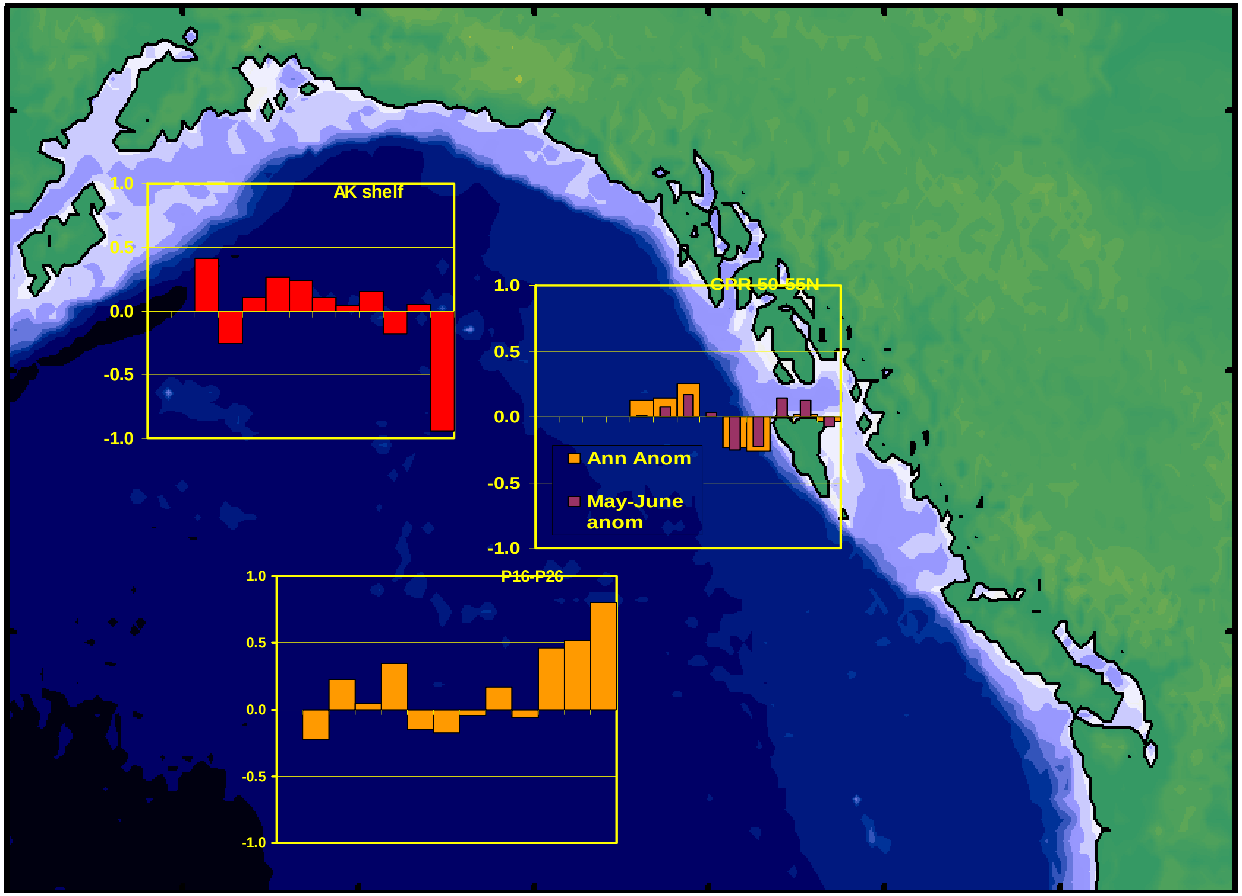
A decade of change in the Alaska Gyre:
Comparison of three NE Pacific zooplankton time series



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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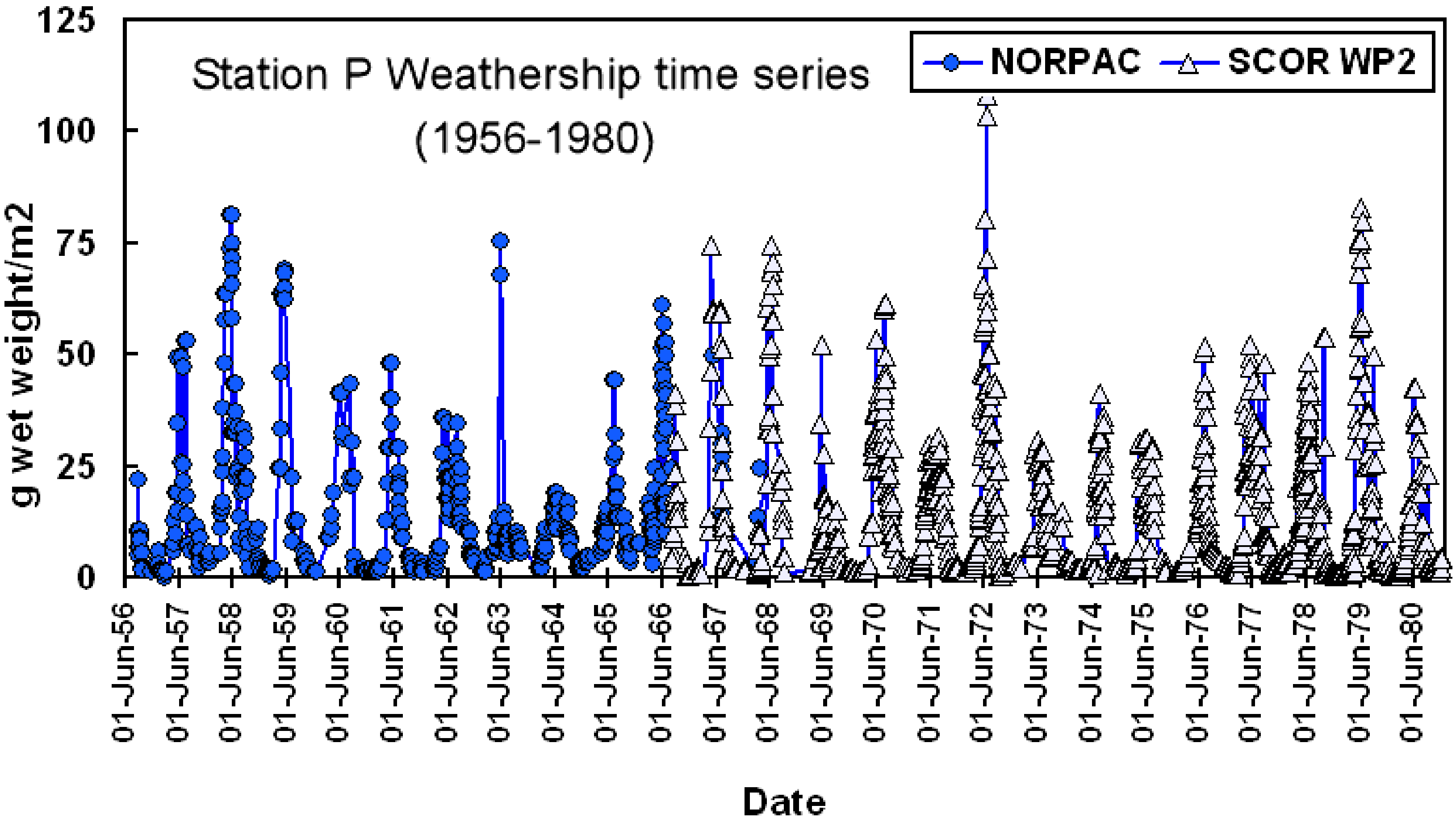
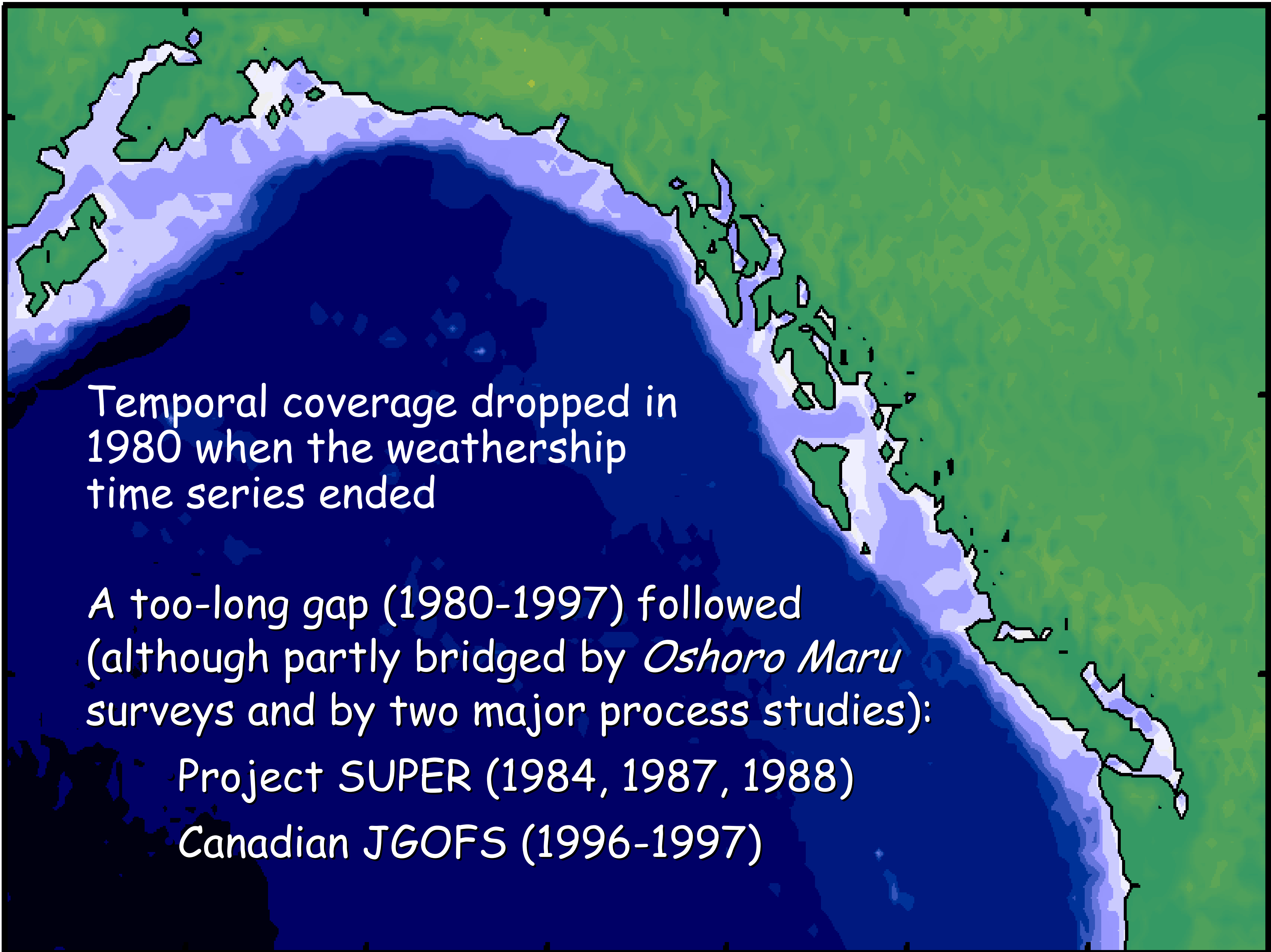
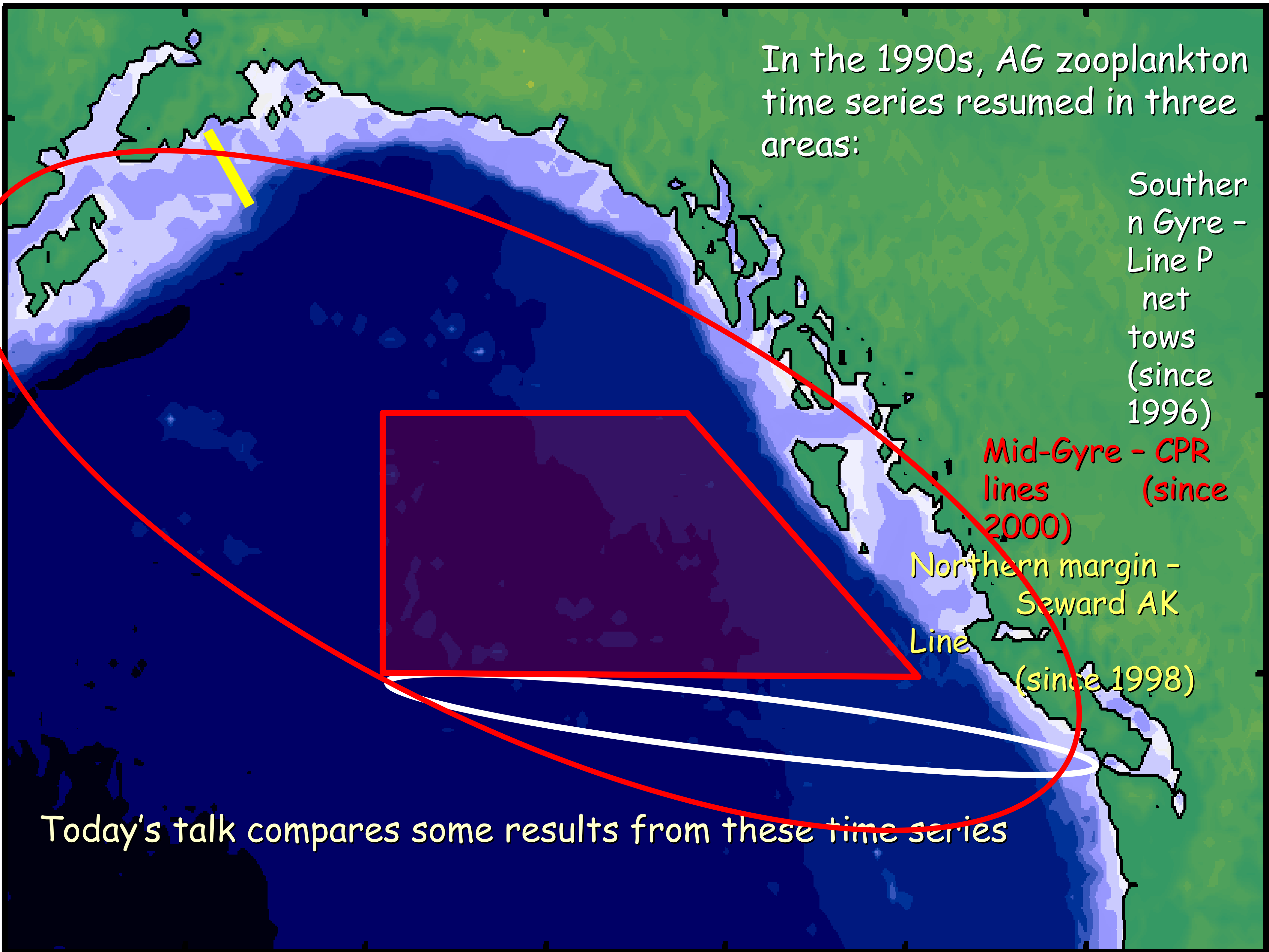
Historic Alaska Gyre zooplankton time series were rich and detailed

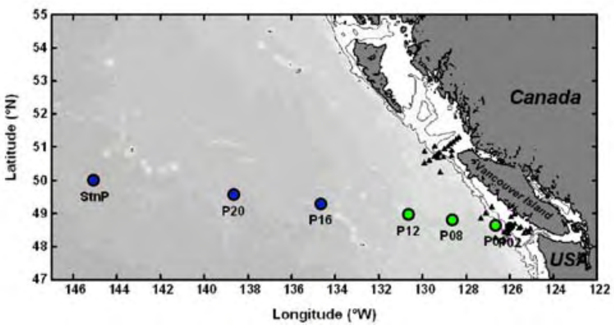



Temporal coverage dropped in 1980 when the weathership time series ended
A too-long gap (1980-1997) followed (although partly bridged by *Oshoro Maru* surveys and by two major process studies):
Project SUPER (1984, 1987, 1988)
Canadian JGOFS (1996-1997)


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



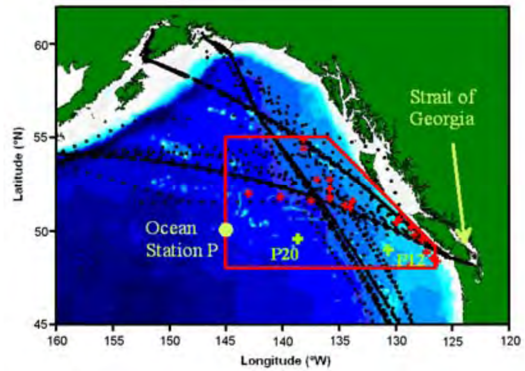
Depth integrated (0-250 m bongos)

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



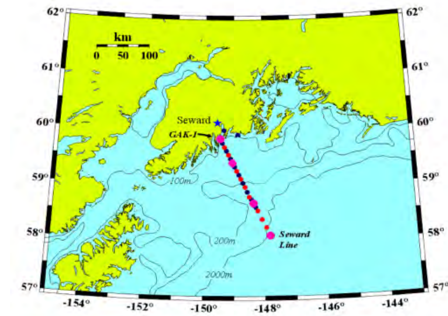
CPR line transects (~18 km horizontal, ~10m depth)

5-9 lines/year, best coverage 50-55N (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

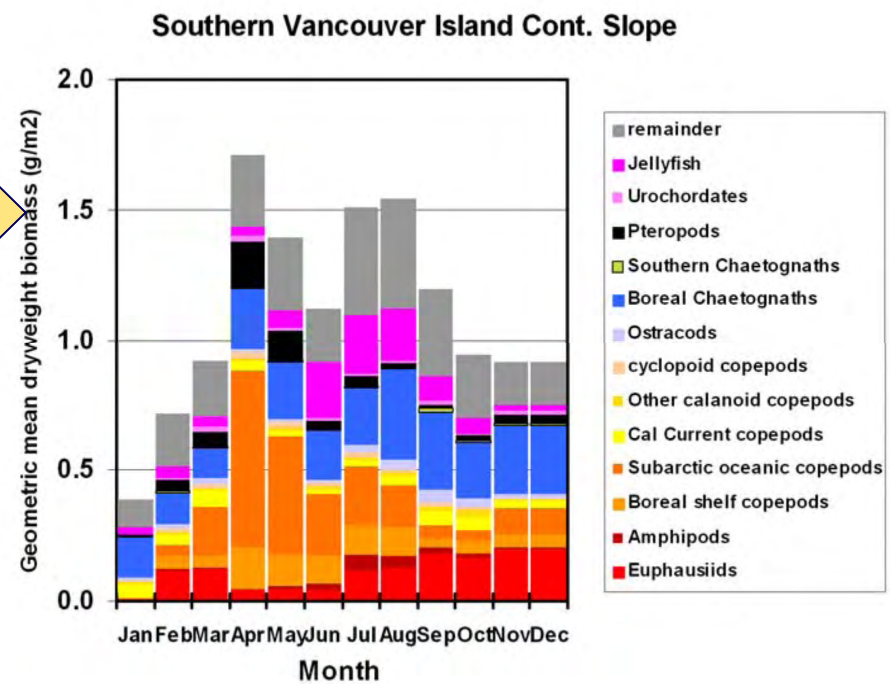
Samples classified into cross-shelf zones: (e.g. 'inner shelf')

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')

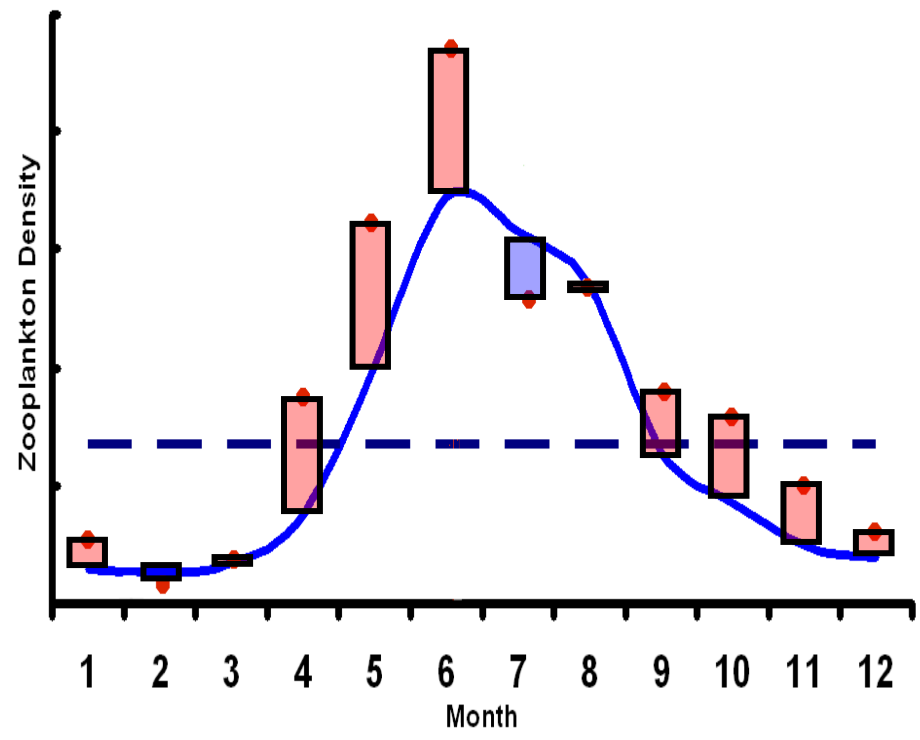


1979-2005 zooplankton climatology for continental margin

Optimal indexing methods for both depend on sampling frequency

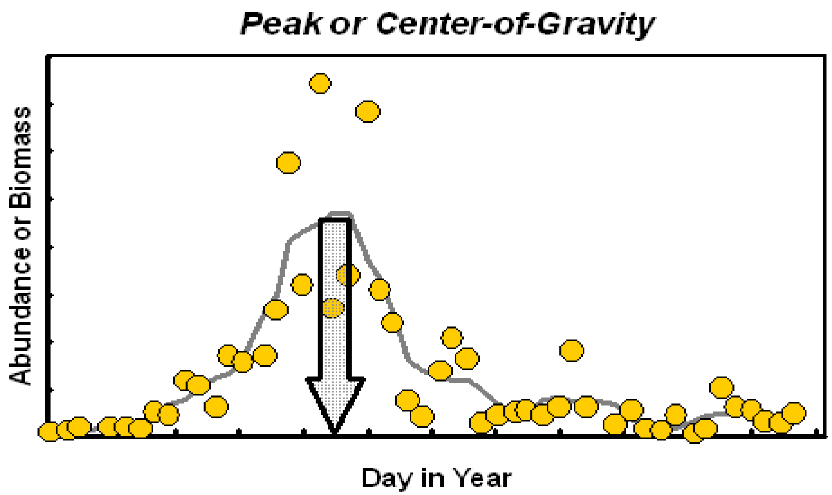
Indexing variability of "amount": Anomalies A_t (differences of data B_t from climatology B)

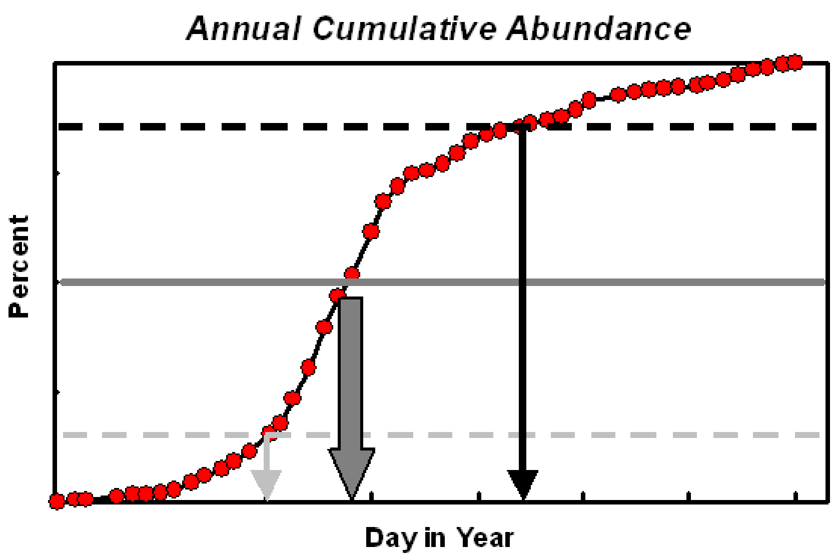
- Monthly anomalies can be averaged to give an annual anomaly A_y
- If seasonal cycle is well-resolved, can also compare annual integrals



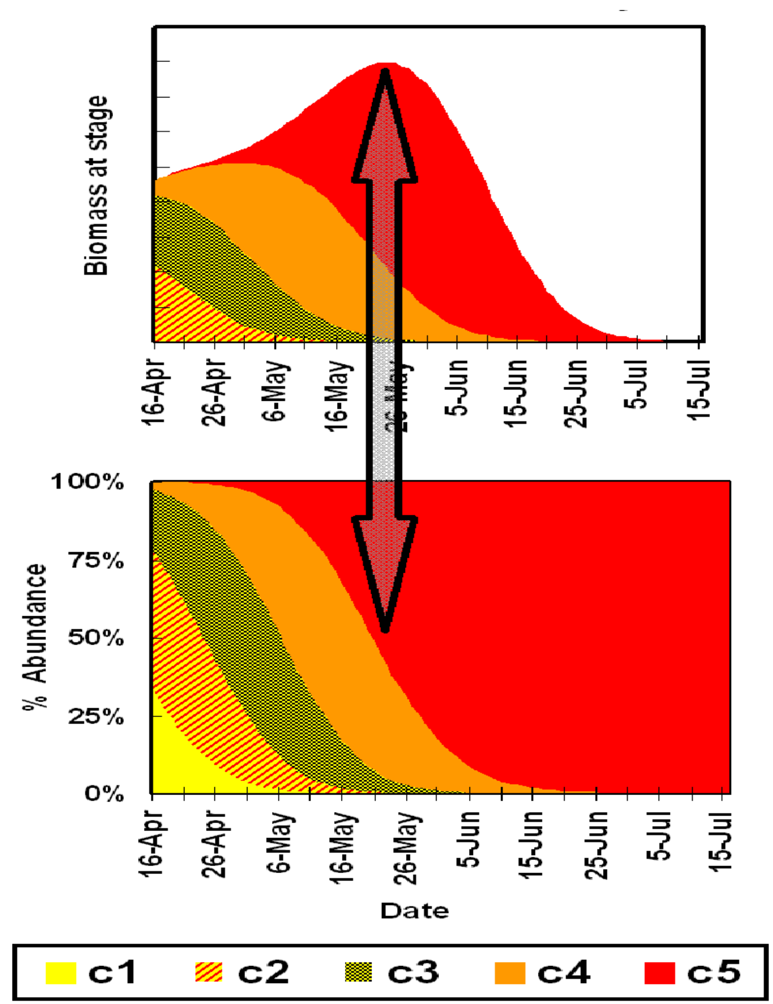
Indexing seasonal timing:

Amount-based



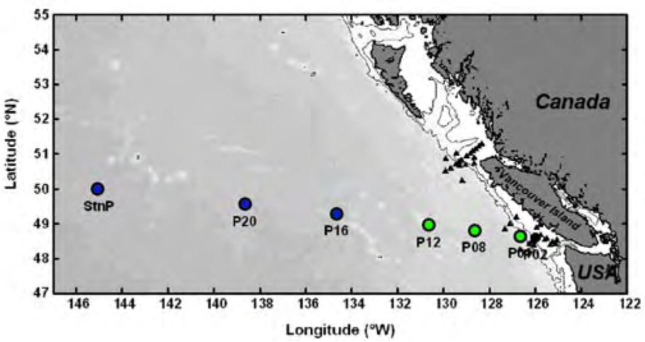


Age-structure-based



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

Line P net tows

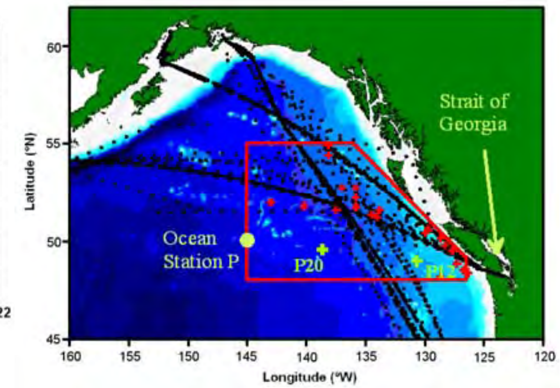


Spatial average abundance converted to biomass

Log scale 'Anomalies' as annual ave. of deviations from monthly climatology

Phenology from stage composition

CPR lines



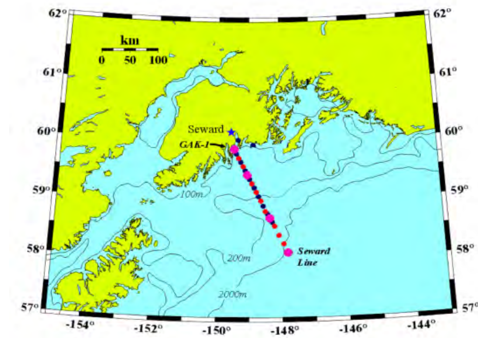
Spatial average abundance converted to biomass

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

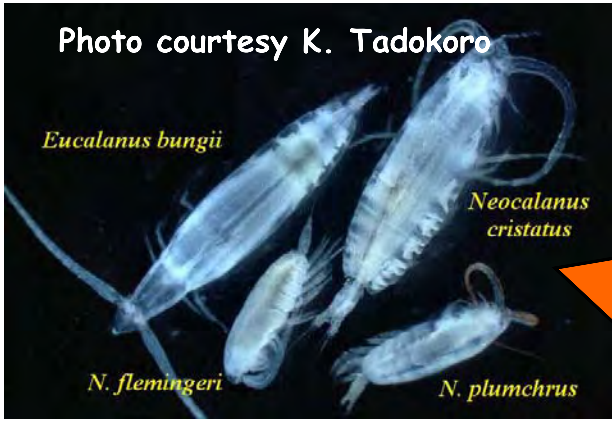
Log scale anomalies = log (May of year/May climatology)

Phenology from stage composition in May

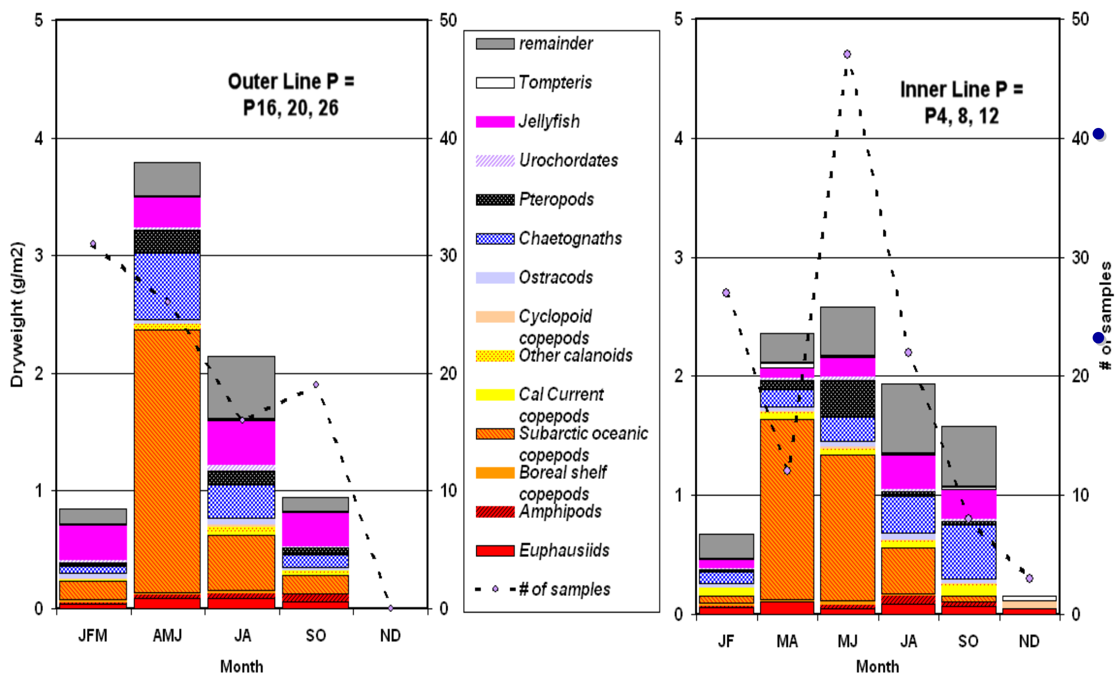
Preview of Results

1. 'Average seasonal cycle' of the zooplankton community along Line P,
2. Recent and important Alaska Gyre physical variability (temperature & circulation)
3. Changes of *Neocalanus* seasonal timing & cohort width
4. Anomalies of amount & composition

Results #1: Line P average seasonal cycle (no big surprises)

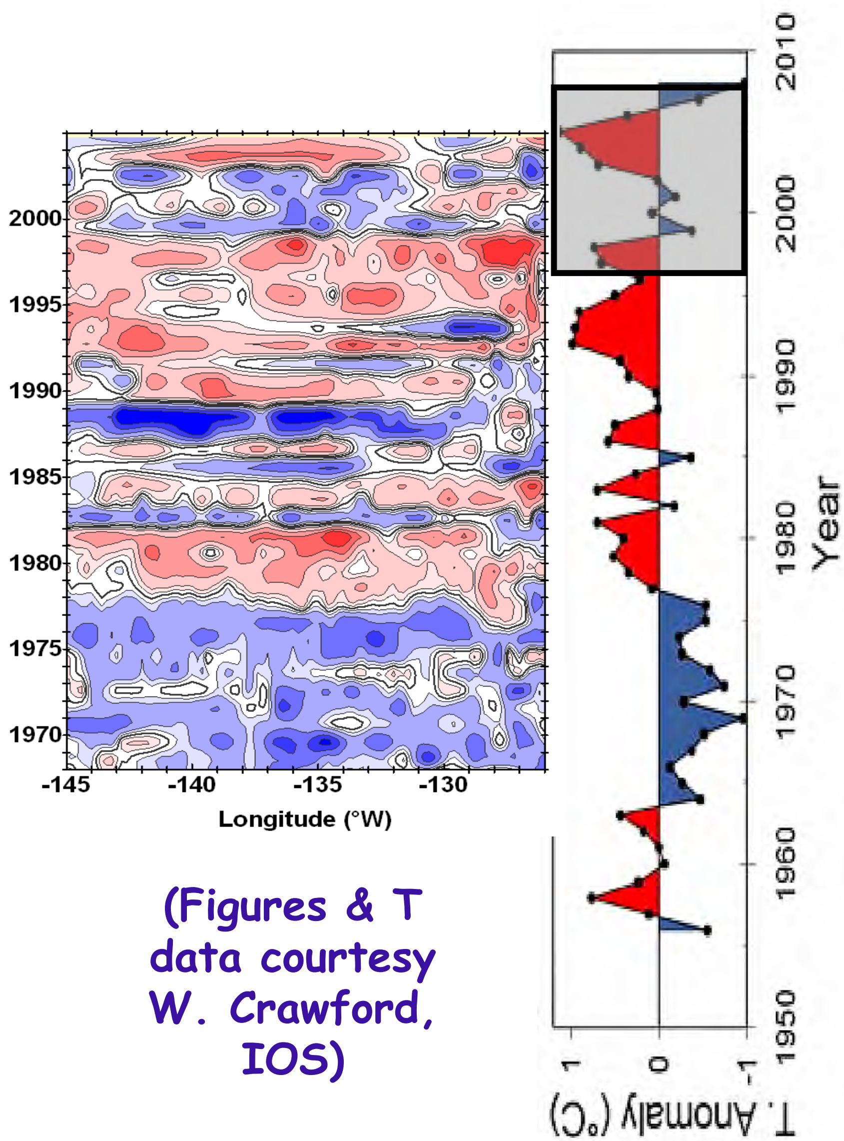


- Same taxa as along BC continental shelf, but altered dominance:
- 'Subarctic oceanic copepods' (*Neocalanus, Eucalanus, Metridia*) are >50% of total in spring and early summer
- Chaetognaths, gelatinous predators, and pteropods are next in rank
- Euphausiids, salps, other copepod groups all less dominant than on/near continental shelf



Result #2: Two modes of recent physical variability

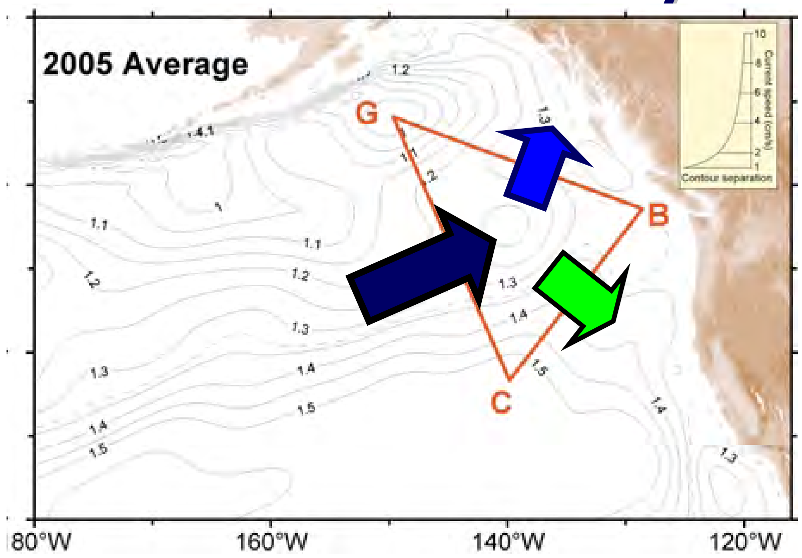
Interannual temperature variability along Line P

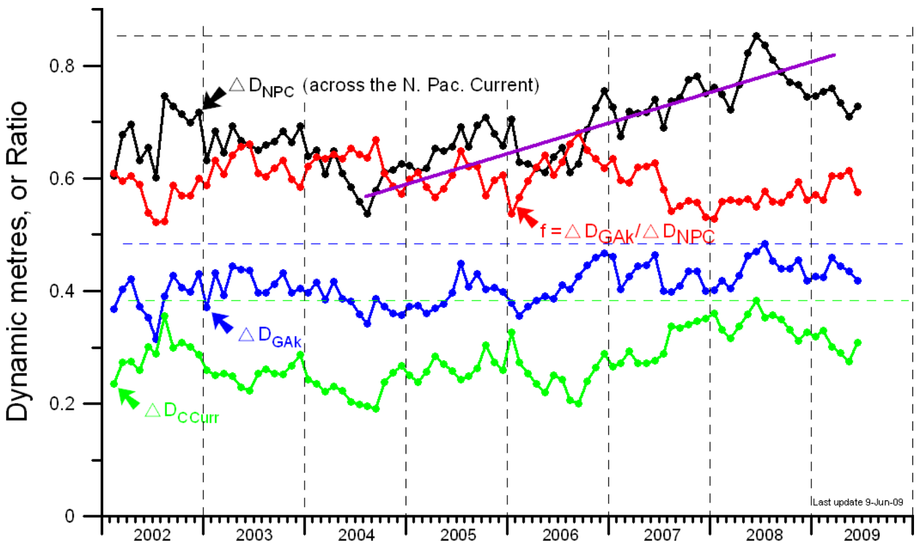


(Figures & T data courtesy W. Crawford, IOS)

- 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



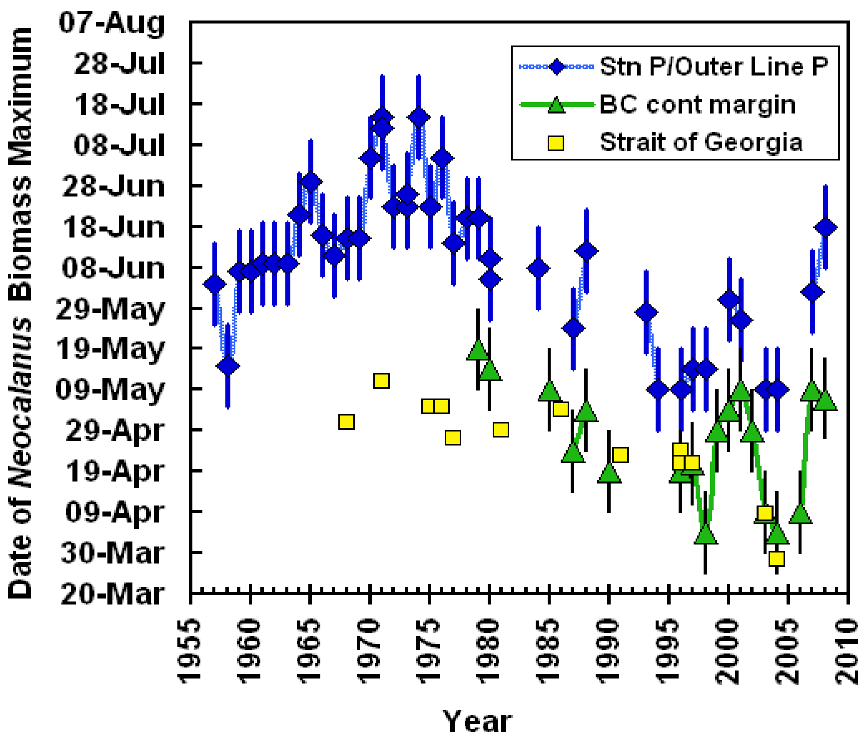


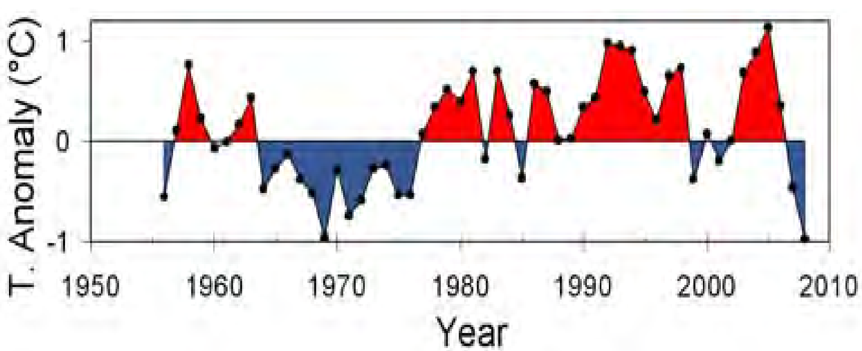
- ARGO drifters now provide frequent and dense T, S, and ρ profiles in the Alaska Gyre
- Useful products: dynamic topography maps (top) and time series (bottom) of transport:
  - North Pacific Current (black)
  - Alaska Current (blue)
  - California Current (green)
- Between 2004 and 2008, the North 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 #3: Variability of zooplankton seasonal timing (later when colder)

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





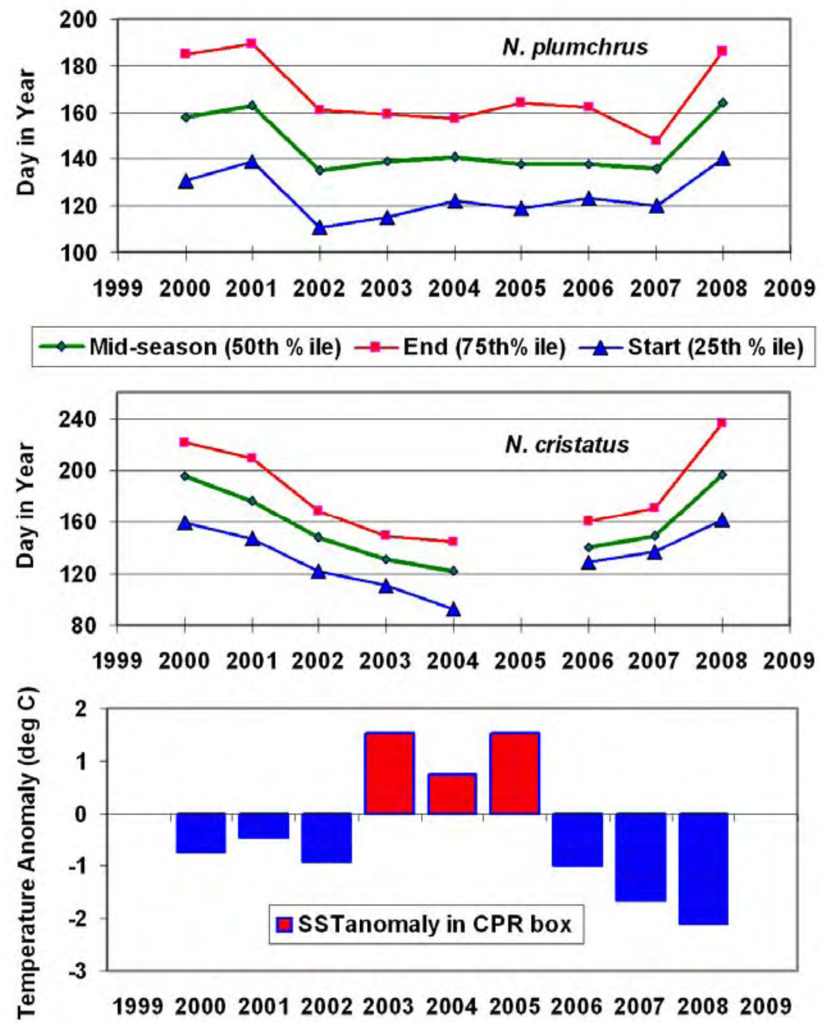
- Our newer Line P data can be used to extend the Stn P time series, and compared to our coastal time series.
- Timing of *N. plumchrus* covaries with upper ocean temperature (early when/where warm, late when/where cold)
- Locations offset in mean timing, but interranual variability is strongly coherent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

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

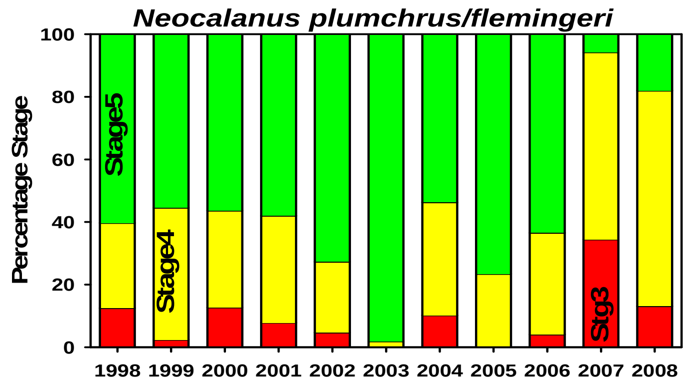
Both *N. plumchrus* and *N. cristatus* had late timing in most cool years, early timing in all warm years.

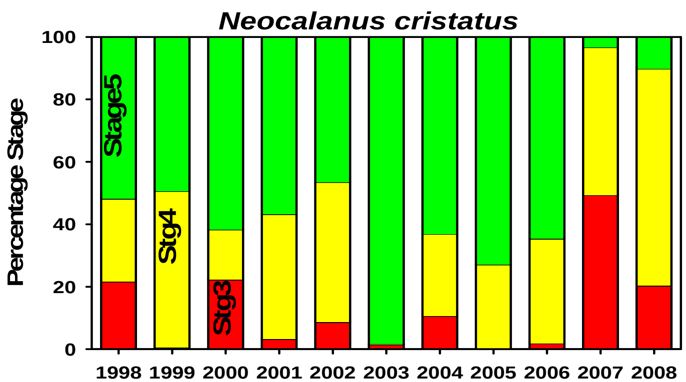
Larger range of timing variation for cristatus (~80d) than for plumchrus (~50d)?

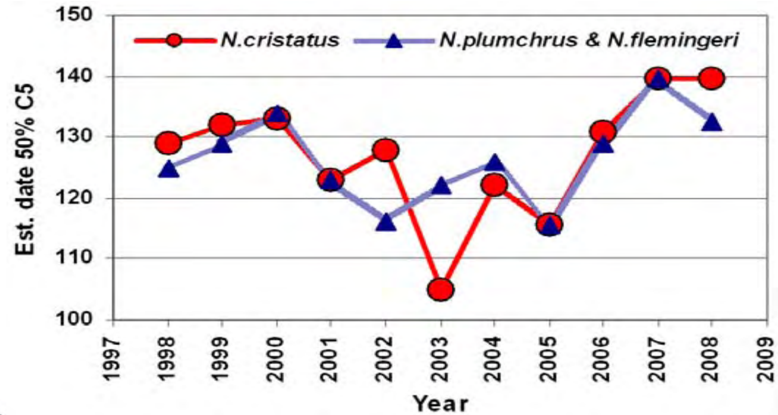
Peak duration also tends to be shorter when timing is early (Batten & Mackas, in press). Increased risk of trophic mismatch??

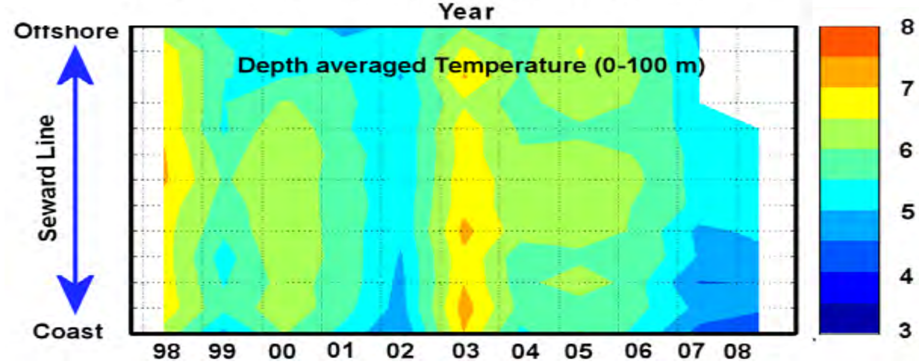


Phenology estimates for Seward Line
Offset (and noisier) but again later when colder





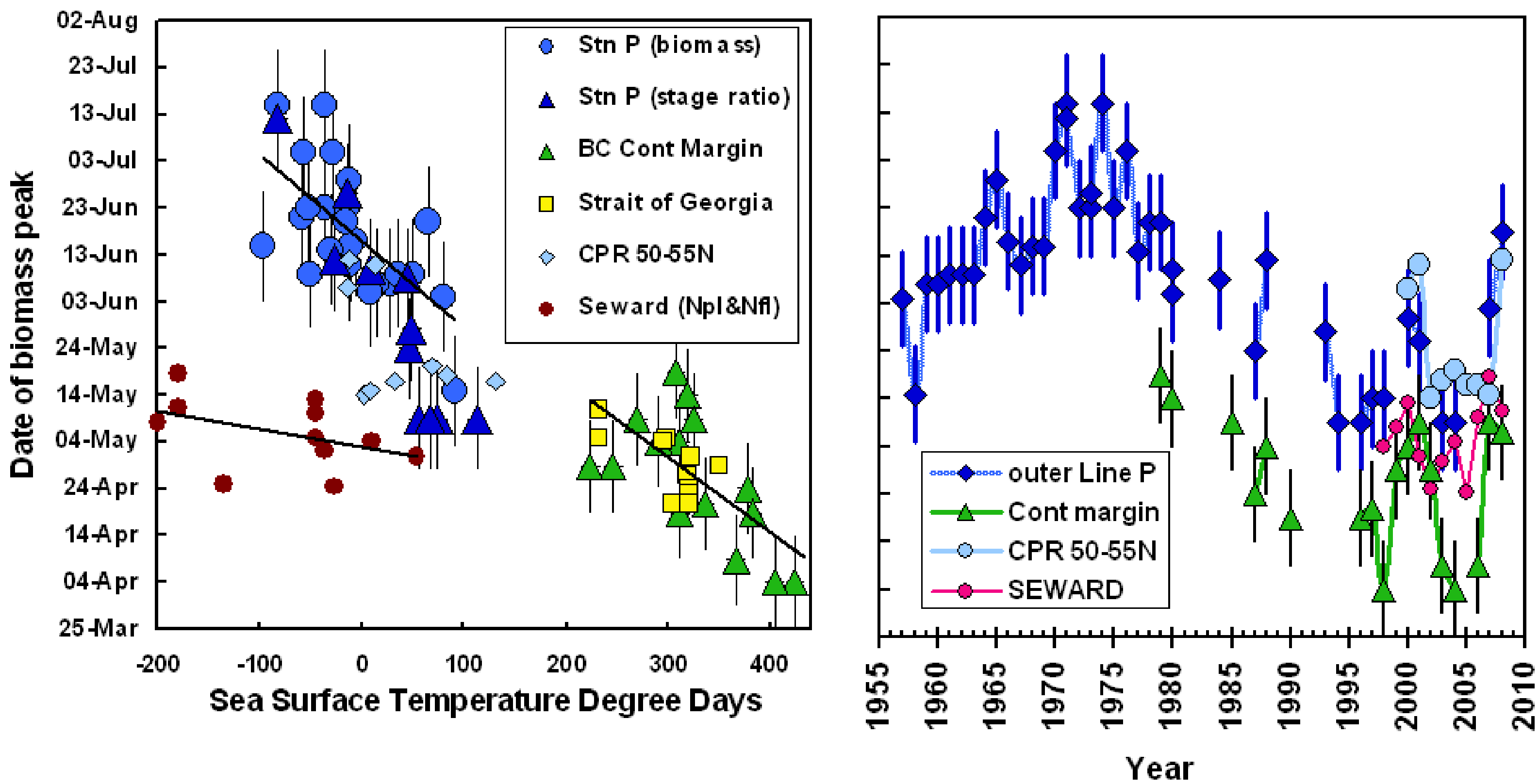




Left: Time series of May stage composition for *N. plumchrus* and *N. cristatus*

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:

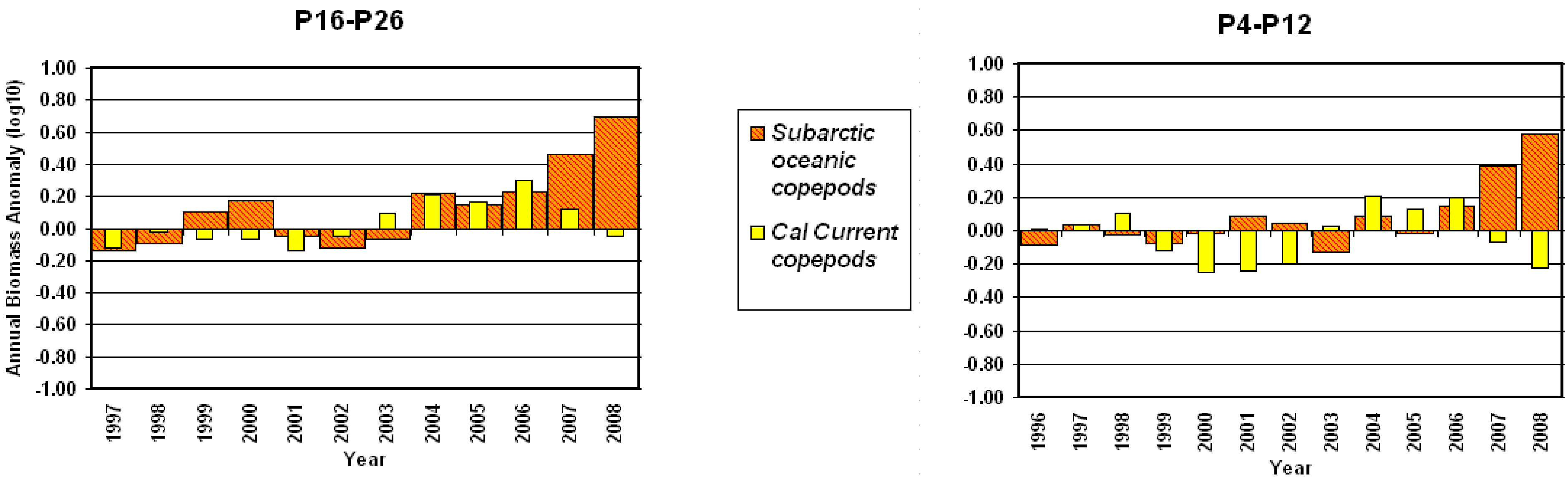


- Phenology has moderate-strong temporal synchrony (basin scale agreement about early/warm vs late/cold years)
- Shared timing-temperature regression except for Seward Line
- Possible causes: Stratification by fresh water? More *N. flemingeri*? Inadequate characterization of temperature in source region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

Results #4: Anomalies of zooplankton amount

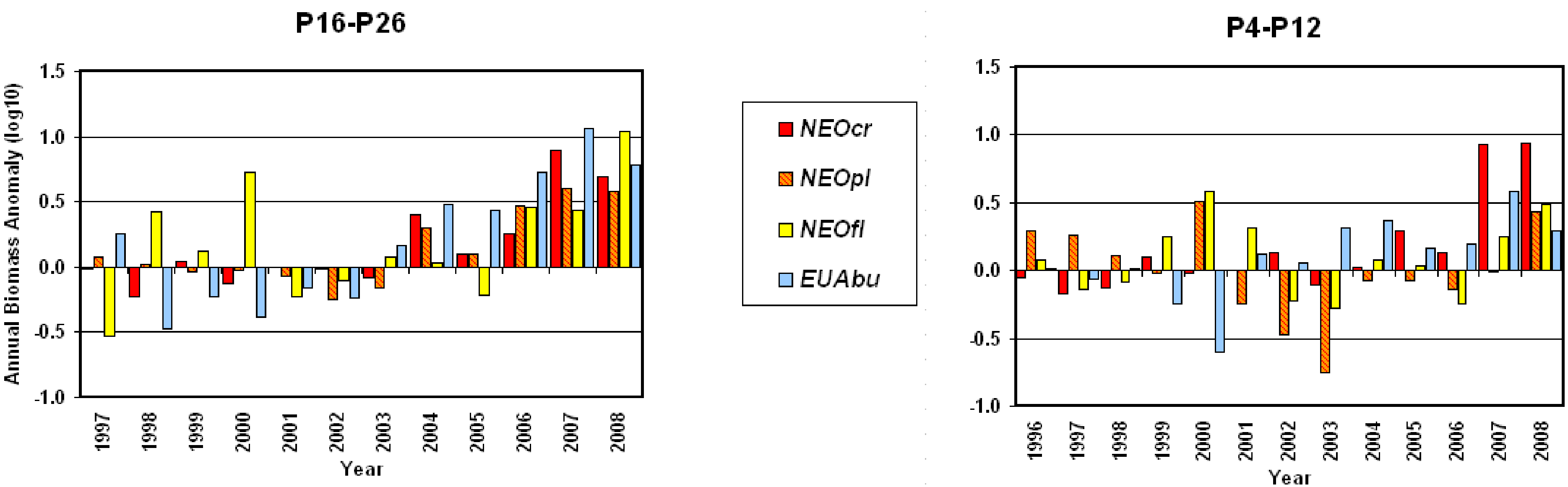
(focus today on *Neocalanus* spp.)

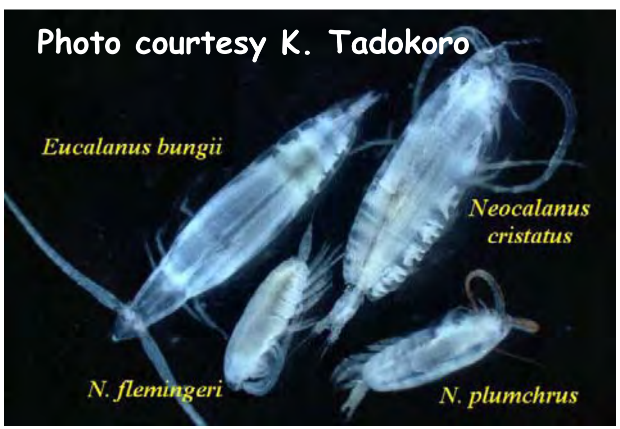
Annual anomalies of amount and community composition along Line P



- 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)

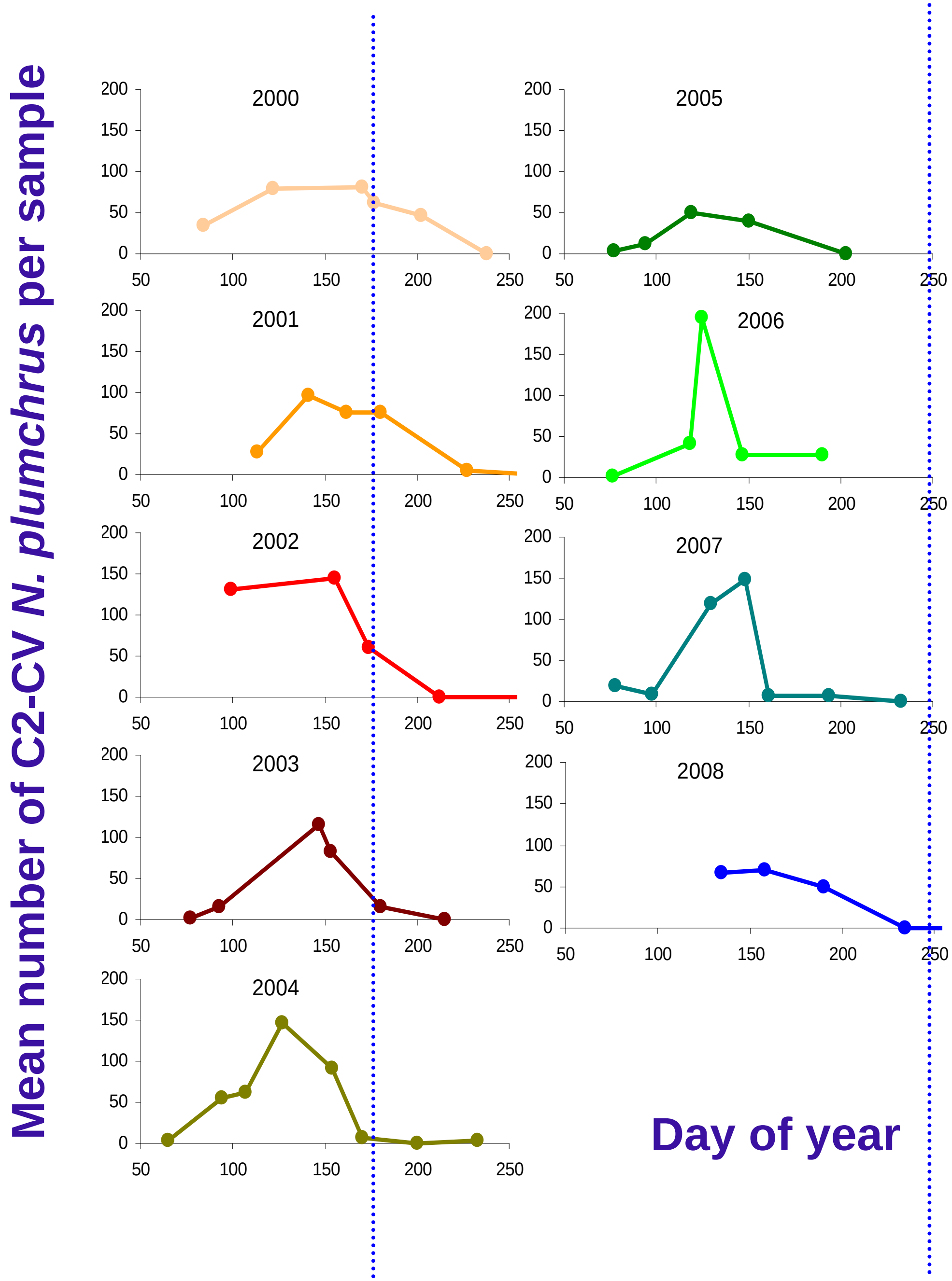
Annual anomalies of amount and community composition along Line P

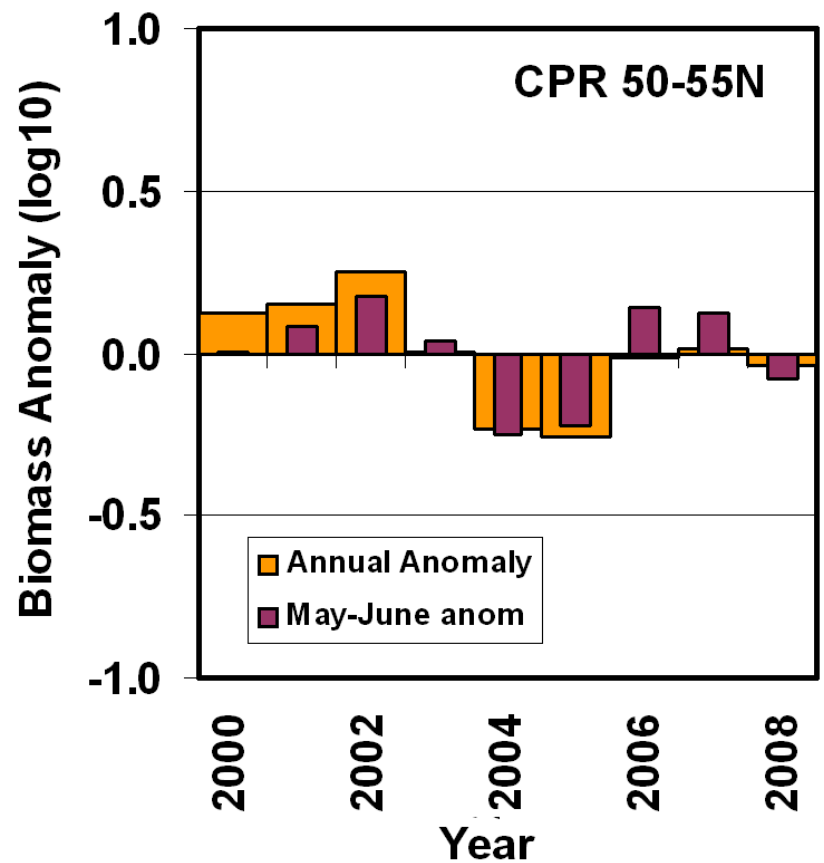




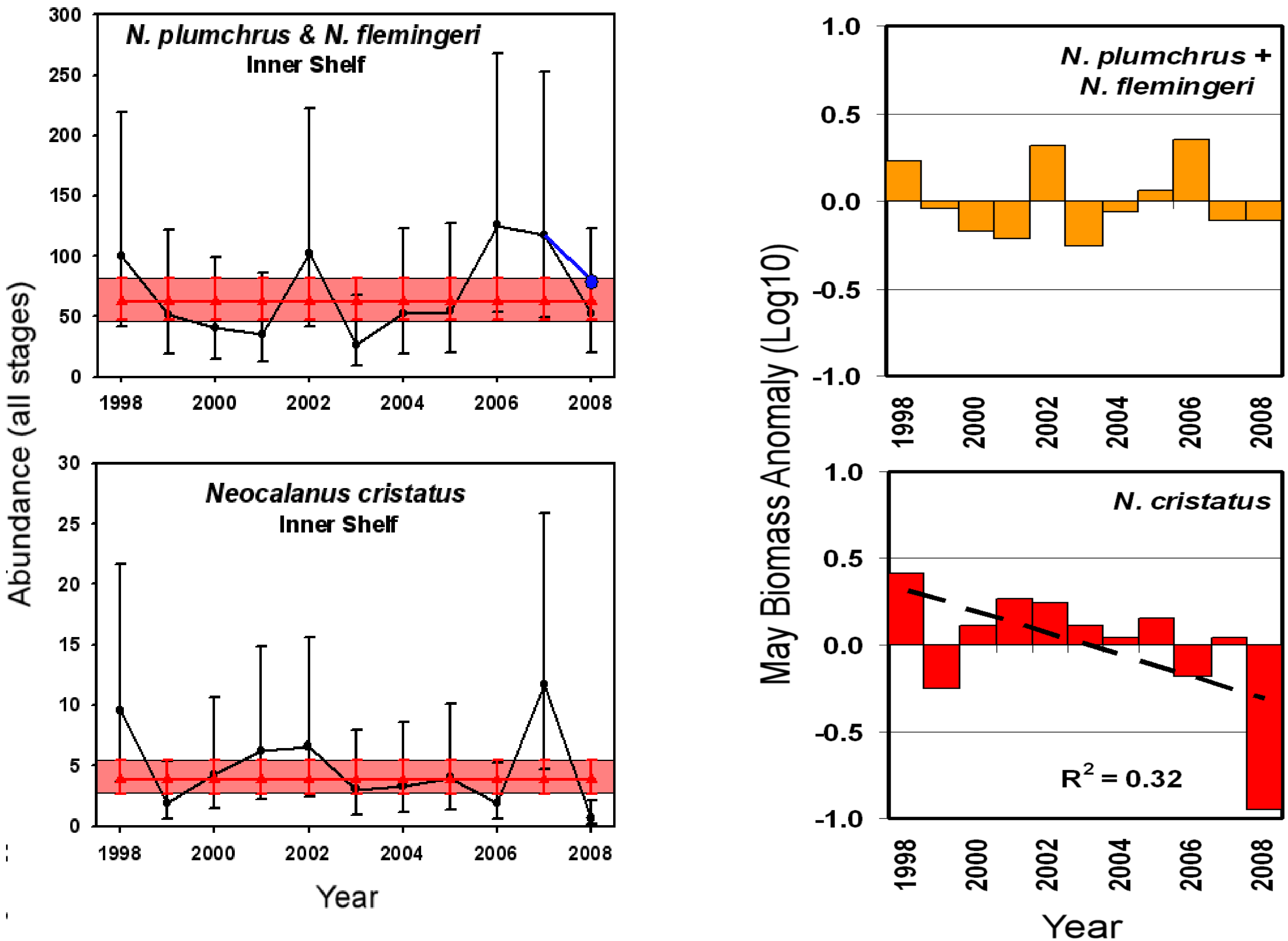
- Within the ‘subarctic oceanic’ copepod group, the species showing the strongest recent increase have been the two largest: *Neocalanus cristatus* and *Eucalanus bungii*
- These also have a longer growing season, and enter diapause later than either *N. flemingeri* or *N. plumchrus*

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

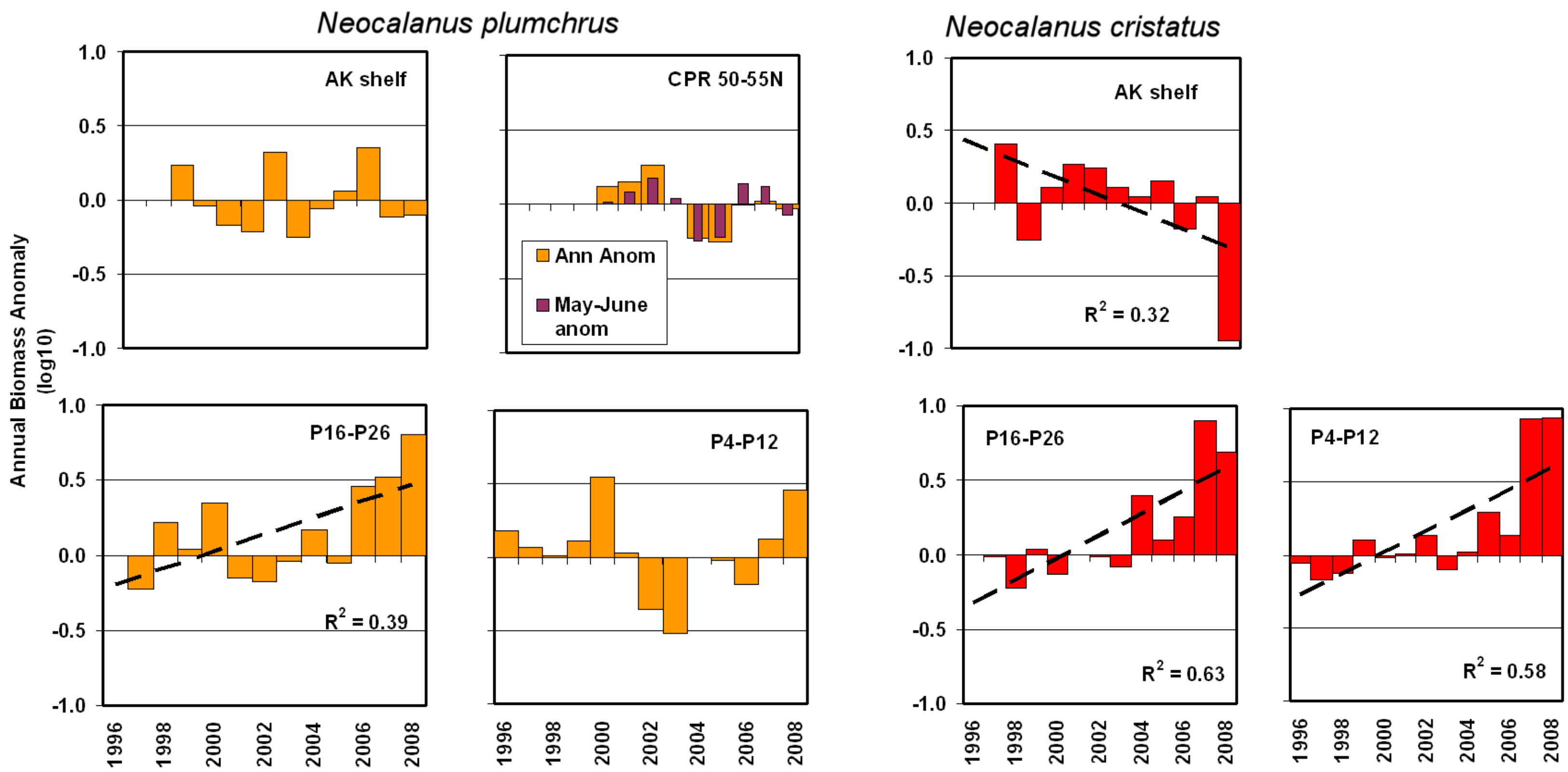




Interannual variability of Seward Line #s (left) & biomass (right)
But here, colder years often have below average May biomass



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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