Extreme climate variability in the NCC: can we explain the current anomalous warm state and its effects on coastal upwelling ecosystem off WA and OR?

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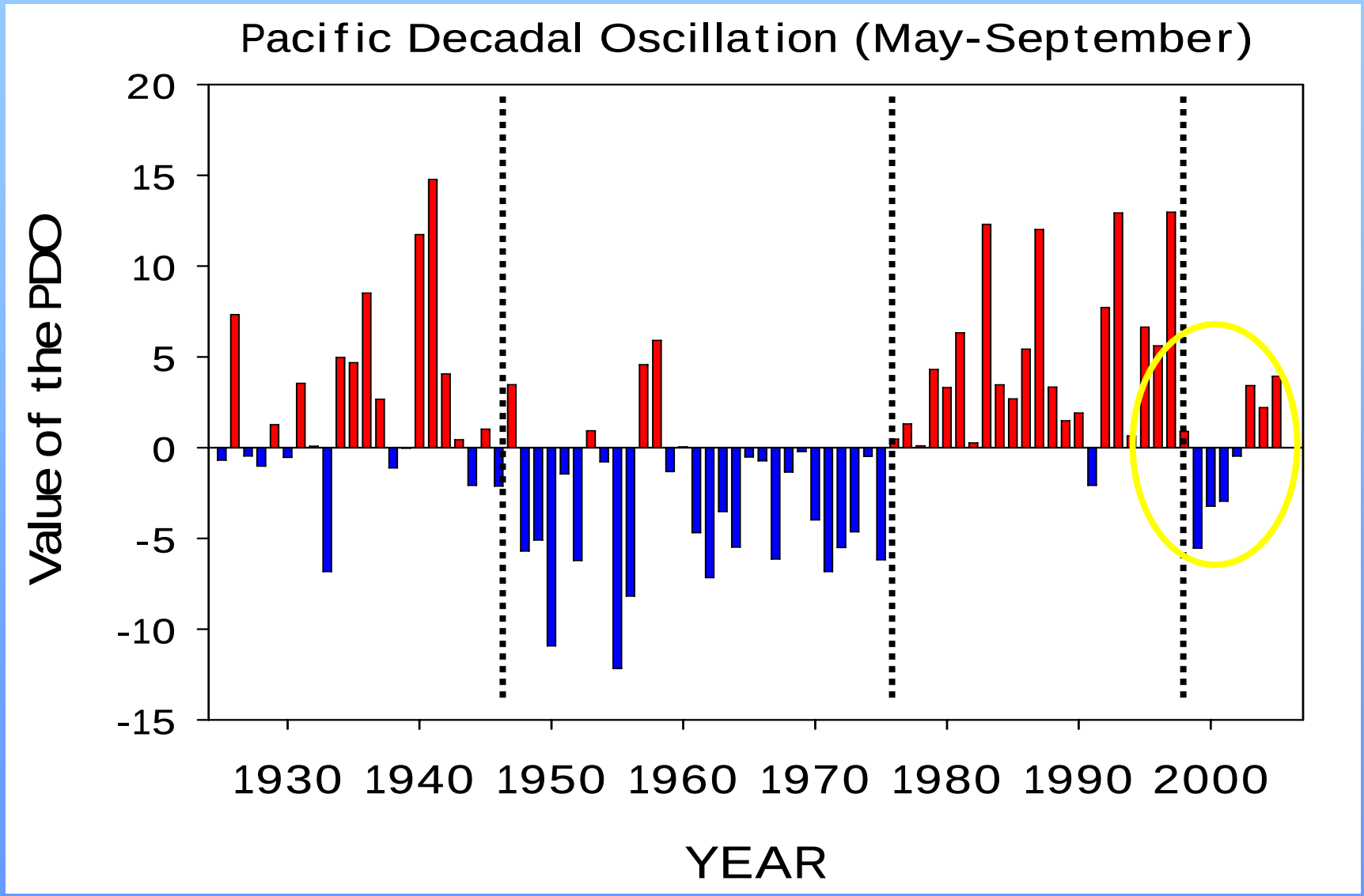
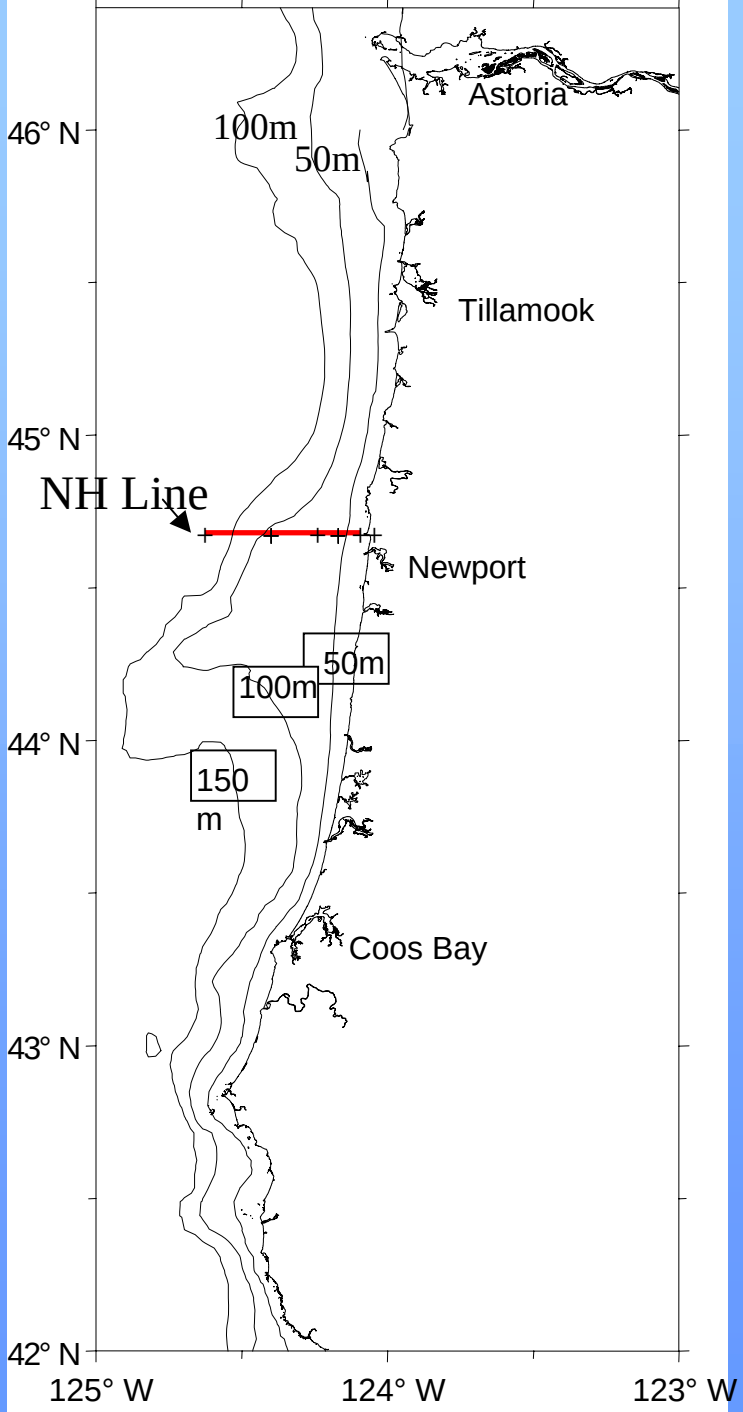
Goal

- Use information on changes in hydrography and zooplankton observed off Oregon to try to understand mechanisms by which PDO (and ENSO) affect ecosystem dynamics in northern California Current

PDO

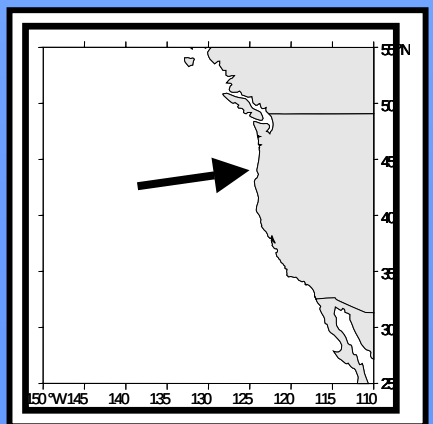

Pacific Decadal Oscillation (May-September)
Value of the PDO
20
15
10
5
0
-5
-10
-15
1930
1940
1950
1960
1970
1980
1990
2000
YEAR



NH-Line Hydrographic and Zooplankton Time Series

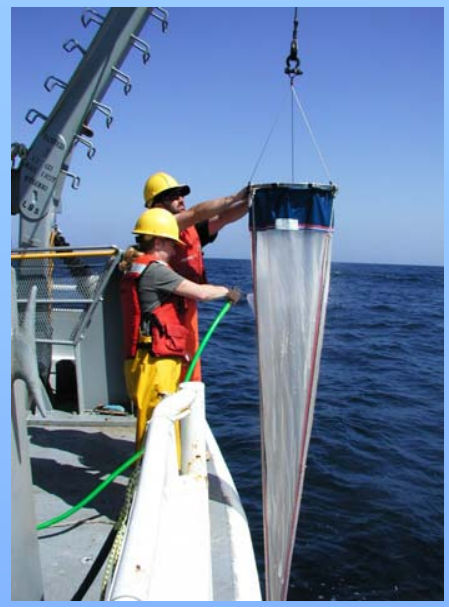
Bi-weekly Sampling:

- **1969 – 1973** (Miller, Pearcy, Peterson)
- **1983** (Miller, Batchelder, Pearcy, Brodeur)
- **1991-1992** (Fessenden and Cowles)
- **1996 – present** (Peterson et al.)



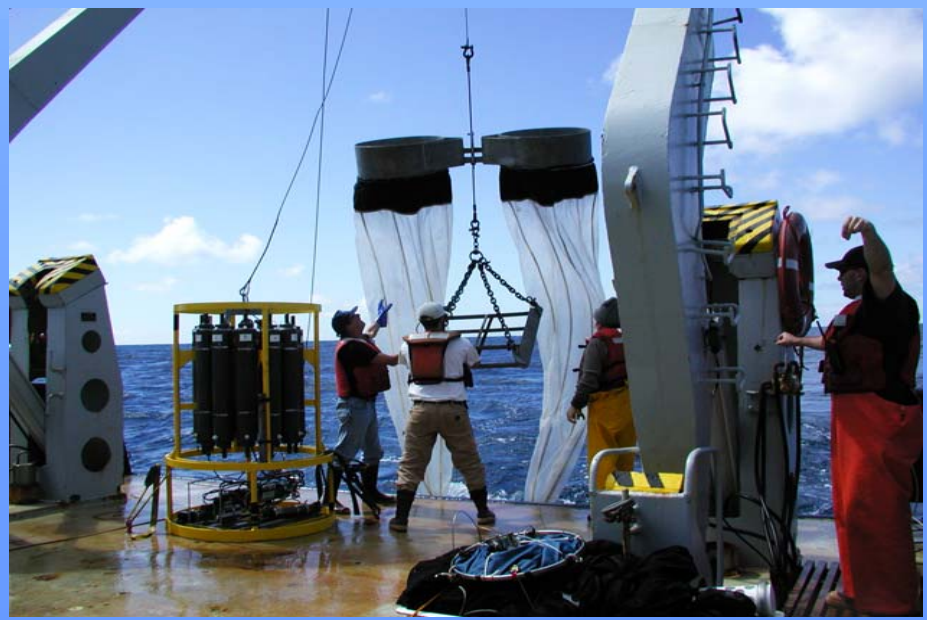
Sampling methods

- Water sampling with CTD, Niskin Bottles, and buckets for hydrography, chl-a and nutrients since 1997

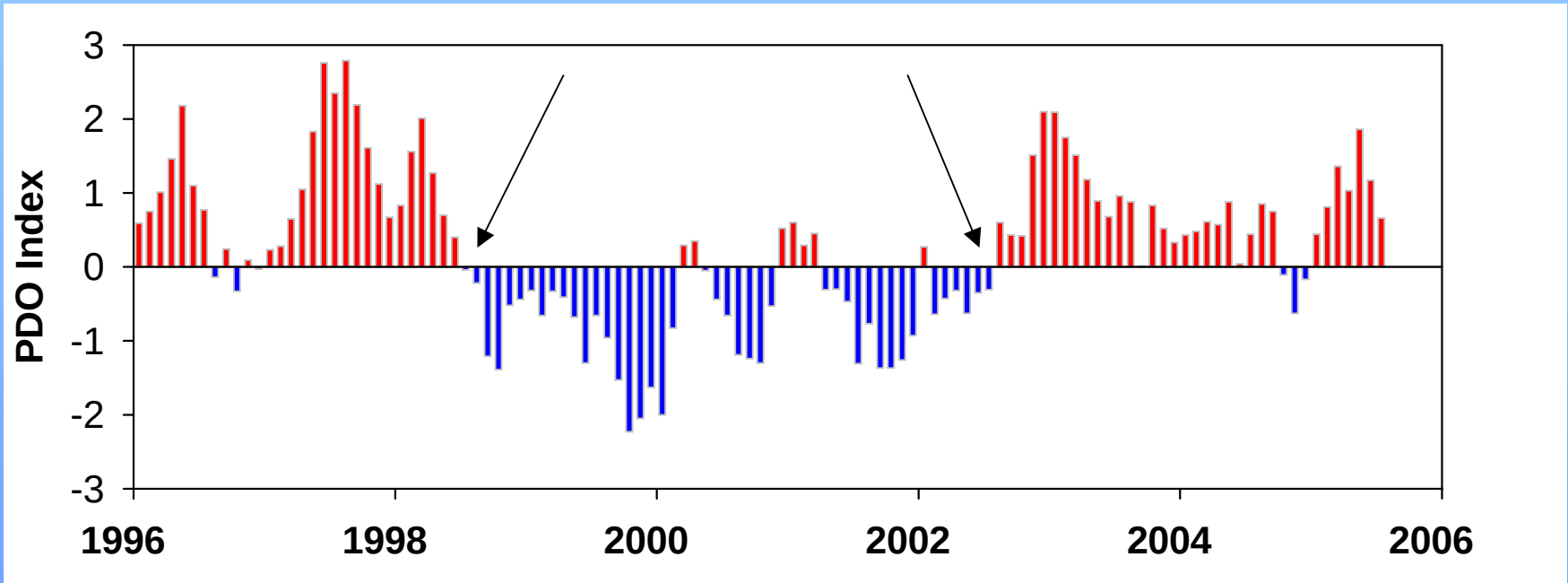


- Mesozooplankton with ½ m 200 um net towed vertically since 1996

- Euphausiids with 70 cm 505 um net towed obliquely at night since 2001

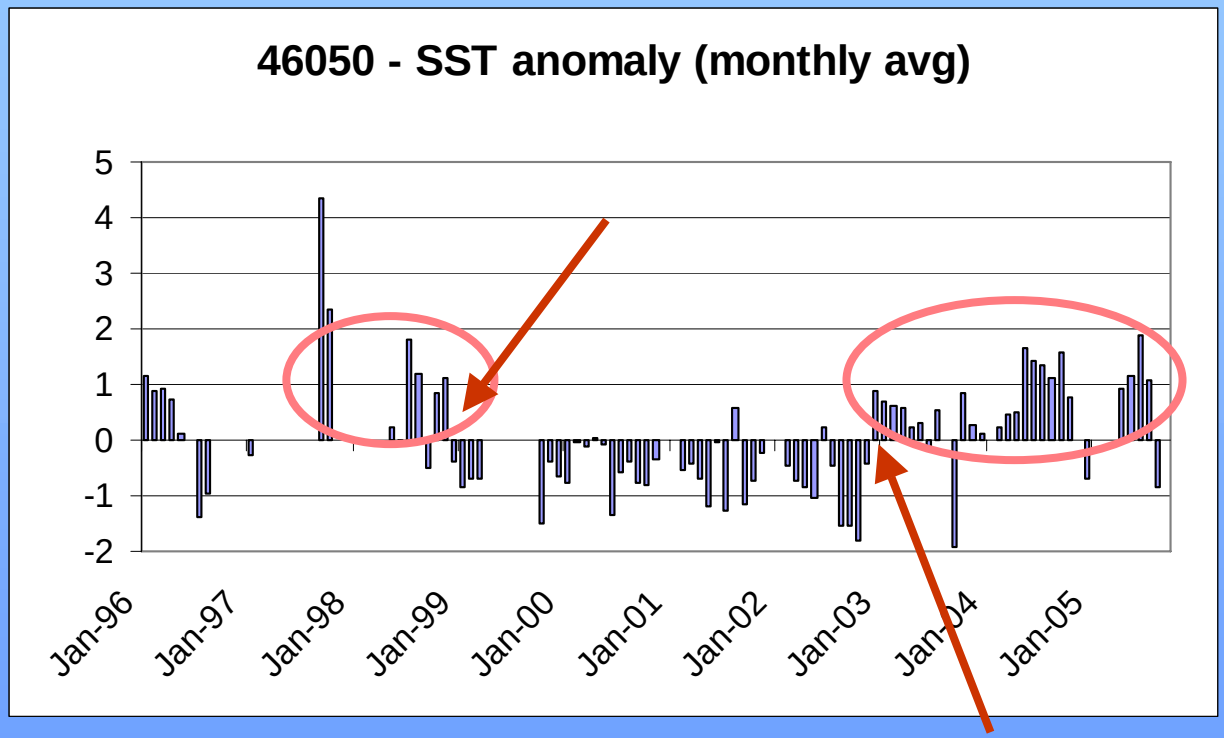


Monthly values of PDO since 1996



- Change points observed in July 1998 and August 2002

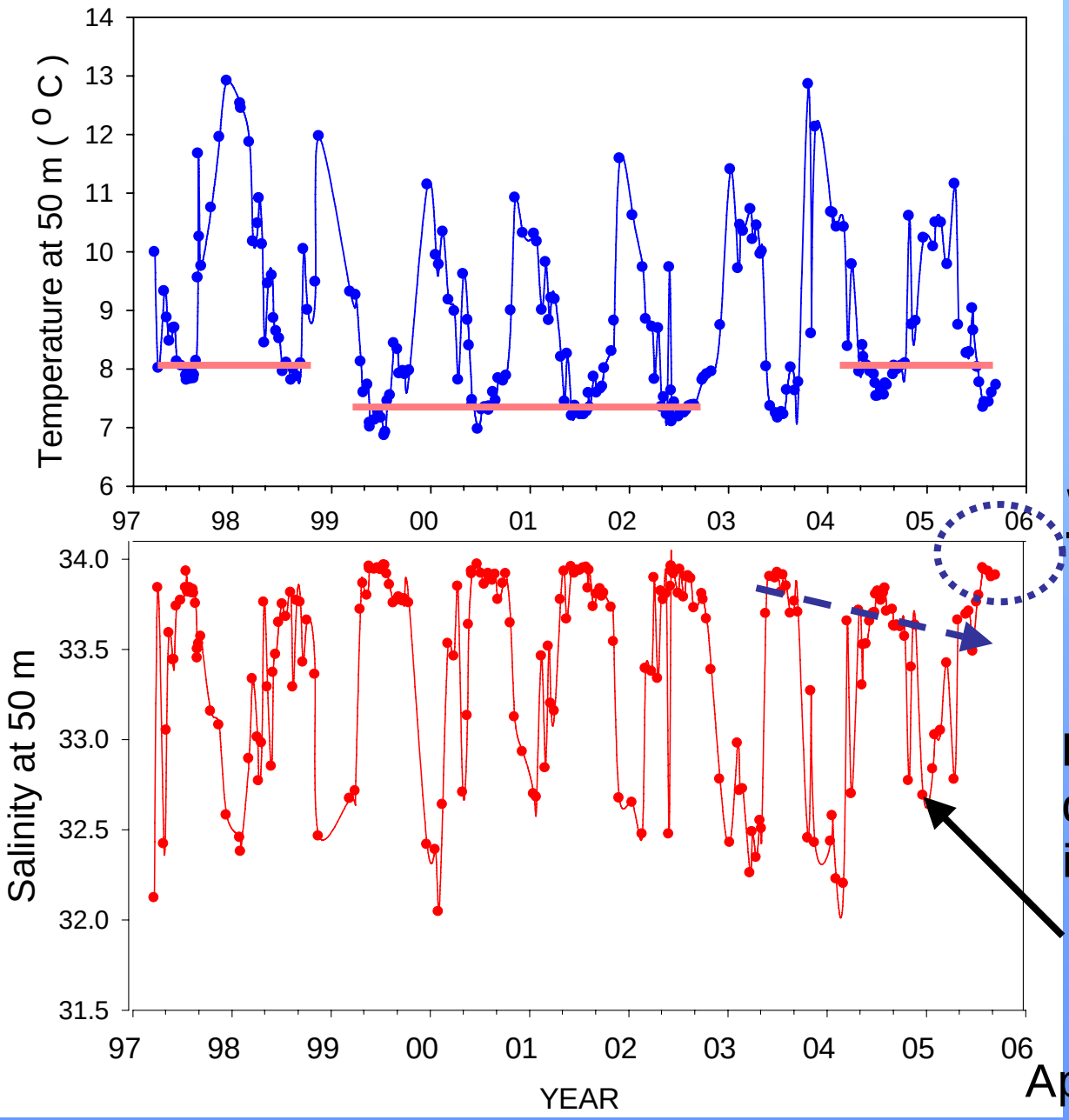
SST anomalies at NOAA Buoy 46050



- Summers of 2003, 2004 and 2005 had SST anomalies similar to those observed during the 1997/98 El Niño
- Exact same result shown for all Canadian buoys, both inshore and offshore

The ocean began to cool in autumn 1998 and warm in autumn of 2002, coincident with the changes in sign of the PDO. Warming has continued for the past 3 years.

Temperature and salinity at NH 05 at 50 m



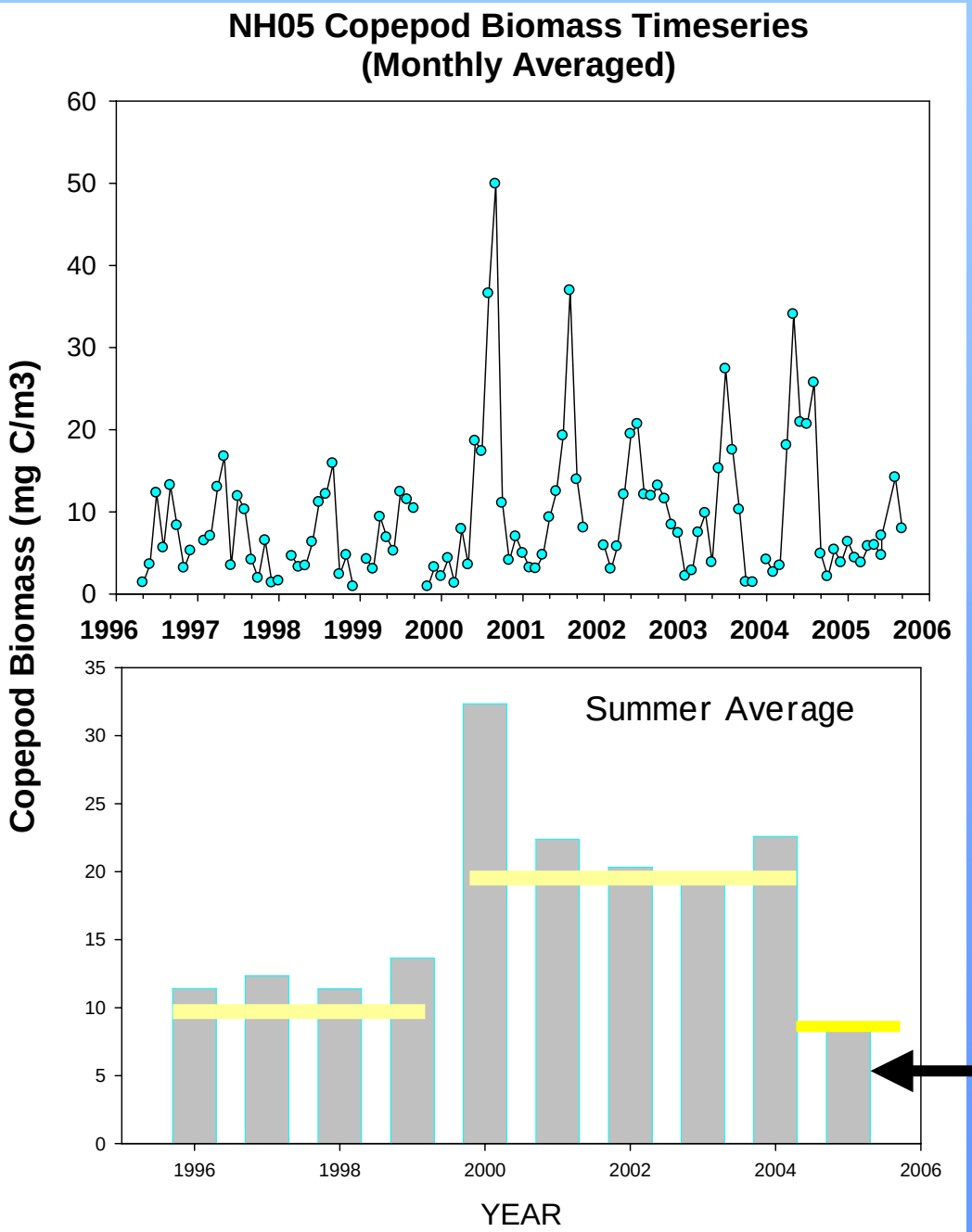
- Note abrupt shift in shelf <u>bottom water</u> hydrography during summers of 1998 and 2003

Fresher and warmer at depth 2003-2005, in summer

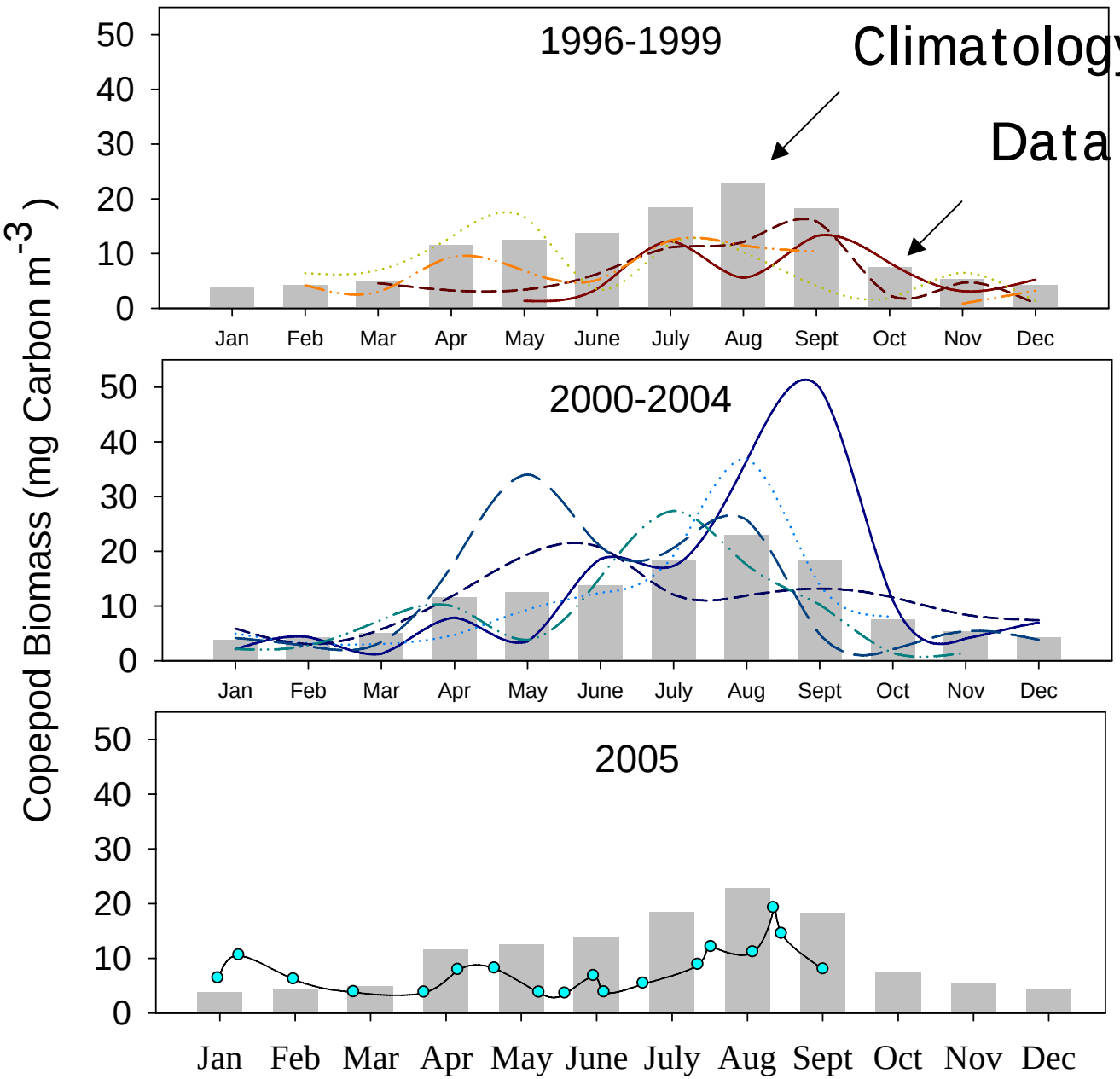
Saltier in winter 04/05.

Appears now to be changing to saltier in summer

Copepod Biomass

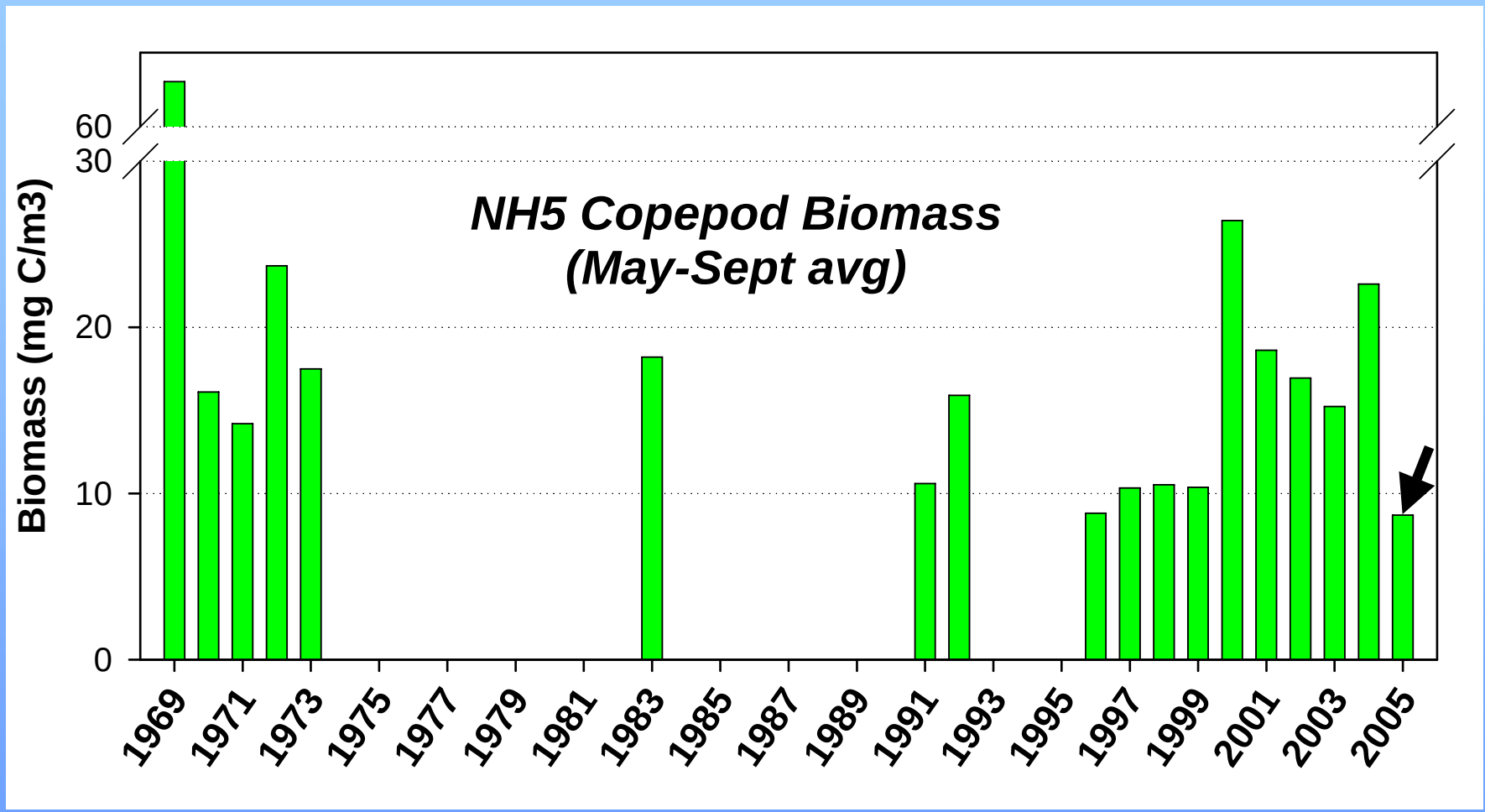


- Seasonal cycle apparent
- Low biomass during warm phase of PDO 1996-1998, and during first year of negative PDO (1999)
- Doubling of biomass during cool phase of PDO, 2000-2002. High values continued into first two years of positive PDO (2003, 2004).
- Values observed in 2005 were 0.4x of 2000-2004 and 0.7x of 1996 -1998



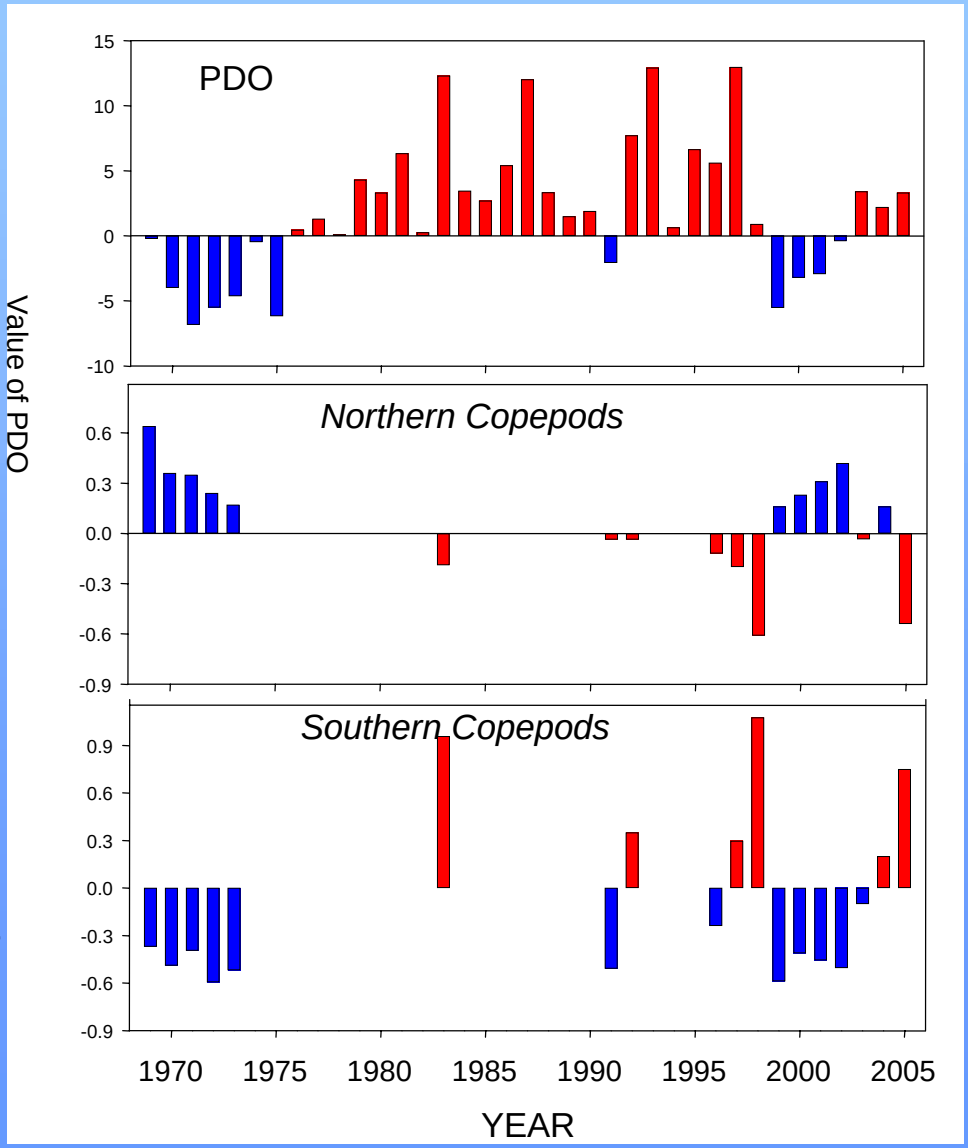
2005 Measured v Ratio of Climatology

J	6.3	1.7
F	4.4	1.0
M	3.8	0.77
A	5.8	0.50
M	5.9	0.51
J	4.7	0.34
J	7.1	0.38
A	14.2	0.62
S	7.9	0.43



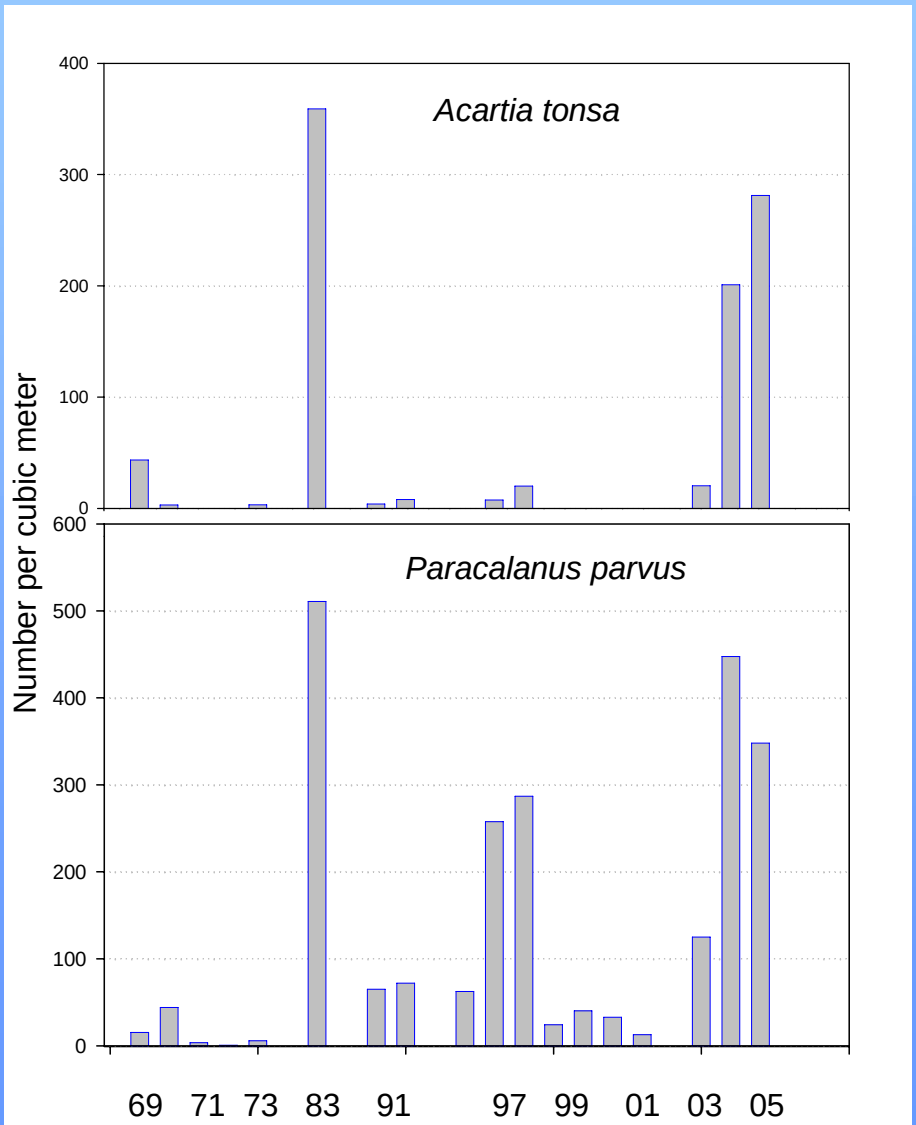
The summer of 2005 had the lowest copepod biomass of all measurements made over 18 years.

PDO v Northern and Southern copepod biomass anomalies



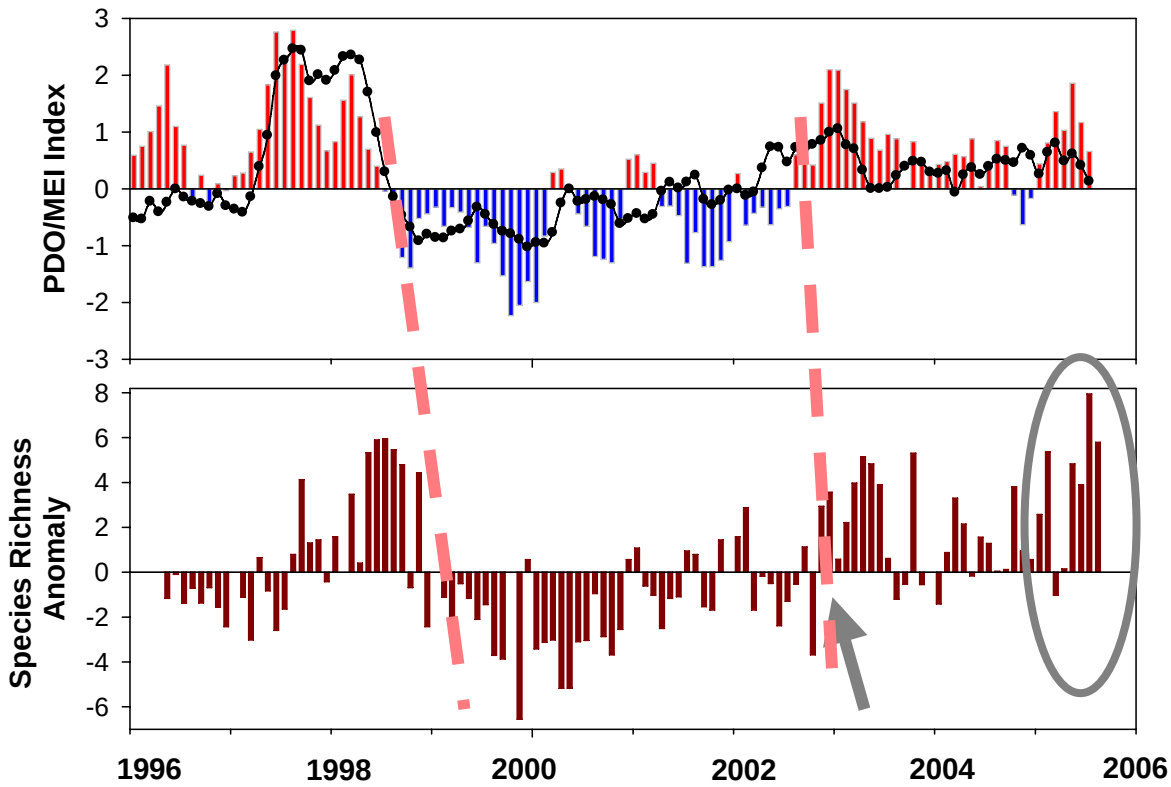
- Strong positive anomalies of southern species and negative anomalies of northern species seen during El Niño events (83, 97/98)
- 2005 showed the same pattern

Two common “southern” species



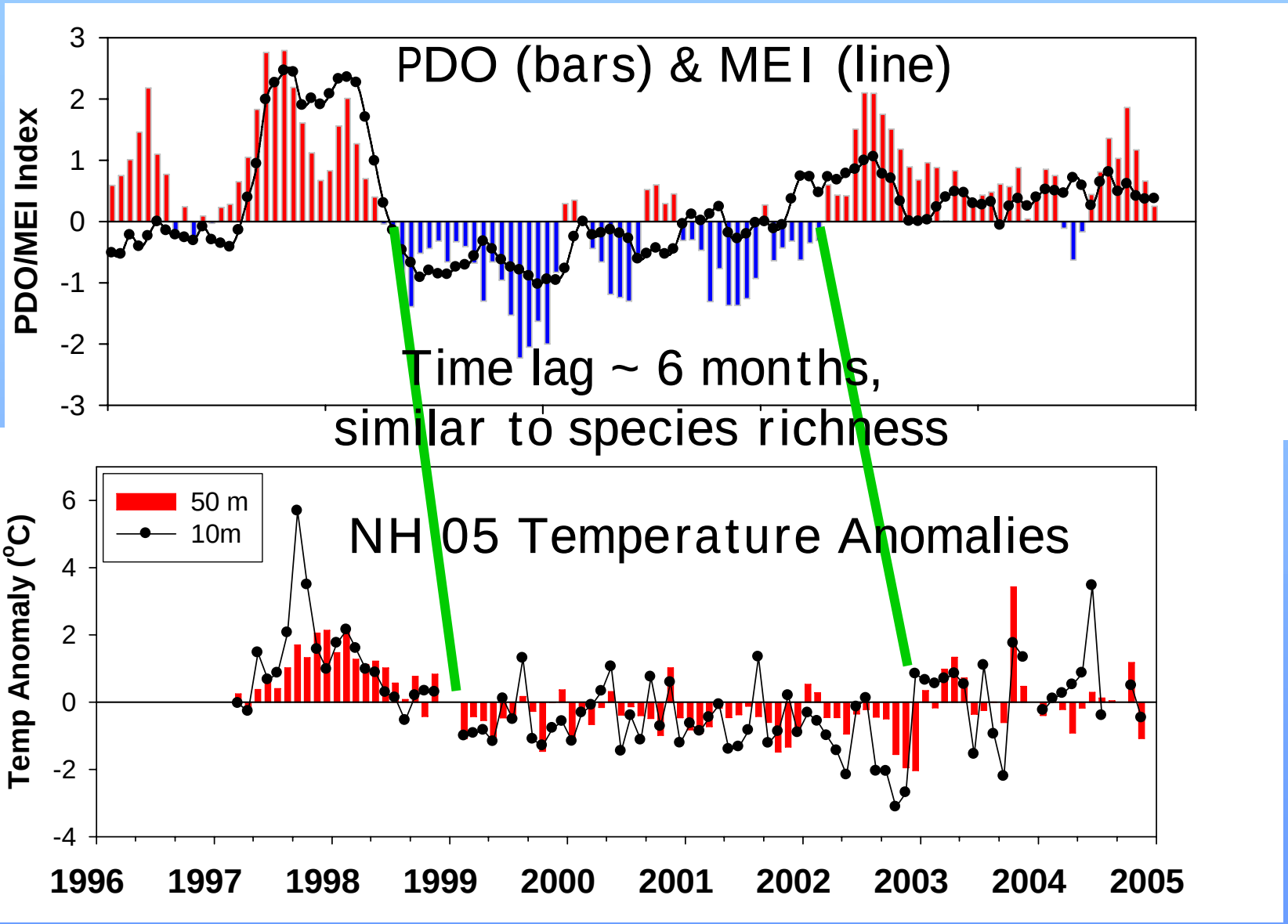
- *Acartia tonsa* and *Paracalanus parvus*
- Peak abundances seen during 1983 El Niño; during 1997-98 El Niño and during 2004-2005 “warm event”.

Copepod species richness anomaly at NH 05



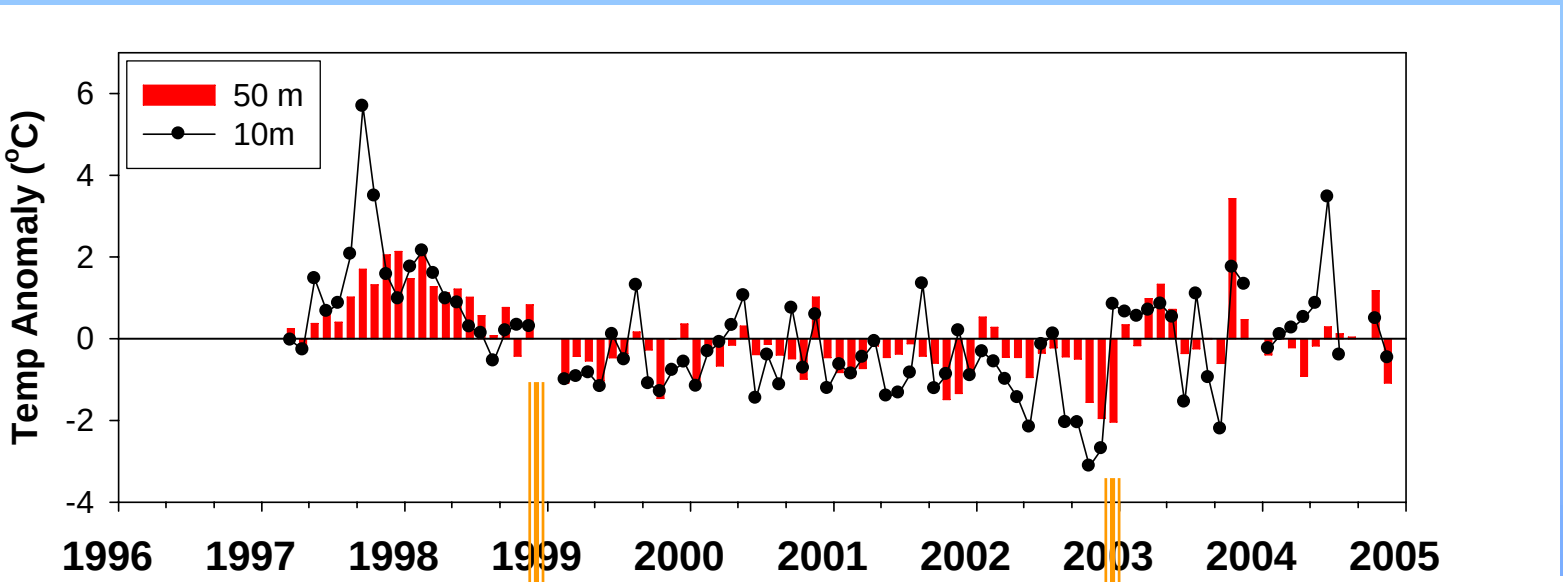
- PDO and MEI correlated with species richness
- Time lags exist but are variable.
- Species richness declined in fall 1998 but began to increase in Nov 02
- Richness values now exceed both the 83 and 97 El Niño events

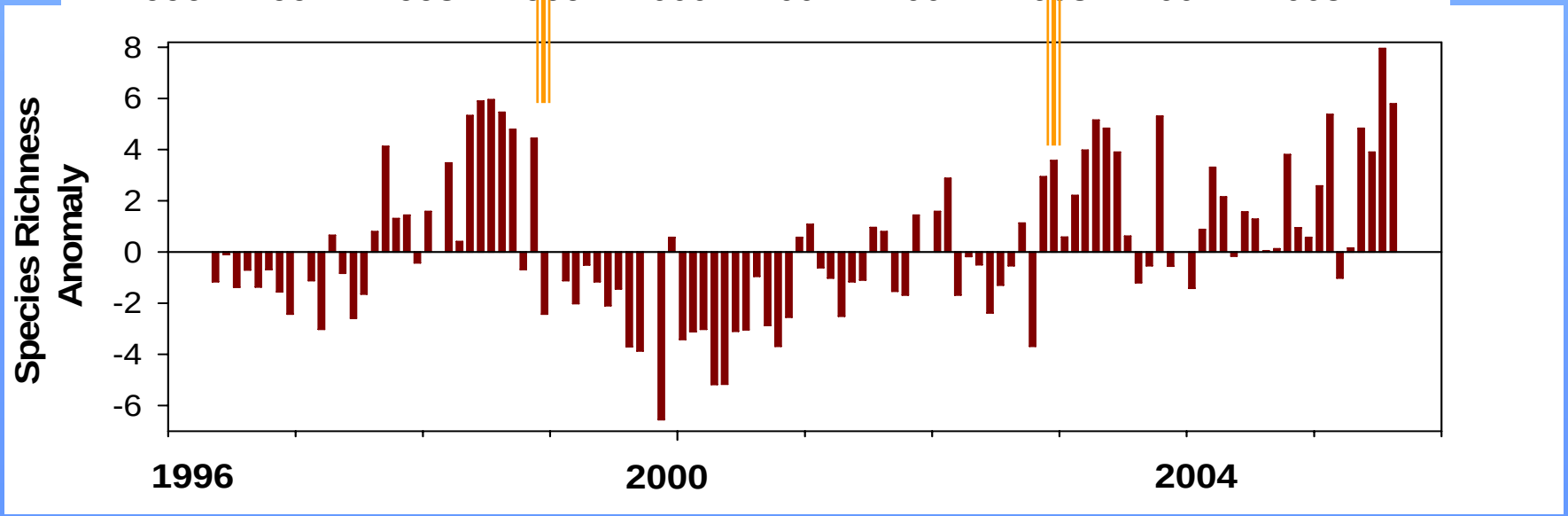
Species richness continued to be high through summer 2005,a strange and unusual condition

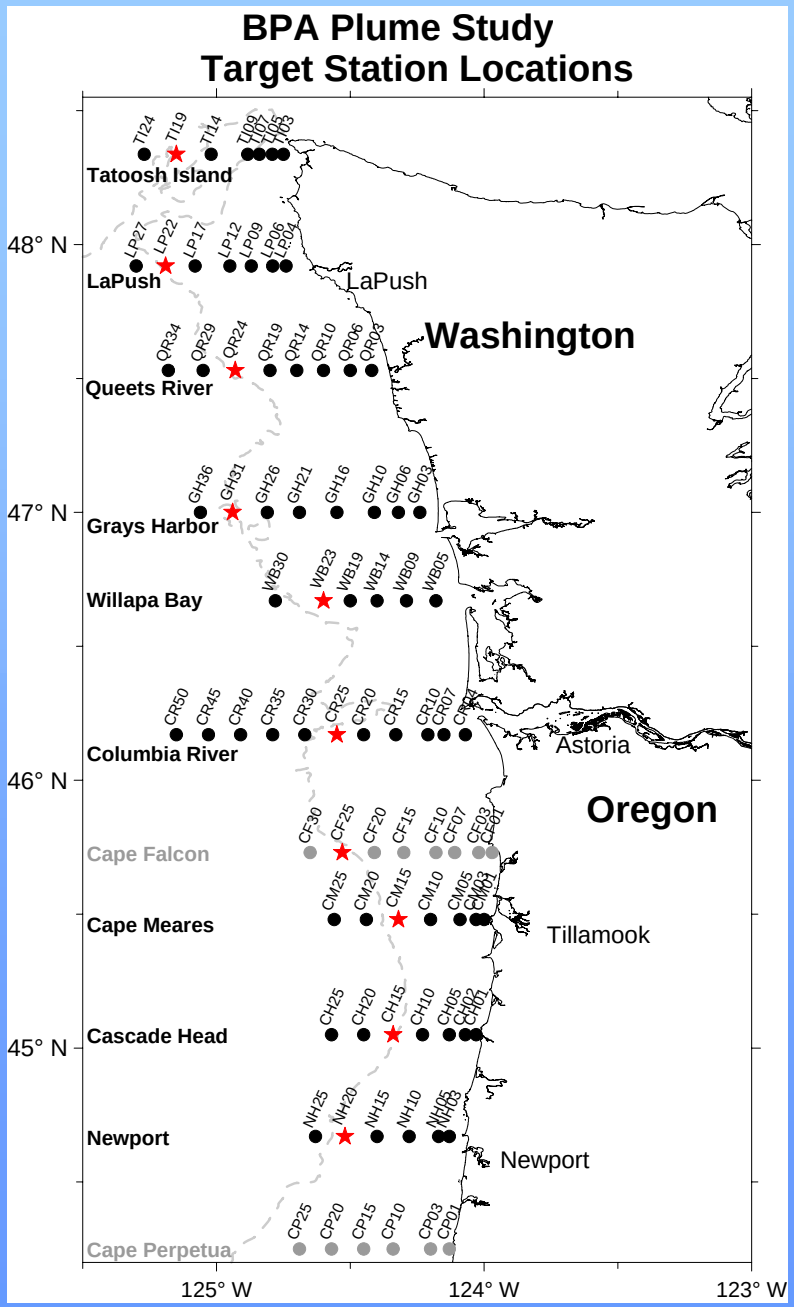


- Hydrography off central Oregon follows both the PDO and MEI. Warm (cool) waters are associated with positive (negative) values of each index.

Monthly averaged species richness anomalies at NH 05 tracks monthly averaged temperature anomalies at NH05



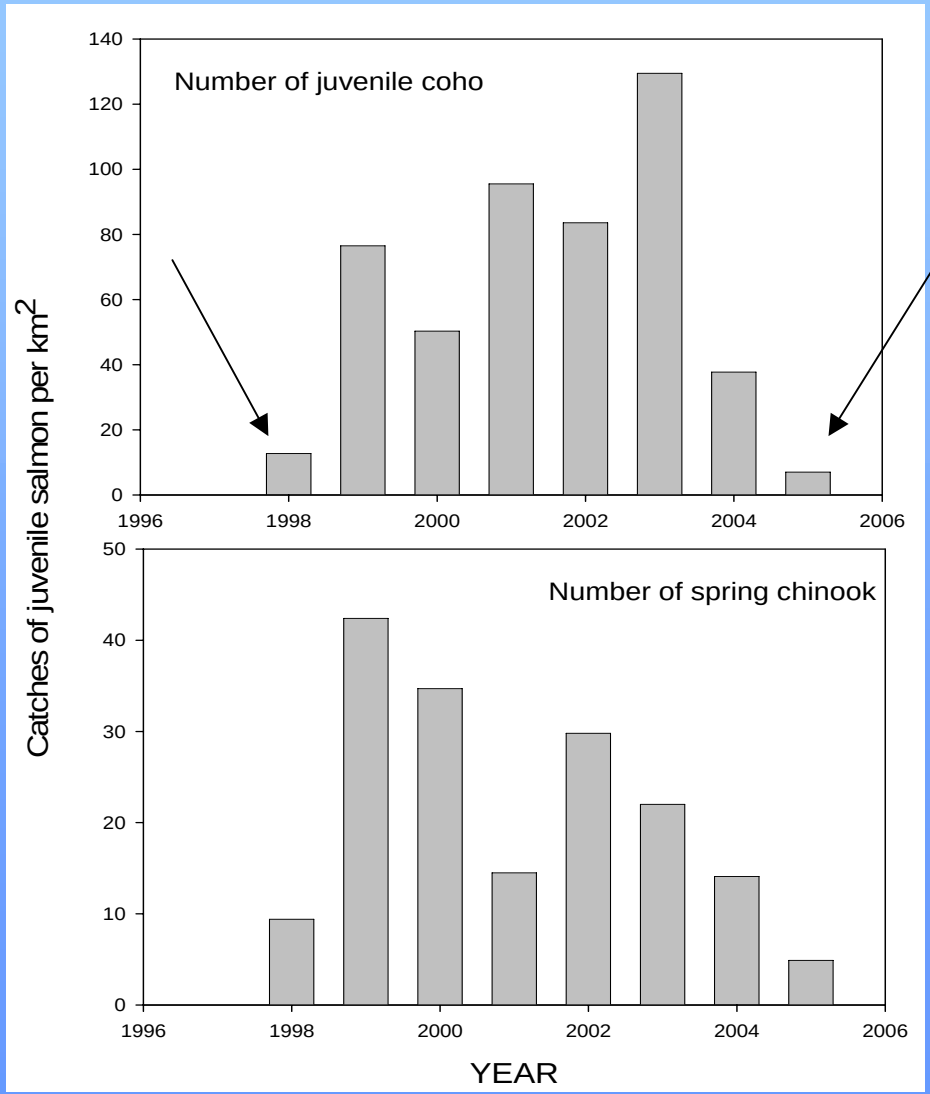




Salmon and Pelagic Fish Sampling

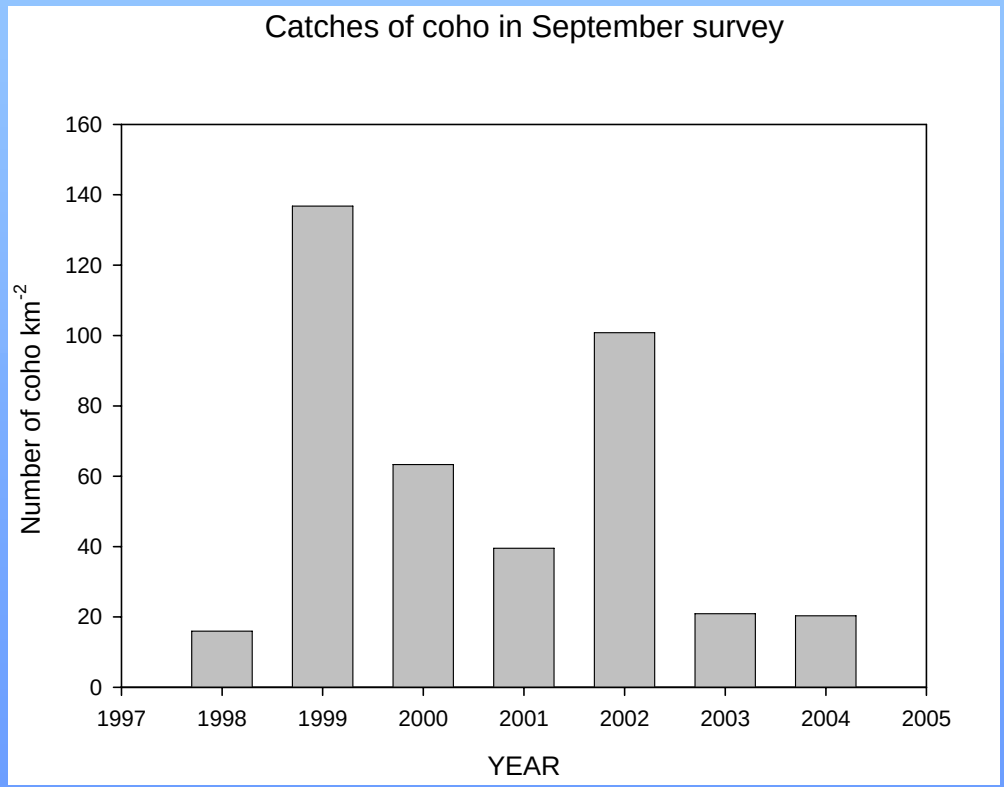
- Sample in May, June and September (DURING THE DAYTIME) at ~ 50 stations since 1998
- Sample Columbia River and Willapa every 10 days from April through July (AT NIGHT) at ~ 10 stations since 1998

Salmon catches in June surveys: 1998-2005



- Catches of coho salmon in June 2005 were lower than June 1998 during the El Niño.
- True also for Chinook salmon

Coho salmon catches in September surveys



- Low coho catches in September of 2003 and 2004 as well, possible evidence of chronic warm (and poor) ocean conditions
- Sept 2005 cruise just finished and not one juvenile coho was caught!

An ecological problem

- What we thought was a regime shift in 1998 has completely fizzled
- Warm temperature anomalies for past three years
- Copepod species diversity has been increasing since 2002 and is now higher than 1997/98 El Niño event
- Coho and Chinook salmon survival declining and small pelagic fishes declining in numbers

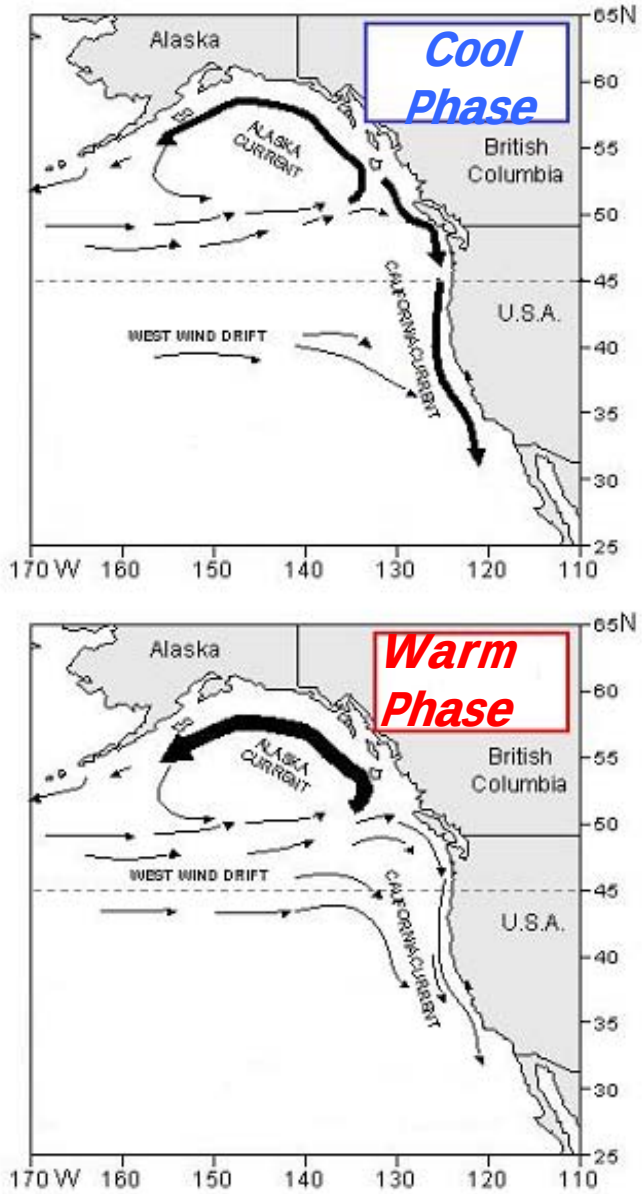
2005: looked like an El Niño

- Waters are warm and fresh both on shelf and in the undercurrent
- Extremely low copepod biomass
- Due to collapse of the food chain, juvenile salmon survival was very low, and adult salmon coho stocks appear to have been affected as well.
- Thousands of birds died (Cassin's auklets, murres and cormorants)
- But…the equator is in a neutral-to-weak El Niño state!

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

⇑ Transport of boreal coastal copepods into NCC from Gulf of Alaska

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



Transport Hypothesis (continued)

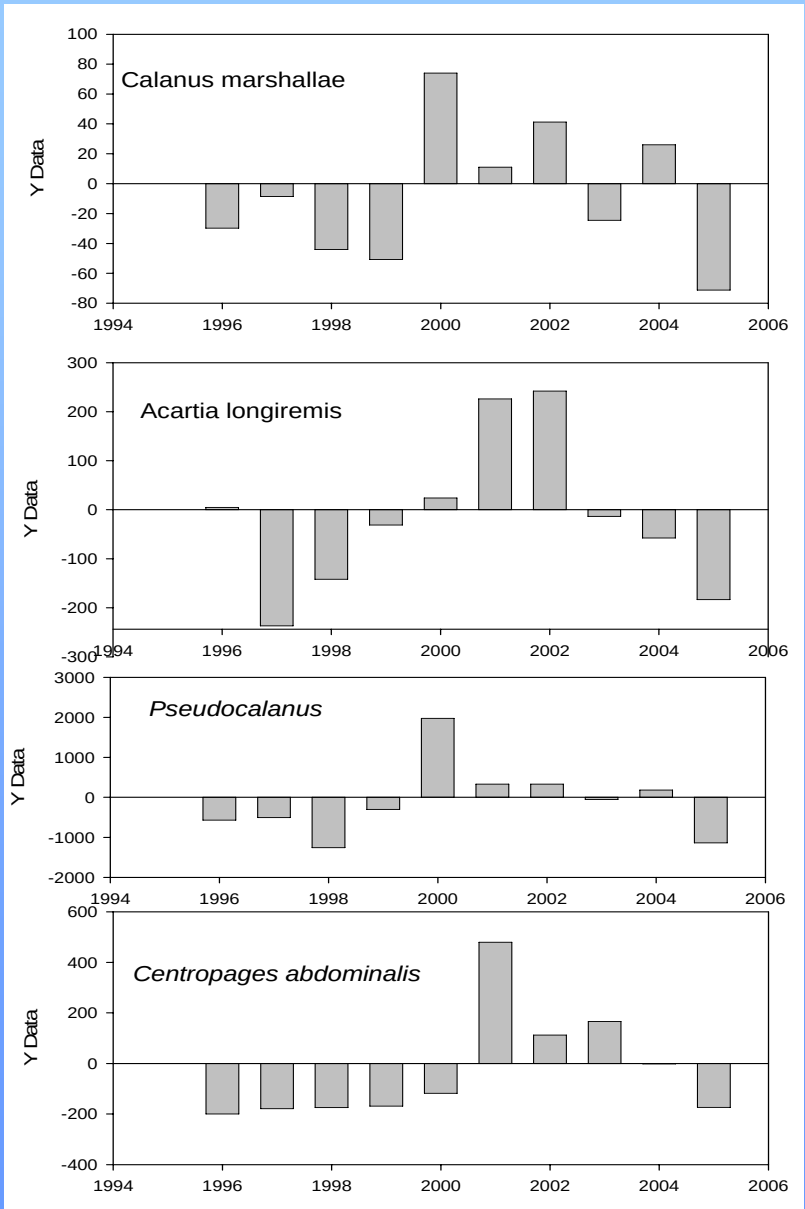
- Time lags of ~ 6 months between change in sign of PDO and changes in both local hydrography and copepod species richness
- No time lag between local change in SST and change in copepod species richness
- Skip McKinnell has some thoughts that he may want to share at this time!

Thank you for you attention!

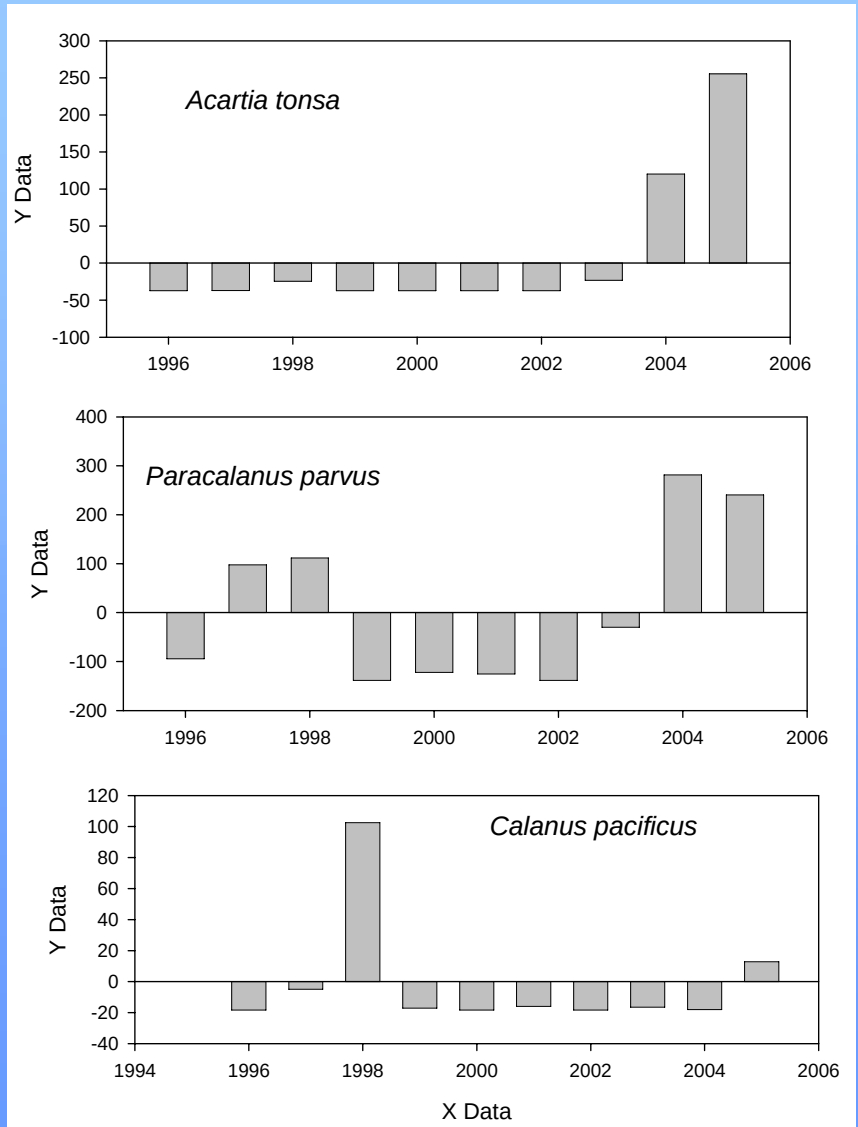
Acknowledgements

- Funding for the 10-year Newport time series has come from NOAA-Fisheries, ONR/NOPP, NSF/NOAA GLOBEC and the NOAA Stock Assessment Improvement Program
- Funding for salmon work is from the Bonneville Power Administration

NORTHERN SPECIES

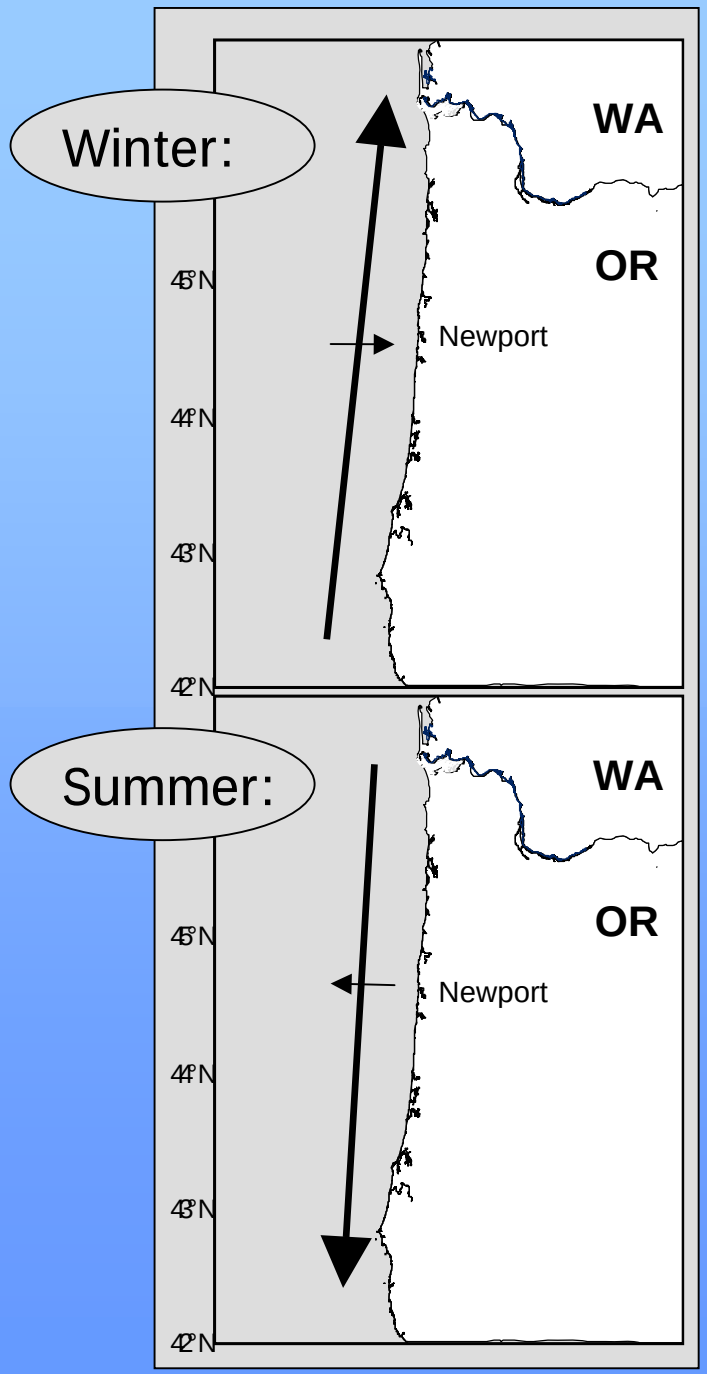


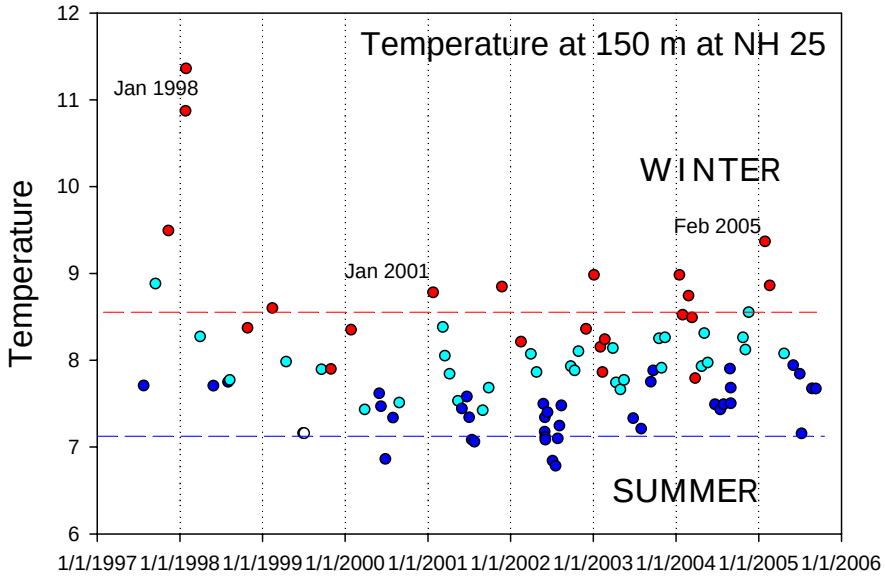
SOUTHERN SPECIES



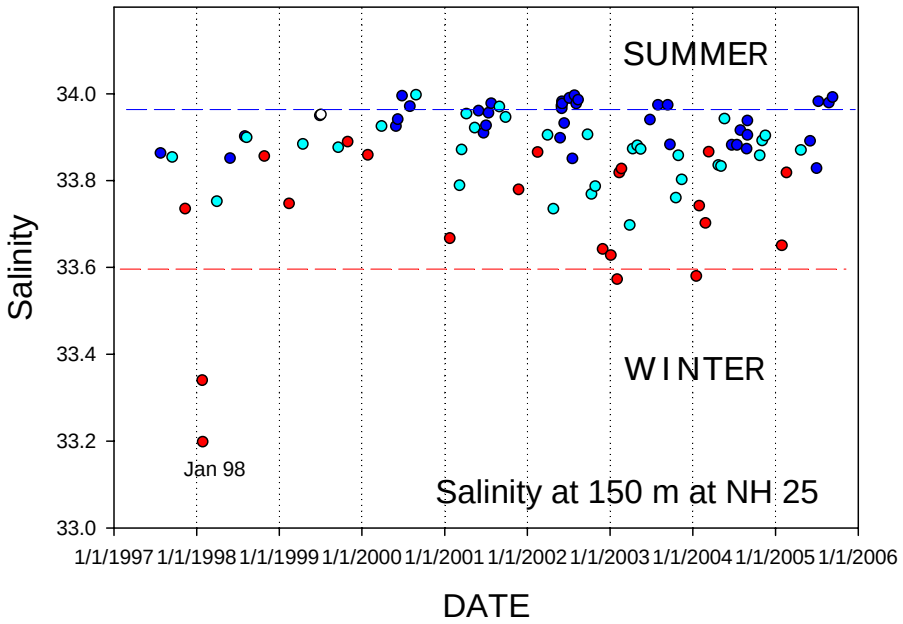
Winds and current structure off coastal Oregon:

- Winter:
  - Winds from the South
  - Downwelling
  - Poleward-flowing Davidson Current
  - Uniform cross-shelf hydrography
- Spring Transition in April/May
- Summer:
  - Strong winds from the North
  - Coastal upwelling
  - Equatorward alongshore transport
  - Strong cross-shelf physical gradients
- Fall Transition in September or October; upwelling-favorable winds cease





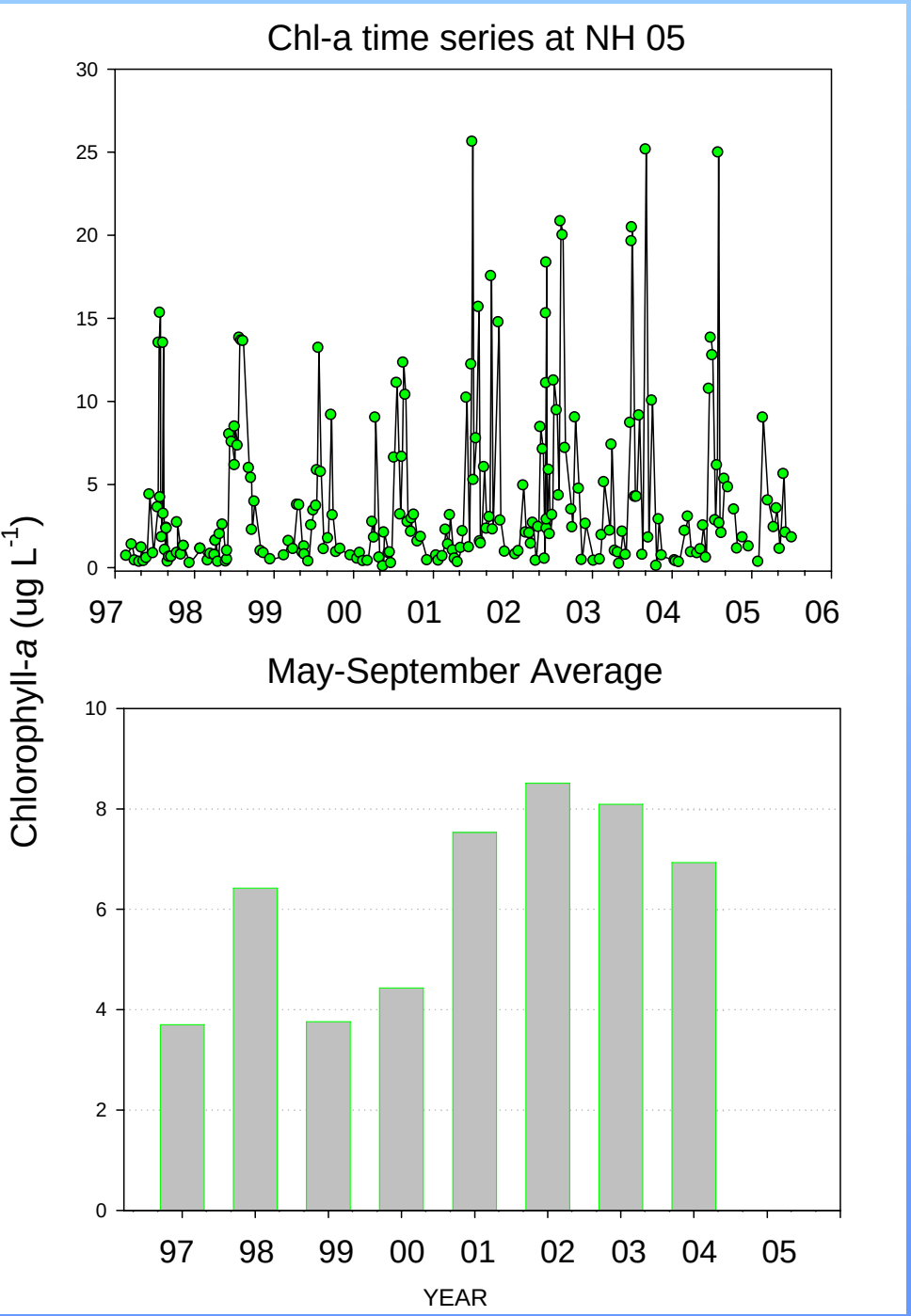
Dotted red and blue lines are 1961-1972 winter (red) and summer (blue) climatology from NH 25, 150m from Huyer and Smith. Red dots are data from winter (November-February), blue from summer (June-August) and cyan spring and autumn.



Deep Water

T & S – NH 25

- Dashed lines are NH 25 climatology from 1960s-1970s for winter (RED) & summer (BLUE)
- Warming trend in 01-05 in W and S
- Salinity in late-summer 05 similar to 02

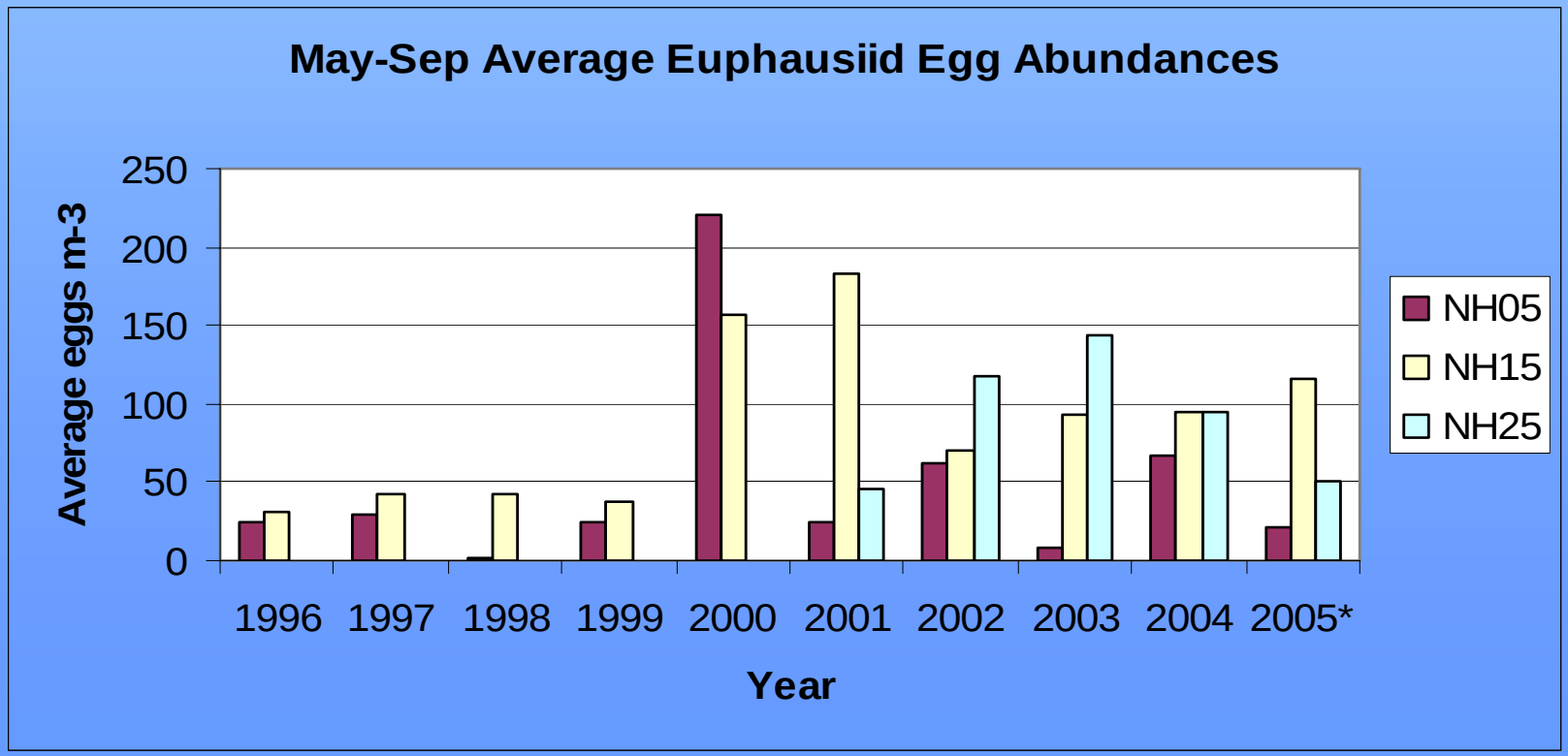


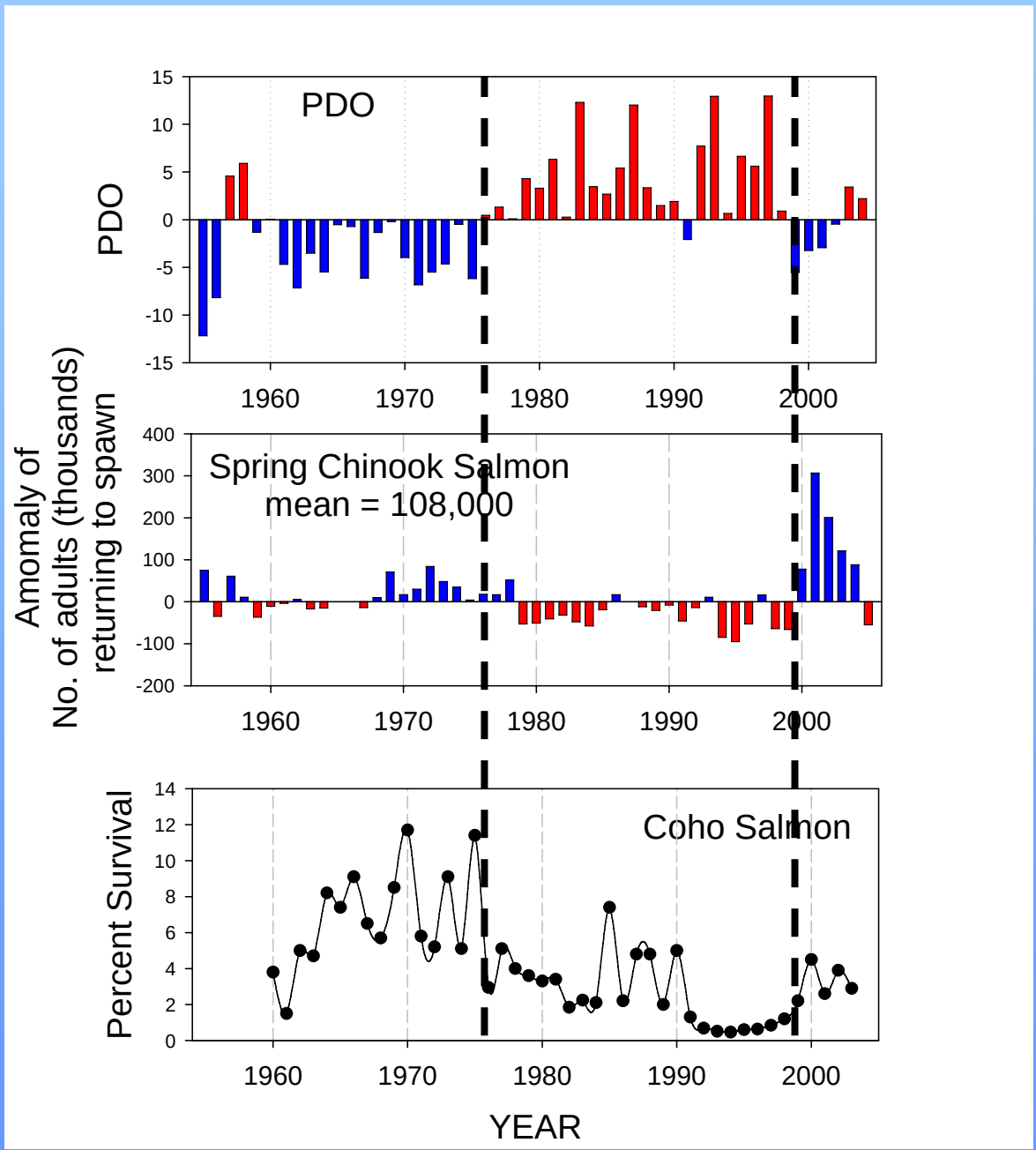
CHLOROPHYLL at NH 05

- Peaks in June and July
- Interannual variability in average summer biomass ranges over a factor of 2
- 2005 data not in yet but chl-a was low in spring but very high after late July, after upwelling began so 2005 will probably appear to be an “average” year.

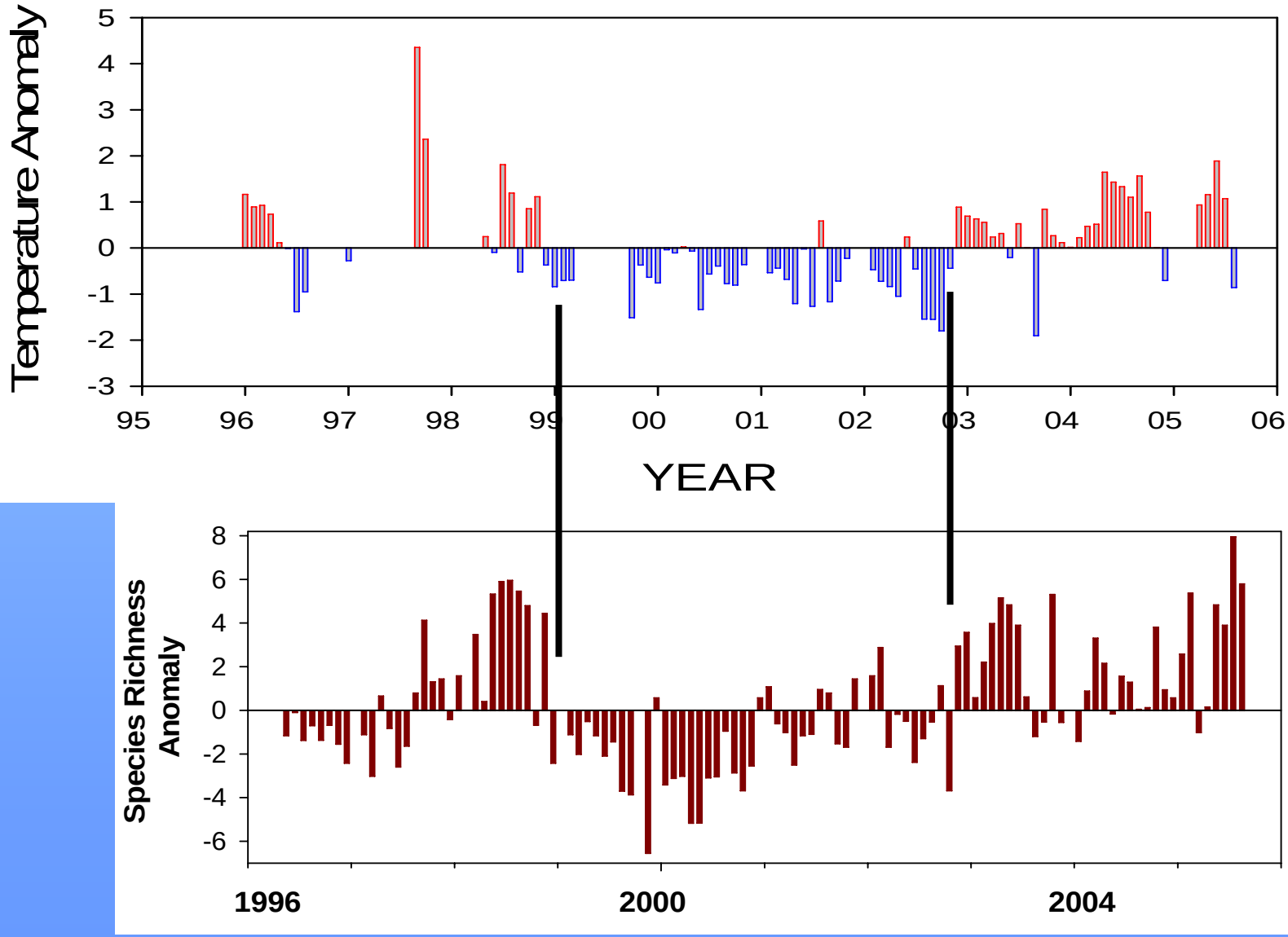
Euphausiids

- Spawning poor 1996-1999, intense in 2000, and during 2001-2004, Very low in 2003 and 2005 at inshore station, but ~ normal at NH 15 and NH 25.



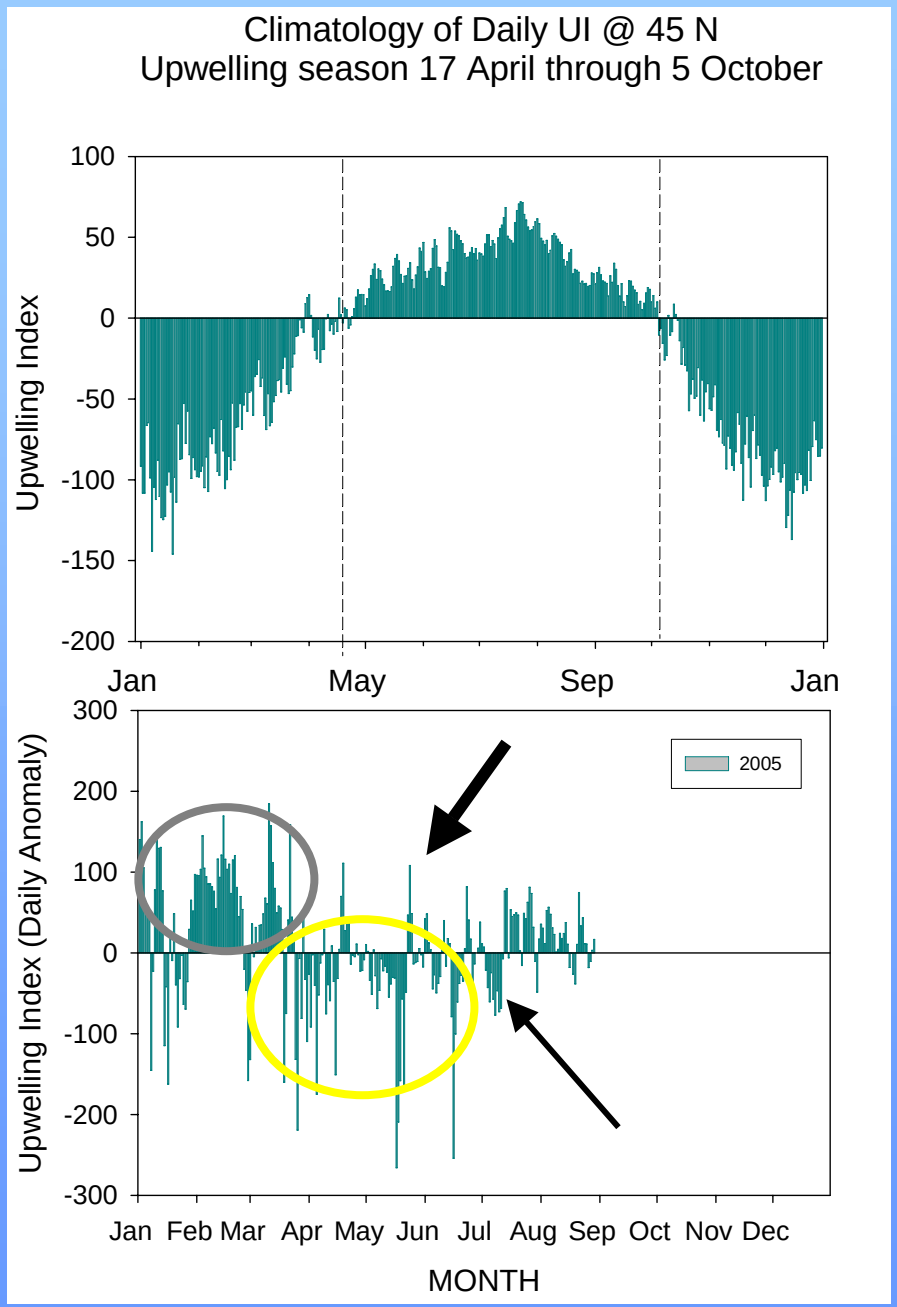


The PDO and salmon survival also appear to be related


Temperature Anomaly
5
4
3
2
1
0
-1
-2
-3
95
96
97
98
99
00
01
02
03
04
05
06
YEAR
Species Richness Anomaly
8
6
4
2
0
-2
-4
-6
1996
2000
2004

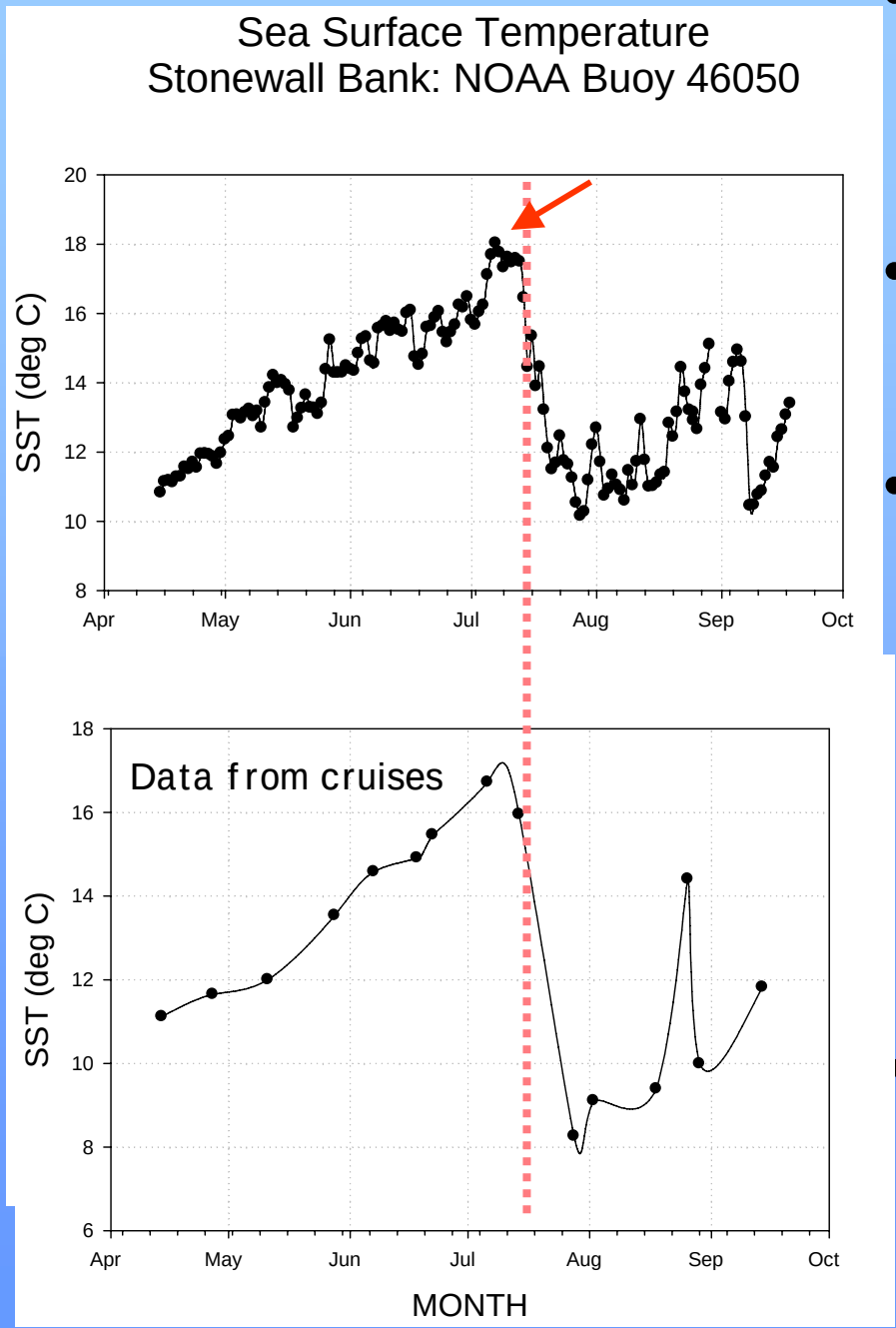
- McGowan, Cayan and Dorman (1998) commented that "…the biological consequences of climate variability are not well understood, largely because of the mismatch between time scales of important atmospheric and oceanographic processes and biological research programs".

We've 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) which is now in its 10th year; and we have sufficient historical data from earlier years to allow comparisons of the present with the past



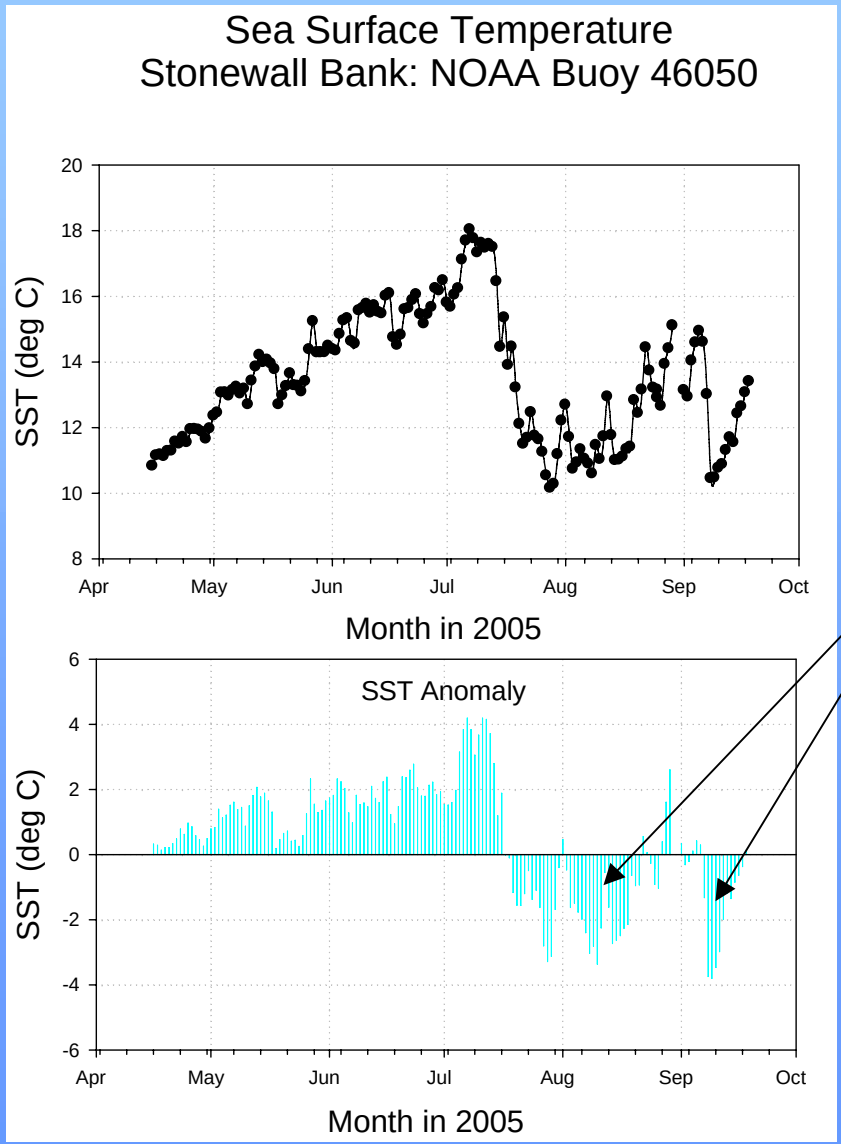
The Upwelling Index

- The climatological upwelling season is 17 April – 5 October
- 2005: got off to a great start in February-March but winter storms rolled through from March until mid-June
- Apparent beginning of upwelling on 23 May but sustained events never got established due to SWly winds in June and early July.



- SST at the NOAA buoy off Newport tells the tale
- > 18 deg C in July, a + 4 deg C anomaly
- Based on SST at the NOAA Buoy and from cruises, upwelling did not begin to express itself in any significant way until ~ 15 July, three months later than climatology
- Major cooling events were seen, mid July and early & late September

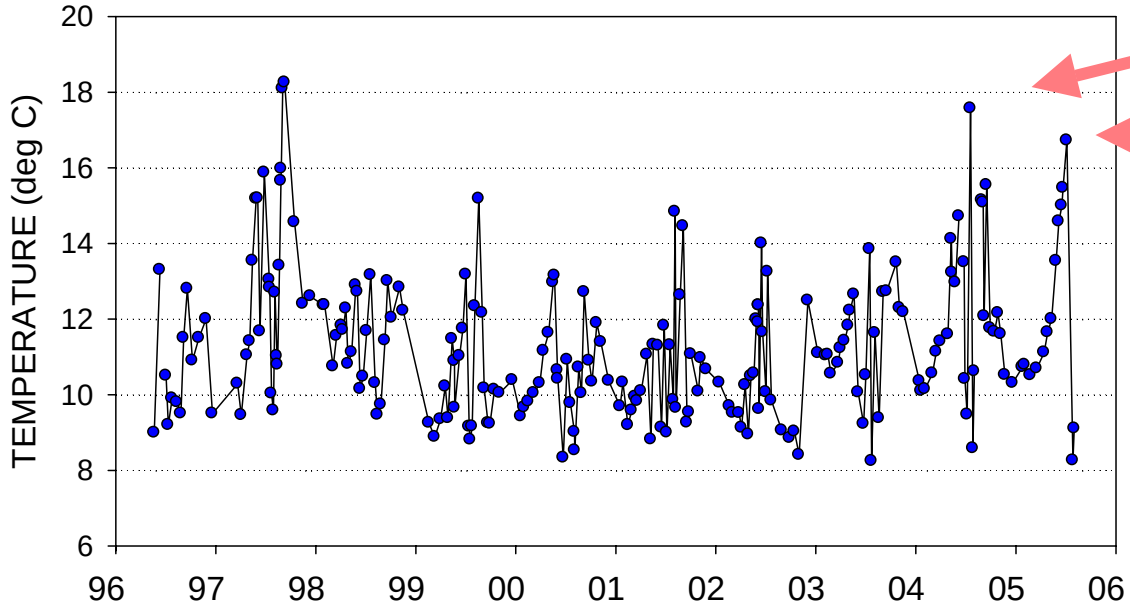
Stonewall Bank Buoy - 2005



- Once upwelling kicked in the negative SST anomalies were extreme!

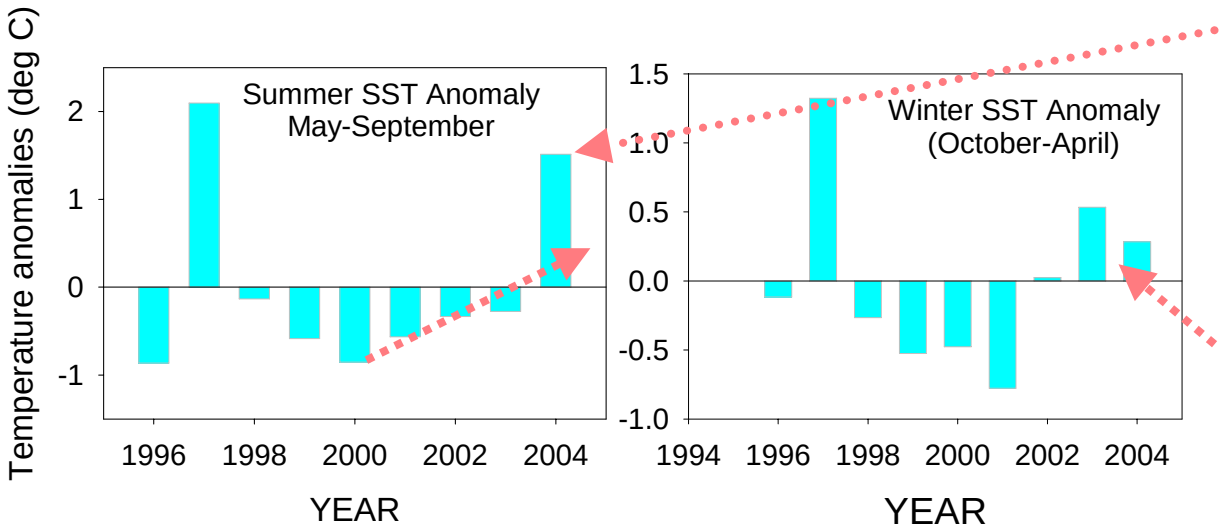
Although the ocean was warm until mid July in 2005, was warming unique to 2005?

SIMILAR PATTERNS AT NEARSHORE STATIONS



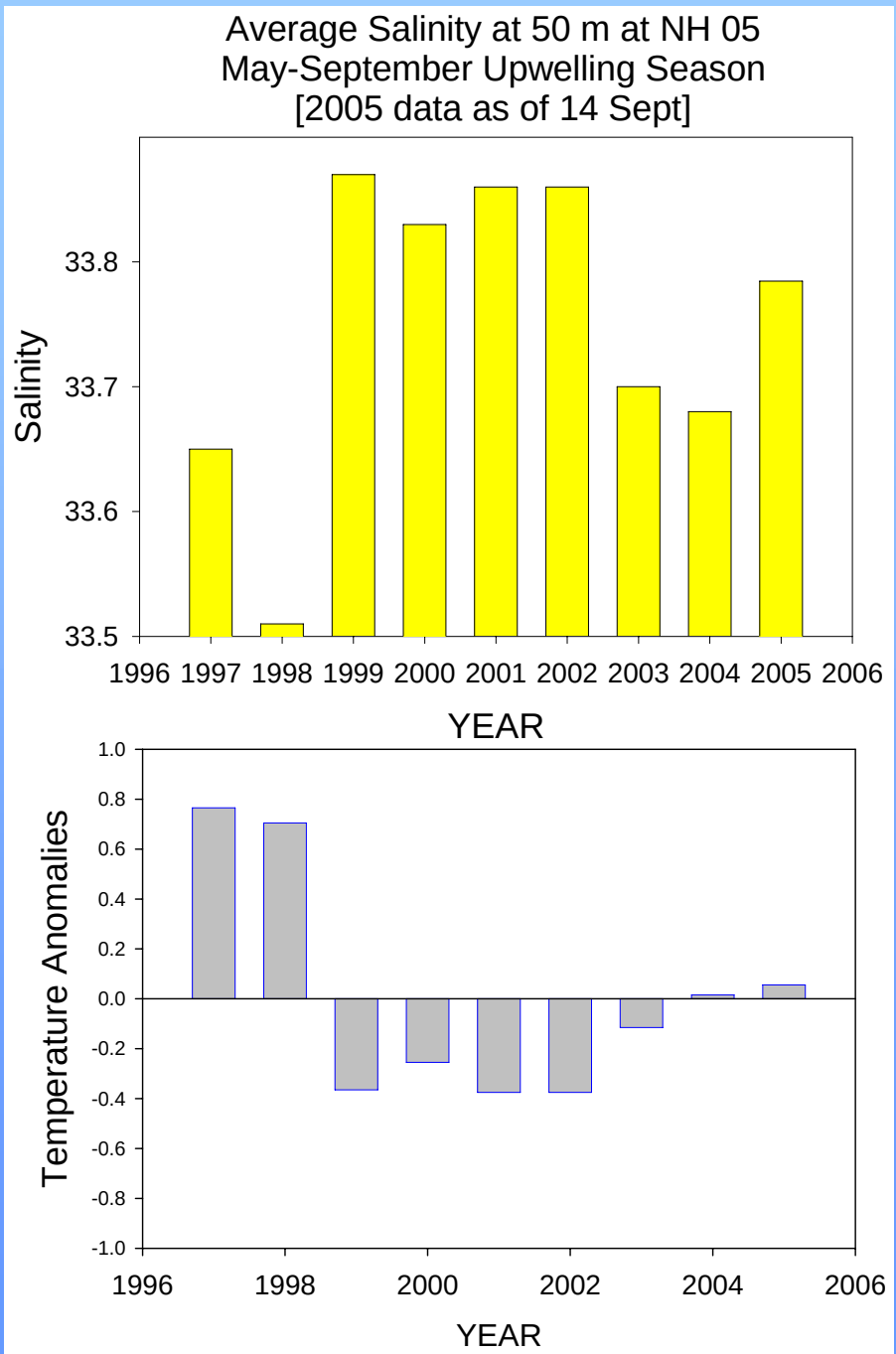
17.6 deg C on 19 July 04

16.7 deg C on 6 July 05; July-September climatology is 10.4º C, thus a + 6.3º C anomaly



- Summer of 2004 was also quite warm
- Warming since 2000

Last two winters have been warm as well.



Perhaps easier to see as summer-averaged salinity and temperature anomalies

- Bottom waters were saltier in summer 1999-2002 then gradually freshened through 03 and 04; now getting saltier (since late July 2005).
- The summers were cooler for five years, 1999-2003, but began to warm slightly in 2003-2005, but now cooling again (since mid August 2005).