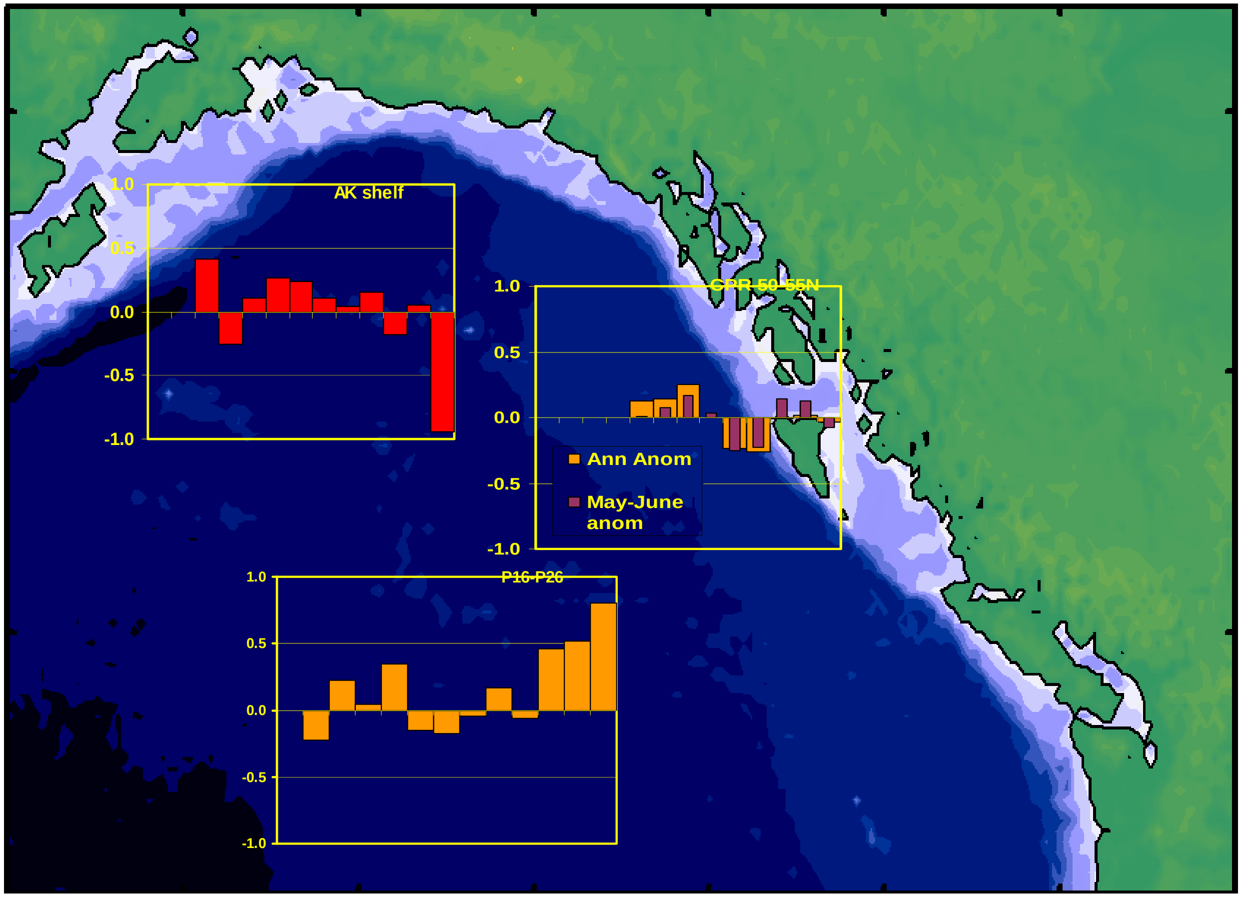
A decade of change in the Alaska Gyre:
Comparison of three NE Pacific zooplankton time series



Marine ecosystems undergo large multi-year changes in productivity and composition.

To describe and understand them, we need good and ongoing time series

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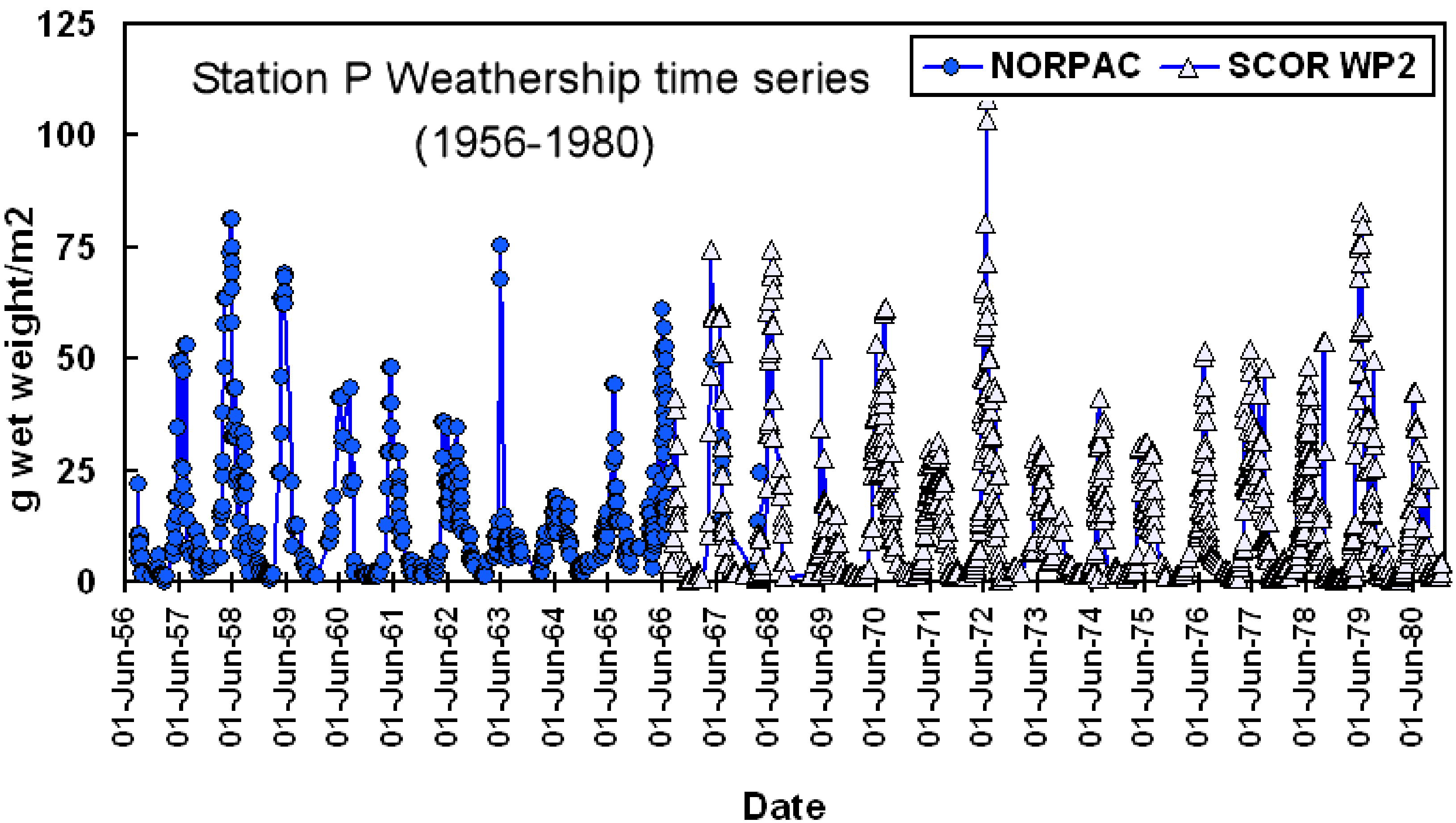
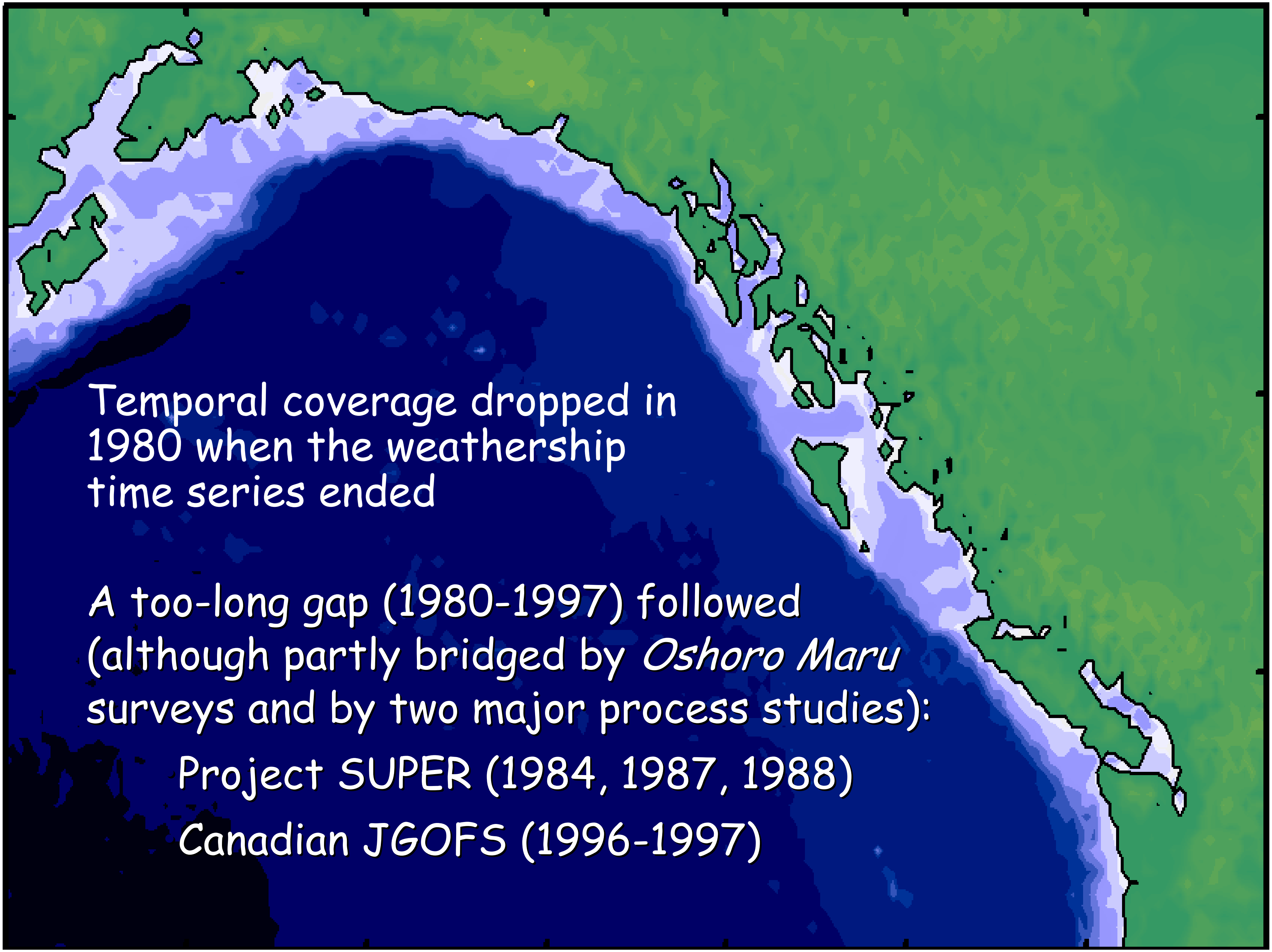
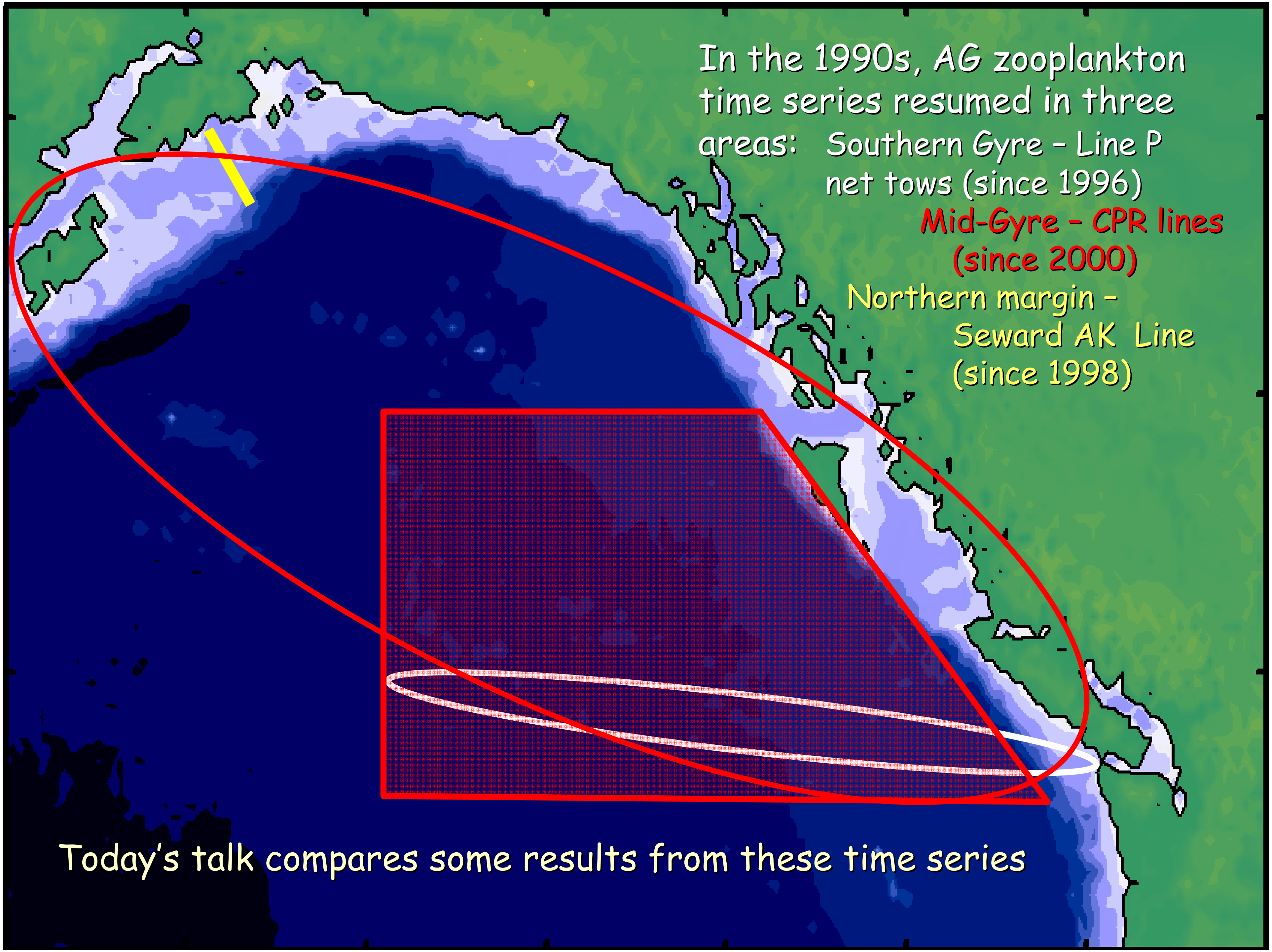
Historic Alaska Gyre zooplankton time series were rich and detailed

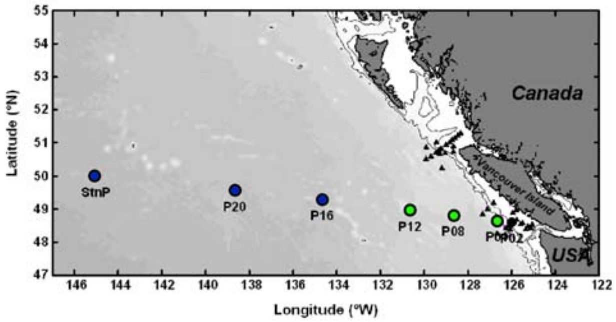
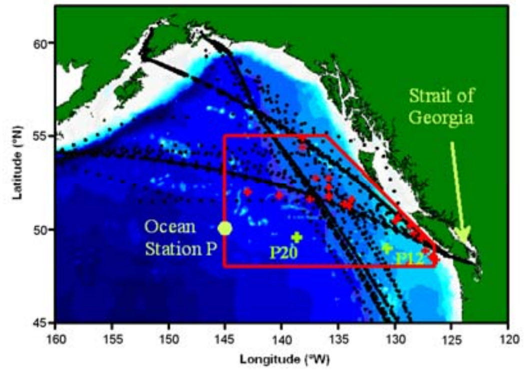
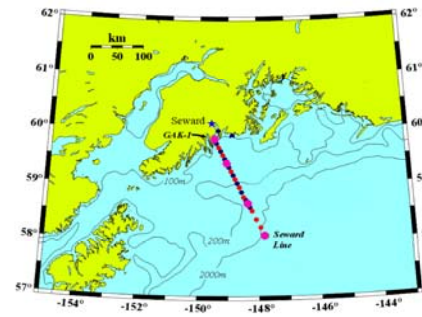




Temporal coverage dropped in
1980 when the weathership
time series ended
A too-long gap (1980-1997) followed
(although partly bridged by *Oshoro Maru*
surveys and by two major process studies):
Project SUPER (1984, 1987, 1988)
Canadian JGOFS (1996-1997)


In the 1990s, AG zooplankton time series resumed in three areas: Southern Gyre – Line P net tows (since 1996)
Mid-Gyre – CPR lines (since 2000)
Northern margin – Seward AK Line (since 1998)
Today's talk compares some results from these time series

Comparisons of 3 Alaska gyre time series: (sampling methodology & schedule)

Line P net tows	CPR lines	Seward line net tows
		

Line P net tows

- Depth integrated (0-250 m bongos)
- 3 surveys/year (Feb, May-June, Aug-Sept)
- Very good resolution of species & stage
- Samples classified into 2 groups: 'outer' vs 'inner' Line P

CPR lines

- CPR line transects (~18 km horizontal, ~10m depth)
- 5-9 lines/year, best coverage 48-55N (outlined in red)
- Fair-to-good resolution of species & stage
- Samples sometimes classified into more latitude bands

Seward line net tows

- Depth integrated (CalVet) & stratified (MOCNESS)
- 6-7/year (1998-2004)
- 2/year (2005-ongoing)
- Very good resolution of species & stage
- Samples classified into cross-shelf zones: (e.g. 'inner shelf')

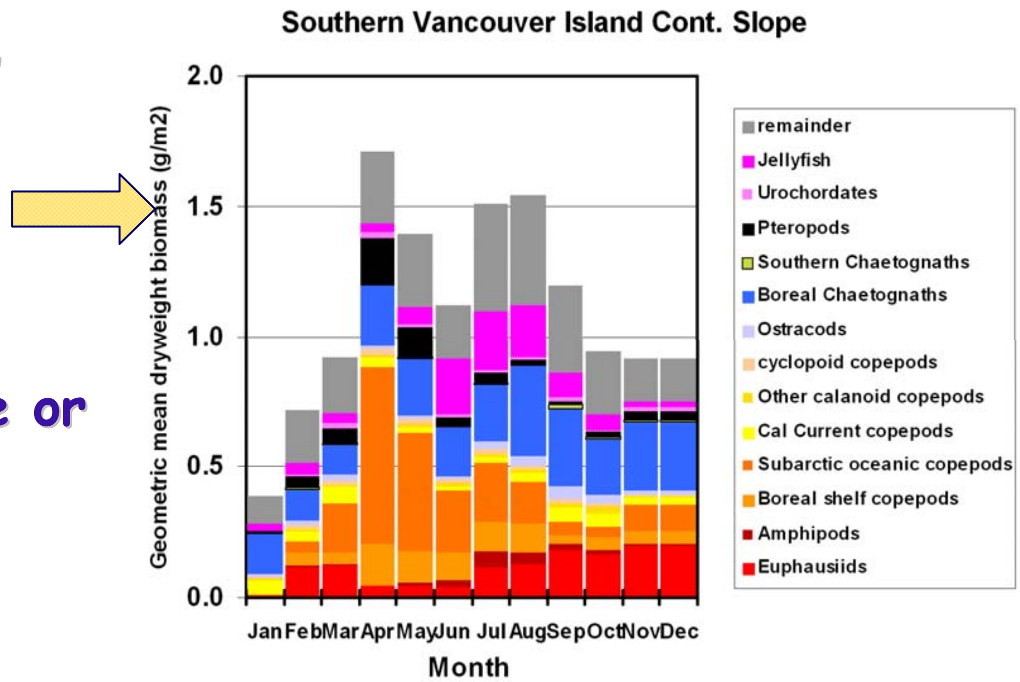
What we want to learn from zooplankton time series

Relative to a long term 'norm' for a region, e.g. interannual variability of:

• "How much of what kinds" (anomalies of biomass at date or of annual integral)

• "When" (seasonal timing = 'phenology')

Optimal indexing methods for both depend on sampling frequency

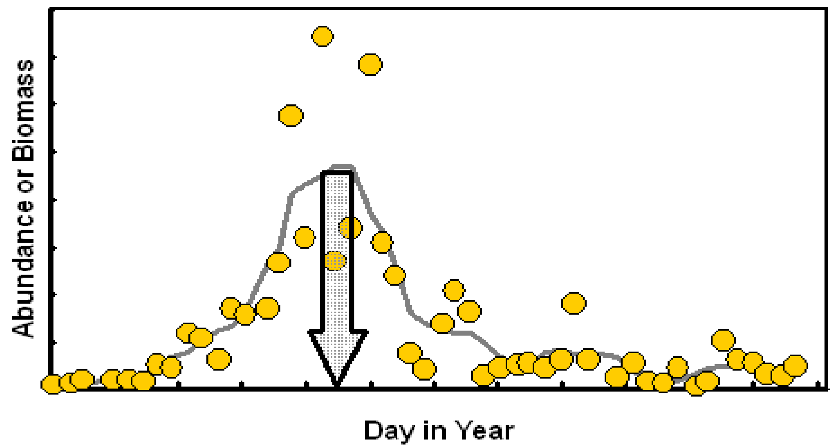


1979-2005 zooplankton climatology for continental margin

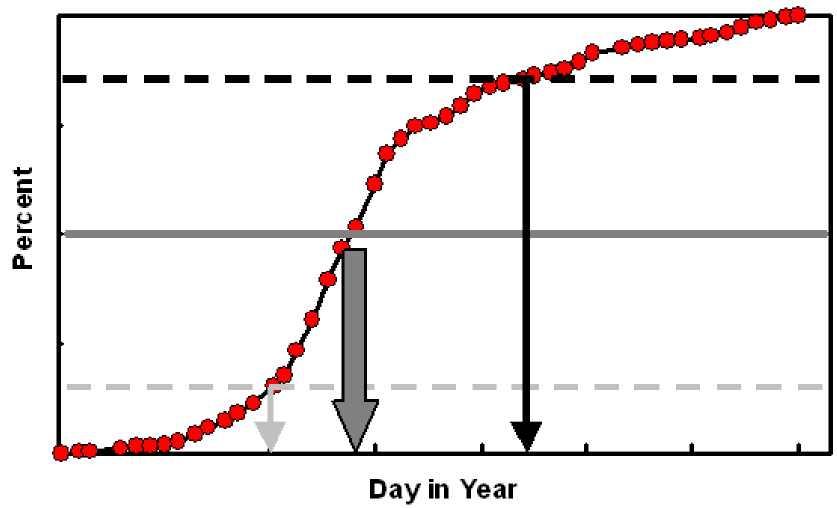
Indexing seasonal timing:

Amount-based

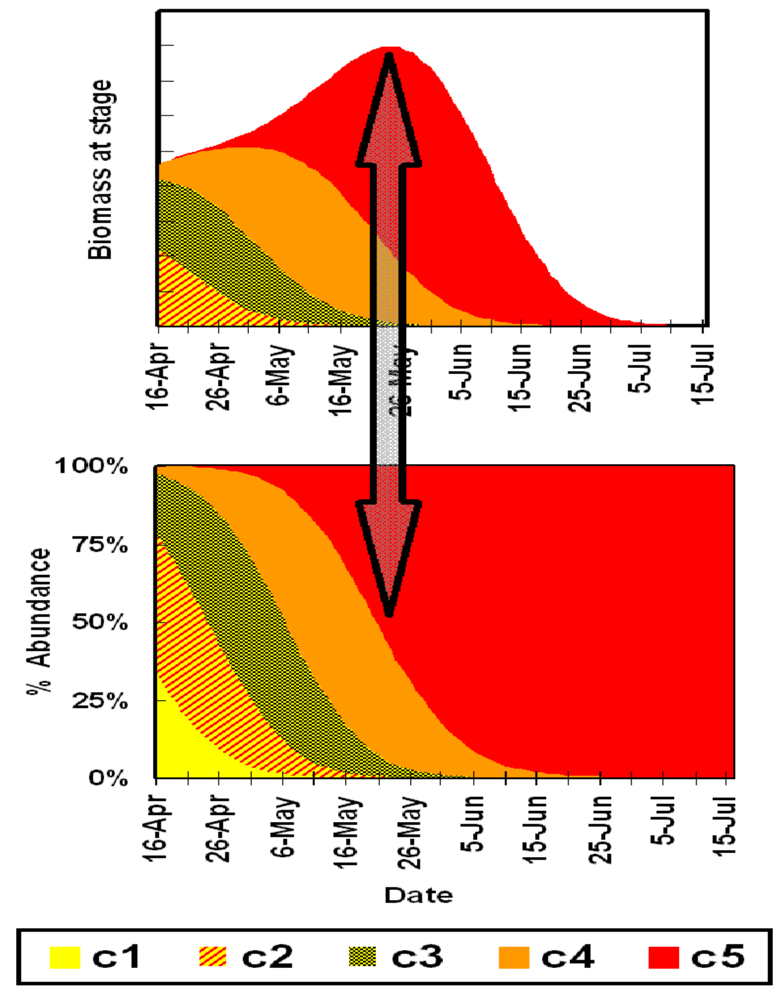
Peak or Center-of-Gravity



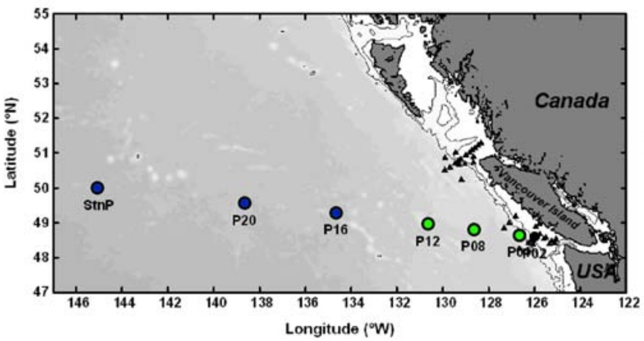
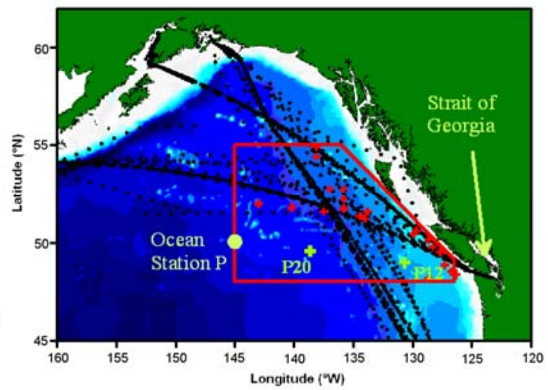
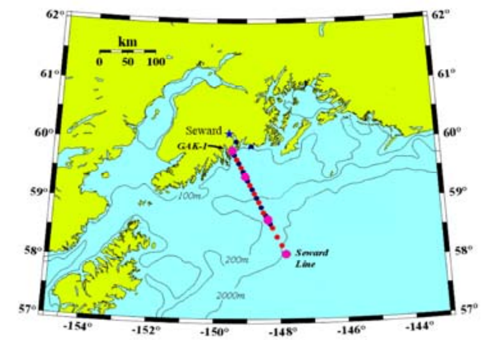
Annual Cumulative Abundance



Age-structure-based



Comparisons of our Alaska gyre time series: (data processing methods)

Line P net tows	CPR lines	Seward line net tows
		

Line P net tows

- Spatial average abundance converted to biomass
- Log scale 'Anomalies' as annual ave. of deviations from monthly climatology
- Phenology from stage composition

CPR lines

- Spatial average abundance converted to biomass
- Annual biomass = integral of biomass vs date curve
- Anomaly=log(year/ave)
- Phenology from cumul. abundance %iles and from stage ratios

Seward line net tows

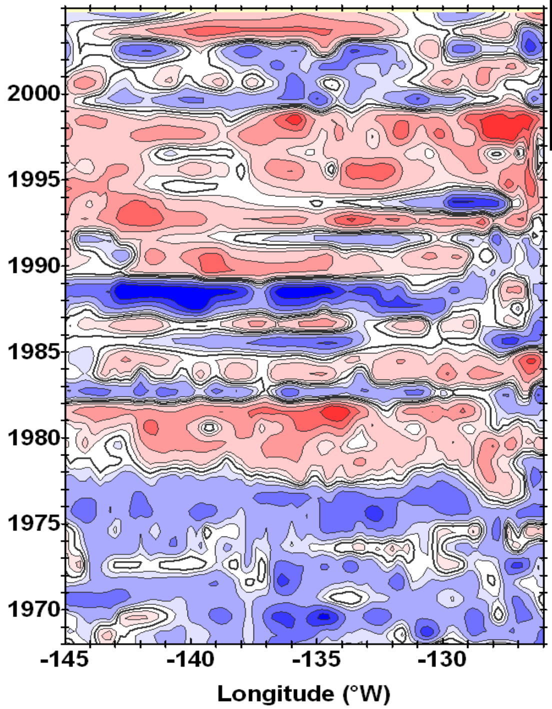
- Spatial average abundance converted to biomass
- Log scale anomalies = log (May of year/May climatology)
- Phenology from stage composition in May

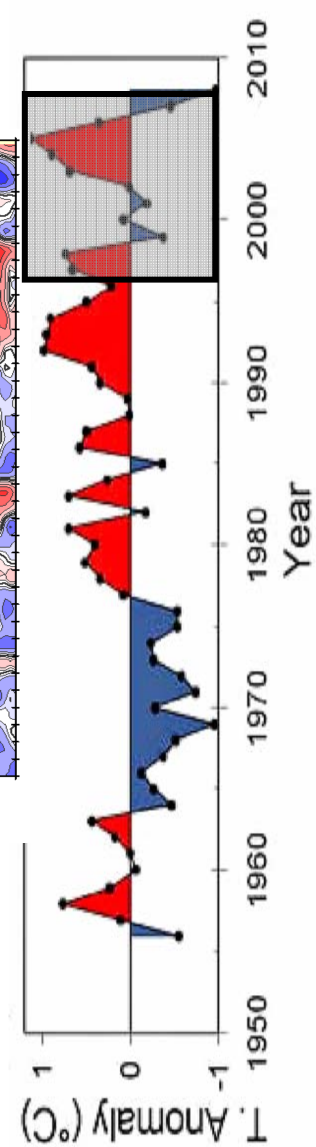
Preview of Results

- Recent and important Alaska Gyre physical variability (temperature & circulation)
- Changes of *Neocalanus* seasonal timing & cohort width
- Anomalies of amount & composition

Result #1: Two modes of recent physical variability

Interannual temperature variability along Line P

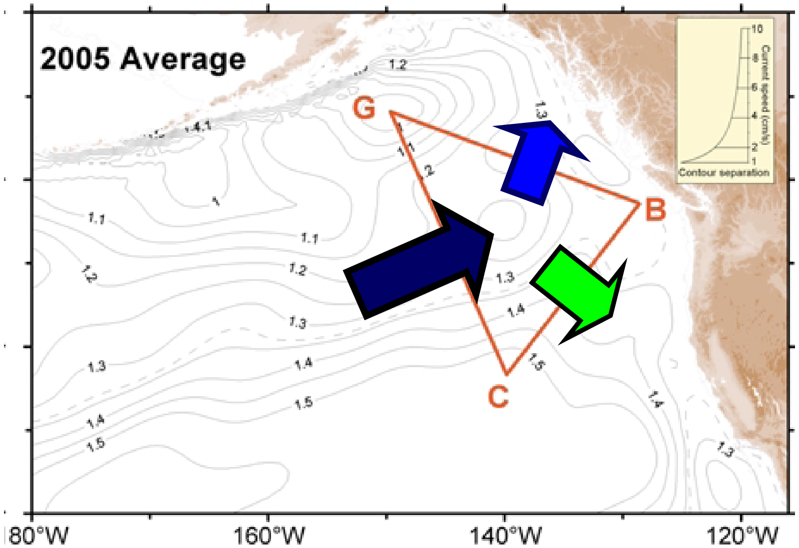


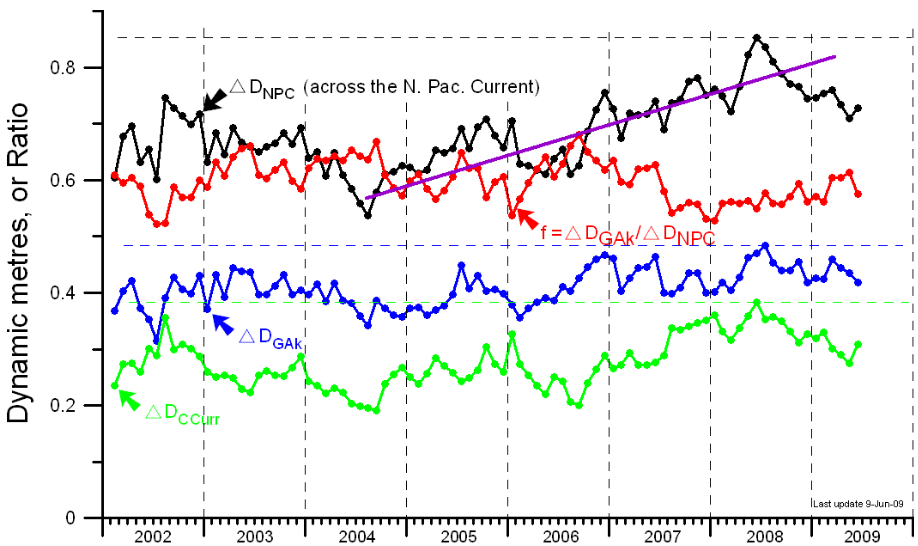


(Figures & T data courtesy W. Crawford, IOS)

- Strong alternation between cool periods (1964-76, 1999-2001, 2007-08) and warm periods (1978-98, 2003-2006)
- Our 12 year zooplankton time series (grey box) include the warmest (2005) and coldest (2008) years in the 55 year record
- The recent alternations between warm and cool also appear to have been more rapid and very steep

Circulation variability in the Alaska gyre as seen by ARGO drifters



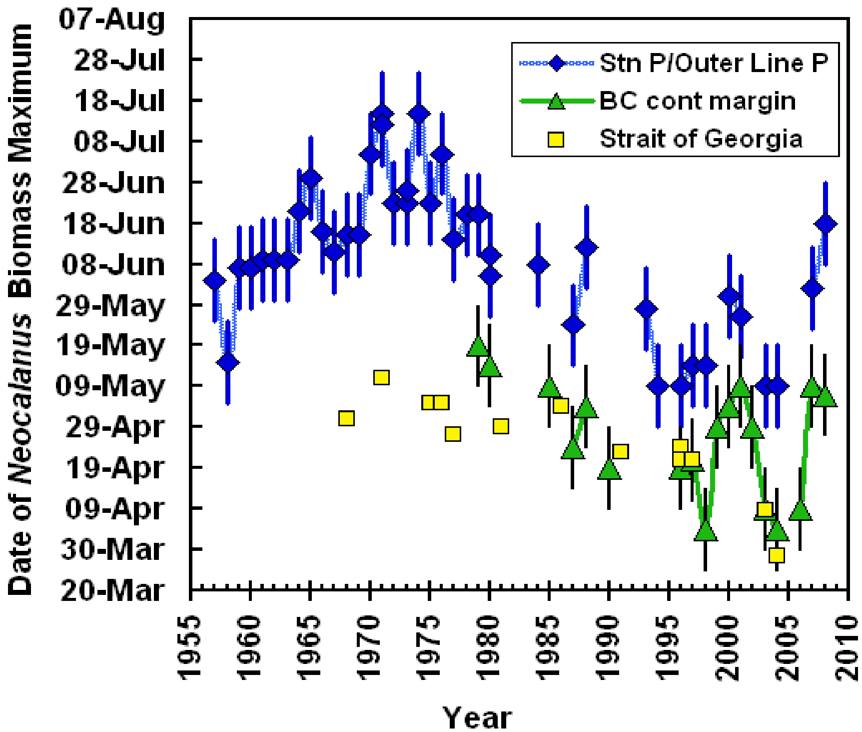


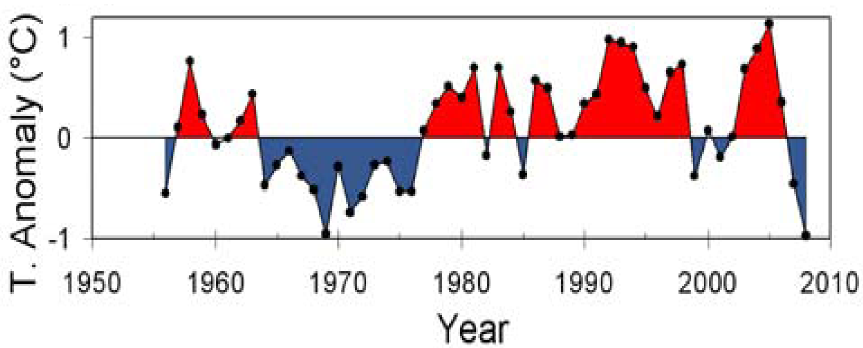
- ARGO drifters now provide frequent and dense T, S, and ρ profiles in the Alaska Gyre
- Useful products: dynamic topography maps (top) and time series (bottom) of transport:
  - North Pacific Current (black)
  - Alaska Current (blue)
  - California Current (green)
- Between 2004 and 2008, the North Pacific Current intensified by nearly 50%!
- Partitioning of this increase between CC and AC has also varied, but with no clear trend.

(analysis & figures courtesy H. Freeland, IOS)

Results #2: Variability of zooplankton seasonal timing (later when colder)

Variability of *Neocalanus* seasonal timing – outer Line P and BC cont margin





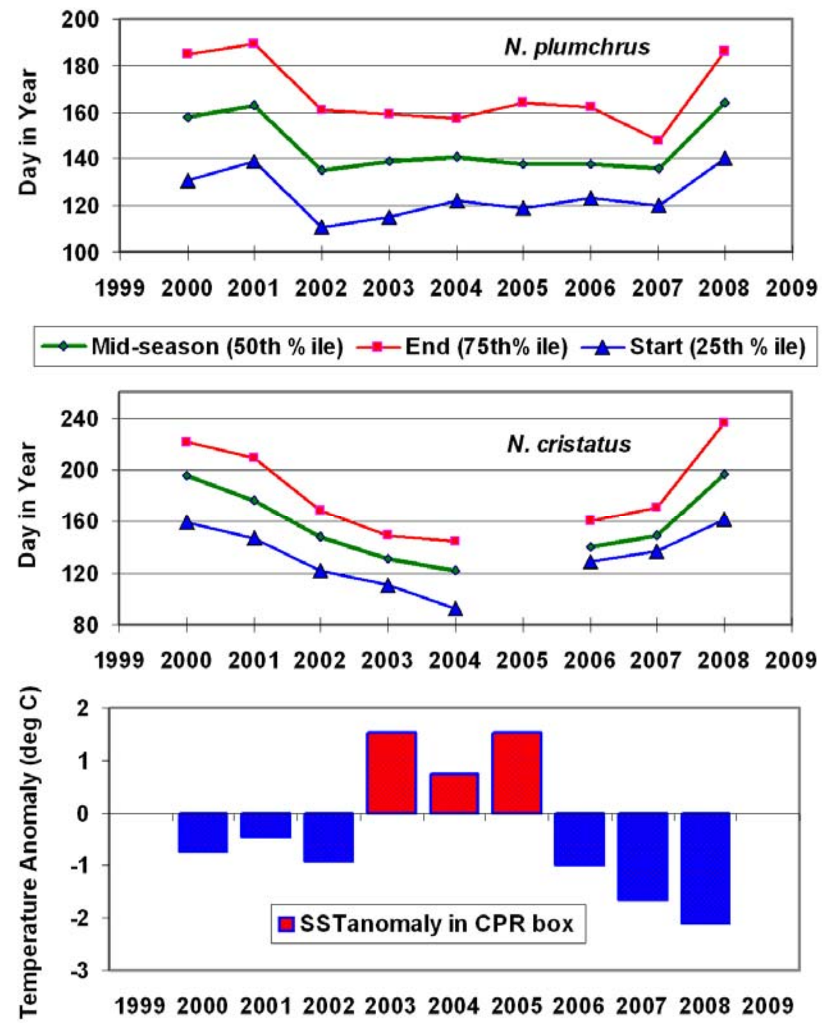
- Our newer Line P data can be used to extend the Stn P time series, and compared to our coastal time series.
- Timing of *N. plumchrus* covaries with upper ocean temperature (early when/where warm, late when/where cold)
- Locations offset in mean timing, but interrannual variability is strongly coherent (r^2~0.8)
- What do the CPR and Seward Line data show??

CPR phenology estimates for the central Alaska Gyre: very similar T°C dependence

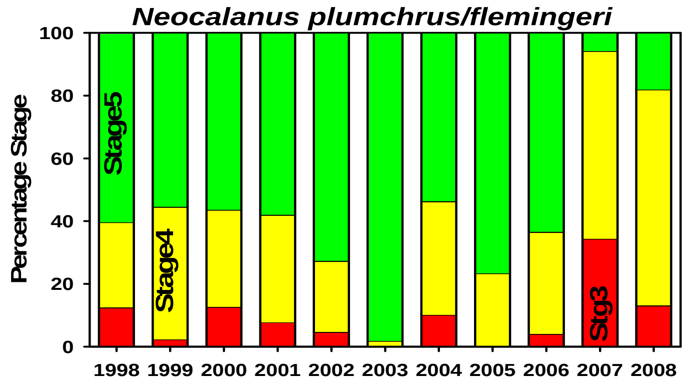
Both *N. plumchrus* and *N. cristatus* had late timing in most cool years, early timing in all warm years.

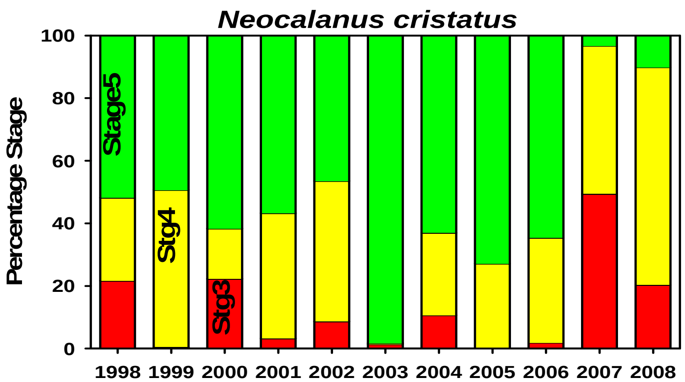
Larger range of timing variation for cristatus (~80d) than for plumchrus (~50d)?

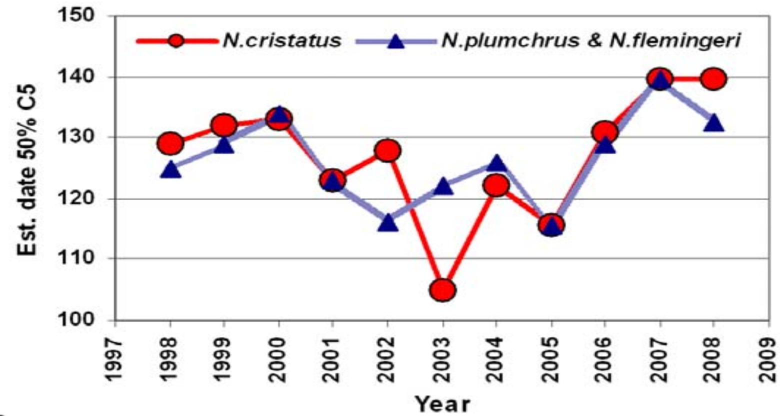
Peak duration also tends to be shorter when timing is early (Batten & Mackas, 2009). Increased risk of trophic mismatch??

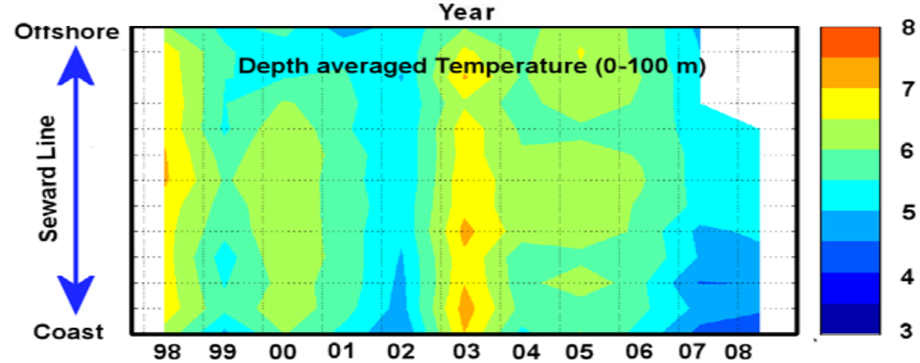


Phenology estimates for Seward Line
Offset (and noisier) but again later when colder





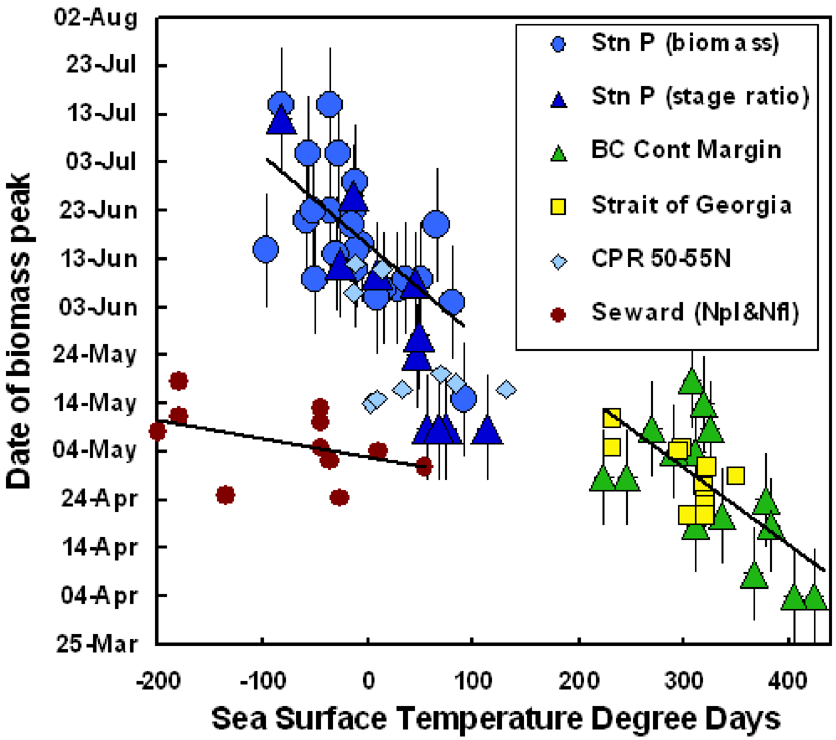


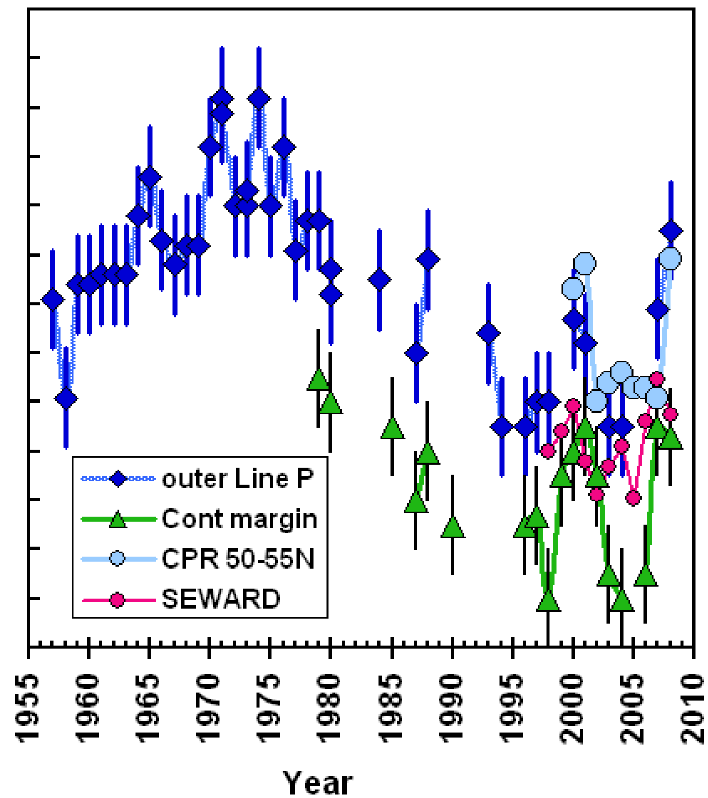


Left: Time series of May stage composition for *N. plumchrus* and *N. cristatus*

Right: Can project copepod stage development forward or backward from sampling date to estimate year-day at which population was 50% C5. This timing index covaries with local temperature

Plotting all NE Pacific regions together:



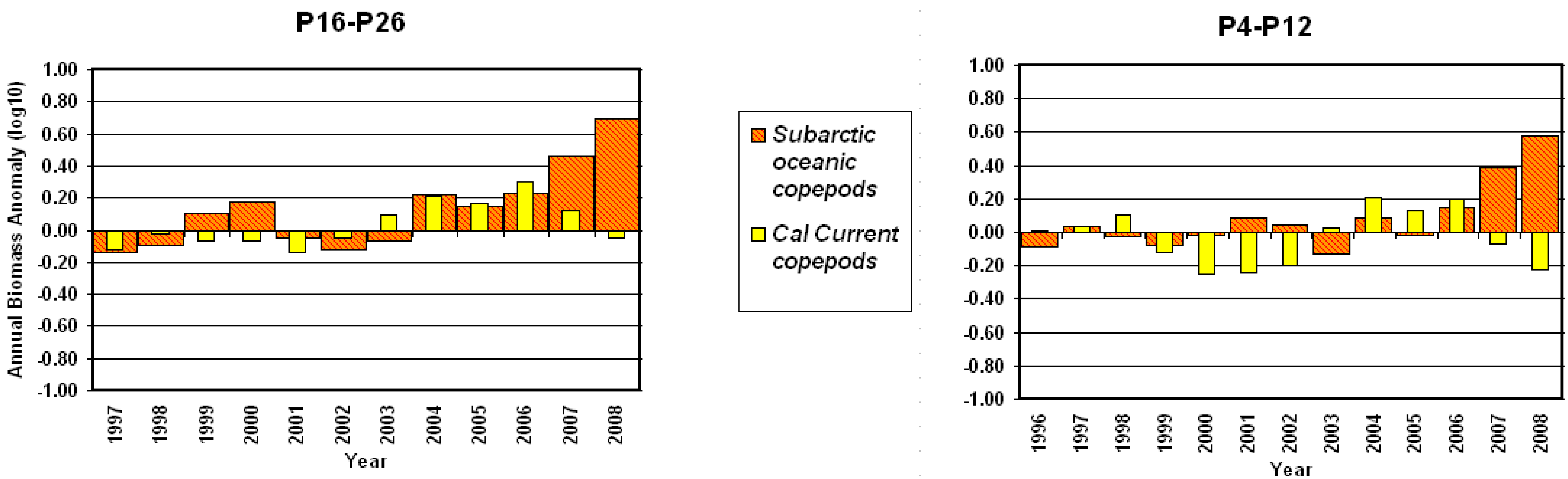


- Phenology has moderate-strong temporal synchrony (basin scale agreement about early/warm vs late/cold years)
- *Shared timing-temperature regression except for Seward Line*
- Possible causes: Stratification by fresh water? More *N. flemingeri*? Inadequate characterization of temperature in source region due to advection, patchiness, ….?

Results #3: Anomalies of zooplankton amount

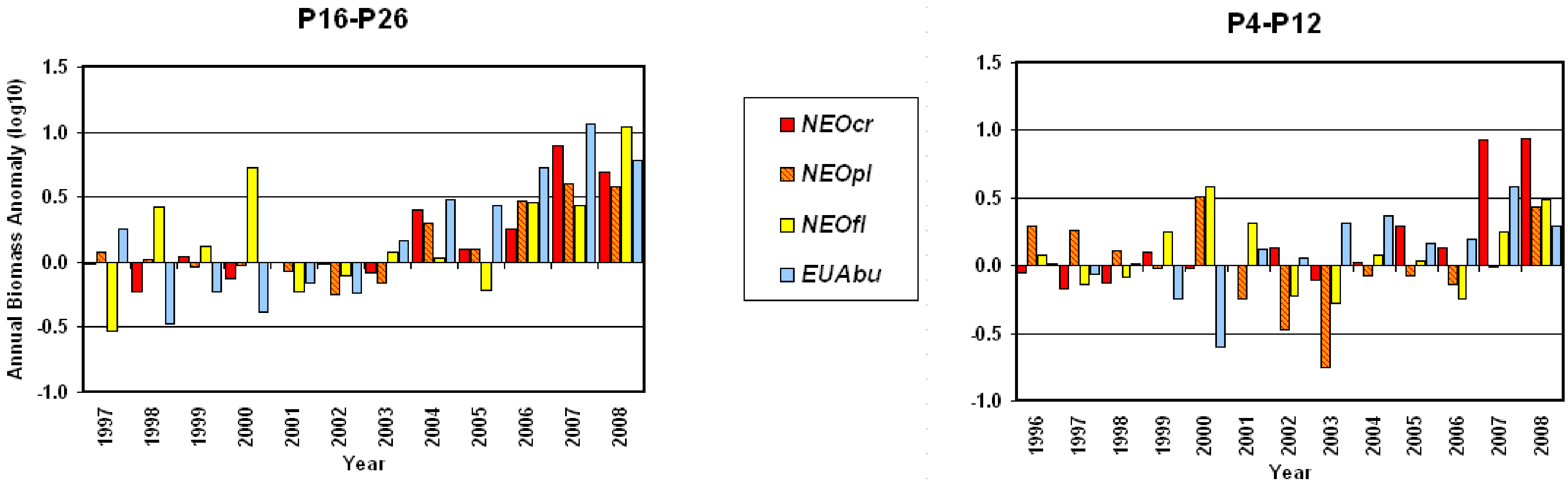
(focus today on *Neocalanus* spp.)

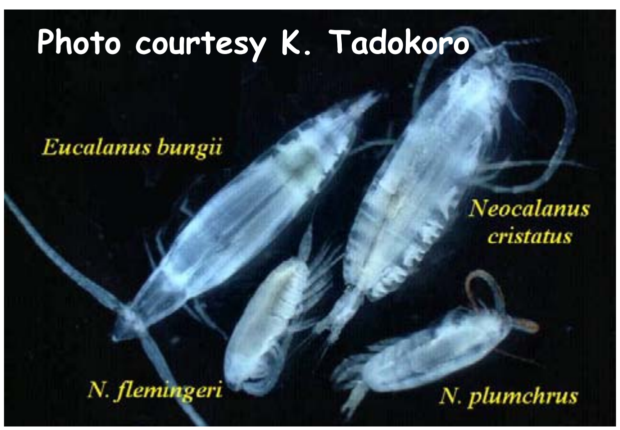
Annual anomalies of amount and community composition along Line P



- Subarctic oceanic copepods (*Neocalanus* spp., *Eucalanus*, and *Metridia)* have increased since ~2003.
- Negative correlation with temperature anomalies (r^2 = 0.3-0.4), but a stronger positive association with Subarctic Current transport (r^2 = 0.5-0.65)
- Subtropical copepods (although rare) are positively correlated with the temperature anomalies (r^2 = 0.6 for P4-P12, decreasing to 0.2 for P16-P26)

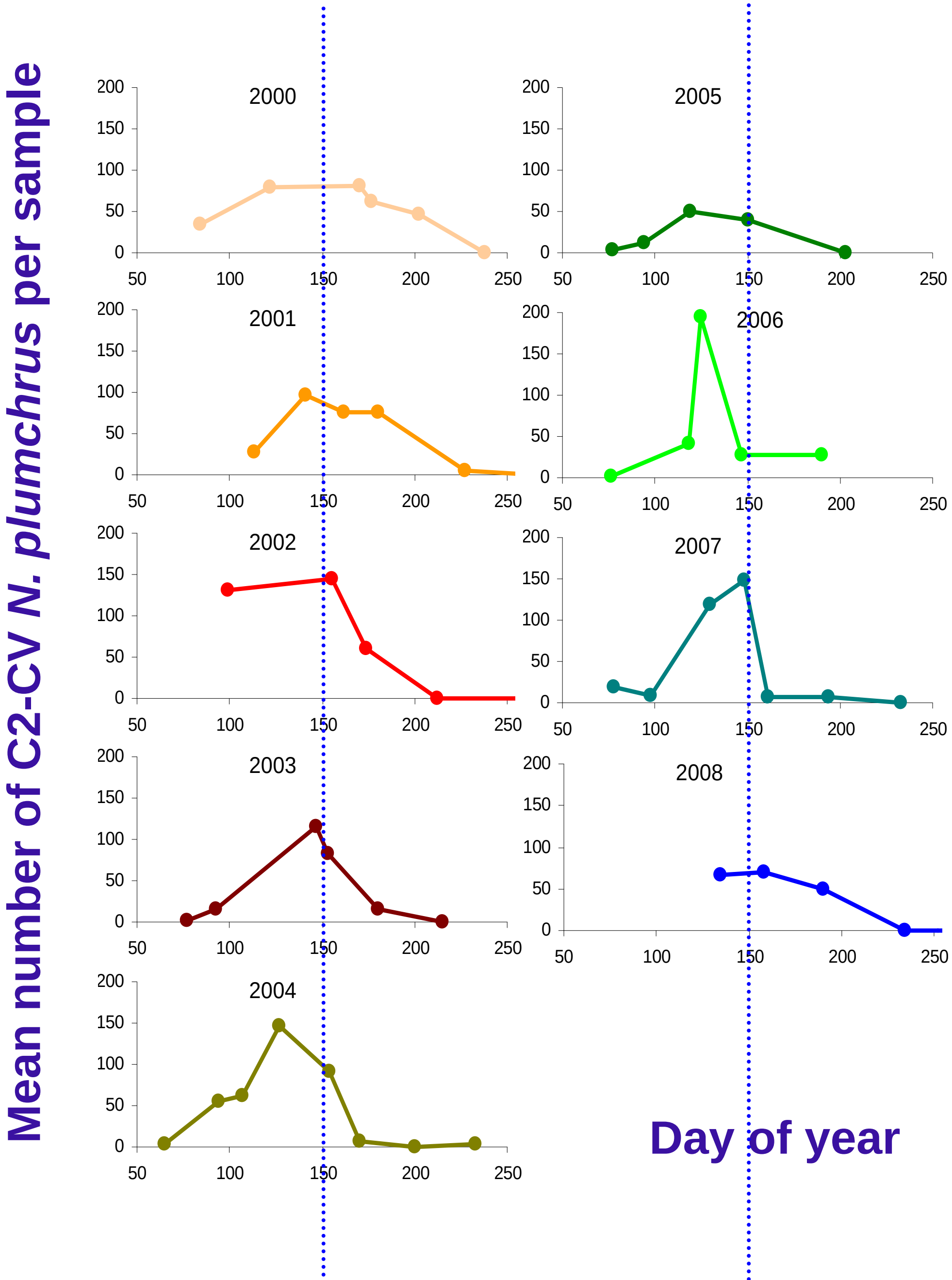
Annual anomalies of amount and community composition along Line P

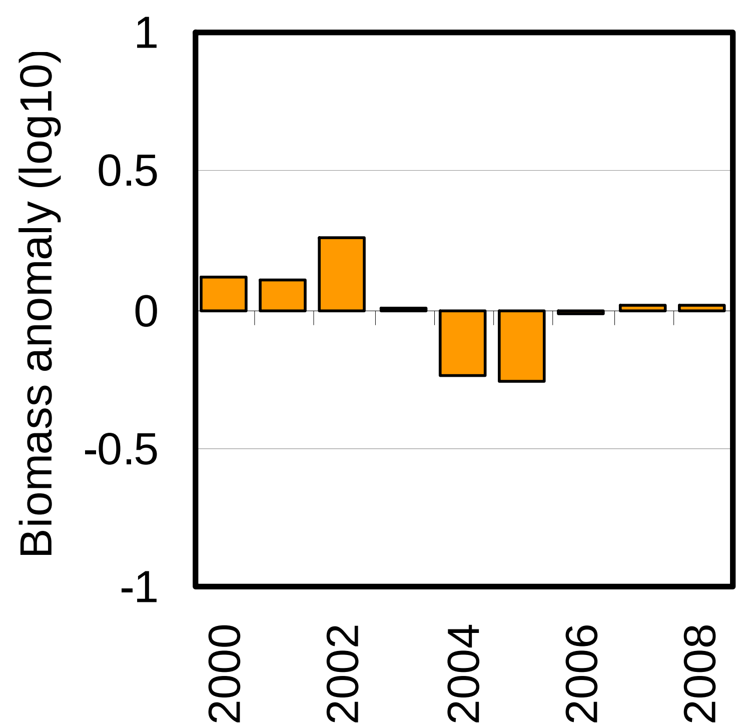




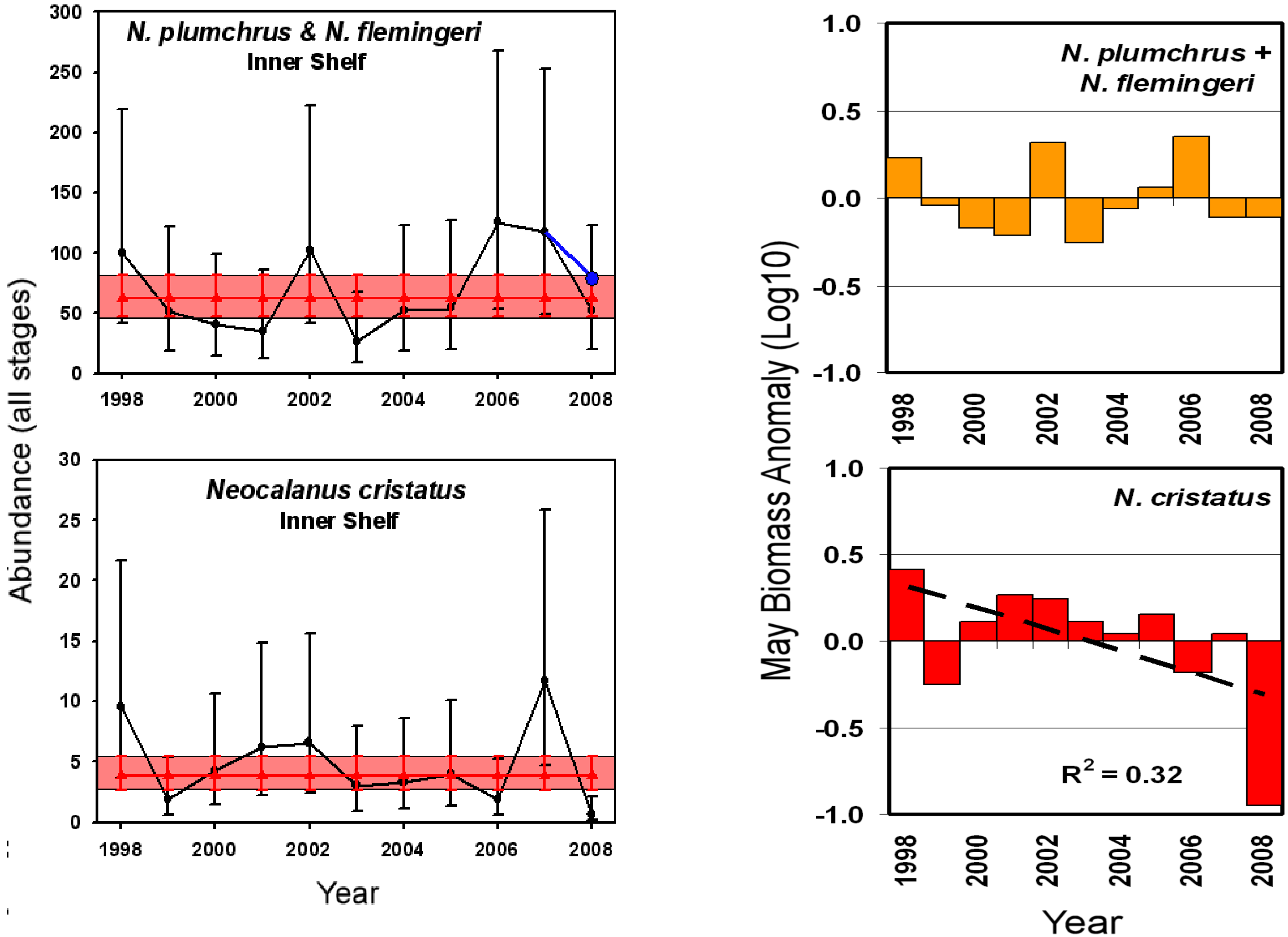
- Within the 'subarctic oceanic' copepod group, the species showing the strongest recent increase have been the two largest: *Neocalanus cristatus* and *Eucalanus bungii*
- These also have a longer growing season, and enter diapause later than either *N. flemingeri* or *N. plumchrus*

CPR data also show big interannual changes in peak abundance (left) and biomass (below)

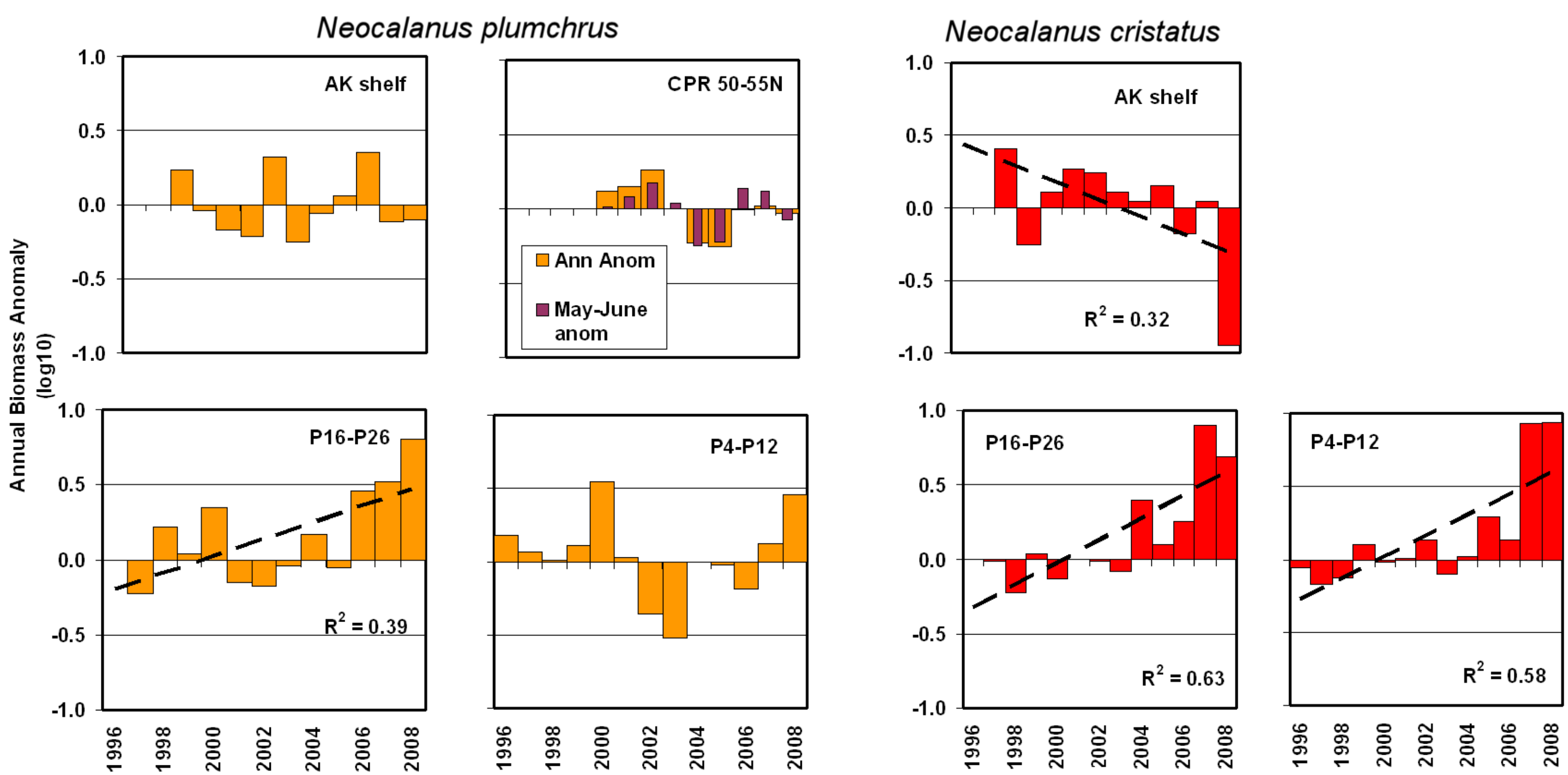




Interannual variability of Seward Line #s (left) & biomass (right)
But here, colder years often have below average May biomass
A low year or a late year?



Comparing all NE Pacific biomass anomalies:



- *N. plumchrus* shows little between-region covariance (no basin scale agreement about high vs low biomass years)
- *N. cristatus* has negative covariance between northern and southern gyres. Real? Or aliased seasonal timing?

Summary

- TIMING: Our three Alaska Gyre zooplankton time series record similar "earlier when warmer" phenology responses to recent climate variation.
- AMOUNT: *Neocalanus* & *Eucalanus* have been increasingly successful since ~2004 in the southern Alaska Gyre. Their upward trends are correlated with increased strength of the North Pacific Current, and also with cool temperatures in 2007-2008.
- In contrast, recent cold years had low May biomass on the Alaskan shelf. Not yet clear how much of this is caused by reduced productivity, how much by very delayed phenology

Acknowledgements

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