

Ocean 621

4/27/09

Pelagic-benthic coupling (especially high latitudes)

a) Introduction

- 1. Definitions**
- 2. Why care**
- 3. General principles**

b) Pelagic-benthic coupling at high latitudes

- 1. Nature of the production cycle: sea ice and light**
- 2. The Seasonal Rectification Hypothesis**
- 3. Pelagic-benthic coupling on the Antarctic shelf**
- 4. Pelagic-benthic production in the Arctic and climate change**

Readings: Kaiser et al., 2005, Chapter 11: Polar Regions

Grebmeier, *et al.* 2006. A Major Ecosystem Shift in the Northern Bering Sea. *Science* 311, 1461-1464.

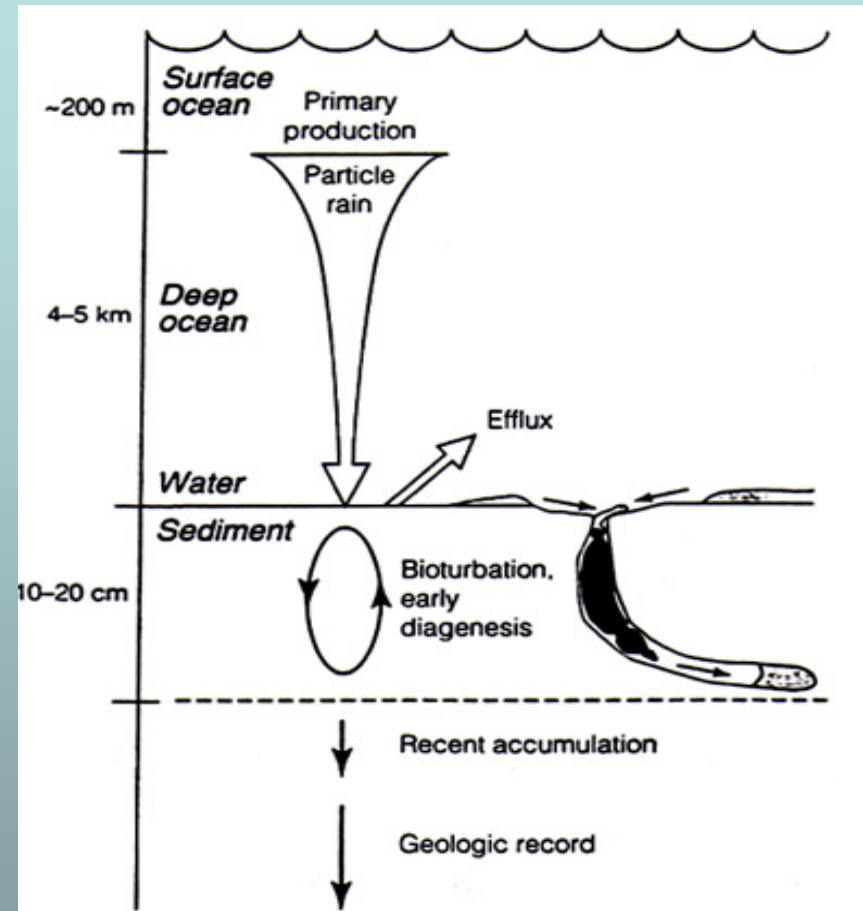
1) Definition:

Pelagic-benthic coupling =

“A causal relationship between water-column and benthic processes”

Top-down example:

The amount of primary production in the overlying water column determines SCOC and biomass at the seafloor.



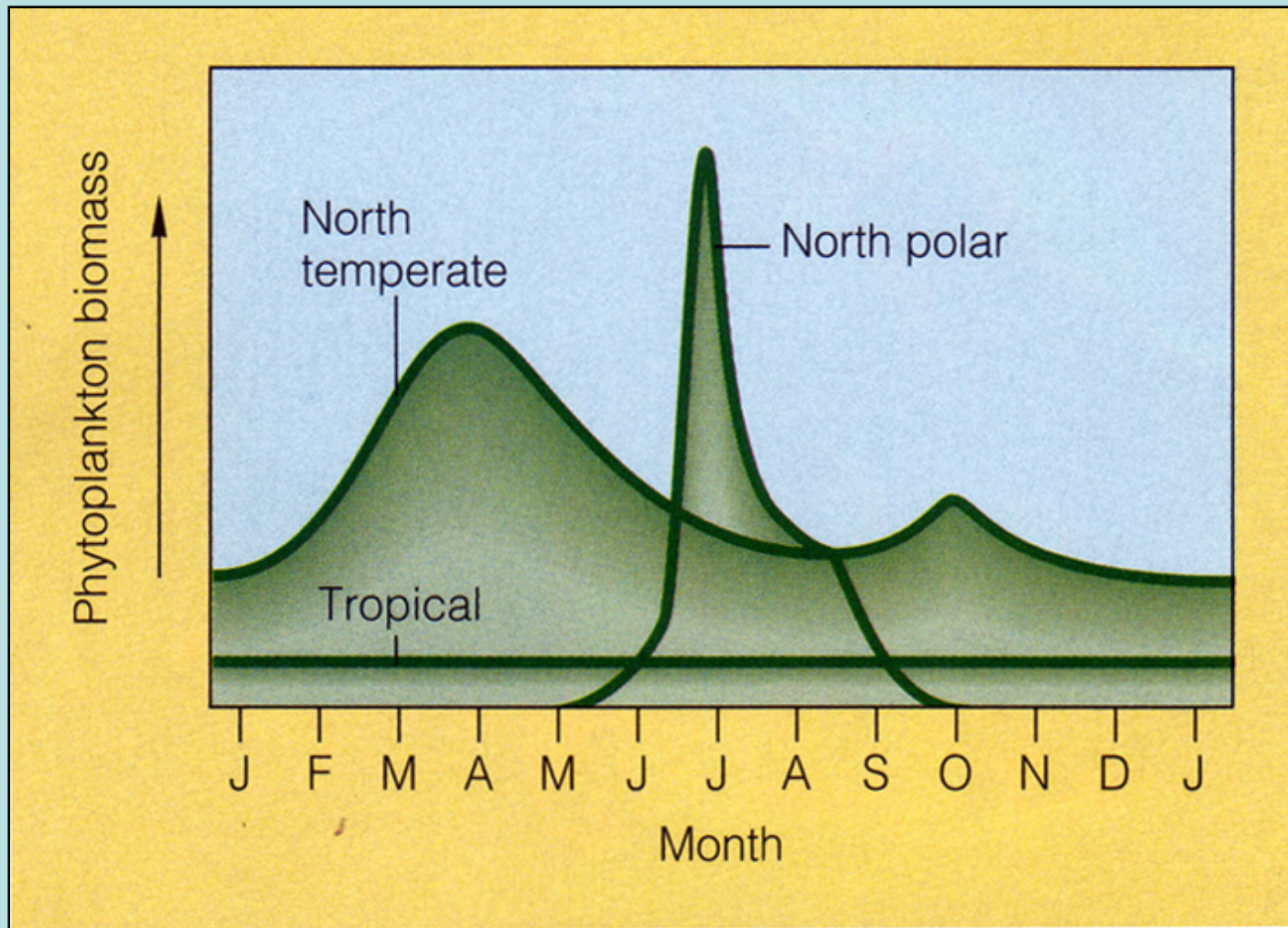
Smith et al. 1997

2) Why is benthic-pelagic coupling important (why care)?

- a. In shelf regions, as much as 6 – 60% of net primary production can sink to the seafloor, and the seafloor can be a major source of nutrients to the water column.
- b. 40% of global fisheries yield, and much of coastal ecosystem biomass (e.g., suspension feeders, fishes, marine mammals feeding on seafloor), is comprised of species dependent on BPC.
- c. Below euphotic zone (i.e. in the deep-sea), virtually all of benthic production, and the structure and dynamics of benthic communities, depend on organic flux from the pelagos.
- d. Seafloor ecosystems provide an integrated view of production processes in the overlying water column.

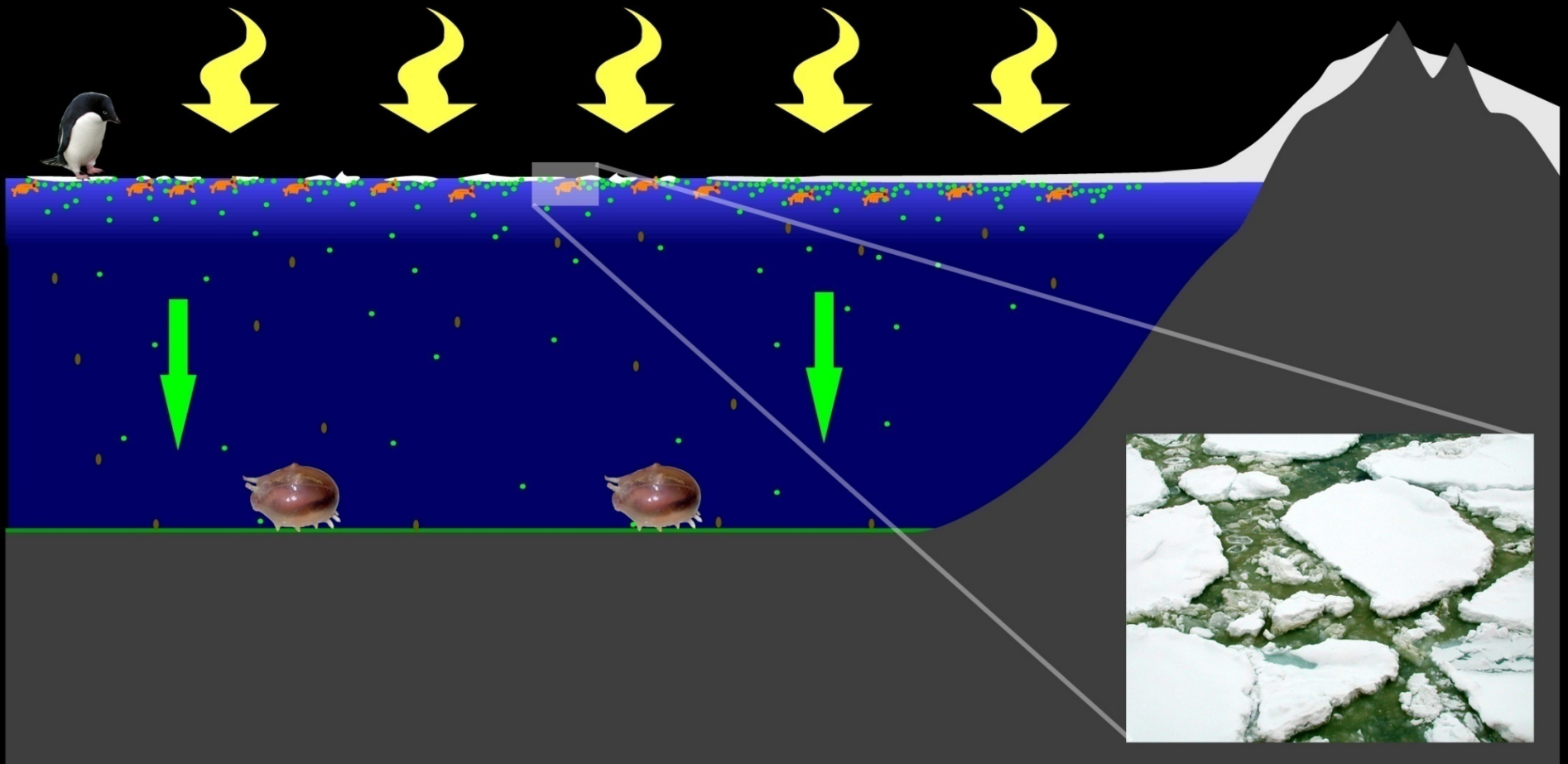
Pelagic-benthic coupling at high latitudes:

Polar regions – extreme seasonality in phytoplankton biomass and primary production



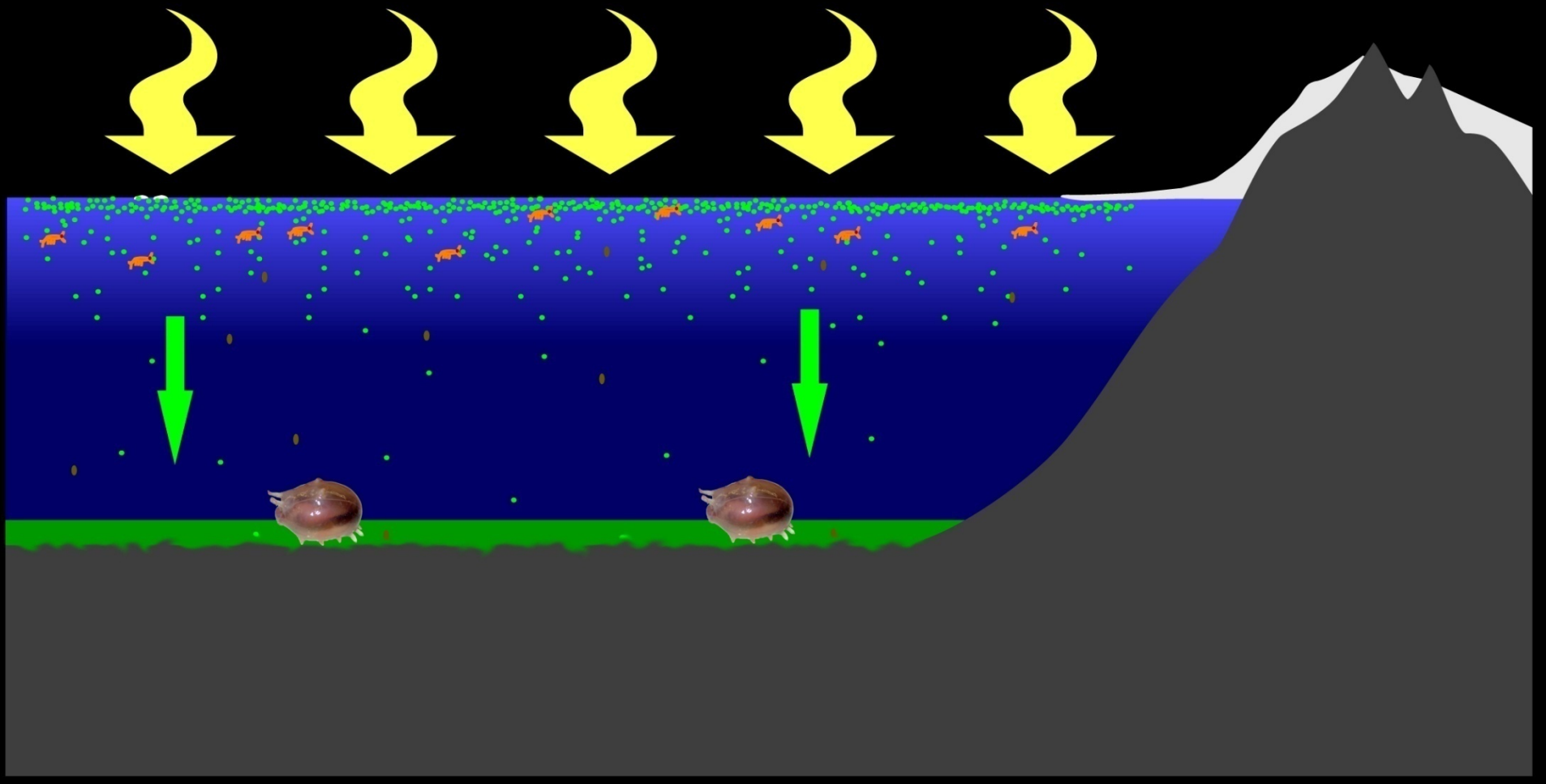
Oct-Nov (Late Spring)

- Sea-ice cover breaking up; nearing 24 hr daylight
- Ice-algae released by melting ice
- Melt water-induced stratification of the water column begins



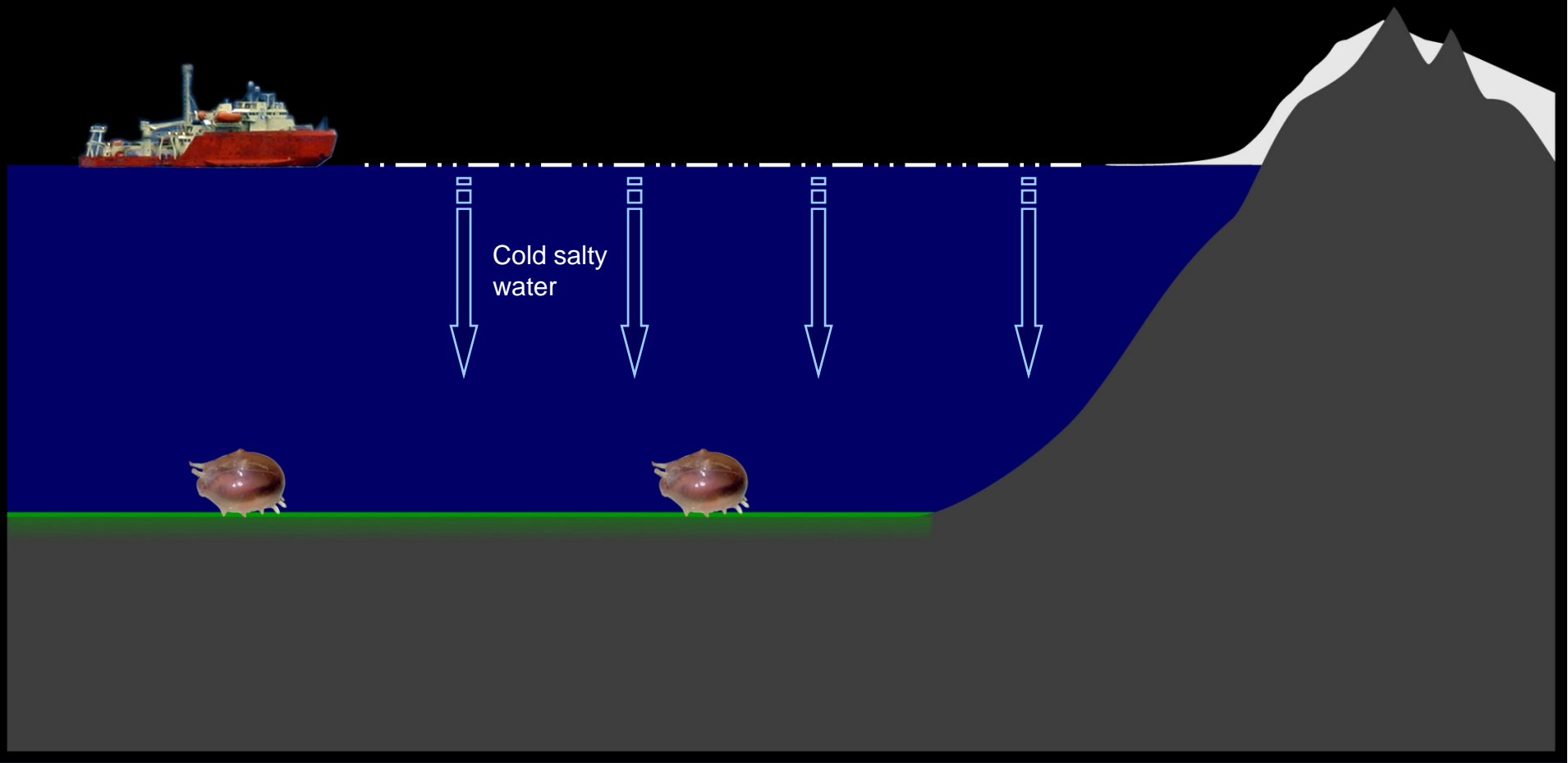
Jan-March (Austral Summer)

- Sea-ice cover receded
- Phytoplankton bloom fully developed; sedimentation of organic material can produce thick phytodetrital carpet



May-July (Late Fall-Winter)

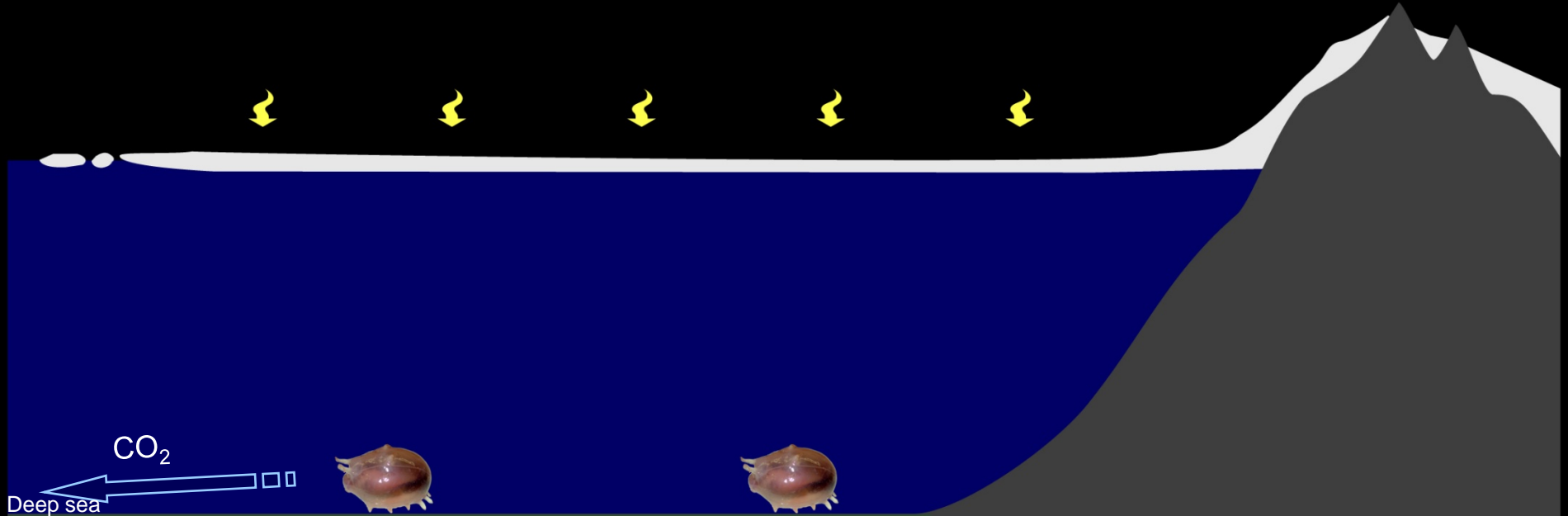
- Nearly 24 hr darkness, sea-ice forms
- Very low phytoplankton biomass



Aug-Sept (Late Winter - Early Spring)

-Period of maximum sea-ice coverage, short but lengthening daylight hours

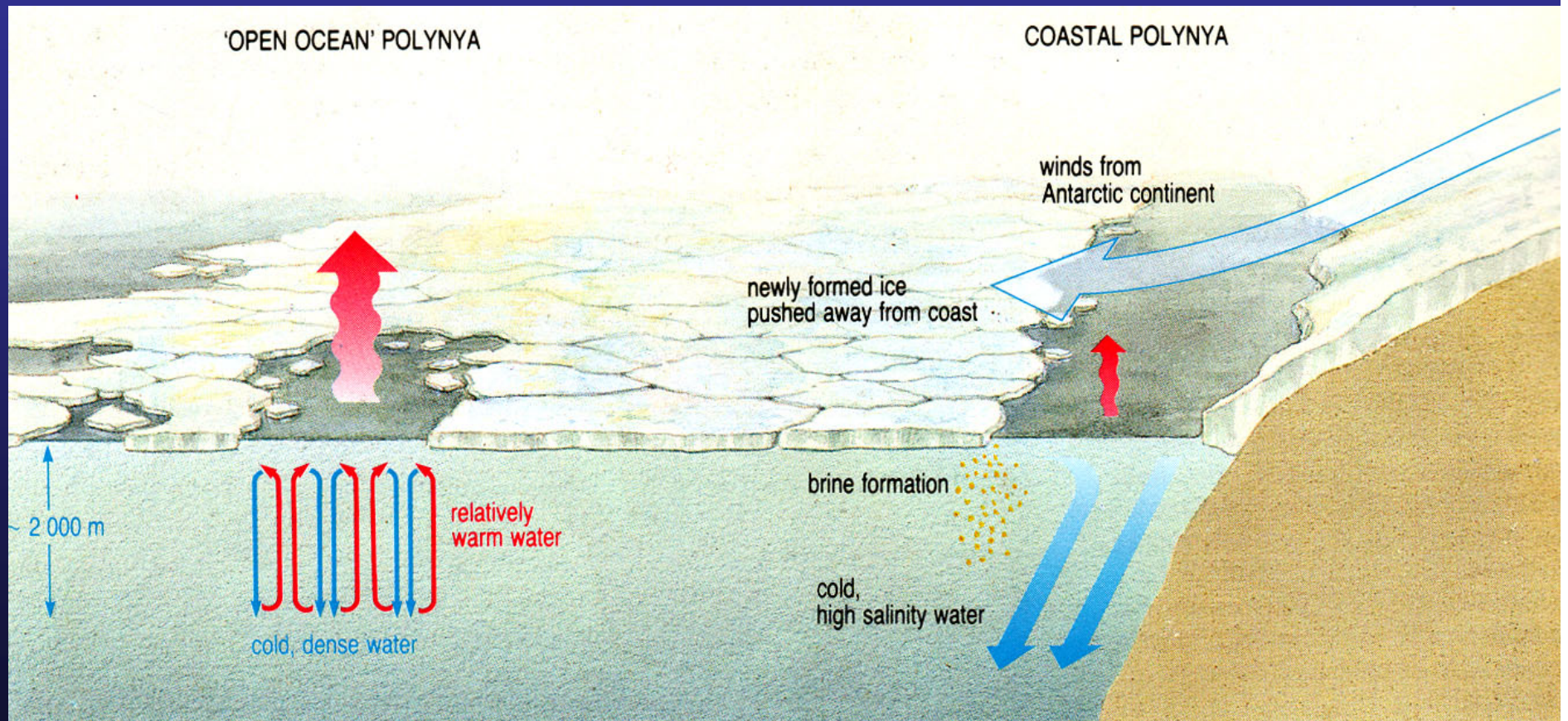
-Relatively austere water column



If much of summer primary production sinks to seafloor and is respired in winter under sea ice "cap", resultant CO₂ may be advected into deep-sea → Seasonal Rectification Hypothesis

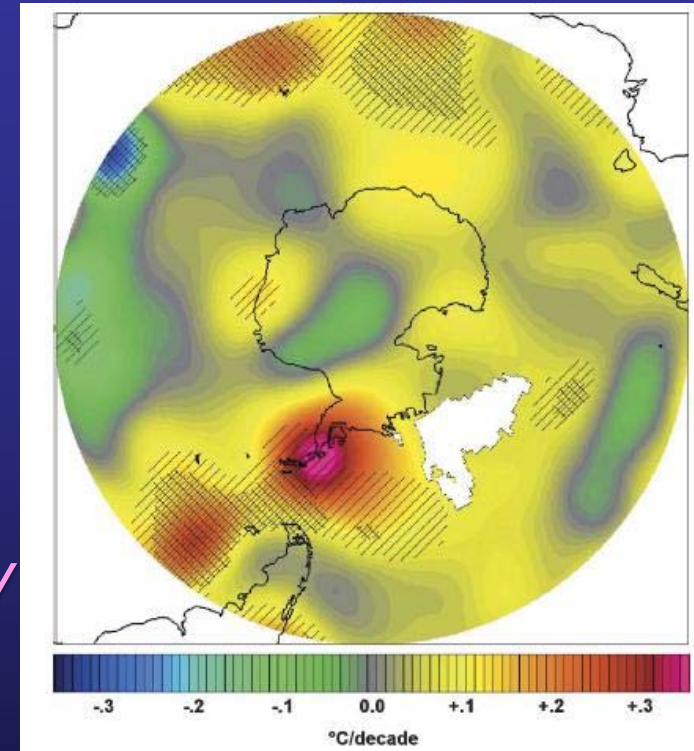
(Yager et al., 1995)

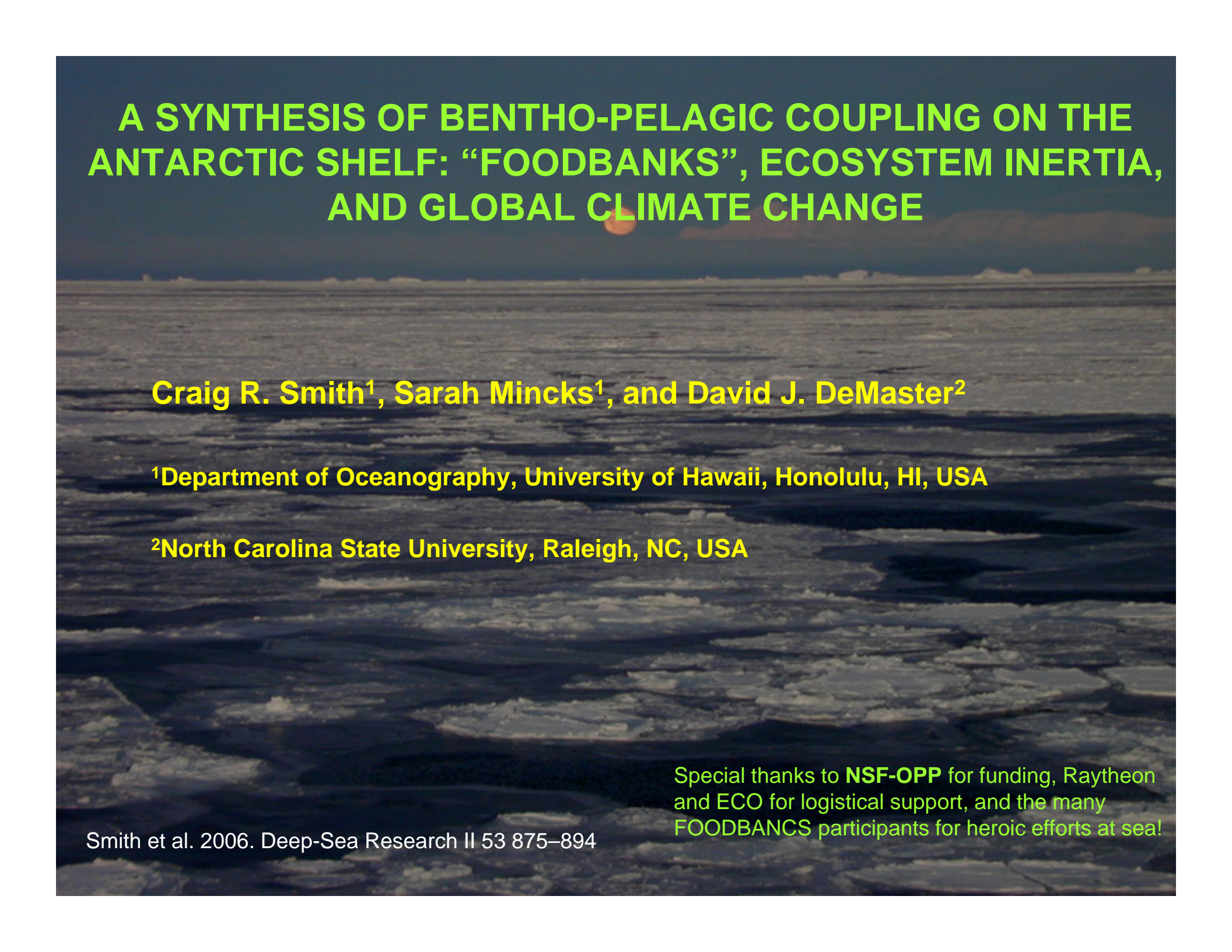
Primary production in polynyas provides another way to advect CO₂ into deep-sea (Yager et al., 1995)



High latitude ecosystems, e.g., the Antarctic Peninsula, are warming faster than anywhere on the globe

- Warming will
 - *Reduce annual sea-ice duration*
 - *Alter quantity and quality of food (POC) flux to the shelf floor*
 - *likely fundamentally change seafloor ecosystem structure and function*



A wide-angle photograph of the Antarctic shelf, showing a vast expanse of sea ice in the foreground and middle ground. The ice consists of numerous small, irregular floes. In the distance, a dark, flat horizon line separates the ice from a dark sky. A single, low sun is visible on the horizon, casting a soft, orange glow. The overall scene is desolate and cold.

A SYNTHESIS OF BENTHO-PELAGIC COUPLING ON THE ANTARCTIC SHELF: “FOODBANKS”, ECOSYSTEM INERTIA, AND GLOBAL CLIMATE CHANGE

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Smith et al. 2006. Deep-Sea Research II 53 875–894

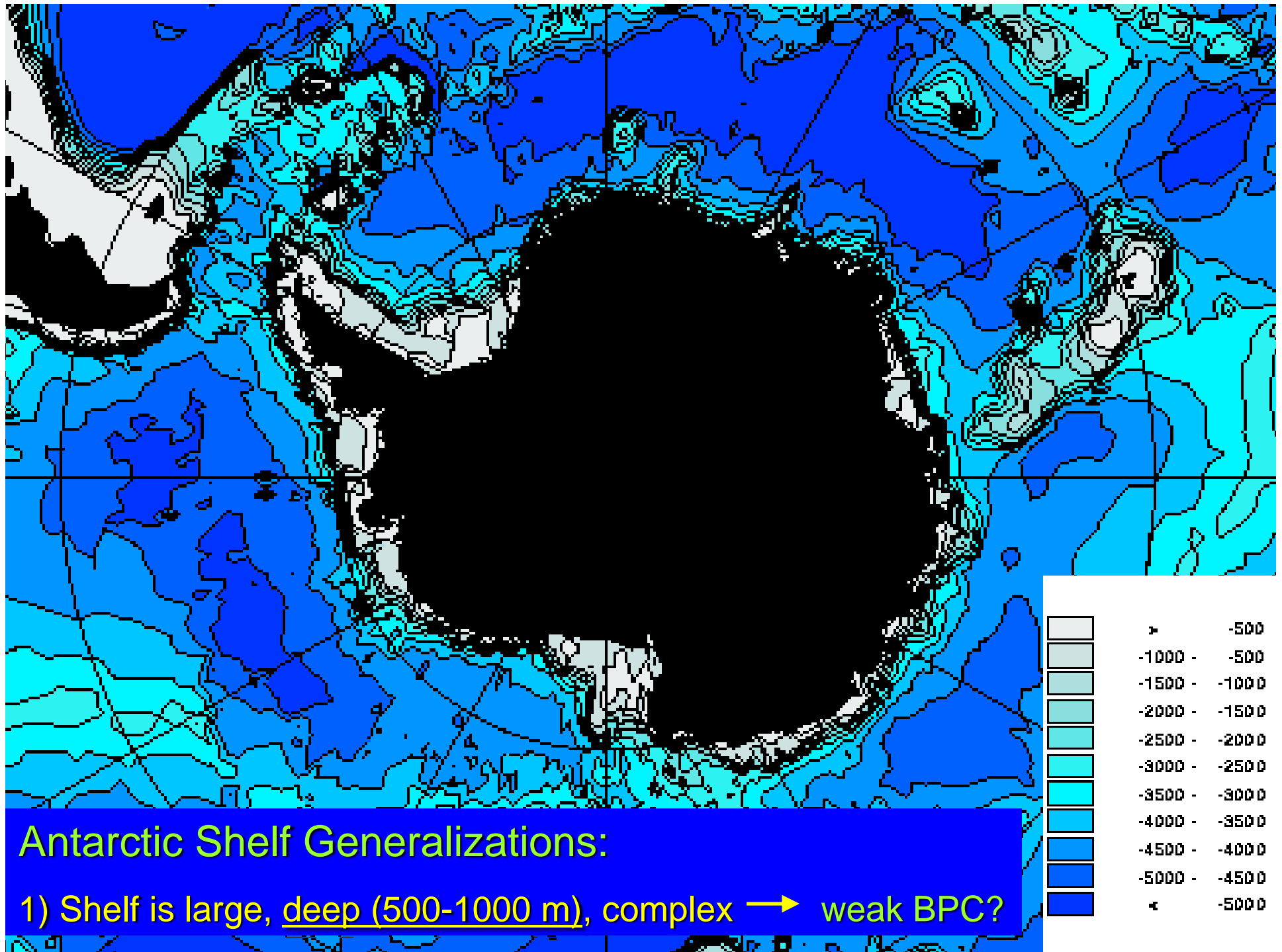
Outline Synthesis:

A) Antarctic shelf generalizations

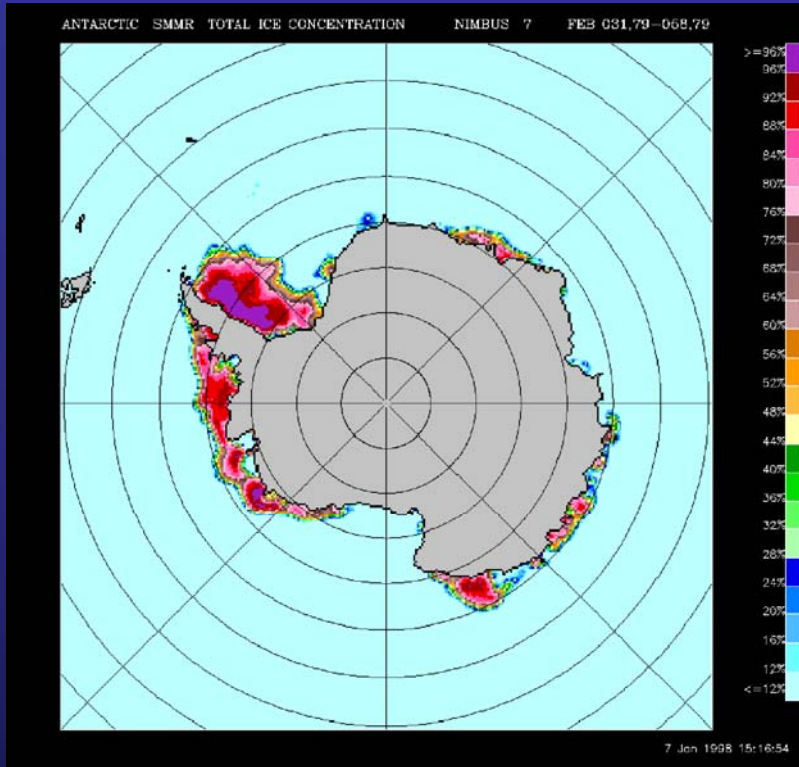
B) Address 4 major BPC questions:

- 1) *Are water column production signals rapidly transmitted to the seafloor?*
- 2) *Do benthic parameters match regional variations in water column processes, such as ice cover and primary production?*
- 3) *Do benthic processes vary in phase with seasonal primary production and flux?*
- 4) *Will patterns of BPC in Antarctica be altered by climate change?*

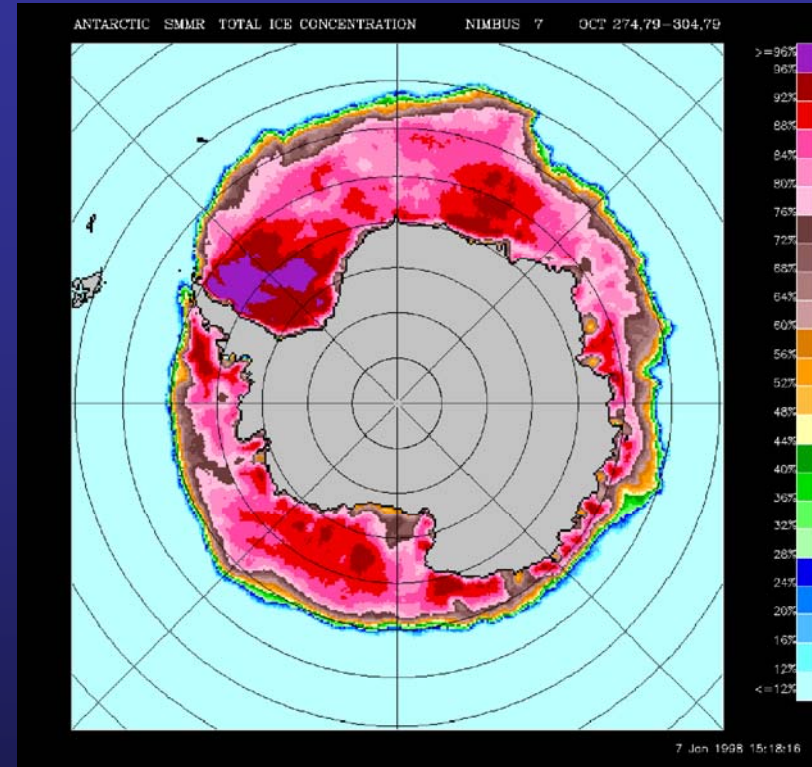
C) Conclusions about BPC on Antarctic shelf



2) Oceanic end member in seasonal/annual variability in water-column production (driven by summer/winter contrasts in light, sea ice, stratification, etc.)



Sea-ice extent – February 1979



Sea-ice extent – October 1979

3) Can have short pelagic food webs (diatoms → krill → fecal pellets)

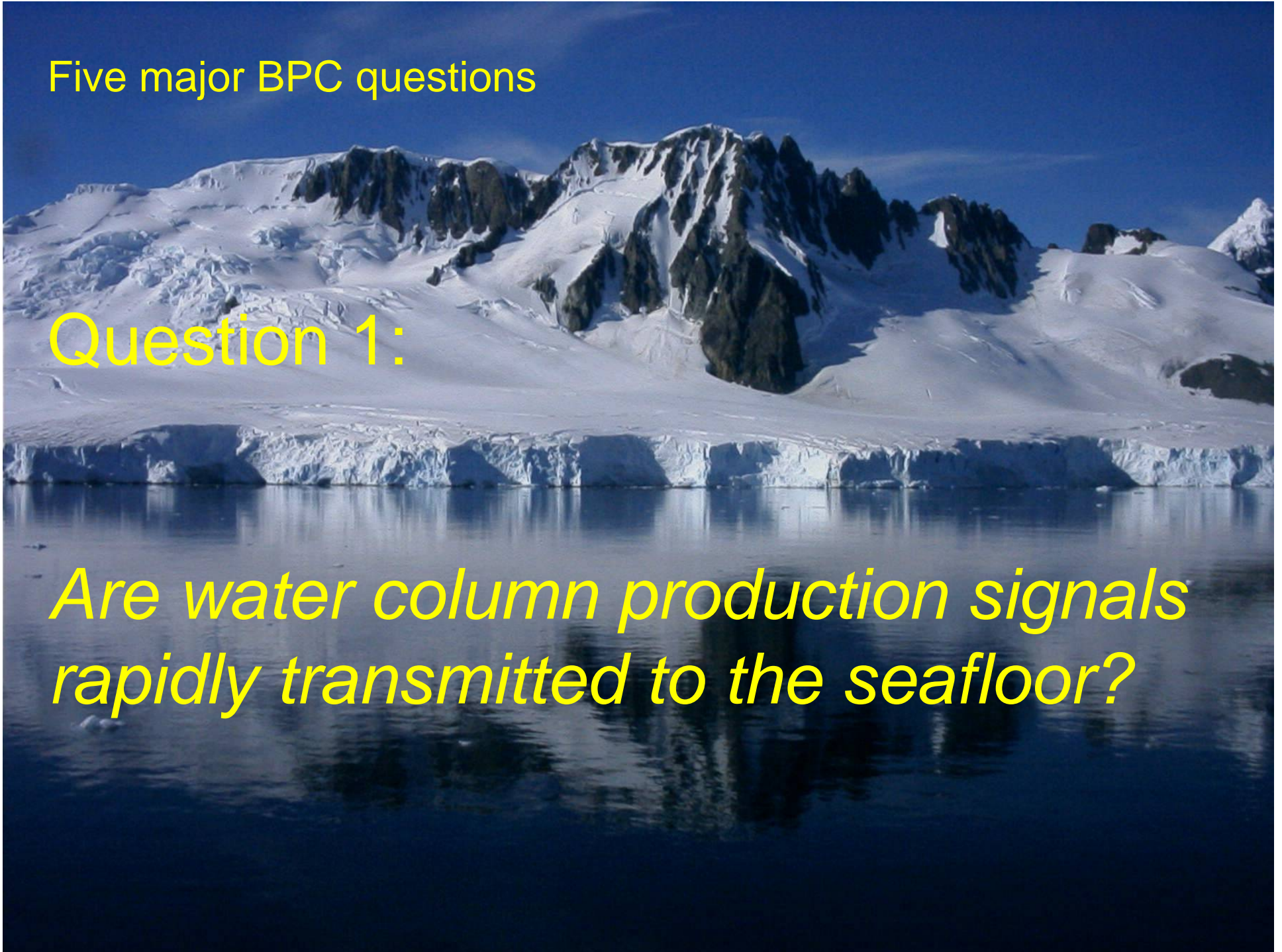
4) Relatively high benthic biomass on the shelf

→ Strong BPC?

Five major BPC questions

Question 1:

Are water column production signals rapidly transmitted to the seafloor?



Deep sediment-trap studies → intense summer pulses of POC flux to shelf floor -

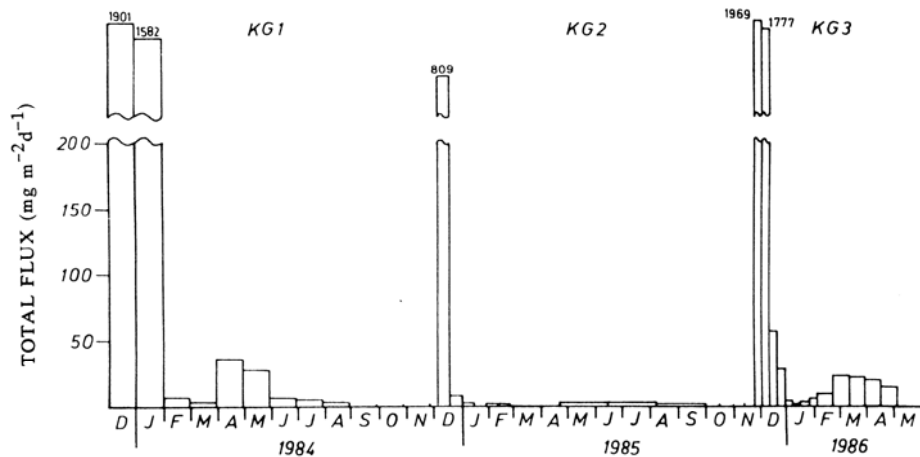
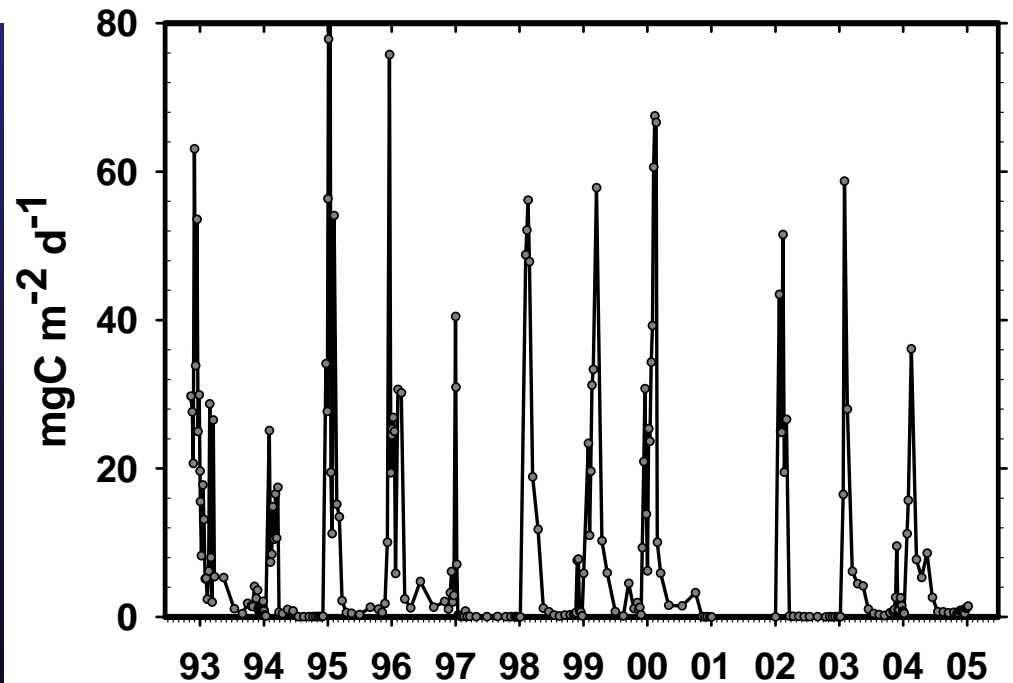


Fig. 6—30-month record of particle flux from the Bransfield Strait (from Wefer et al. 1988, and unpublished data)

Bransfield Strait;
trap depth = 494 m
(Wefer et al., 1988
& unpublished)

Palmer LTER
region, Antarctic
Peninsula shelf;
trap depth = 150 m
(Ducklow et al.
2006)



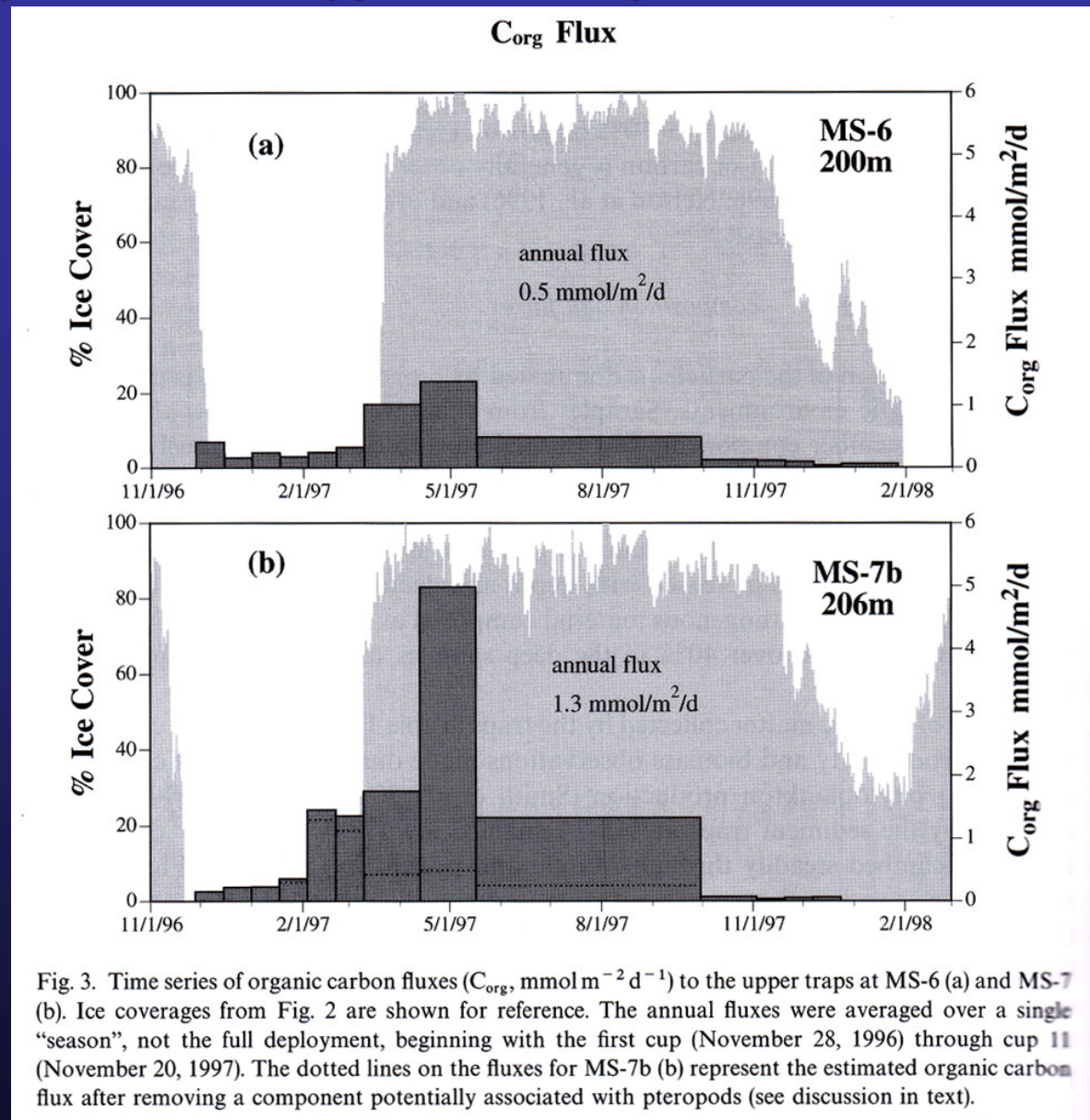
Flux pulses not always coupled to ice disappearance or plankton blooms -

E.g., Collier et al. (2000) in Ross Sea (another e.g., Dunbar et al., 1998)



Time lags due to:

- complex bloom/current structure
- wind vs. melting-induced sea-ice removal
- development times of grazer assemblages



Conclusion for Question 1:

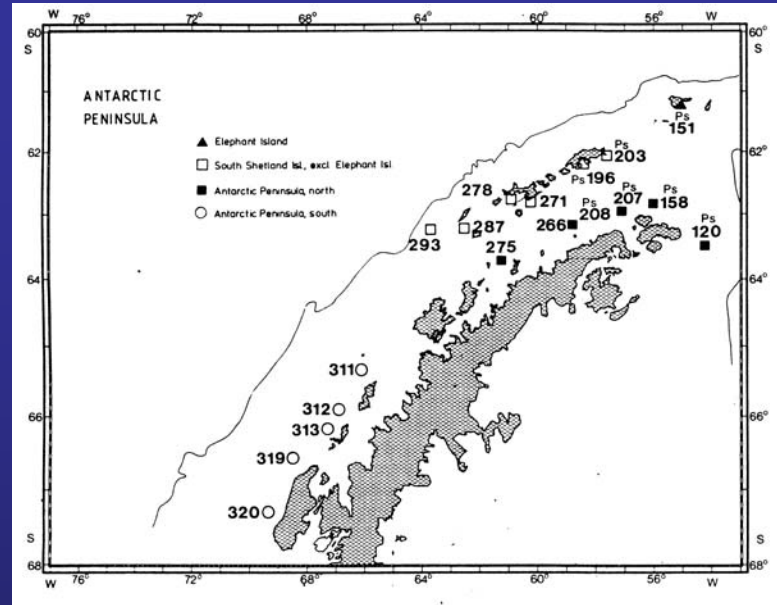
Intense production pulses are transmitted to seafloor, but these are not always tied tightly (in space and time) to local ice/bloom conditions overhead.

Question 2:

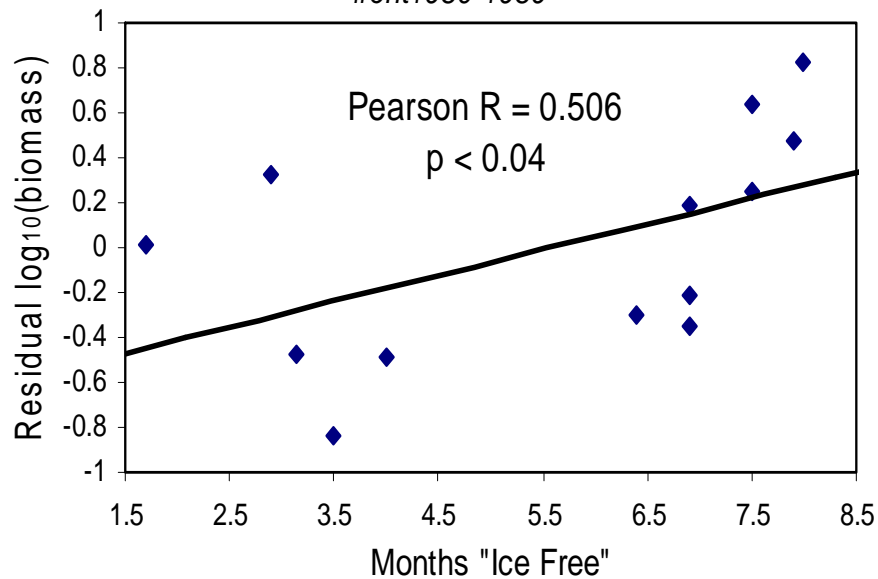
Do benthic parameters match regional variations in water column processes, such as ice cover and primary production?

Regional \geq 100 km scale

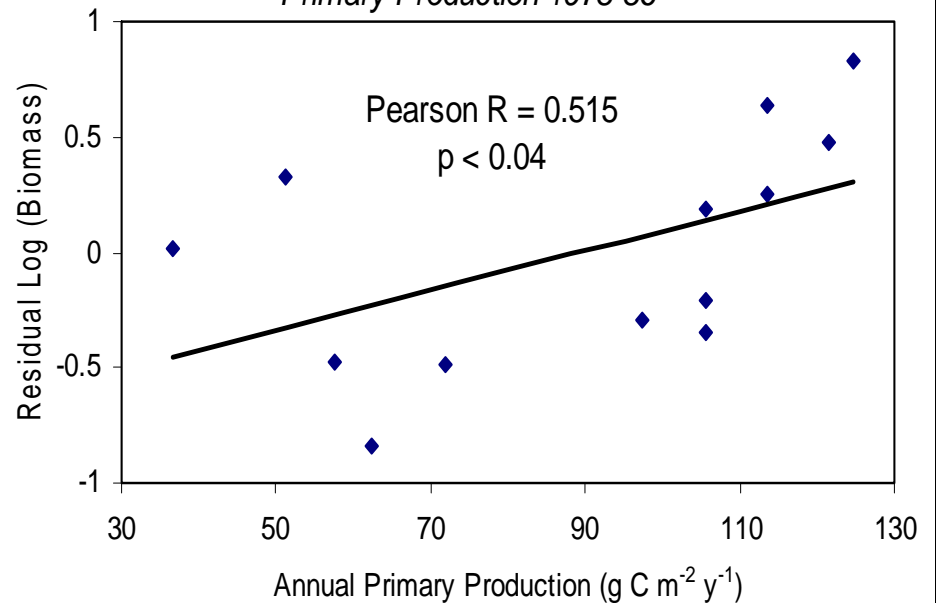
Comparison of macrobenthic biomass to sea-ice duration and annual primary production (after removal of depth effects). (Smith et al., 2006)



Macrofaunal residual biomass versus months north of ice front 1980-1989



Macrofaunal Residual Biomass versus Regional Primary Production 1978-86





Question 3:

Do major benthic processes vary in phase with seasonal primary production and POC flux?

Initial expectation = “generally yes”

Sediment Community Oxygen Consumption?

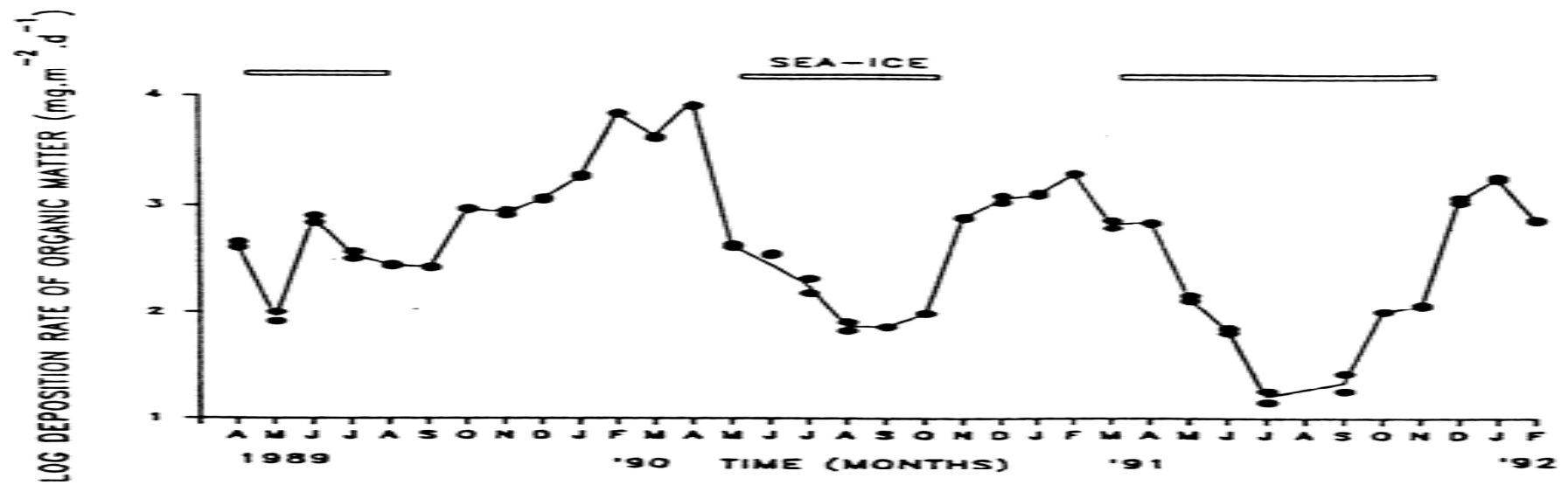


FIG. 4. Settlement rates of organic matter in the water column. Duplicate traps were used.

E.g., Nedwell et al. (1993), Signy Island –

Weak seasonal coupling with strong interannual variability.

Baldwin & Smith (2003), Deception Is. – similar pattern.

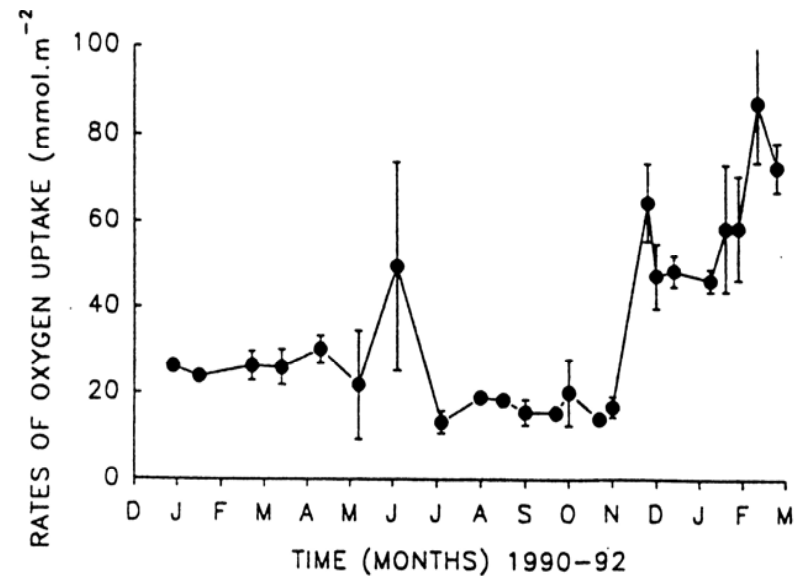
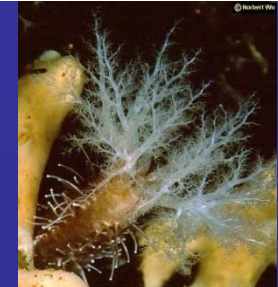


FIG. 1. Rates of O₂ uptake by bottom sediments in Factory Cove, Signy Island. Bars indicate standard errors; n = 3.

Seasonality in suspension feeding?



High seasonality expected due to large seasonal variations in chlorophyll-a concentrations (from large phytoplankton).

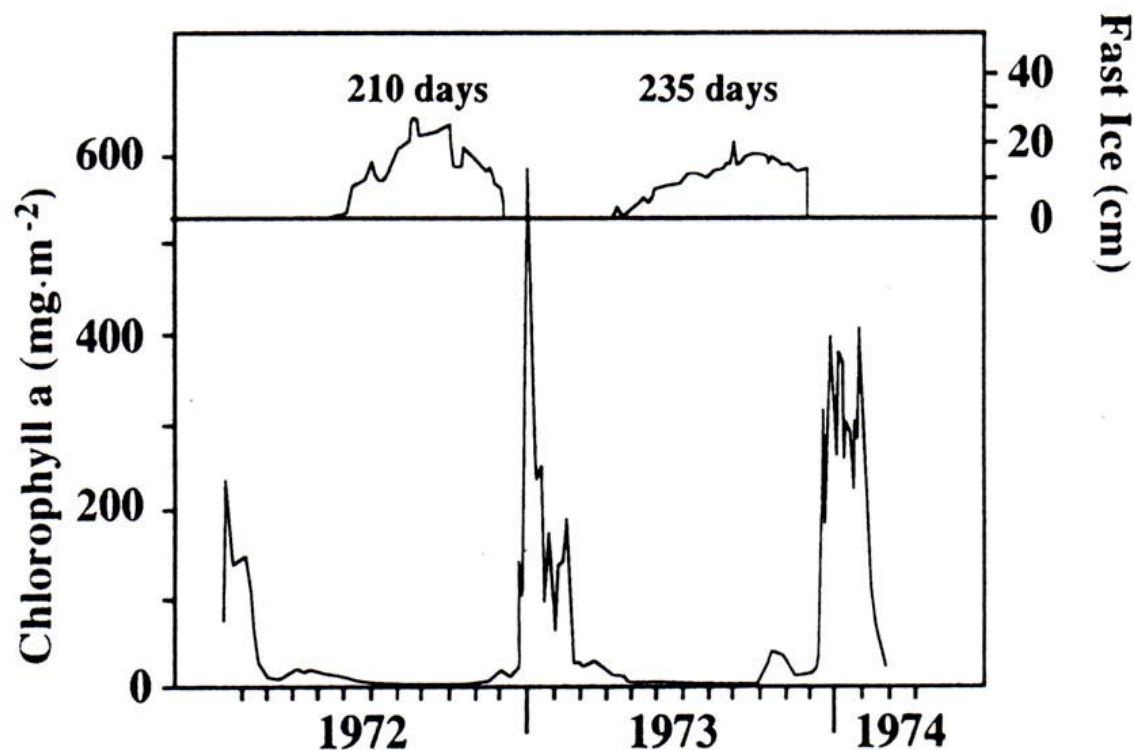
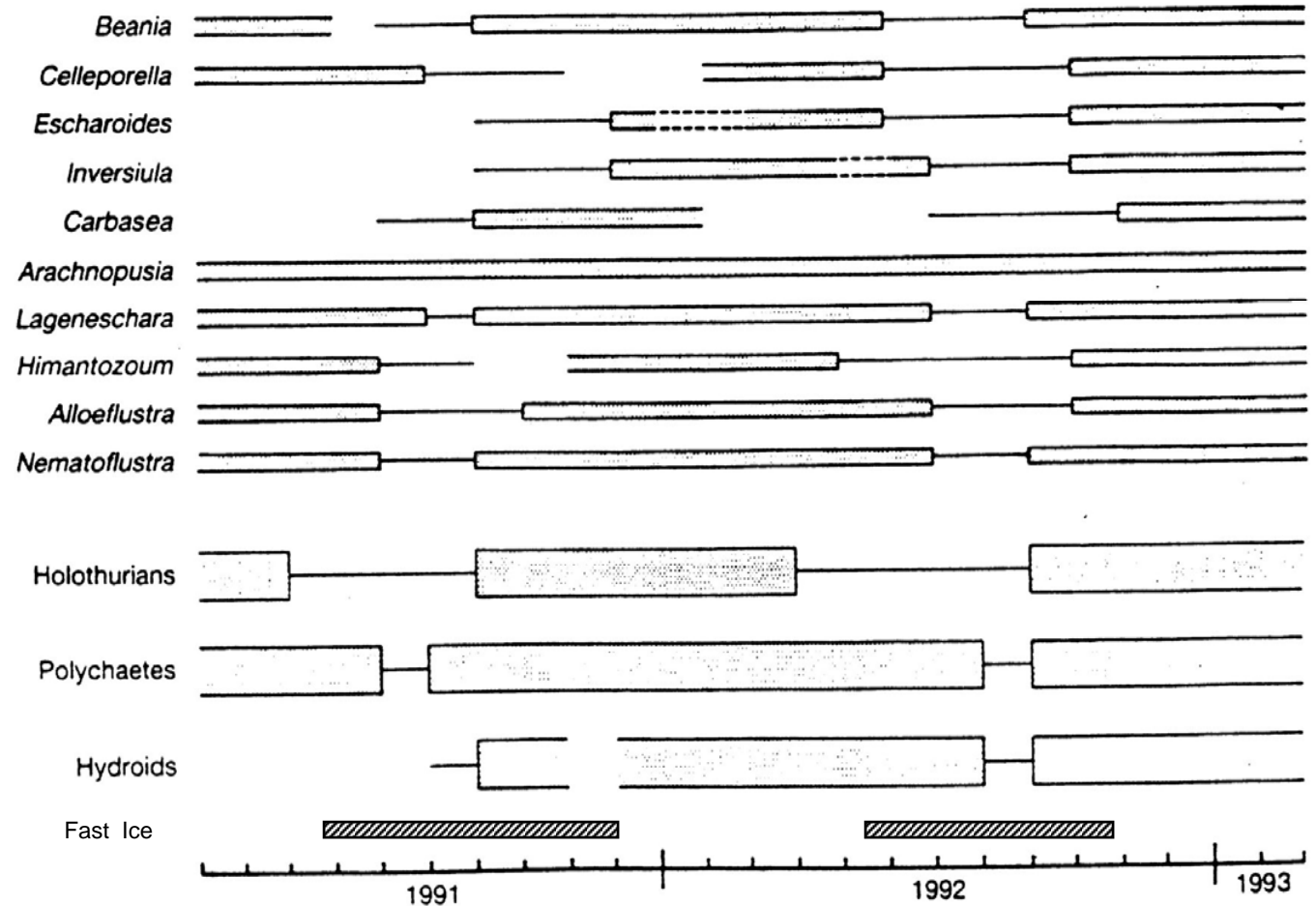


Figure 5 Annual cycle of chlorophyll *a* biomass and fast ice thickness in Borge Bay, Signy Island, South Orkney Islands. (Redrawn from Clarke 1988 after Whitaker 1982).

Barnes and Clarke, (1995), Signy Island

Fig. 2 Feeding activity (shaded blocks) and inactivity (lines) of various benthic suspension feeders with month of year, for 1991–1993. Results are meaned between sites. Dotted lines in *Escharoides* and *Inversiula* mark periods of likely feeding although actual data suggested inactivity (probably because of high currents)



Many species do stop feeding, but often for < 2 - 3 months even though fast ice and low-chlorophyll concentrations last for 5 - 6 months!

Seasonality in deposit feeding? Few studies

Best = Brockington et al. (2001) for *Sterechinus neumayeri*, at Rothera (relatively high latitude – 68° S).



S. neumayeri

Sterechinus feeding = highly seasonal

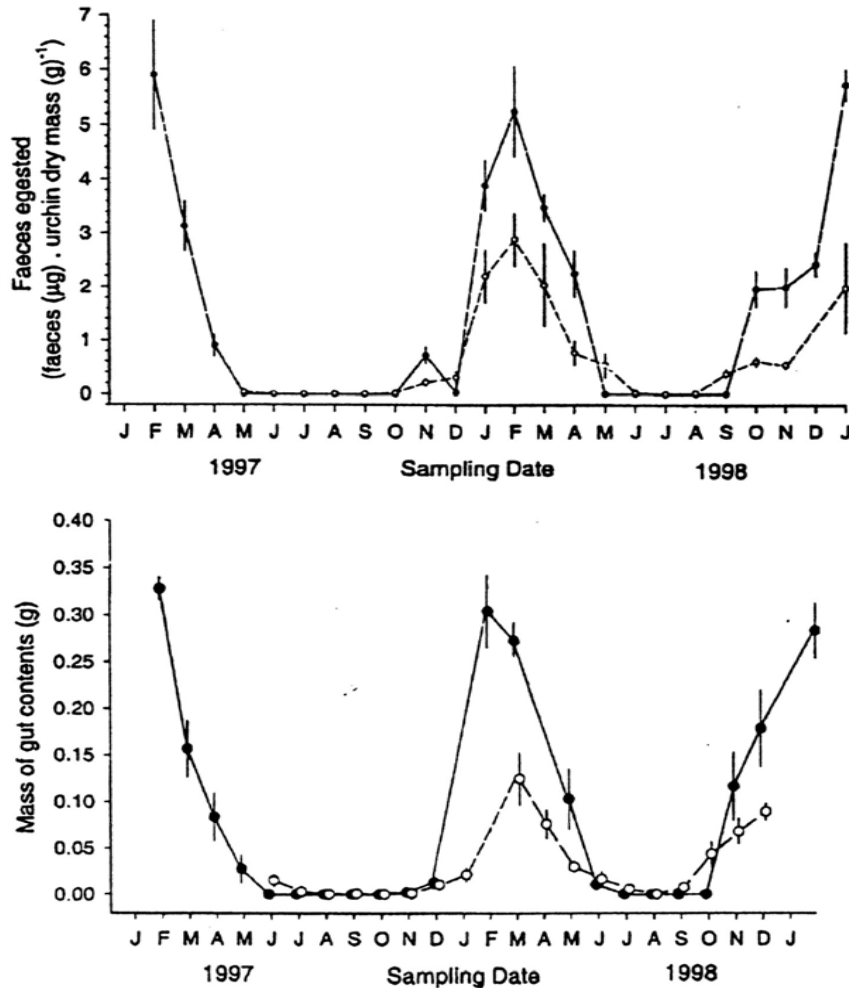
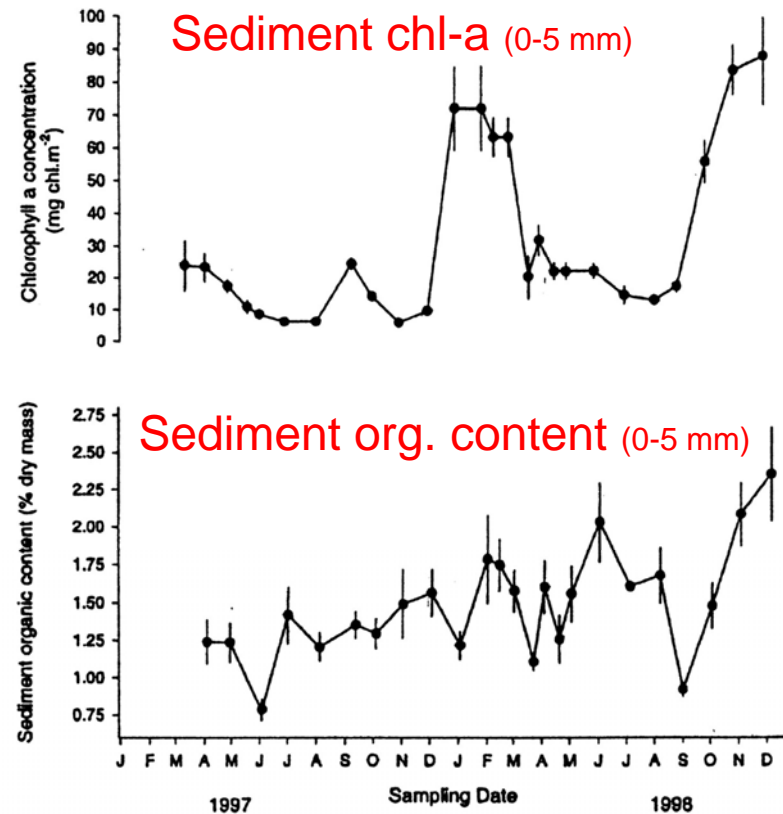


Fig. 4A, B *Sterechinus neumayeri*. A Seasonal variation in feeding (as measured by faecal egestion) from both North (●) and South Cove (○) at Rothera Point. Each point represents a mean of four

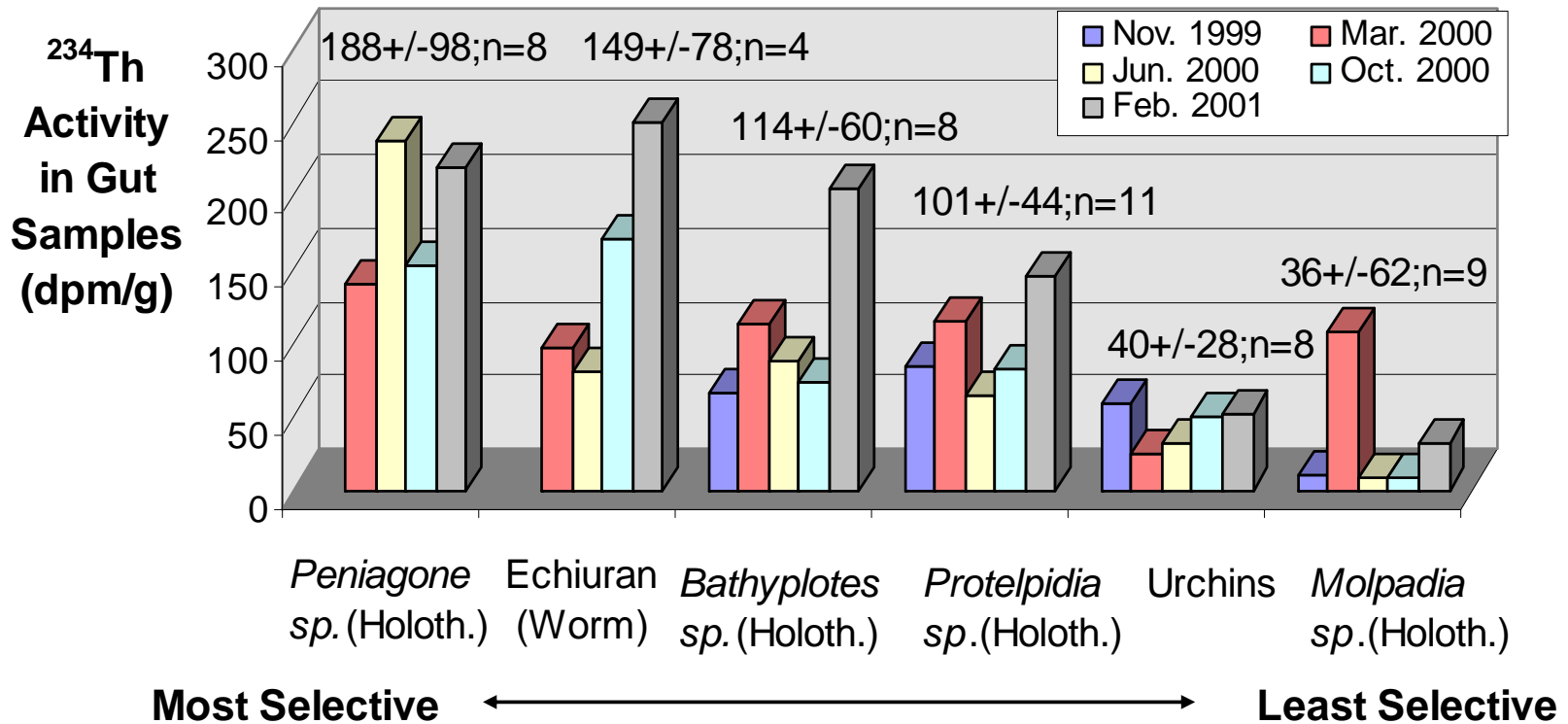


Contrasts with FOODBANCS studies – deep shelf near Palmer Station (64° S)

Sea ice for ~ 4 mo



²³⁴Th Activities in Animal Gut Samples Collected from the Antarctic Shelf



DeMaster et al., in manuscript

All species contain high quality material in gut in summer and winter

Conclusions regarding phasing of benthic processes with seasonal primary production (Question 3):

Most benthic processes initially expected to vary in phase with boom/bust water-column production cycle.

In fact, many processes (including SCOC, feeding and reproduction) often are poorly coupled.

WHY??

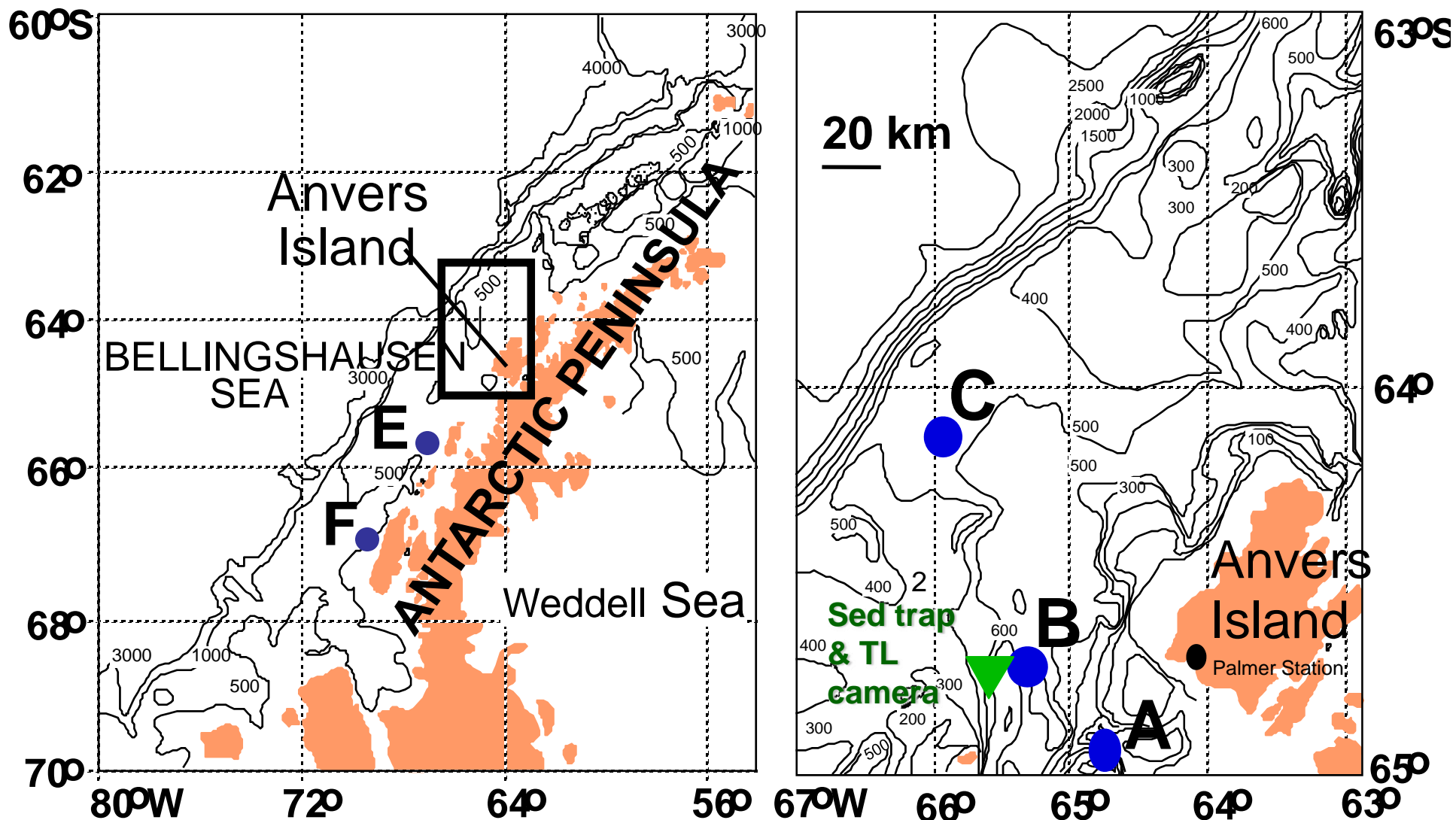
Best insights likely obtained from integrative, time-series study of benthic ecosystem response to seasonal/interannual production patterns.

“Food Bank” Hypothesis

- Large amounts of summer bloom detritus are rapidly deposited on the WAP shelf floor
- Because of slow decomposition at low AA water temperatures, the phytodetritus provides a “food bank” for benthic detritivores during lean winter months

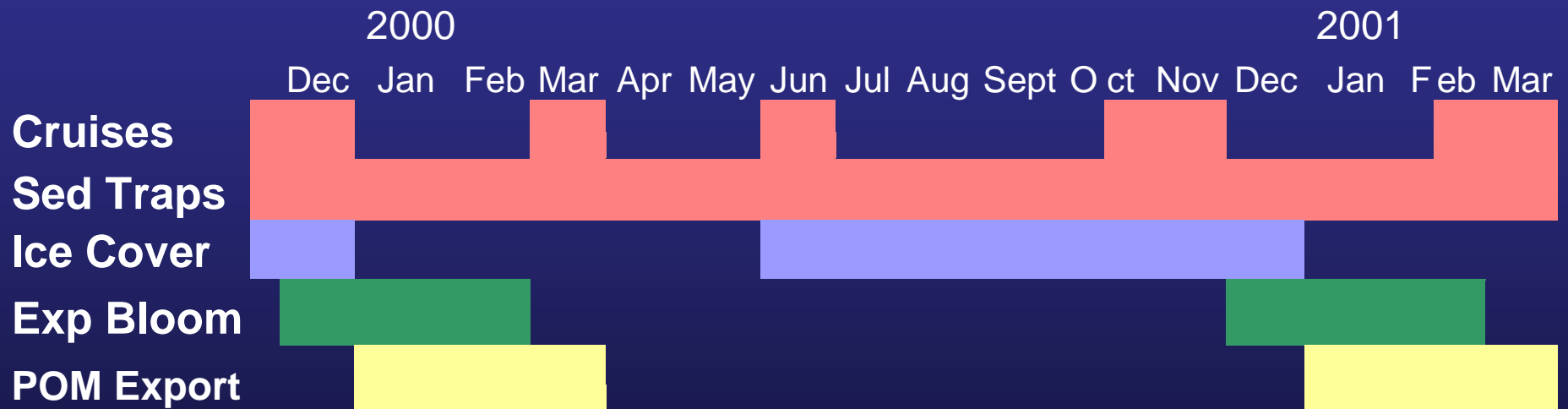
FOODBANCS Study – Nov 99 – Mar 01

(Food for Benthos on the Antarctic Continental Shelf)



Smith and DeMaster (2008)

Sampling Time-line



Broad range of parameters sampled $\geq 5x$ over 15 months (Nov 99 – Mar 01):

- Sediment traps - moored ~150 mab at Sta. B
- Seafloor video surveys – all stations
- Time-lapse photography – picture every 12 h of 2 m² of seafloor at Sta. B
- Megacore samples – microbes–macrofauna, sediment geochemistry and radiochemistry
- Respirometry - whole core incubations
- Otter trawls - megafauna

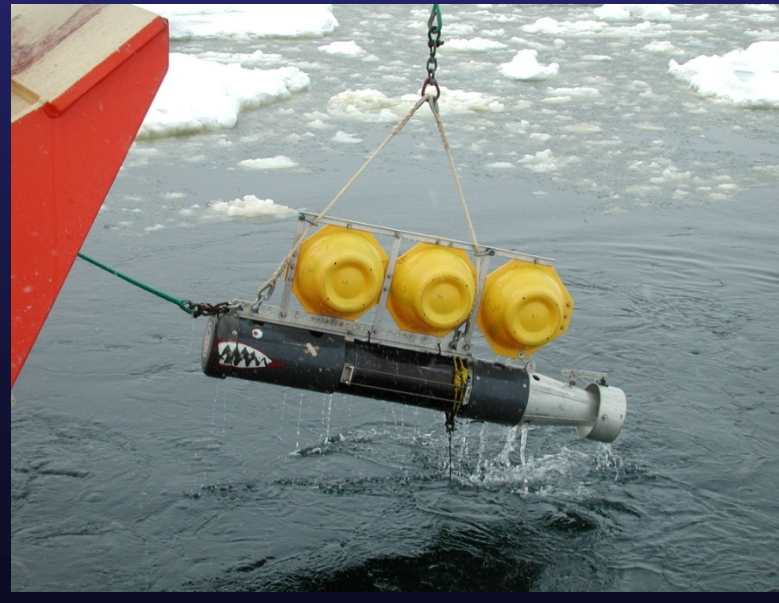
SEDIMENT TRAP
RECOVERY



MEGACORE



TOWED SEAFLOOR VIDEO SURVEY SYSTEM

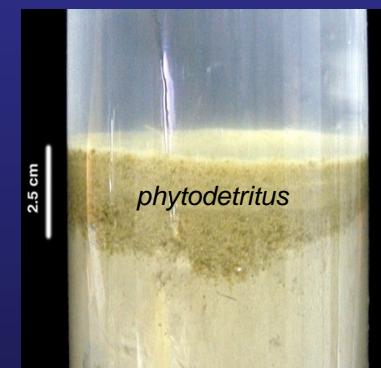
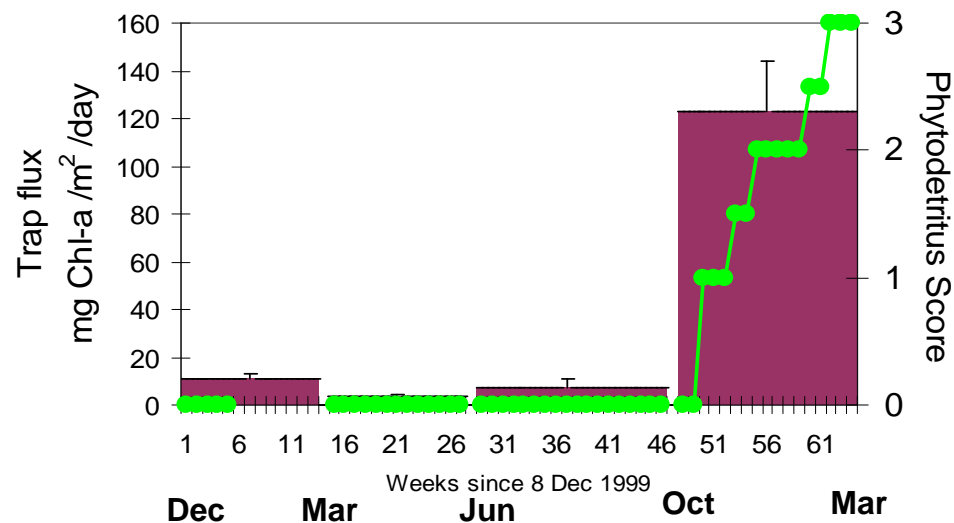


Phytodetritus obvious in FOODBANCS video surveys during March 2001



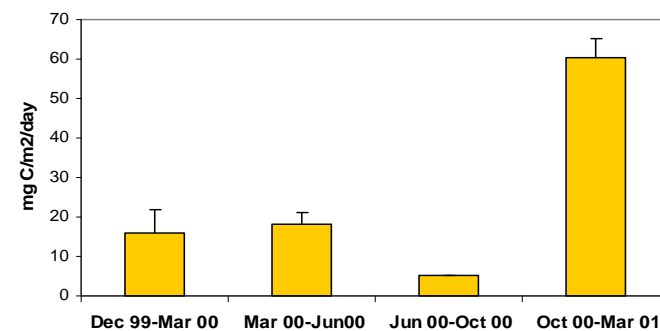
Laser dots are separated by 10 cm

Chlorophyll-a Flux into Sediment Traps (150 mab)
& Seafloor Phytodetritus Score

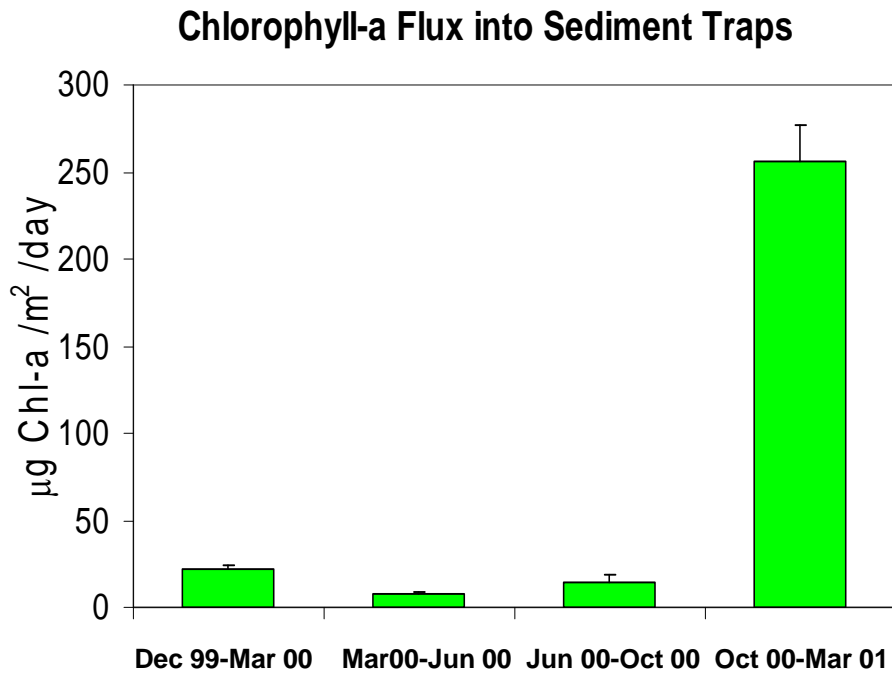


Megacore sample

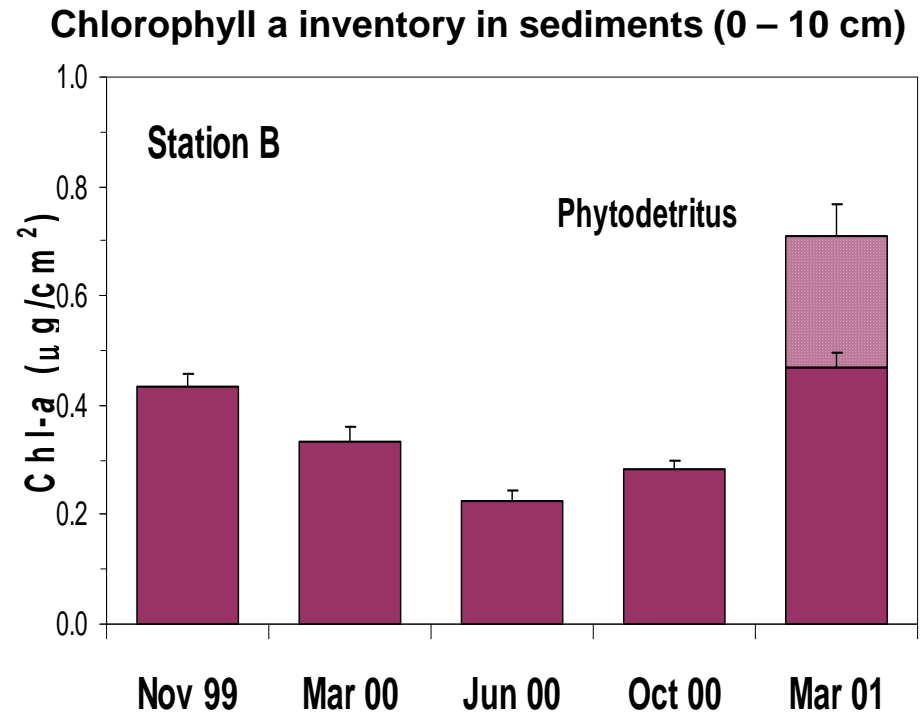
Particulate Organic Carbon Flux into Sed Traps
Station B - 150 mab



Benthic response is muted compared to water column variability



Interannual variability = 11.5 X



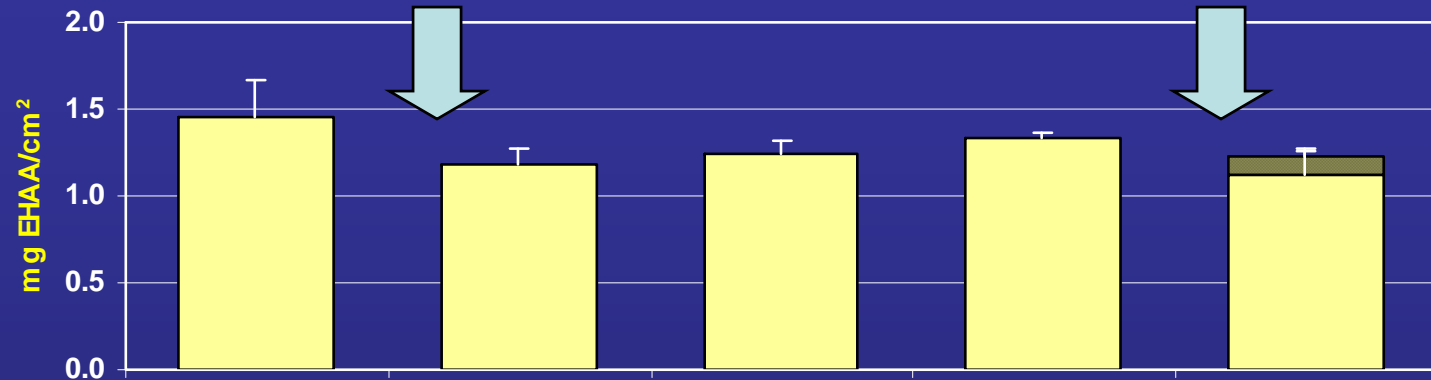
Interannual variability ~ 3 X

Half life of Chl-a inventory in the top 10 cm of sediment ~ **50 - 400 d** -

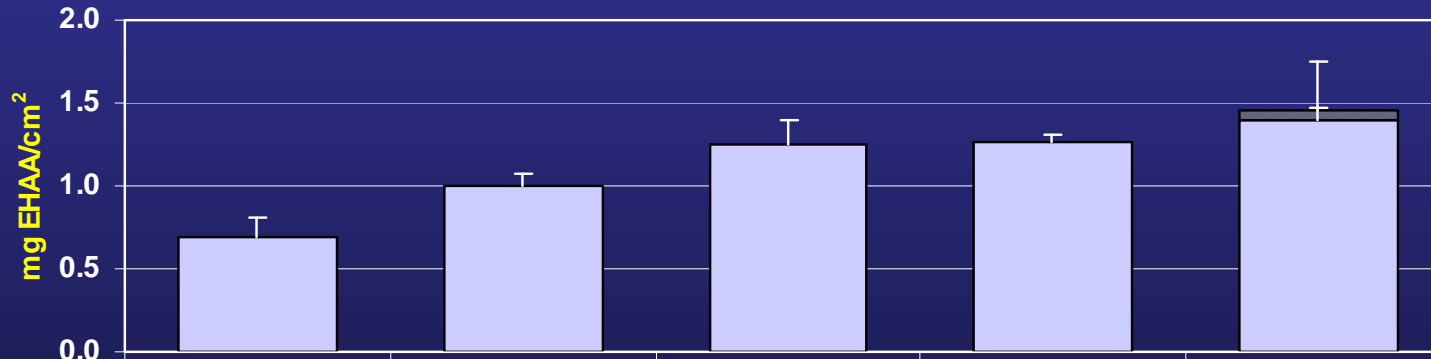
i.e., there is persistent labile organic material in sediments.

Sediment EHAA Inventories (DF'er food)

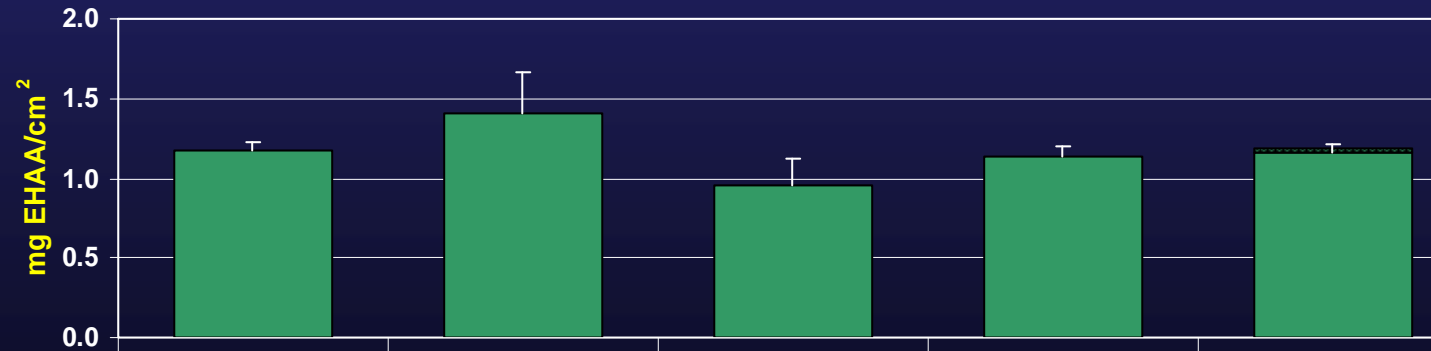
Stn A



Stn B



Stn C



Nov-99

Mar-00

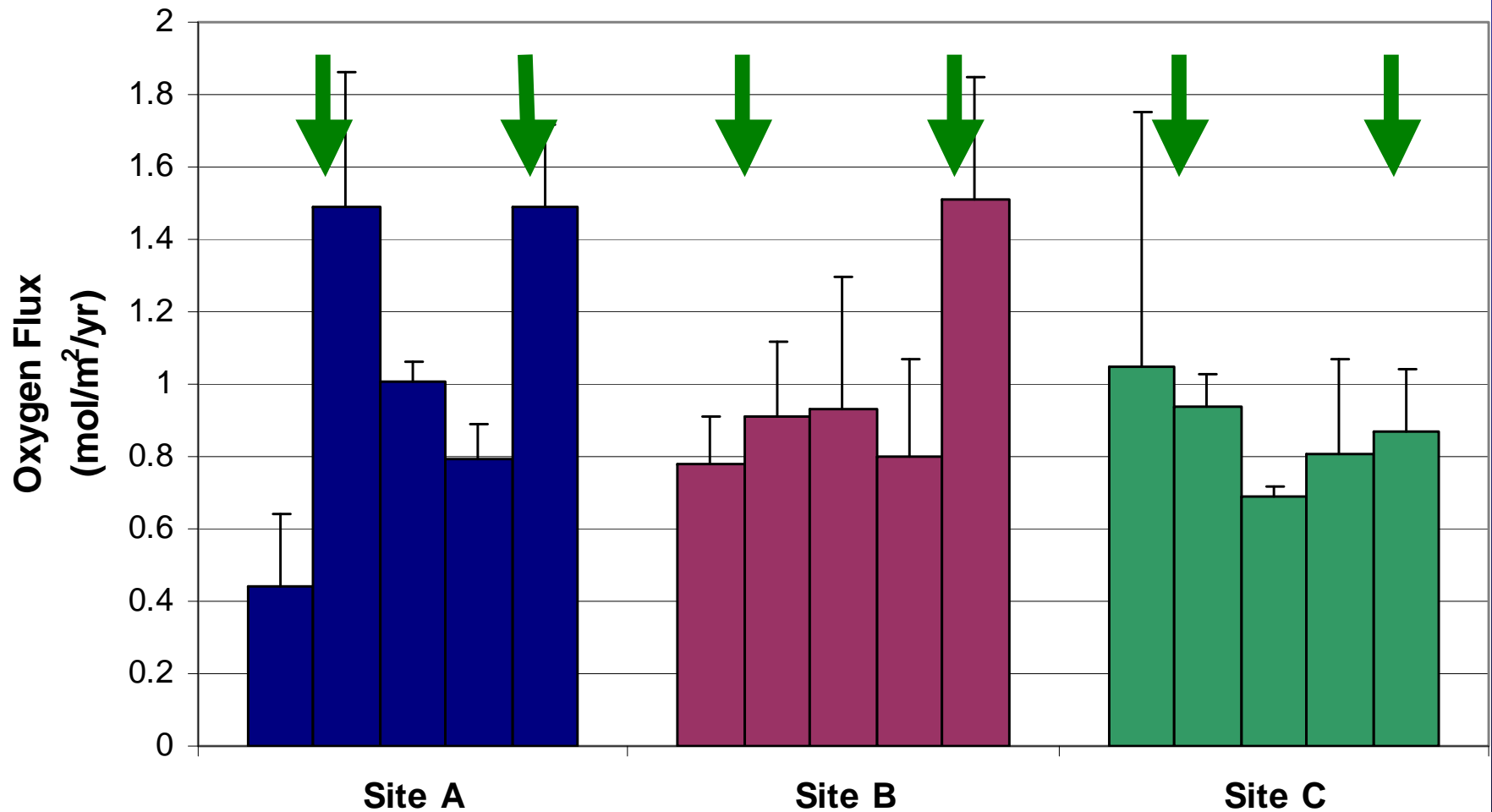
Jun-00

Oct-00

Mar-01

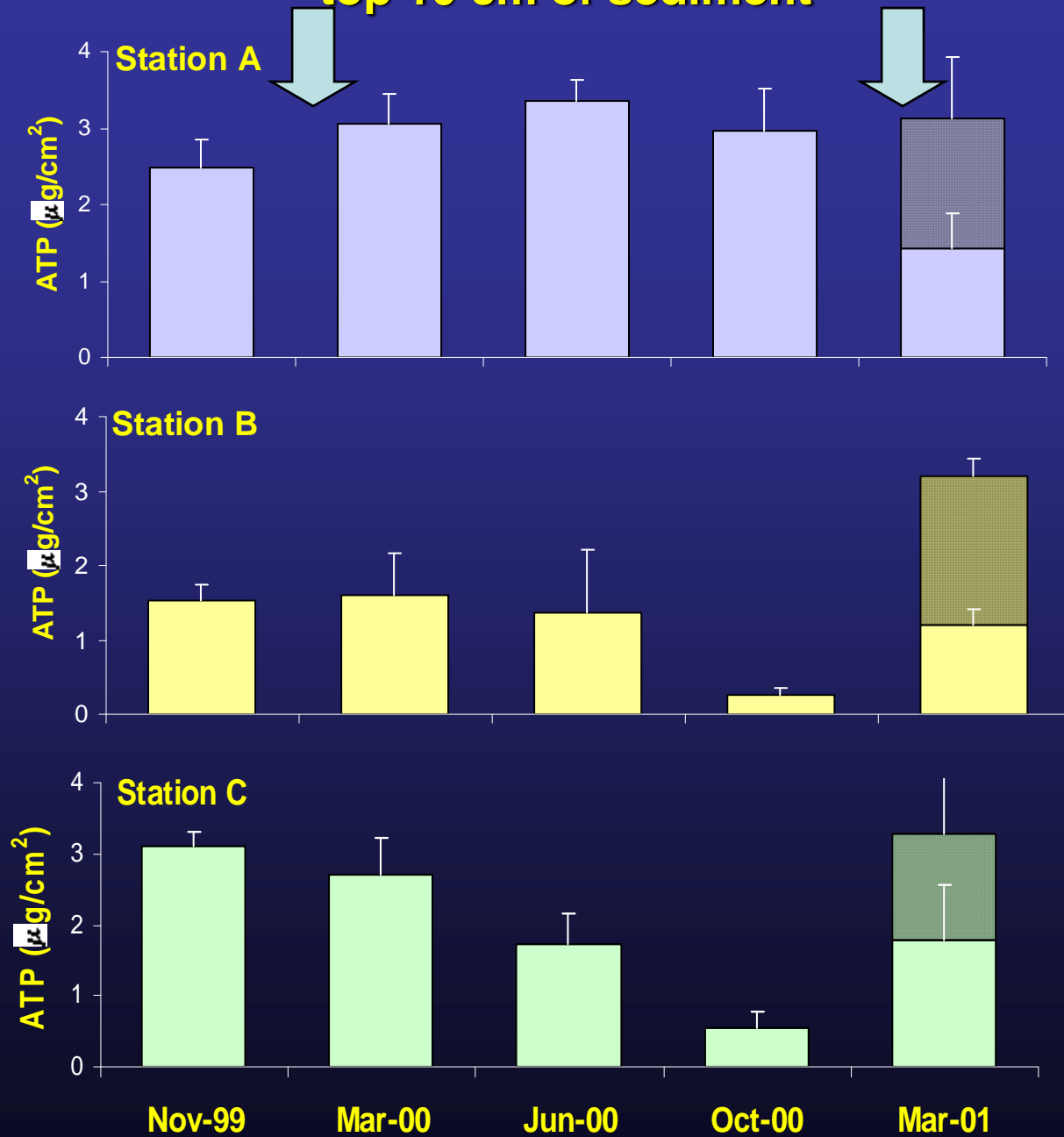
Seabed Respiration

(Nov-99 to Feb-01)



Respiration rates vary 1.3 – 2 fold at Stations B and C (versus >4-fold variability for sediment trap POC flux at Sta. B)

Sediment ATP Inventories – Measure of microbial biomass in top 10 cm of sediment



In summary: Despite highly pulsed flux, labile organic matter accumulates in WAP sediments yielding a predictable “*food bank*” for deposit feeders during low-productivity winter periods. (Smith et al , 2008: Deep-Sea Research II 55 2404–2414)

NB: Large “Food Bank” may result from high substrate requirements for sediment bacteria at very low (< 1 C) temperatures (see Mincks et al. 2005)

Conclusions regarding Question 3:

Benthic ecosystem response to summer flux pulses has substantial *inertia* (in part due to presence of sediment “food bank”).

Many benthic processes may act as “low-pass filters” – primarily recording longer-term (e.g., inter-annual) trends in water-column processes.

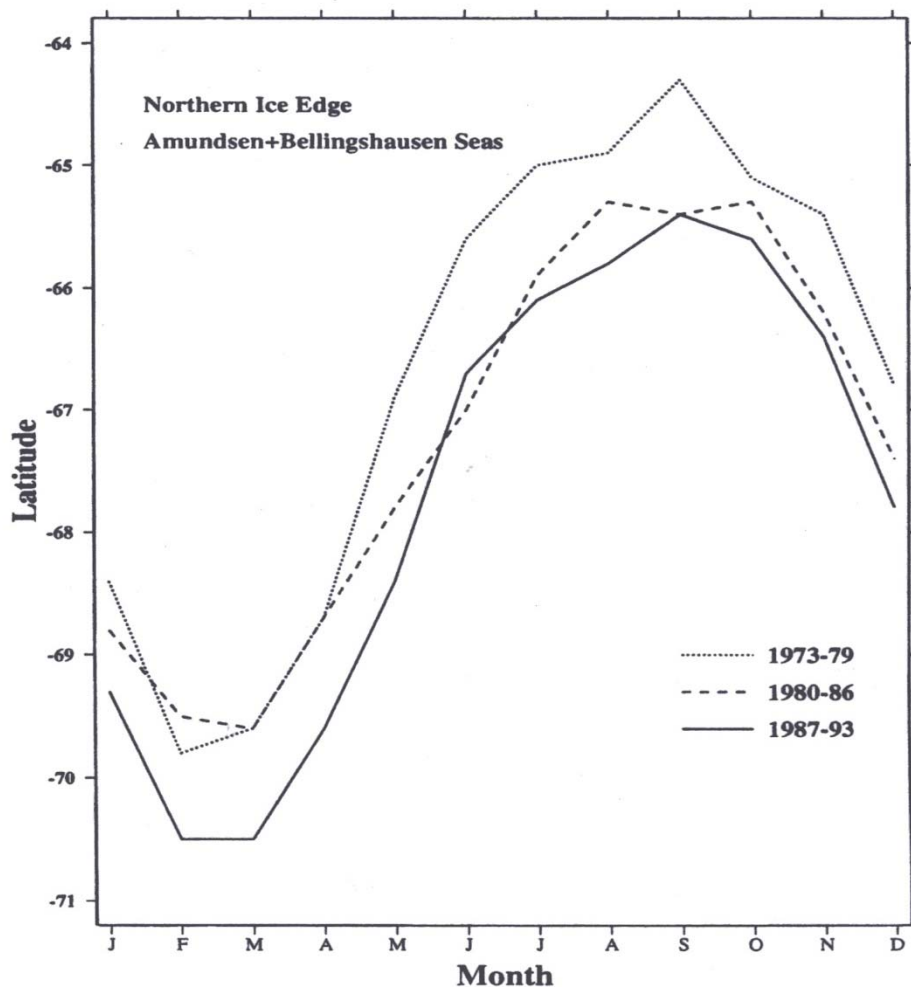


Question 4:

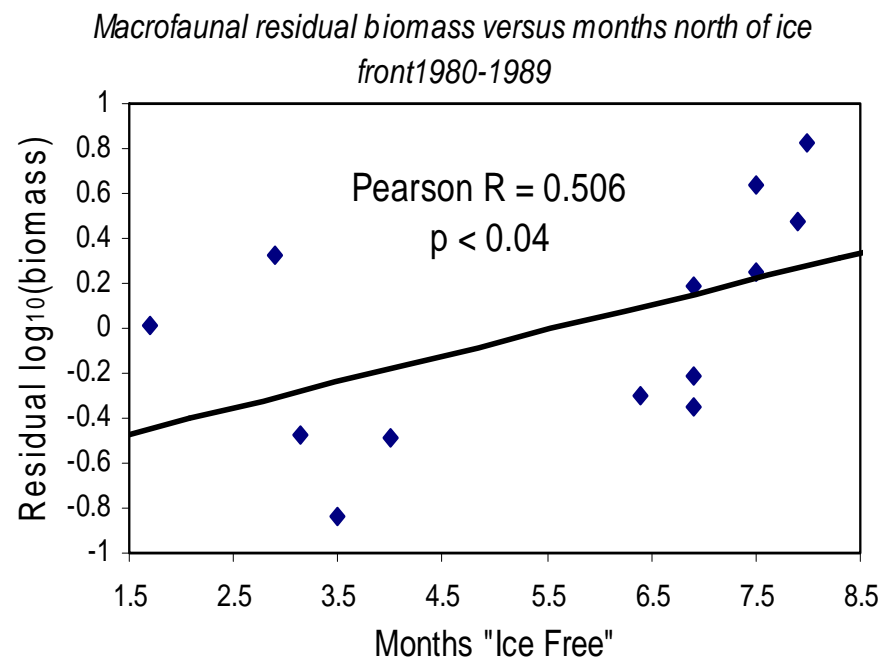
Will patterns of benthic-pelagic coupling be affected by climate change (e.g., by Antarctic Peninsular warming)?

Very likely YES! For example:

Warming is yielding reduction in duration of sea-ice cover -



And duration of sea-ice is correlated with shelf macrofaunal biomass -



Jacobs and Comiso, 1997

Smith et al (2006) Deep-Sea Research II 53 (2006) 875-894

A photograph of several large, white icebergs floating in a dark blue ocean under a clear sky. The icebergs are of various shapes and sizes, some appearing as large, flat sheets and others as more jagged, blocky structures. The water is calm, and the sky is a pale, clear blue.

Other potential changes to Antarctic benthic ecosystems due to climate warming include:

1. A shift among suspension-feeder to favor species with the “fast” (or seasonal) feeding pattern (Orejas et al., 2003) as the summer bloom season becomes longer.
2. A shift in benthic recruitment patterns to more closely resemble the temperature zone, specifically with stronger summer peaks in recruitment (cf. Bowden, 2005).
3. A decrease in the importance of benthic prey to pelagic predators (e.g., Weddell and elephant seals) as the water column remains highly productive for a greater portion of the year.

Many other impacts of warming on benthopelagic coupling also extremely likely –



Especially because the structure and export production of Antarctic pelagic ecosystems is heavily modulated by sea ice.

OVERALL CONCLUSIONS REGARDING PELAGIC-BENTHIC COUPLING ON THE ANTARCTIC SHELF

- 1) POC flux to the Antarctic shelf floor is dominated by large summer pulses – BUT pulses often are offset in time or space from overlying plankton blooms.
- 2) Despite initial expectations, many benthic processes (including SCOC, suspension feeding, and deposit feeding) are only weakly phased to seasonal patterns of water-column production, exhibiting substantial “*inertia*” (due to presence of *food banks*).
- 3) Because of this “*inertia*”, benthic processes may act as low pass filters and be useful indicators of long-term trends in Antarctic ecosystem function.
- 4) Climate warming will substantially impact pelagic –benthic coupling in Antarctica because the structure and export production of Antarctic pelagic ecosystems is heavily modulated by sea ice.