Comparisons among North Pacific Zooplankton Time Series

David Mackas

IOS

Fisheries and Oceans Canada | Pêches et Océans Canada

Sonia Batten

CONTINUOUS PLANKTON RECORDER SURVEY

SAHFOS

Marc Trudel

Pacific Biological Station

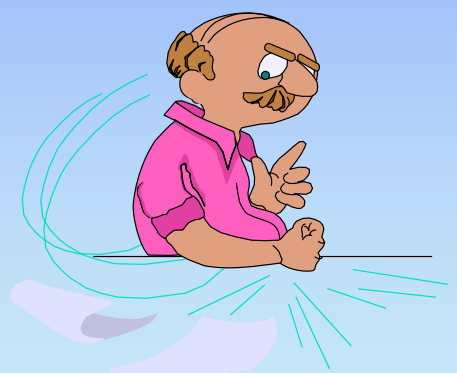
Fisheries and Oceans Canada | Pêches et Océans Canada

Table of Contents:

- Why long time series?
  Why zooplankton?
- Variables & methods
- North Pacific zooplankton time series:

  (Where & when)
- Results from “within-data-set” analyses
- Results from “comparisons”

Why do we need long time series?



“The world today just isn’t like it used to be!!”

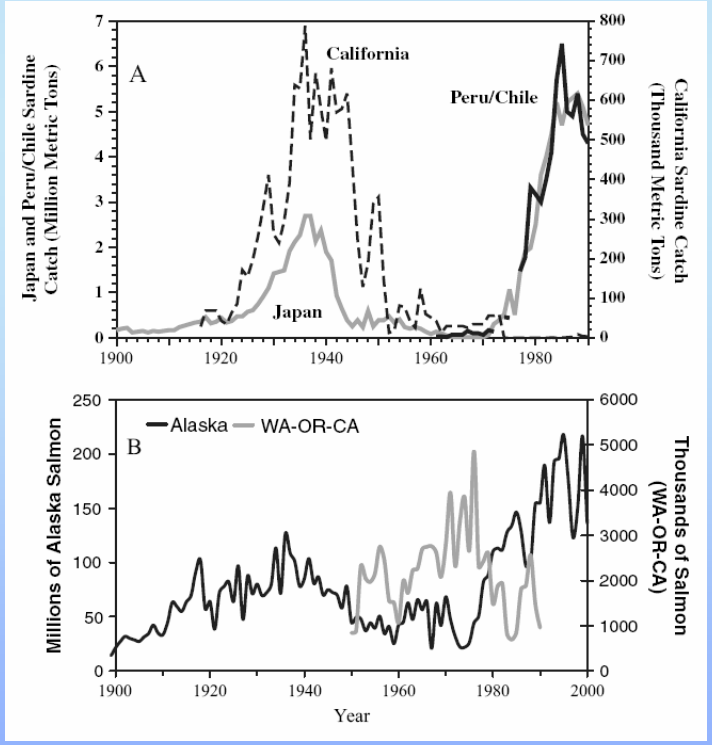
- **Former trademark opinion of ‘grumpy old men’**
- **Now a fair summary of scientific knowledge about environmental constancy**
- **Need an ongoing history of observations to characterize past changes and recognize future changes (sorry, but *models* can’t do it alone)**

Why zooplankton?

- **Key link between “physics” and “fish”**
- **Zooplankton sampling methods are (relatively) :**
    - **simple,**
    - **intercomparable,**
    - **fishery-independent**
- **Time scale of population response (~1 year or less) gives very good tracking of climate forcing at interannual-decadal time scales**
- **Long zooplankton time series are now available from several different parts of the ocean**
- **Recent improvements in tools for data analysis & data exchange/management**

Why compare zooplankton time series?

- Can improve statistics of “short” autocorrelated time series by ensemble averaging
- Apply/compare the same suite of analysis methods
- Explore type & sequence of alternative “regimes”
- Look for evidence of global “synchrony” of zooplankton regime changes (do zooplankton resemble fish)??



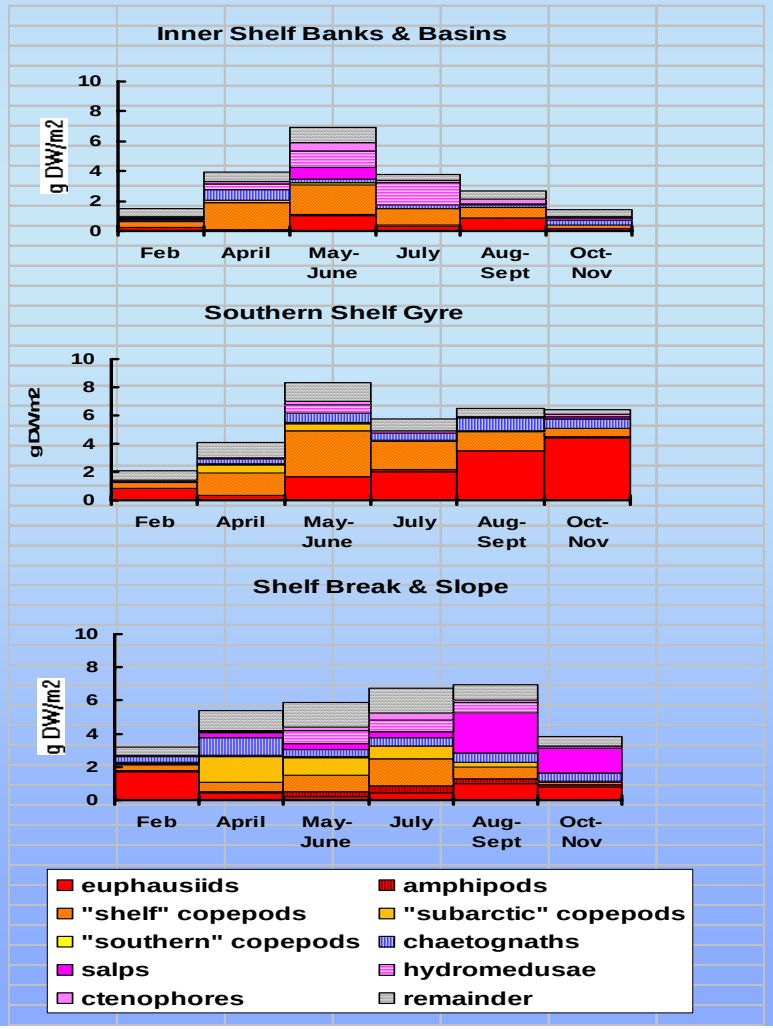
Modes of zooplankton variability

- **“How much?” = total biomass or biovolume**
- **“What kinds?” = partitioning of total based on species composition (allows broader interpretation of cause & consequence)**
- **“Timing window?” = seasonal phenology, (allows interpretation of match-mismatch) usually indexed as date of annual peak**
- **“Fat & happy?” = body size & condition indices**

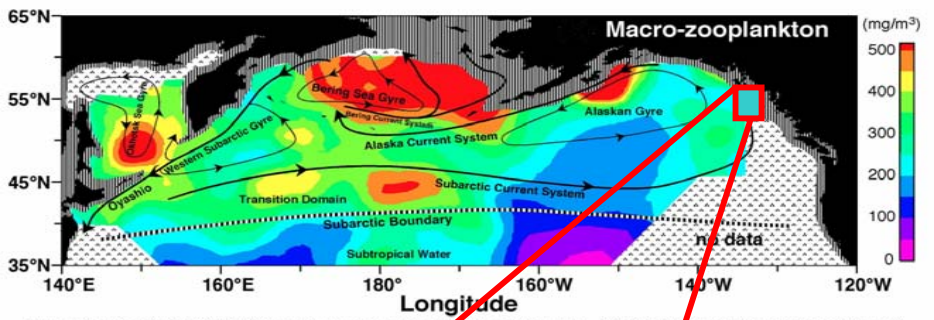
Interannual zooplankton variability is BIG!

But to see it clearly, need to isolate it from three other 'big' components of variance

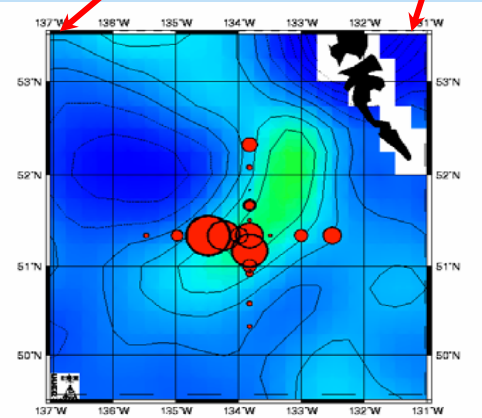
(1) Local seasonal cycle



(2) Persistent 'regional' patchiness



Mean horizontal distribution of summer zooplankton biomass, 1956-199[illegible] (courtesy K. Tadokoro)

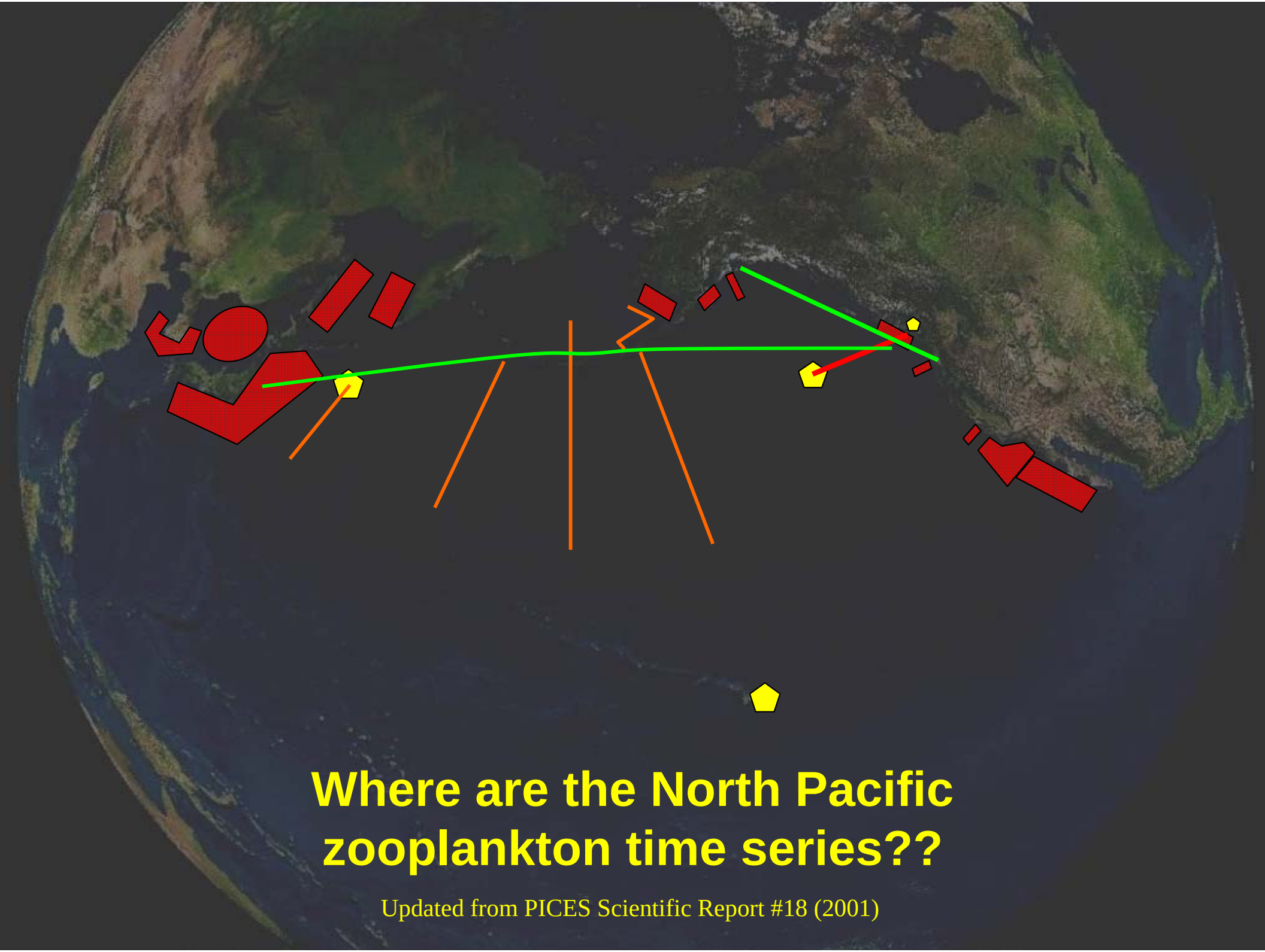


Pseudocalanus mimus abundance (red circles) near a coastal-origin eddy (mapped sea surface height). Mackas & Galbraith 2002.

(3) Transient 'small-scale' patchiness

Zooplankton sampling & analysis strategy: Separate components of total variance at different spatial and temporal scales

Source & scale of variability	*How dealt with*
Unresolved small-scale patchiness plus sampling error	**Minimized by averaging of 'replicates' at all levels**
Persistent mesoscale spatial structure	**Stratification into 'regions' based on proximity, statistical similarity, &/or oceanographic processes**
Annual seasonal cycle ('Climatology')	**Block averaging within seasons and across years.**
Interannual variability	**WHAT'S LEFT: Anomalies from climatology averaged within years and regions.**



Where are the North Pacific zooplankton time series??

Updated from PICES Scientific Report #18 (2001)

Many/most share the following traits:

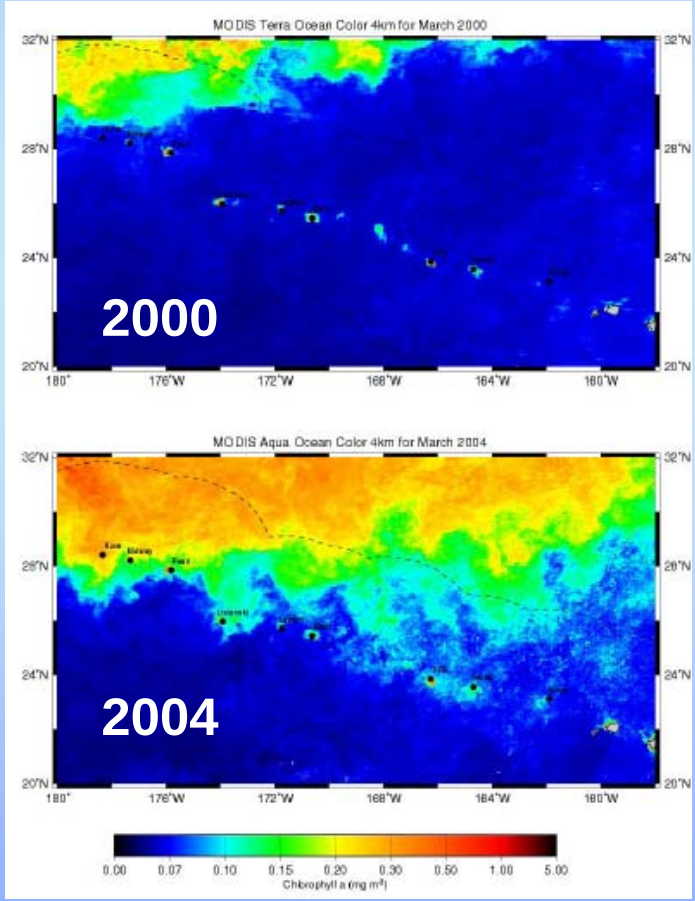
- Densest coverage along continental margins
- Sampling gear fairly basic ( OK!!)
- Best for mesozooplankton (~1mm - 1 cm)

  (smaller, larger, & fragile taxa under-sampled).
- Sampling interval monthly-to-annual (varies with distance to home port)

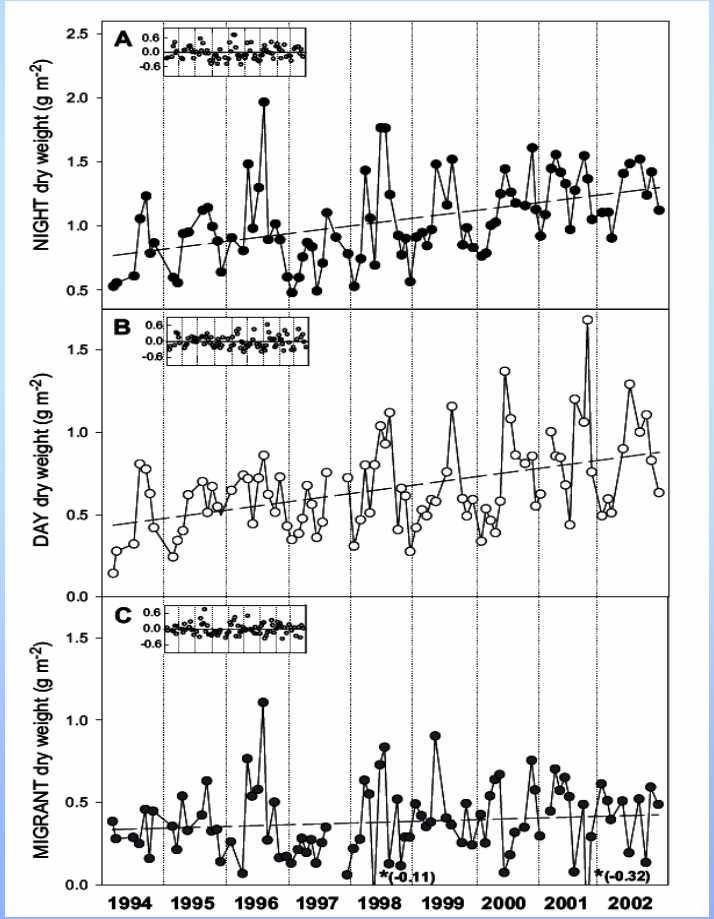
Historical review by Region: 1. Subtropical Oceanic

Oceanic Subtropical N. Pacific

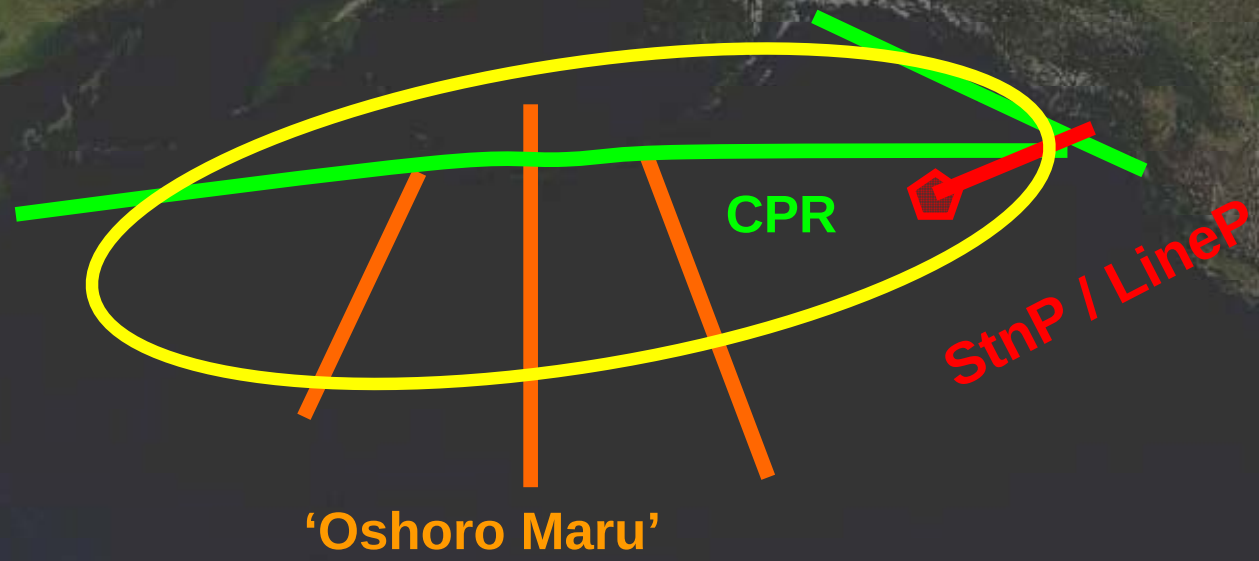
- **Huge and mostly under-sampled area, originally thought "stable & monotonous"**
- **Satellite & *in situ* time series are altering this view:**



Shifting chlorophyll gradients: (Polovina et al. 2006)

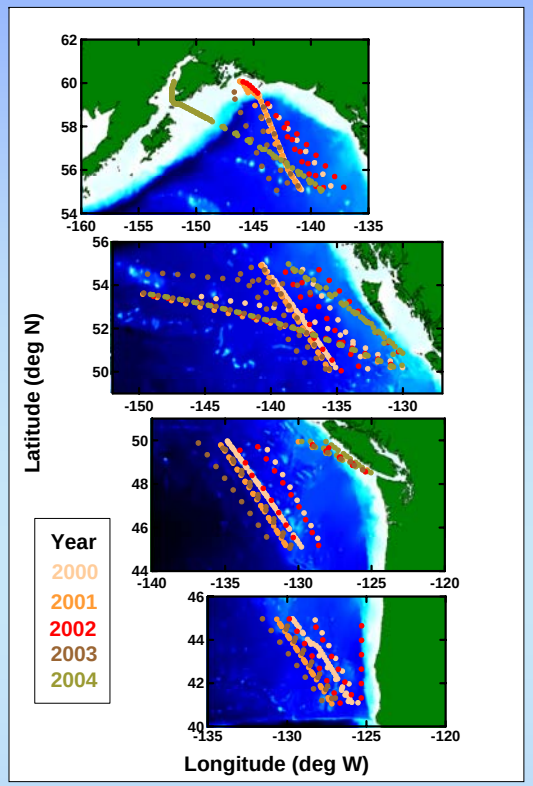


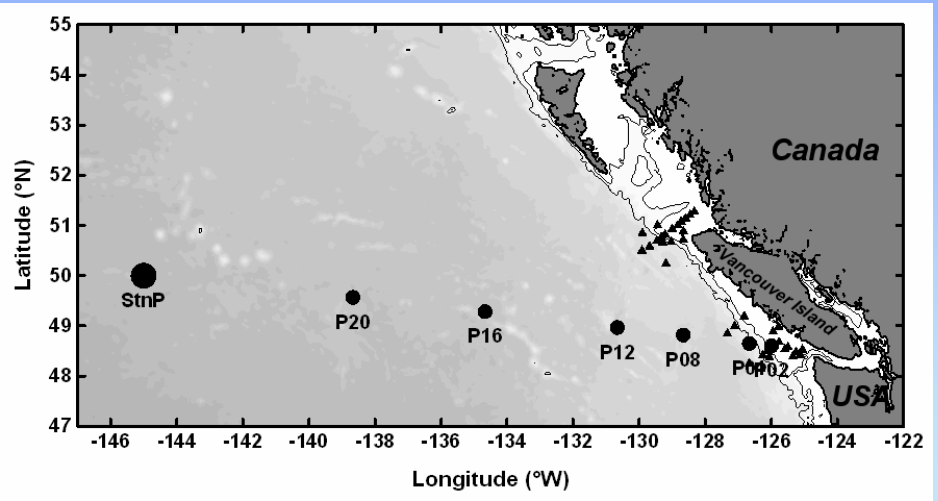
HOTS zooplankton: (Sheridan & Landry 2004)



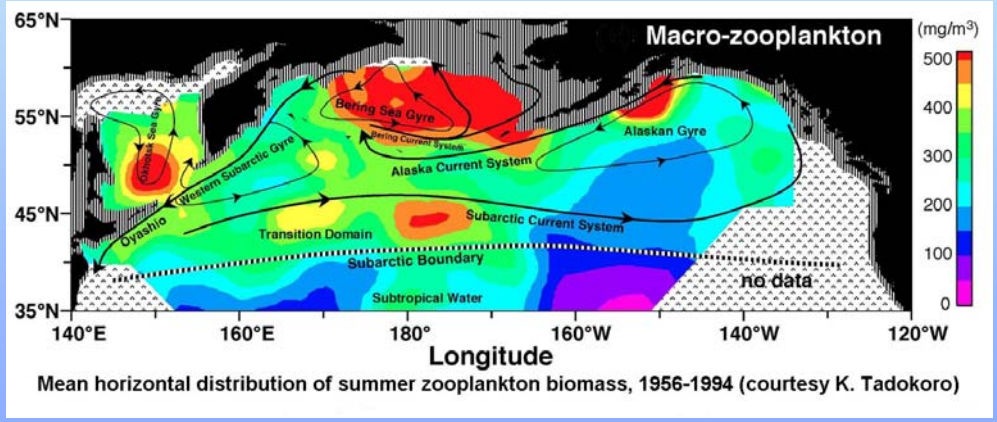
Historical review by Region: 2. Subarctic Oceanic

Oceanic Subarctic Pacific



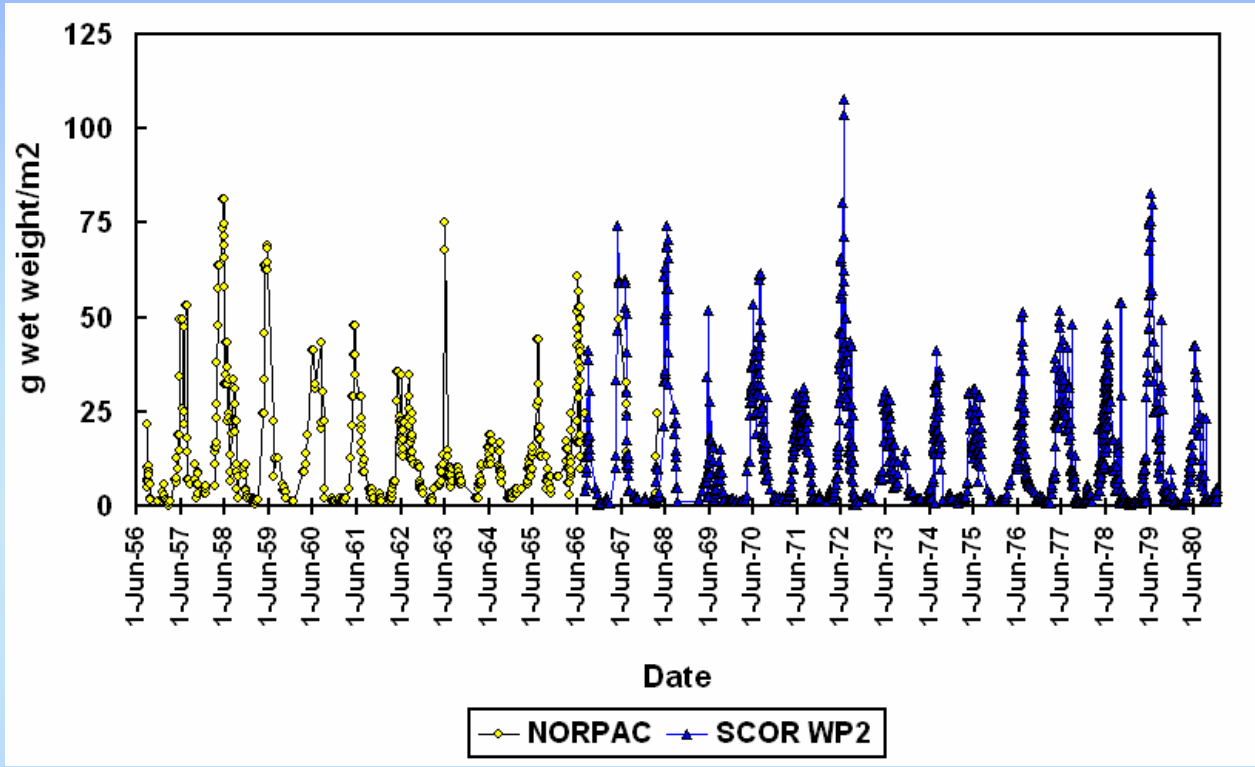


- 50+ years of observations
- Multiple programs in various years and locations



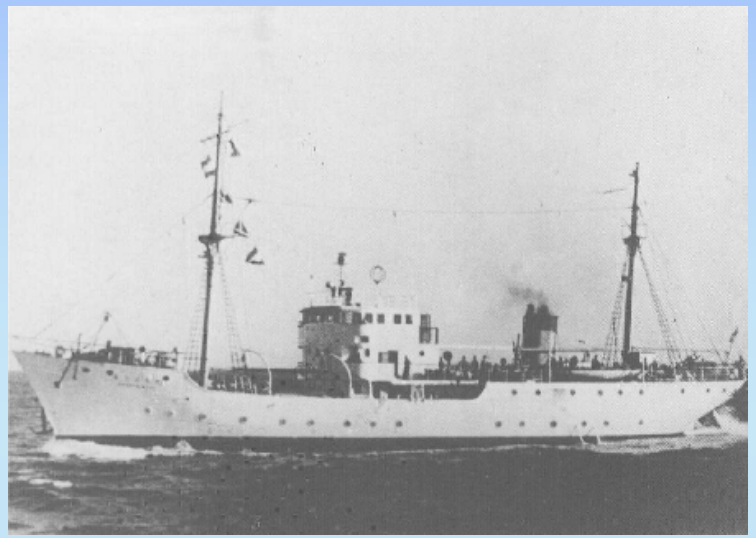
Mean horizontal distribution of summer zooplankton biomass, 1956-1994 (courtesy K. Tadokoro)

Station P (50N 145W) "Weathership" time series



- Oldest detailed 'open-ocean' time series in the Pacific
- Very frequent vertical net tows (0-150m) from 1956-1981, processed for wet weight biomass + (rarely) for taxonomy
- Electronic archive (Waddell & McKinnell 1995), sampling gear re-calibrated during GLOBEC Canada (McKinnell & Mackas 2003)
- <u>No</u> remaining sample archive (discarded due to H&S concerns)

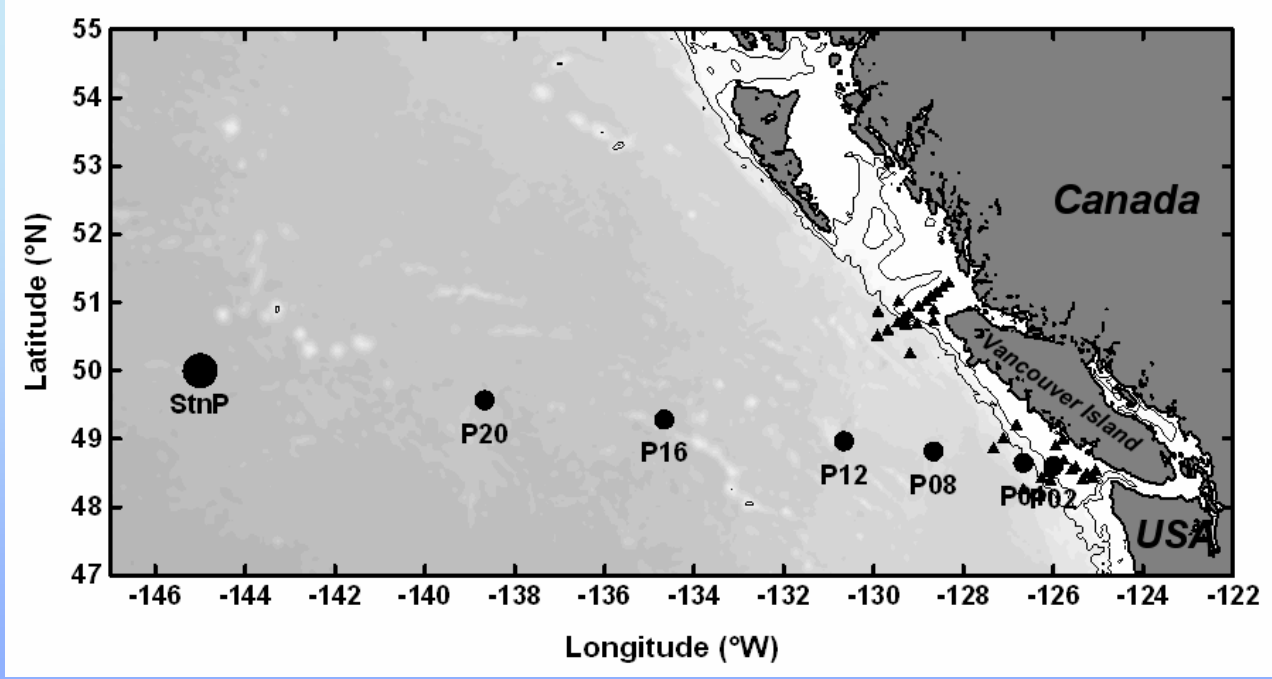
"*Oshoro Maru*" time series: 1953-present



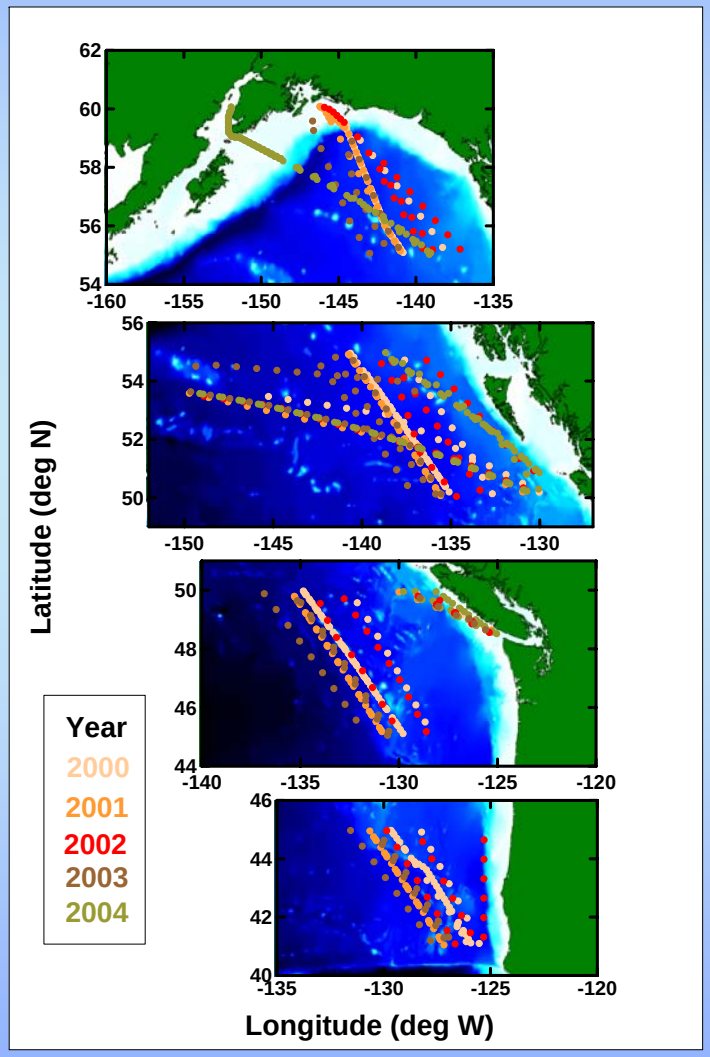
- Annual summer cruises by Hokkaido University training ships (Oshoro Maru & Hokusei Maru)

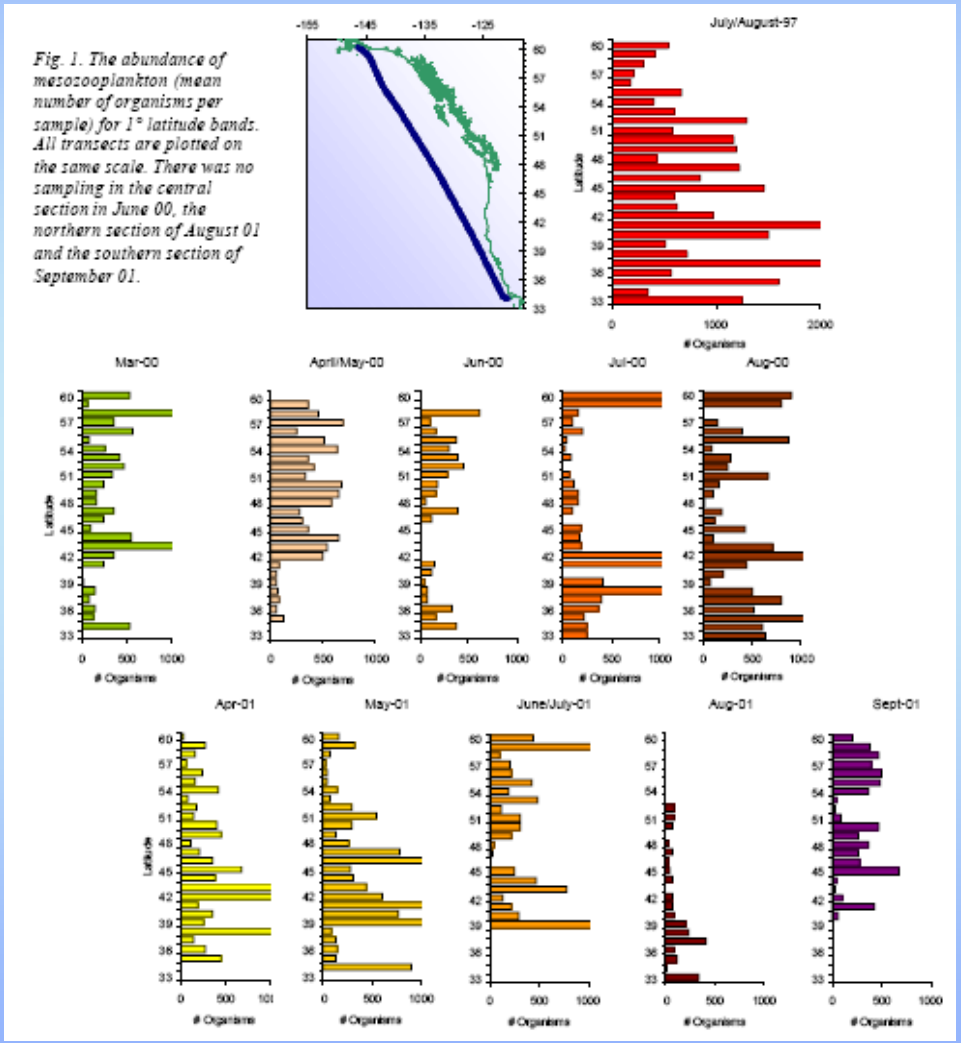
Post 1981: Stn P/LineP

- **Intensive field programs at Stn P in:**
  - **1984, 1987 & 1988 (SUPER);**
  - **1996 & 1997 (CJGOFS);**
  - **2002 (SERIES)**
- **Annual Line P cruises (usually 3/year)**



1997 and since 2000:
North Pacific CPR Survey (S. Batten)





(data in SAHFORS archive, some at IOS)

What have we learned from the Subarctic Pacific zooplankton data?

- Community composition
- Life history strategies
- Variability of total biomass
- Variability of individual size
- Variability of life cycle timing

Subarctic Pacific zooplankton biomass is dominated by large copepods with strongly seasonal life cycles

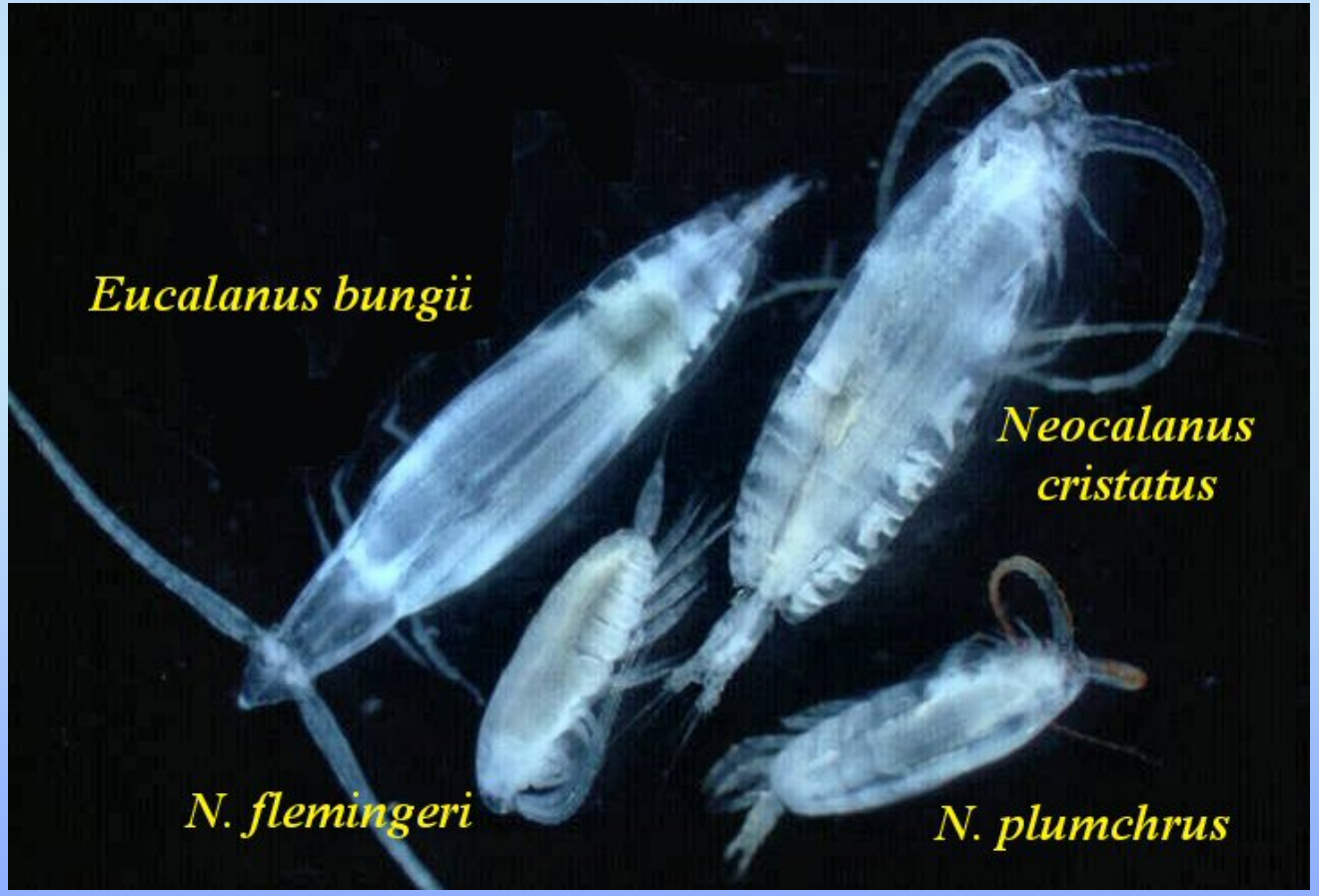
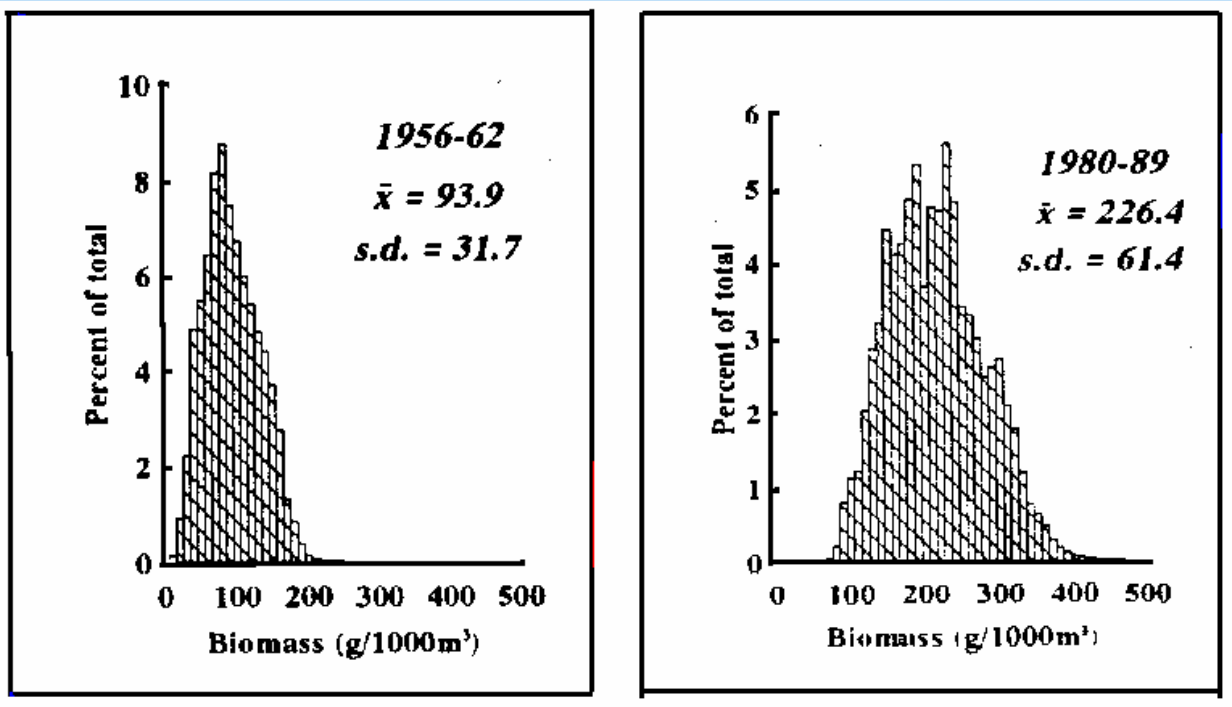


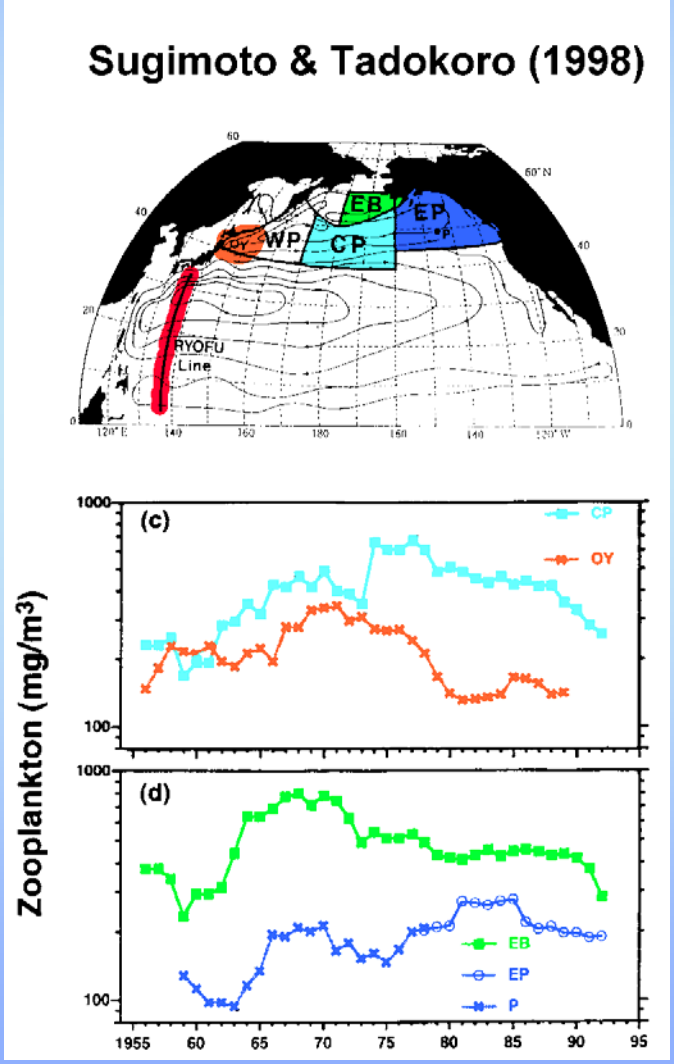
Photo courtesy K. Tadokoro

'Regime Shifts' meet Zooplankton:

Station P, Oshoro Maru, & NorPac data show 2-3x interdecadal variability of total zooplankton biomass

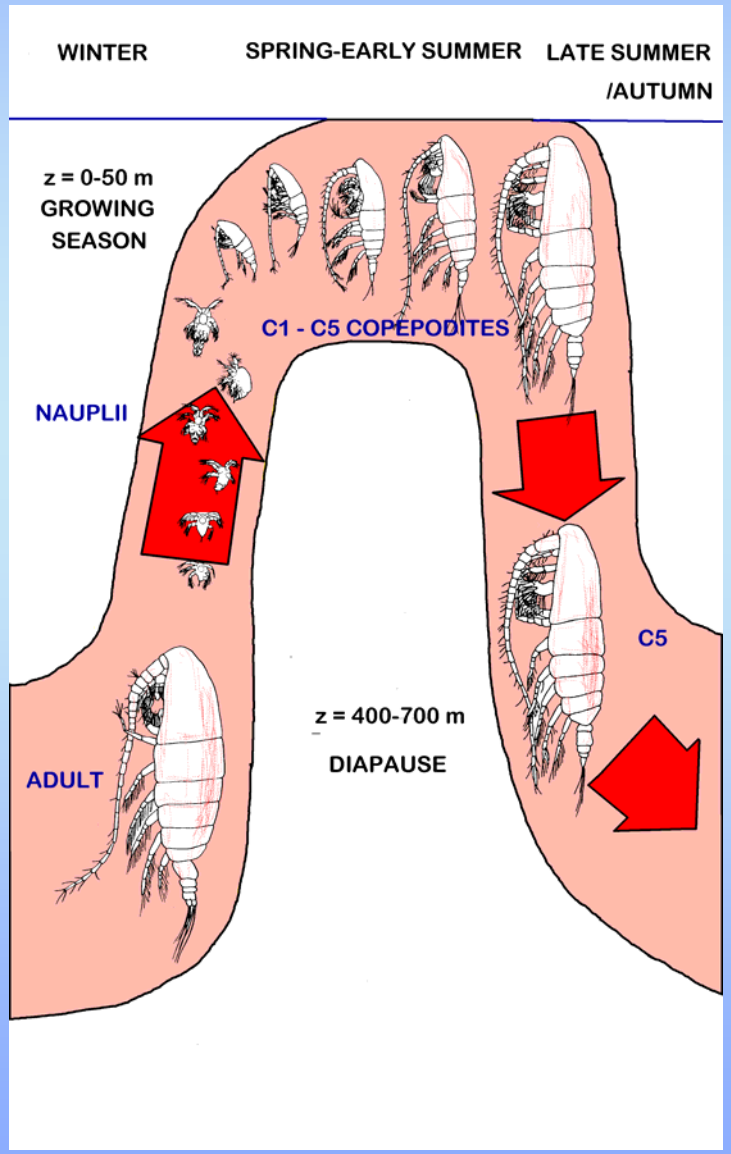


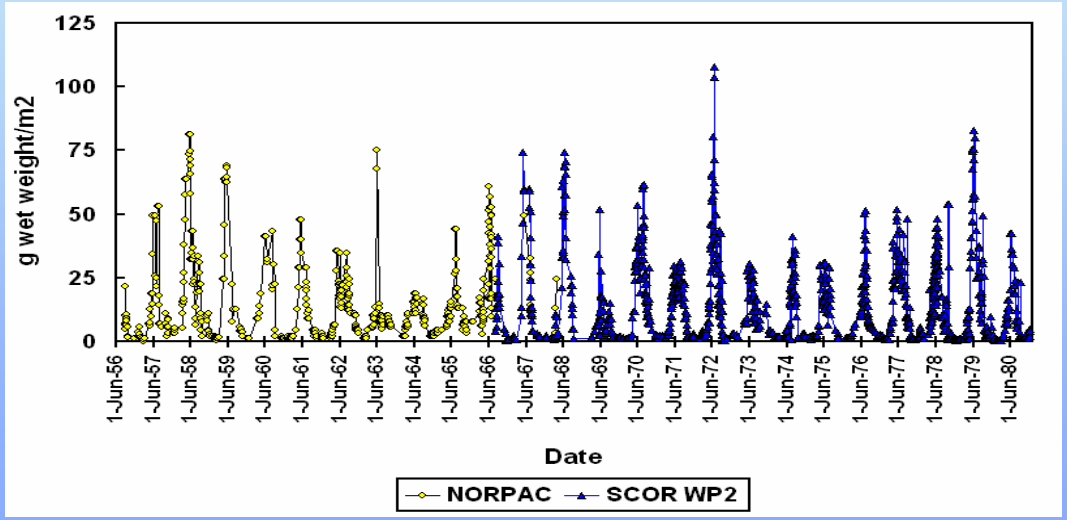
Alaska Gyre - Brodeur & Ware (1992)



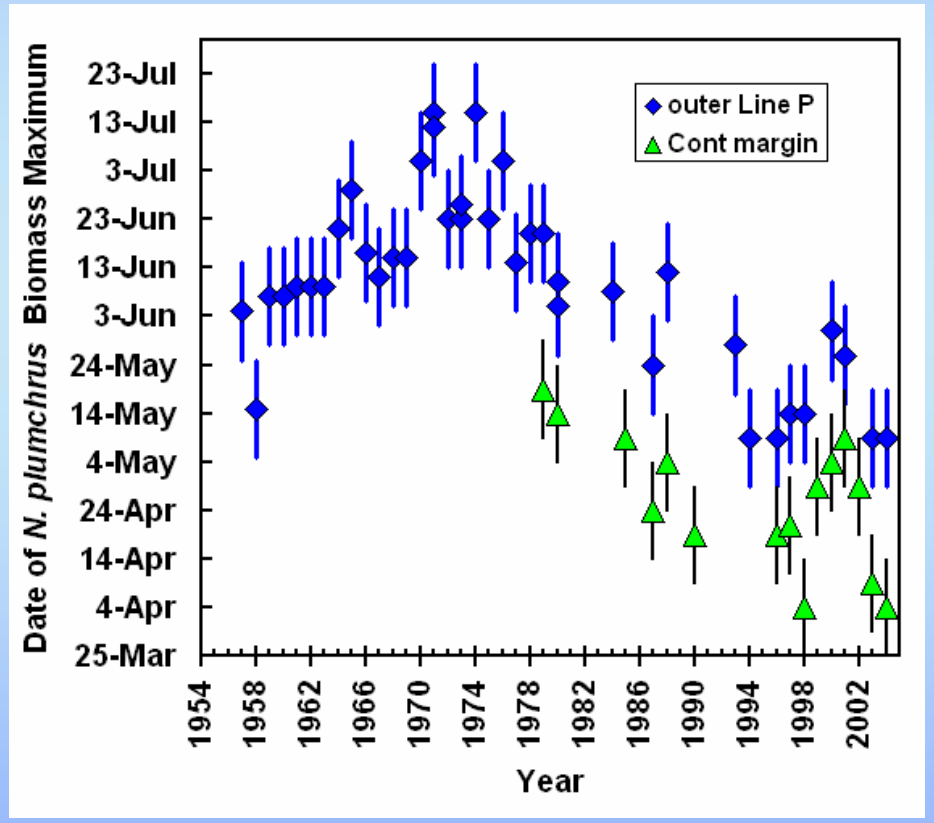
Strong biomass seasonality is related to Neocalanus life cycle

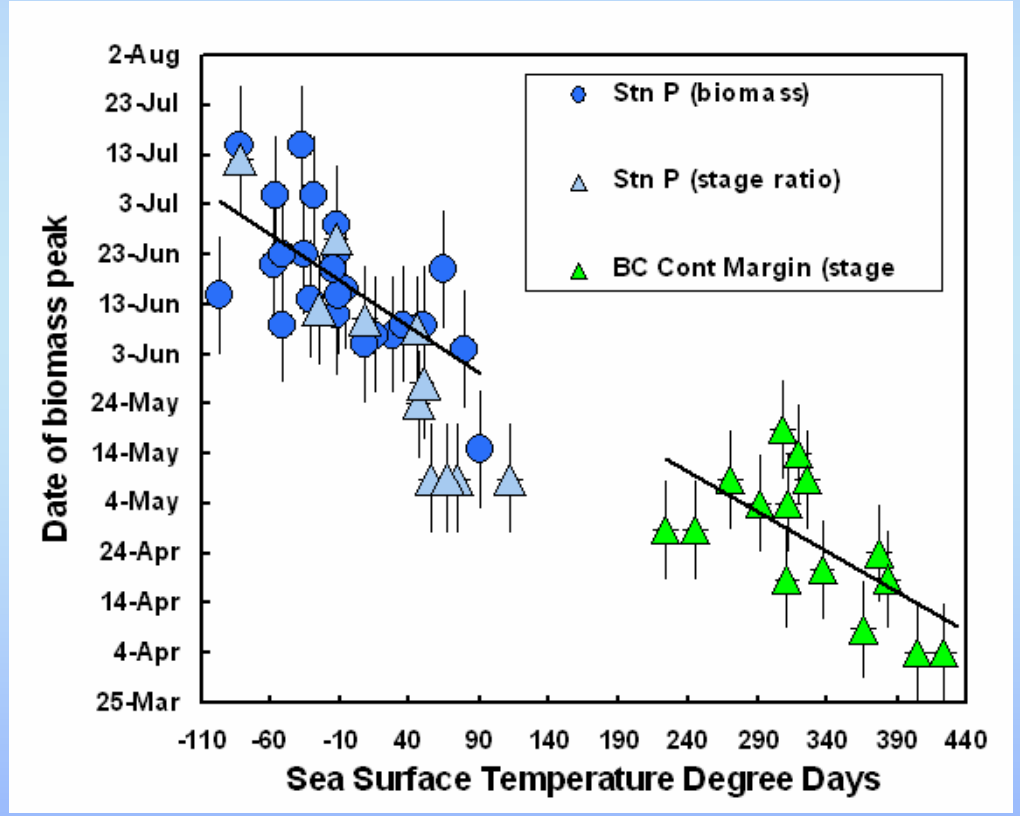
- **"Dormant" much of year at >400m**
- **Onset of dormancy is locally ~synchronous but varies with latitude and proximity to coast**
- **Also large interannual timing fluctuations: complicates sampling but also a BIG ecological signal**



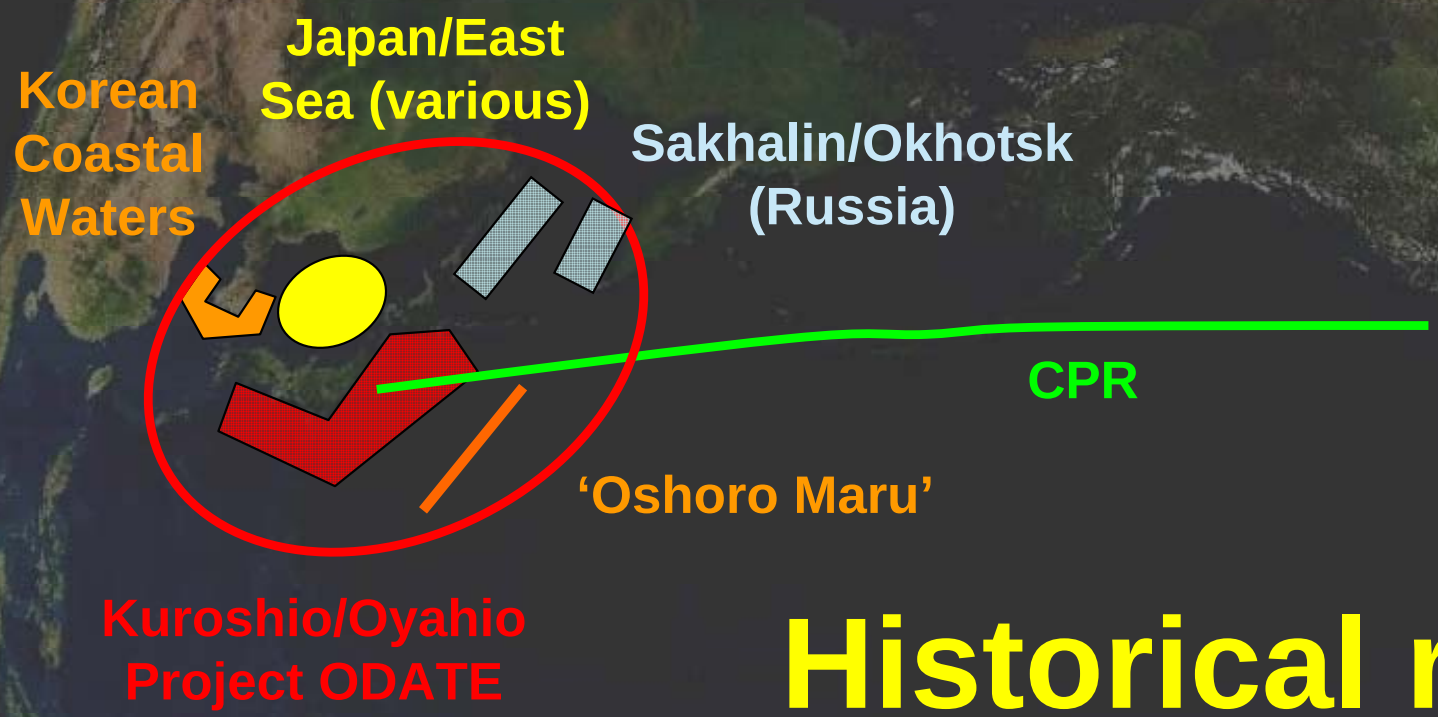


Neocalanus timing variability is correlated with mixed layer temperature during the spring growing season





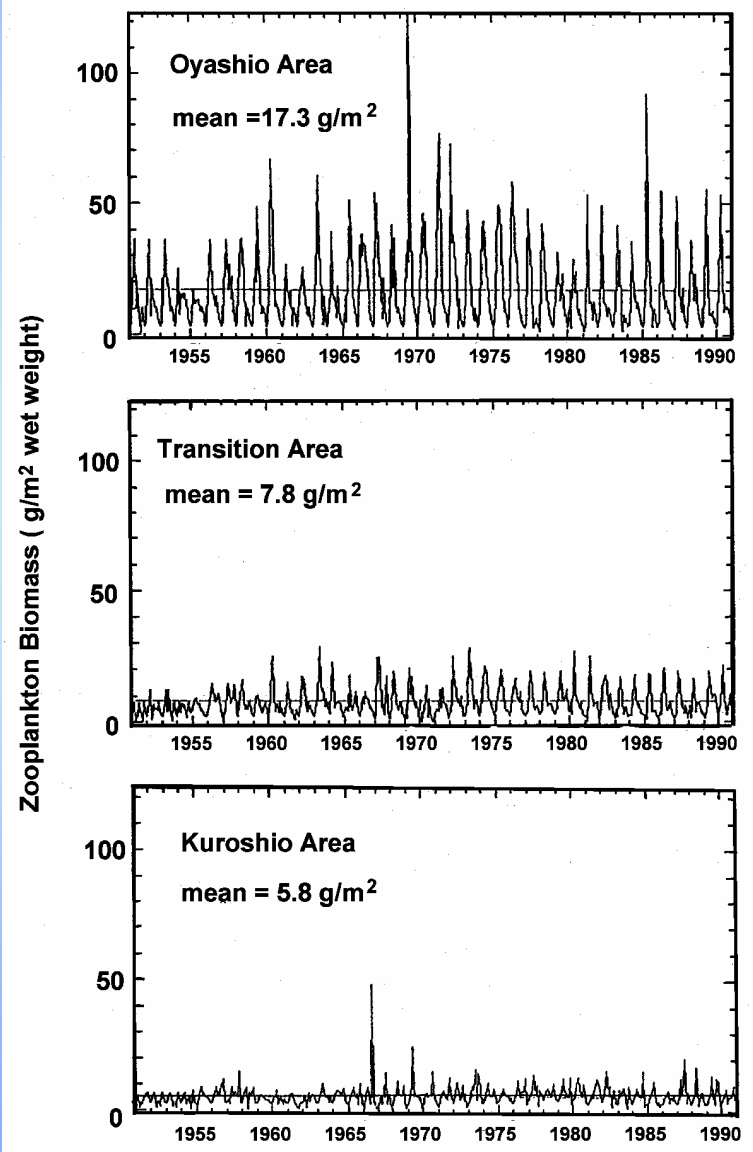
$\Delta T = 6°C$



Historical review by Region: 3. Western Margin

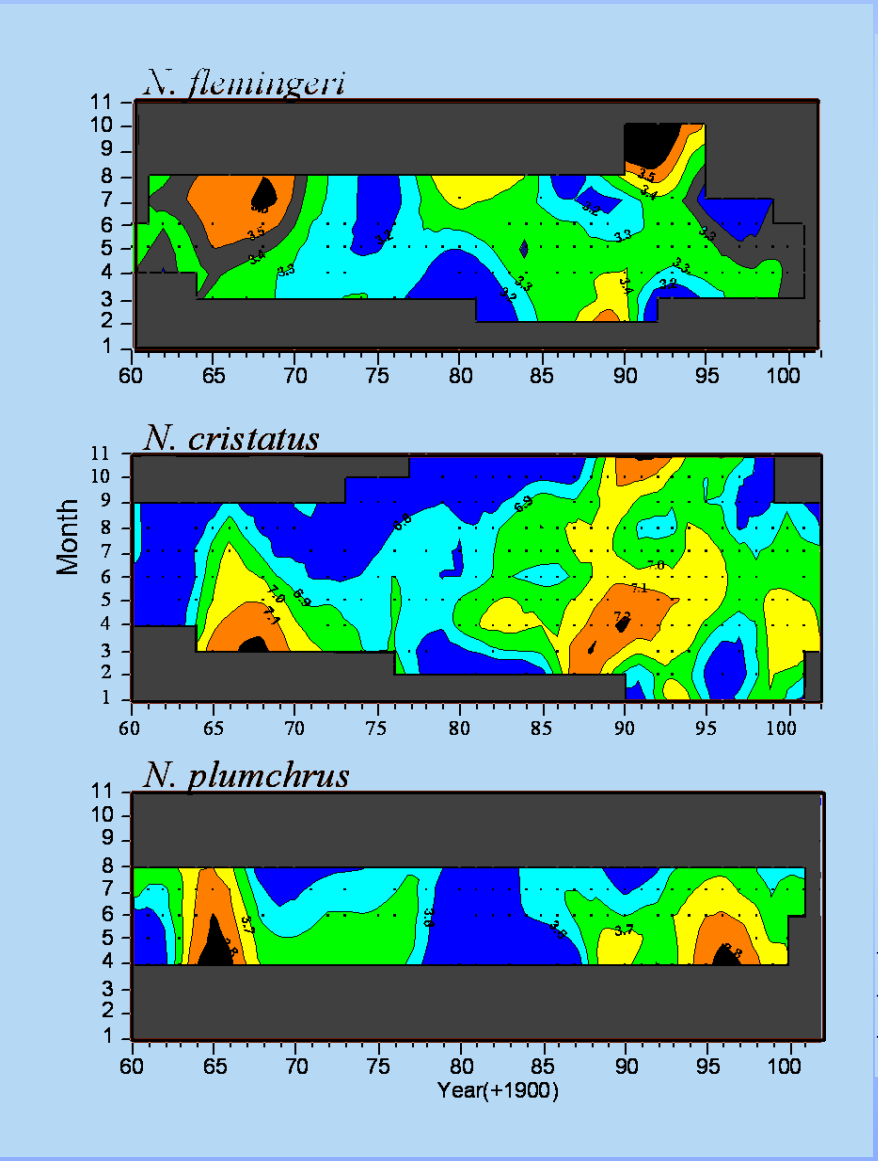
Project ODATE: zooplankton in the Oyashio, Transition & Kuroshio areas

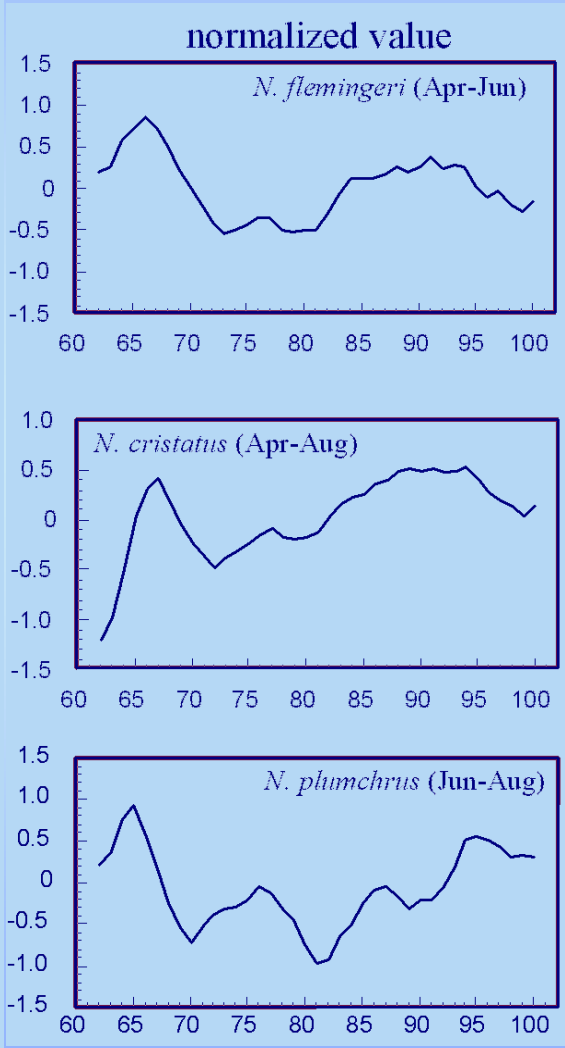
- Time series predates Stn P and CalCOFI
- Originally mostly biomass data
- Sample archive is intact & now being reanalyzed for many variables



(from K. Odate, 1994)

Example: Copepod size variability in Oyashio



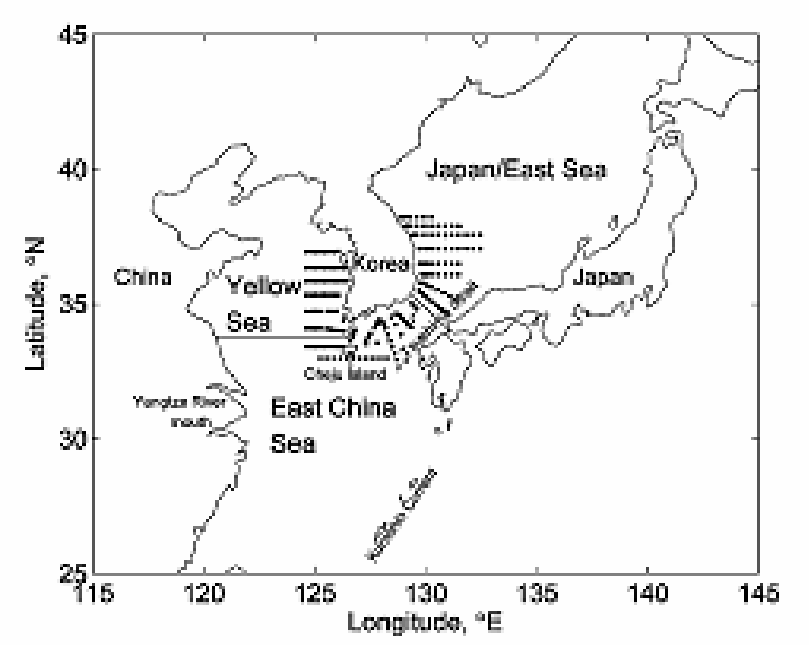


Tadokoro et al. 2005

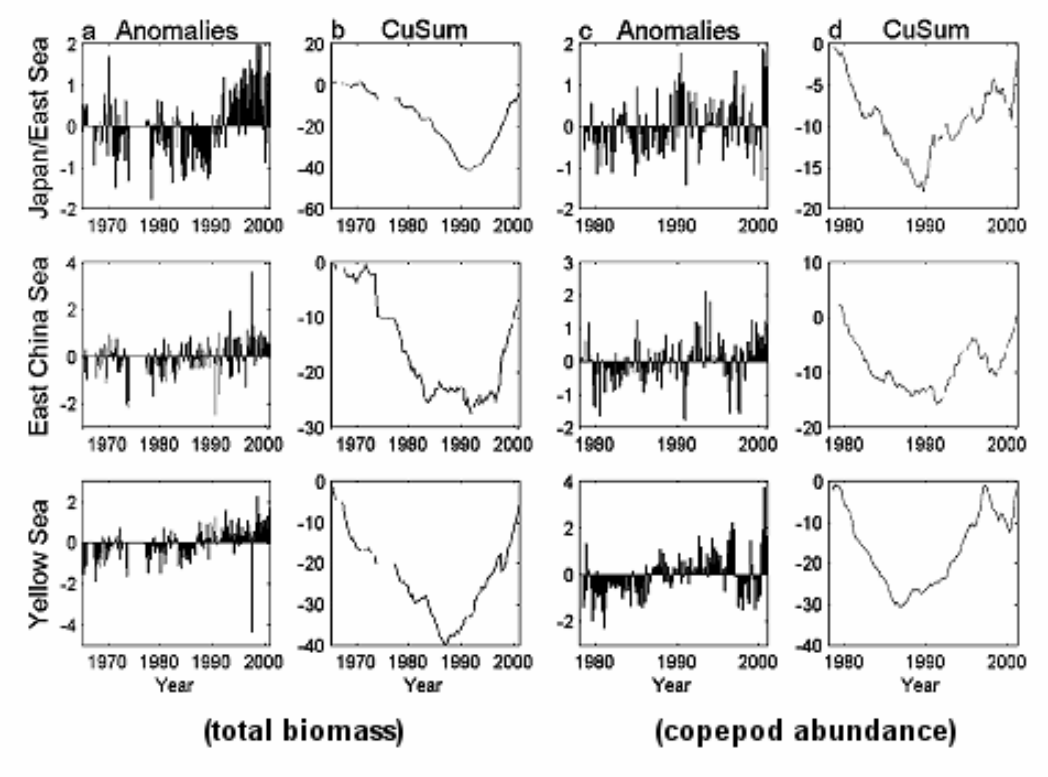
- *Neocalanus* spp. all covary, (small in 1970s)
- Individual species size also covaried with population biomass, and with [PO_4]

Korean coastal regions

(25+ years, 3 very distinct seas)



Rebstock and Kang, 2003

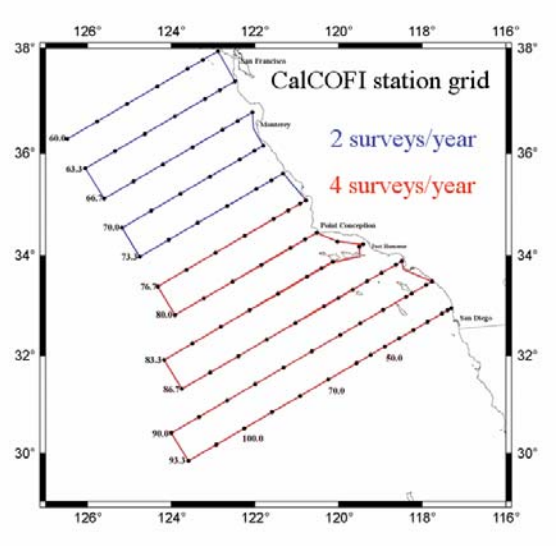


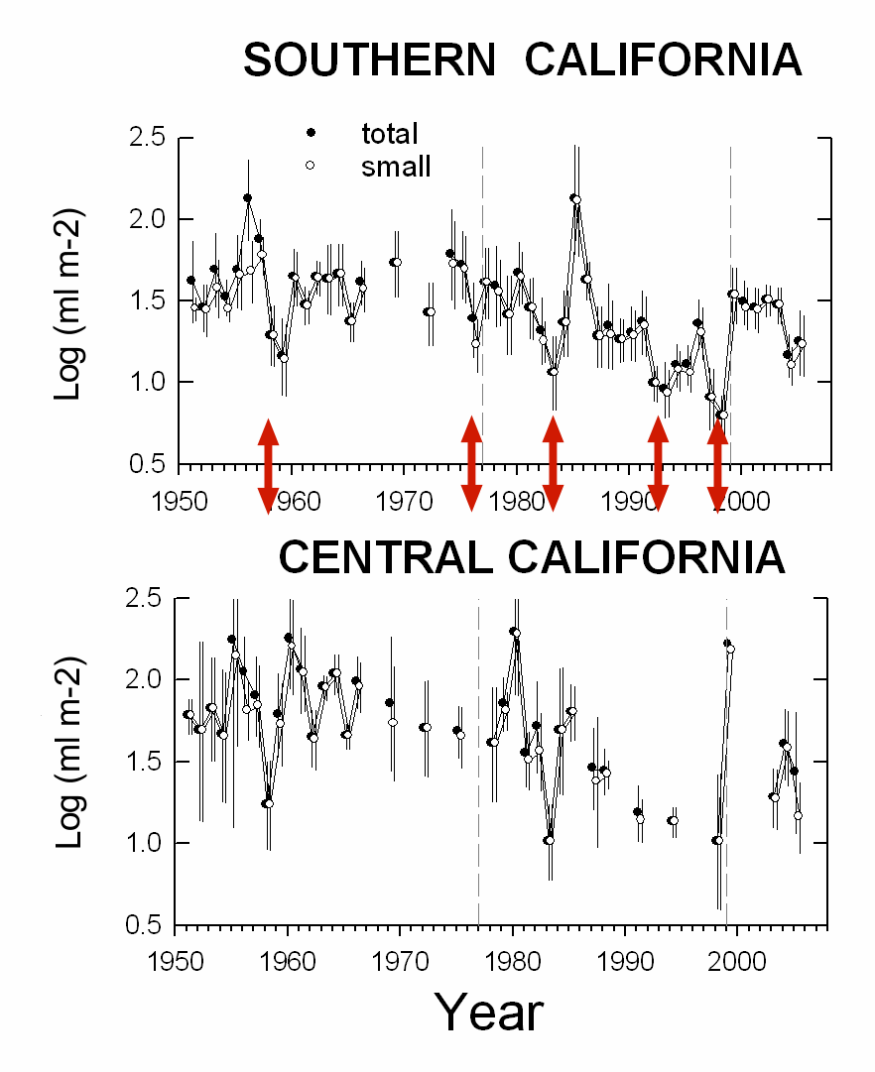
At decadal time scale, all 3 regions and several taxa share similar timing of highs and lows

Historical review by Region: 4. Eastern Margin

CalCOFI

55+ years of the California Current
(longest EBC time series)



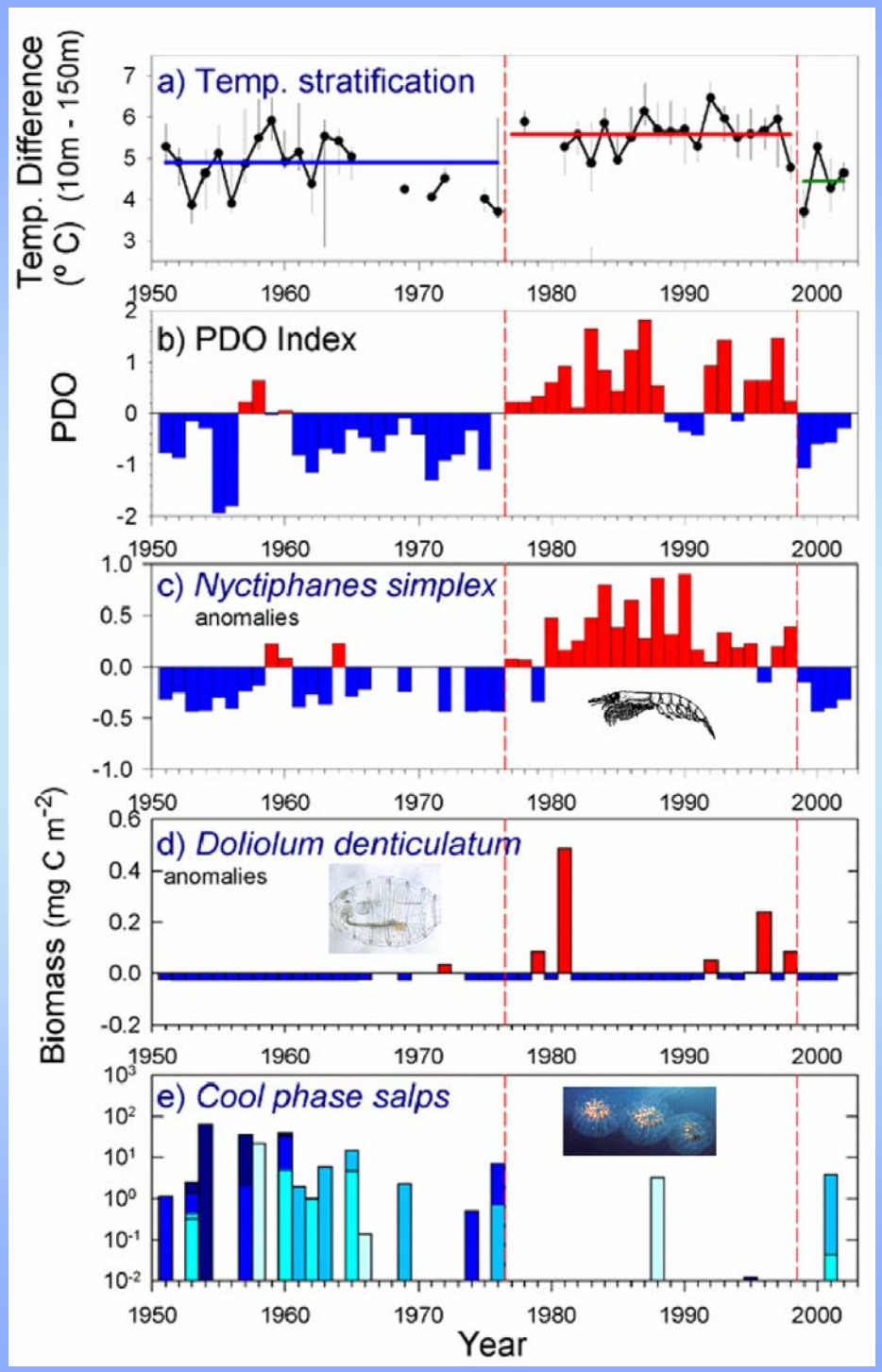


Multiple time scales !!

- **Trend (~5-8x decline)**
- **Decadal 'regimes'**
  (~ 5x fluctuation)
- **1-2 year El Niño events**
  (~5x decline)

Strong alongshore coherence

M. Ohman, updated from Lavaniegos & Ohman 2003



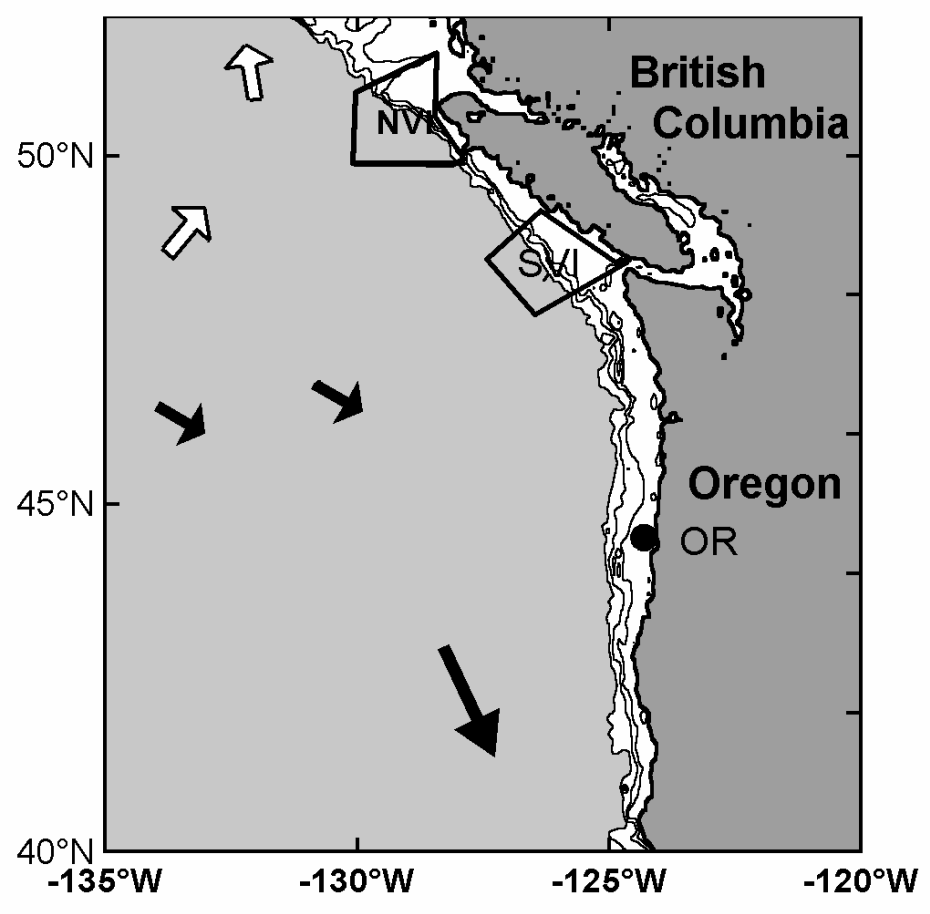
Ohman & Venrick, 2003

CalCOFI-California Current

Species-level responses to "regime shifts" can be very strong (20-100x)

Results (to follow) from the Pacific Northwest are very similar

NE Pacific continental margin (British Columbia to Oregon)



Main results:

- **Moderate biomass anomalies**
- **Bigger species composition anomalies**
- **Many environmental correlates**
- **Strong alongshore spatial autocorrelation (to 1000 km separation)**

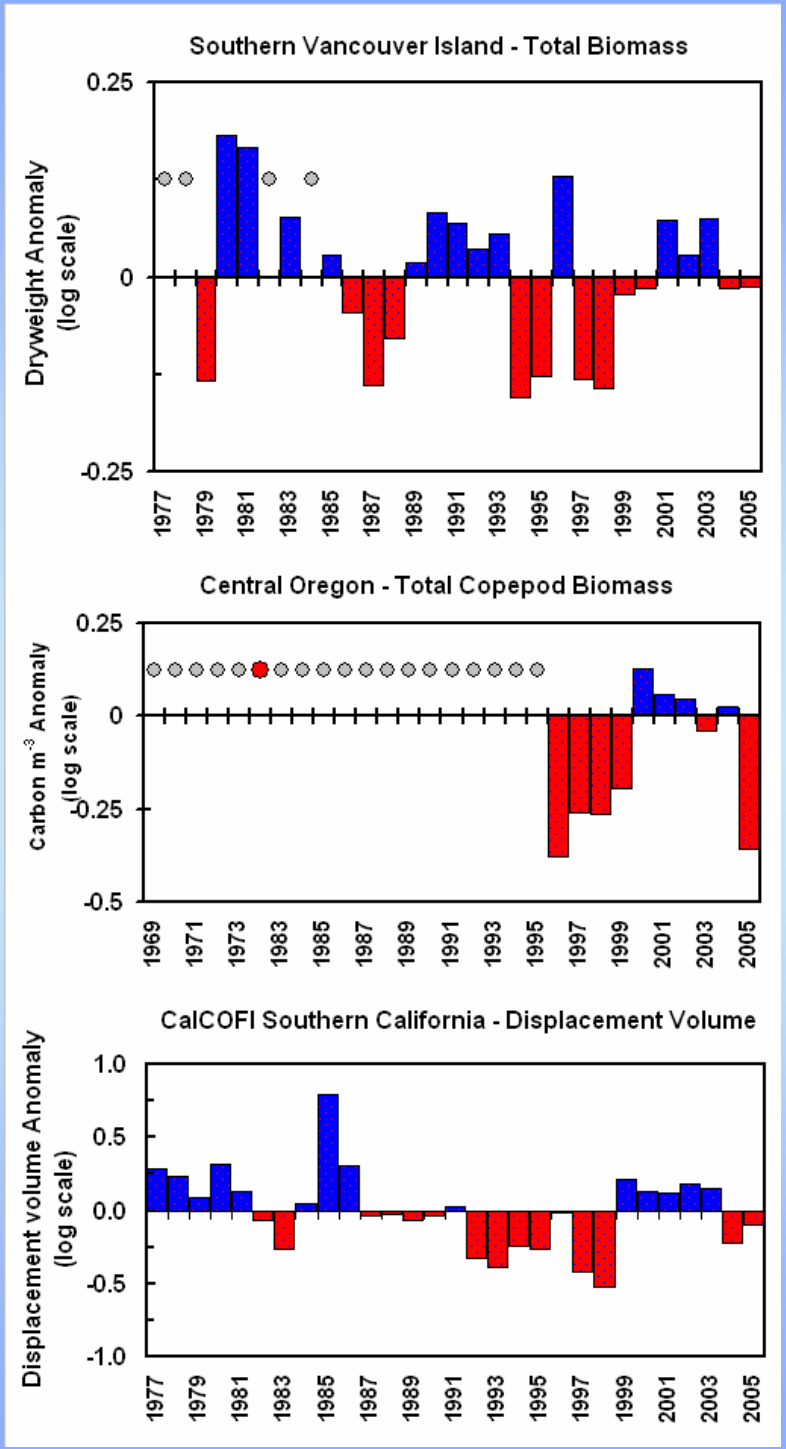
Anomalies of total biomass: N to S

Alongshore similarity:

- **HIGH 1970s-early 80s**
  (followed by)
- **LOW in 1990s**
  (followed by)
- **Brief upswing ~1999-2003**
  (followed by)
- **LOW 2004-2005**

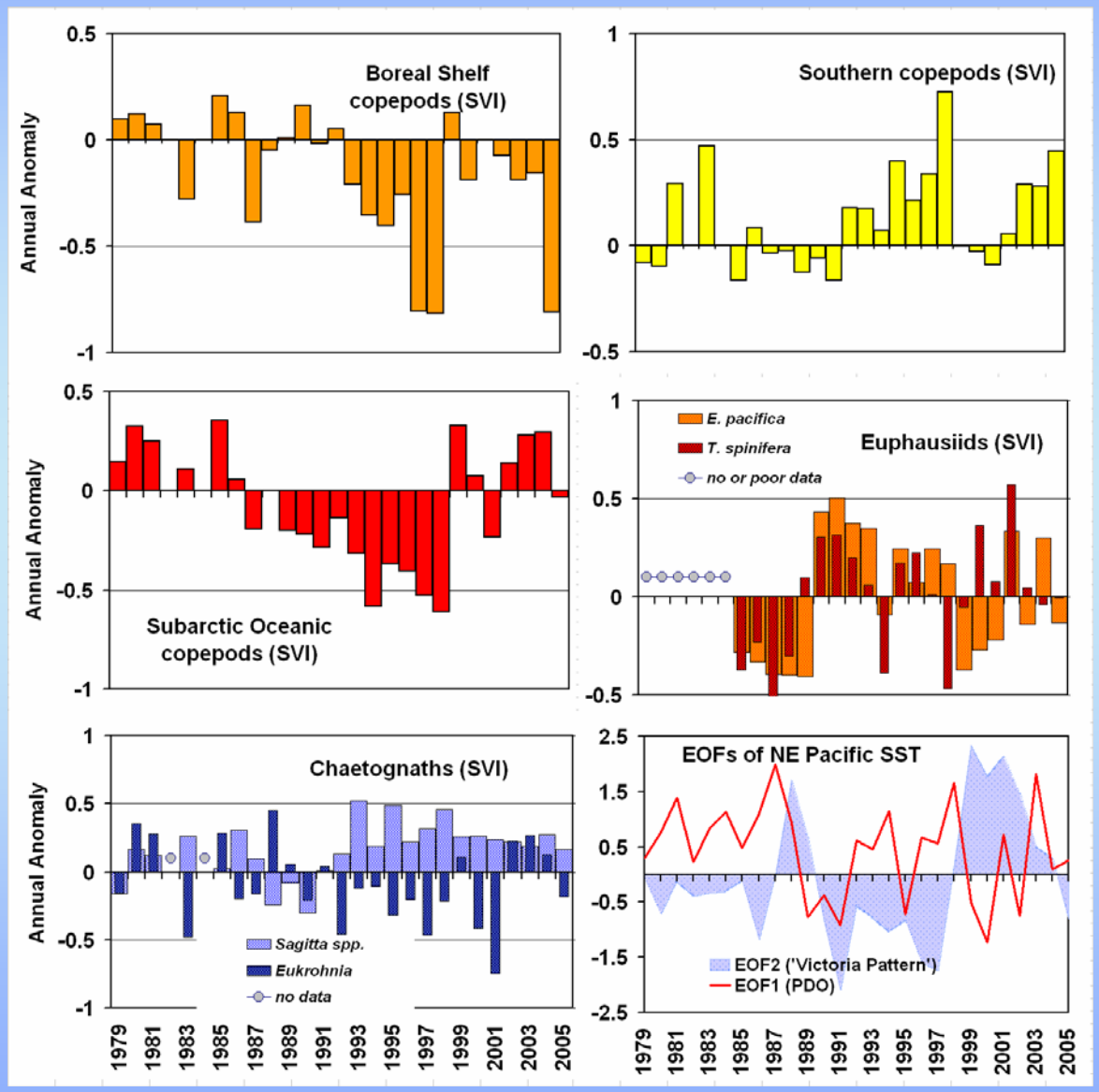
Range of biomass variation decreases with latitude:

- **~8x off Southern Calif.**
- **~3x off Oregon**
- **~2x off Vancouver Island**



Mackas, Peterson, Ohman & Lavaniegos, 2006

Anomalies of community composition



Off Canada:

~2x larger than anomalies of total biomass

Strongly correlated

- **Among adjoining regions (alongshore scale~1000 km)**
- **Within "species groups" sharing zoogeography & habitat preferences**

Species groups (and individual taxa) are correlated with multiple environmental indices, and vice versa

Environmental index	Euphausiids	Boreal copepods	Southern copepods	Subarctic copepods	Sagitta spp.	Eukrohnia	Jellies
Local Currents:							
Alongshore - 35m	0.5					-0.5	
Alongshore - 100m	0.4				0.6		
Cross-shore - 35m		0.6	-0.8		-0.6	0.4	
Cross-shore - 100m						-0.5	
Climate indices:							
SOI						0. 6	
NOIx		**0.5**	***-0.7***		**-0.7**	**0.6**	
NPI			-0.5				
PDO	***-0.5***						
Upwelling:							
Bakun anom. (winter)			-0.6		-0.5		
Winter shear index		**0.5**	-0.7		-0.7		
Bakun anom.(summer)	-0.5	0.5		**0.7**			
Summer shear index	**-0.6**						
Temperature:							
Winter 5m		-0.7	**0.9**			-0.4	
Summer 5m			0.6				
Winter 75m		-0.6	0.9		0.5	-0.3	
Summer 75m			0.7		0.6	-0.7	
Amphitrite summer	0.4					**-0.6**	
Salinity:							
Winter 5m							**0.7**
Summer 5m		0.5					
Summer 75m			-0.5		-0.6		

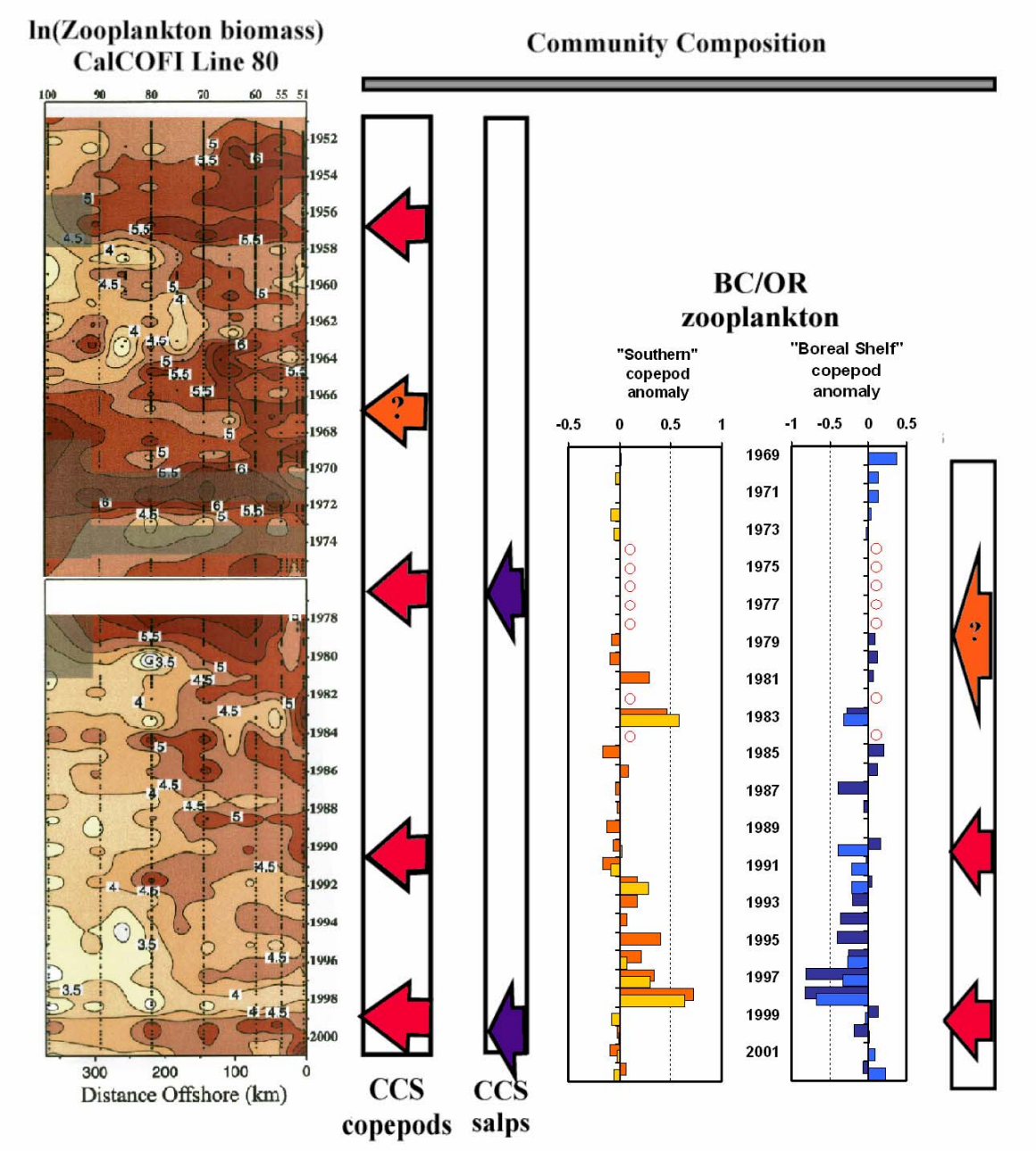
Shown: product moment; shading indicates most useful predictors from stepwise regression

Anomalies of species composition:N to S

'Resident' & 'Northern' species do well when:

T(°C) cool, stratification weak, upwelling strong, & total biomass high

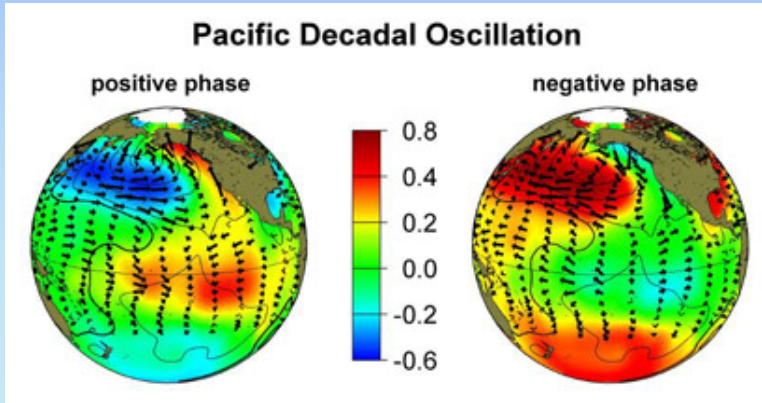
'Southern' species increase when T(°C) warm, stratification strong, poleward flow, upwelling weak, & total biomass low



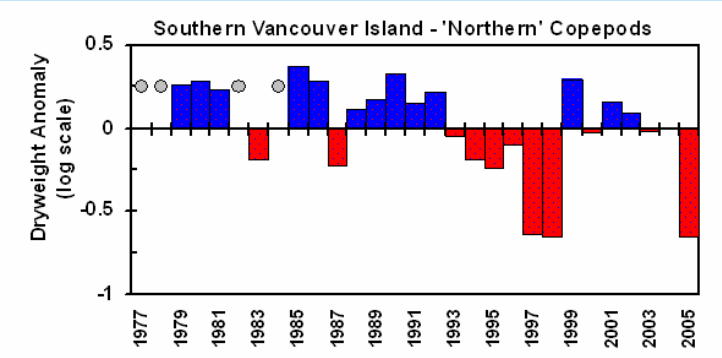
Mackas 2006 & PICES 2004, (based on data from McGowan, Rebstock, Ohman & Lavaniegos, Mackas, Peterson, Zamon)

Comparison of zooplankton time series with 'climate' & 'predator' time series

Can we get from here:



To here:



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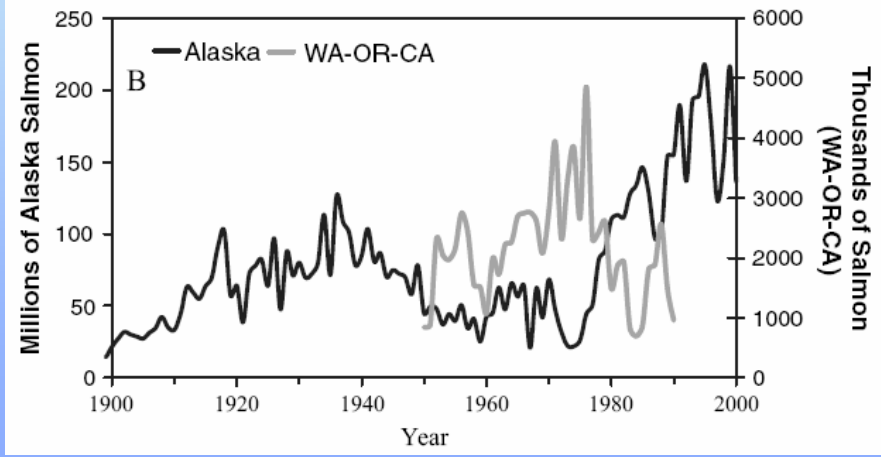


Short answer: YES

- **EVERYTHING covaries in the NE Pacific**

BUT

- **Zooplankton and "fish" share *amplification of low-frequency* physical variability & *rejection of high-frequency* "noise"**
- **Zooplankton reveal their story sooner than "fish"**

(Watch for low-frequency synchrony in the following)

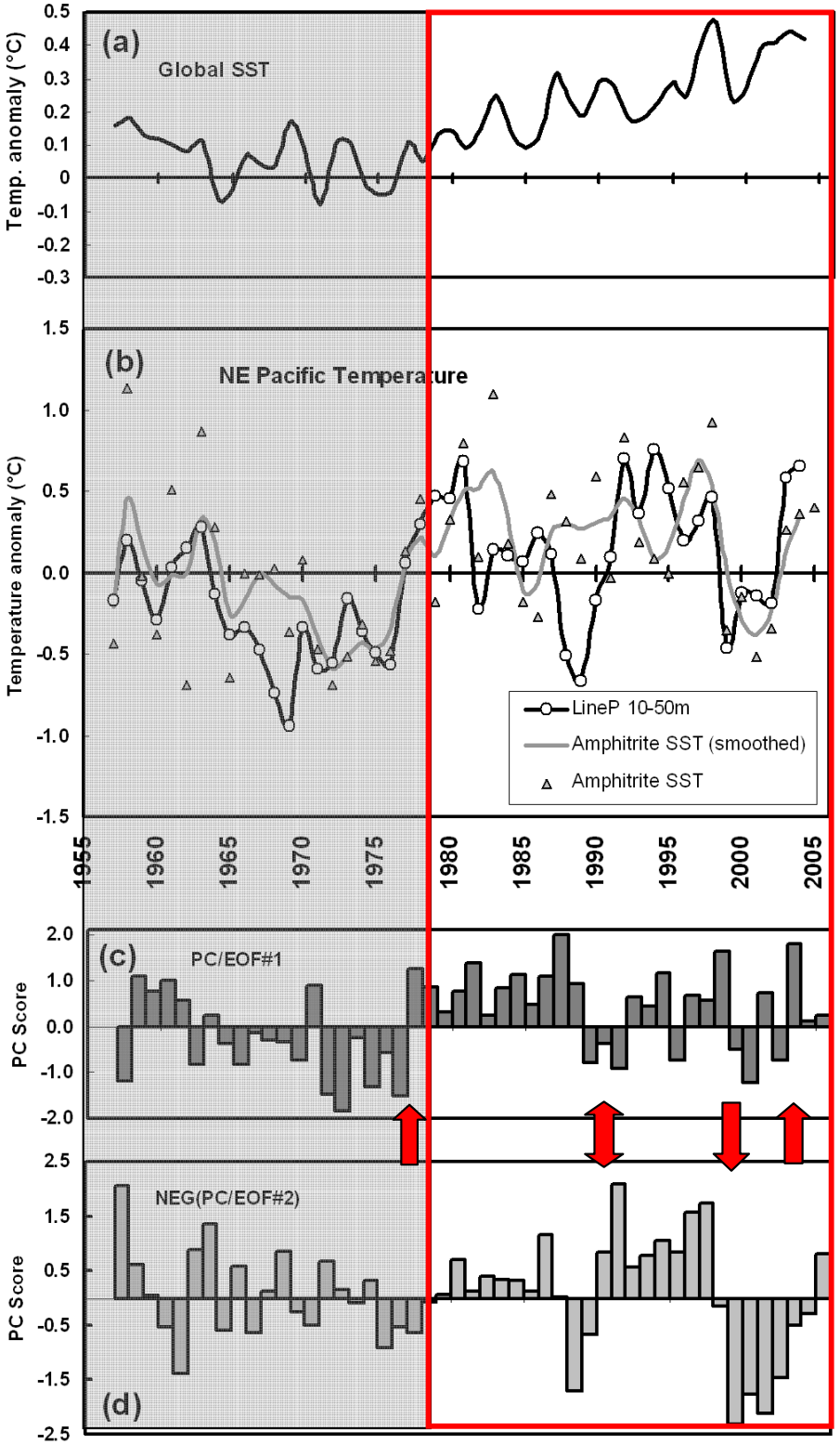
Upper-ocean Temperature
(& proxy for much else)

Top: Global
(trend + fluctuations)

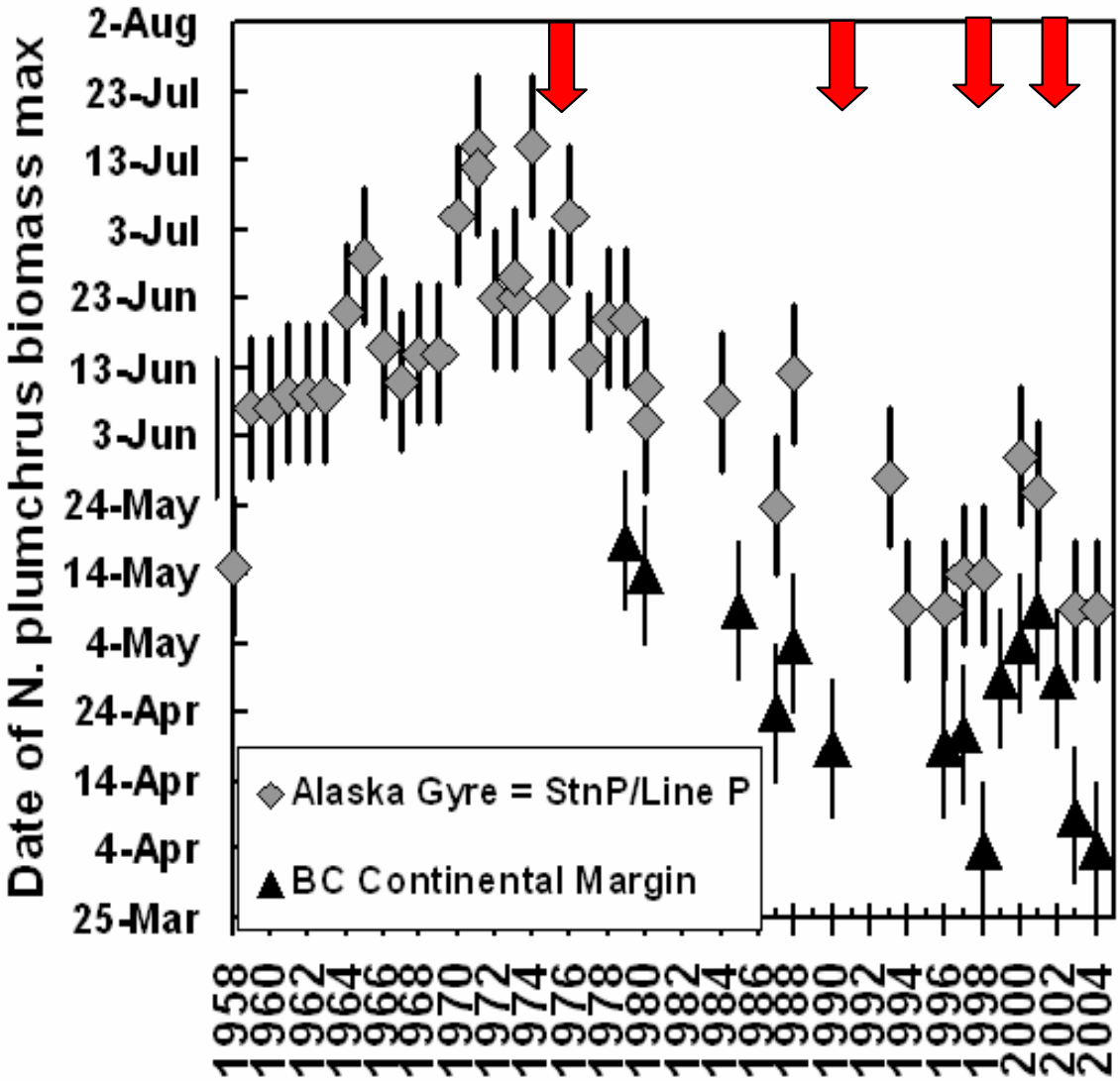
Middle: Regional
(~same trend + bigger fluctuations)

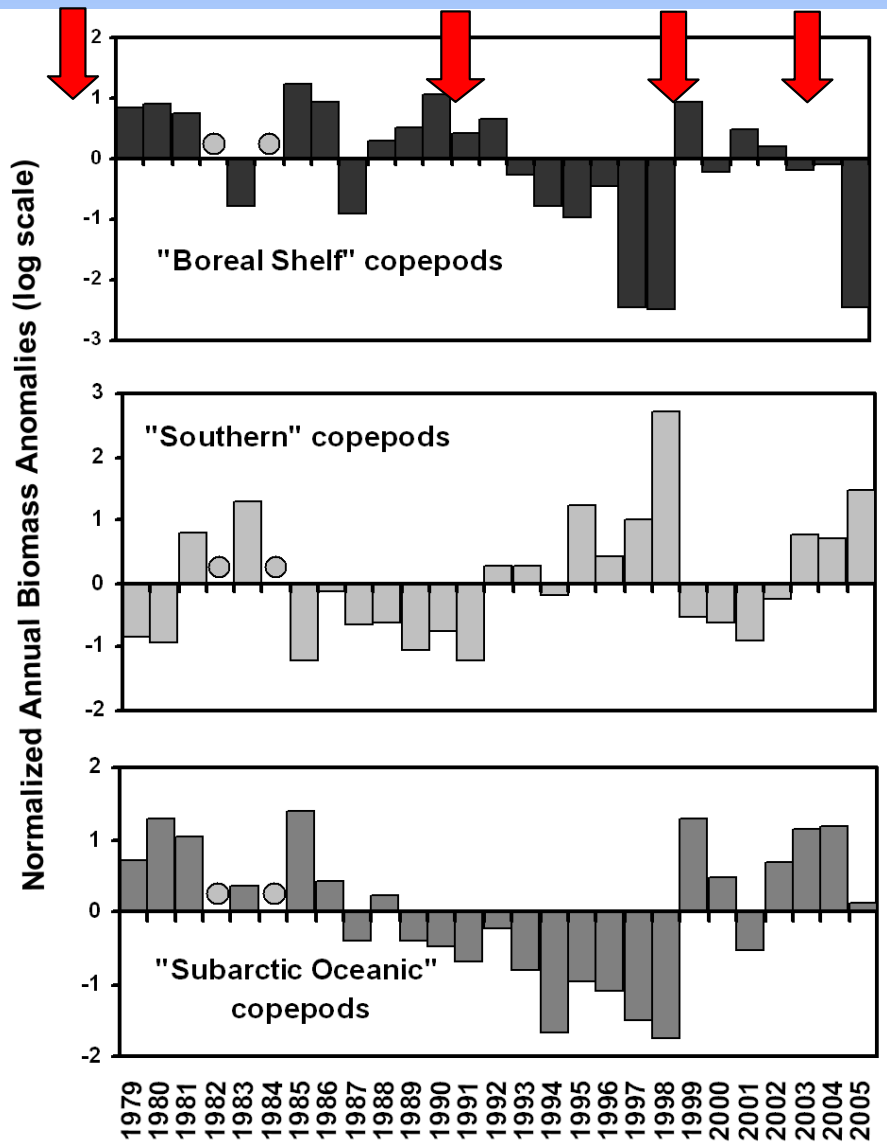
Bottom pair: N Pacific EOFs of detrended SST
(trend discarded, fluctuations partitioned based on spatial covariance)

Arrows mark 1976, 1990, 1999, 2003

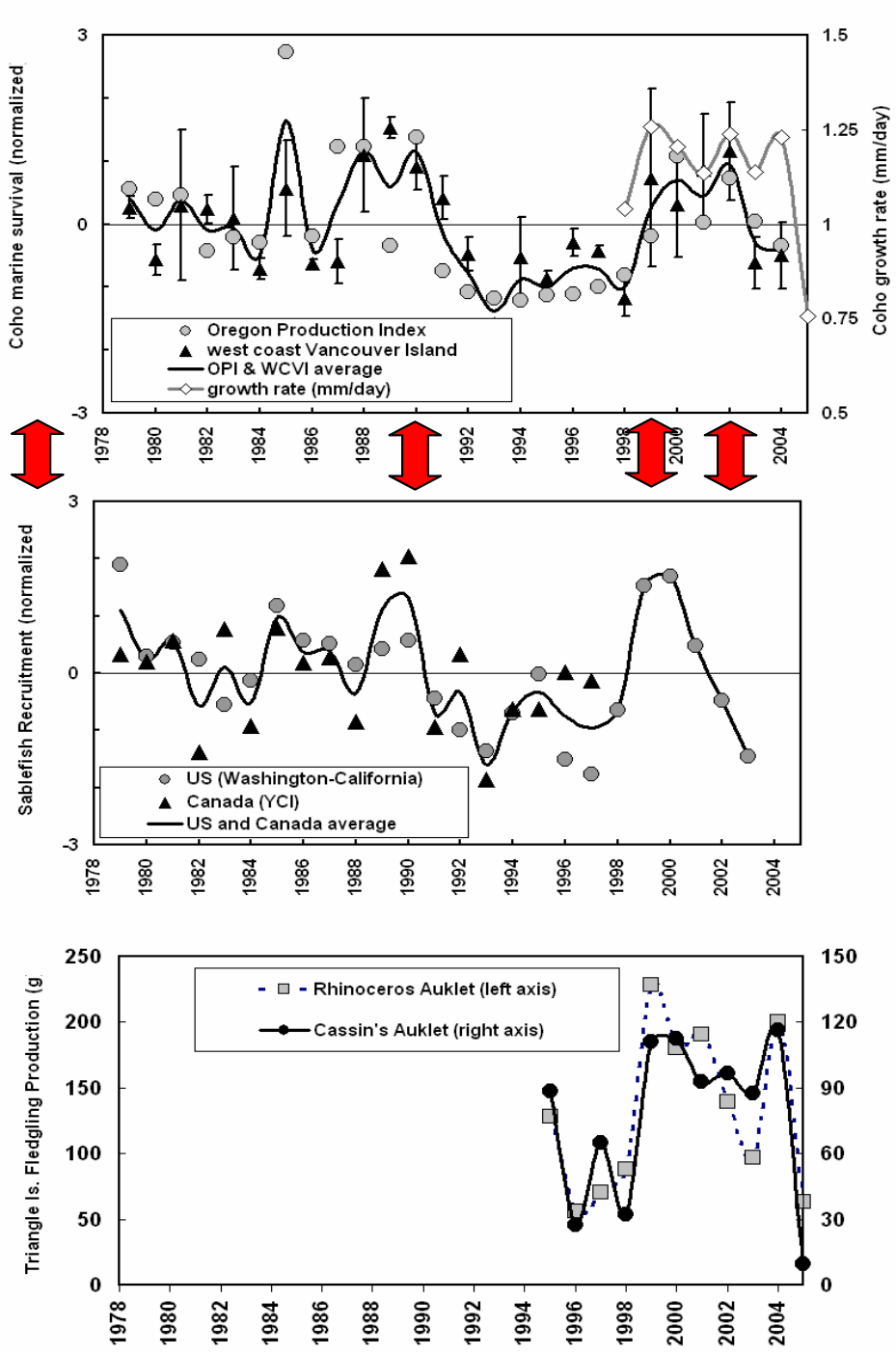


Zooplankton anomalies of timing & composition





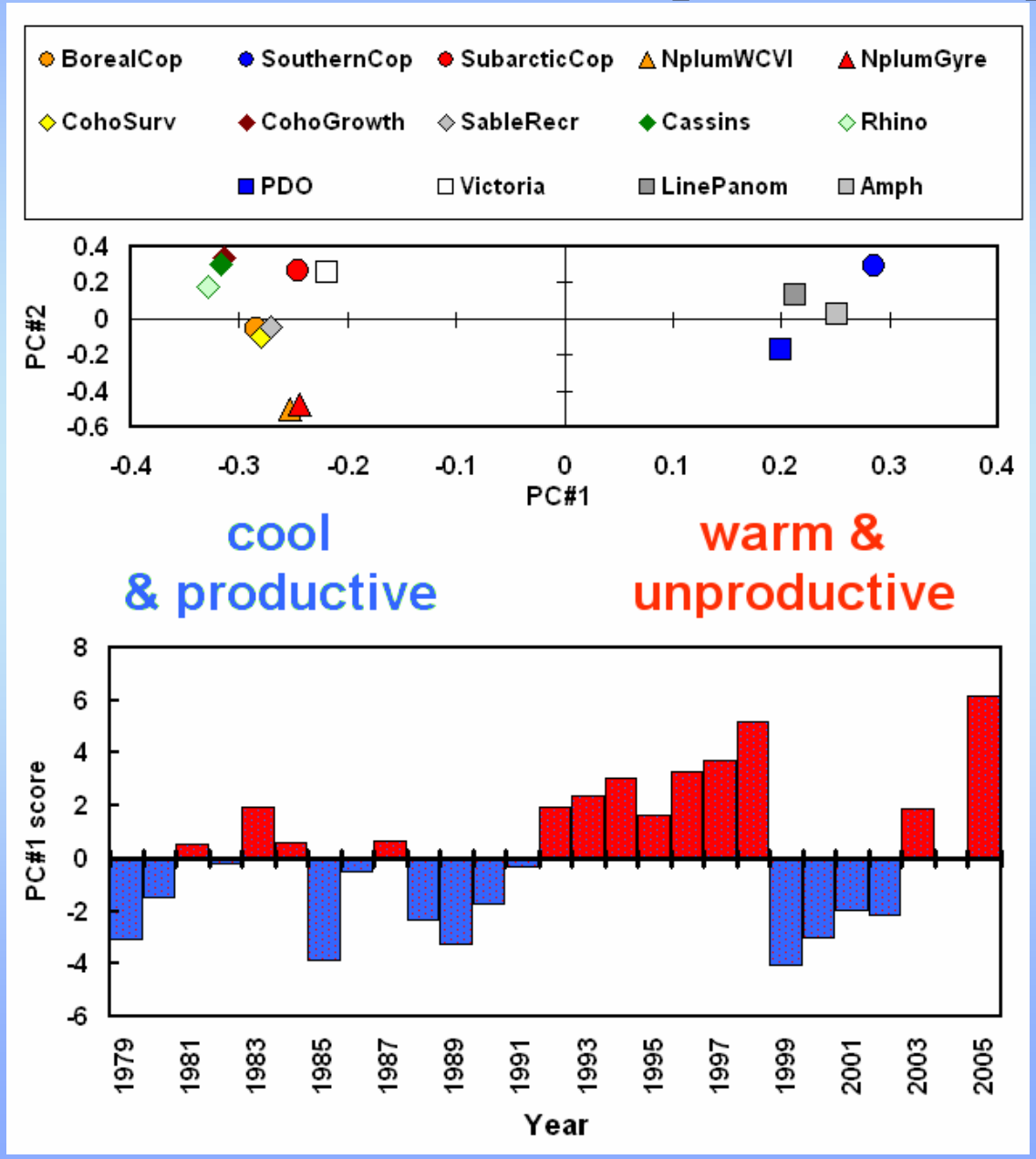
Indices of “Predator success”



- Coho salmon survival & growth
- Sablefish recruitment
- Seabird reproduction (planktivore & piscivore)

Strong shared message:

PCA of SST, zooplankton & 'predator' correlations

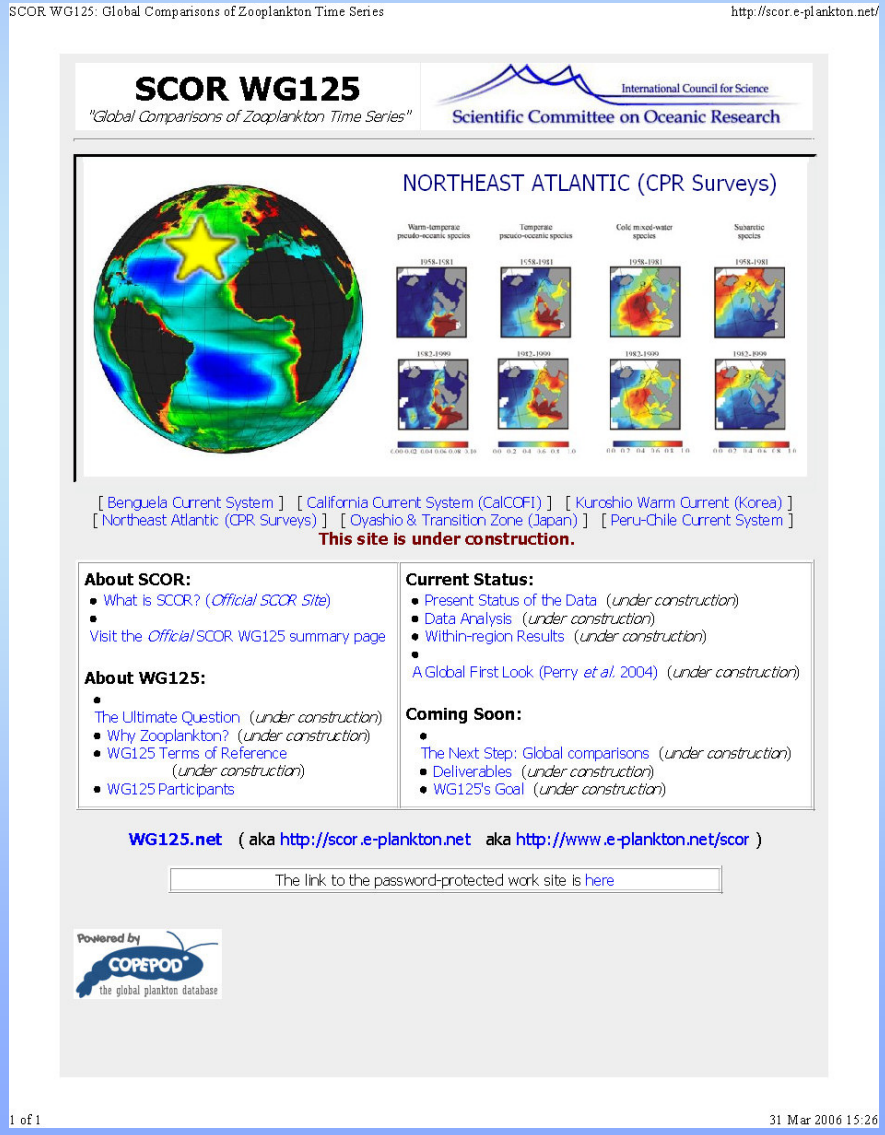


- Lead EOF (56% of variance) corresponds qualitatively to a "cool & productive" vs. "warm & unproductive" gradient
- "Biological" variables all weight/respond more strongly than all SST indices

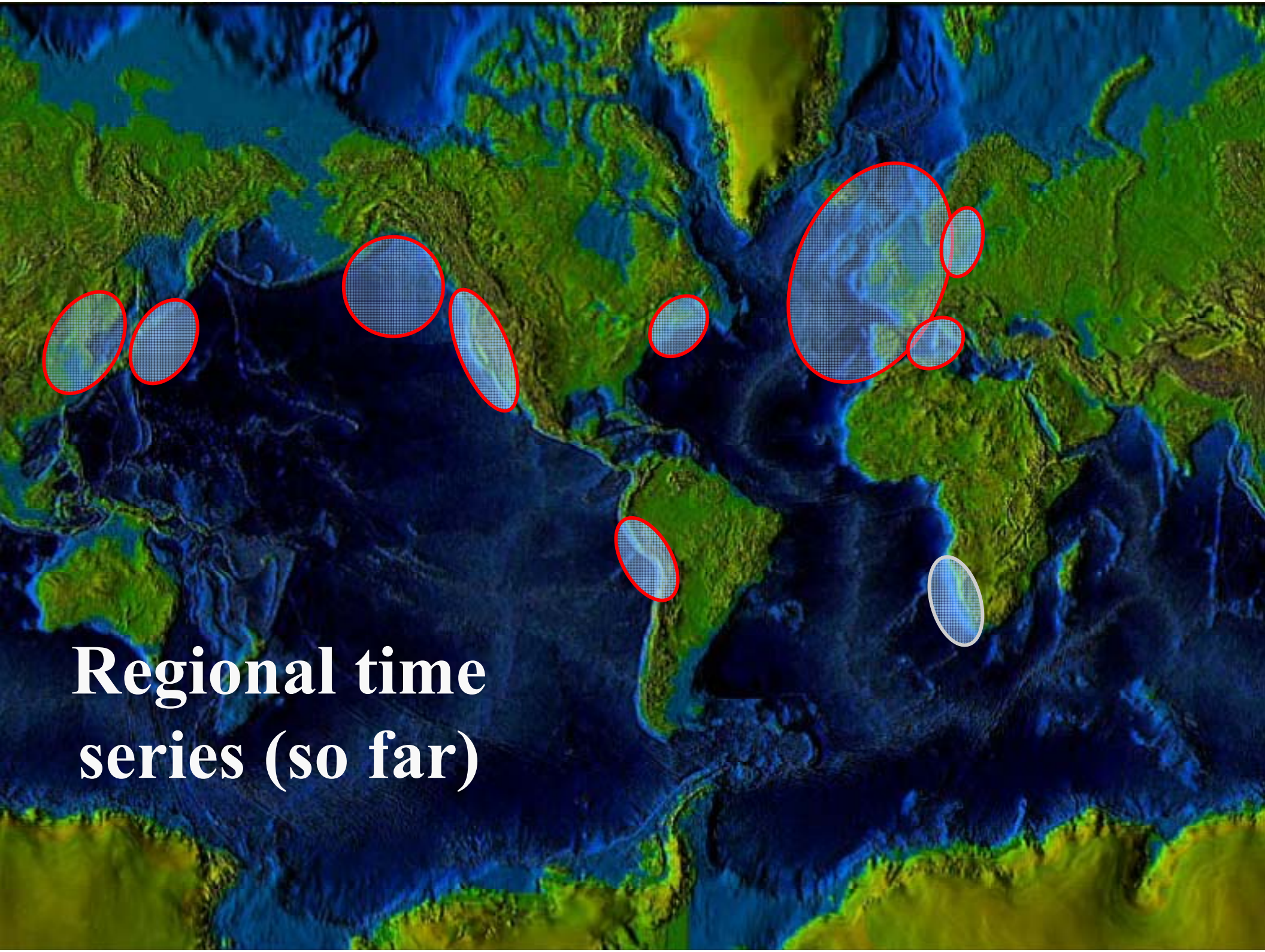
Performance:

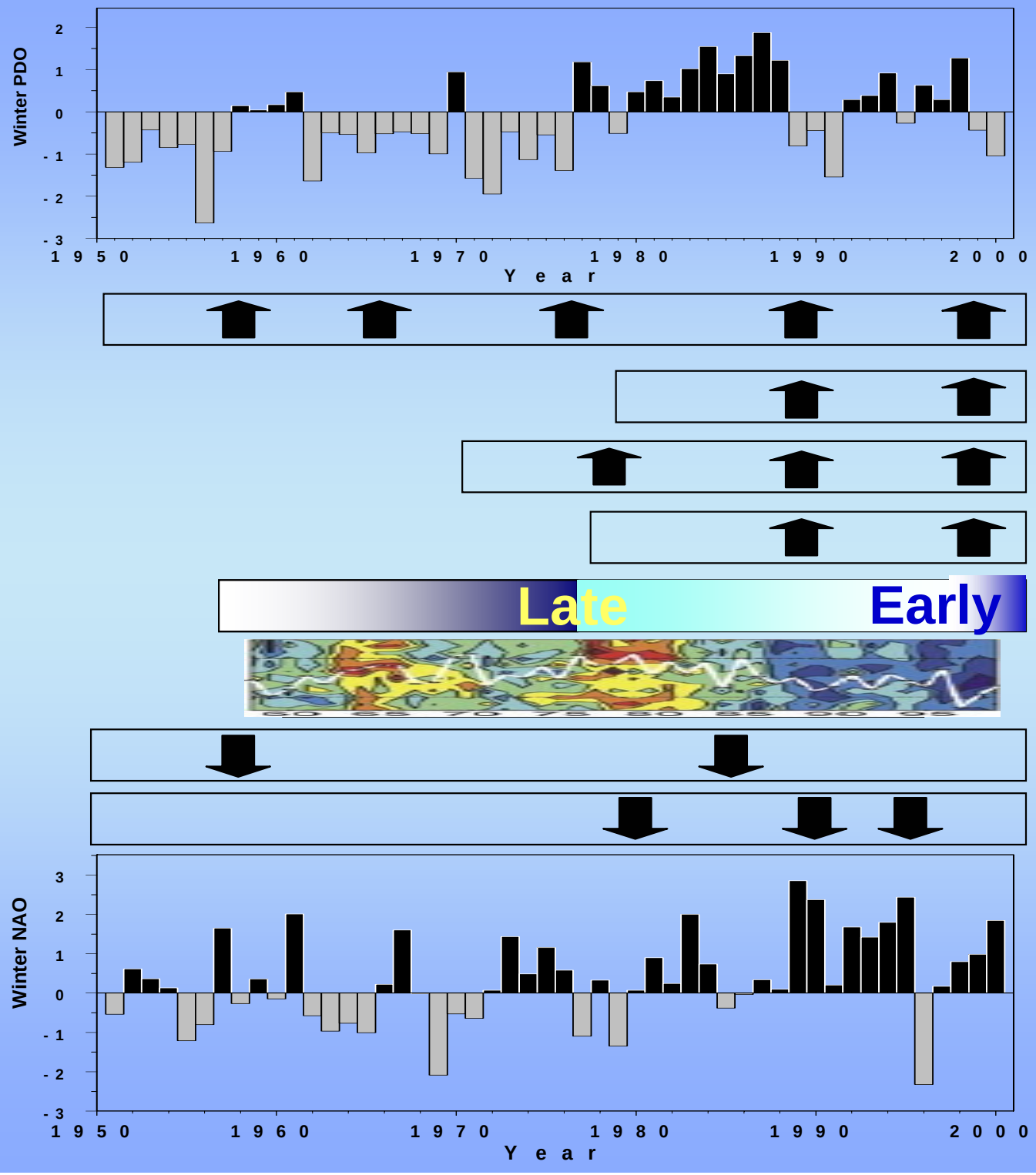
- Average pairwise $|r|$ among variables = 0.48
- Average $|r|$ with PC1=0.72
- r vs. reconstructed time series 0.8-0.95

The next step: SCOR WG125 "Global Comparison of Zooplankton Time Series"



- **Formed in 2005**
- **http://scor.e-plankton.net/**
- **Develop a suite of analysis methods, and apply to available "long zooplankton time series"**
- **Quantify amplitudes, time scales, and 'synchrony'**


Regional time
series (so far)



Winter Pacific Decadal Oscillation (PDO)

CaCOFI copepods

BC & Oregon copepods

Kuroshio copepods

Korea zooplankton

***Neocalanus* peak timing (NE Pacific)**

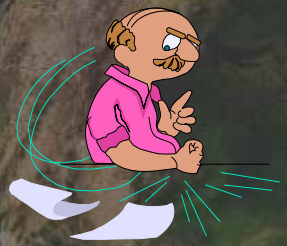
North Sea plankton & cod

NE Atlantic plankton

NW Atlantic copepods

Winter North Atlantic Oscillation (NAO)

Perry et al. 04



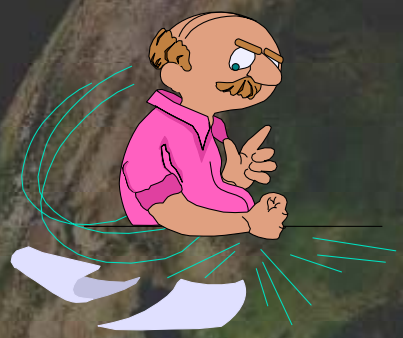
My own very preliminary "synthesis" of WG125 (will evolve):

1. Scale of zooplankton spatial correlation (distance over which a similar 'change' occurs at a similar time) is proportional to event duration
2. For 5-20 year time scale the correlation length is ~1000 km
3. 'Synchrony' scale ('change' of differing variables, but similar duration and onset timing) may be trans Pacific, but probably not global

‘Physics’ & ‘Zooplankton’ share time scales of variability but amplitudes differ!!

Mode of variation	Physics (e.g. SST)	Zooplankton (e.g. species abundance)
Seasonal cycle	~ 10°C	~ factor of 3-10
Latitudinal gradient	~ 20°C	~ factor of 5
ENSO anomaly	~ 1-3°C	~ factor of 5
Decadal anomaly	~ 1-3°C	~ factor of 5-10
Climate trend	4-5°C??	∞? (extinction?)

Zooplankton (and fish) have a stronger response to low frequency variation. WHY?



Why small interannual changes in physics produce large changes in ecosystem structure

- Steady or predictably-varying conditions (mean, tidal, seasonal = the ‘first order’ physics) are already ‘discounted’ by prior evolutionary adaptation

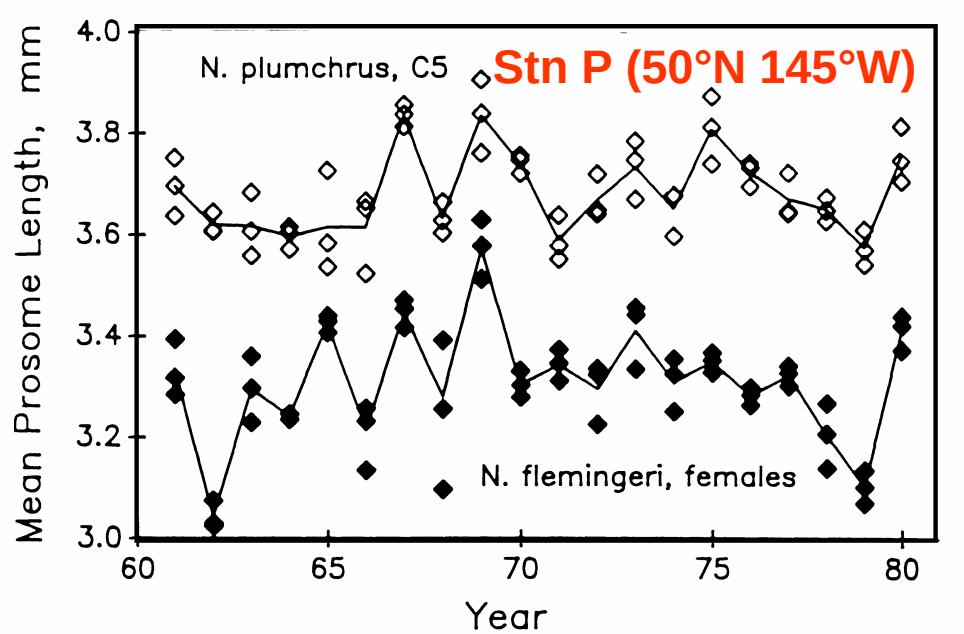
- Differential advantage is ability to respond to ‘unpredictable’ change (‘second order' physics: aperiodic & weak precursor signals)

- We need to understand more about what cues make a change ‘predictable’, and also how and when cues are ‘misinformation’

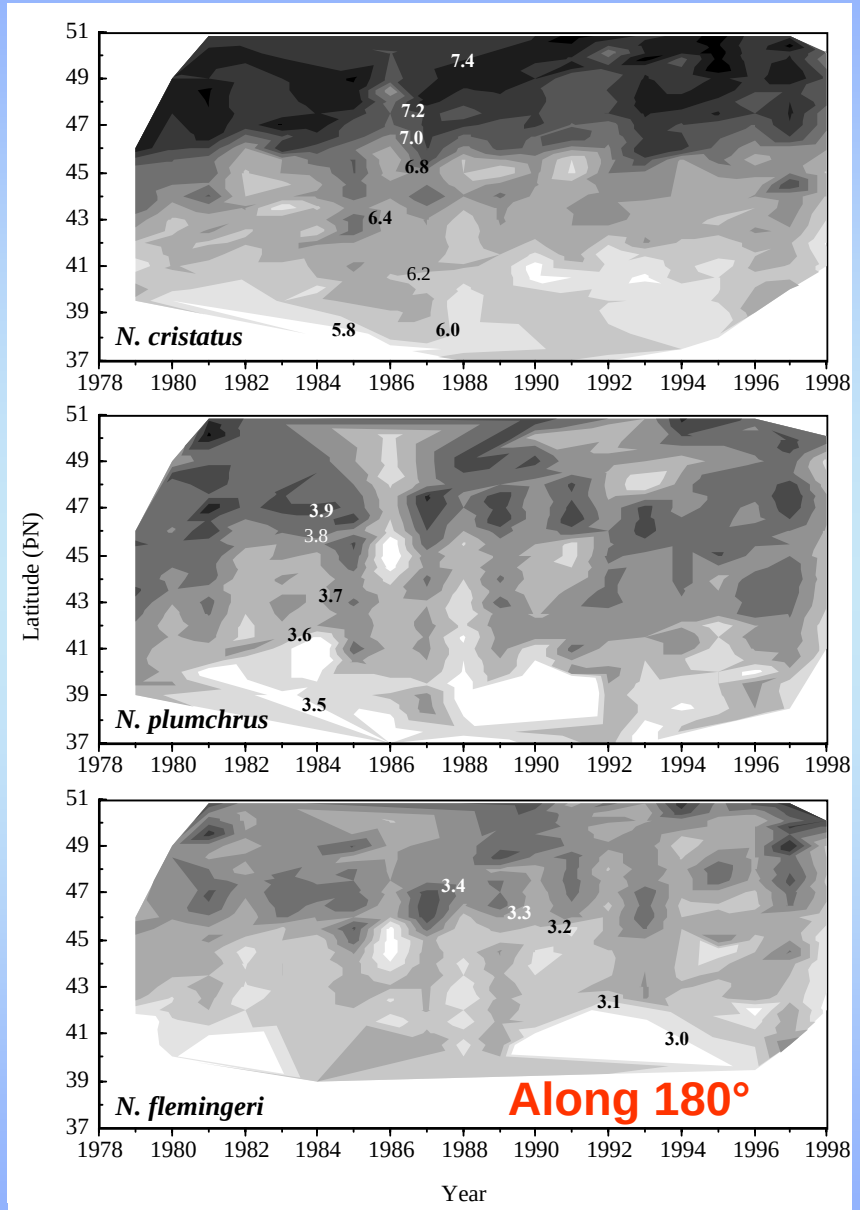
Spare slides to answer questions

Within-species body size variation

- **Interannual : 10-20% in length, ~ 30-70% in weight**
- **Correlated among species and across latitudes**
- **Overlaid on persistent large-scale spatial gradient**

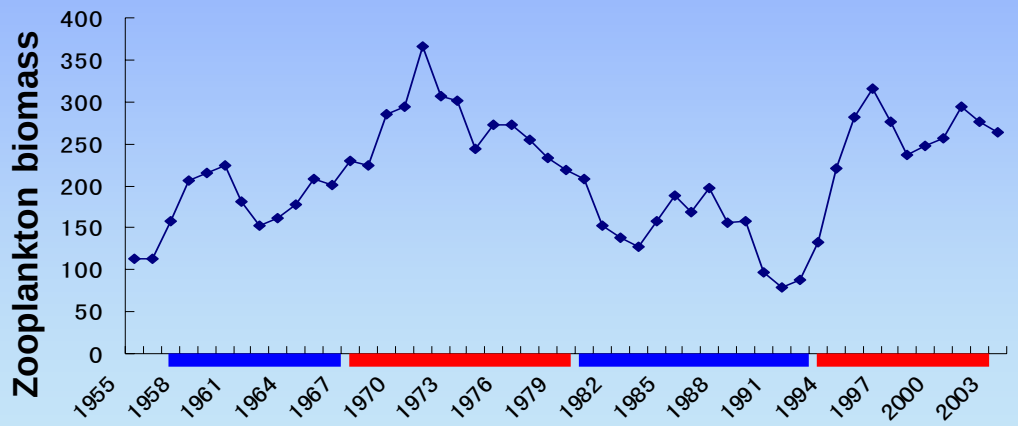


Miller, Fulton & Frost (1992)

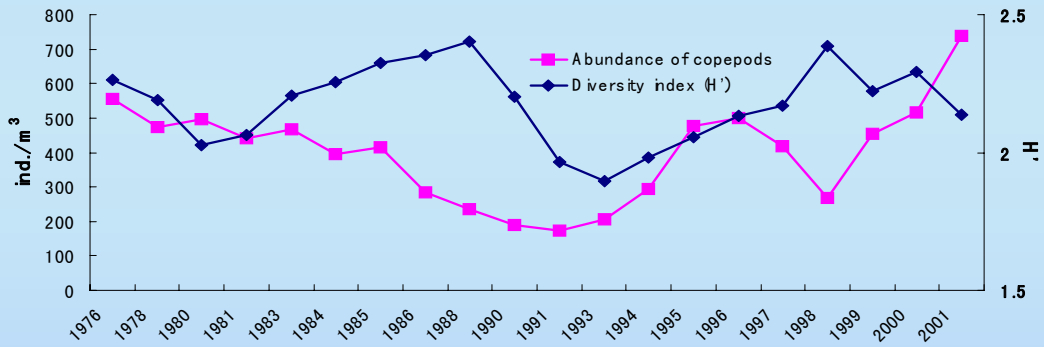


Kobari & Ikeda (2001)

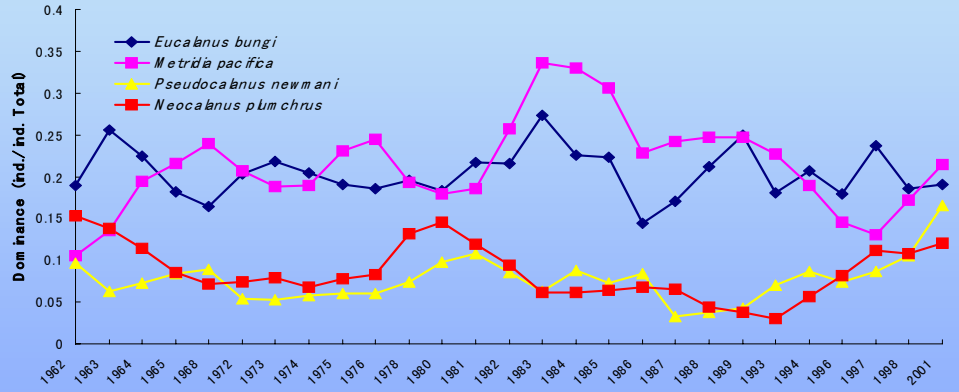
ODATE workup is nearing completion for Oyashio samples, shows:



2-5x changes in biomass



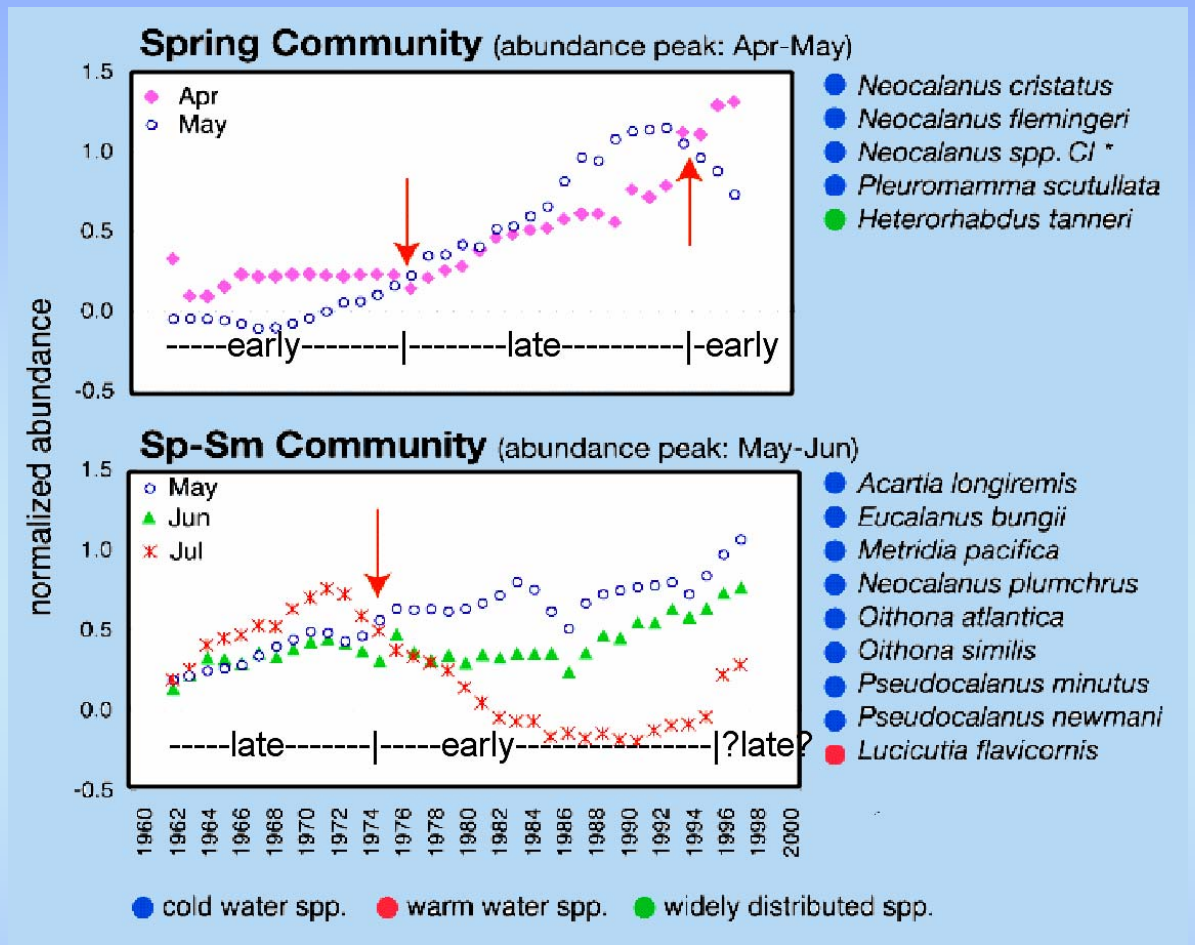
Changes in diversity & copepod abundance

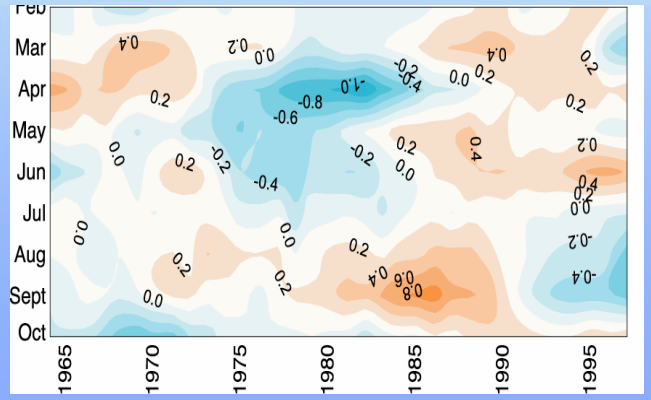


Changes in ranking of dominant species

H. Sugisaki 2005

Seasonal timing variability in Oyashio waters:





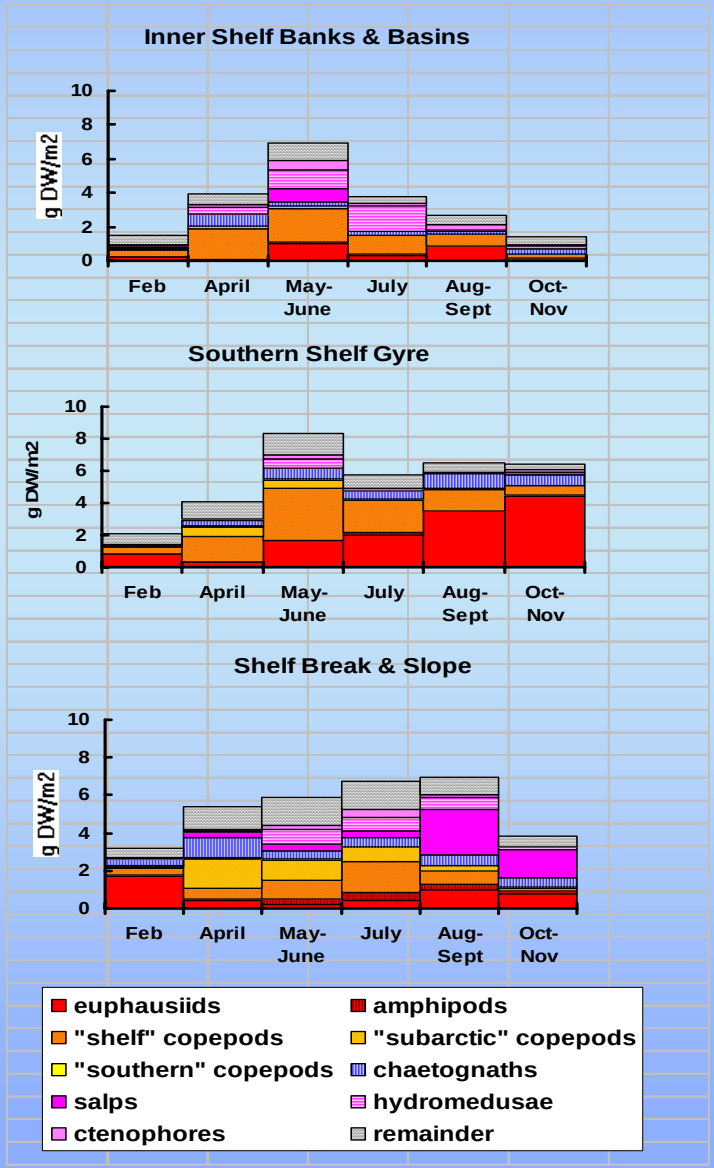
S. Chiba et al. (2005)

- **Differing responses of 'spring' vs. 'summer' zooplankton species**
- **Best indexed by seasonal (not annual) temperature anomalies**
- **Seasonal peaks of individual species narrower than in eastern subarctic?**

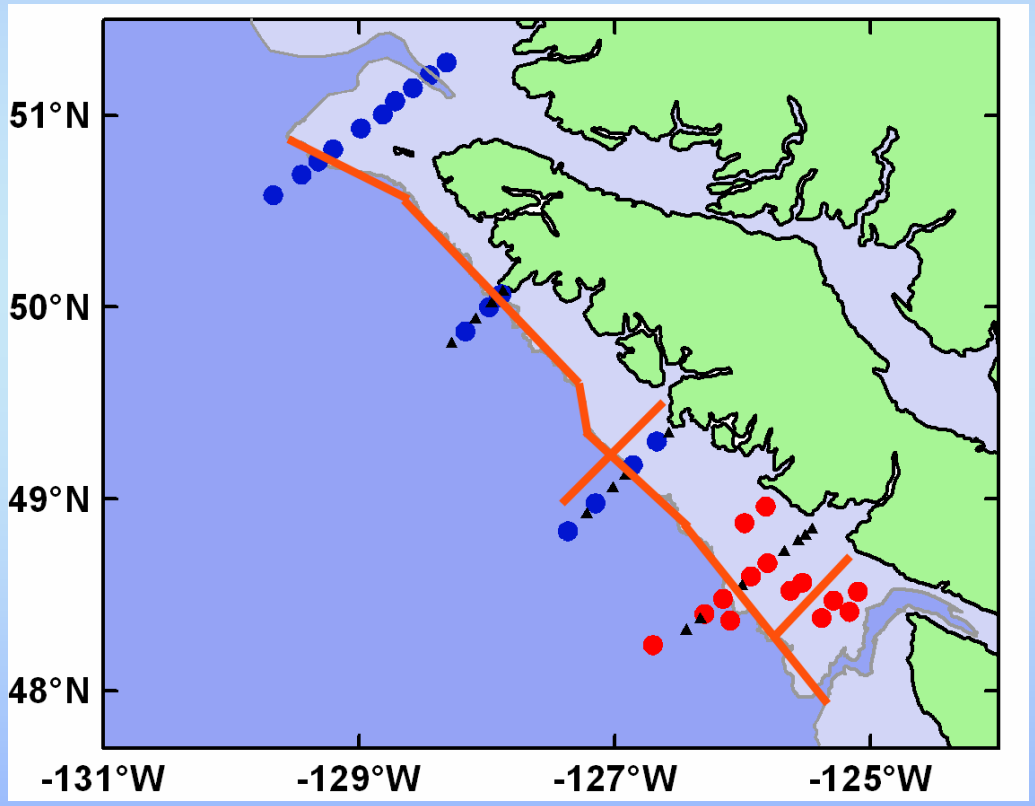
Average Seasonal Cycles ⇒ Anomalies

Within cruise spatial averaging of regional "replicates"

- Time averaging across years within regions to produce *seasonal climatology for each species* (summarized at right -note differences in species dominance and timing between adjoining regions)
- Produce time series of *annual anomalies* for total biomass and for individual species (and species groups) by within-year averaging of:
  log (*observed*) - log (*multiyear average for that season and region*)
- Annual anomaly of +1.0 means 10x more than long term average
- NO smoothing of anomalies across years



Zooplankton Sampling: 1) Off Vancouver Island



Vertically-integrated bongo net tows (black net, 0.23 mm mesh)

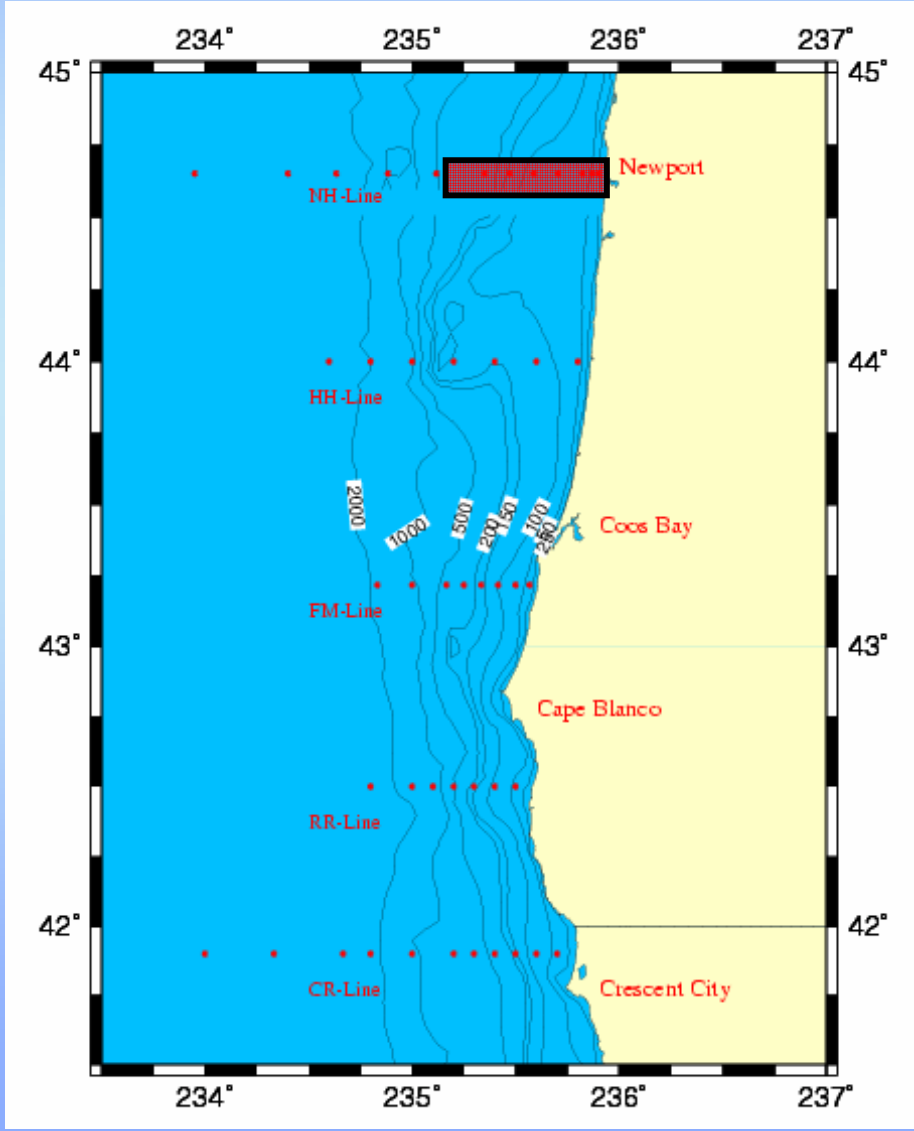
Sample 3-6 time periods each year

- since 1979 off southern Vancouver Island (red dots are standardized grid used since 1985)
- since early 90s off central and northern Vancouver Island (blue)

Spatial stratification (areas defined by orange lines) based on bathymetry and current patterns

Identify and count zooplankton to species and stage, multiply by individual size and sum to estimate dryweight biomass m^{-2} for each species at each site

Zooplankton Sampling: 2) Off Oregon



Five USGLOBEC LTOP lines (●) sampled 4-5 times per year since 1997:

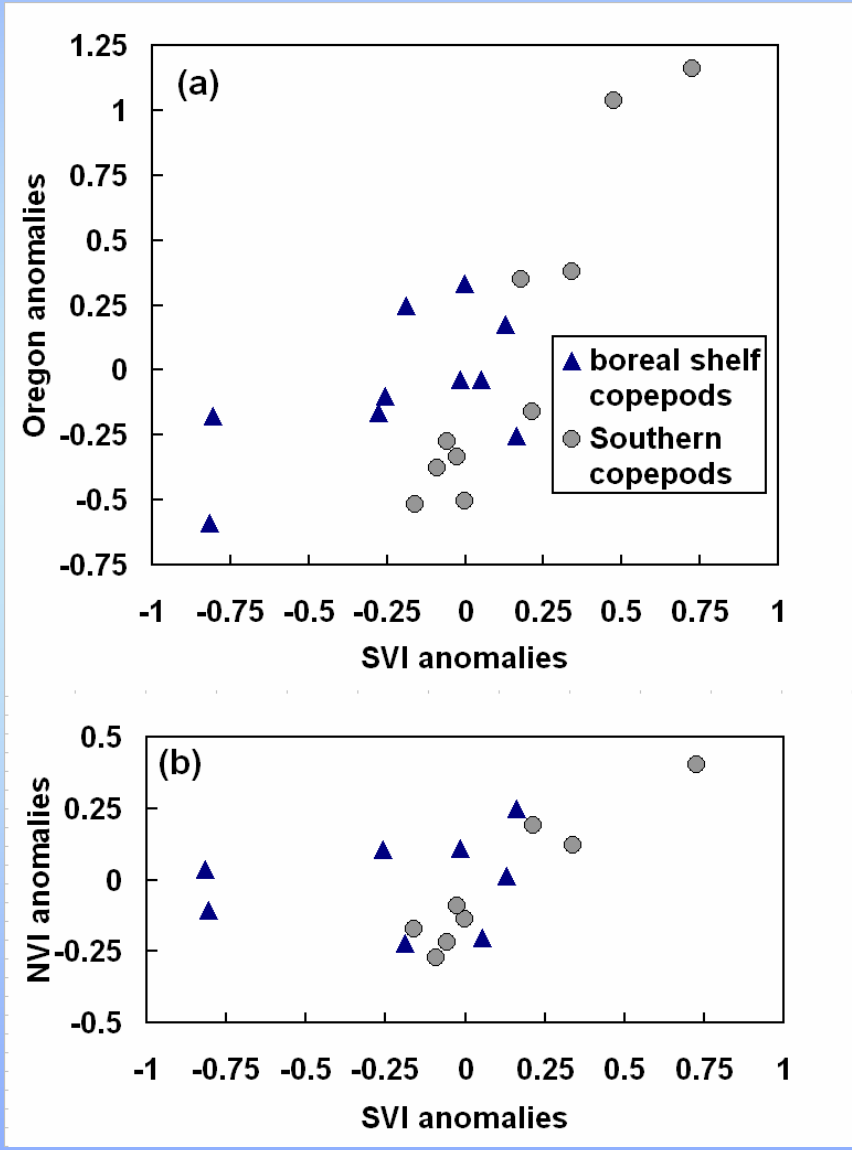
- vertically-integrated bongo net tows.
- CTD and water chemistry

For the inner Newport Line (▭), a longer and higher resolution zooplankton time series:

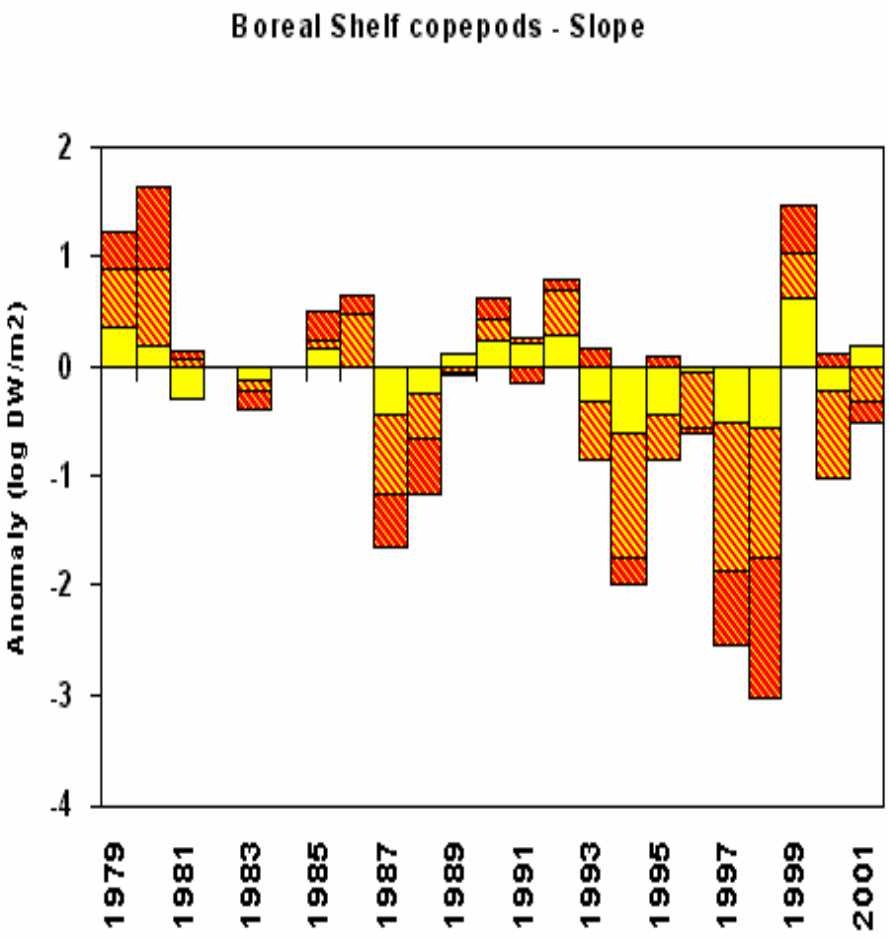
- 1969-1973 (Peterson et al.), 1983 (Miller), and 1996-2002(Peterson et al.):
- vertical net hauls with a mix of net types
- sampling biweekly to monthly spring-autumn

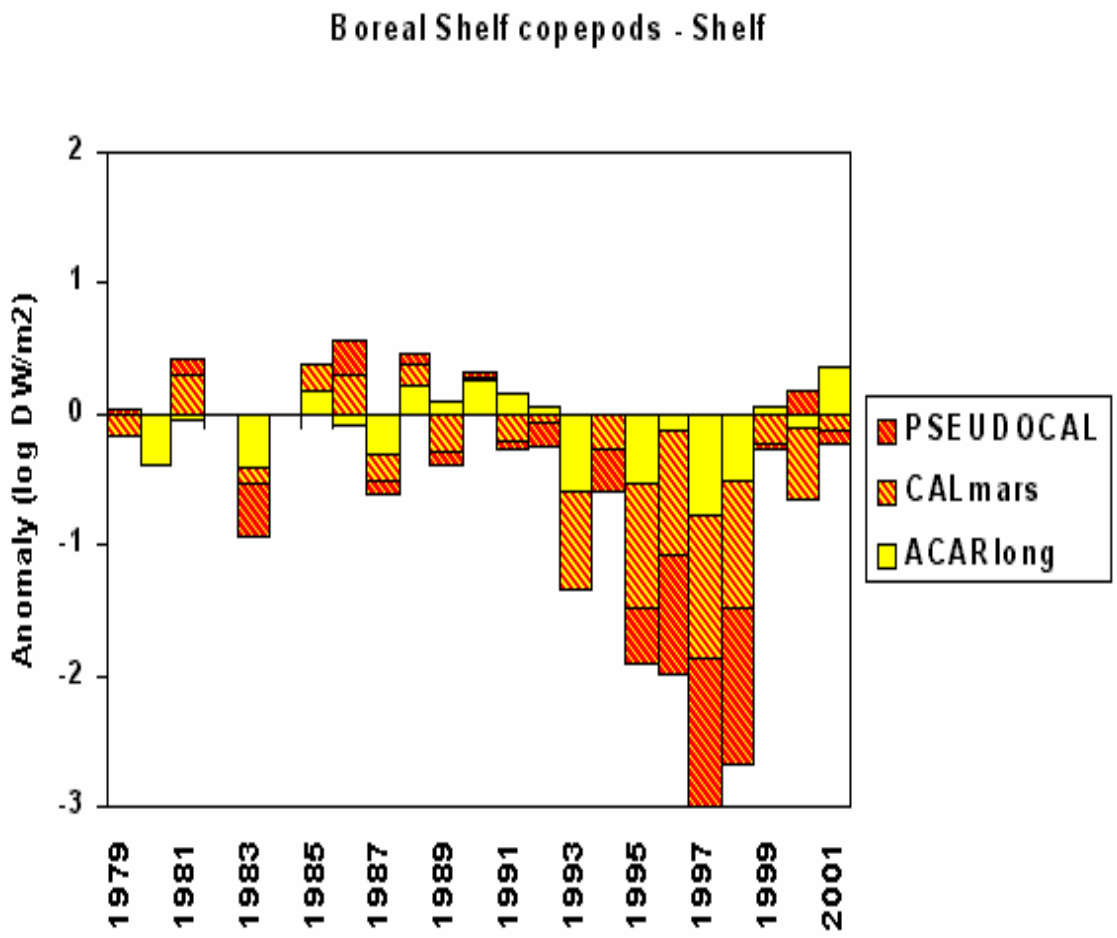
Anomaly time series also very similar between BC and Oregon

- (Mackas, Peterson & Zamon, 2004)
- r = 0.3 – 0.95
- Amplitude of anomalies declines from south to north

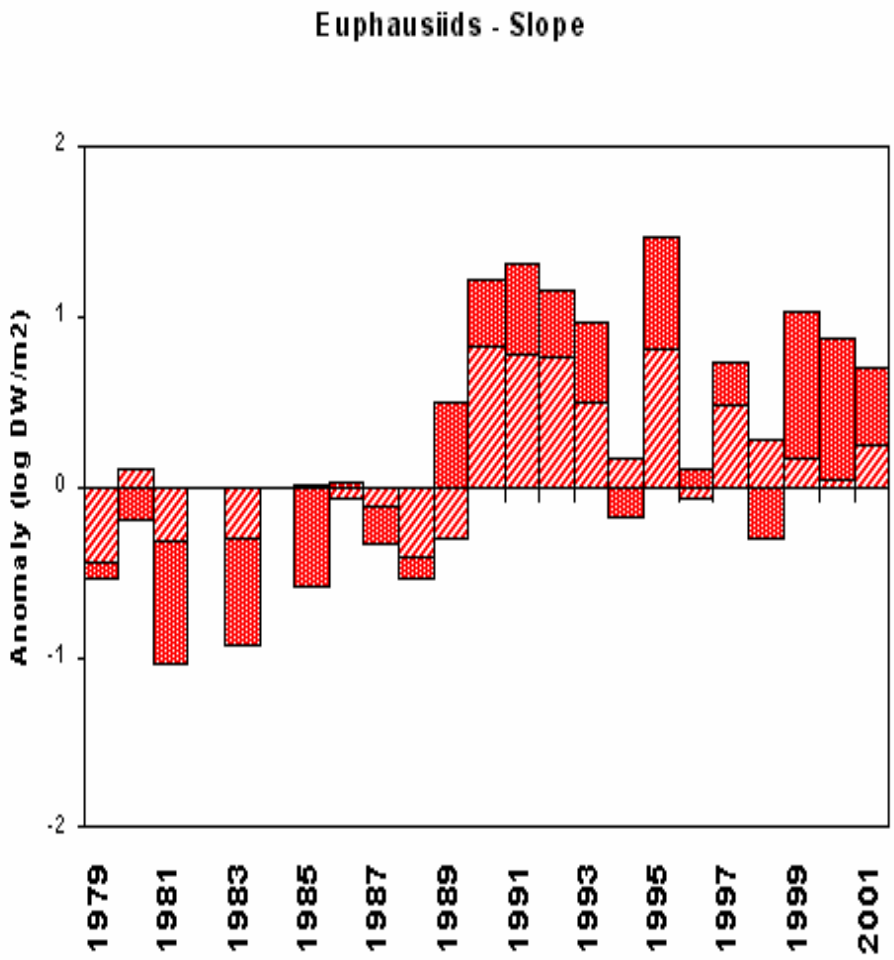


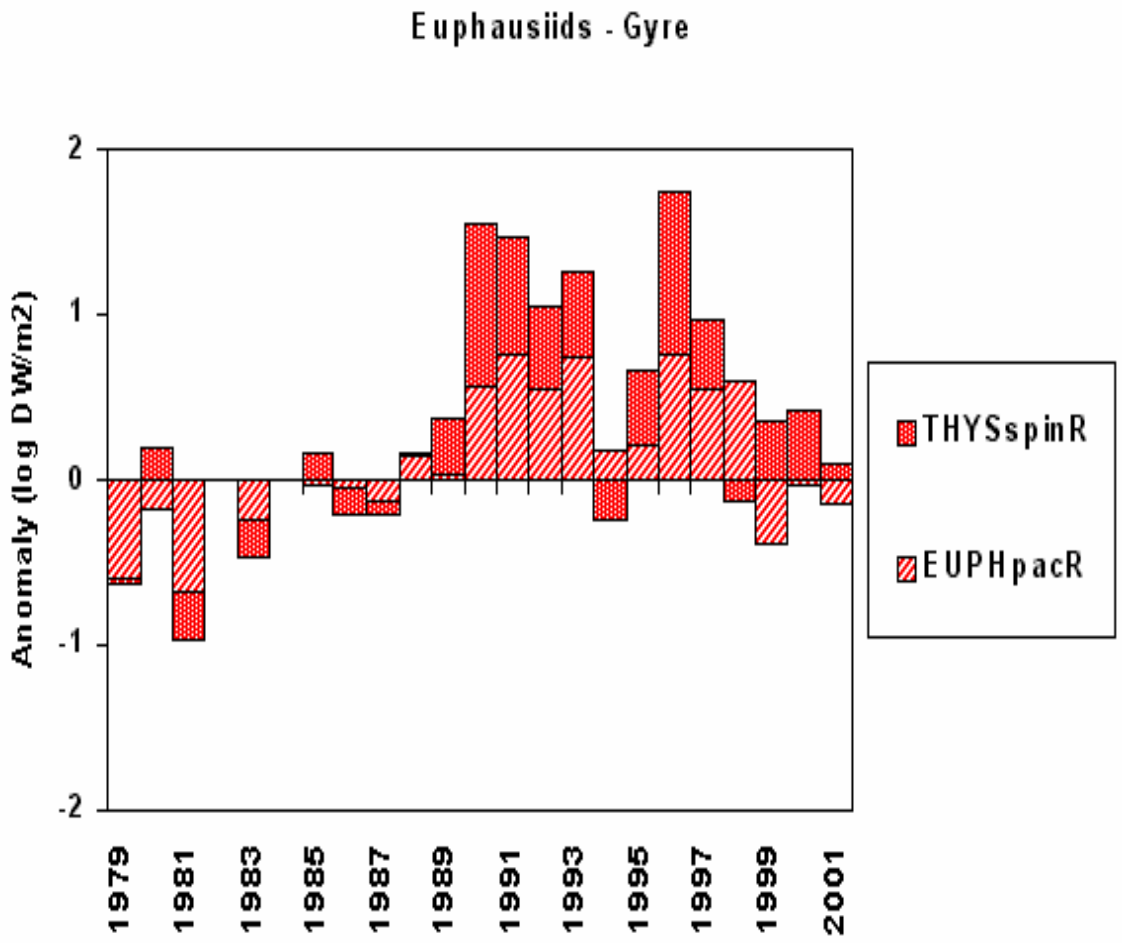
Example:
Big 1990-98 declines, 1999-2000 recovery for "boreal continental shelf" species: *Calanus marshallae, Acartia longiremis, Pseudocalanus* spp.





Example : Big fluctuation in euphausiids (up at end of 80s, down in mid-late 90s): *Euphausia pacifica, Thysanoessa spinifera*





Standardization & intercalibration of sampling methods

Any method change risks loss of time continuity (a serious concern)

Net intercalibrations are feasible (e.g. McKinnell & Mackas 2003):

- **Mesh size, flow metering, tow depth all matter, <u>but</u>**
- **Modern nets (if flow-metered) perform similarly**
- **Correction factors often small compared to real signal**