 1998 El Niño, cluster fidelity was stunning!

PDO vs date of 'biological spring transition (UPPER) and number of days that a cold water community persisted in a given year (LOWER)





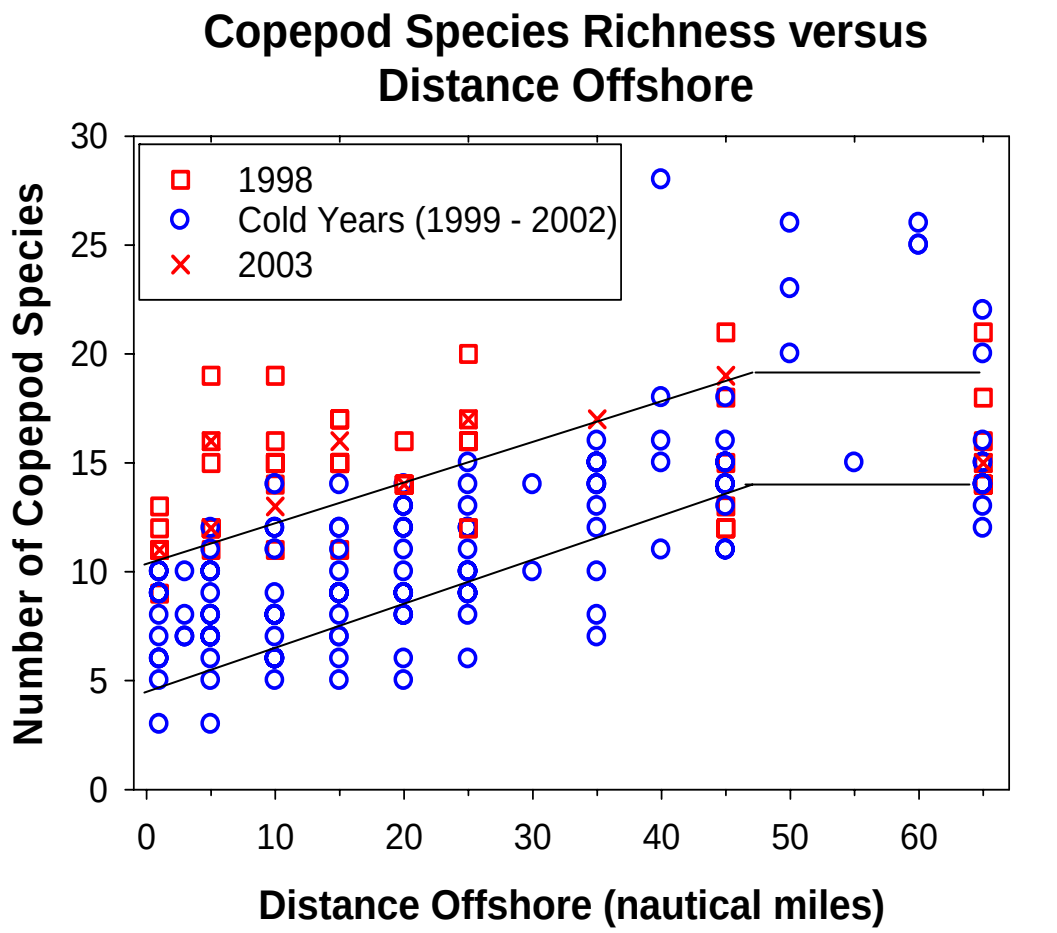
- The more negative the PDO, the **earlier** the date of "biological spring"
  - 'Zero' point is day 10 April
- The more negative the PDO the **longer** a cold water community persists.
  - 64-154 d when PDO positive
  - 174-231 d when PDO negative



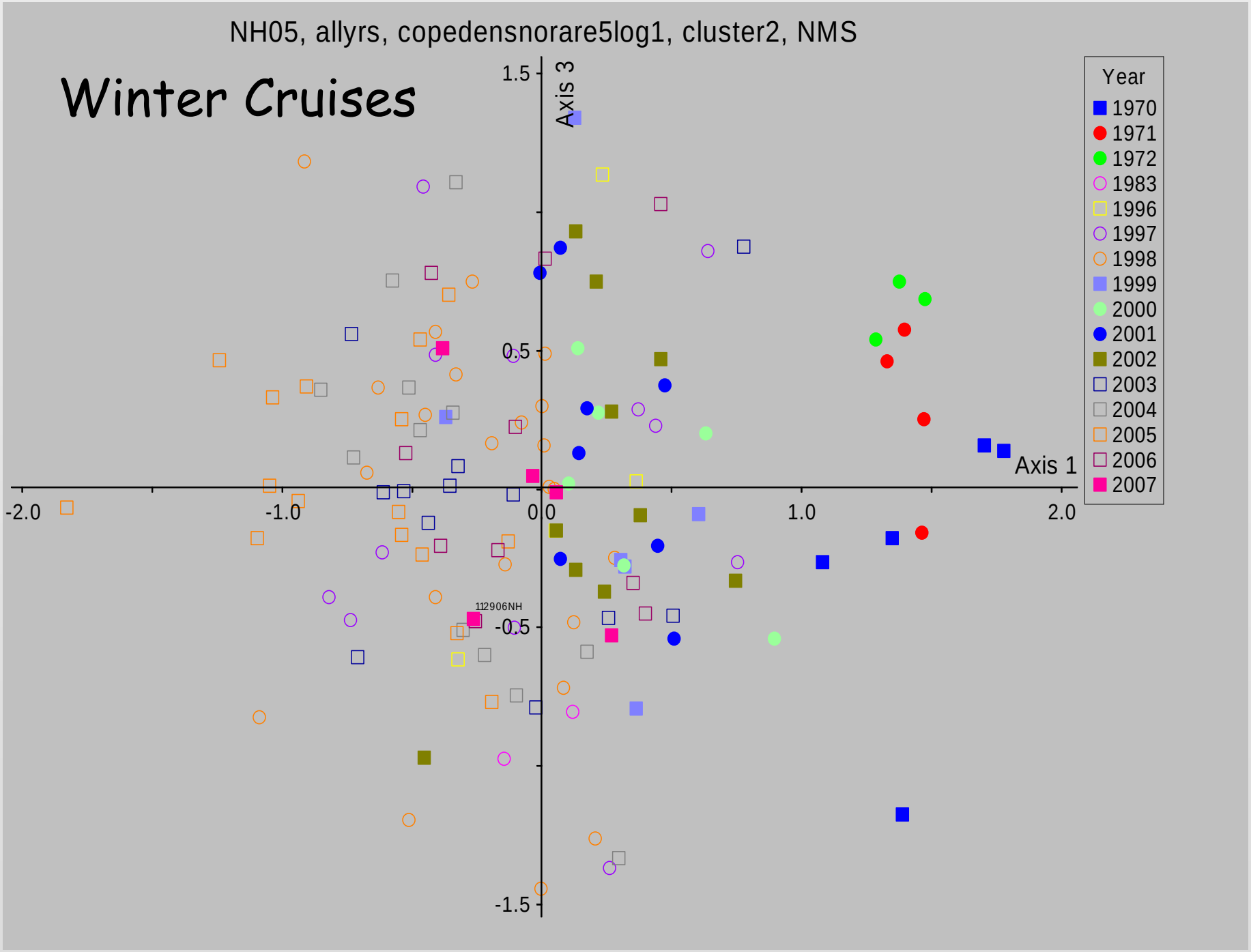
When we average the ordination scores by summers, we find similar communities in years with common patterns of PDO and SST:

- Cold Ocean (Negative PDO) in 1969-1973, 1999-2002
- Warm ocean (positive PDO in 1983, 1996-1998, 2003-2006.

Cross shelf variations in species richness: 28 transects sampled to 65 miles from shore



- Suggests that high species richness in shelf waters is due to onshore transport of warm, transition zone water
- See a similar latitudinal gradient (Morgan et al. poster, S1)


NH05, allyrs, copedensnorare5log1, cluster2, NMS
Winter Cruises
Axis 3
Axis 1
1.5
0.5
-0.5
-1.5
-2.0
-1.0
0.0
1.0
2.0
112906NH
Year
1970
1971
1972
1983
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007