Food Webs

Relatively few species
(discounting the controversy over the number of microbes)

Yet:

1) High diversity in terms of trophic mode, e.g., herbivory, carnivory, mixotrophy, omnivory
2) Trophic level changes with developmental phase (egg to adult) within a species
3) Prey selection based on size, but not necessarily at a ratio of 1:10, especially for raptorial/direct interception consumers
4) Behaviors lead to niche partitioning, even though environment relatively uniform, e.g., diel vertical migration

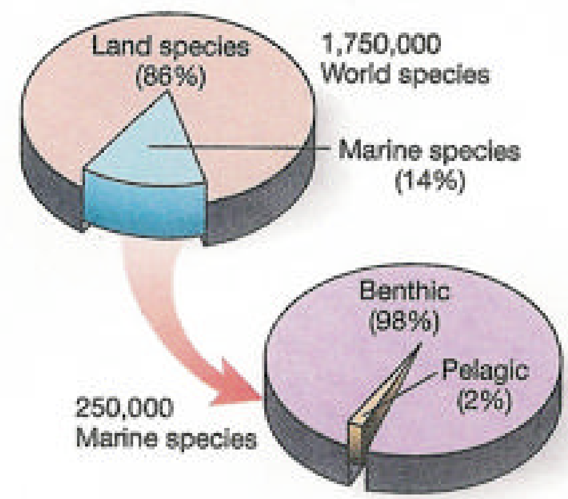


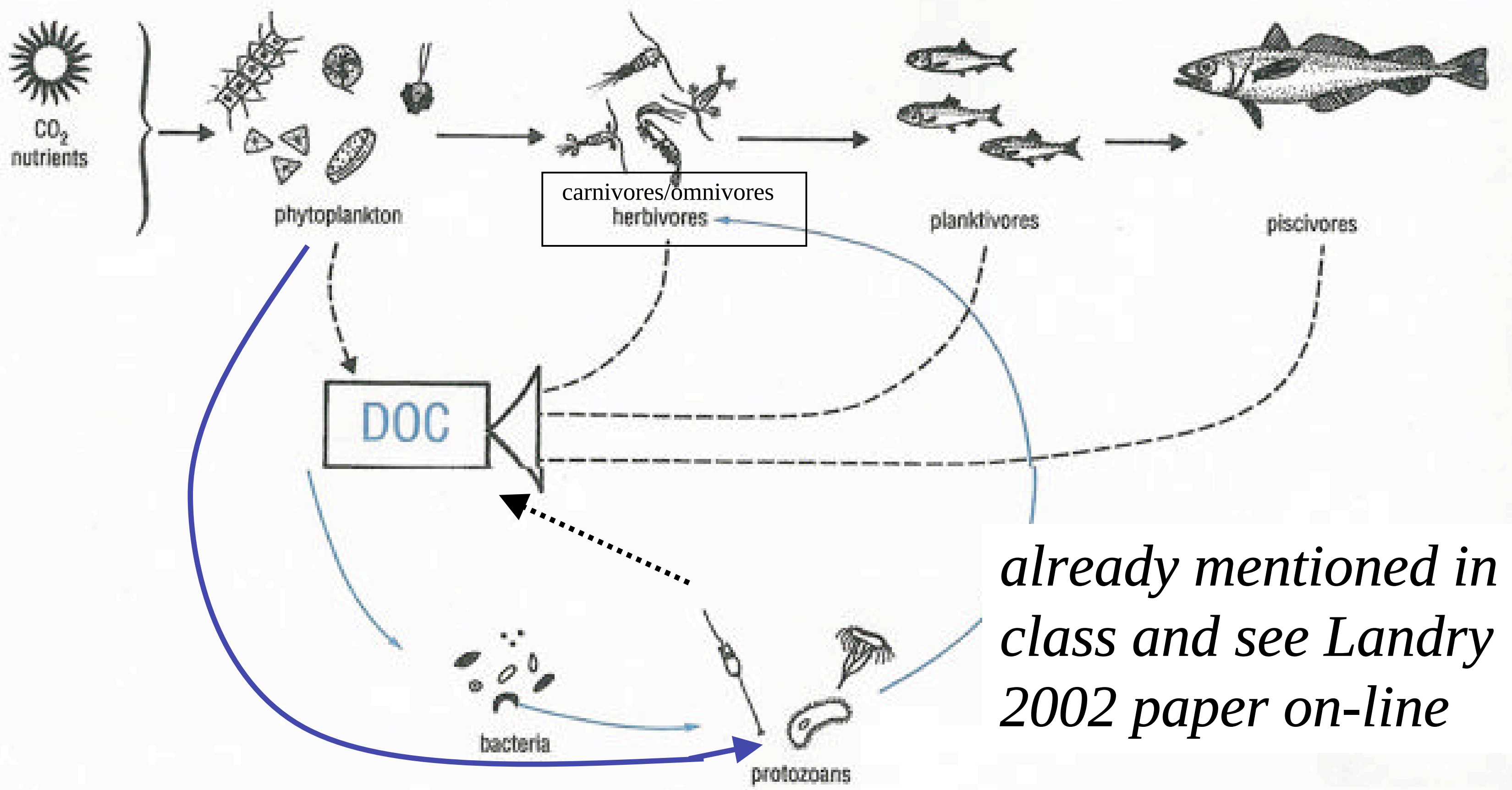
Figure 13–6 Distribution of species on Earth.

Of the 1,750,000 known species on Earth, 86% inhabit land environments and 14% inhabit the ocean. Of the 250,000 known marine species, 98% inhabit the benthic environment and live in or on the ocean floor, while only 2% inhabit the pelagic environment and live within the water column as either plankton or nekton.

Given this background, how would we expect food webs to look?

Integrating Classical and Microbial Loop Food Webs

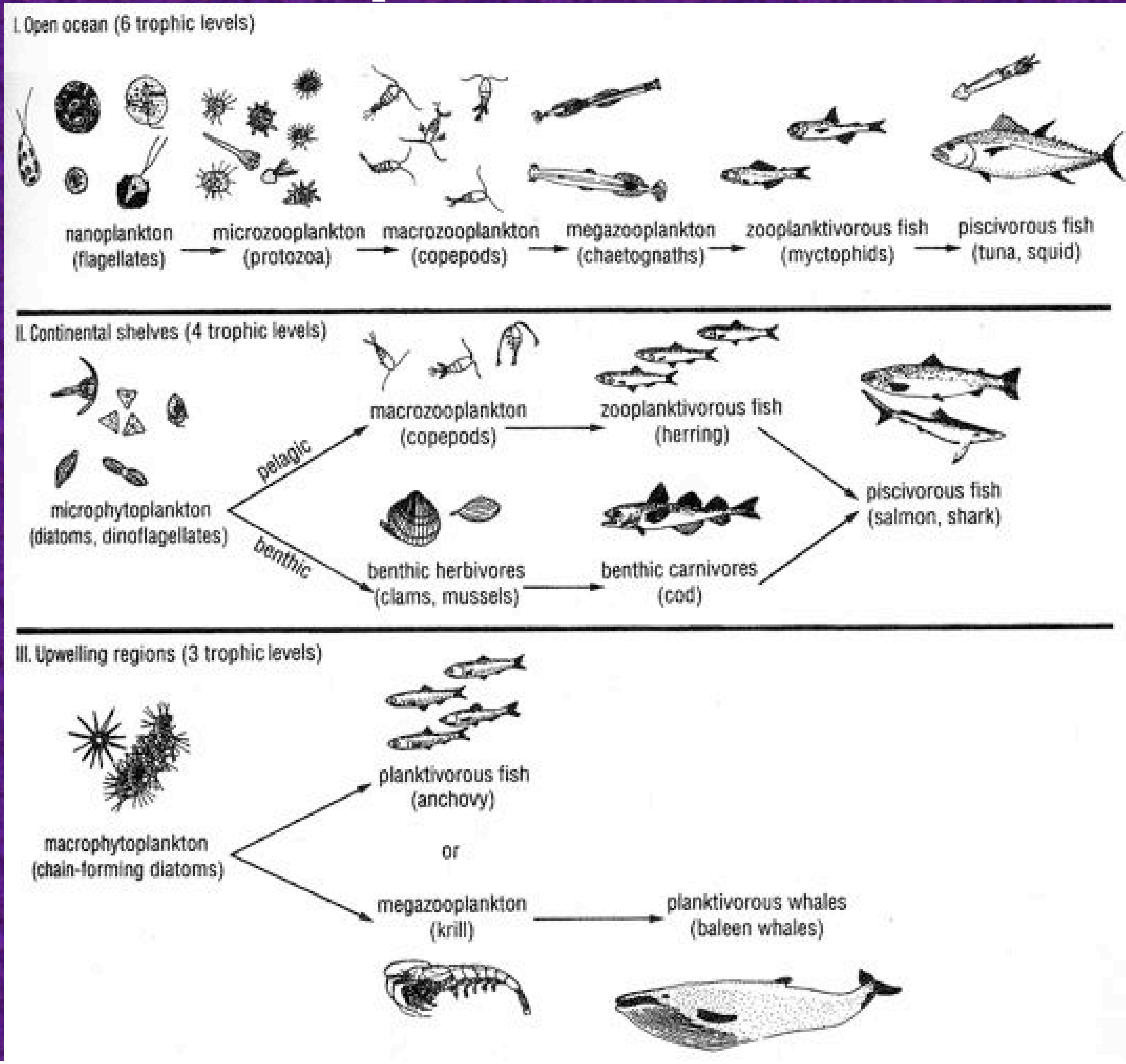
Figure 5.7 A schematic illustration showing the coupling of the pelagic grazing food chain (phytoplankton to piscivorous fish) and the microbial loop (bacteria and protozoans). Dashed arrows indicate the release of dissolved organic material (DOC) as metabolic by-products. The DOC is utilized as a source of carbon by heterotrophic bacteria. The bacteria are consumed by protozoans, which in turn are eaten by larger zooplankton.



already mentioned in class and see Landry 2002 paper on-line

modified from Lalli & Parsons 1997

Comparison of food web structures



oligotrophic

eutrophic

Lalli & Parsons 1997

NW Atlantic Food Web

Humans (7 - 10)

Whales/porpoises/ birds (6 - 9)

Squid (5 - 8)

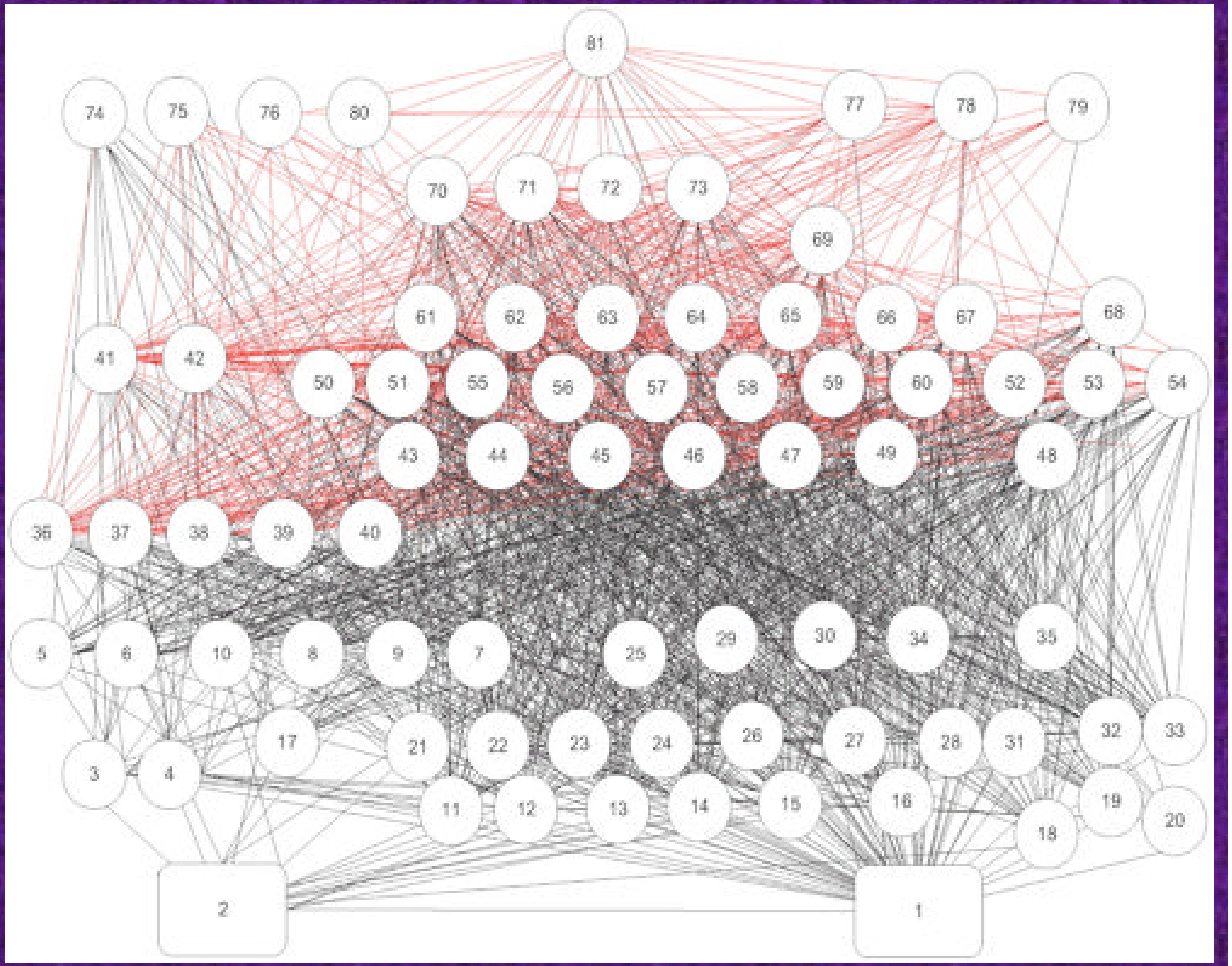
Bigger fish (4 - 7)

Small fish (4 - 6)

Ctenophores/ Chaetognaths (3 - 5)

Copepods (2 - 4*)

Phytoplankton (1)



Link, 2002

Trophic Transfer Efficiency

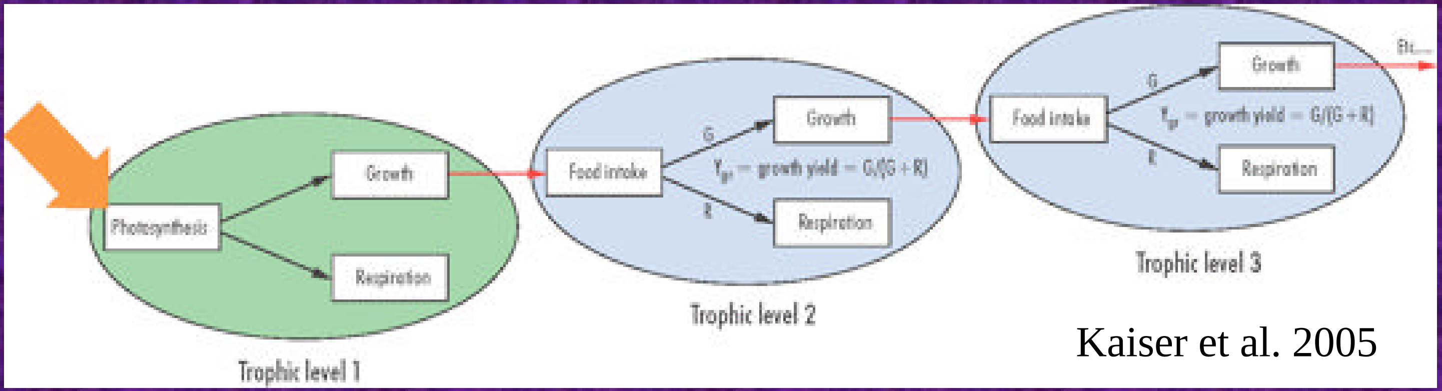
TTE (or Trophic Yield) = *Amount of production at trophic level (X+1) relative to production at trophic level X*

-- *Usually thought to be lower than GGE, because of other modes of death (e.g., viral lysis, natural death...)*

-- *Because of losses to metabolism/egestion at each step, longer food chains result in less yield to the top predator*

How to apply to actual food chain?

Overall Food Chain Efficiency = TTE(2)*TTE(3)*TTE(4)*TTE(n)

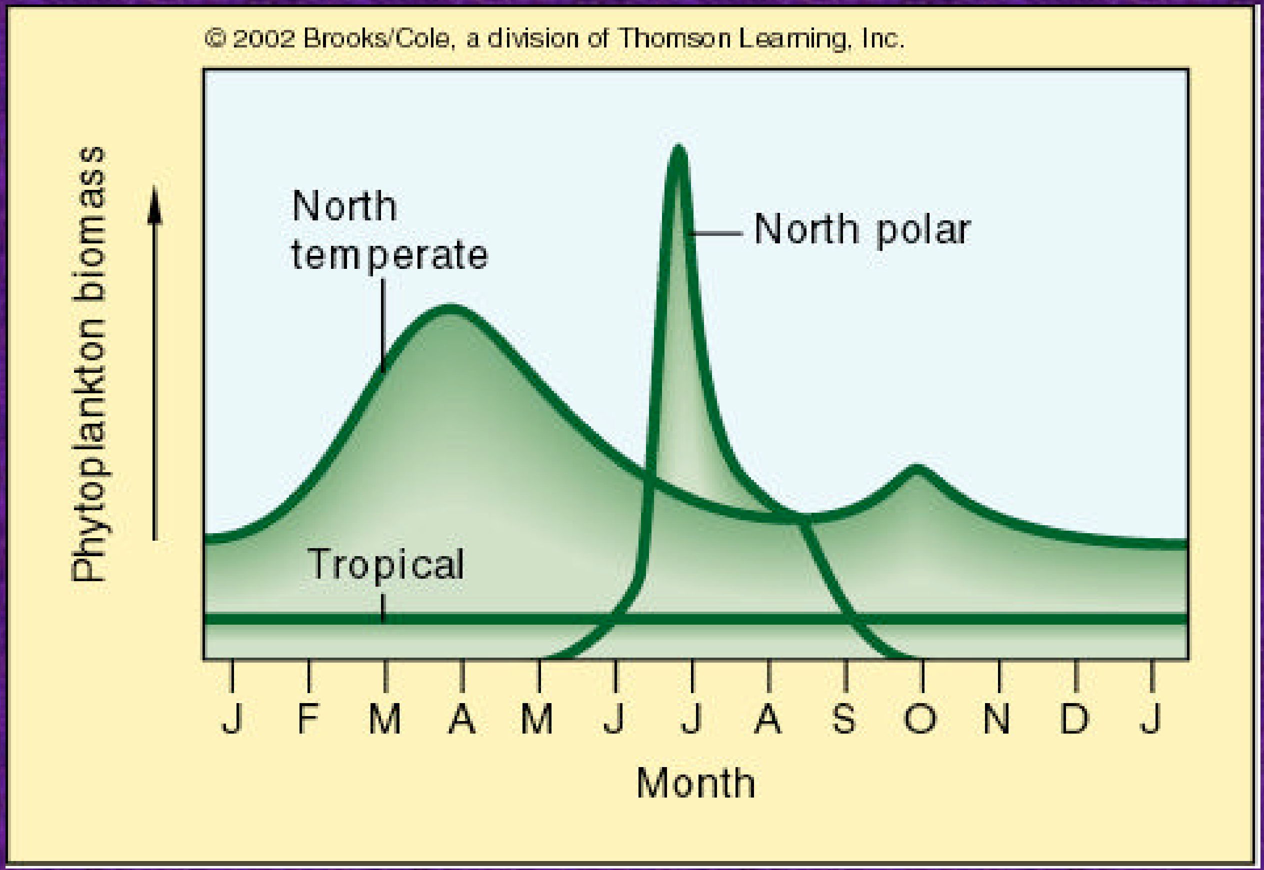


Kaiser et al. 2005

How does biomass change over a seasonal cycle and what does it mean?

Spring blooms

biomass, not production



This is the general view of three of the ocean ecosystems on the planet...

Historical Observations of Seasonal Cycles

- Using net tows, catch diatoms, large dinoflagellates and zooplankton
- From these catches, infer food web relations and seasonal cycles
- Did use *in situ* chlorophyll measurements around the world's seas to generate maps

(note: didn't have large scale, synoptic maps such as we have today with satellites)

North Atlantic Bloom

1) Phytoplankton low through the winter:
   light limited, nutrients sufficient
   deep winter mixing

2) Spring Bloom
   reduced winds, stratification near surface
   increased light, nutrients sufficient

3) Summer: Low phyto biomass
   grazers consume the phytoplankton
   nutrients depleted and not renewed

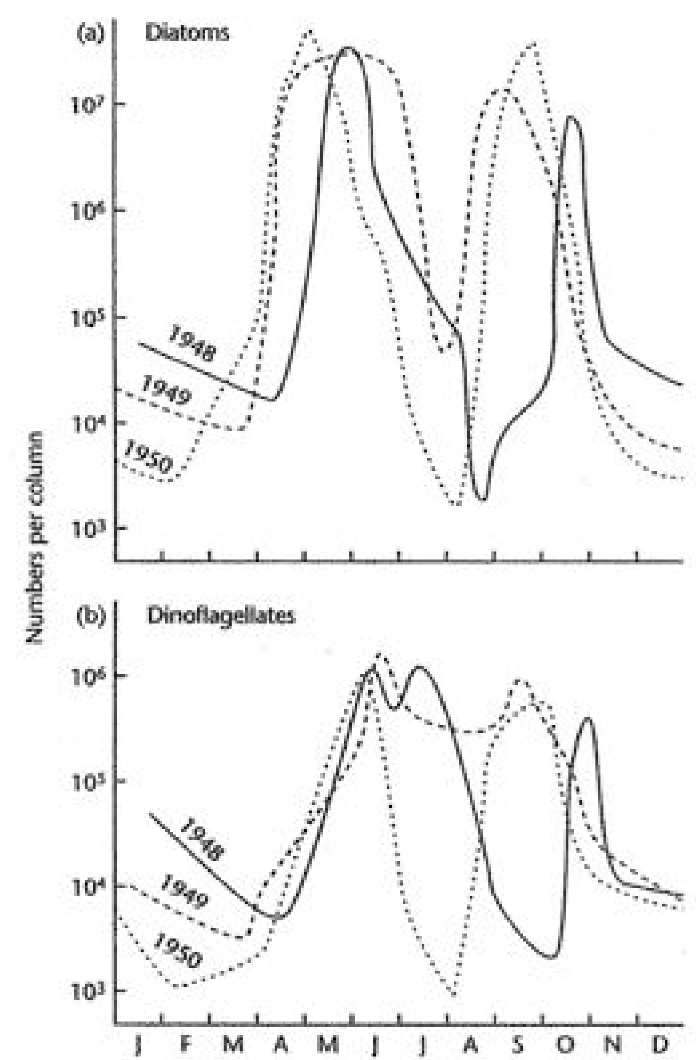
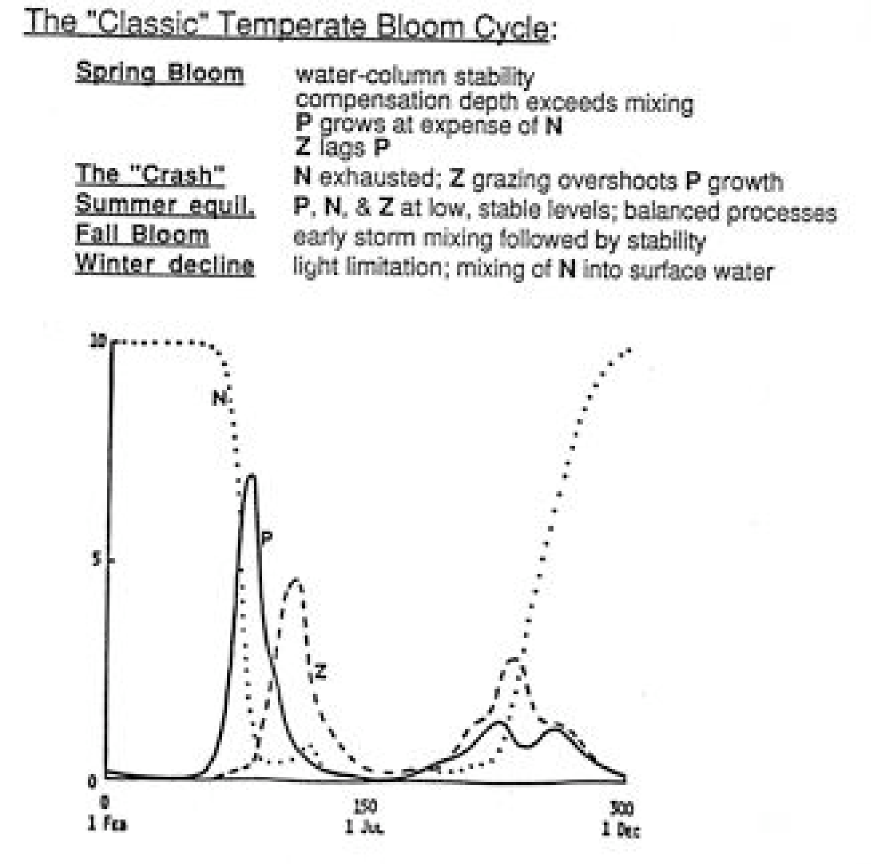


Fig. 1.12 Seasonal cycles of (a) diatoms and (b) dinoflagellates at Station "I" (60°N, 20°W) in the North Atlantic. Diatoms bloom, and then are replaced by dinoflagellates. Bloom timing varies among years by a month or more. Cells were counted with a microscope. (After Corlett 1953.)

End of North Atlantic Bloom

4) Fall: Second bloom
   - Fewer grazers: non-feeding stage
   - Intermittent storms
   - Inject nutrients, but still stratified
   - Light sufficient

5) Early winter:
   - Storm mixing
   - Re-supply of nutrients to surface
   - Set for next Spring Bloom



In places where phytoplankton cycles are strongly different (most of the rest of the world's oceans!), they are usually discussed in contrast to the spring bloom cycle.

An ecosystem change?
Jellyfish in the North Atlantic

Hot topic -- *Hydrobiologia* special issue in 2009

Usual top predator: Cod or other fish species

Observation:

Jellyfish increasing in frequency in North Sea

Data from Continuous Plankton Recorder

(towed monthly behind merchant ships at 6.5 m -- records presence/absence of nematocysts)

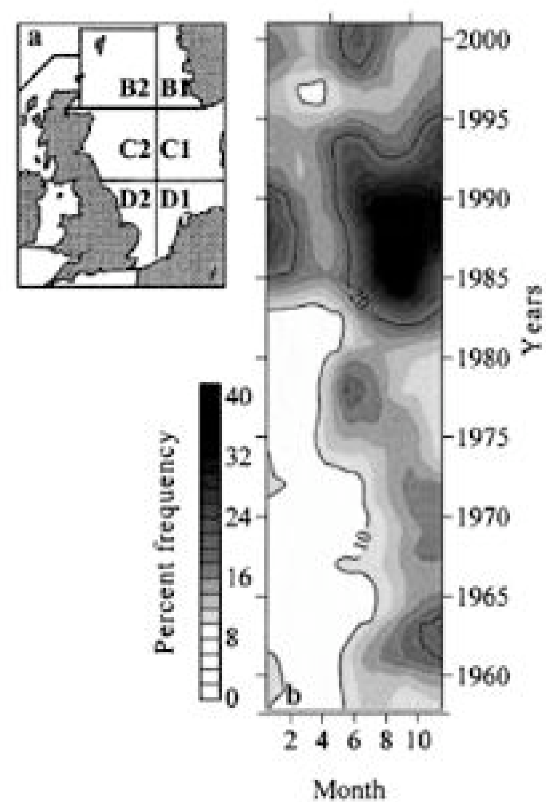


Fig. 1. (a) Diagram of North Sea indicating standard CPR areas sampled in this study. (b) Trends in jellyfish frequency (% occurrence) since 1958: Monthly averages for whole North Sea region (Gaussian smoother applied).

Attrill et al. 2007

Volume 616, Number 1 / January, 2009

Journal: Hydrobiologia
Publisher: Springer Netherlands
Pages: 1-289

Editorial View | Condensed List View | Expanded List View

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Extension of methods for jellyfish and ctenophore trophic ecology to large-scale research	23-50
Patterns of jellyfish abundance in the North Atlantic	51-65
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Stock enhancement of the edible jellyfish (Rhopilema esculentum Kishinouye) in Liaodong Bay, China: a review	113-118

Bad years for herring = good years for jellyfish?

Data set from a 15 year survey (1971-1986), with jellyfish as by-catch

herring recruitment

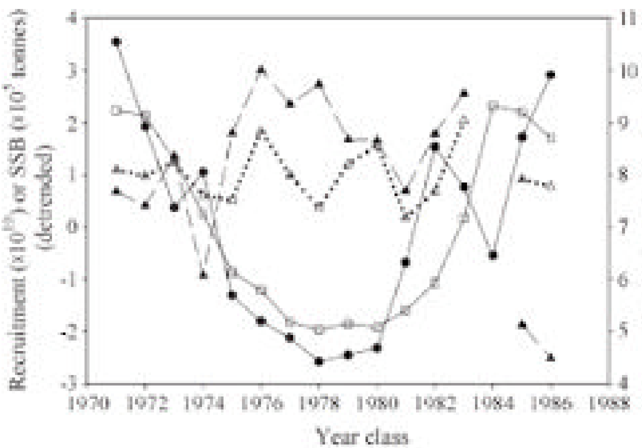


Fig. 4. *Clupea harengus*, *Aurelia aurita* and *Cyanea capillata* in the North Sea. Detrended time series of herring recruitment (solid line, ●), SSB (solid line, □) and the abundance of *A. aurita* (dashed line, ▲) and *C. capillata* (dotted line, Δ). For ease of comparison, the *C. lamarckii* data are all +5. Correlation coefficient between herring recruitment and SSB, r = 0.79; between herring recruitment and medusa abundances: *A. aurita* r = −0.67 and *C. capillata* r = −0.68 (all p < 0.01)

jellyfish abundance

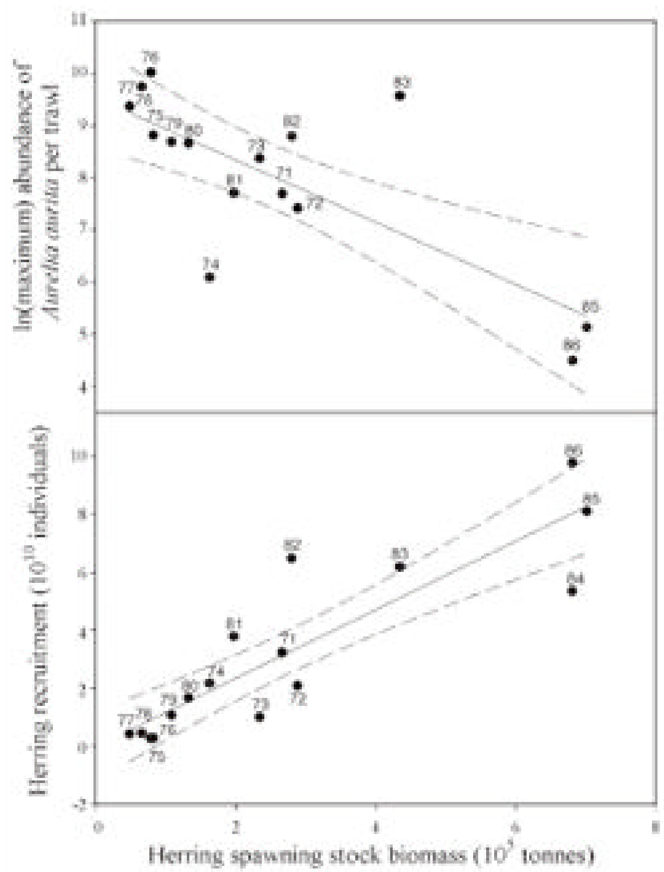


Fig. 2. *Clupea harengus* and *Aurelia aurita* in the North Sea. Correlations between the raw herring SSB (spawning stock biomass) and recruitment (r = 0.89, p < 0.01, bottom panel) and between SSB and the ln(maximum) abundance of *A. aurita* (r = 0.75, p < 0.01, top panel)

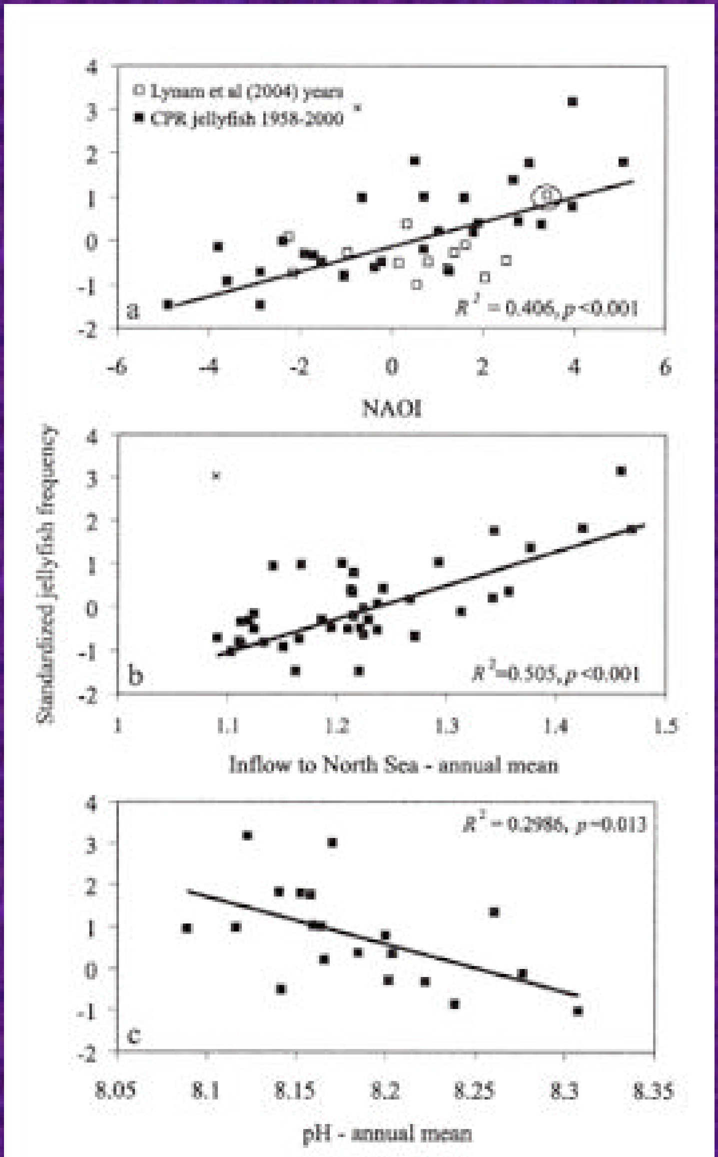
Lynam et al. 2005

Why? Natural Environmental Variability (NAO) *and/or* effect of overfishing

Jellyfish (medusoid Scyphozoa) eat larval herring and also compete with them for their zooplankton prey

Adult finfish and jellyfish also compete for prey

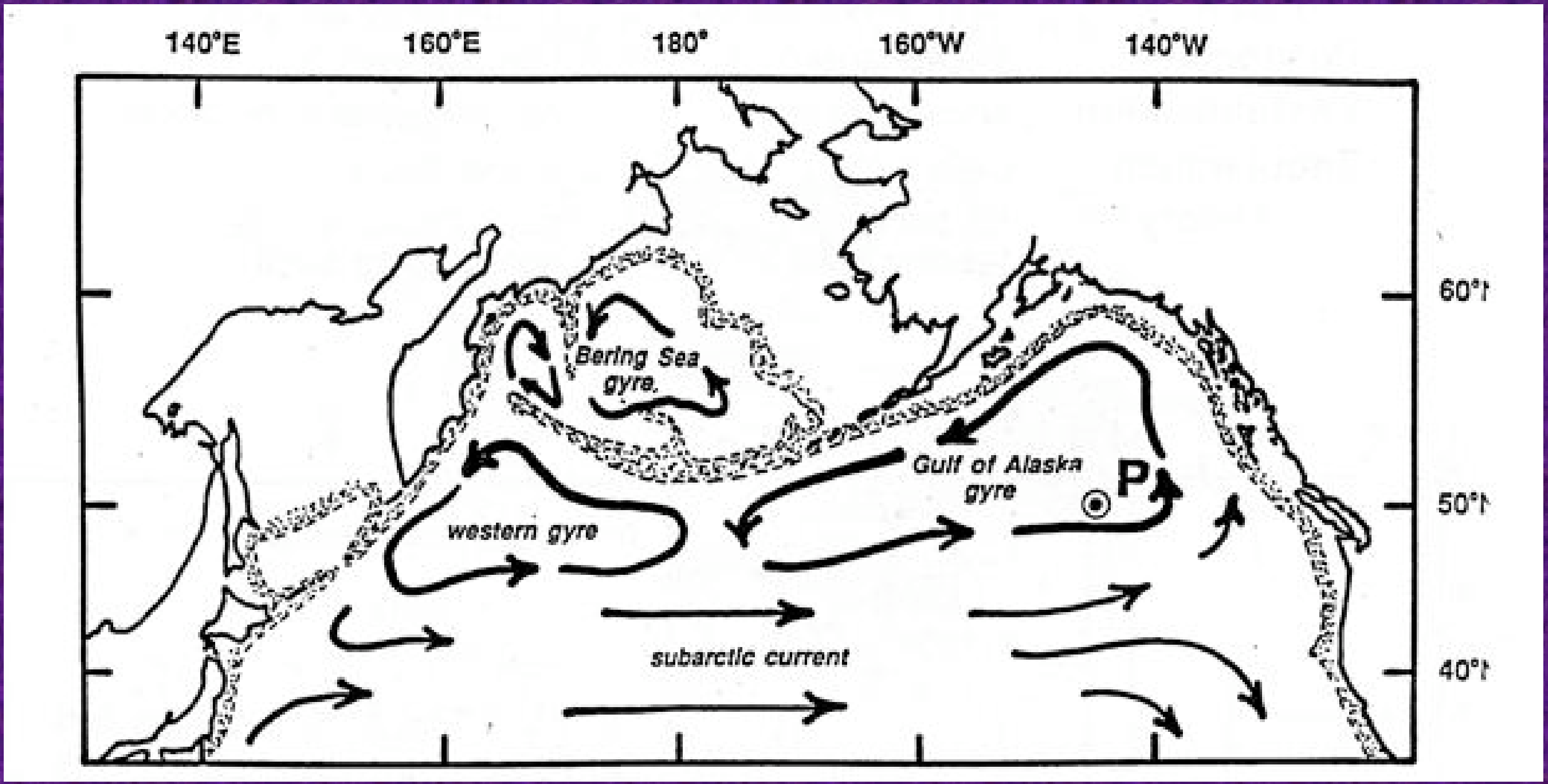
Reduced larval herring stocks, and therefore adult herring, further allow jellyfish to outcompete them



Attrill et al. 2007

Subarctic Pacific - HNLC region

- Objective: to test the "Major Grazer" Hypothesis (1980)
- Experimental goal: Can mesozooplankton grazers control phytoplankton stocks?



Miller et al. 1991
L & O 36:1600-1615

Observations

- Seasonal blooms do not occur --- Canadian weathership at Station P (50°N, 145°W)
- Occupied station from 1950s until mid-1981

This is in contrast to the North Atlantic -- chlorophyll levels >1 mg/m^3 every year

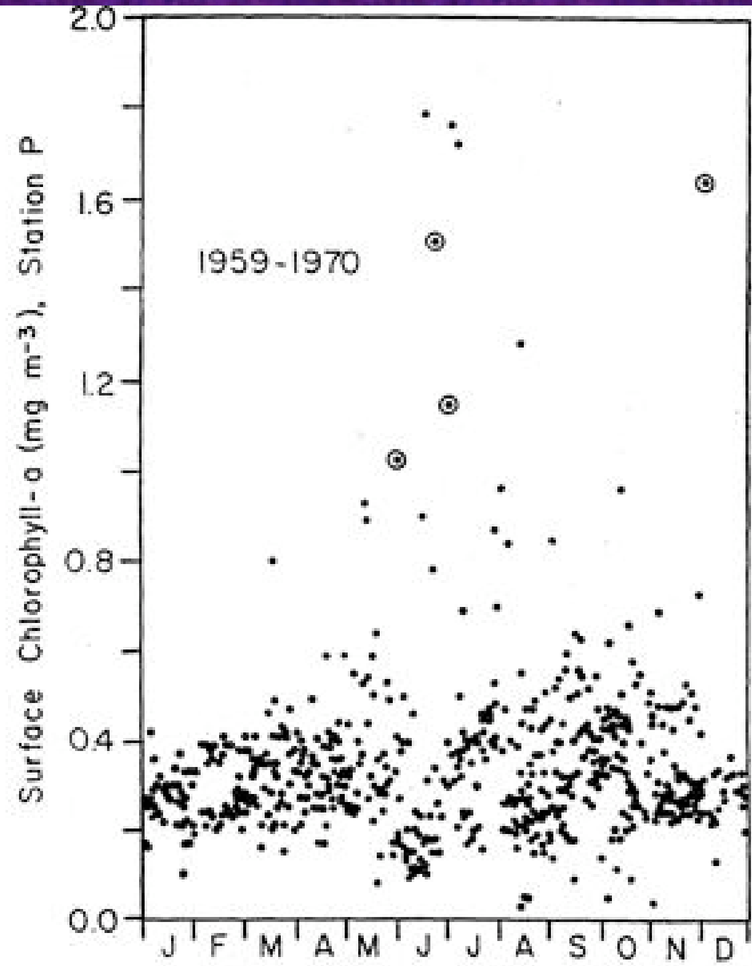


Fig. 1. Cumulative chlorophyll-a data from Ocean Stn. P over 10 years. Note that scale extends only to 2.0 mg/m^3. Circled points are all additional values over 1.0 mg/m^3 during 1970–76. From Anderson et al. (1977).

Characteristics of Subarctic Ecosystems

- deep winter mixing in Atlantic, but a permanent halocline in the Pacific
- low summer nitrate in Atlantic, but still high in summer in Pacific

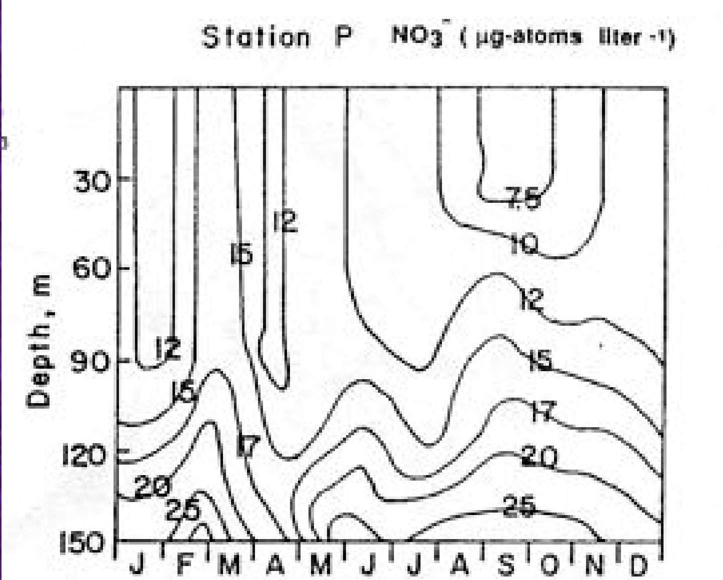
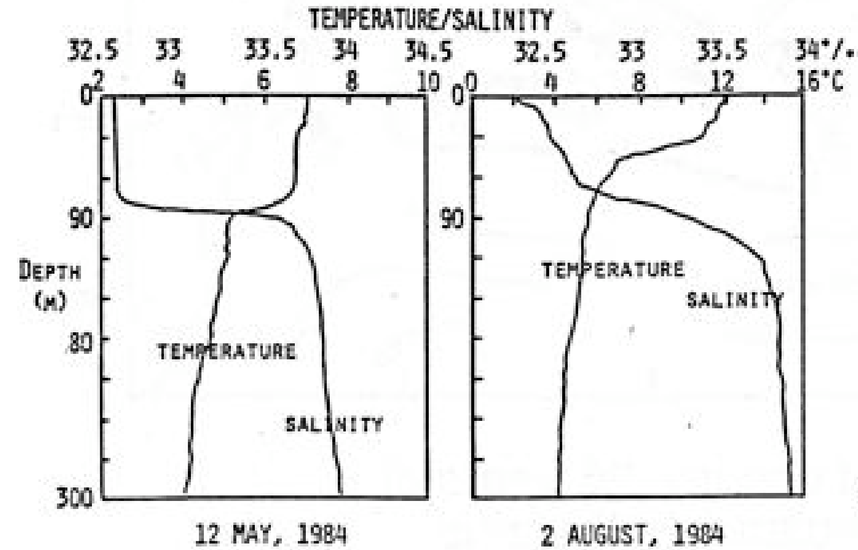
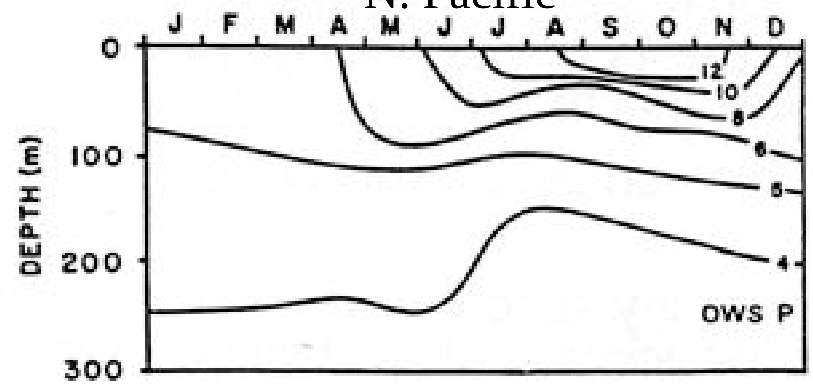


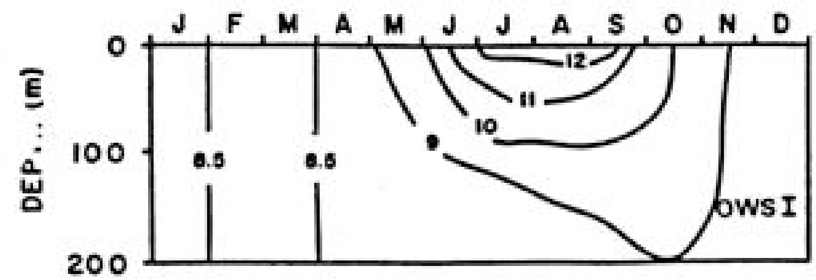
Fig. 6. Annual variation in upper-layer NO3 concentration at Ocean Station P. Redrawn from Anderson et al. 1977.



N. Pacific



N. Atlantic

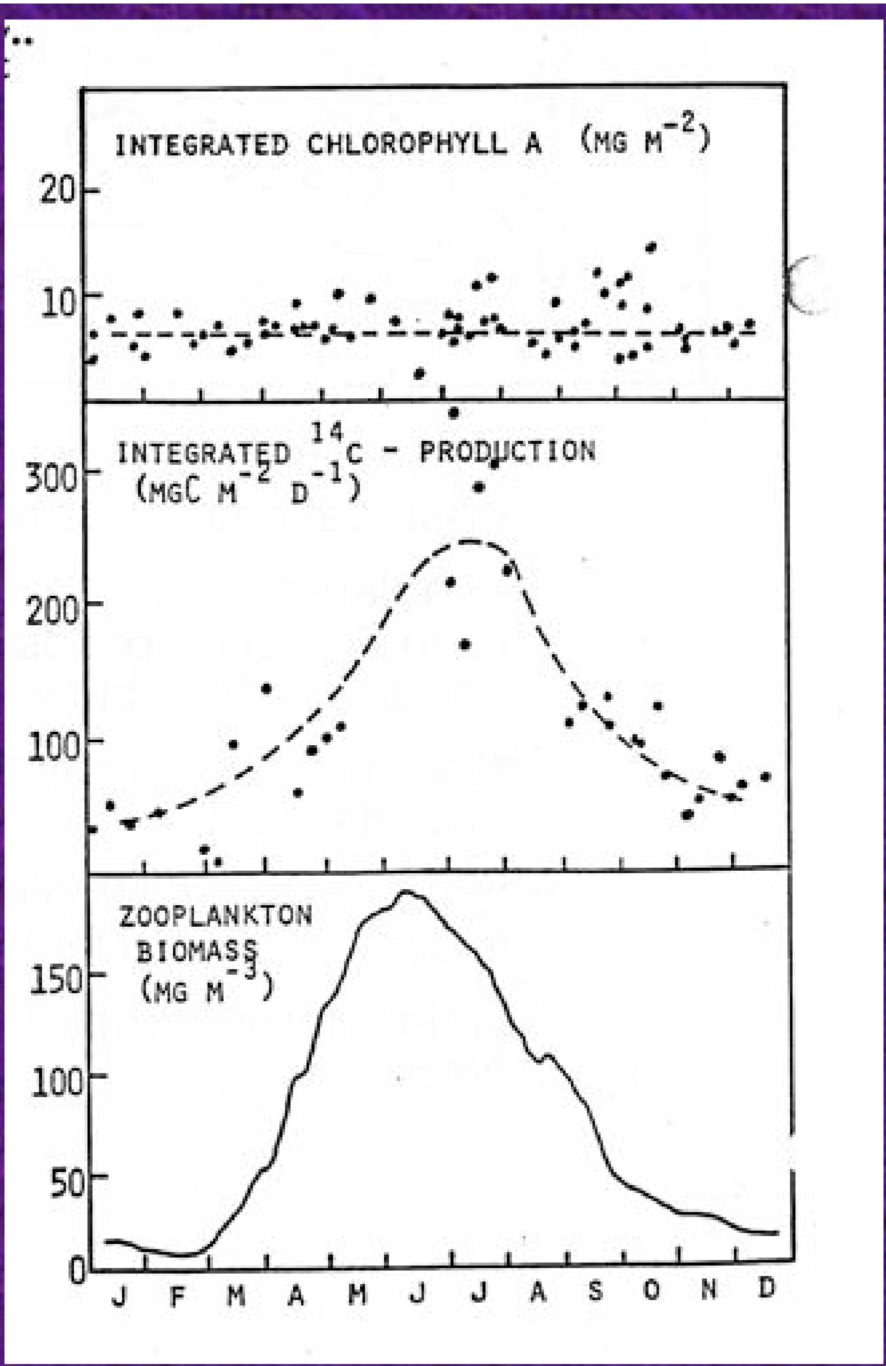


Plankton

• Phytoplankton concentration low & nearly constant year round despite excess nutrients (nitrate) & physical conditions favoring a seasonal bloom.

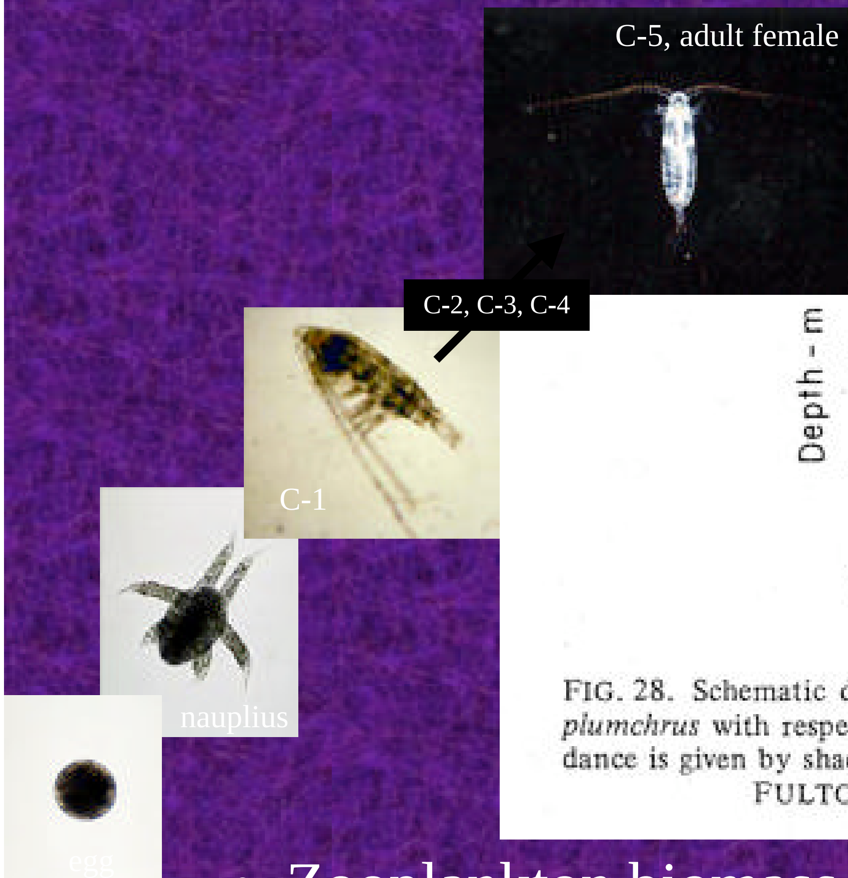
• Seasonal signal in phytoplankton production, but not abundance

• Phytoplankton dominated by tiny species, similar to tropics, not large forms associated with high nitrate



Seasonal migration of *Neocalanus plumchrus*

- Zooplankton dominated by large species, *Neocalanus (4-5 mm)*



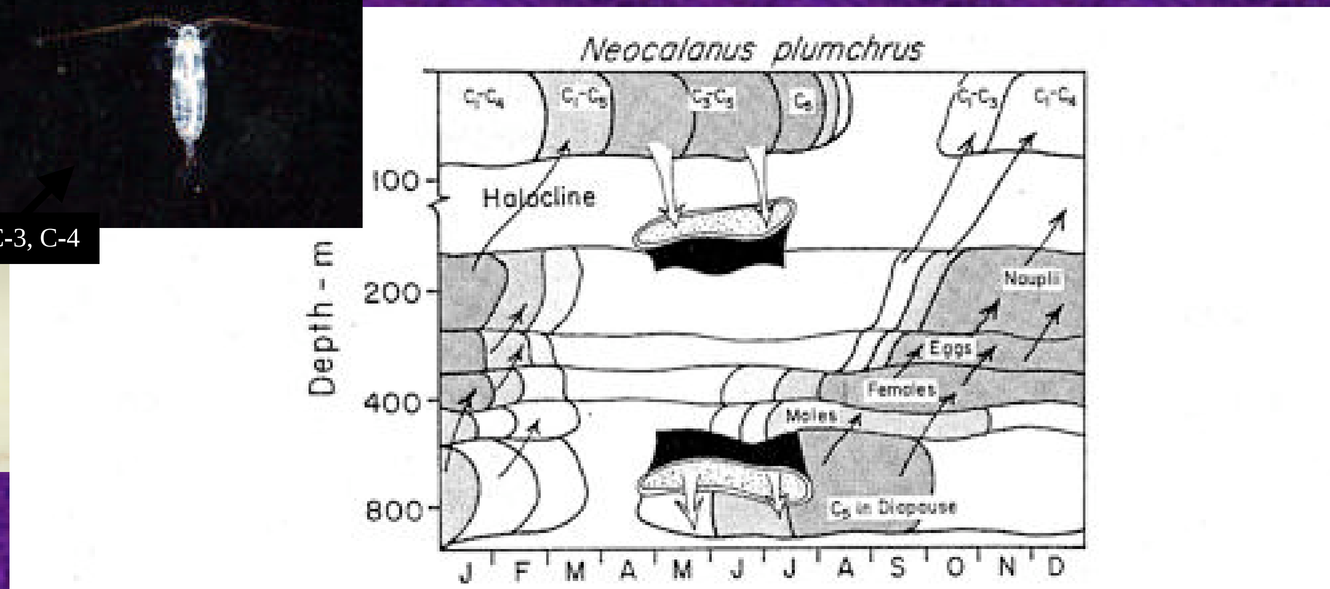


FIG. 28. Schematic diagram showing the distribution of the life cycle stages of *Neocalanus plumchrus* with respect to season (abscissa) and depth (ordinate). A rough indication of abundance is given by shading: darker implies greater abundance. Drawn in the format of Fig. 5 of FULTON (1973) for comparison to the Strait of Georgia situation.

Miller et al. 1984

- Zooplankton biomass peaks in summer: leads to historical hypothesis that phytoplankton controlled by grazing by large copepods.

Images from: http://tnfri.fra.affrc.go.jp/eindex.html and www.pac.dfo-mpo.gc.ca/. ../copepoda_e.htm

Control Capabilities of *Neocalanus*

- Could consume cells 2-30 µm, but *food limited* at ambient concentrations
  - Could keep phytoplankton in check at an abundance of 1 copepod/Liter
    - Without them present, phytoplankton did bloom

But: not present in sufficient density to control blooms (only ~0.2/L)

- Another role: to consume smaller grazers...

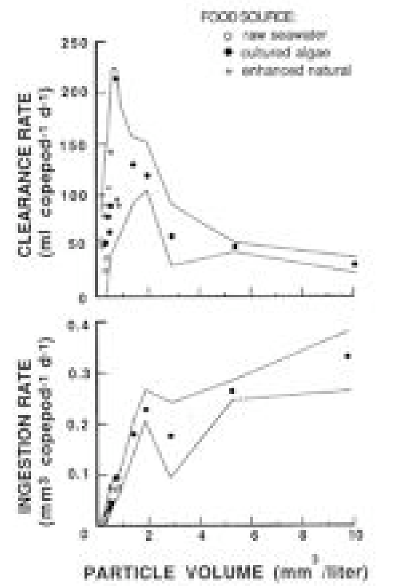


Fig. 3. Effect of food concentration (total particle volume 2–40 µm ESD) on clearance and ingestion rates of *Neocalanus plumchrus*. The figure summarizes the results of feeding experiments with natural particulates from the subarctic Pacific, natural particulates grown to higher abundance levels in shipboard incubations, and mixed phytoplankton cultures (*Isochrysis galbana* and *Thalassiosira weissflogii*). Each point represents the mean of 3–5 rate measurements. The upper and lower lines bound the complete range of variability observed in individual replicate bottles.

Left: Rate estimates from bottle expts.

Right: Experiments in 60-L microcosms

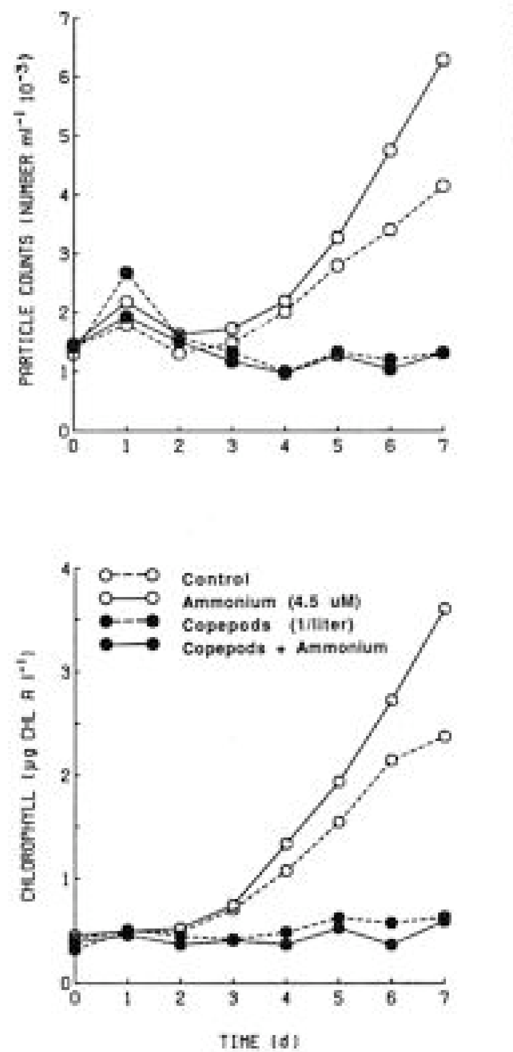


Fig. 4. Observed temporal changes in the abundance of phytoplankton, measured as particle densities (top) and chlorophyll (bottom), when natural seawater from the subarctic Pacific was incubated in microcosms with added ammonium (5 µM), copepods (*Neocalanus plumchrus* C5s – 1 copepod/liter), or ammonium and copepods.

Landry & Lehner-Fournier 1988

Role of Protists

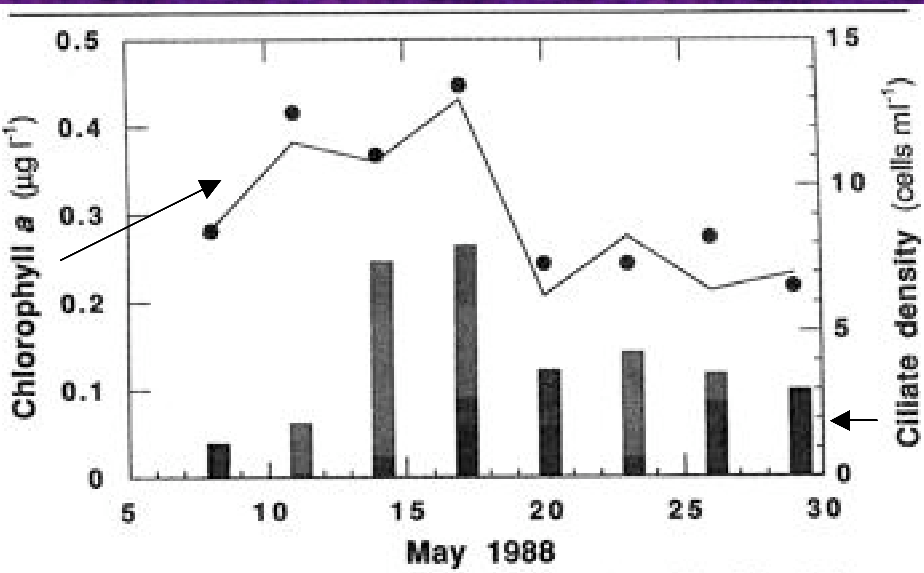
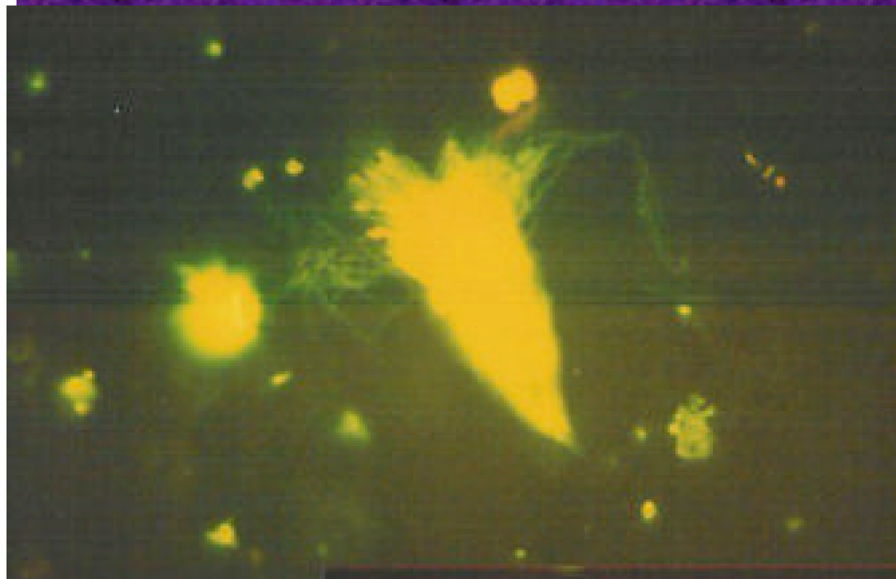


Fig.4. Temporal relationships among predicted and observed values of chlorophyll and ciliate density at Station P in May 1988. Filled circles are observed chlorophyll concentrations in the mixed layer from the measurements made at the start of dilution experiments (Table 1). Line represents the predicted chlorophyll concentration based on net growth rate (mean of r_{24} and r_{48}) determined in dilution experiments. Histogram shows the density of ciliates from water collected at the start of each experiment (Table 1).



Abstract – Dilution experiments were conducted on SUPER Program cruises in June 1987 and May and August 1988 to assess the role of microzooplankton in controlling phytoplankton stocks in the subarctic Pacific. Net growth rates of chlorophyll *a* varied in individual experiments from -0.4 to +0.7d^{-1}. Experiments incubated for 48h gave higher net estimates than 24h incubations (0.01 to 0.22 d^{-1} for different cruises), exaggerating the imbalance between growth and grazing. Specific growth rates (µ) and grazing mortality (m) for 24h incubations were approximately balanced for the June and May cruises, and net growth estimates from the dilution experiments predicted changes in chlorophyll concentrations for May that closely matched those observed in the field, A major decline in phytoplankton abundance in the middle of May coincided with a high abundance of ciliates. Cell counts indicated that *Synechococcus* and small autotrophic nonflagellates were always kept in check by microzooplankton grazing, even when chlorophyll indicated uncontrolled phytoplankton growth in August 1988 experiments. Diatoms showed high growth potential in most incubations and dominated among the cells that bloomed in August. Our results support the hypotheses that micrograzers are major consumers of phytoplankton in the subarctic Pacific and that their grazing can control some elements of the phytoplankton community. However, growth limitation, presumably from iron deficiency, remains essential to the explanation of phytoplankton control in mid to late summer.

Landry et al. 1993

Subarctic Pacific Ecosystem

1) Major grazers were not eating enough phytoplankton to provide for their own growth -- omnivores, eating phagotrophic protists

2) Too few mesozooplankton to keep phytoplankton in check

3) Microzooplankton grazing provides the top-down control on the system

4) First project to start to explore Fe-limitation to phytoplankton growth -- we know from subsequent studies that Fe-limitation alone is not sufficient to explain the system, need grazing regulation, too

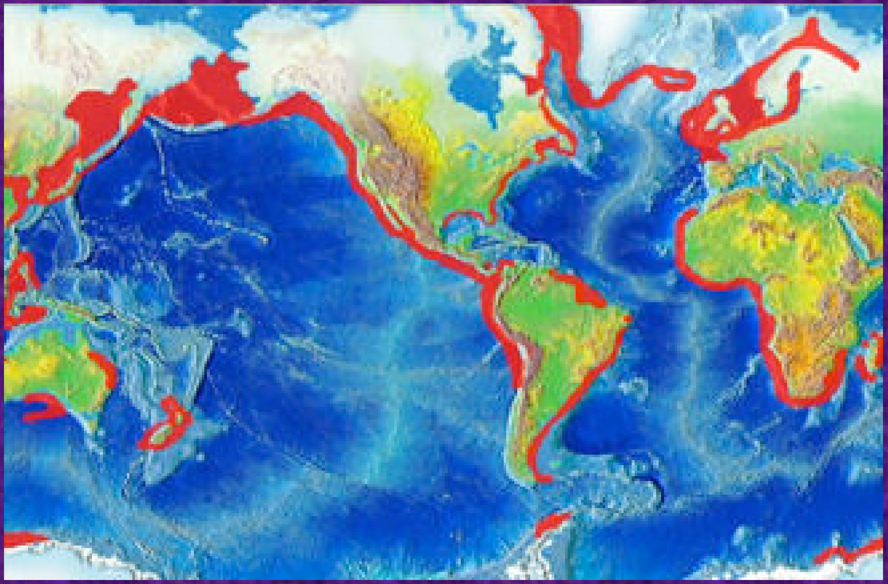
Upwelling Zones

Continental Shelf Ecosystem

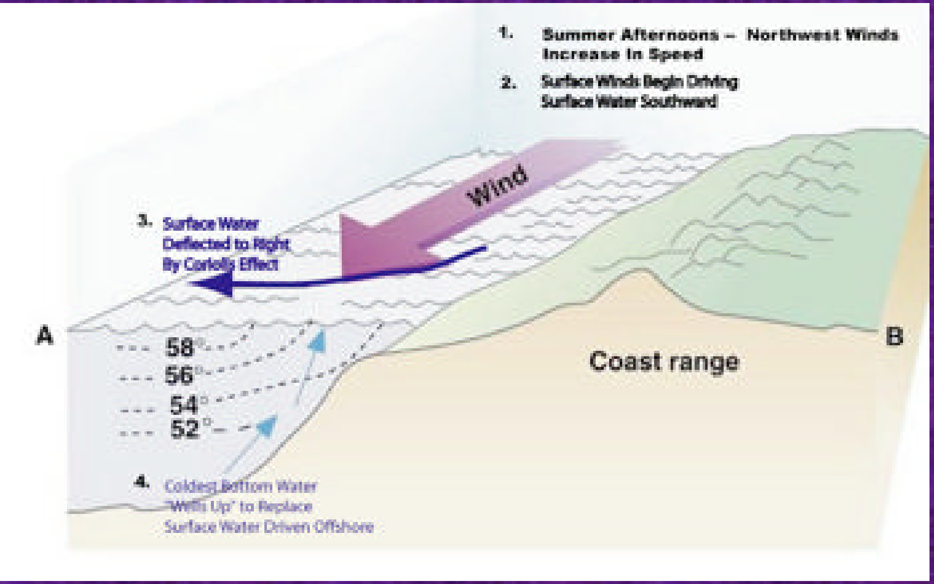
“Classical” coastal upwelling regions of eastern boundary currents and other coasts. Narrow shelf, river effluent influences minor.

Primary producers: diatoms

Primary herbivores: copepods, anchovies and/or sardines



http://oceanservice.noaa.gov



tornado.sfsu.edu

Small (<5 µm) Phytoplankton in Upwelling Zones

Despite dominance of diatoms in upwelling zones -- smaller phytoplankton are present, too

Table 3
Abundances (10^4 cells ml^{-1}) of coccoid cyanobacteria and of photosynthetic eukaryotes in the euphotic zone of upwelling ecosystems

Upwelling region	Coccoid cyanobacteria 10^4 cells ml^{-1}	Photosynthetic eukaryotes 10^4 cells ml^{-1}	Reference
Banc D'Arguin, Mauritania	0.01–6	0.06–0.62	Bak and Nieuwland (1993)
Mauritanian upwelling	up to 40	—	Partensky et al. (1996)
Arabian Sea, Monsoons	1.2–18	0.07–1.6	Brown et al. (1999)
Arabian coast	45	—	Burkill et al. (1993)
Costa Rican Dome	up to 150	—	Li et al. (1983)
New Zealand coastal upwelling	0.3–2	0.15–1.2	Hall and Vincent (1990)
Santa Barbara Channel, California Current system	12.3 ± 2.4	—	Putt and Prezelin (1985)
Northern Gulf of Alaska, SE Bering Sea	6–8	4	Liu et al. (2002)
Upwelling front, Oregon coast	2–29	0.08–0.39	Hood et al. (1992)
Oregon upwelling system	0.05–58	0.01–8.6	This study

Sherr et al. 2005

Distribution of Small vs. Large Phytoplankton in Oregon Upwelling System

onshore → offshore

Near Shore, relatively few small (<5 µm) phytoplankton -- mostly diatoms

Offshore, phytoplankton biomass dominated by small cells

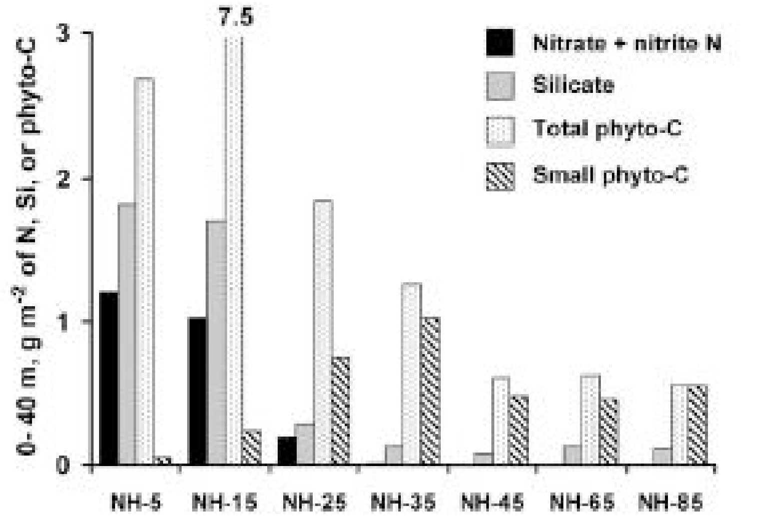
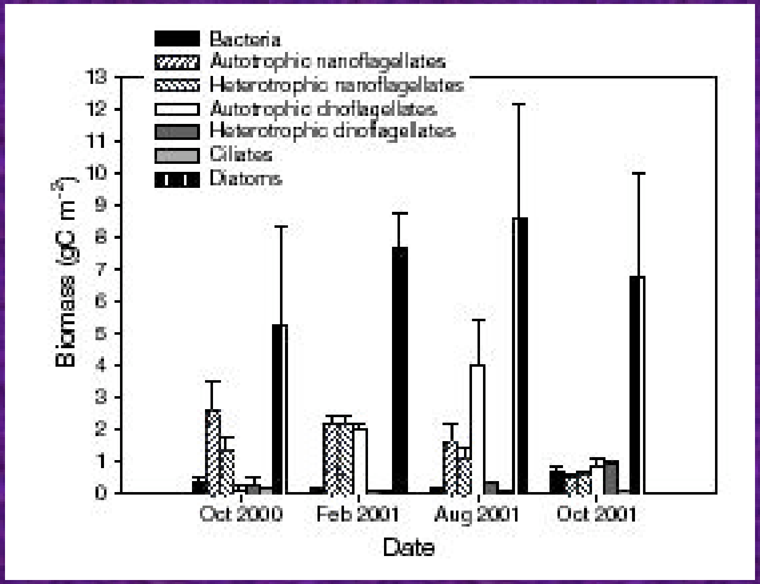
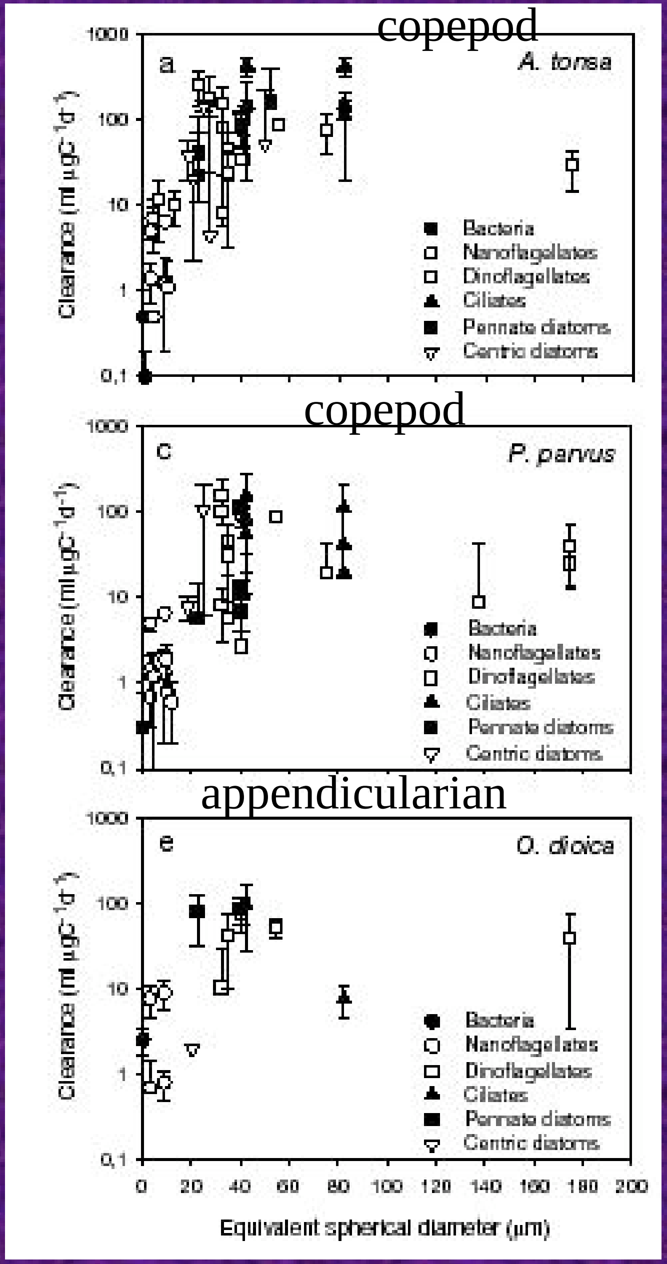


Fig. 4. Comparison of integrated 0–40 m stocks of nitrate + nitrite (g N m^{-2}) and of silicate (g Si m^{-2}) with biomass (g C m^{-2}) of total phytoplankton based on chlorophyll-*a* concentration and of small phytoplankton (SYN + small PEK) based on flow cytometric analysis across the Newport Hydroline in July 2001.

Sherr et al. 2005

Food Webs in Chilean Upwelling System





Biomass dominated by diatoms

Copepods and appendicularians have high clearance rates on microzooplankton, too -- omnivory

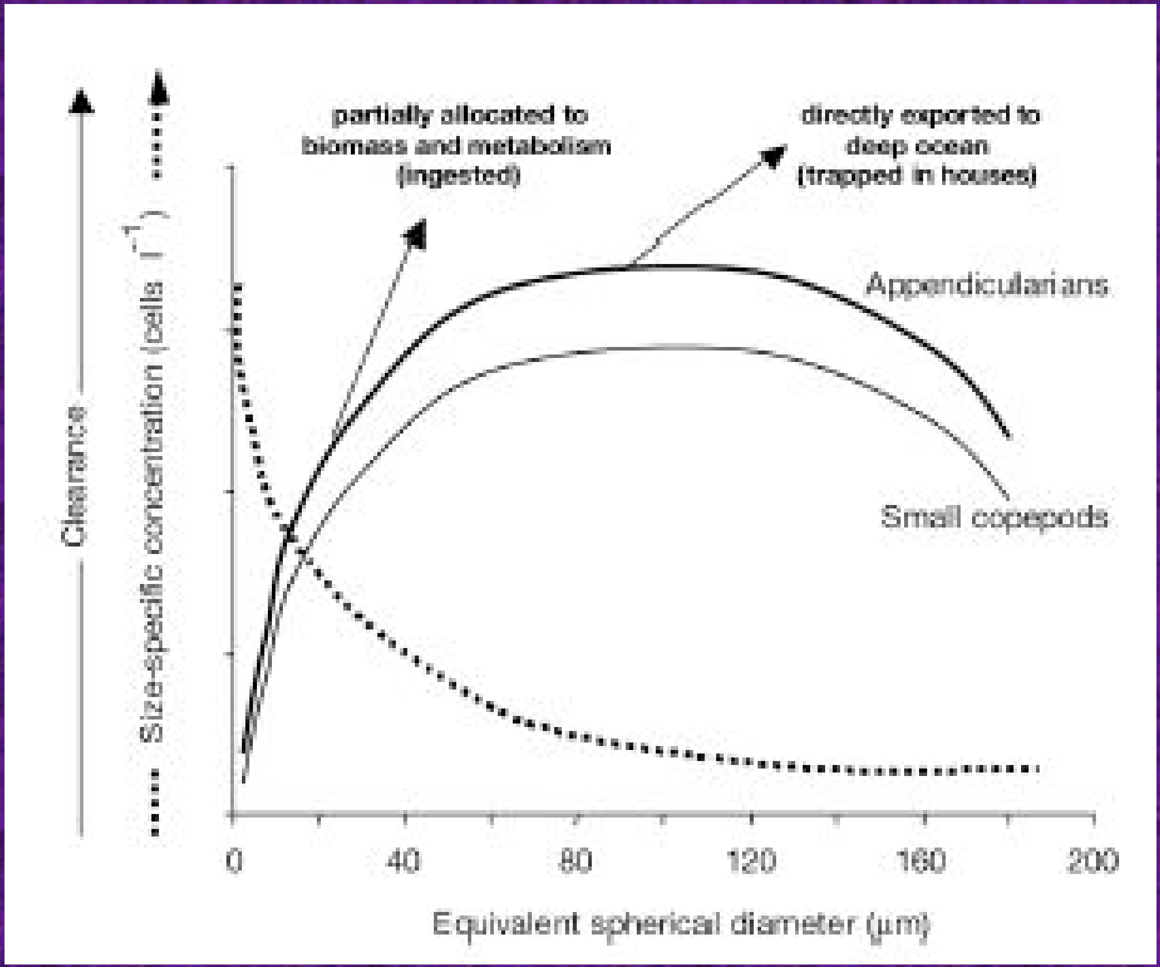
K.Selph, OCN 621 Spring 2010

Vargas & Gonzalez 2004

More than one pathway for export flux...

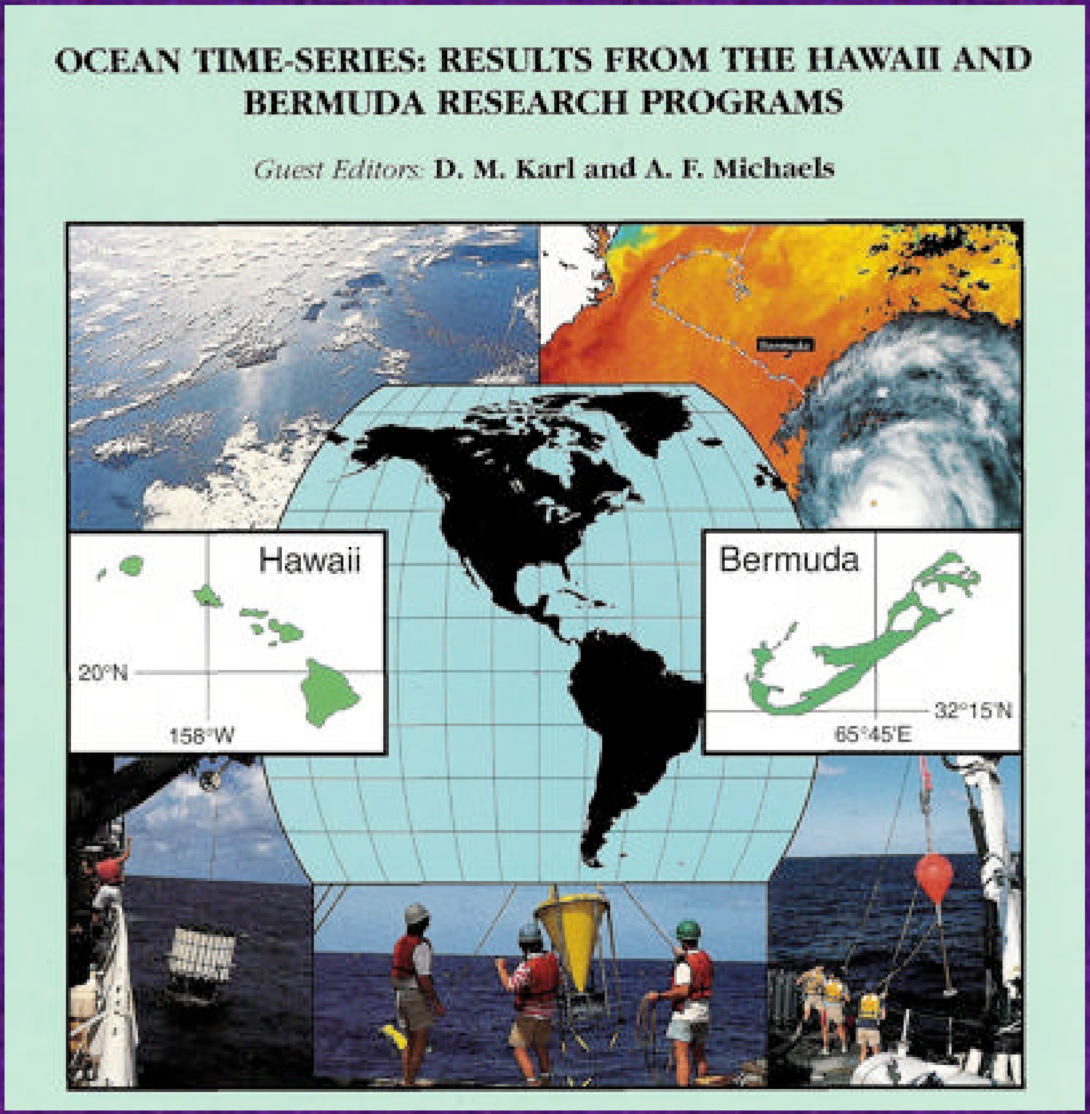
Clearance rates show optimum prey size

Appendicularians -- consumers and responsible for passive particle scavenging



Vargas & Gonzalez 2004

SubTropical Ecosystems



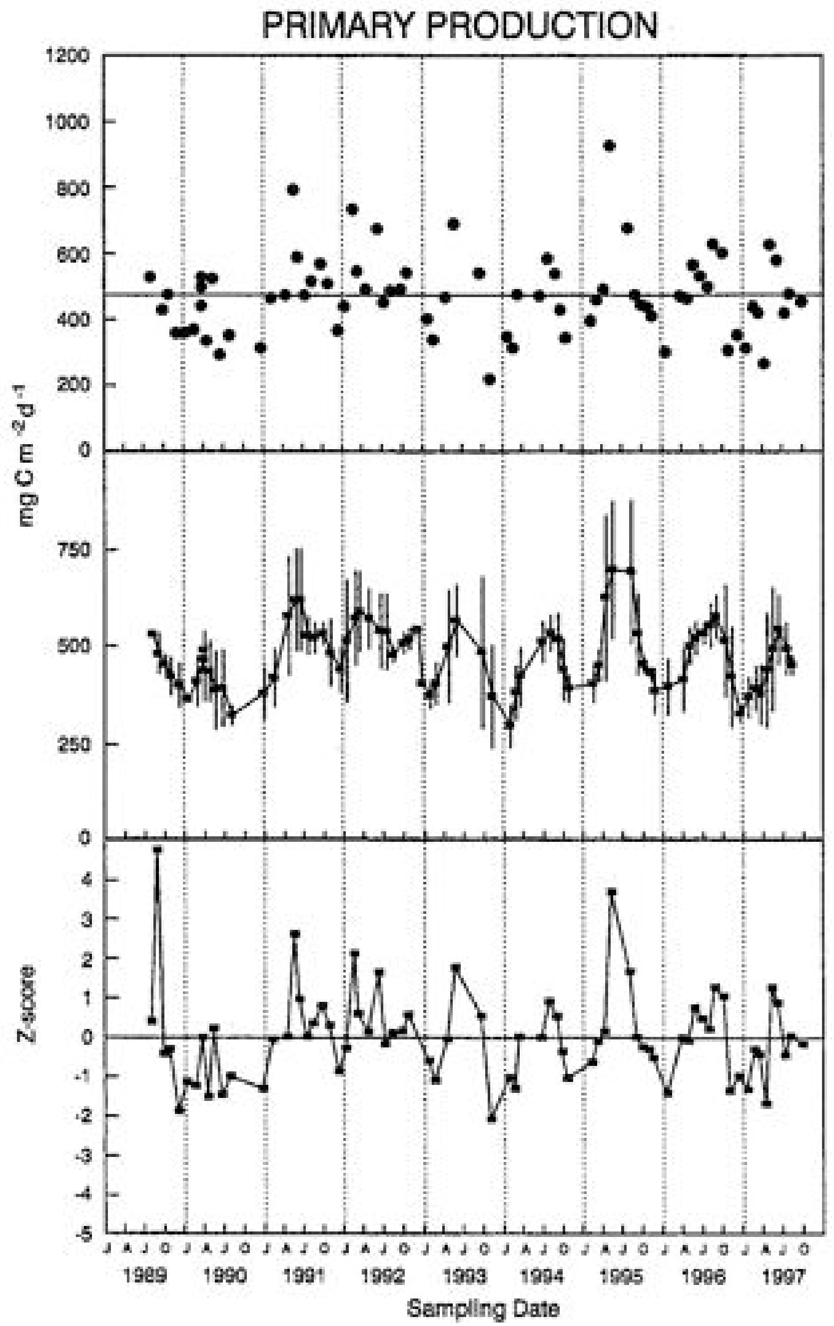
DSR II 1996 Vol 43
DSR II 2001 Vol 48

DSR II 2006 Brix et al.
Vol 53:698-717

HOT Site: 22°45'N, 158°W
BATS Site: 31°40'N, 64°10'W
1988 to present

HOT -- Primary Production

Figure 7. Temporal variability in depth-integrated (0–200 m) primary production measured at Sta. ALOHA over the first 9 y of the HOT program. **Top** Total euphotic-zone primary production (mg C m^{-2} d^{-1}) measured during in situ ^{14}C incubation experiments approximately monthly. The solid line is the mean value (473 mg C m^{-2} d^{-1}) for the full data set (n = 74). **Center** Three-point running mean (±1 SD) for the data presented in the top panel. **Bottom** Standard deviate (Z-scores; Z = [value-mean]/SD) for the primary production data set showing evidence for both seasonal and interannual variability.



D. Karl 1999 Ecosystems 2:181-214

summer usually sees the highest phytoplankton biomass/production

BATS -- Primary Production

Spring bloom (not summer like HOTS)

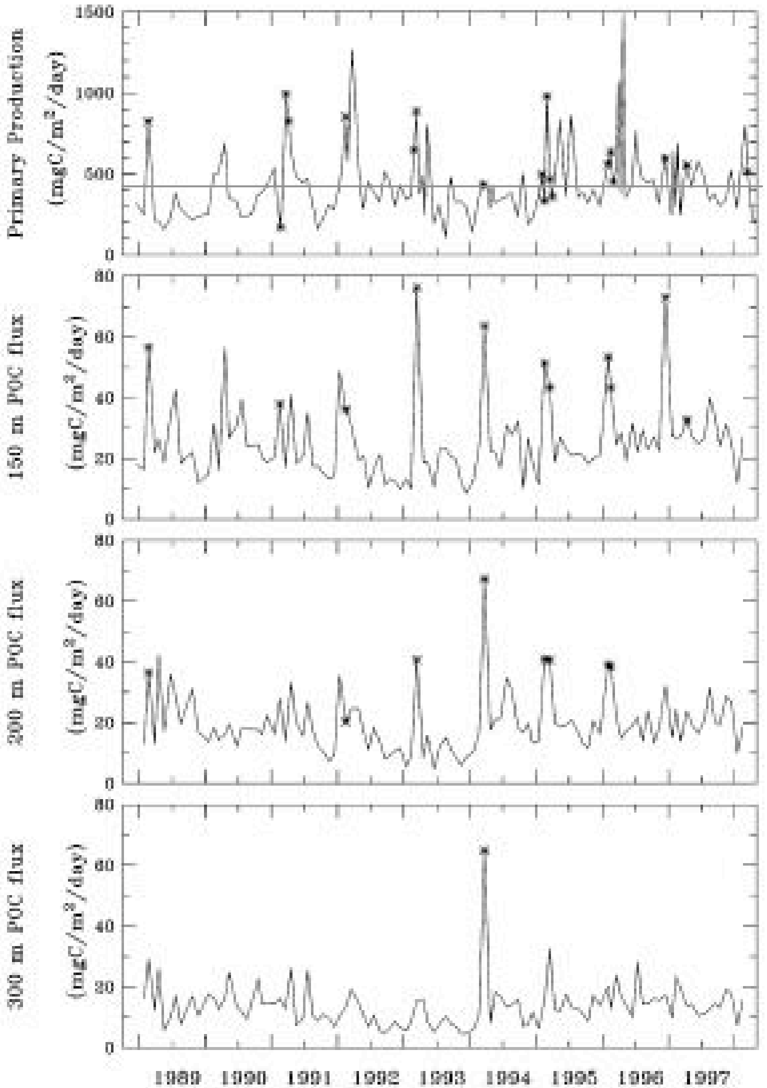


Fig. 10. Time series of integrated primary production (0–140 m) compared to the particulate organic carbon flux measured with a sediment trap at 150, 200, and 300 m. Stars indicate times of the year when physical mixing was deeper than the depth of the measurement (e.g. mixing was deeper than 150 m for integrated primary production and 150-m trap flux, and deeper than 200 m for 200-m trap flux).

Steinberg et al. 2001 DSR II, 48, 1405-1447

Data Comparison

Table 2

Variability in primary production (^{14}C method), particulate carbon export (measured at 150 m using sediment traps) and the export ratio (e-ratio) for the 11-year BATS and HOT data sets

Parameter	BATS	HOT
Primary Production (mg C m^{-2} d^{-1})		
Mean ± SD	416 ± 178	480 ± 129
Range	111 to 1039	184 to 923
Number of observations	125	94
Particulate Carbon Flux (mg m^{-2} d^{-1})		
Mean ± SD	27.2 ± 13.9	28.3 ± 9.91
Range	8.7 to 76.1	10.7 to 57.0
Number of observations	125	98
Export Ratio		
Mean ± SD	0.072 ± 0.038	0.062 ± 0.026
Range	0.016 to 0.214	0.020 to 0.149
Number of observations	125	89

Ecosystem Structure in Gyres

Multi-level, start out with small primary producers (picoplankton)...

how many trophic levels?

Trophic Cascades

- Microbial loop organisms the most important (recycling system)

- Size fractionation experiments suggest several trophic levels smaller than 20 µm

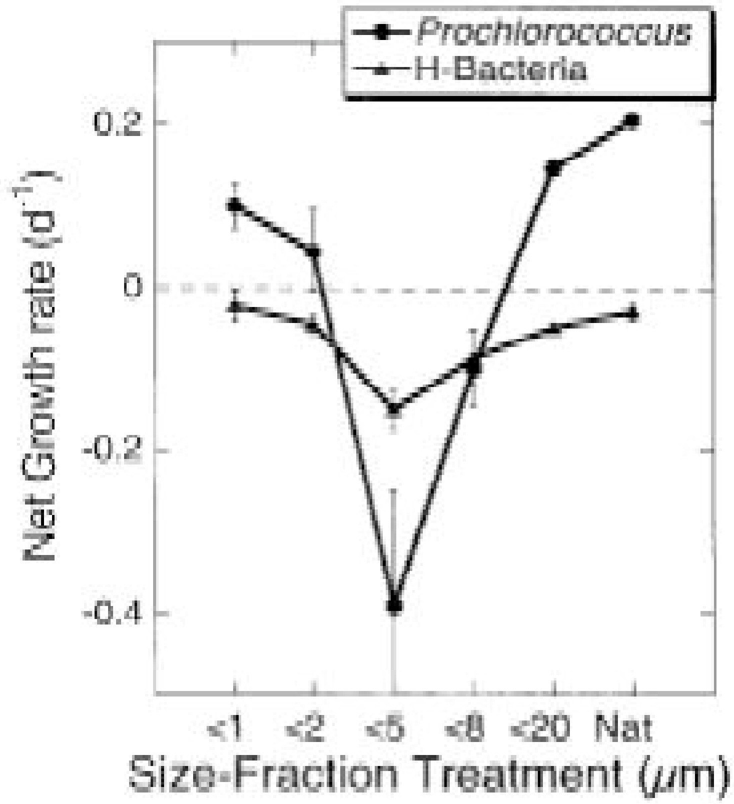


Figure 2. Effects of size-fraction removal of protistan consumers on the net growth rate of heterotrophic bacteria and *Prochlorococcus*. Seawater was collected from 110 m in the subtropical Pacific (Stn. ALOHA). Net population changes were determined from flow cytometric analyses on initial and final samples incubated at 1% surface light for 24 h after filtration through polycarbonate membrane filters of 1–20 µm pore size (Nat=natural sample control with no filtration). Vertical bars show standard errors of 4 replicates (modified from Calbet & Landry, 1999).

Mesozooplankton Biomass, HOT site

Timing of maximum is the most puzzling:
In the summer, when the water column is the most stratified (as opposed to the spring, after winter mixing)

Coincides with blooms of N_2 fixers, such as *Trichodesmium*

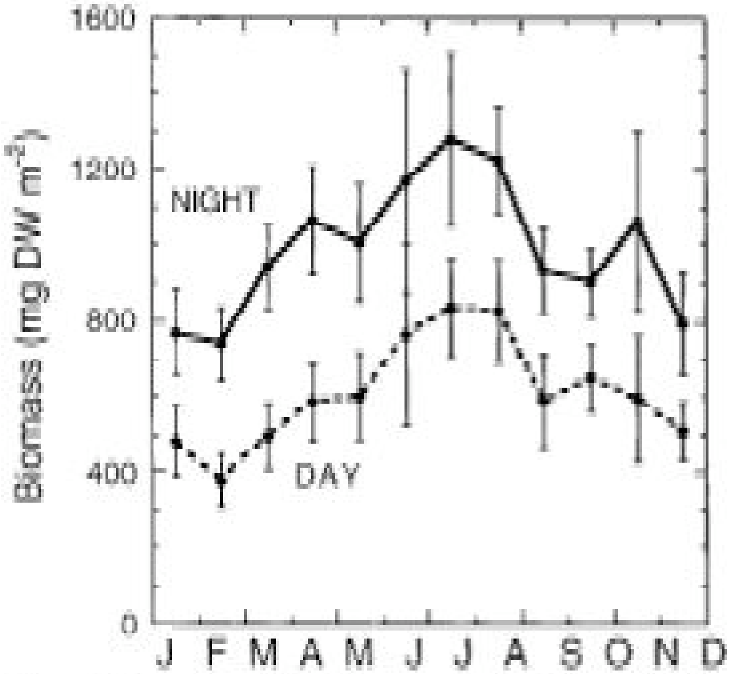


Figure 5. Seasonal variation of mesozooplankton biomass in day-time (1000–1400) and nighttime (2200–0200) net collections at Stn. ALOHA, subtropical North Pacific. Dry weight samples were taken from integrated oblique hauls over the euphotic zone (mean tow depth=155 m) with a 1-m^2 net and 200-μm mesh (Landry et al., 2001). Error bars are 95% confidence intervals for the means of all samples collected within each month from 1994 through 2000.

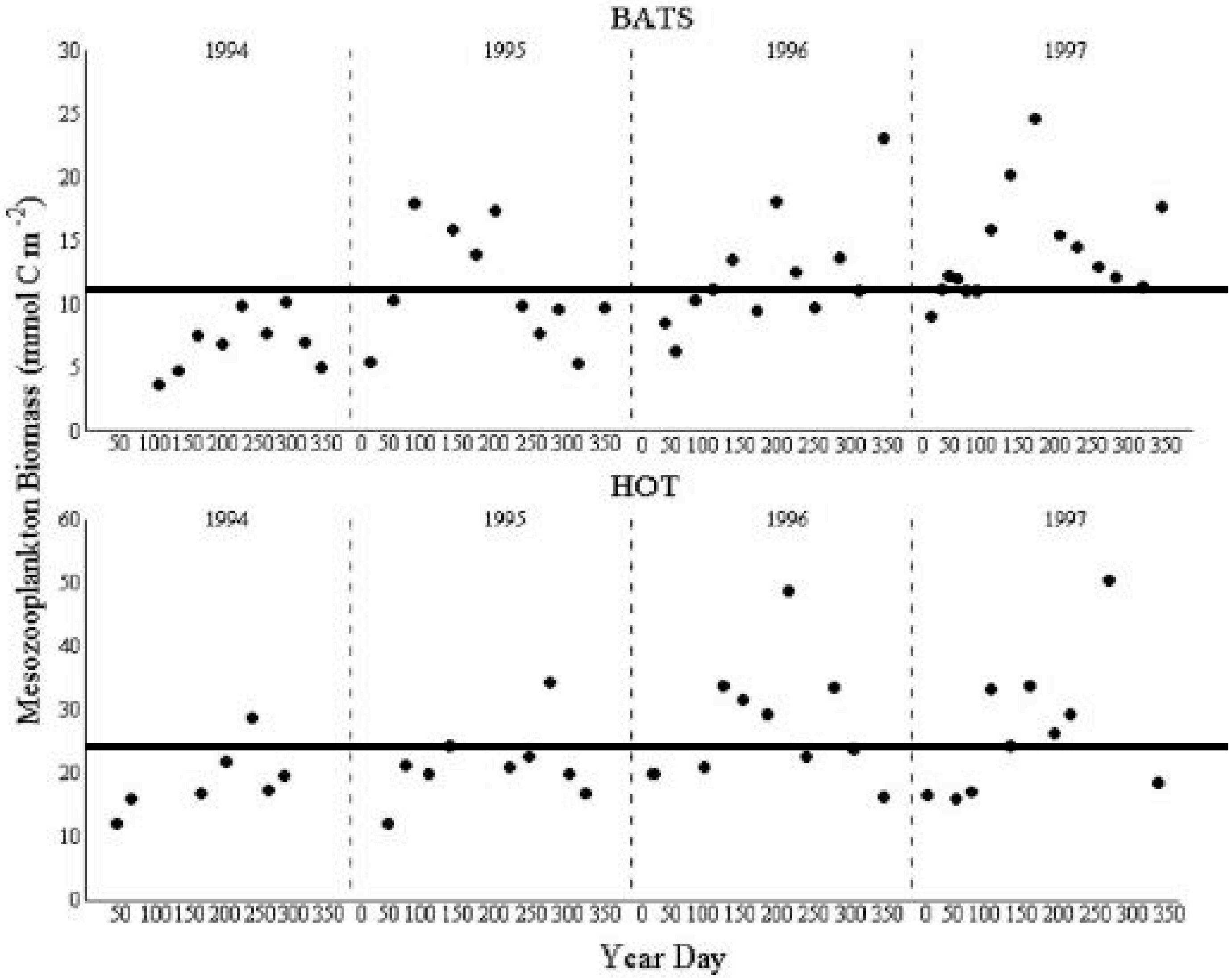


Fig. 1. Mesozooplankton biomass (mmol C m^{-2}) in the surface 150 m at BATS and HOT for 1994–1997.

HOT/BATS MesoZP comparison

Table 1
Hawaii ocean time series and Bermuda Atlantic time series 1994–1997[a]

	$Mean^{HOT}$	SD^{HOT}	N^{HOT}	$Mean^{BATS}$	SD^{BATS}	N^{BATS}
0.2–0.5 mm zooplankton mmol C m^{-2} (% total)	4.33 (18.16)	1.42	36	2.46 (21.62)	0.98	47
0.5–1 mm zooplankton mmol C m^{-2} (% total)	5.66 (23.74)	2.49	36	3.01 (26.45)	1.24	47
1–2 mm zooplankton mmol C m^{-2} (% total)	6.69 (28.06)	3.26	36	2.54 (22.32)	1.09	47
2–5 mm zooplankton mmol C m^{-2} (% total)	5.64 (23.66)	2.80	36	2.46 (21.64)	1.26	47
> 5 mm zooplankton mmol C m^{-2} (% total)	1.52 (6.38)	1.17	36	0.91 (8.00)	0.62	47
Total zooplankton mmol C m^{-2}	23.84	8.85	36	11.38	4.61	47
Zoopl production and egestion mmol C m^{-2} d^{-1}	2.25	0.73	35	0.95	0.30	46
Zooplankton ingestion mmol C m^{-2} d^{-1}	7.49	2.42	35	3.17	1.00	46
Zooplankton mortality mmol C m^{-2} d^{-1}	2.20	0.80	35	0.93	0.34	46
Temperature (C°)	24.32	1.05	36	21.50	1.53	47
Sinking flux mmol C m^{-2} d^{-1}	2.14	0.49	31	2.26	0.74	43
Primary production mmol C m^{-2} d^{-1}	41.08	9.84	34	35.31	8.05	46

[a]Values integrated from surface to 150 m.

Roman et al. 2002, DSR II, 49: 175-192

Table 3
Integrated annual values (mol C m^{-2} yr^{-1})

	Primary production	Zoopl prod and egestion	Zoopl./prim prod ratio	Sinking flux	Eges/sinking ratio
BATS					
1994	13.00	0.20	0.02	1.03	0.20
1995	14.01	0.34	0.02	0.73	0.46
1996	14.92	0.37	0.02	0.91	0.41
1997	11.79	0.42	0.04	0.85	0.49
$Mean_{SD}$	$13.43_{1.17}$	$0.33_{0.08}$	$0.02_{0.01}$	$0.88_{0.11}$	$0.39_{0.11}$
HOT					
1994	13.66	0.62	0.05	0.68	0.91
1995	18.61	0.70	0.04	0.67	1.05
1996	14.14	0.92	0.07	0.77	1.20
1997	13.25	0.90	0.07	0.92	0.98
$Mean_{SD}$	$14.92_{2.16}$	$0.79_{0.13}$	$0.05_{0.01}$	$0.76_{0.10}$	$1.03_{0.11}$

Why the difference? Don't know for sure, but...

- Salps and sarcodines at BATS -- not quantified well with net tows (grazers and mixotrophs)
- Mesoscale eddies at BATS leading to episodic nutrient enrichments -- uncoupling of 1° producers and consumers

www.pbs.org

L. Madin, WHOI

On the relationships between primary, net community, and export production in subtropical gyres, 2006, Deep-Sea Res. II, 53:*698-717,*
Holger Brix, Nicolas Gruber, David M. Karl and Nicholas R. Bates

- Export POC/Net Primary Production
  - If ratio high, then "export pathway" ecosystem (larger phytoplankton)
  - If ratio low, then "regeneration" ecosystem (microbial loop organisms dominate)
- Switch between these states by addition of increased nutrients
- 10 year data set at HOTS and BATS:
  - BATS: Export pathway in Spring, Regeneration Pathway in Summer, Fall
  - HOTS: Regeneration pathway all year round

Aside: Modern Primary Production Measurements vs. Historical

Subtropical Gyres: 111 - 1039 mg $C/m^2/d$

(~40 - 380 g $C/m^2/y$)

historical: <100 g $C/m^2/y$

Note that fisheries oceanographers still use the lower numbers, along with lower estimates of trophic levels leading to fish -- the combined effect of these opposing trends may luckily end up with fisheries yields that aren’t too far off...

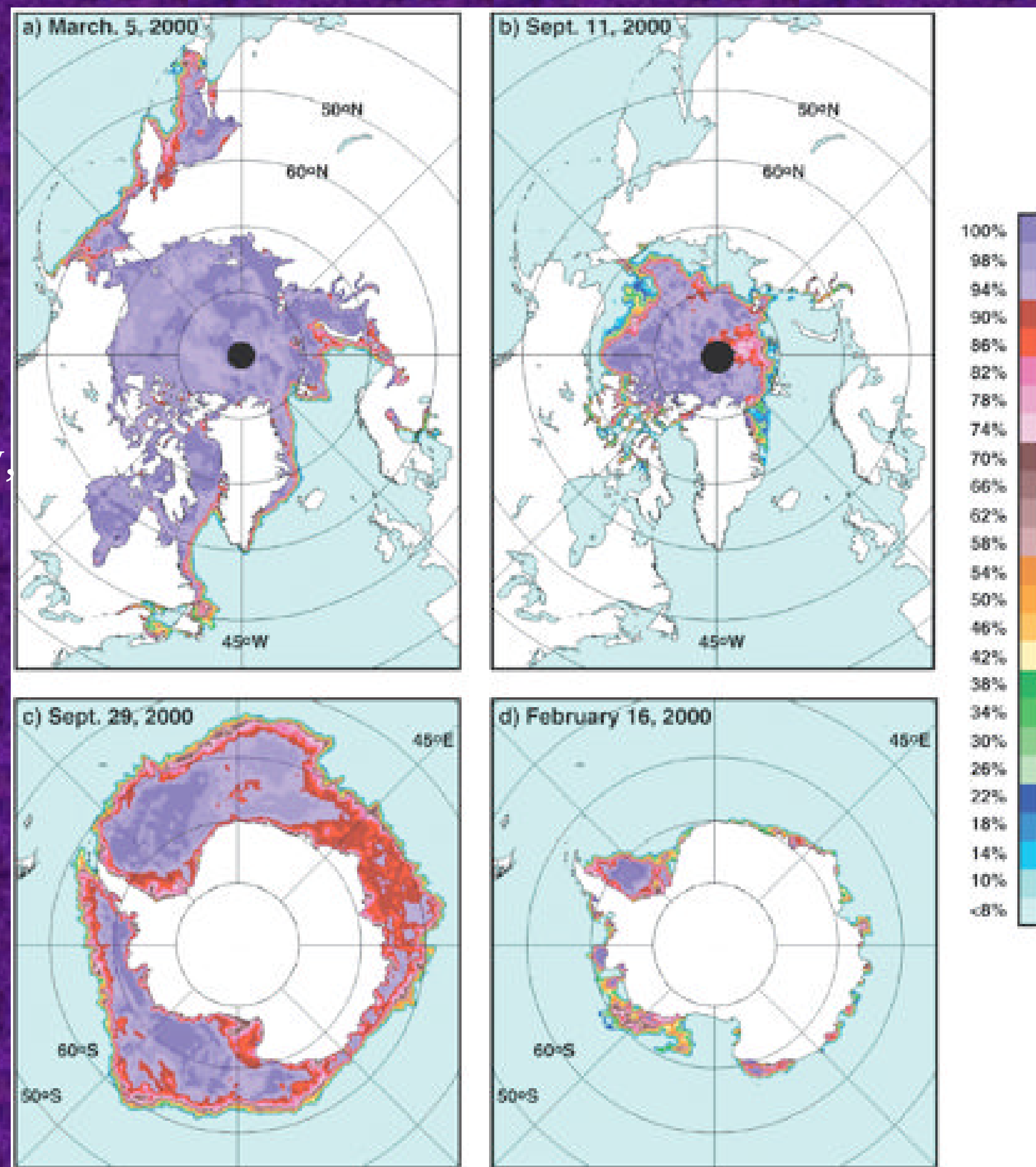
Polar Ecosystems: Arctic vs. Antarctic

- Size (15 mill km^2 vs. 36 mill km^2)

-Arctic Sea Ice only 2-fold annually, whereas it is 5-fold lower in the Southern Ocean over that period

- Sea surrounded by Land vs. Land surrounded by Sea, so ability to exchange with other regions very different

Max (end of winter) Min (~Fall)



Kaiser, textbook

Arctic vs. Southern Ocean -- very different

- 1/3 of Arctic Ocean is shelf seas (≤100 m), mean depth 1800 m

- Continental shelves of Antarctica very narrow, with pack ice zone over deep ocean basins (4000 - 6500 m deep)

- Arctic affected by freshwater flows from surrounding rivers and their contents (high productivity in coastal/upwelling areas, but short-lived)

- Southern Ocean fairly isolated from land (HNLC area) -- high productivity in areas affected by shelf sediments, otherwise Fe-limited and fairly low

Arctic Ocean

Ice effect on Bloom Timing
e.g., bloom relatively late in year as ice needs to melt

- Results in short growing season (tied to light)
- Zooplankton: grow slowly, have short feeding season, rest at depth over winter
- May take two-three years to complete growth cycle e.g., *Calanus glacialis* & *C. hyperboreus*

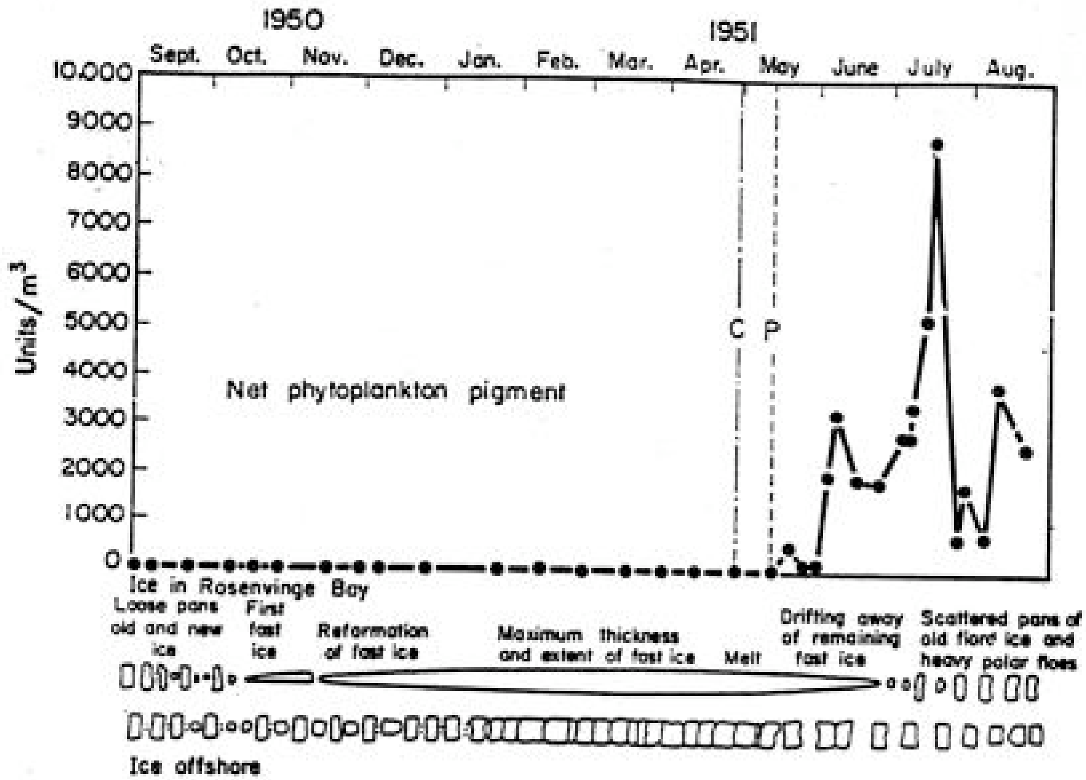
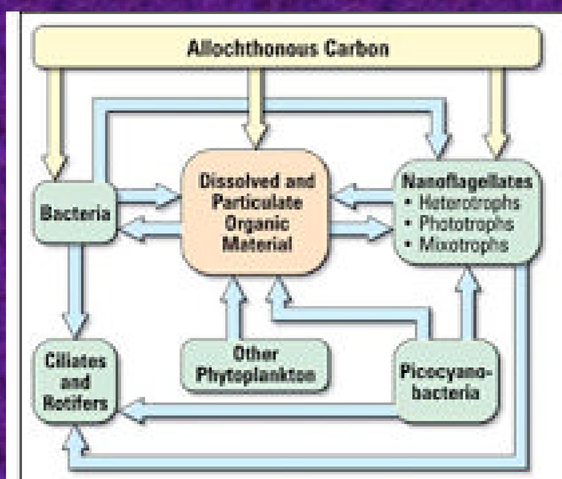
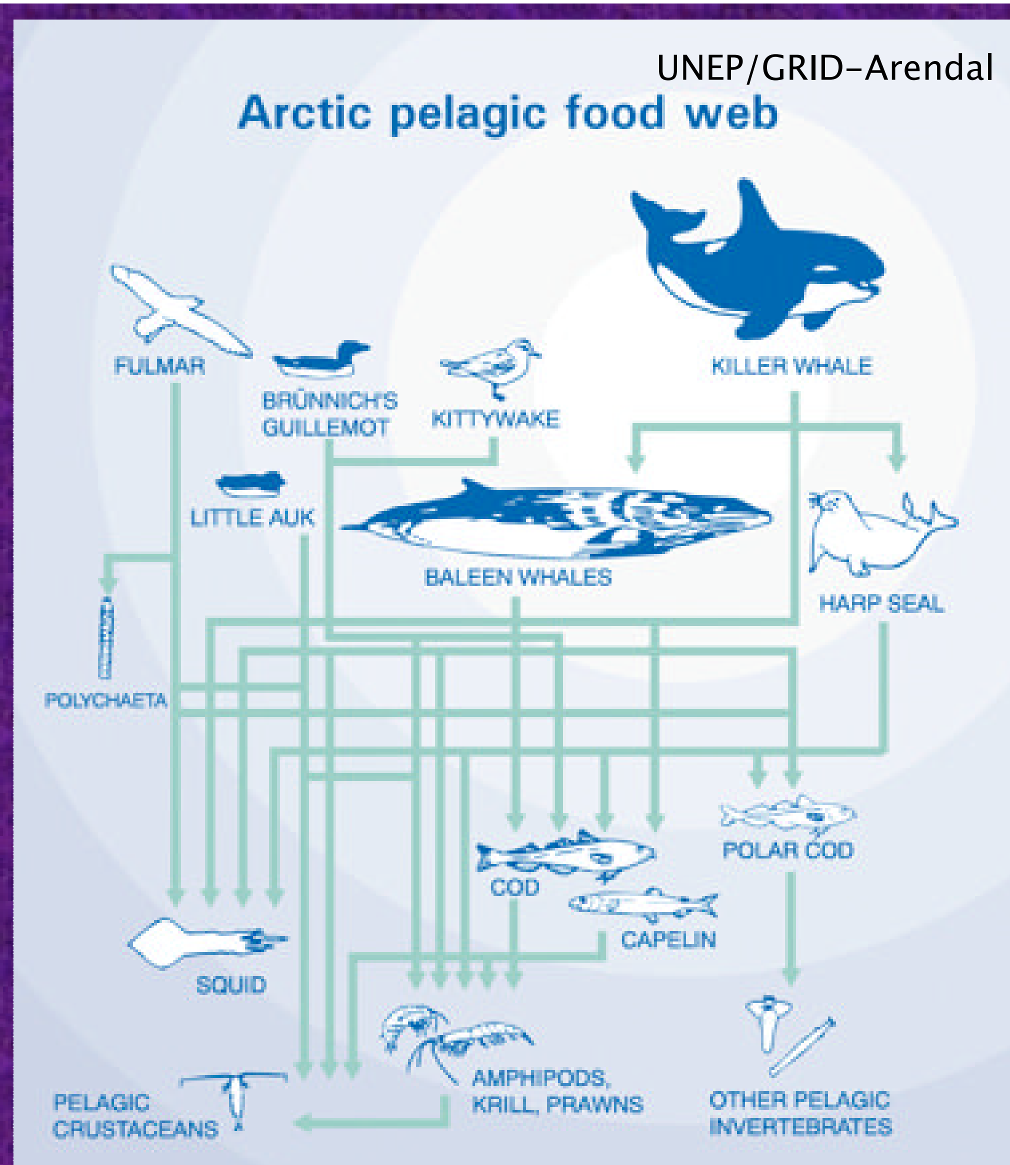


FIG. 8.2 Seasonal changes in growth of phytoplankton and in ice conditions in Scoresby Sound, Greenland.
C = date of onset of phytoplankton growth as seen by cell counts.
P = date by which phytoplankton growth was indicated by net pigment (after Digby, 1953).

Arctic Pelagic Food Web

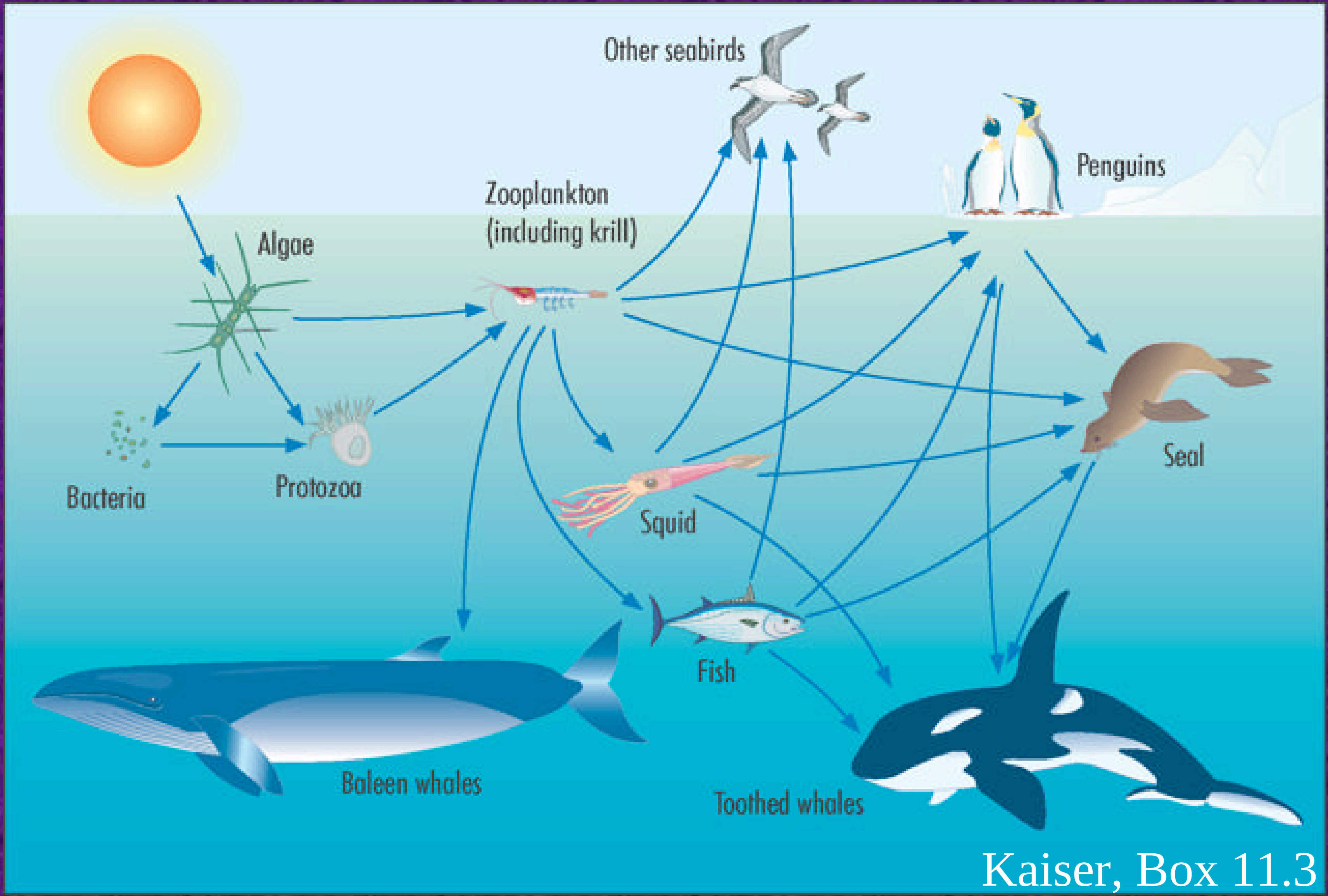


http://www.cen.ulaval.ca/merge/index.php?url=11214



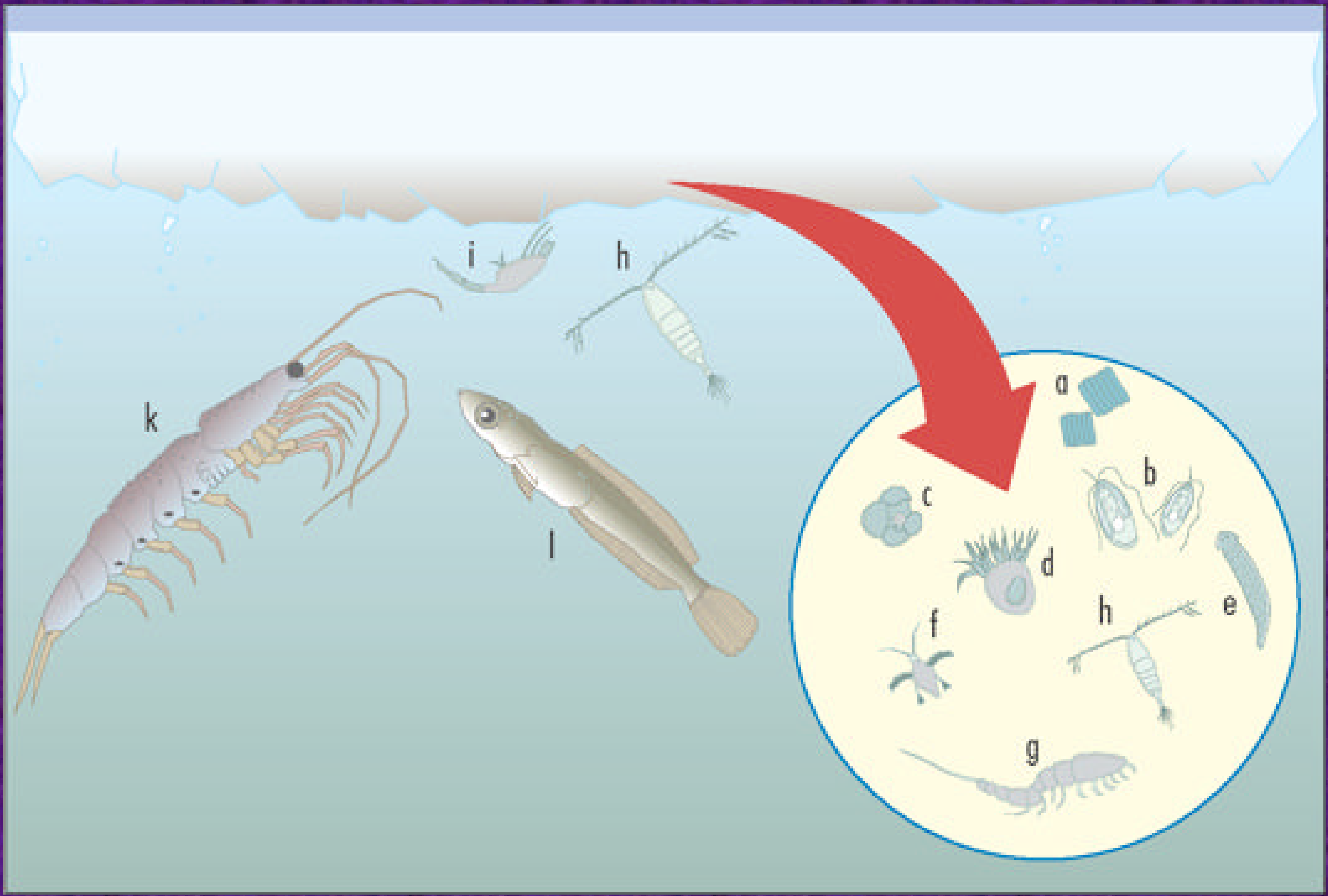
http://maps.grida.no/go/graphic/arctic-pelagic-food-web

Antarctic: Southern Ocean Krill as a Keystone Species



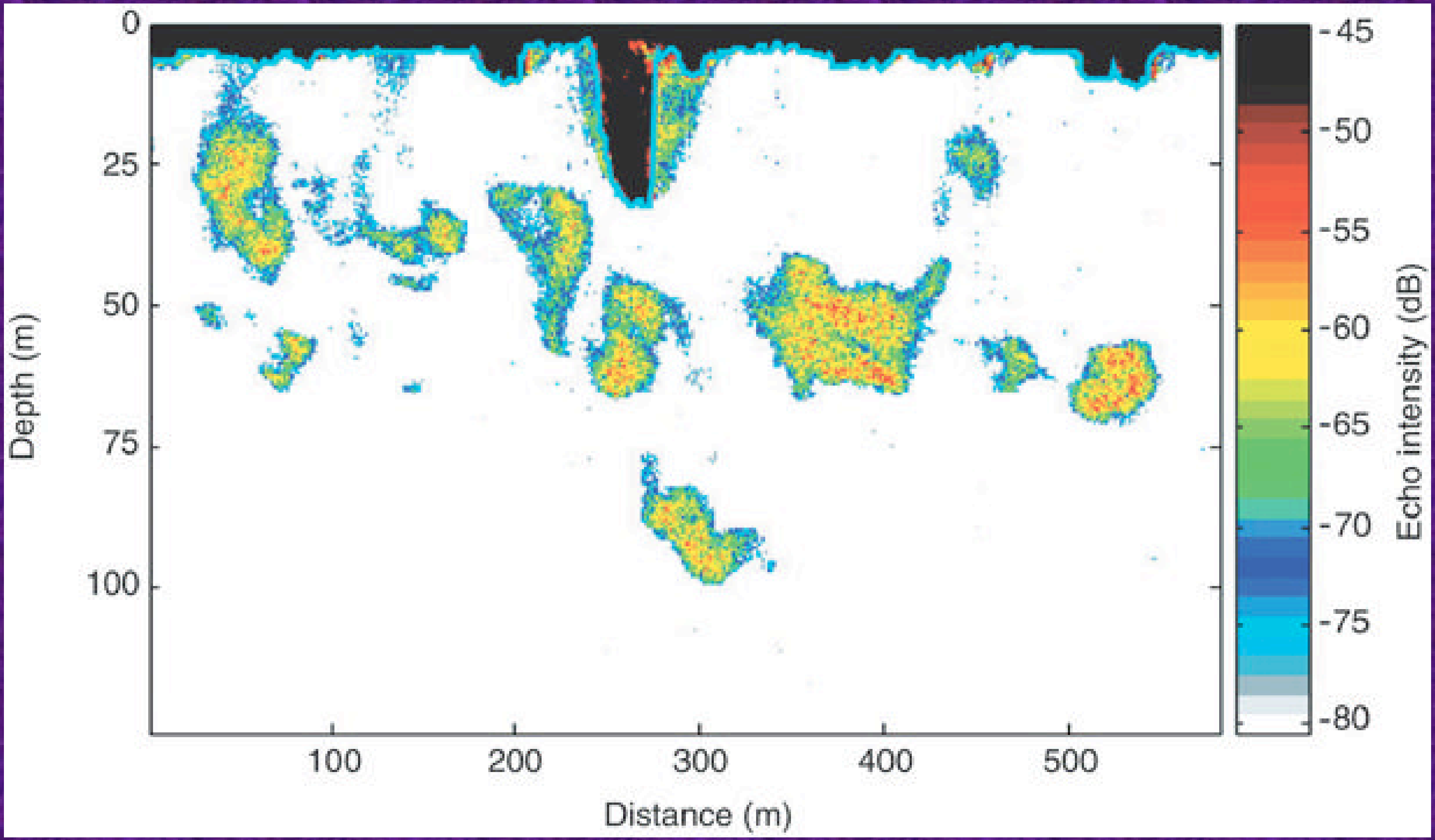
Kaiser, Box 11.3

Antarctic Sea Ice Community



Kaiser, Fig. 11.8

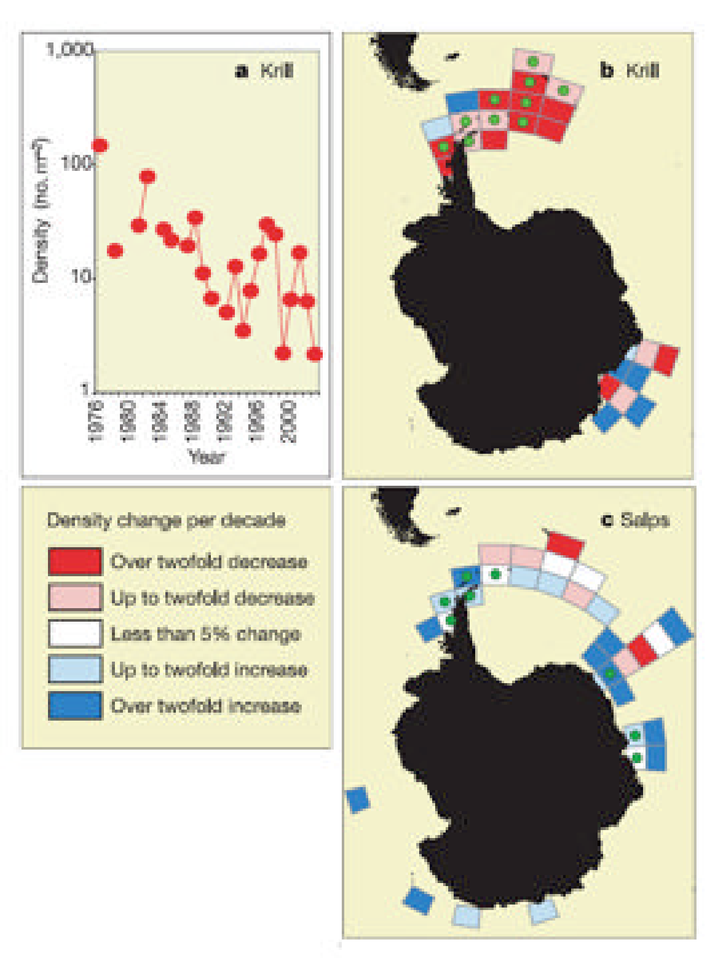
Krill Swarms under the Sea Ice



Kaiser, Box 11.3

Krill vs. Salps

- Changing Ecosystem -- may be due to decline in sea ice
  - Since 1926, decline in krill populations (38 - 75%) and an increase in salps (>66%)
  - krill need sea ice algae nutrition prior to spawning & for juvenile stages in winter and feed on Spring bloom phytoplankton
  - salps can survive in warmer water and at lower phytoplankton concentrations and do not feed on sea ice



Atkinson et al. 2004

Summary:
Why are marine ecosystems so different?

Why does the North Atlantic bloom so dramatically?
Why doesn’t the North Pacific?
Why aren’t there ever blooms in the vast open ocean regions?

Extraordinarily Simplistic Answer

All systems have microbial organisms, as well as the larger phytoplankton and consumers, but physical processes force the system towards dominance of one ecosystem over another.

Dominant Pathways are determined by physical processes

- Small cells are more efficient in competing for low N (high surface area:volume)
- General size hierarchy of consumers based on energetic considerations, i.e., for like organisms, reduced size and biomass of prey makes the environment more suitable for smaller consumers
- Energetic reasons why small primary consumers are favored in oligotrophic open ocean systems (subtropical gyres):
  - reduced [phyto] ⟶ **I** declines for given $\mathbf{F_{max}}$
  - decreased phyto size ⟶ $\mathbf{F_{max}}$ declines for consumer of given size
  - increased T°C ⟶ higher **I** is required for maintenance or to sustain a given level of growth

Diatoms : "dynamic" component in the food web

Diatoms are responsive to high nutrient conditions and can escape "control" of grazers.

In the absence of "external energy" to stimulate diatom blooms, a eutrophic system shifts to oligotrophic system

-seasonally, e.g., spring to summer in temperate systems

-spatially, e.g., distance from upwelling source

Diatoms decrease in relative abundance from:

- –Eutrophic Systems → Oligotrophic Systems
- –High Latitude → Low Latitude
- –Spring Season → Summer Season
- –Upwelling Source → Distance from Upwelling

100 um

Chaetoceros, Asteromphalus, Nitzschia

Low Energy Stable Systems

Low energy → Lack of nutrient re-supply

↓

Low nutrients (oligotrophic) ← (Lack of nutrient re-supply)

↓

Small Phytoplankton (high surface:volume ratio)

↓

Long food chains (small consumers at base)

↓

Relatively stable system (high recycling)

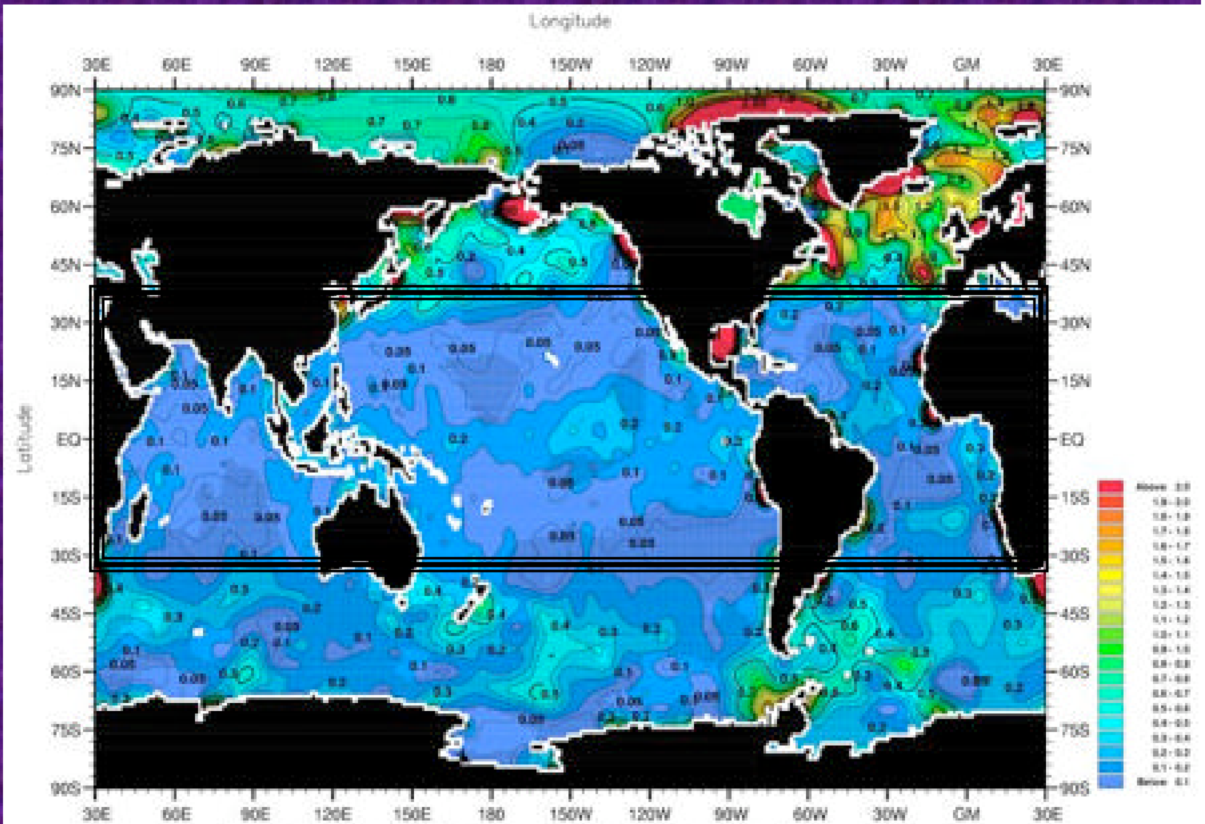


Fig. C2-1. Spring (Apr.-Jun.) mean chlorophyll (µg/l) at the surface.

Minimum Value= 0.00 Maximum Value= 13.42 Contour Interval: 0.10

World Ocean Atlas 2001
Ocean Climate Laboratory/NODC

High Energy Unstable Systems

High energy
(storm activity, eddy action, upwelling, etc.)

↓

High nutrients
(eutrophic)

↓

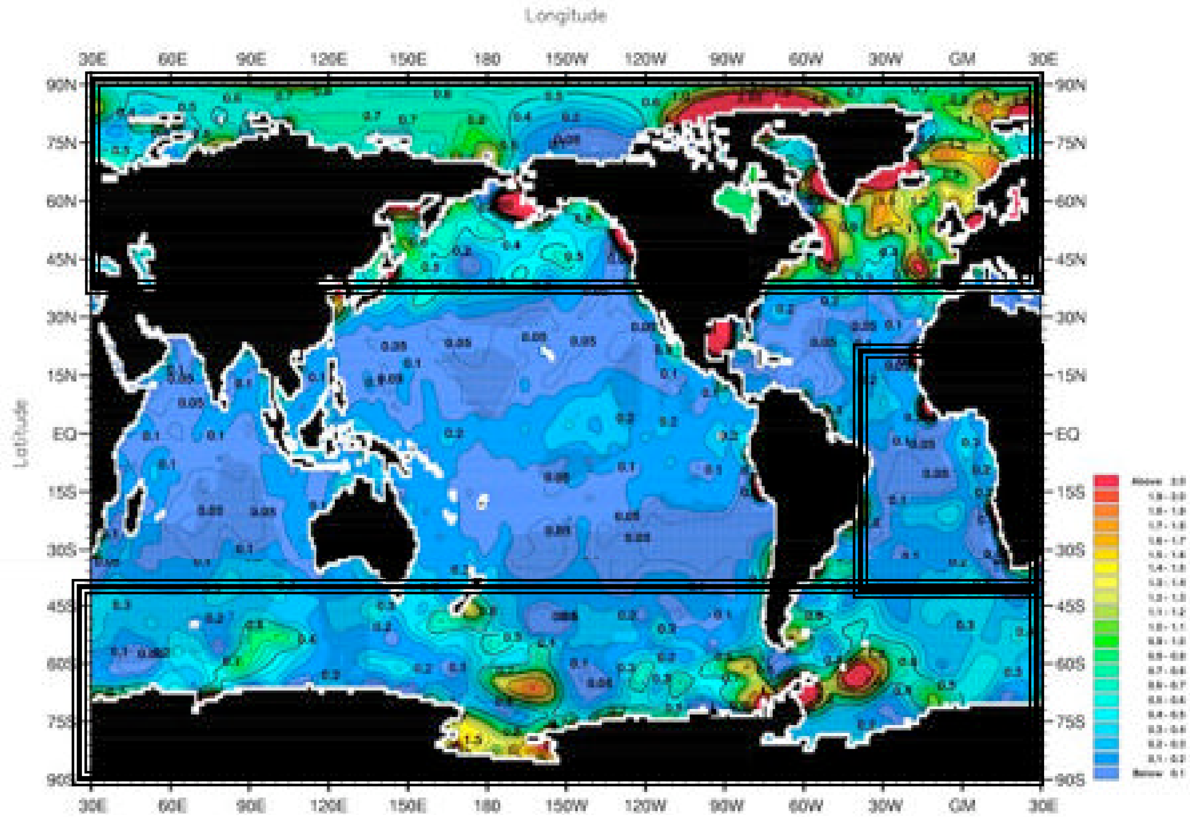
Large Phytoplankton
(small, too)

↘

Short food chain (dynamic)
(superimposed on stable long food chain)

→

Unstable (dynamic) system
(High "new" production)



Composite Spring Picture
Mean Chlorophyll (µg/l) at the surface