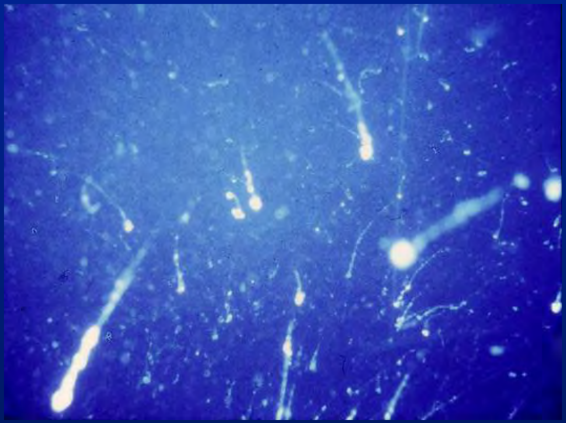
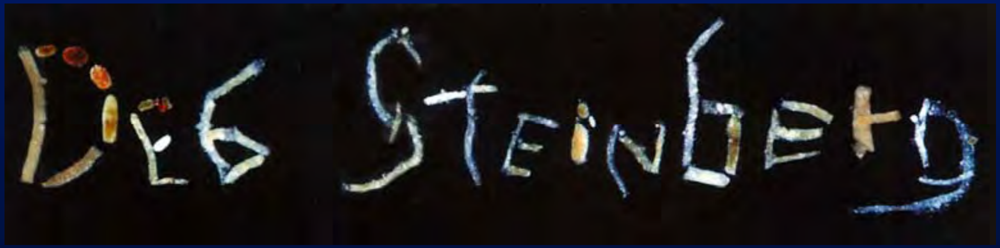
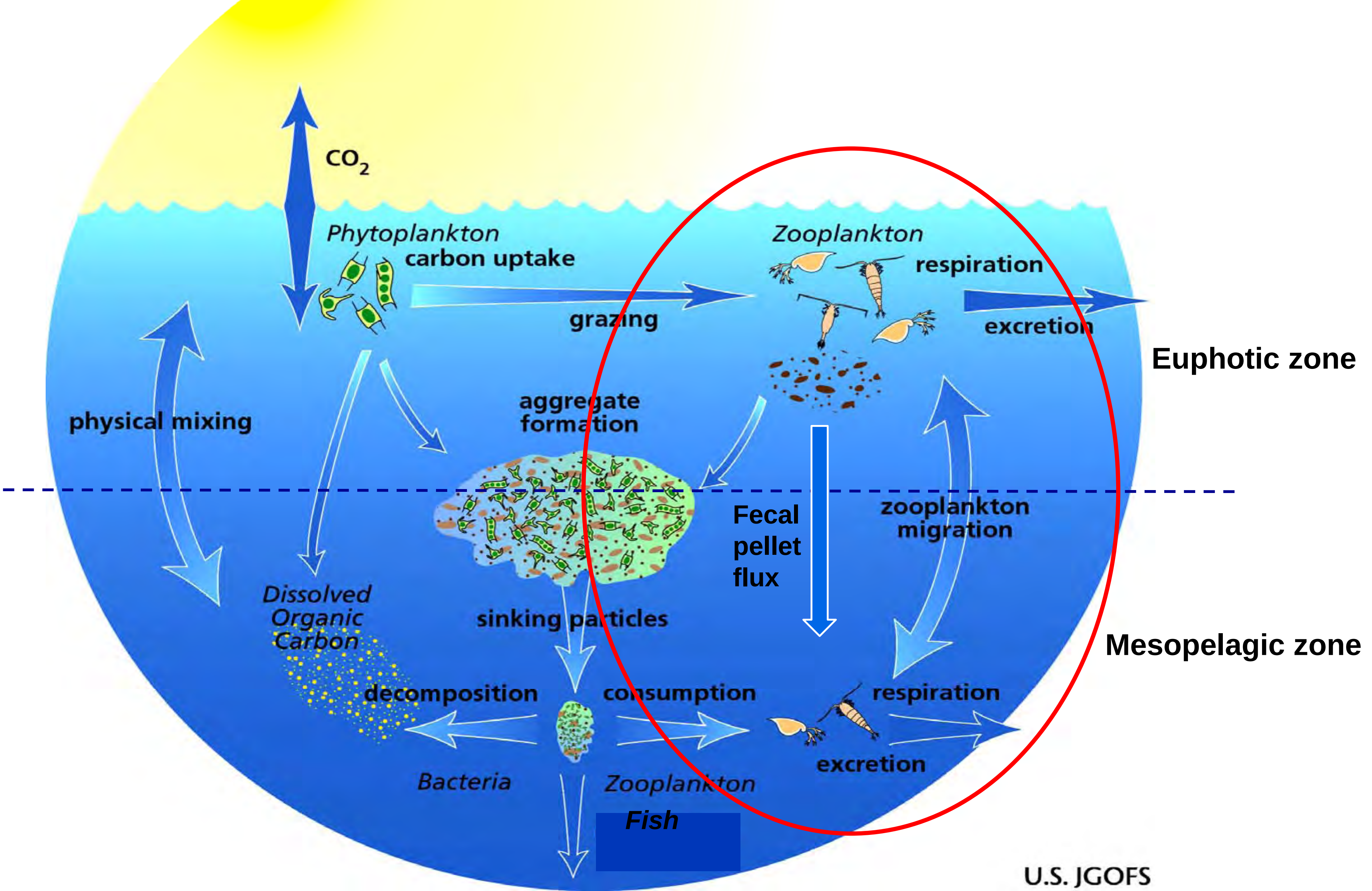
Zooplankton role in biogeochemical cycles: Progress and prospects for the future

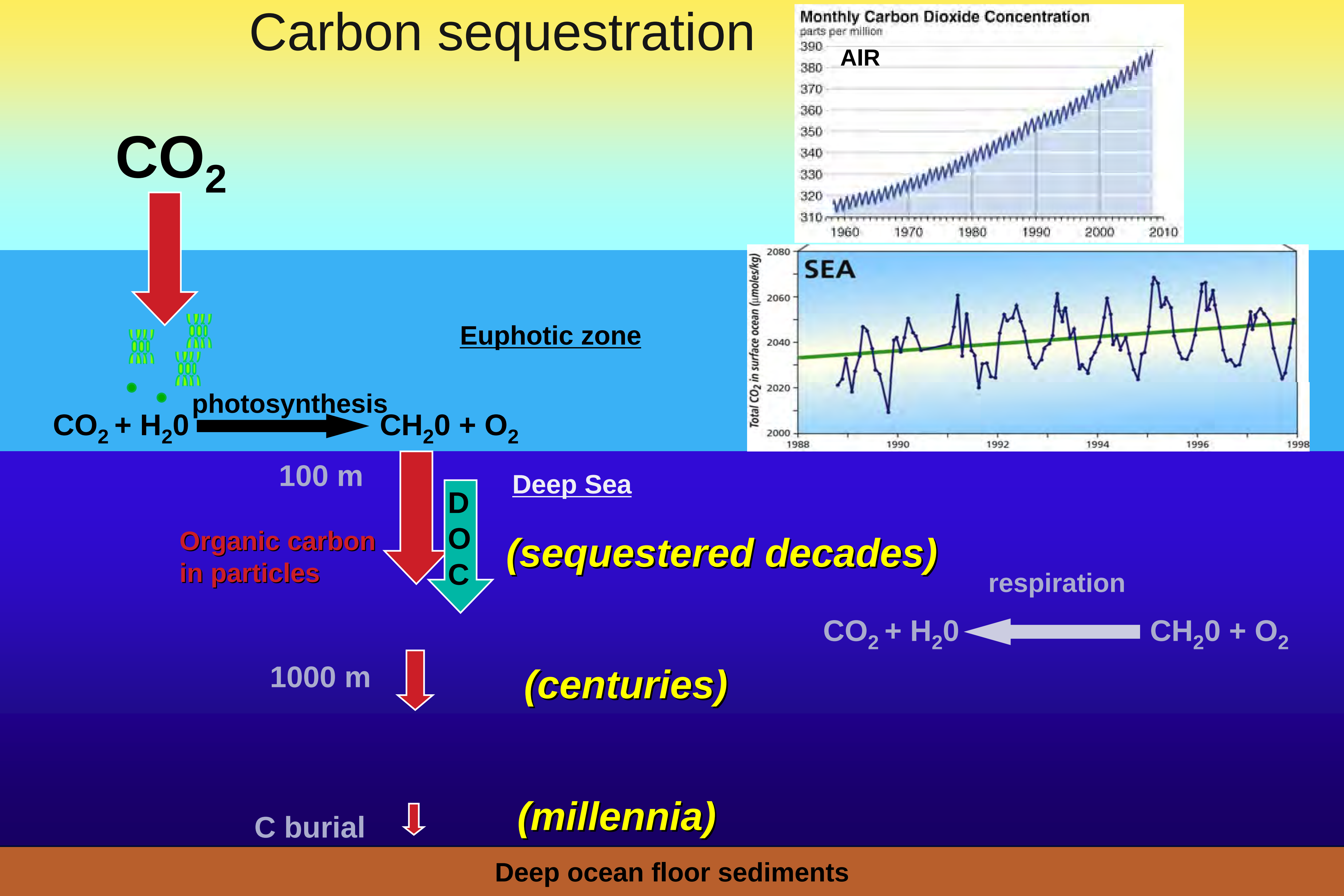




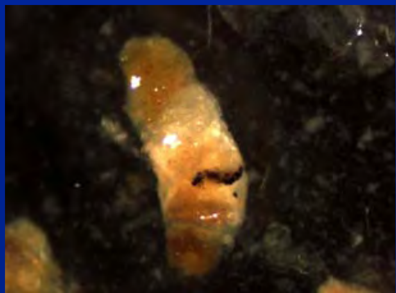
William & Mary
VIMS
Virginia Institute of Marine Science
School of Marine Science

Vertical export and biogeochemical cycling




Carbon sequestration
Monthly Carbon Dioxide Concentration
parts per million
AIR
390
380
370
360
350
340
330
320
310
1960
1970
1980
1990
2000
2010
SEA
Total CO2 in surface ocean (µmoles/kg)
2080
2060
2040
2020
2000
1988
1990
1992
1994
1996
1998
CO2
Euphotic zone
photosynthesis
CO2 + H20
CH20 + O2
100 m
Deep Sea
D
O
C
Organic carbon
in particles
(sequestered decades)
respiration
CO2 + H20
CH20 + O2
1000 m
(centuries)
C burial
(millennia)
Deep ocean floor sediments

Feeding the deep sea



Fecal pellet from gut of Myctophid

DOM

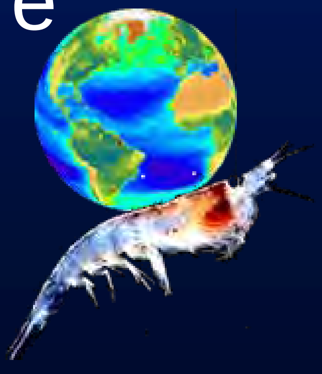
Copepod (*Scopalatum*) and marine snow

Sea cucumber -deposit feeder

Outline

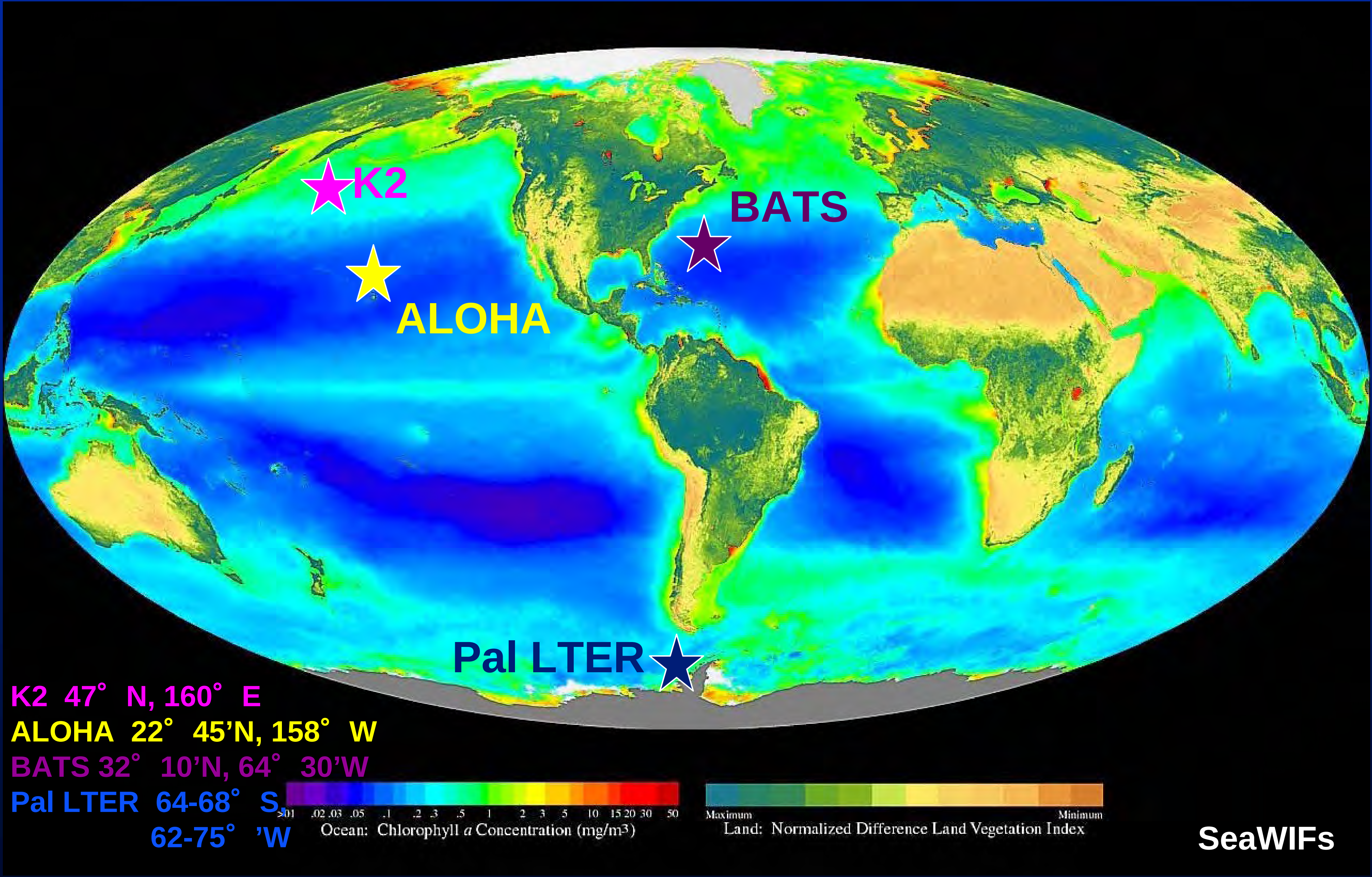
- Ecosystem comparison of fecal pellet flux & active transport
- Long-term changes in zooplankton-mediated export
- Lesser known -

  DOM cycling, deep sea, gelatinous zooplankton
- Prospects & considerations for the future
- Conclusions



Ecosystem comparison of fecal pellet flux & active transport

Study sites



K2
BATS
ALOHA
Pal LTER
K2 47° N, 160° E
ALOHA 22° 45'N, 158° W
BATS 32° 10'N, 64° 30'W
Pal LTER 64-68° S,
62-75° 'W
>.01 .02 .03 .05 .1 .2 .3 .5 1 2 3 5 10 15 20 30 50
Ocean: Chlorophyll a Concentration (mg/m³)
Maximum
Minimum
Land: Normalized Difference Land Vegetation Index
SeaWIFs

Zooplankton community comparison

K2

Neocalanus copepods

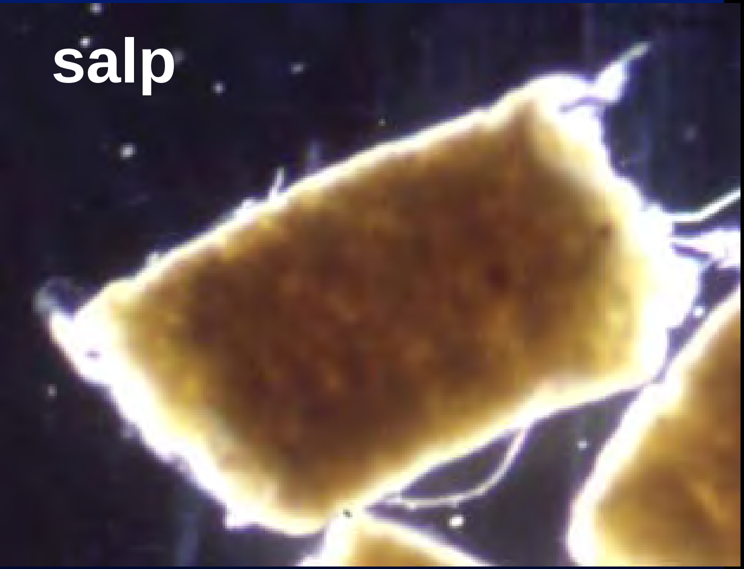
Pal LTER

ALOHA and BATS

Zooplankton scatology

Shape, size – taxa

Color – diet



C,N content:
Directly measured &
Volume - C
conversion

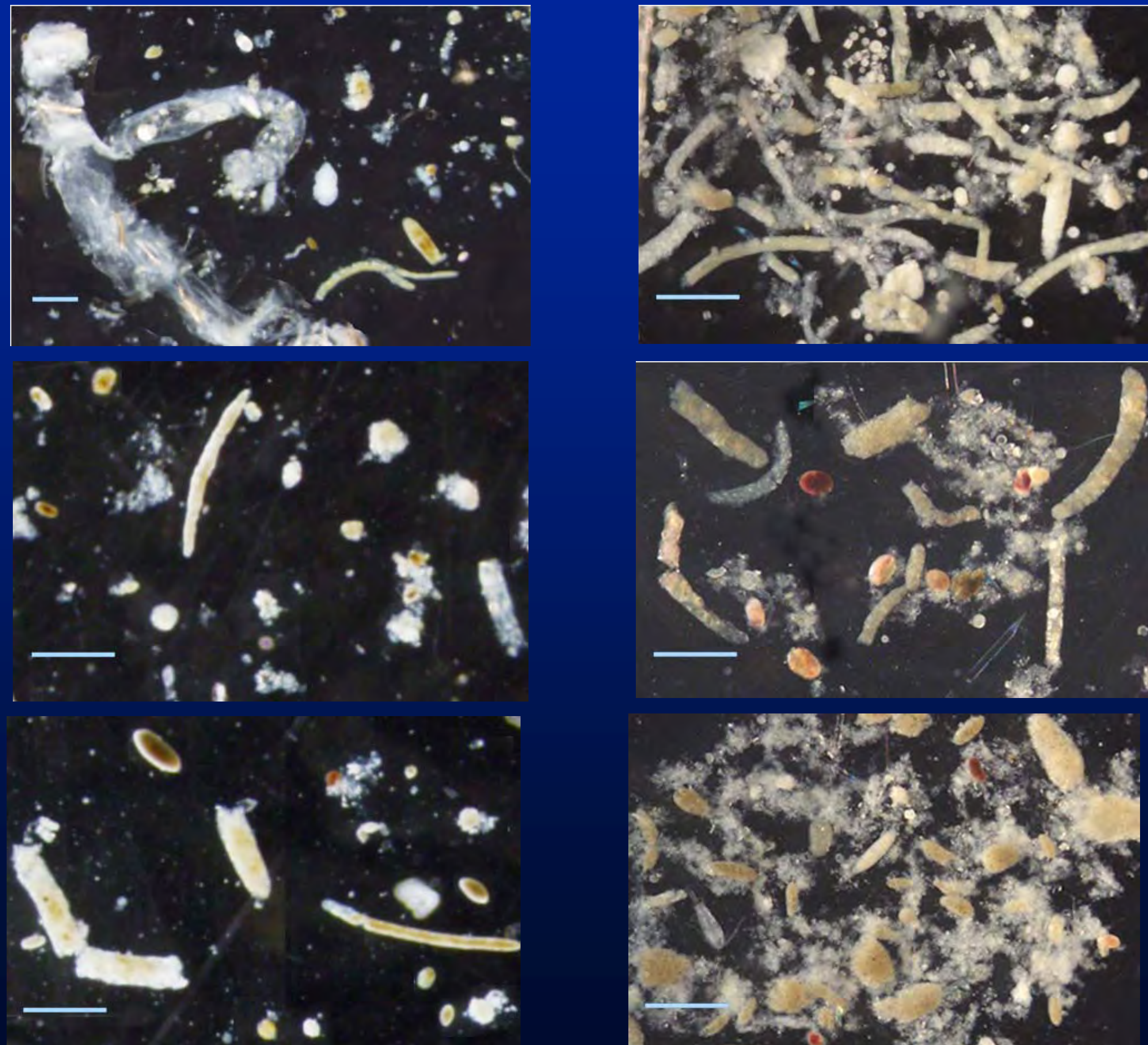
Changes in fecal pellet classes with depth

ALOHA | **K2**

150m

300m

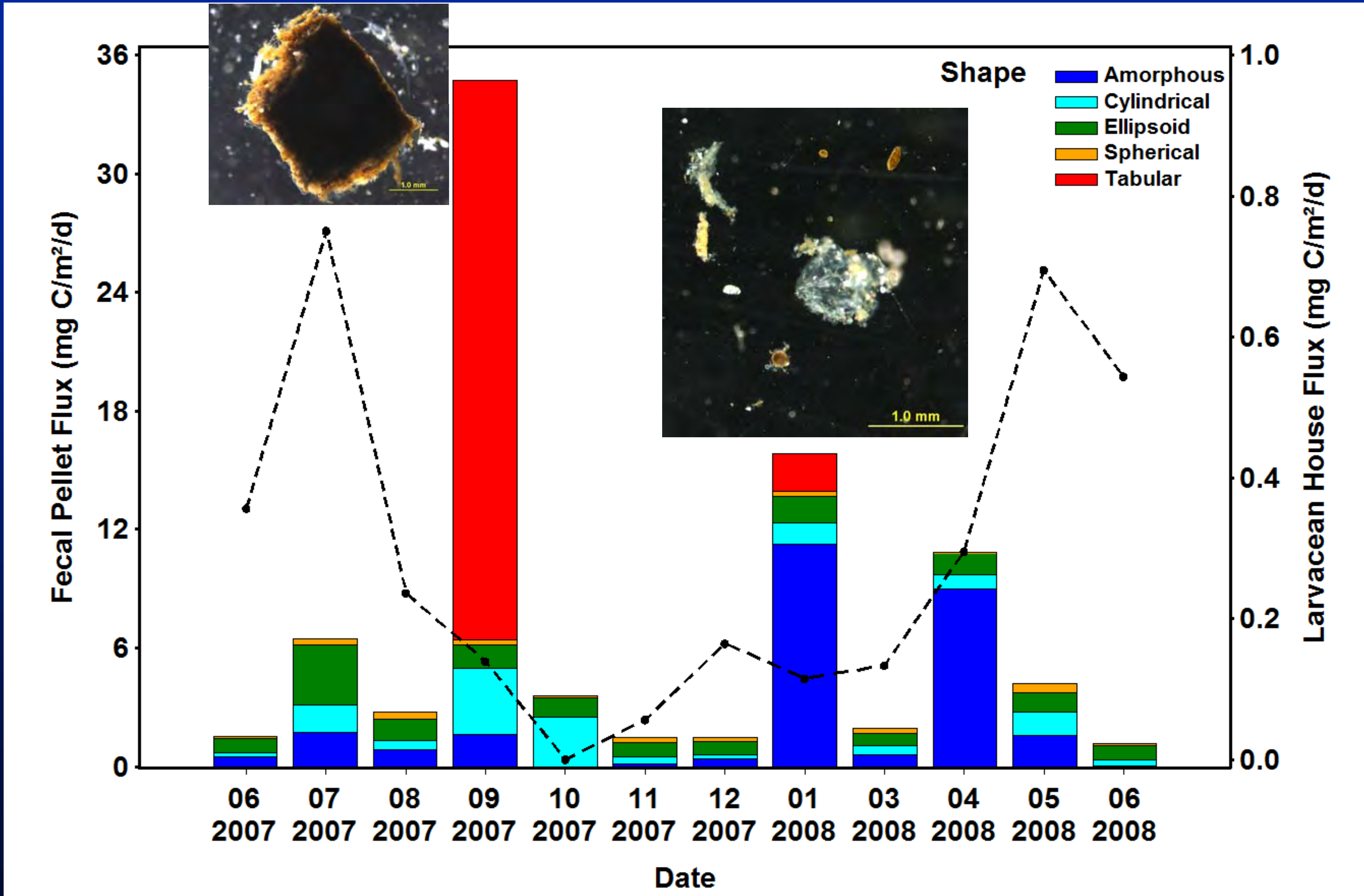
500m



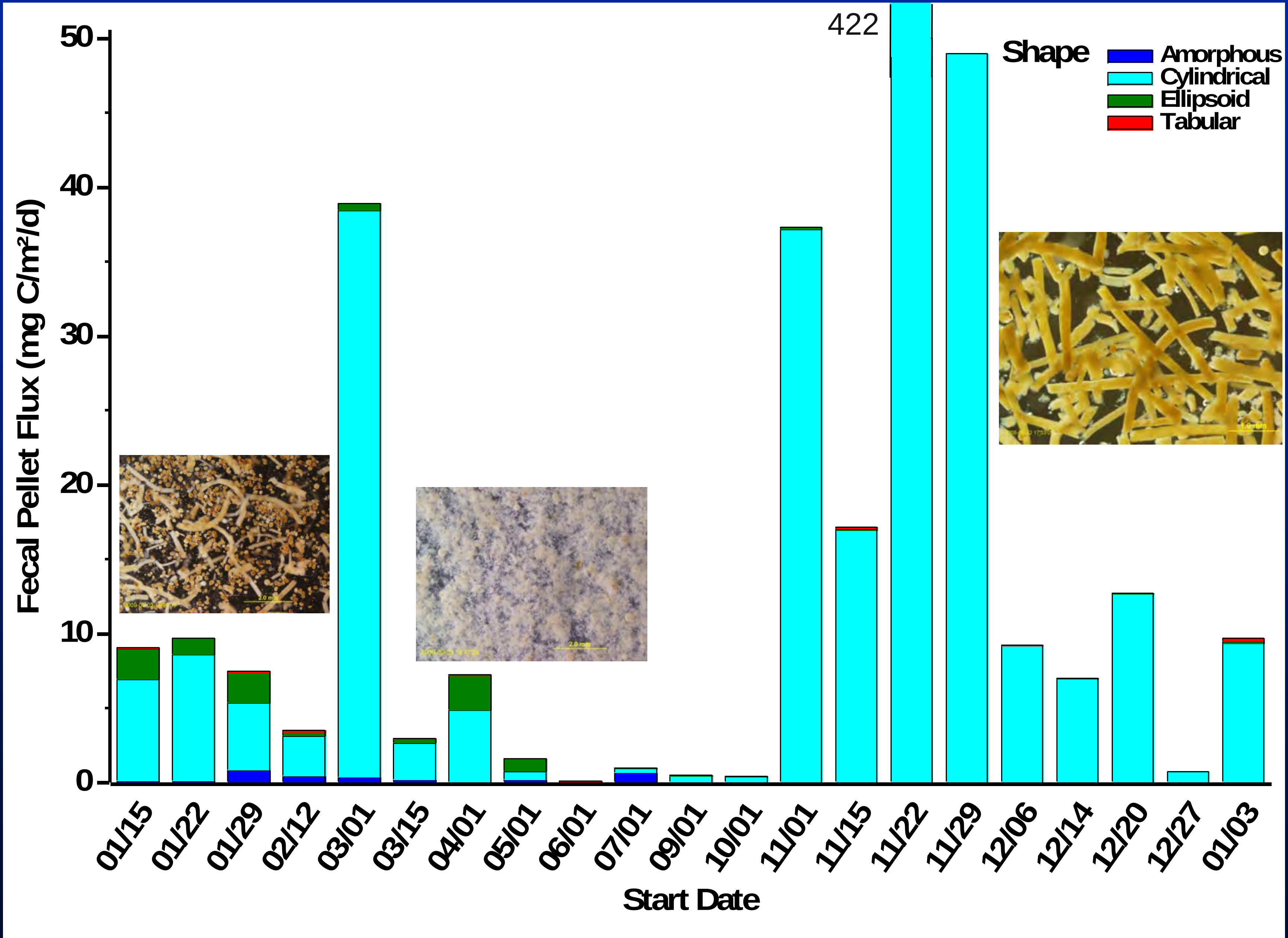
Scale bar = 500 µm

Wilson et al. (2008)

BATS fecal pellet flux time series (June ‘07-June ‘08)

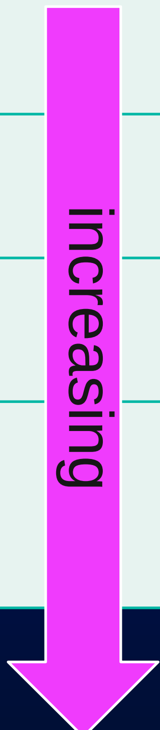


Pal LTER Fecal Pellet Flux (Jan-Dec. 2008)

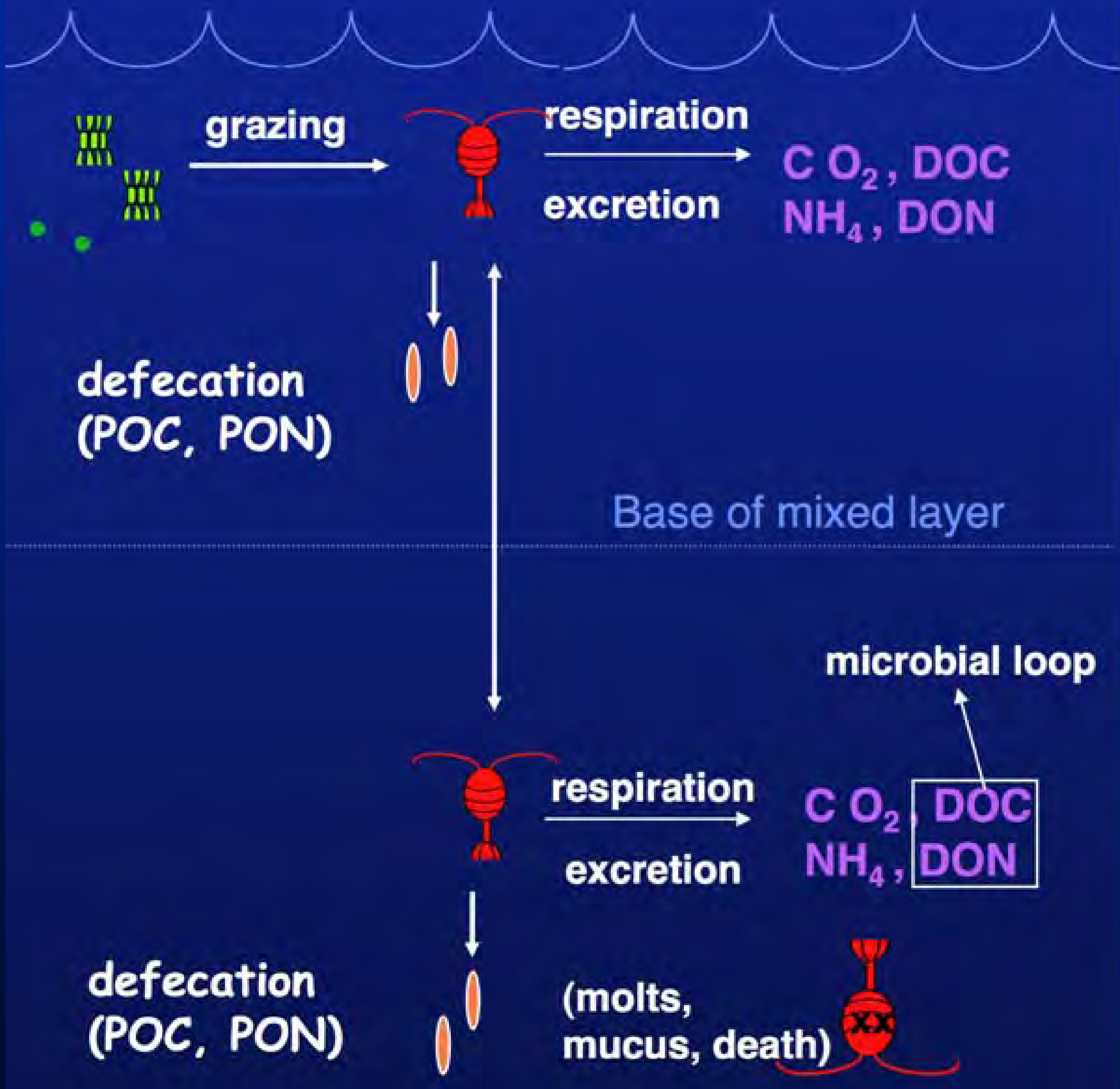


Overall fecal pellet comparison between sites

Site- Summer (annual)	Median POC/pellet (ugC/ pellet)	Pellet Flux across 150 m (mg C/m2/d)	Total POC flux (mg C/m2/d)	Pellets/ total POC flux (%)
BATS (annual)	0.009 (0.01)	3 (6.5)	13 (29 for BATS)	24 % (56 %)
ALOHA	0.04	2.5	18 (29 for HOT)	14 %
K2	0.17	6.5 - 7.4	23 - 62	12-28 %
PAL LTER (annual)	1.3 (0.79)	42 (31)	73 (6)	57% (>100 %)



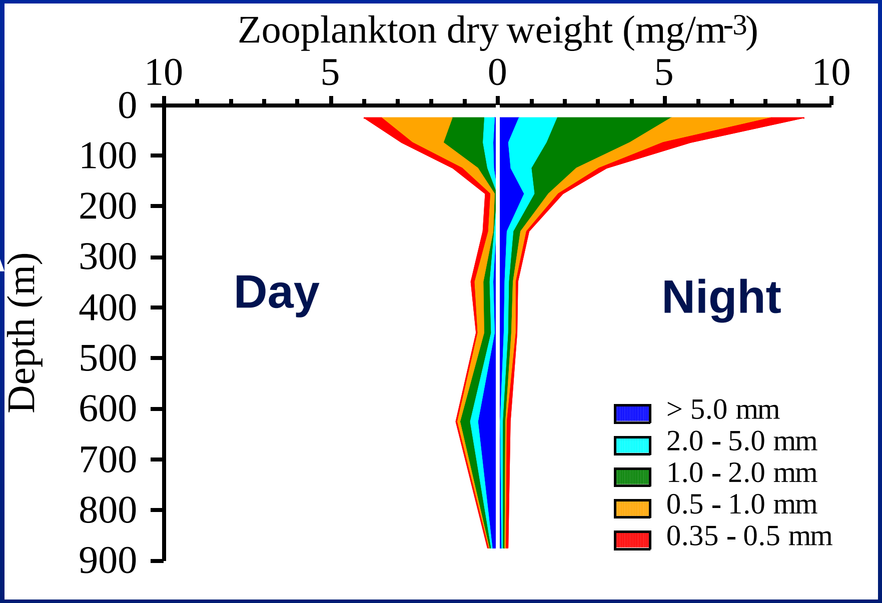
Vertical Migration and active transport

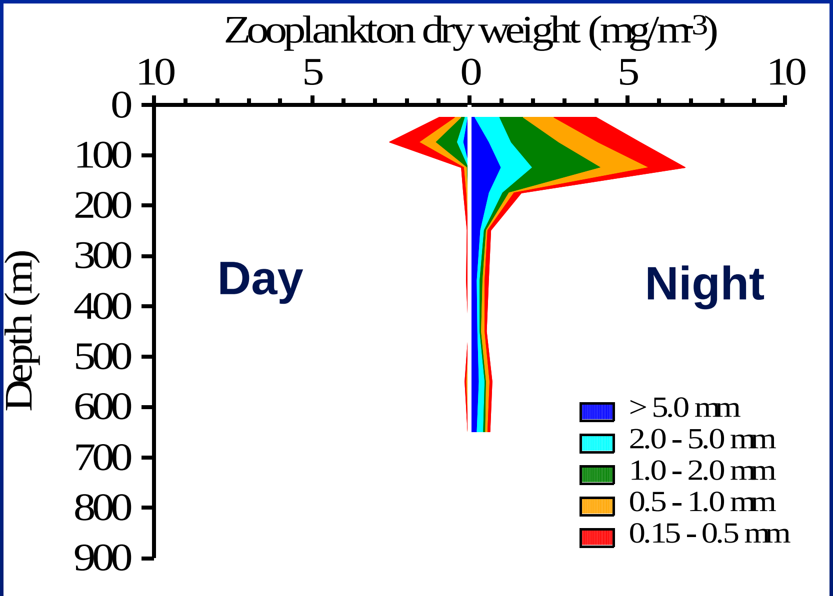


Vertical migrators

Mesozooplankton vertical biomass profiles

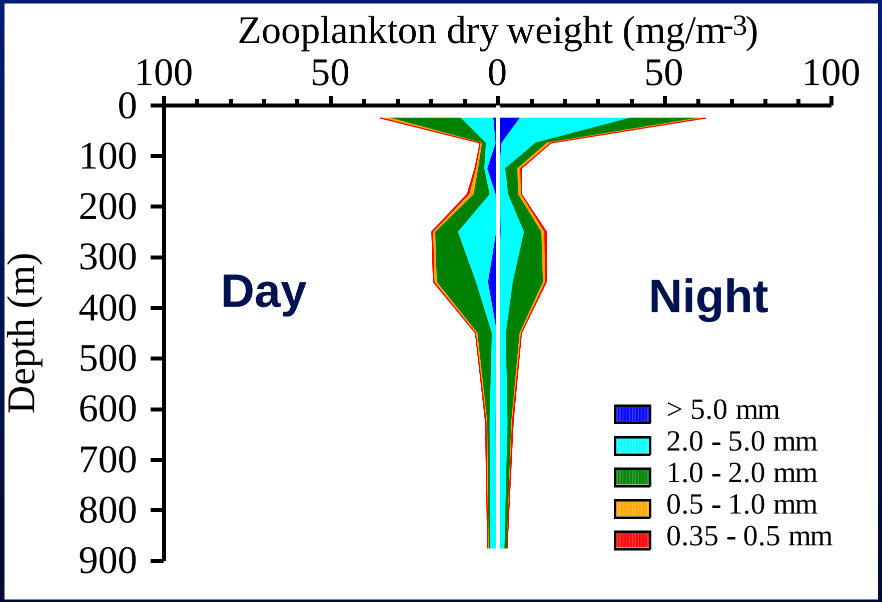
ALOHA





BATS/ Sargasso Sea

K2



mean, n=2

Steinberg et al. (2008), Goldthwait & Steinberg (2008)

Overall active transport comparison between sites

Site- Summer (annual)	Mean active CO_2 +DOC+POC flux (mg C/m2/d)	Trap POC flux (mg C/m2/d)	Active transport/ Trap POC flux (%)
(BATS)	(4)	(29)	(14 %)
ALOHA (HOT*)	2-8 (5)	18 (29)	11-44 % (19 %)
K2	16-46	23 - 62	26-200%

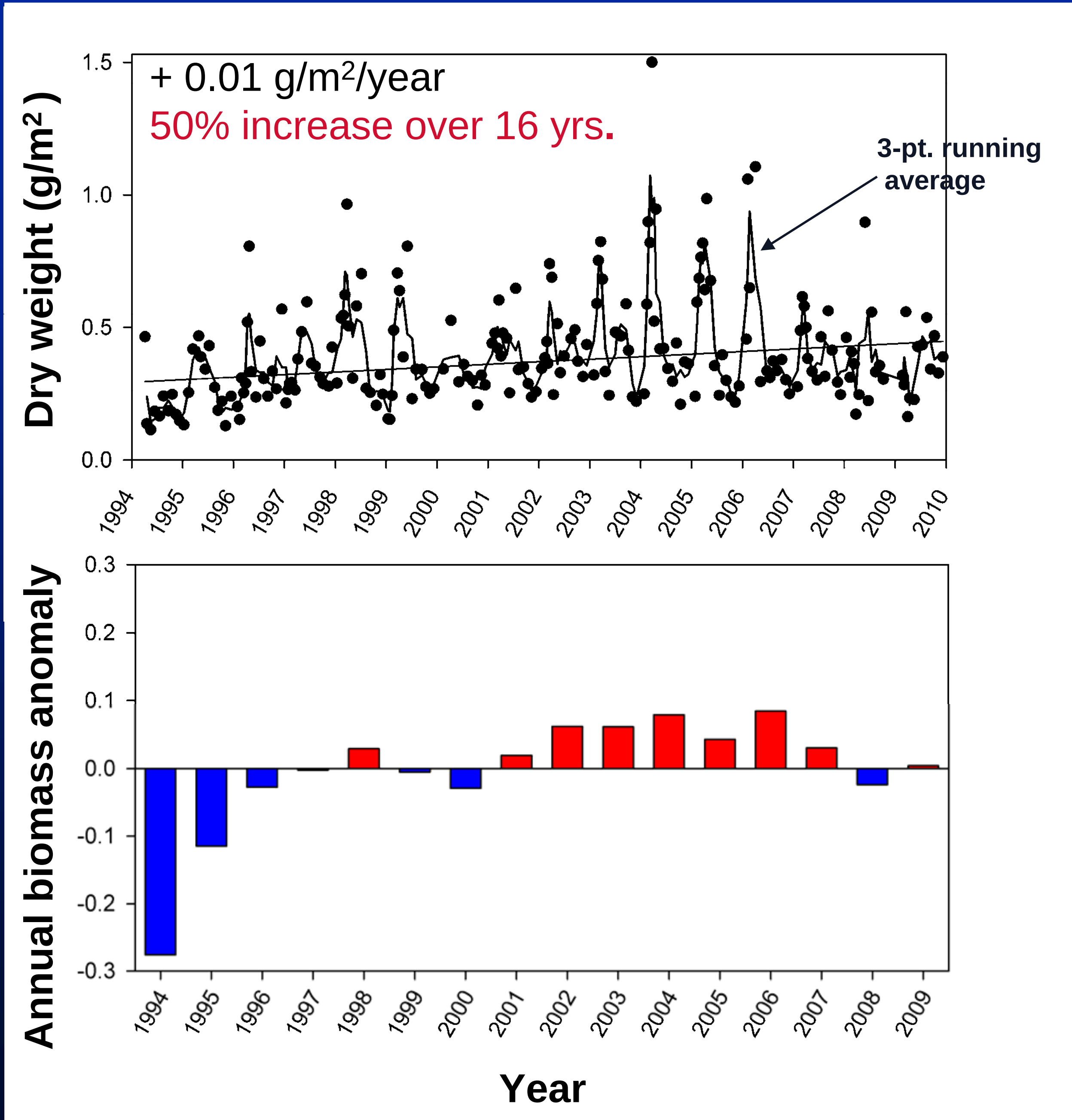
increasing

* Hannides, Landry, et al. 2009

Examples of long-term changes in zooplankton-mediated export

- Sargasso Sea (BATS)
- Western Antarctic Peninsula (Pal LTER)

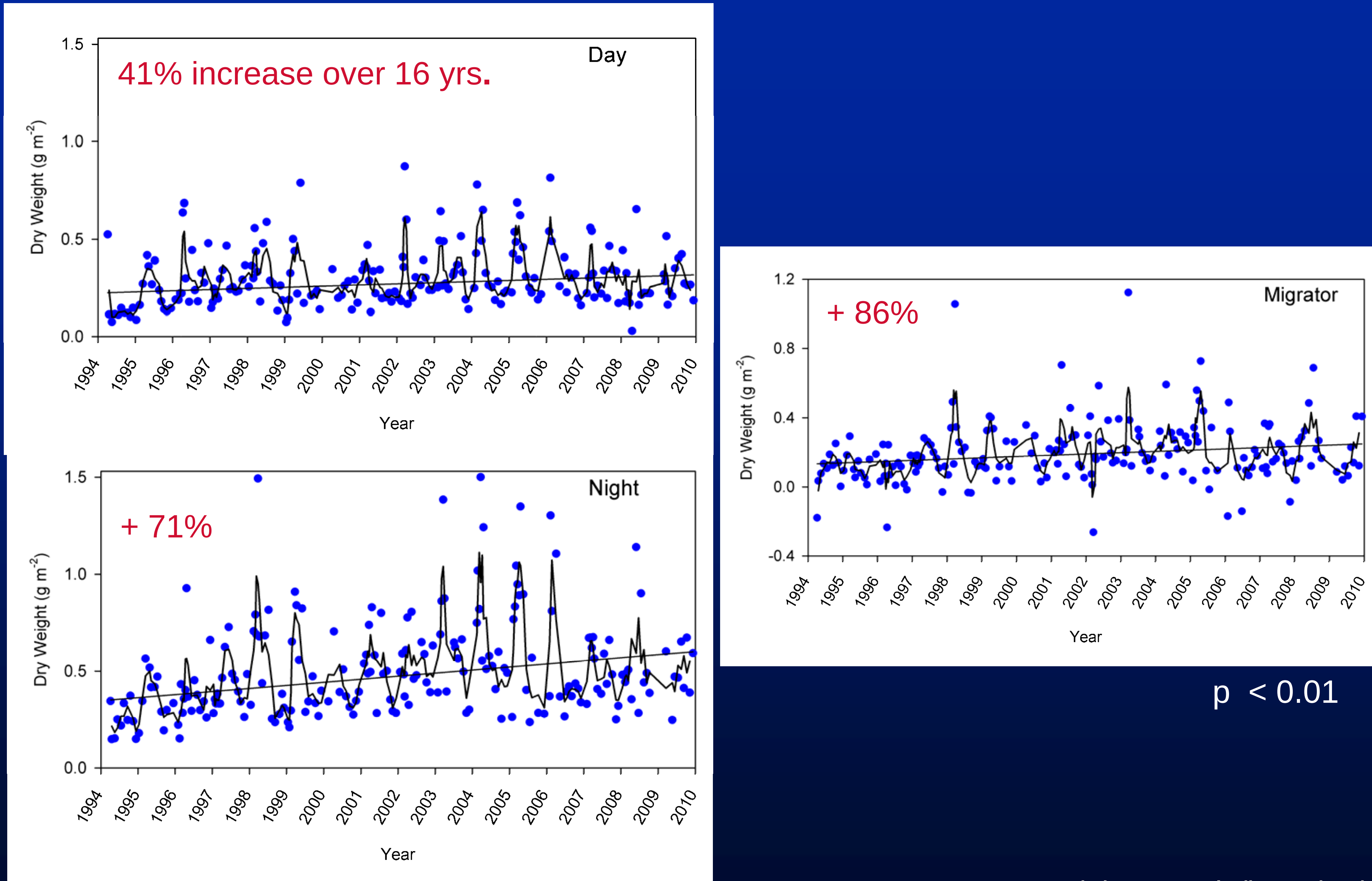
Increase in mesozooplankton biomass (top 150 m) at BATS



Day & night combined
$n = 213$
$r^2 = 0.07$
$p < 0.0001$

Steinberg et al. (in review)

Increased more at night



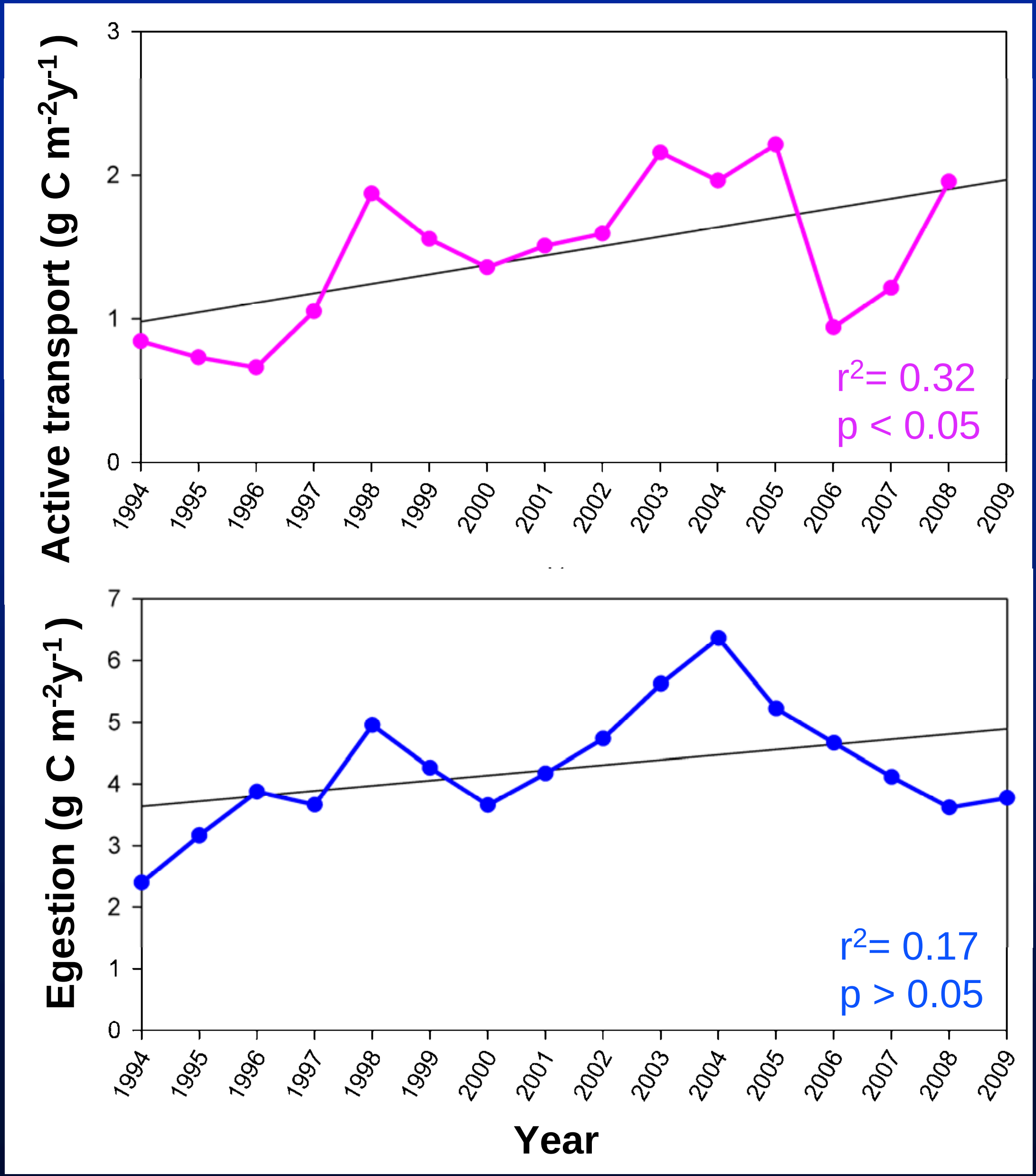
p < 0.01

Steinberg et al. (in review)

Increase in active transport and fecal pellet production at BATS

Annual migratory CO_2 + DOC + POC flux across 150 m

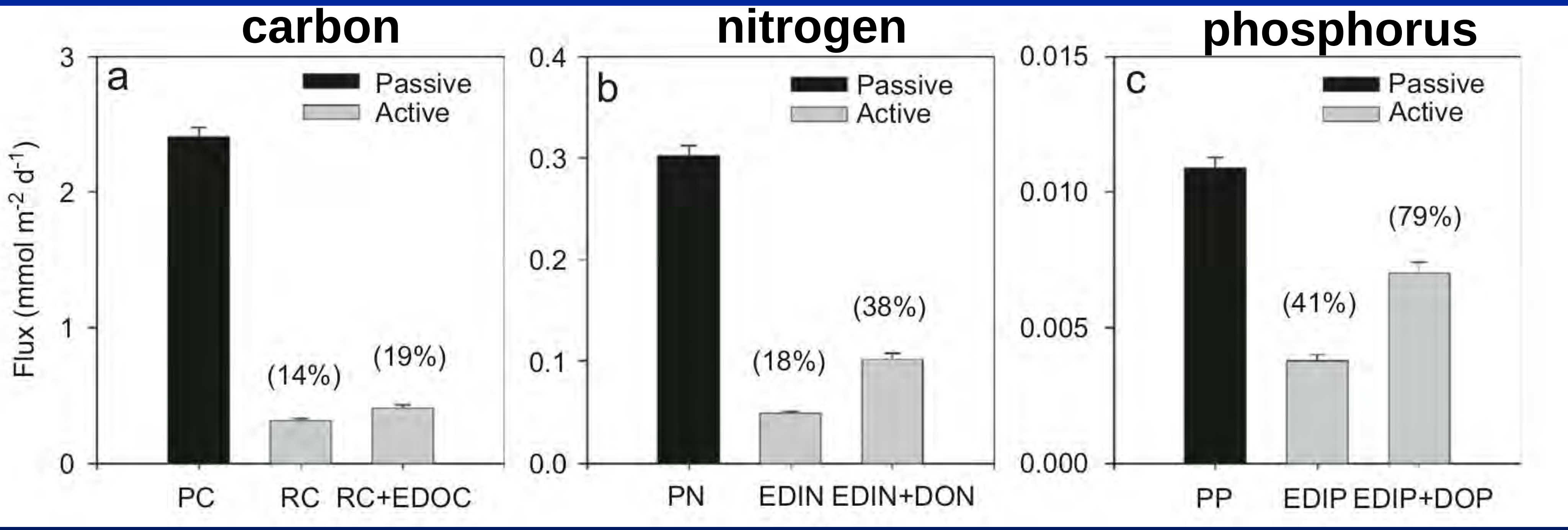
Annual fecal pellet production (egestion) in top 150 m



Steinberg et al. (in review)

Stoichiometry of active transport

North Pacific subtropical gyre- HOT station ALOHA



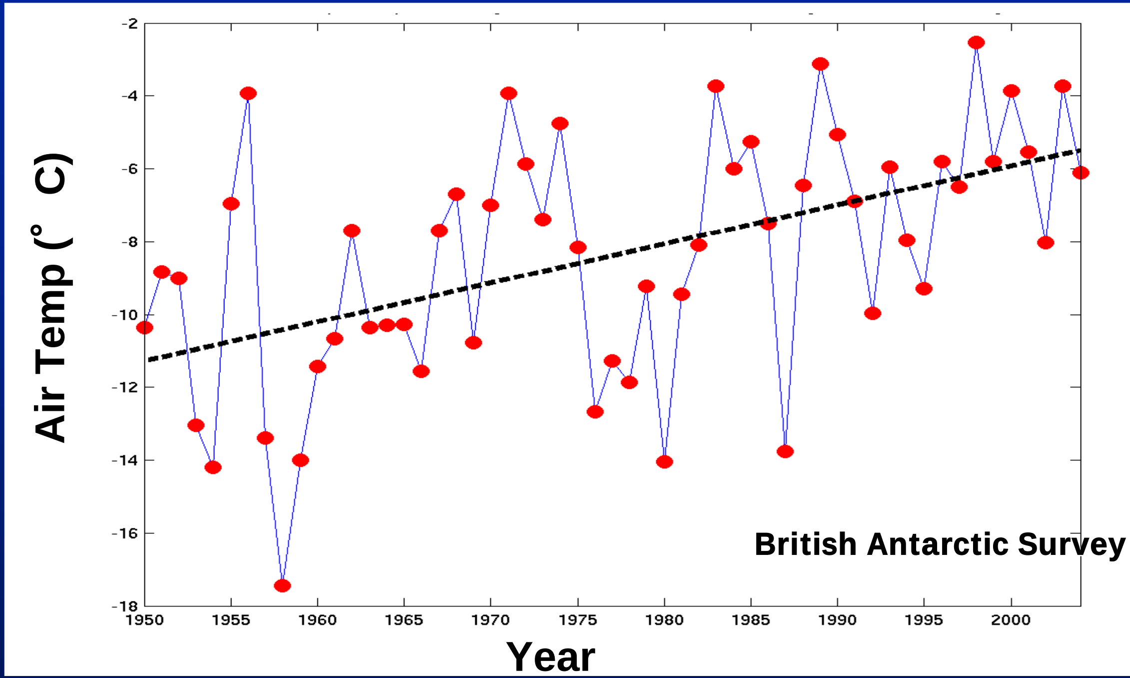
Active transport especially important mechanism for phosphorus (P) removal from the euphotic zone

Enhanced P-limitation of biological production in the N. Pacific subtropical gyre

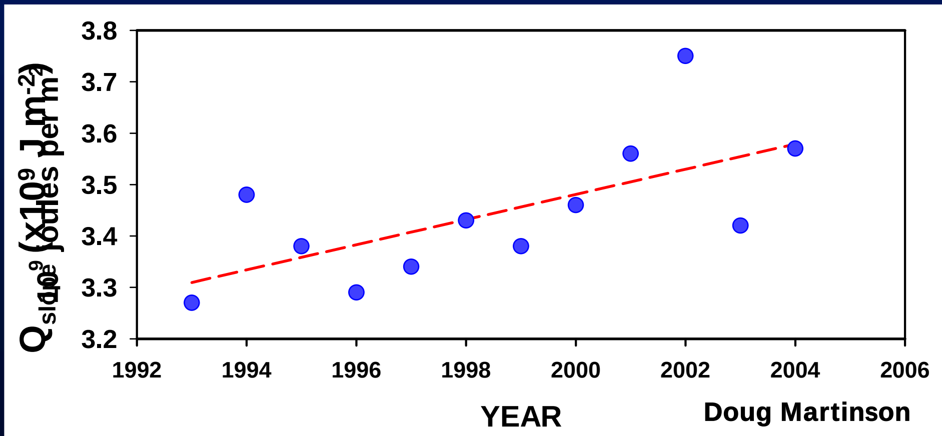
(Hannides, Landry, et al. 2009)

Warming in the Western Antarctic Peninsula

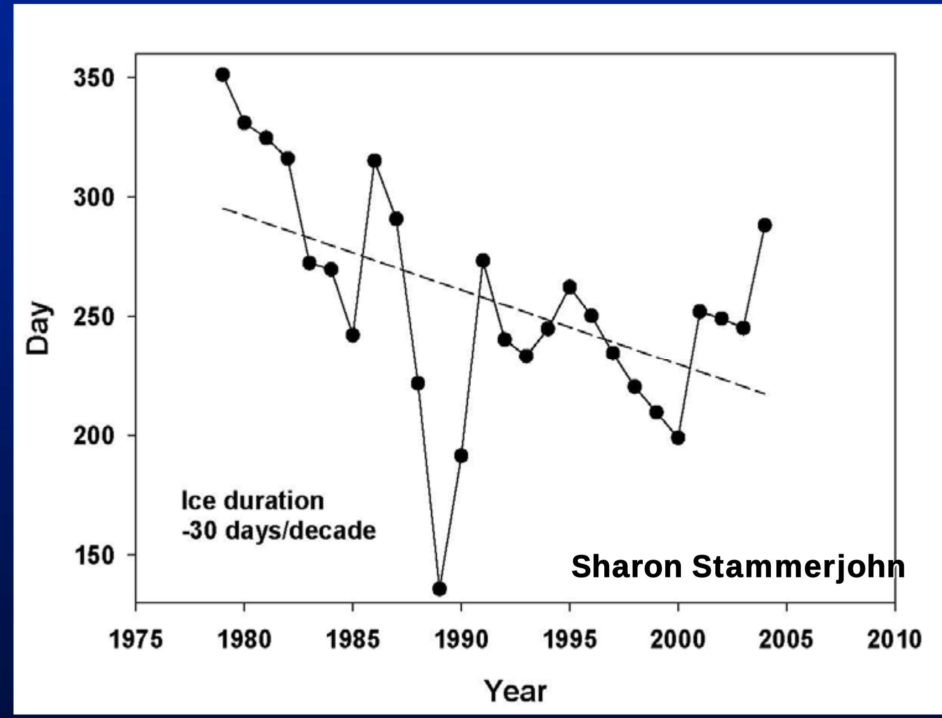
Average winter (June-Aug.) temperature
+1.1°C per decade: 6°C since 1950: 5x global ave.



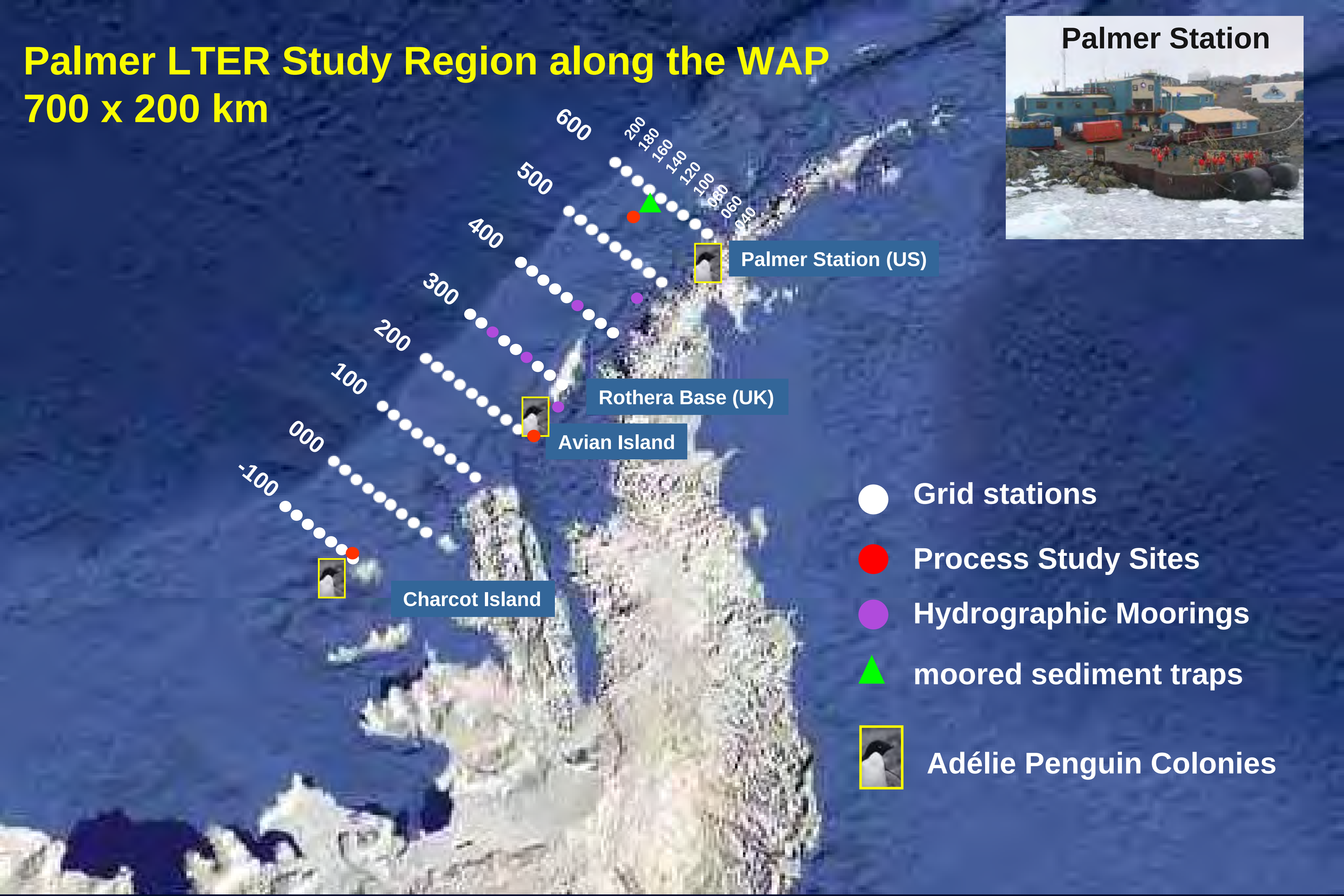
Increase in Heat Content of Water Over Shelf



Sea ice is declining



Sensitive to ENSO, Southern annual mode (SAM)

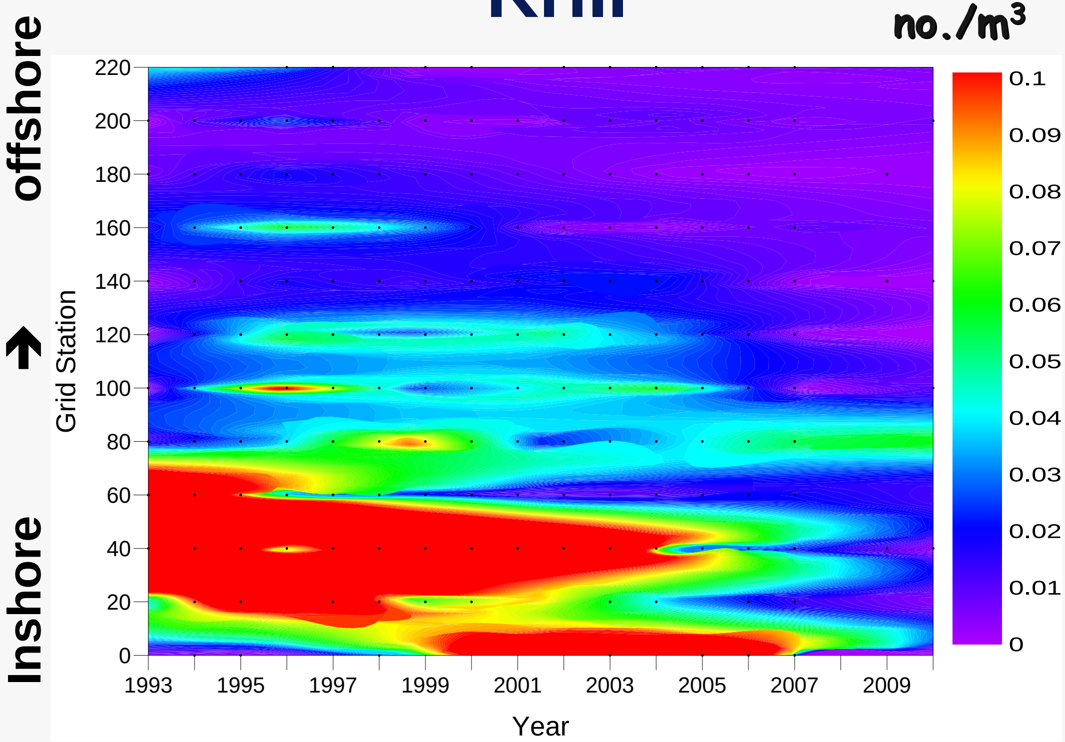

Palmer LTER Study Region along the WAP
700 x 200 km
Palmer Station
600
500
400
300
200
100
000
-100
200
180
160
140
120
100
080
060
040
Palmer Station (US)
Rothera Base (UK)
Avian Island
Charcot Island
Grid stations
Process Study Sites
Hydrographic Moorings
moored sediment traps
Adélie Penguin Colonies

Long-term changes in zooplankton in the Antarctic Peninsula

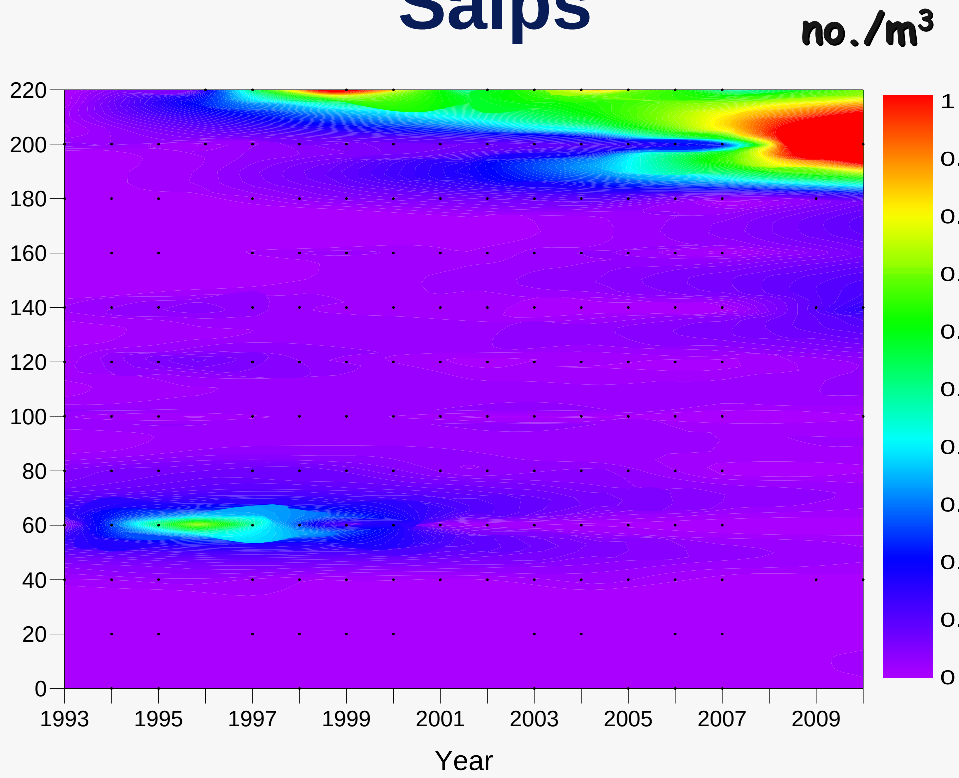
Decreasing and shifting closer inshore?

Increasing over time (and expanding over shelf)?

Krill



Salps



(Grid line 600 -North)

Zooplankton composition change effects on particle export

krill fecal pellets

Mean sinking rate = 200 m/ d

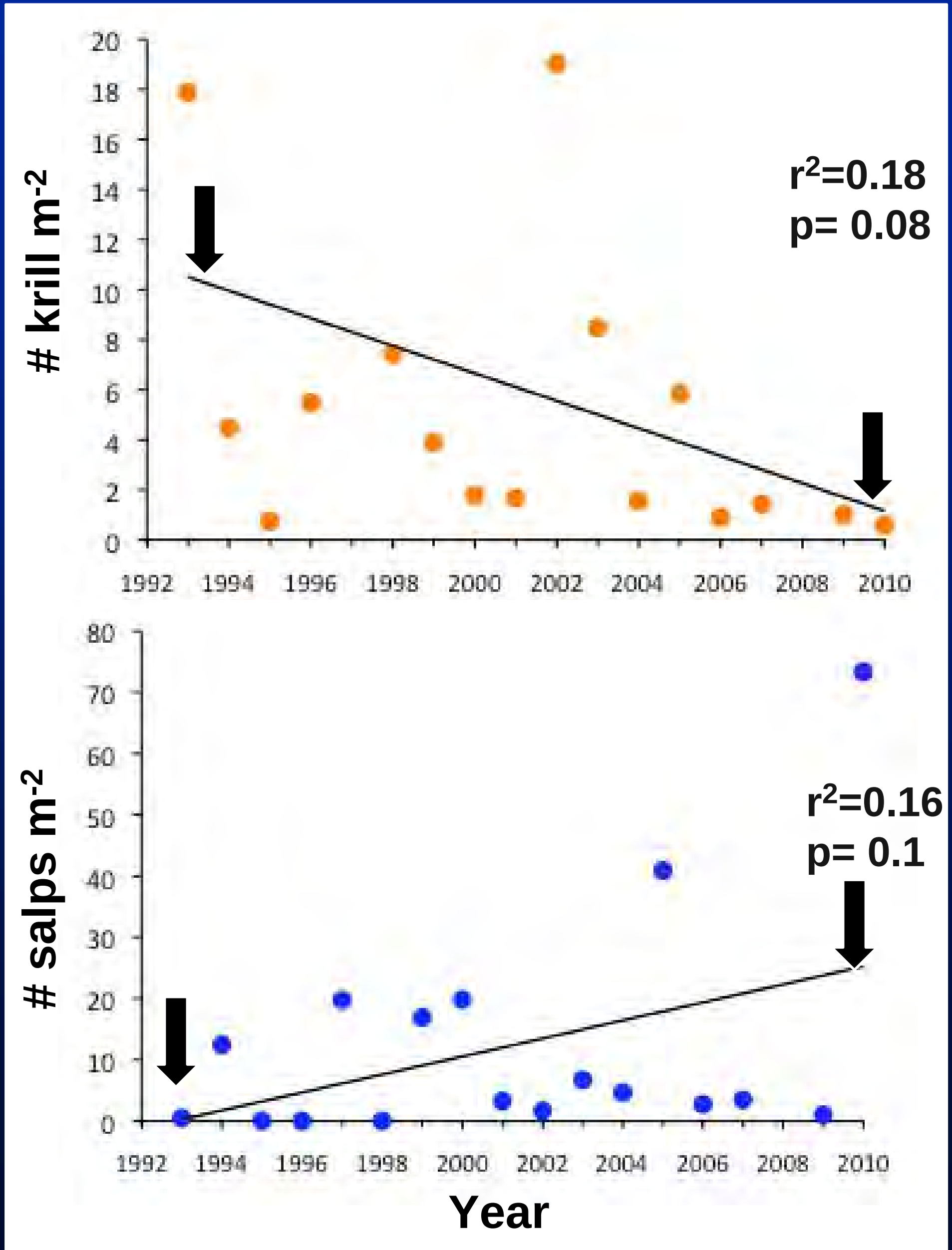
salp fecal pellet

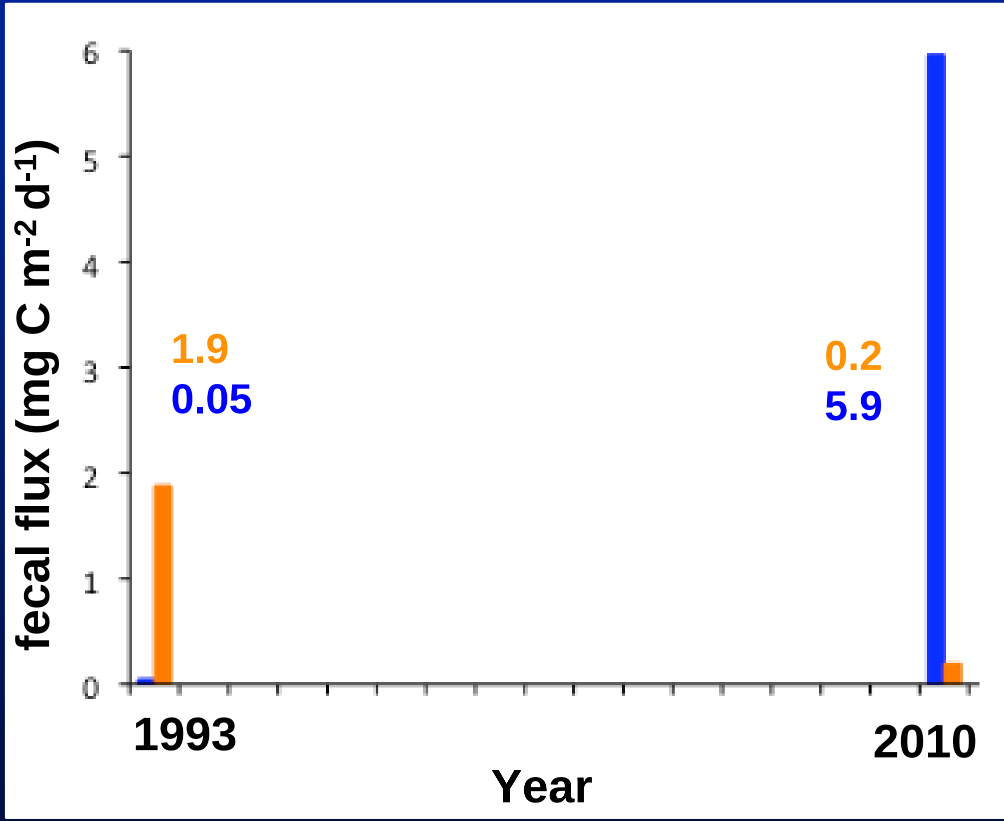
= 700 m/ d

(Steinberg et al., in prep)

(Phillips et al. 2009)

Changes in krill, salps, & fecal pellet flux
North (600 line, all stations averaged)



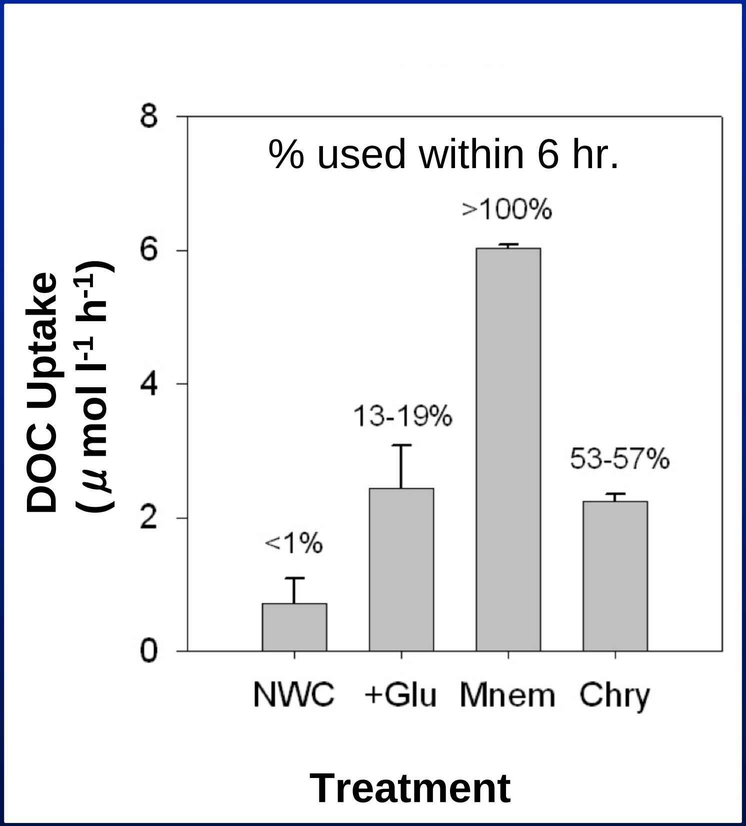


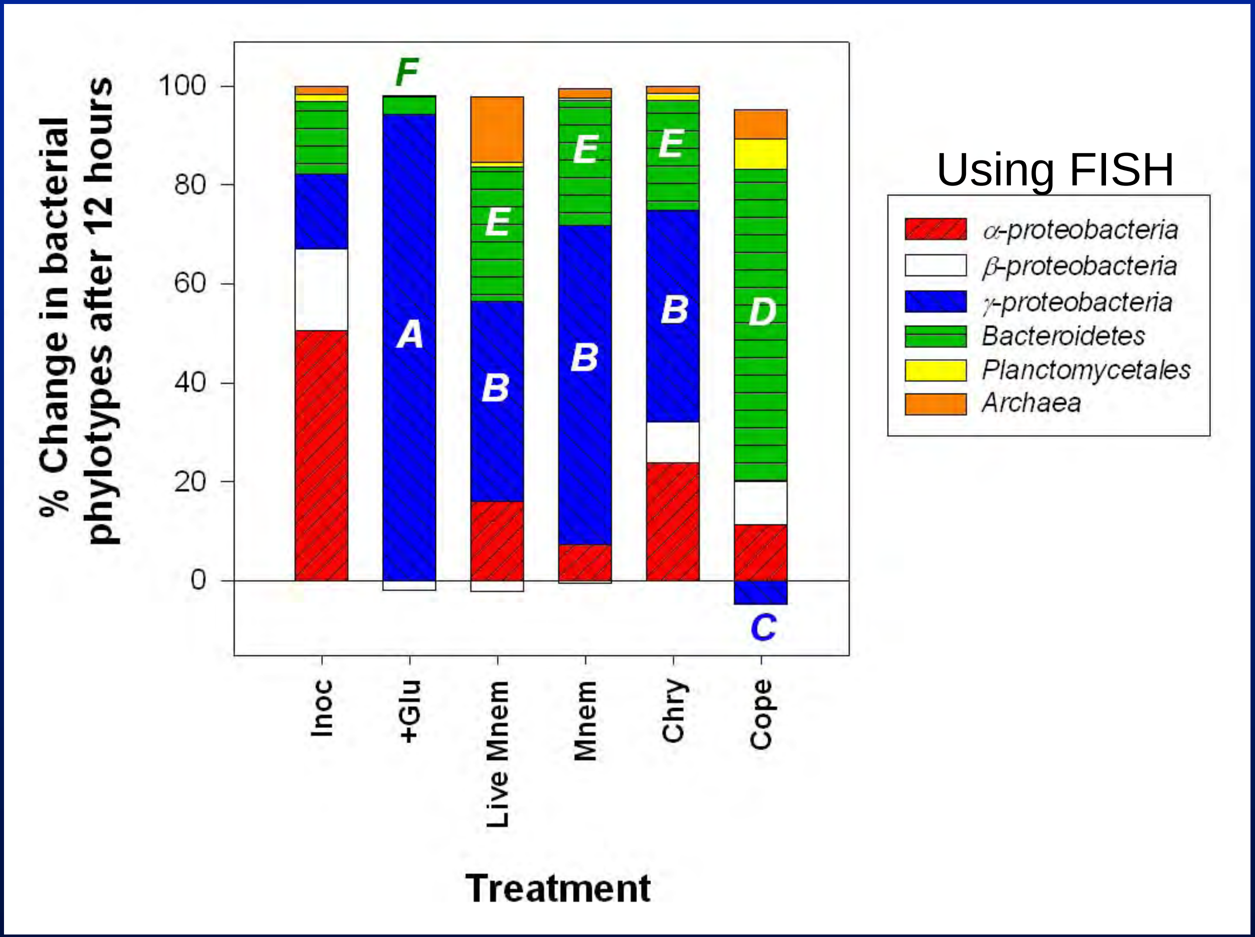
Potential increase in overall flux

Lesser known -

- role in DOM cycling
- processes/rates in meso- & bathypelagic
- role of gelatinous zooplankton
- top-down control & cascading effects *

Links between zooplankton-DOM and microbial community

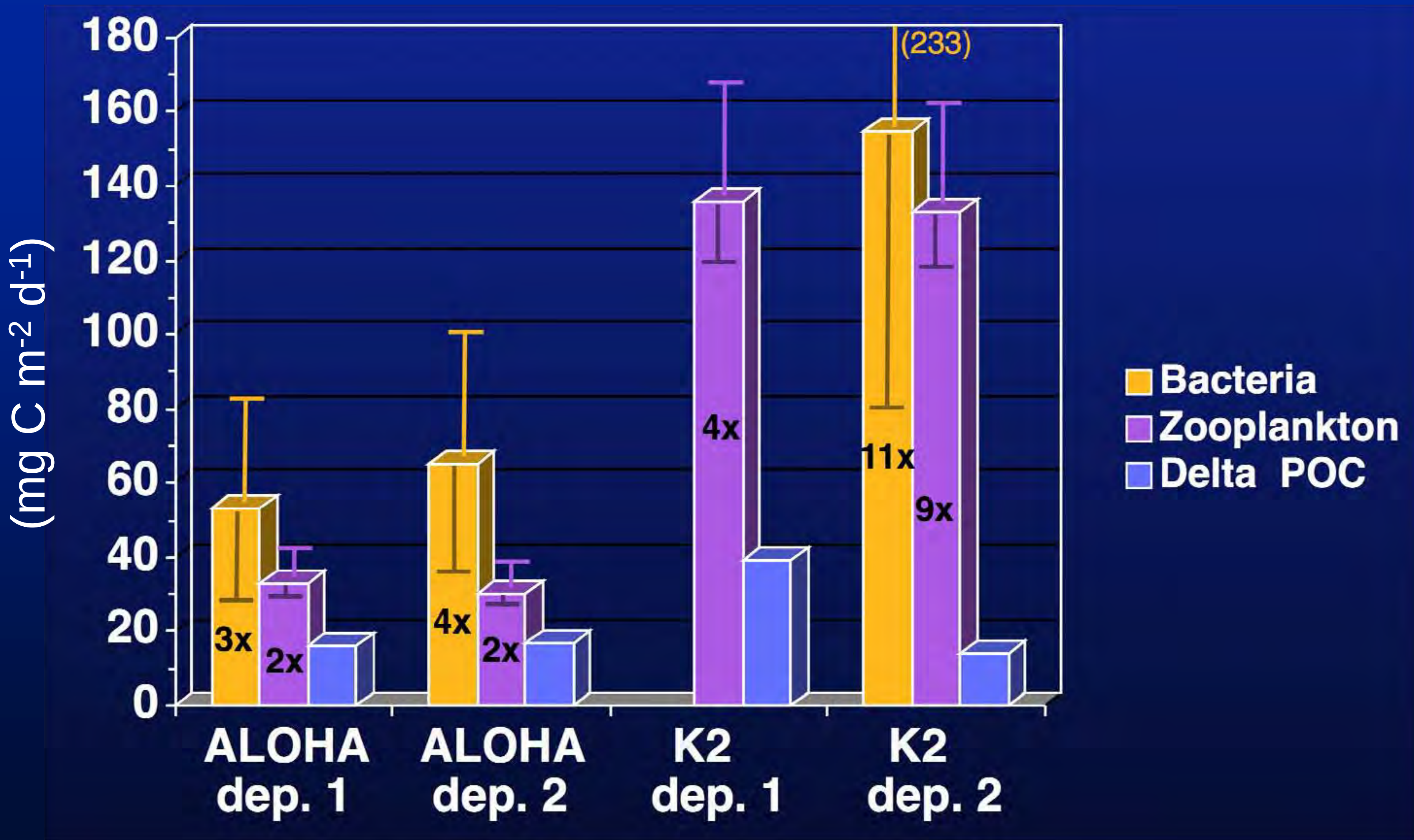




Condon et al. (in review)

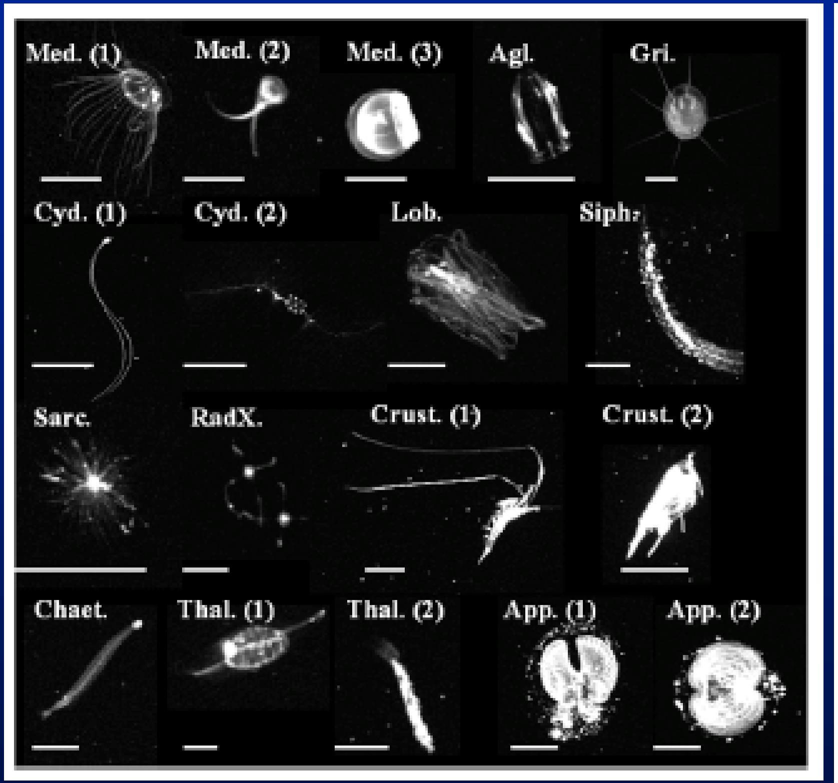
Metabolic C requirements vs. sinking POC attenuation

Integrated 150-1000 m

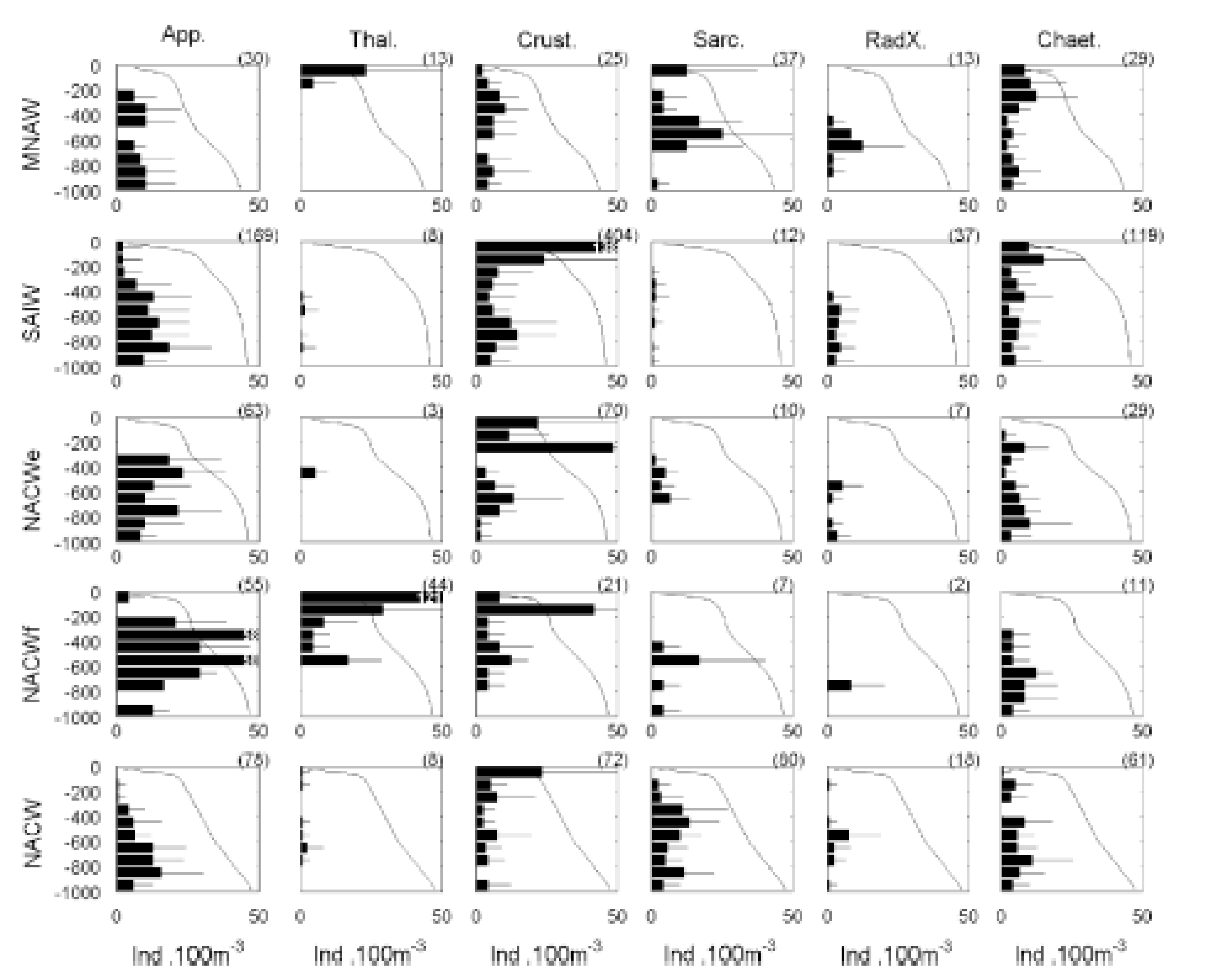


Steinberg et al. (2008, Limnol. Oceanogr.)

Mesopelagic zooplankton distribution- North Atlantic- importance of particle feeders, gelatinous zooplankton



UVP-underwater video profiler



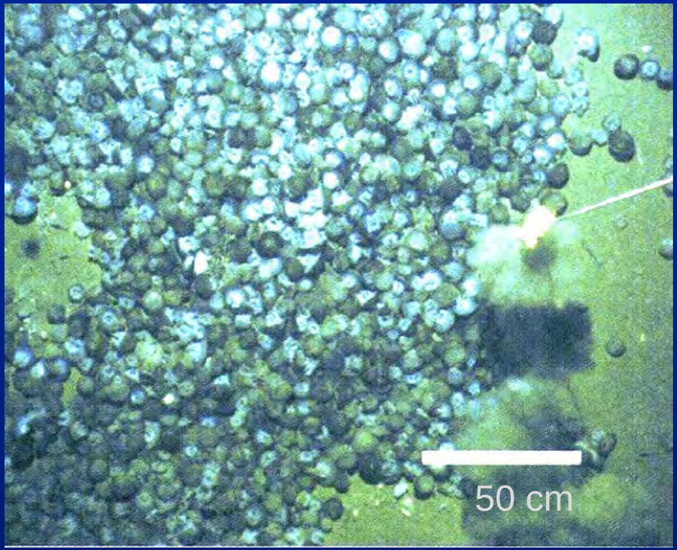
Stemmann et al. (2008, DSRII)

Jelly falls

Pyrosoma off W. Africa, >350 m

Lebrato & Jones (2009)

Arabian Sea, 1400 m



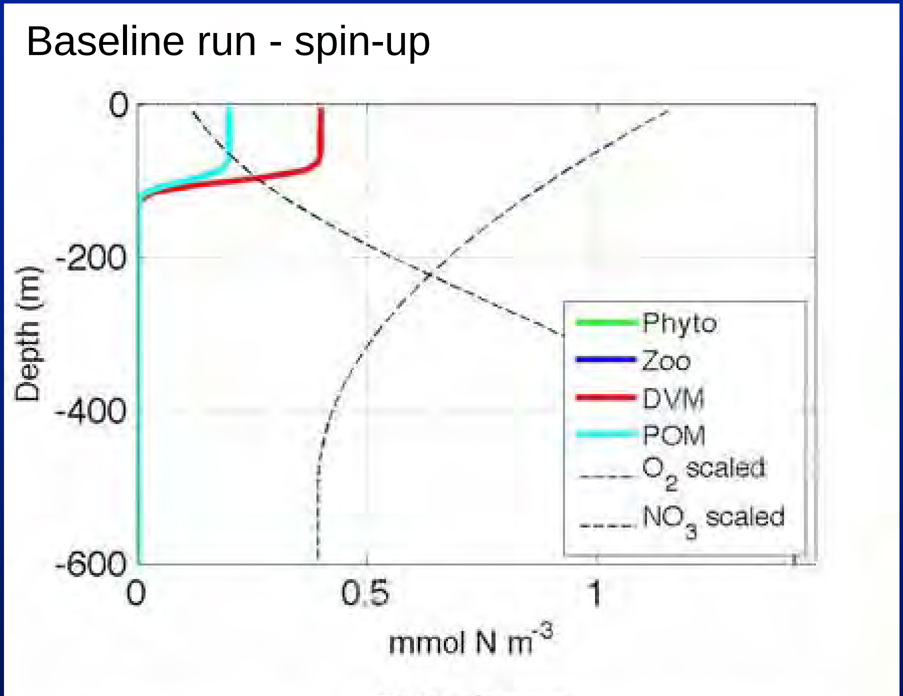
Billett et al. (2006)

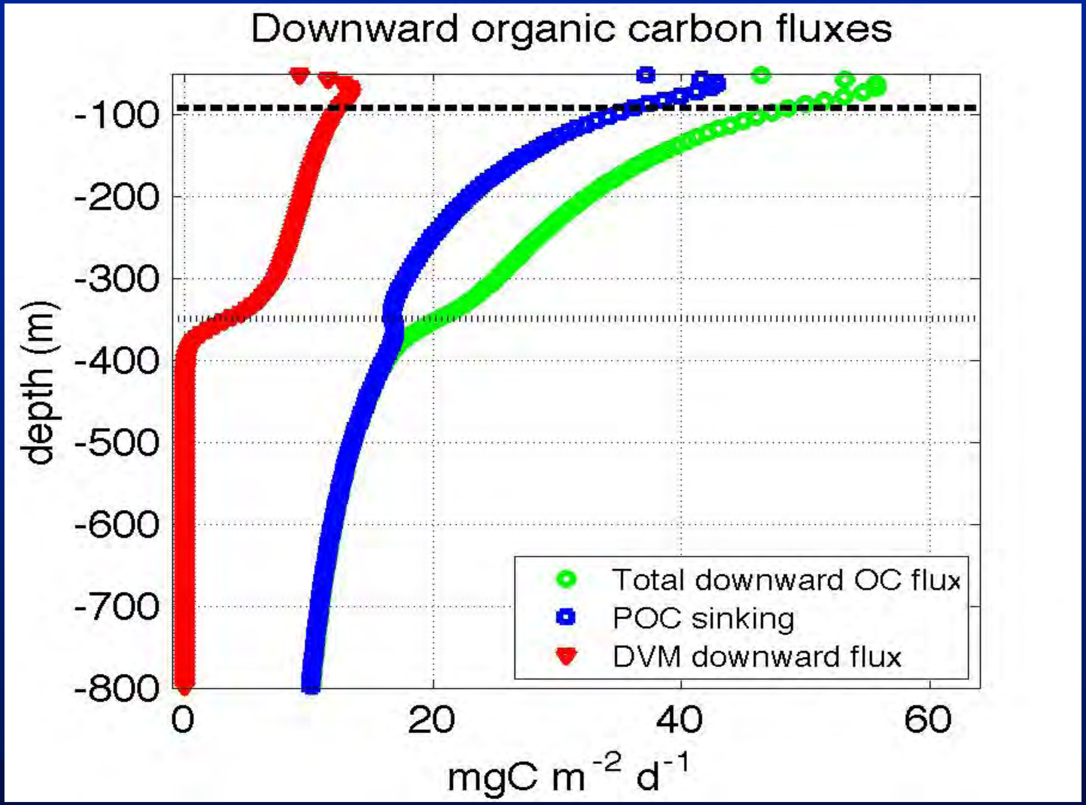
Nemopilema, Sea of Japan, ~200 m

Yamamoto et al. (2008)

A few considerations & prospects for the future

Modeling the biogeochemical impact of diel vertical migration

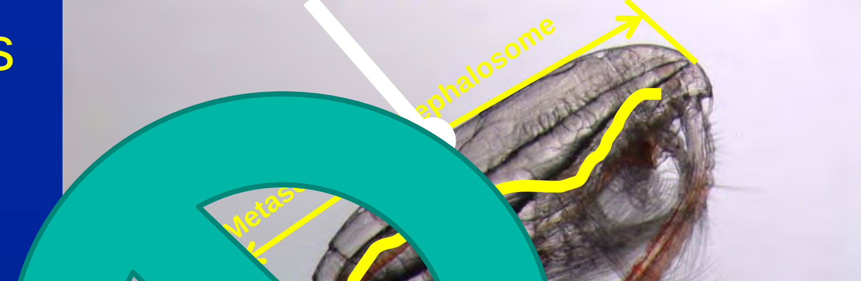


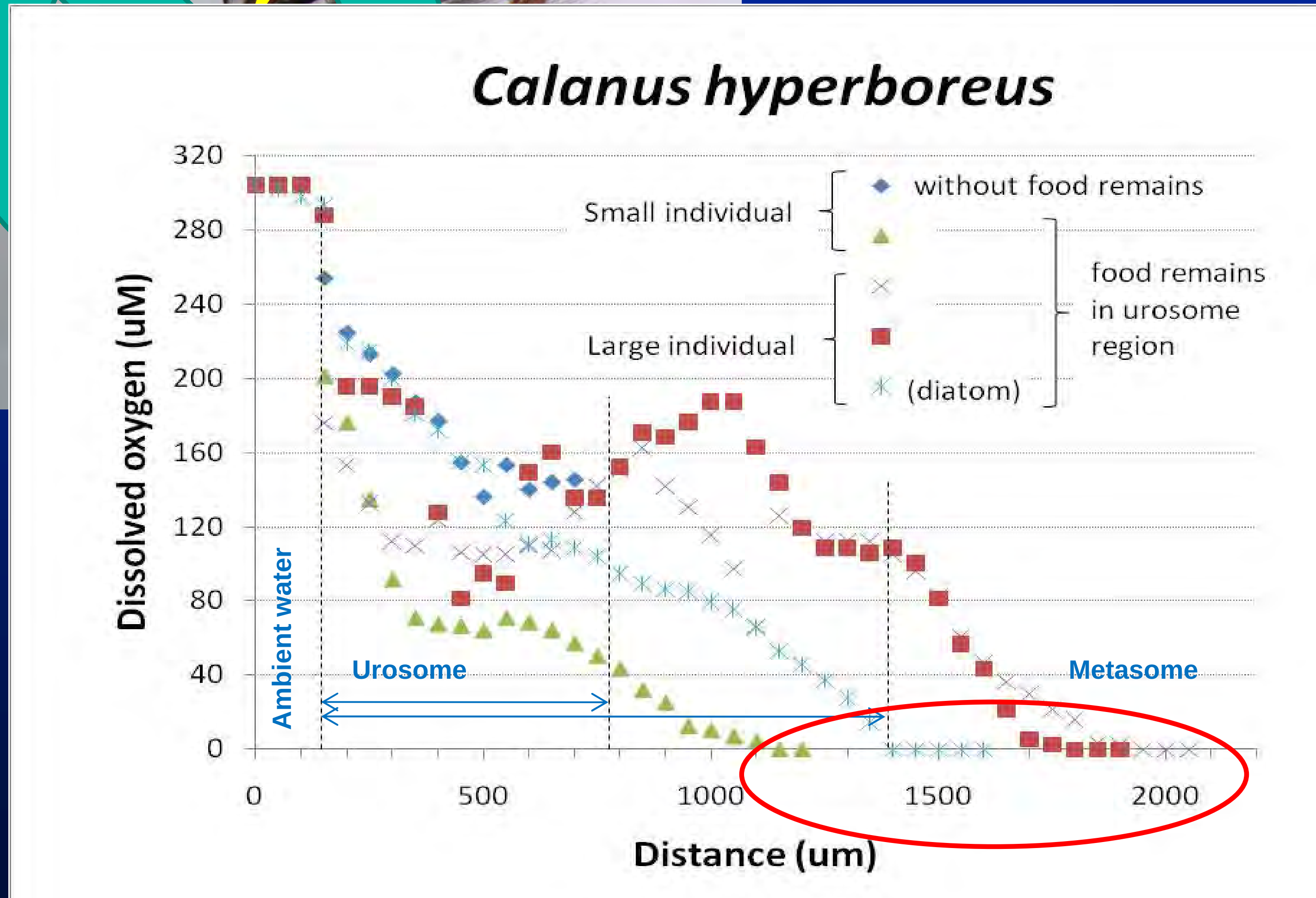


DVM fluxes are significant above the daytime resting depth

Bianchi, Galbraith, Kearney, Stock, & Sarmiento (in prep)

Microscale processes





Biogeochemical implications:

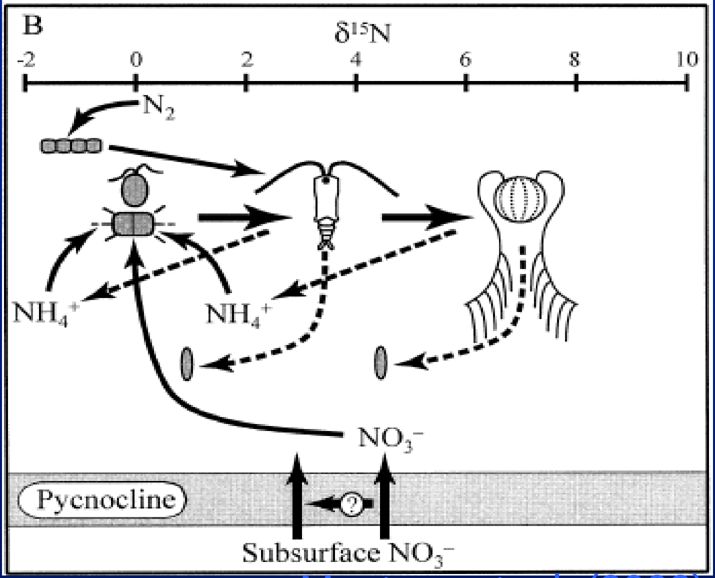
•Methanogenesis in gut

•Facilitate Fe dissolution and remineralization

Courtesy of K. Tang
Tang, Glud, Glud, Rysgaard & Nielsen (2011) Limnol. & Oceanogr.

Biogeochemical tracers

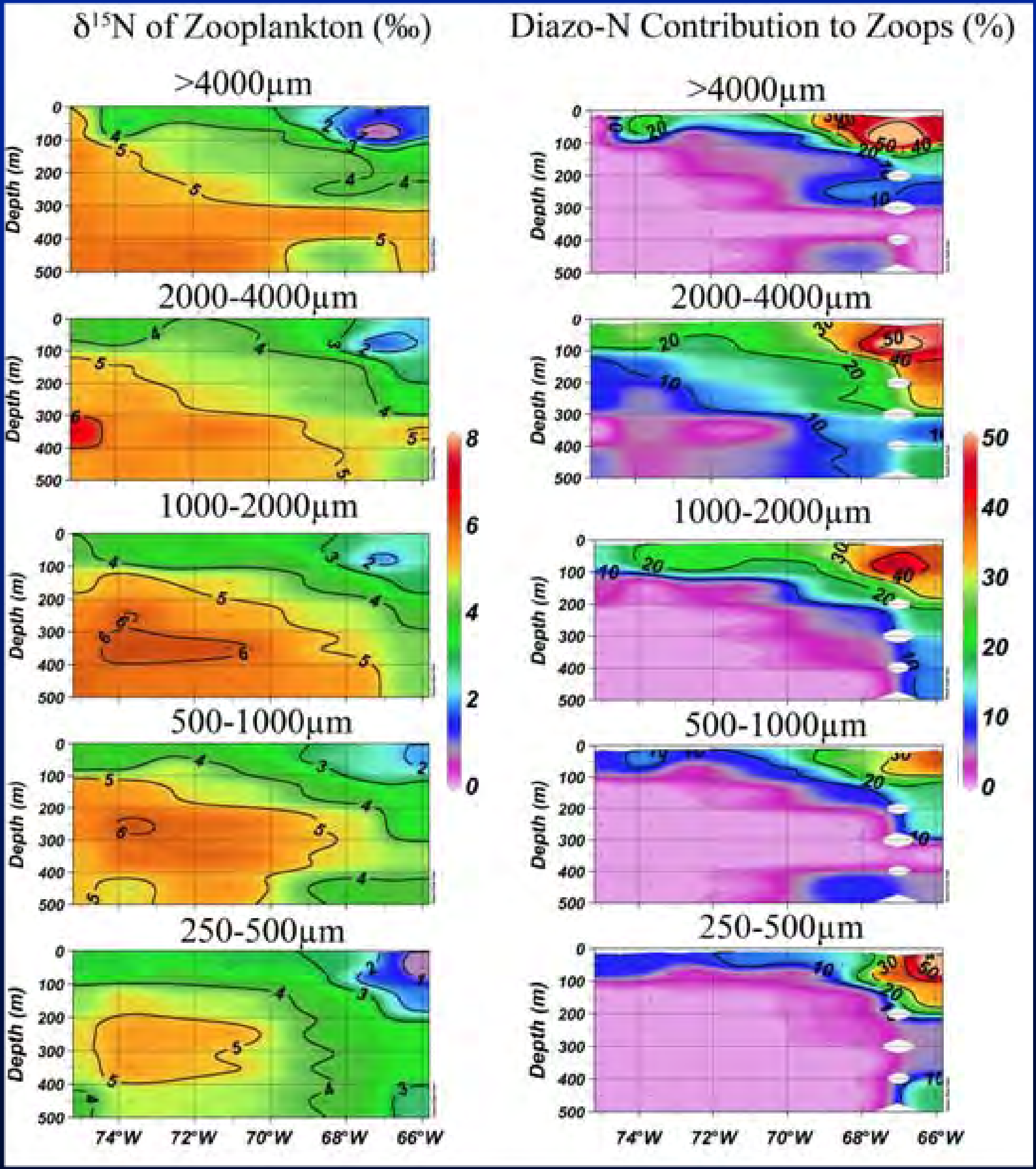
Stable N isotopes



Montoya et al. (2002)

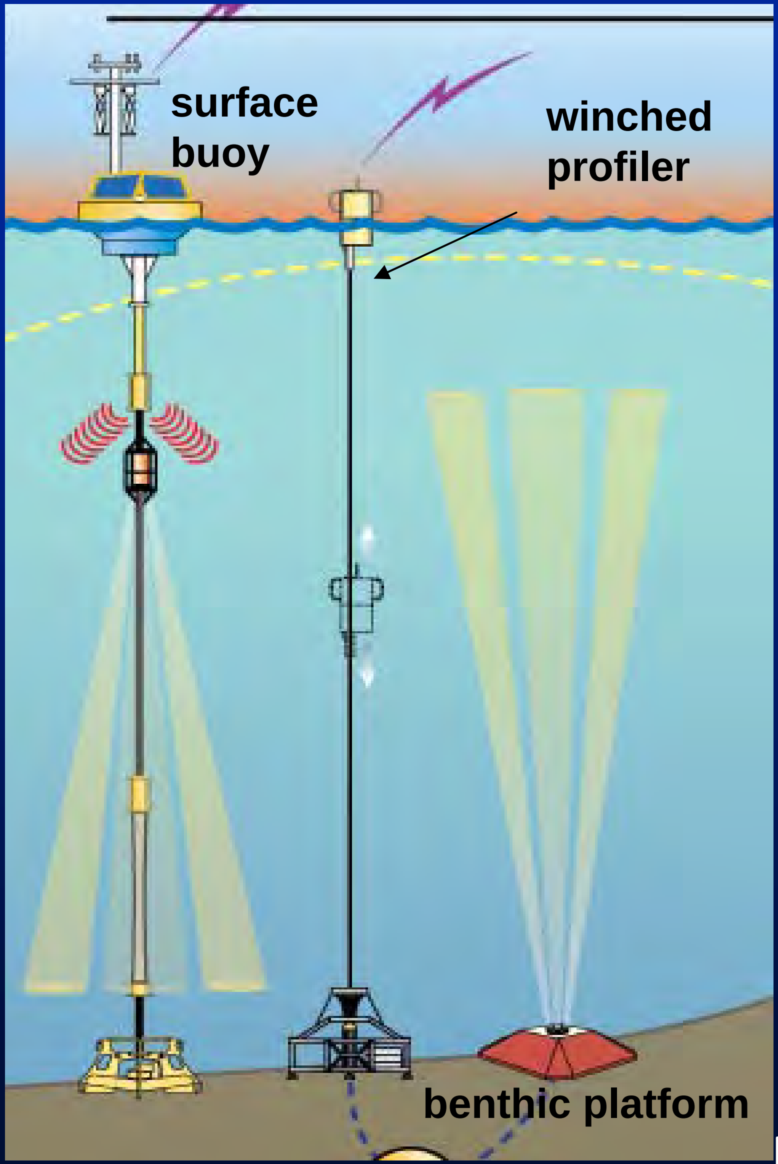
N_2 fixers (diazotrophs) determined to be food for mesozooplankton via $\delta^{15}N$ measurements

A mechanism by which new N is cycled in the food web

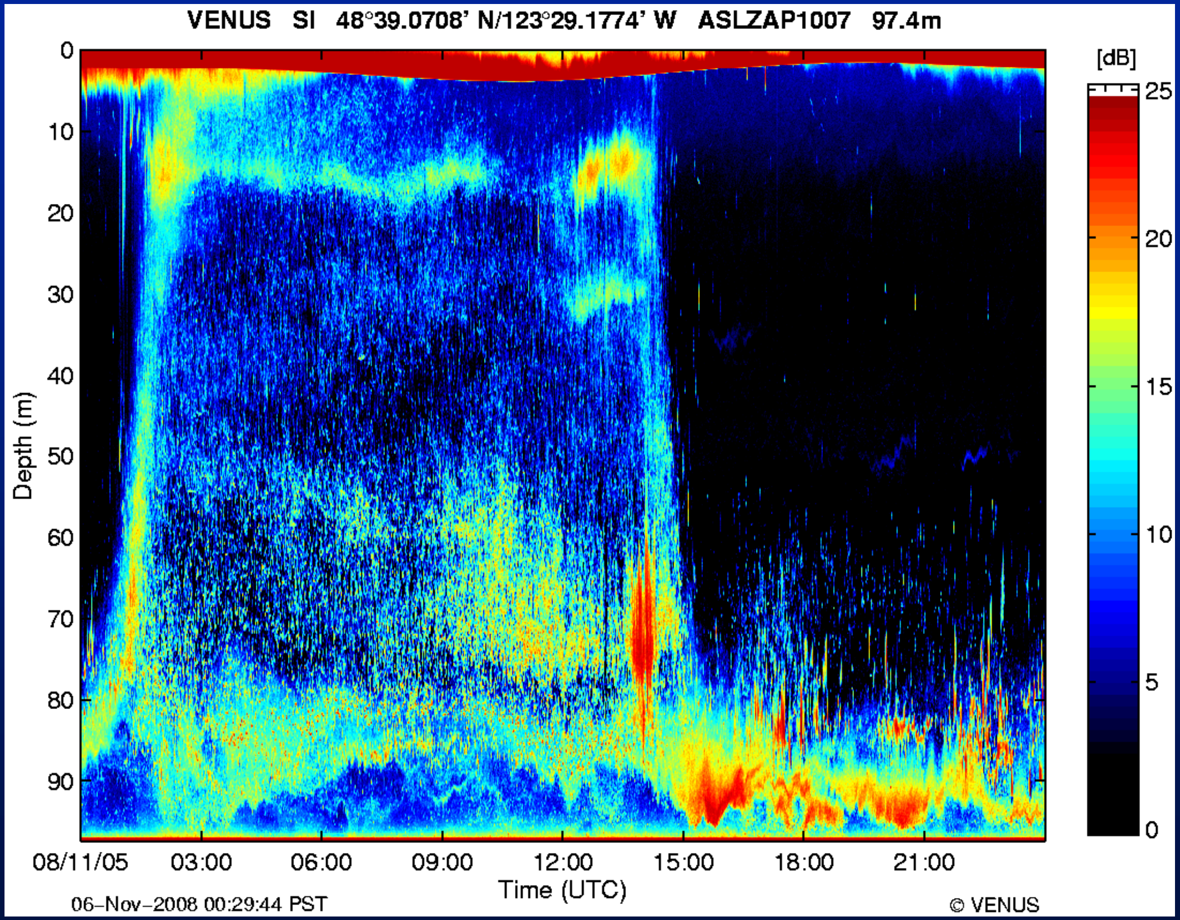


Landrum et al. (in press, DSR I)

Ocean observing systems



Courtesy of Bob Collier



Courtesy of V. Tunnicliffe & C. Barnes

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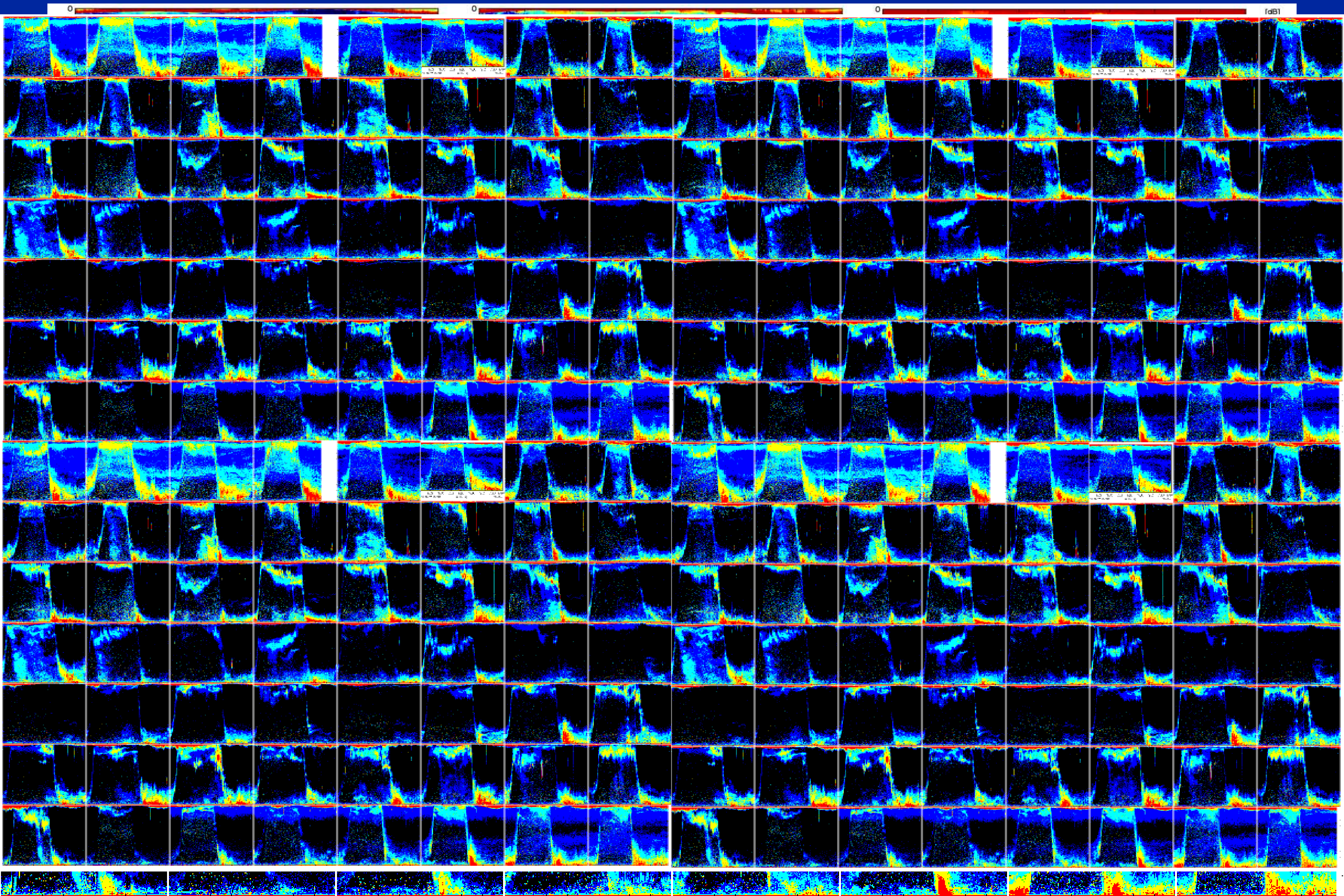
OOI OCEAN OBSERVATORIES INITIATIVE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Summary & Conclusions

- Fecal pellet flux & active transport increased with increasingly productive environments (caution-dependant upon season).
- Changes in zooplankton community structure over time, or in space, differentially alters organic matter export & C sequestration. Implications for feeding the deep sea too.
- The role of some major groups (e.g., gelatinous zooplankton) and process rates in major habitats (the meso- and bathypelagic zones) are still insufficiently known, & are needed to incorporate the role of zooplankton into predictive biogeochemical models.
- New technologies, more sensitive measurement techniques, novel biogeochemical tracers, & our input as a community into design of ocean observatories will be key to continued progress.

Muchas gracias!

- Zooplankton symposium organizers & local hosts
- VERTIGO, BATS, HOT, Pal LTER coauthors & collaborators
- Kam Tang, Daniele Bianchi, Bob Collier

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