Technical University of Denmark

The role of vertically migrating zooplankton in biogeochemical flux

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Josephine Grønning, Anne Morgen Mark

Outline

- Different roles of zooplankton in the biological pump

- Diel vertical Migration - DVM

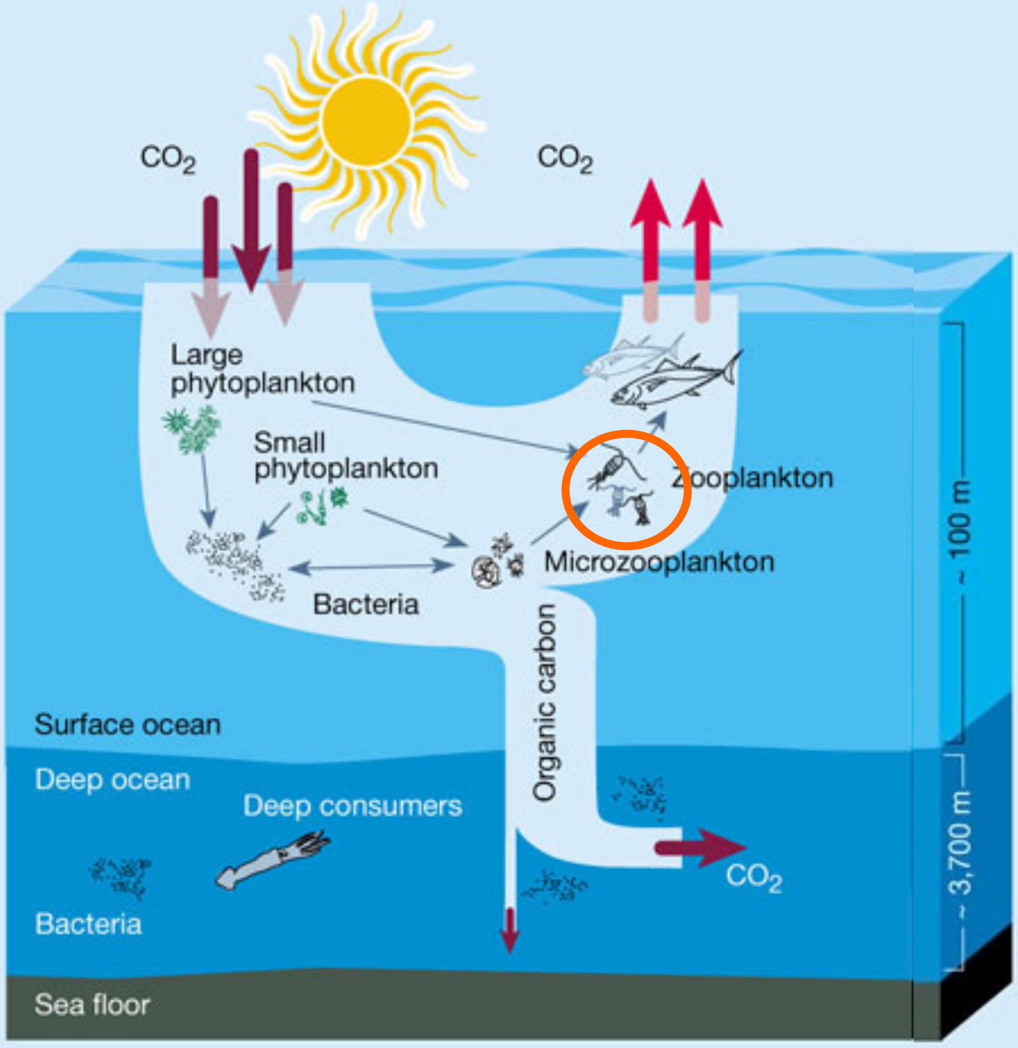
  Active N:P transport by zooplankton

- Ontogenic vertical Migration - OVM

  The Lipid Pump – now with N & P

  The Lipid Shunt

Biological pump



S.W. Chisholm, Nature 2000 Vol 407

Passive flux of POM

Role of zooplankton in flux

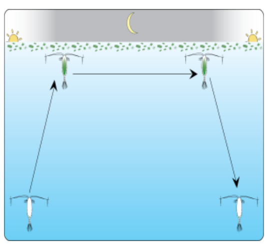
Photo: Eric Selander

Grazing 0-50 m
Packaging - Compacting small into large faster sinking particles

Sloppy feeding – releasing nutrients

Photo: Sigrun Jonasdottir

Scavengers – mid waters
Breaking up marine snow to smaller slower sinking particles releasing DOM and slowing down POM flux.



Drawing: Jamie Pierson

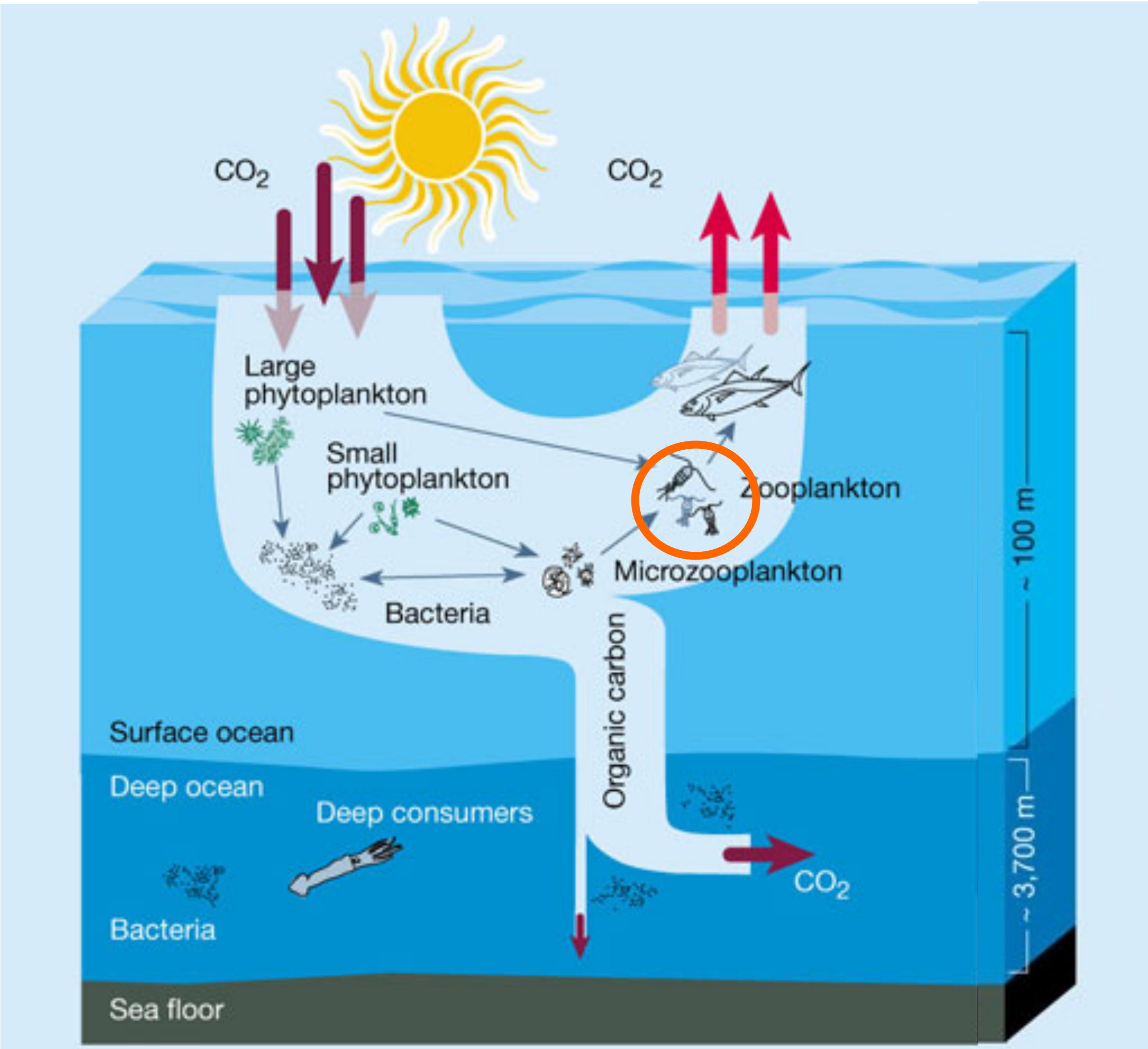
Diel Vertical Migration DVM - up-to 400 m depth
Fast track for faecal pellet flux + Excretion of nutrients @ depth

Photo: Sigrun Jonasdottir

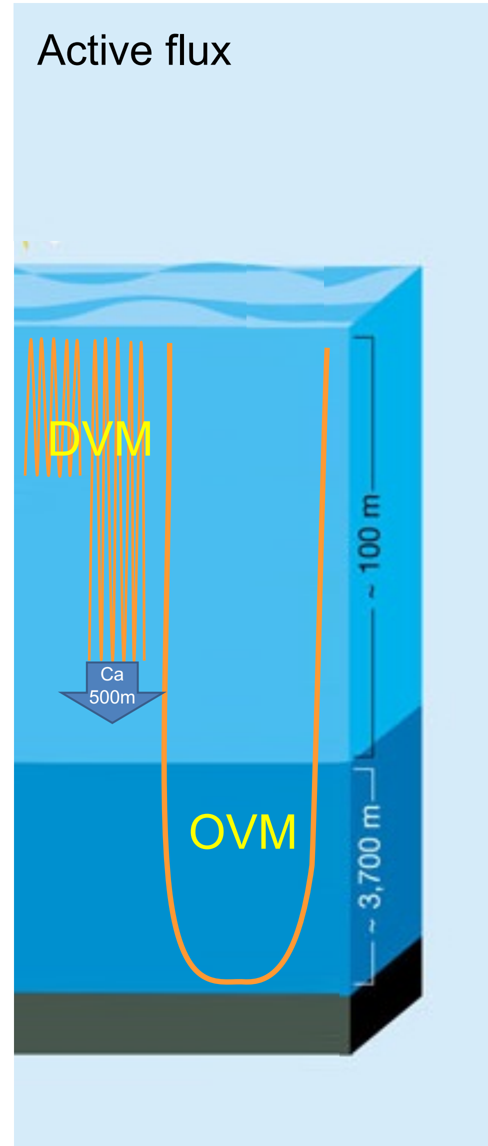
Ontogenic Vertical Migration OVM 500-3000 m
Lipid pump CO_2 sequestration, Lipid shunt

Mortality: lipid rich carcasses

Active flux by zooplankton

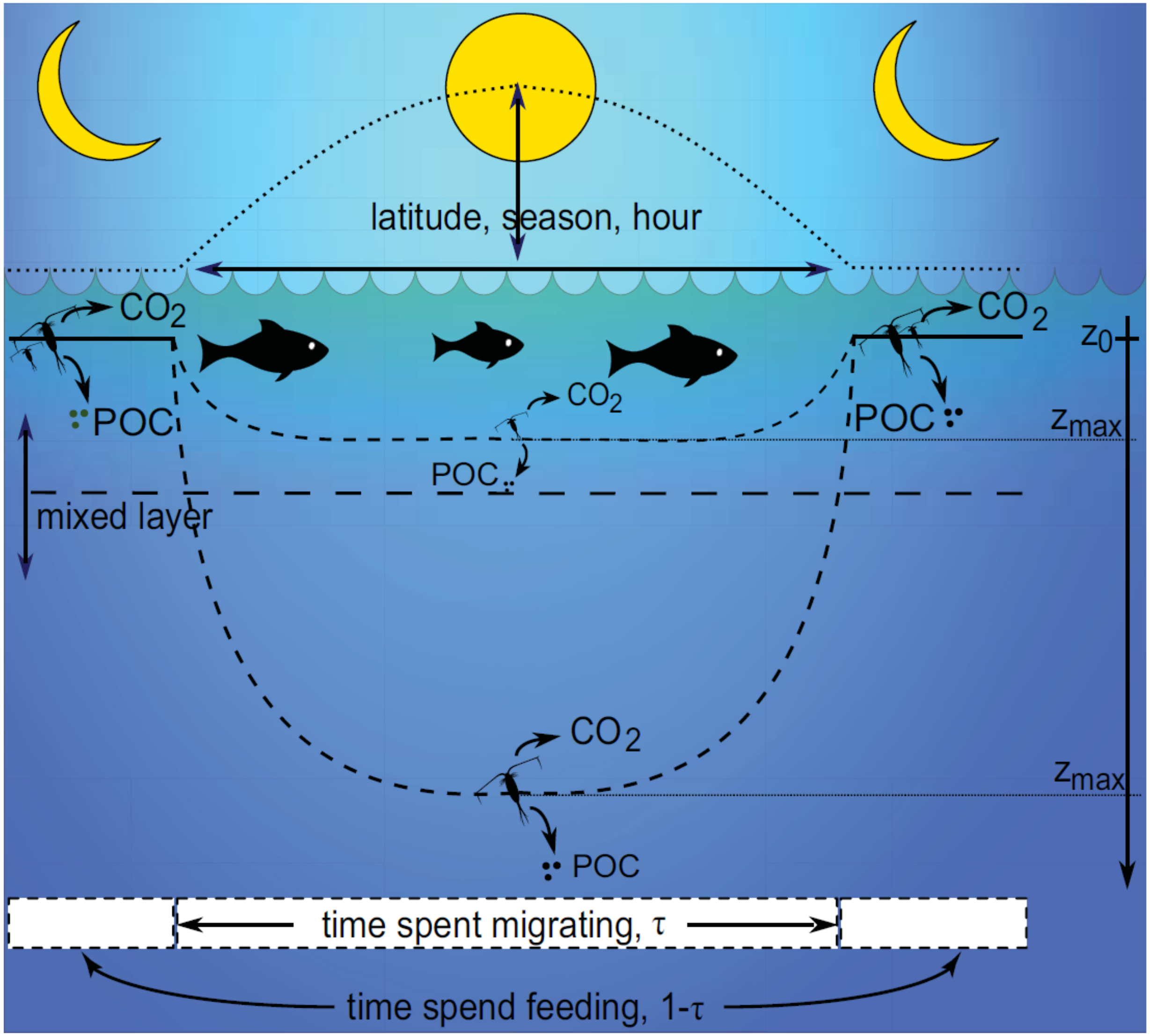


S.W. Chisholm, Nature 2000 Vol 407



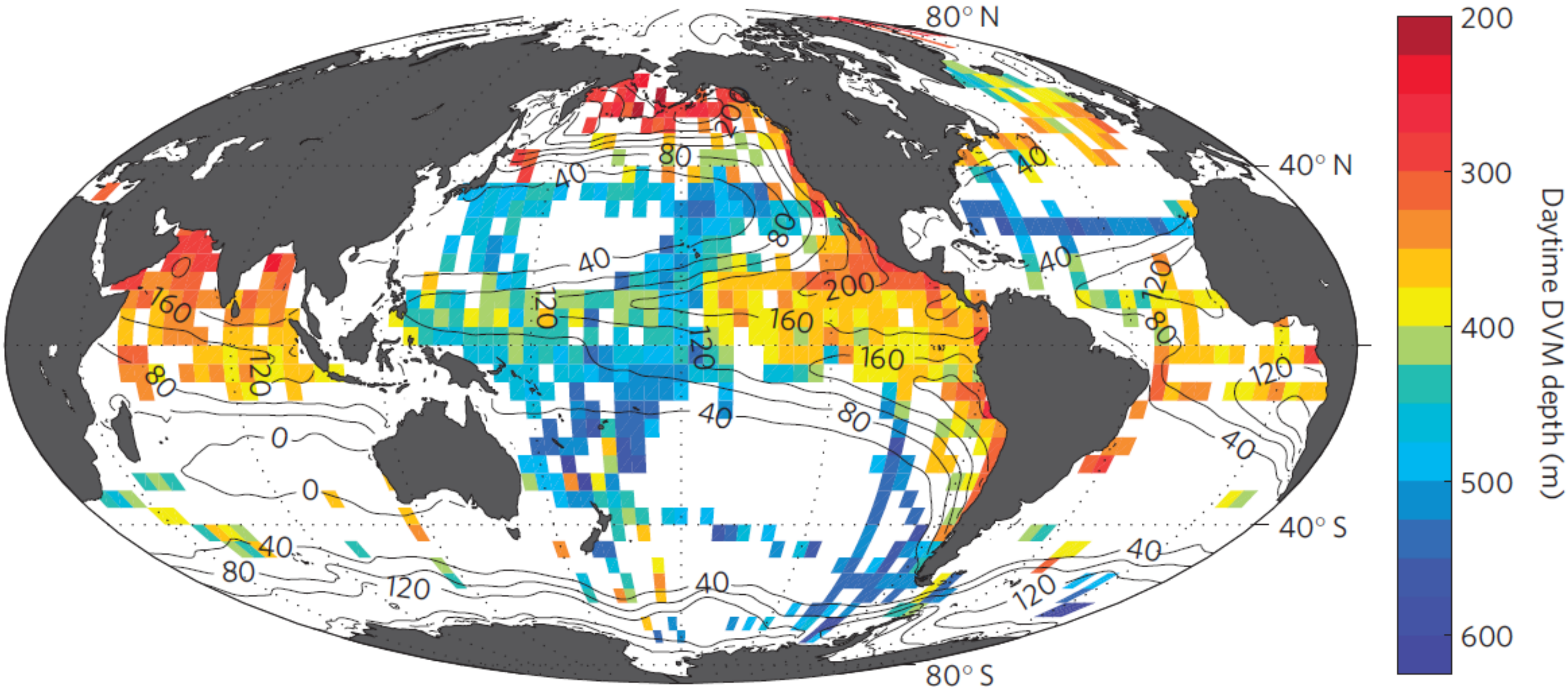
Diel Vertical Migration - DVM

- Trade-off: risk, feeding & cost
- Varies between latitudes
- Varies seasonally



Hansen & Visser (2016) L&O 61

Depth of DVM



Bianchi et al. (2013) Nature Geoscience 6

DVM - estimated C flux

Carbon export by vertically migrating zooplankton: an optimal behavior model

L&O 2016

Agnethe N. Hansen*, André W. Visser
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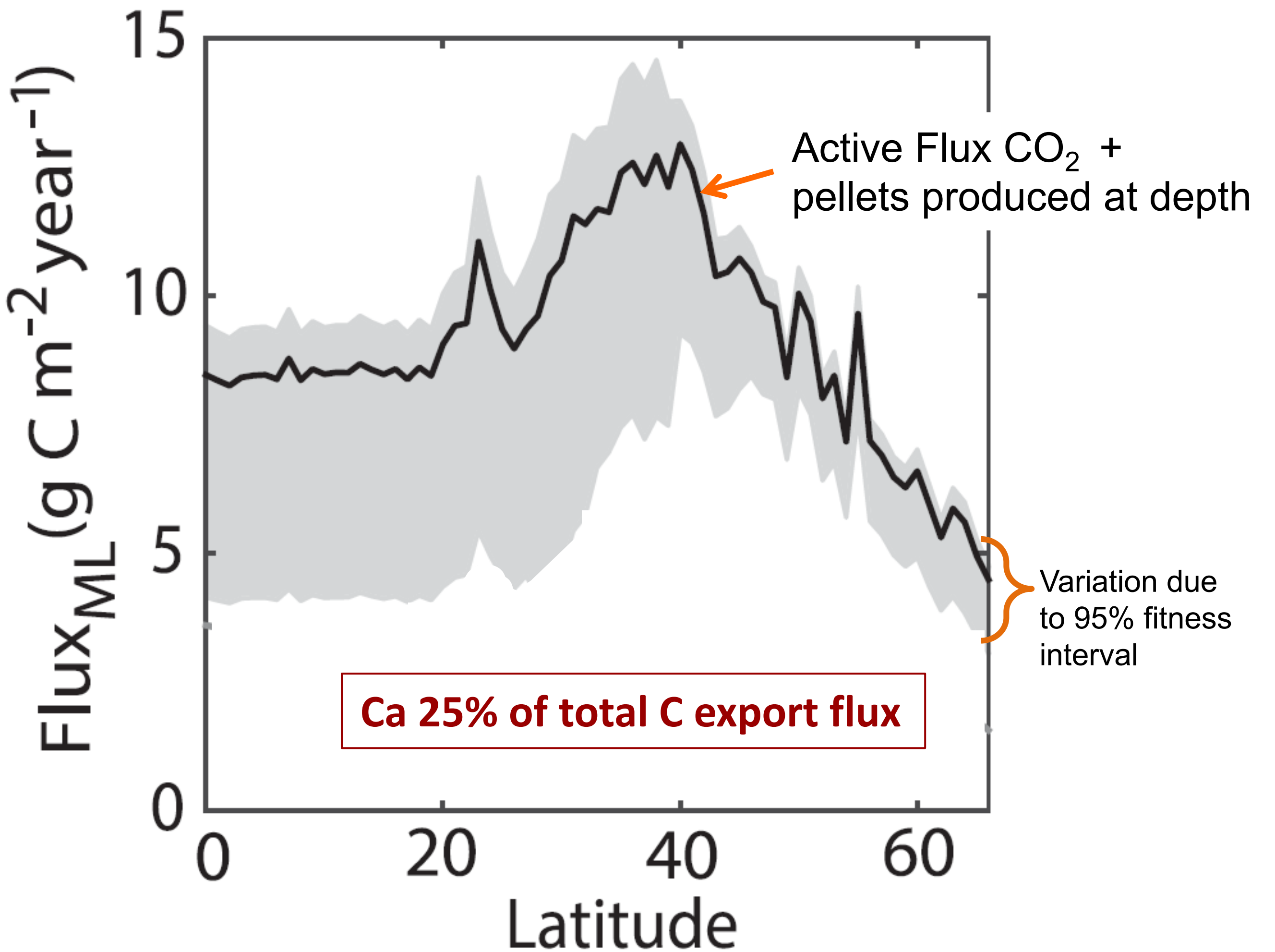
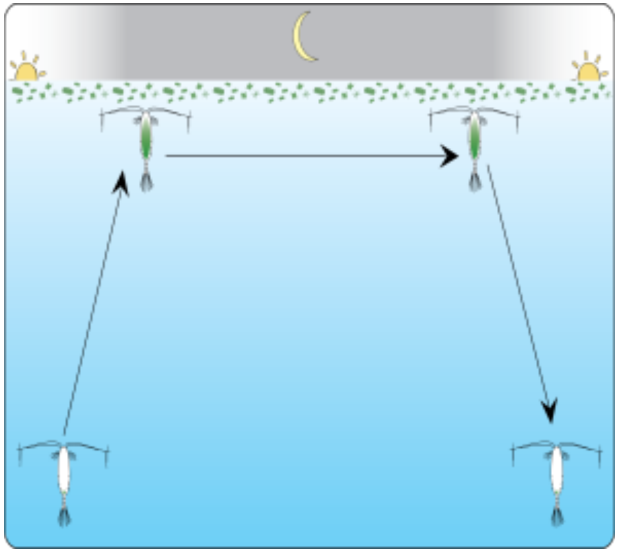
Trade-off based model

Fitness =>
Feeding opportunity v.s predation risk

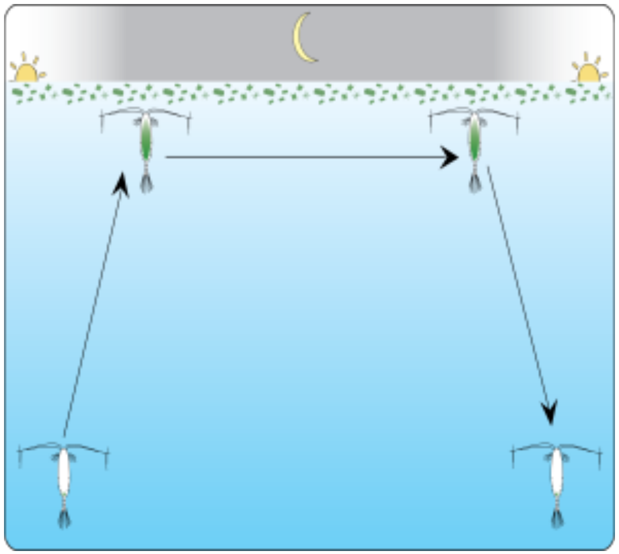
Based on
- Productivity
- Seasonality



How about Excretion of nutrients?



How about Excretion of nutrients?



PERGAMON

Deep-Sea Research I 49 (2002) 1445–1461

DEEP-SEA RESEARCH
PART I

www.elsevier.com/locate/dsr

Zooplankton vertical migration and the active transport of dissolved organic and inorganic nitrogen in the Sargasso Sea

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Deep-Sea Research I 56 (2009) 73–88

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journal homepage: www.elsevier.com/locate/dsri

ELSEVIER

Export stoichiometry and migrant-mediated flux of phosphorus in the North Pacific Subtropical Gyre

Cecelia C.S. Hannides[a,*,1], Michael R. Landry[b], Claudia R. Benitez-Nelson[c], Renée M. Styles[c], Joseph P. Montoya[d], David M. Karl[a]

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[b] Scripps Institution of Oceanography, University of California, San Diego, 9500 Gilman Drive, La Jolla, CA 92093, USA
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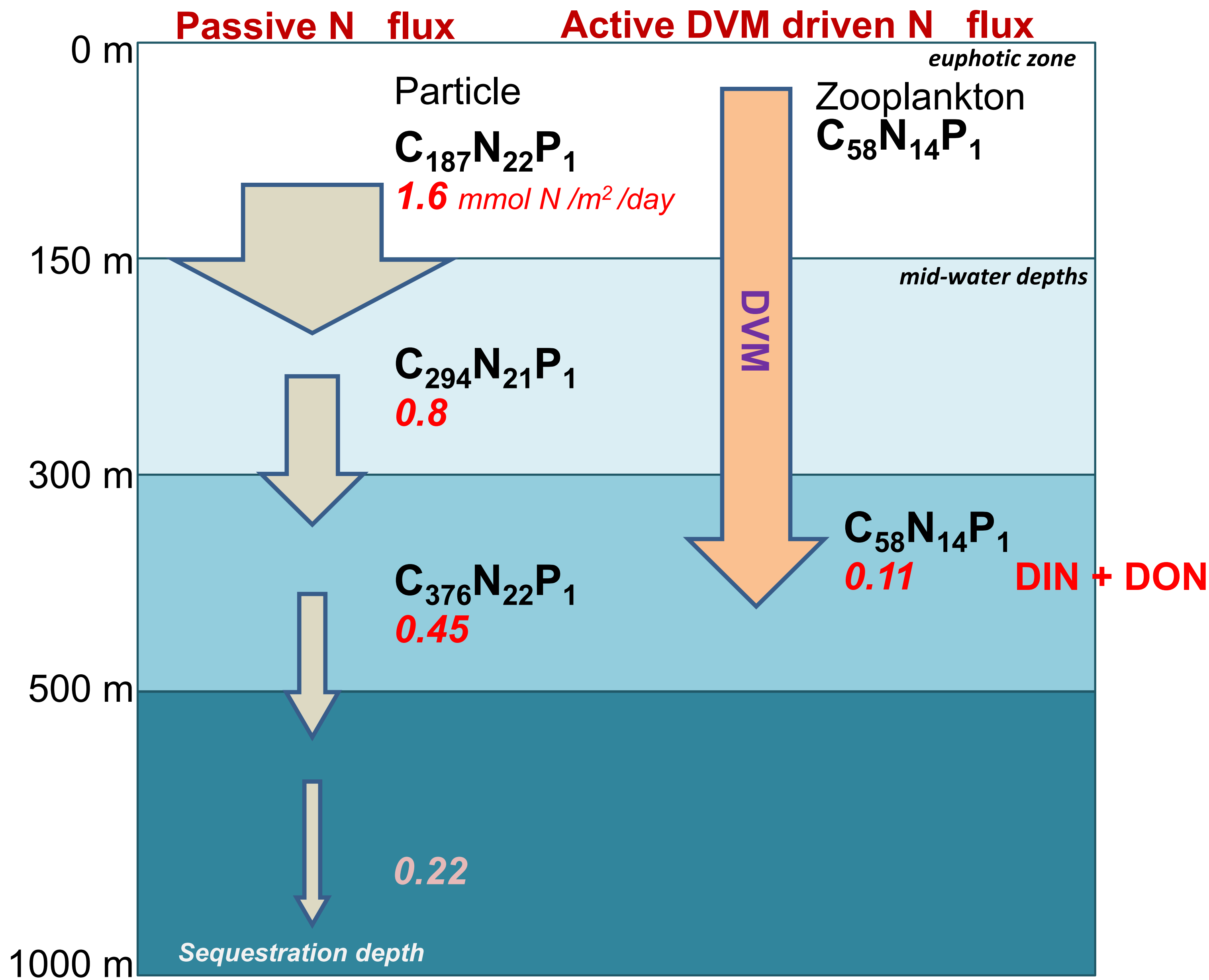
[d] School of Biology, Georgia Institute of Technology, 310 Ferst Drive, Atlanta, GA, USA

Active Flux DVM

Martin etal. 1993 DSR II 40
C:N:P Hannides et al 2009

Steinberg et al. 2002, DSR I 49



Active Flux DVM

Martin etal. 1993 DSR II 40
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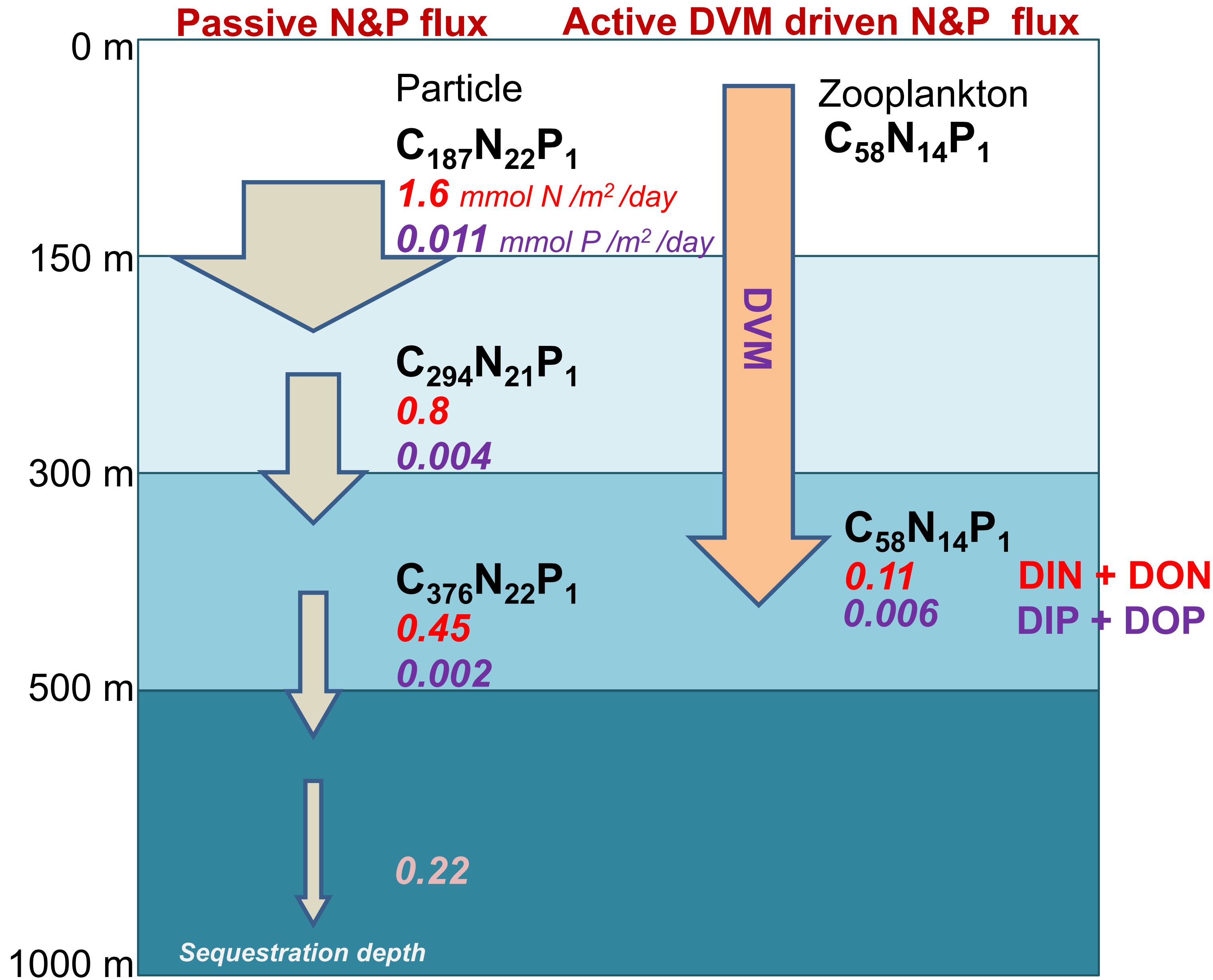
Hannides et al. 2009, DSR I 56:73-88
Steinberg et al. 2002, DSR I 49



Active Flux DVM

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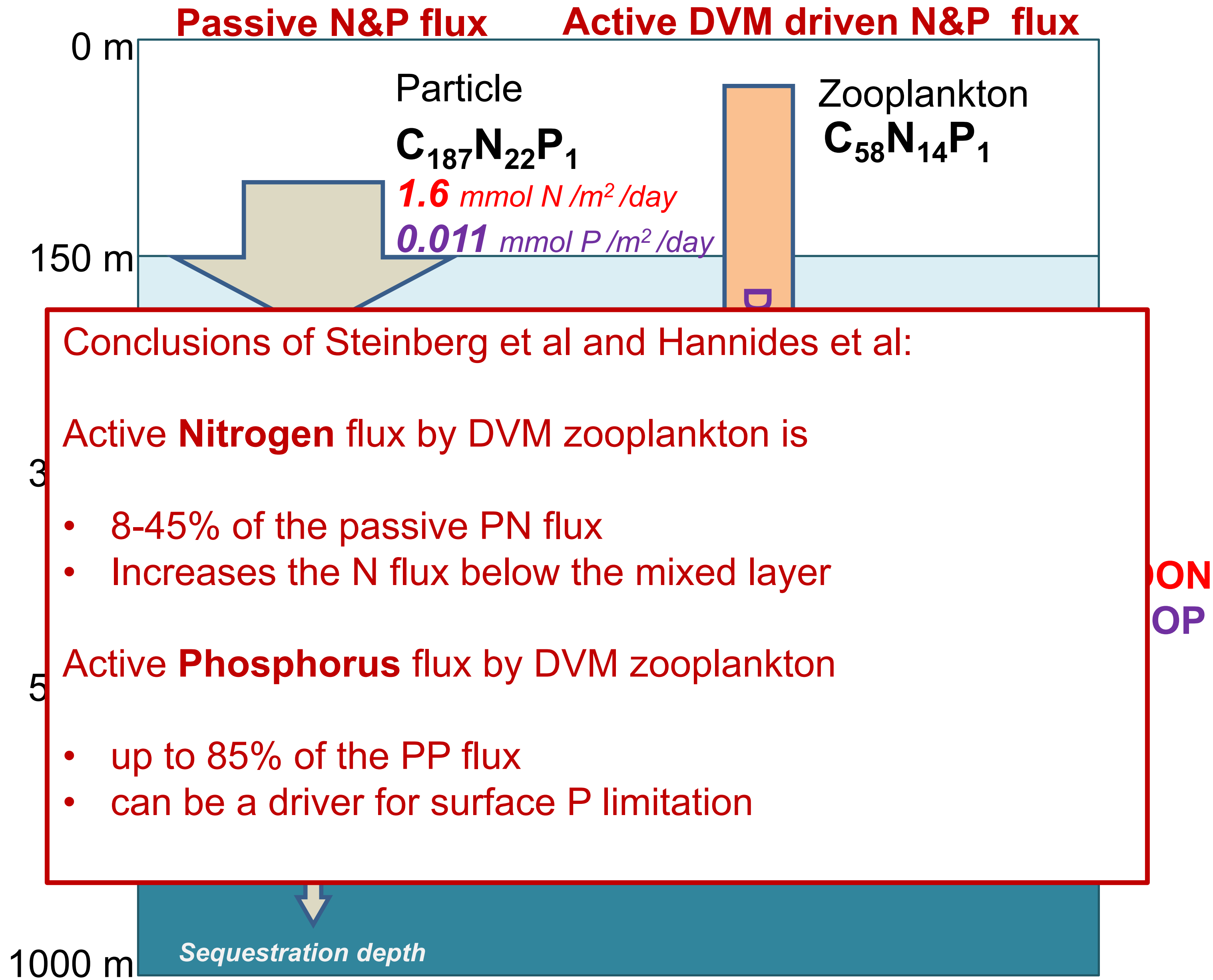
Hannides et al. 2009, DSR I 56:73-88
Steinberg et al. 2002, DSR I 49



Conclusions of Steinberg et al and Hannides et al:

Active **Nitrogen** flux by DVM zooplankton is

- 8-45% of the passive PN flux
- Increases the N flux below the mixed layer

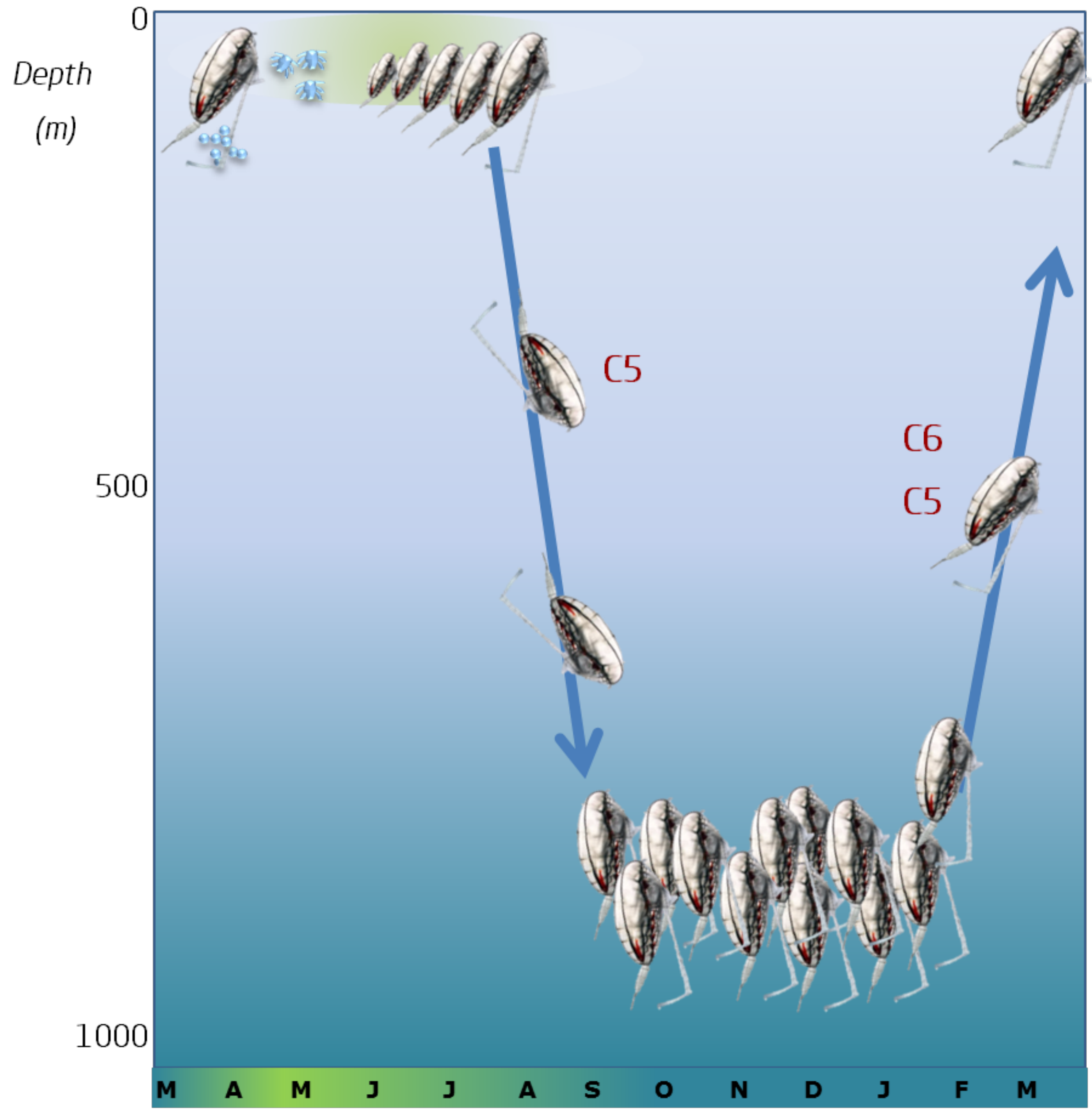
Active **Phosphorus** flux by DVM zooplankton

- up to 85% of the PP flux
- can be a driver for surface P limitation

Ontogenic Vertical Migration - OVM

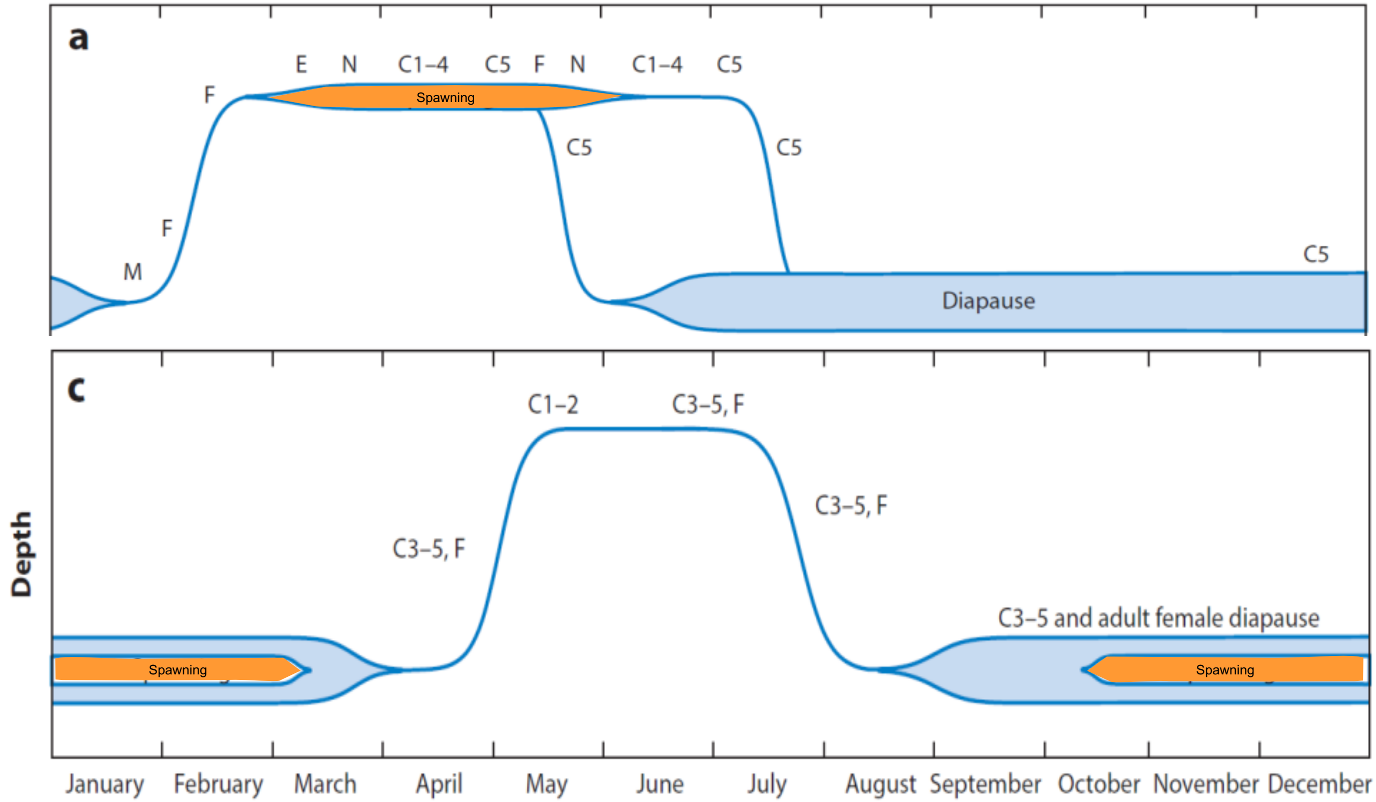
Diapause:
Arrested development
Lowered metabolism
No feeding
Torpid
Low predation

Lasts Up to 9 months



Overwintering strategies

Overwintering depths >600m



Income breeders

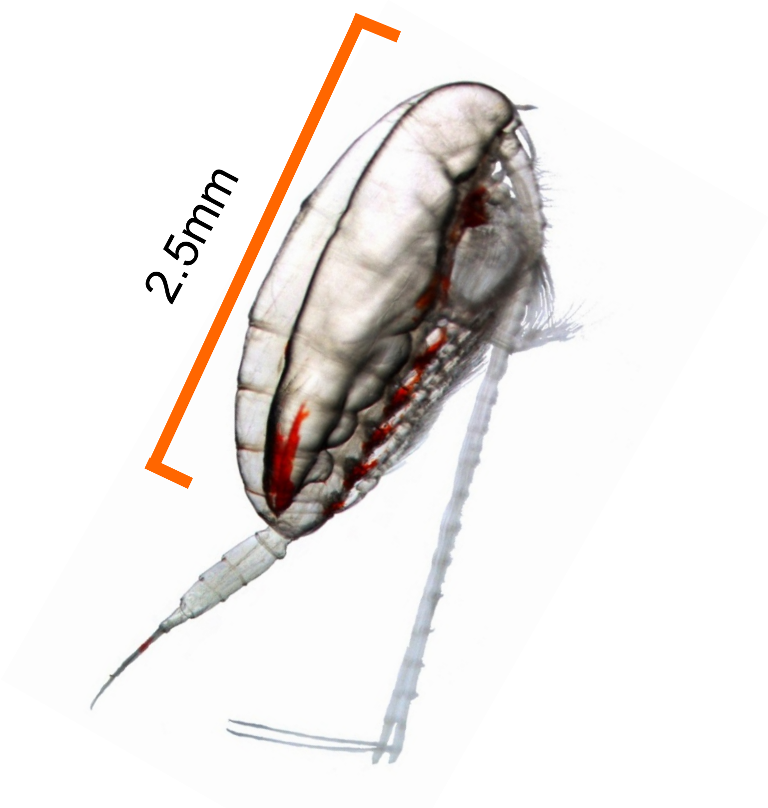
e.g. Calanus finmarchicus, *Calanoides acuspes*

Capital breeders

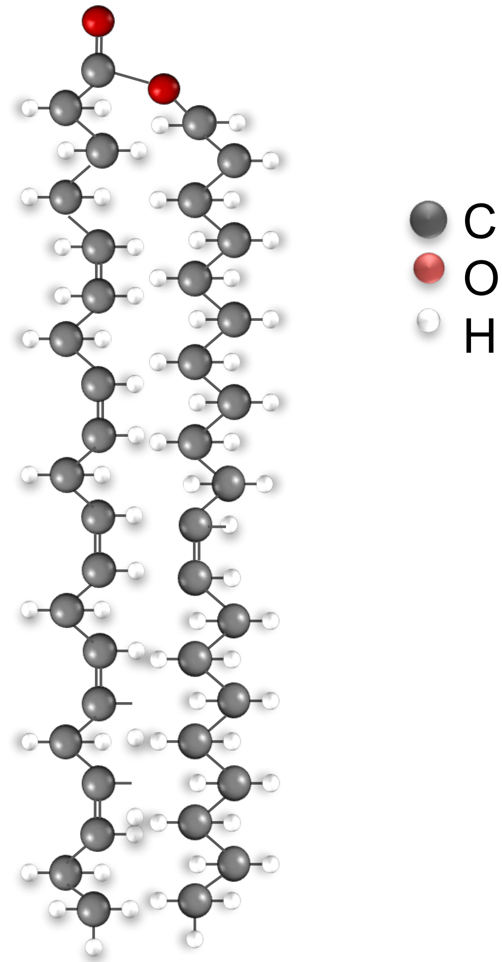
e.g. Calanus hyperboreus, *Neocalanus flemingerii*, *N. plumchrus*

Baumgartner and Tarrant 2017 Ann.Rev.Mar.Sci

Lipid accumulation

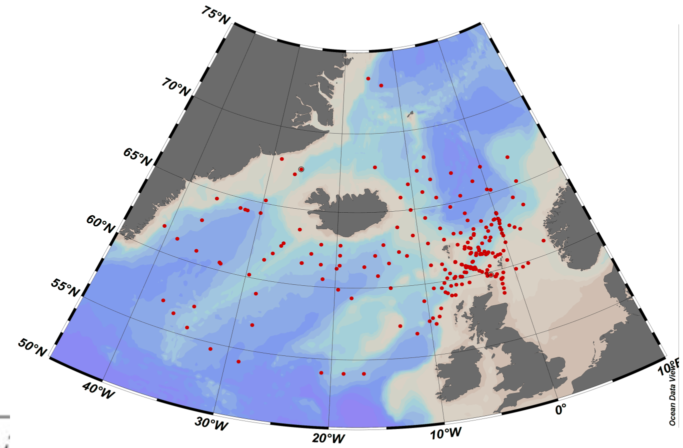


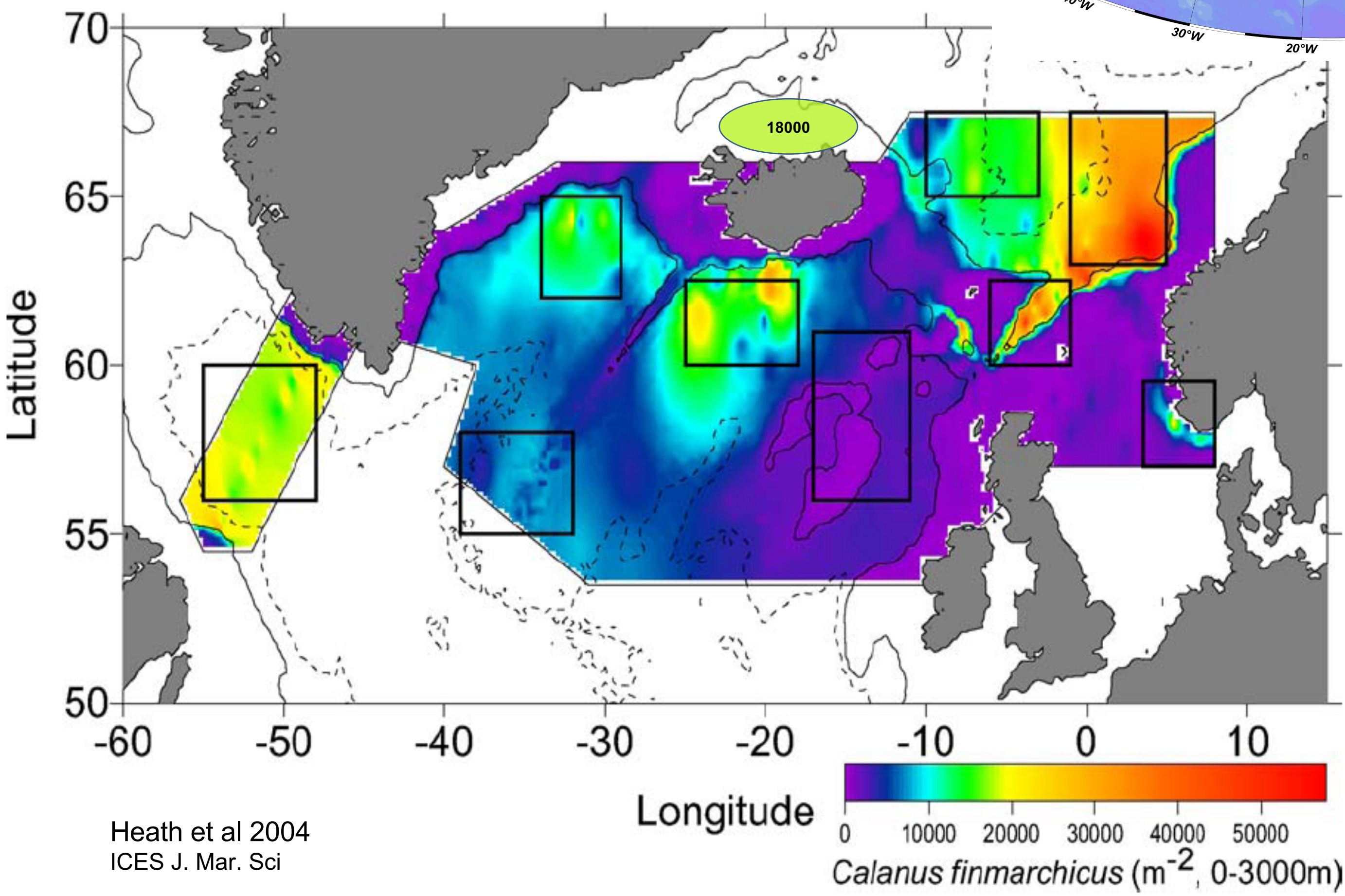
Oil sac: 100% WE
WE: 70% DW



Wax Ester ca 80% Carbon

Winter densities and distribution of *Calanus finmarchicus*





Heath et al 2004
ICES J. Mar. Sci

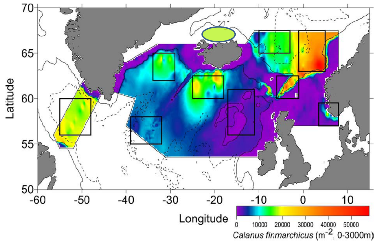
Annual Carbon transport

ca 0.5-10 gC m^{-2} yr^{-1}

Total: 5 MT C transported $year^{-1}$
in this area by *Calanus finmarchicus* only.

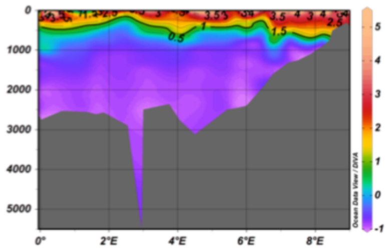
> 600 km coal train

Lipid pump – what is left behind – respired CO_2

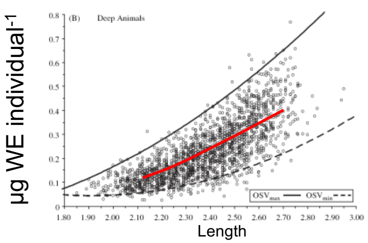


Population Abundance in diapause
Life history strategies => Capital or income breeder

If capital breeder – Number of eggs produced



OW temperatures for respiration



Size / Stage structure for estimating lipid content

Assumptions:

Metabolic rate 2.5×10^{-7} $\mu gC^{1/4}$ s^{-1}
Arousal of diapause when 85% $lipid_{max}$ content is burned
Mortality (non predatory) : 0.001 d^{-1}

Model calculations length of diapause

PNAS

CrossMark click for updates

Seasonal copepod lipid pump promotes carbon sequestration in the deep North Atlantic

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Limnol. Oceanogr. 00, 2017, 00–00

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Calanus hyperboreus and the lipid pump

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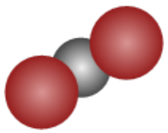
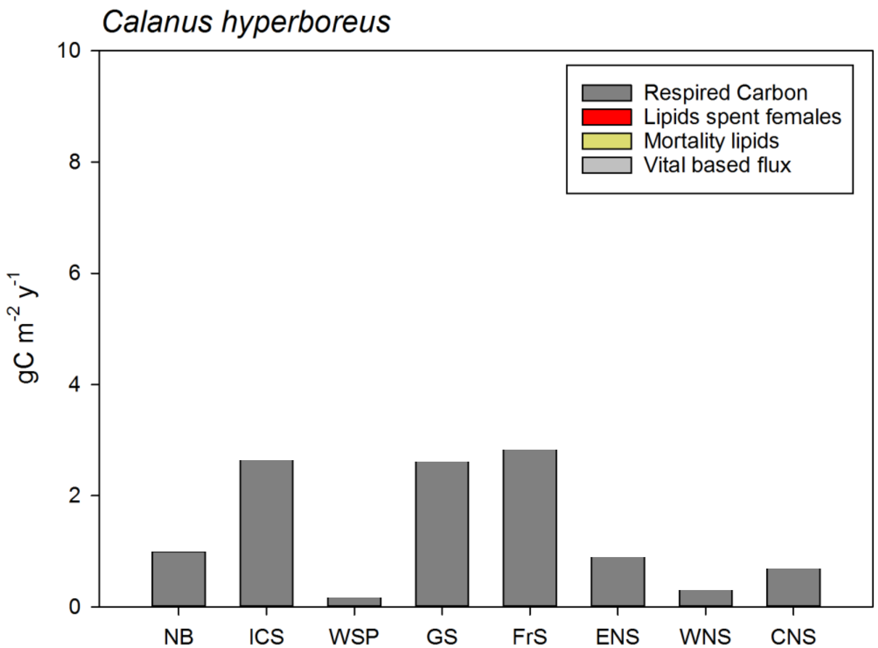
Limn. Oceanogr. **62**, May 2017

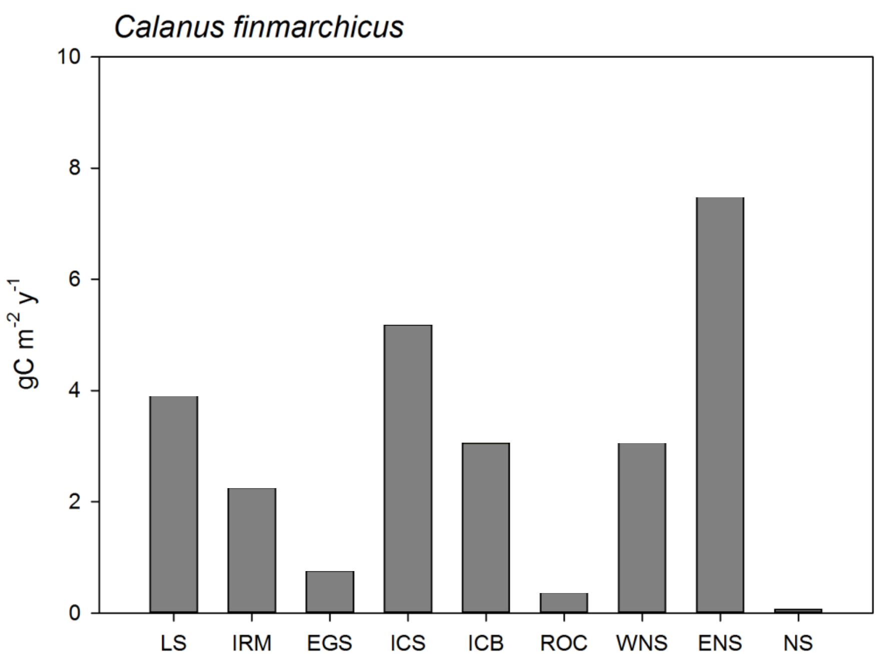
The Lipid Pump

Respired C

during diapause

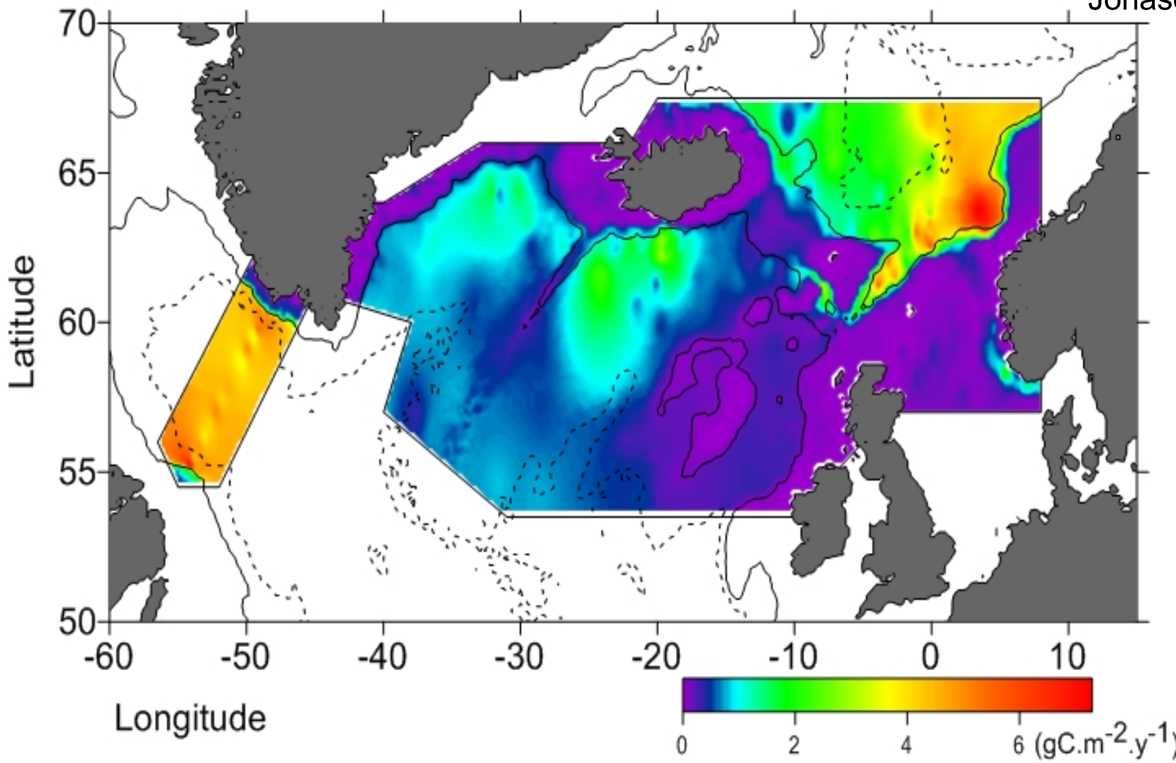






The Lipid Pump

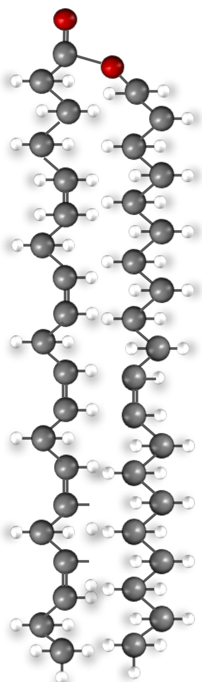
Jónasdóttir et al 2015 PNAS



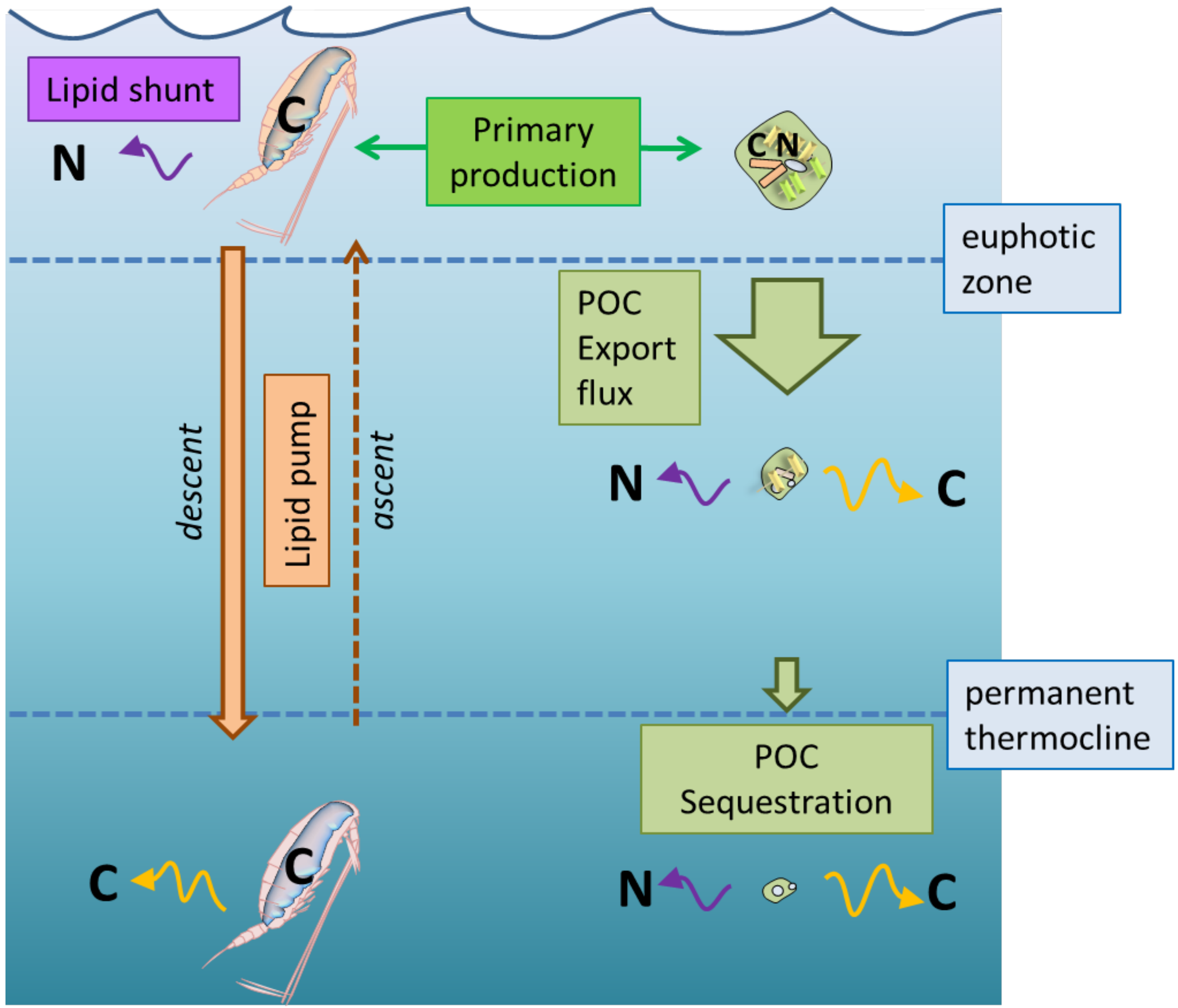
Sequestration of overwintering *C. finmarchicus* and *C. hyperboreus*

0.5 to 8 gC m^{-2} yr^{-1} => 2 to 8 gC m^{-2} yr^{-1} sinking passive C flux @ same depth

Lipid Pump & Lipid shunt



Wax Ester
– ca 80% Carbon
– No Nitrogen
- No phosphorus



Jónasdóttir et al 2015 PNAS

Wax ester synthesis

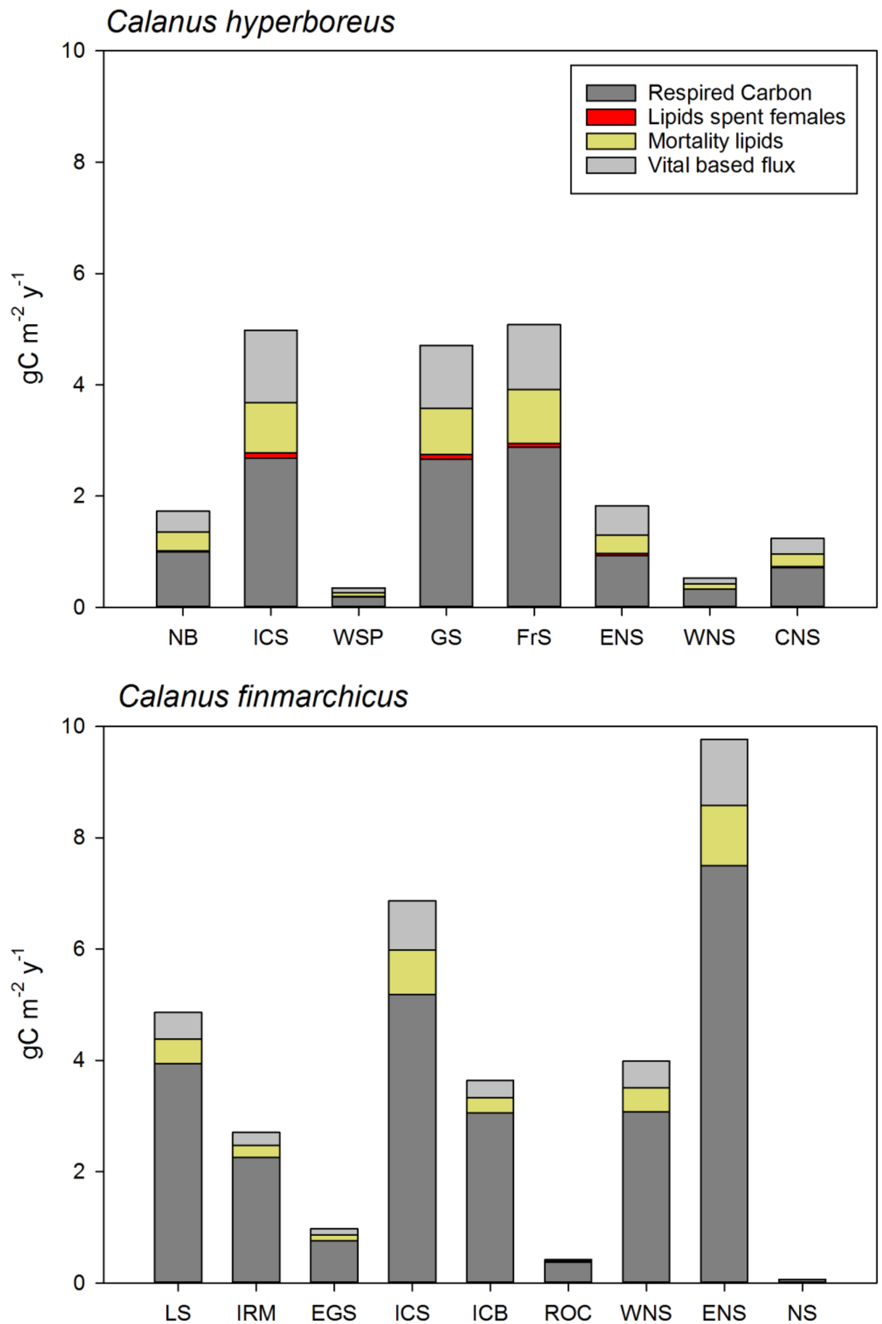
"Actively feeding copepods characteristically excrete copious amounts of ammonia derived from dietary amino acids….. the animal may be channelling dietary amino acids away from growth and instead discarding amino N as ammonia leaving the carbon skeletons of amino acids to form fatty alcohol"

Sargent et al 1977

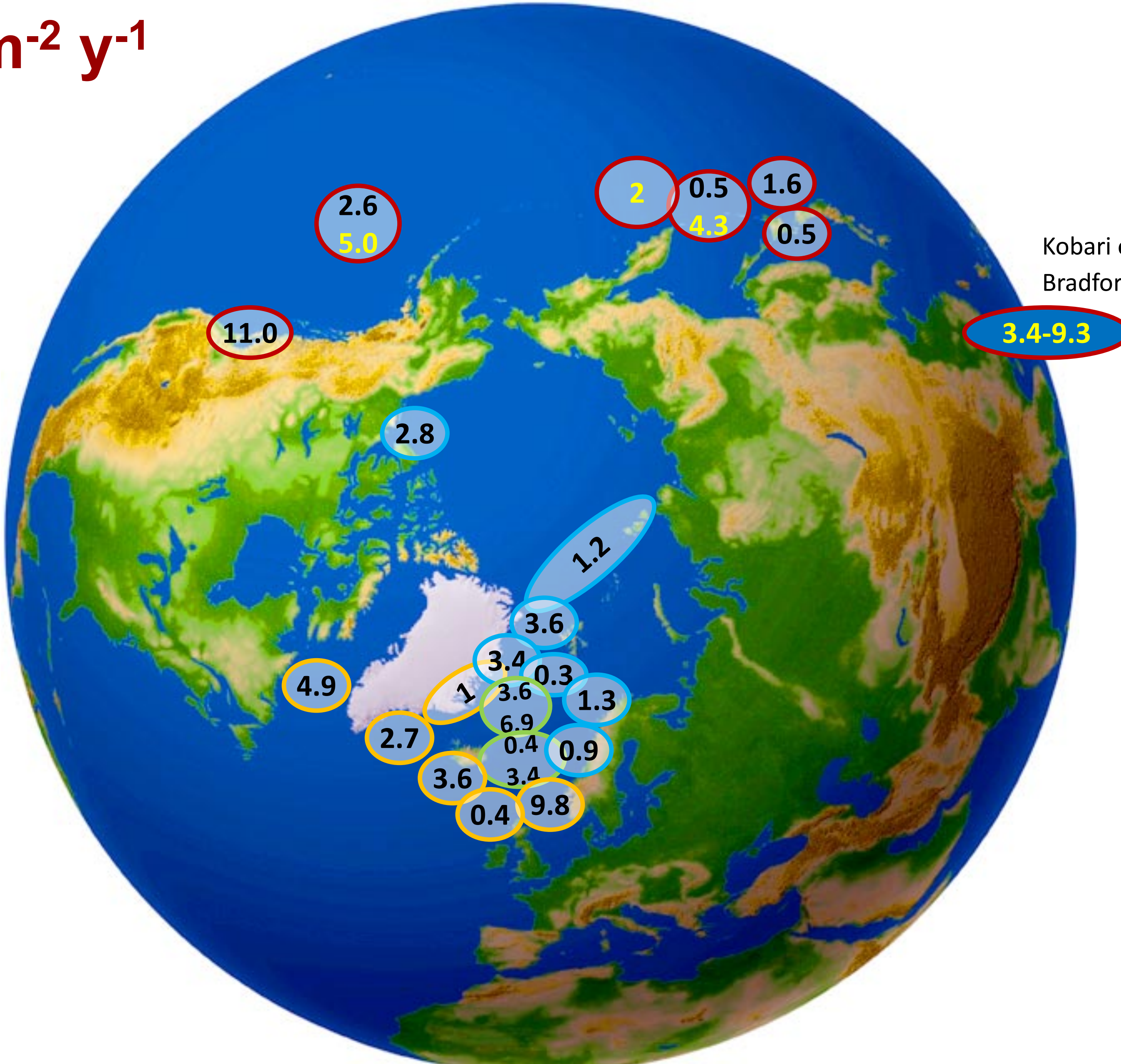
Including mortality

Structural mass

Lipid mass



gC m^{-2} y^{-1}



Kobari et al. 2008

Bradford -Grieve et al. 2001

Neocalanus sp.

C. hyperboreus

C. finmarchicus

C. fin & C. hyp

Deep-Sea Research I 98 (2015) 76–82

Contents lists available at ScienceDirect

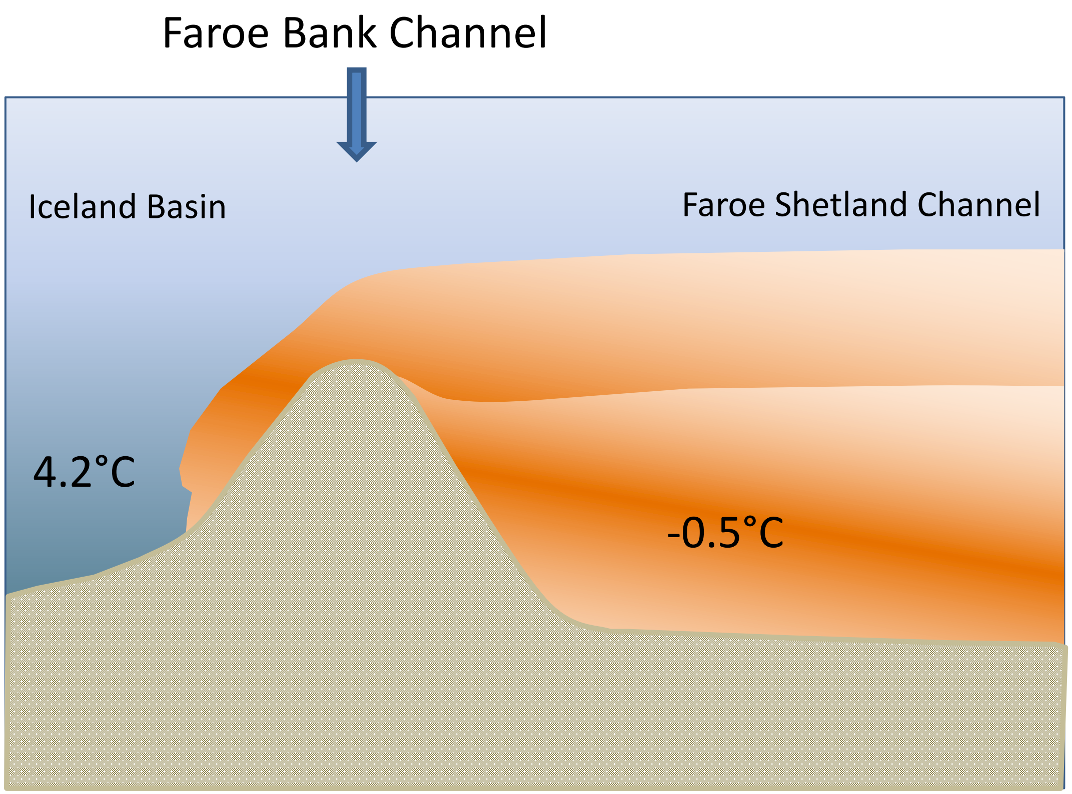
Deep-Sea Research I

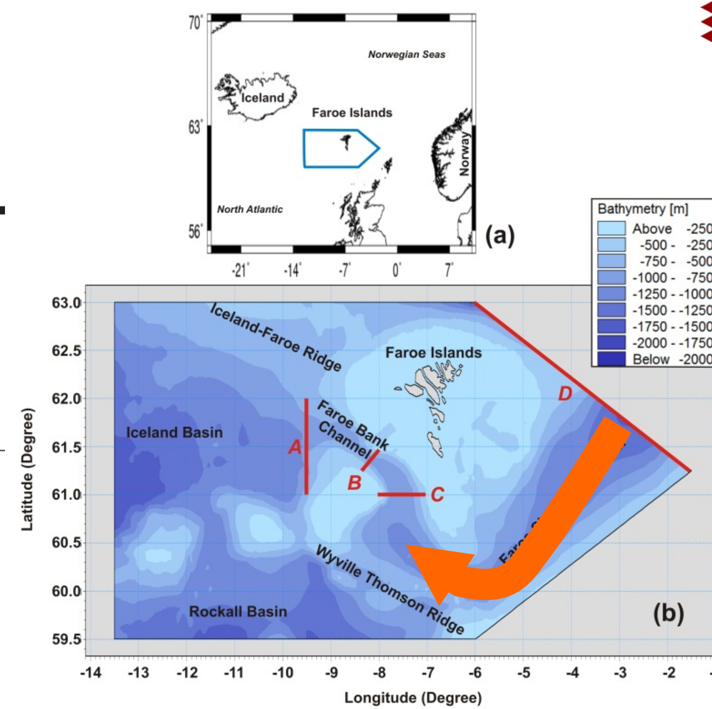
journal homepage: www.elsevier.com/locate/dsri

Advective loss of overwintering *Calanus finmarchicus* from the Faroe–Shetland Channel

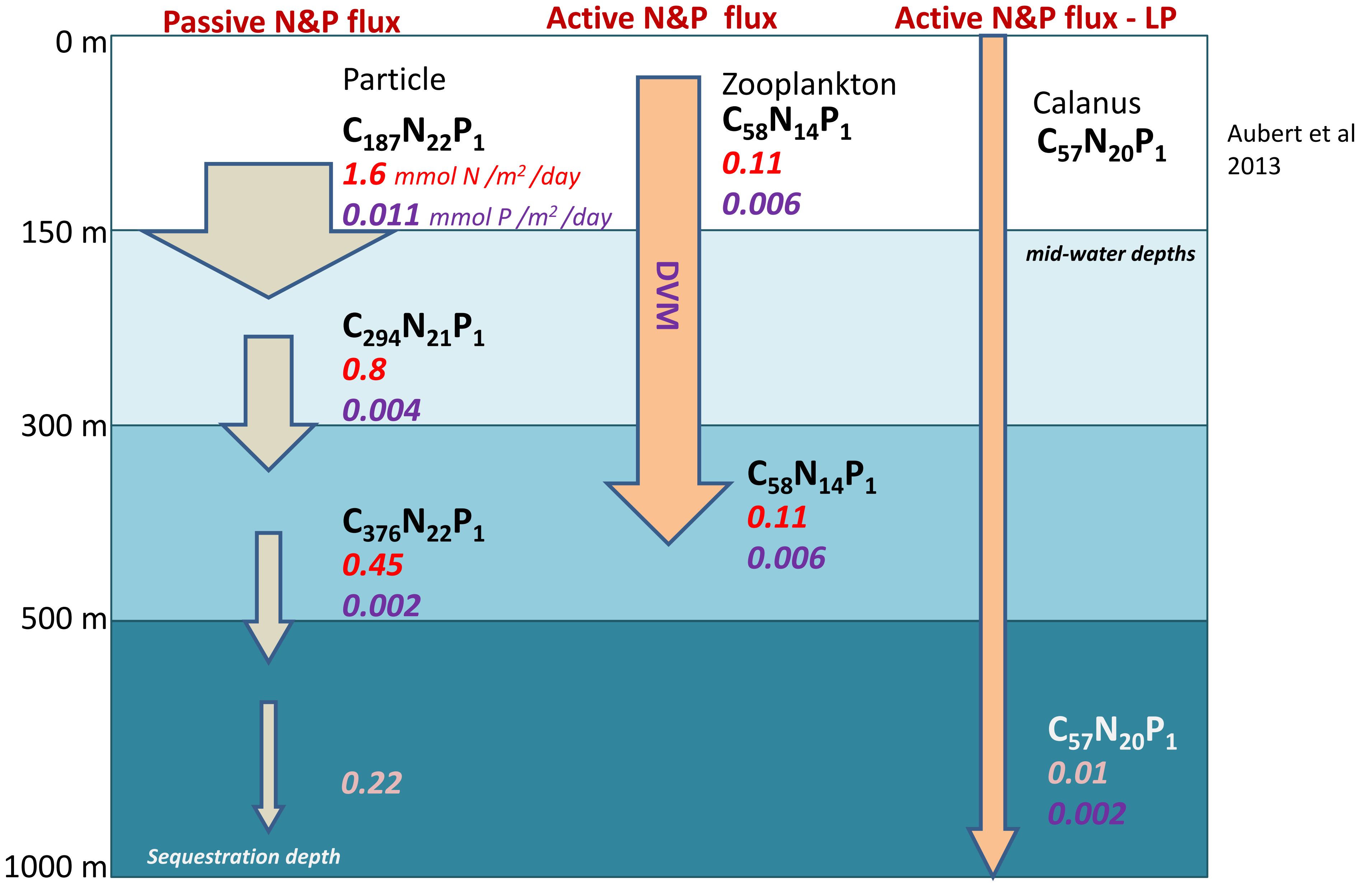
Arief Rullyanto*, Sigrún H. Jónasdóttir, André W. Visser

Centre for Ocean Life, National Institute for Aquatic Resources, Technical University of Denmark, Kavalergaarden 6, 2920 Charlottenlund, Denmark

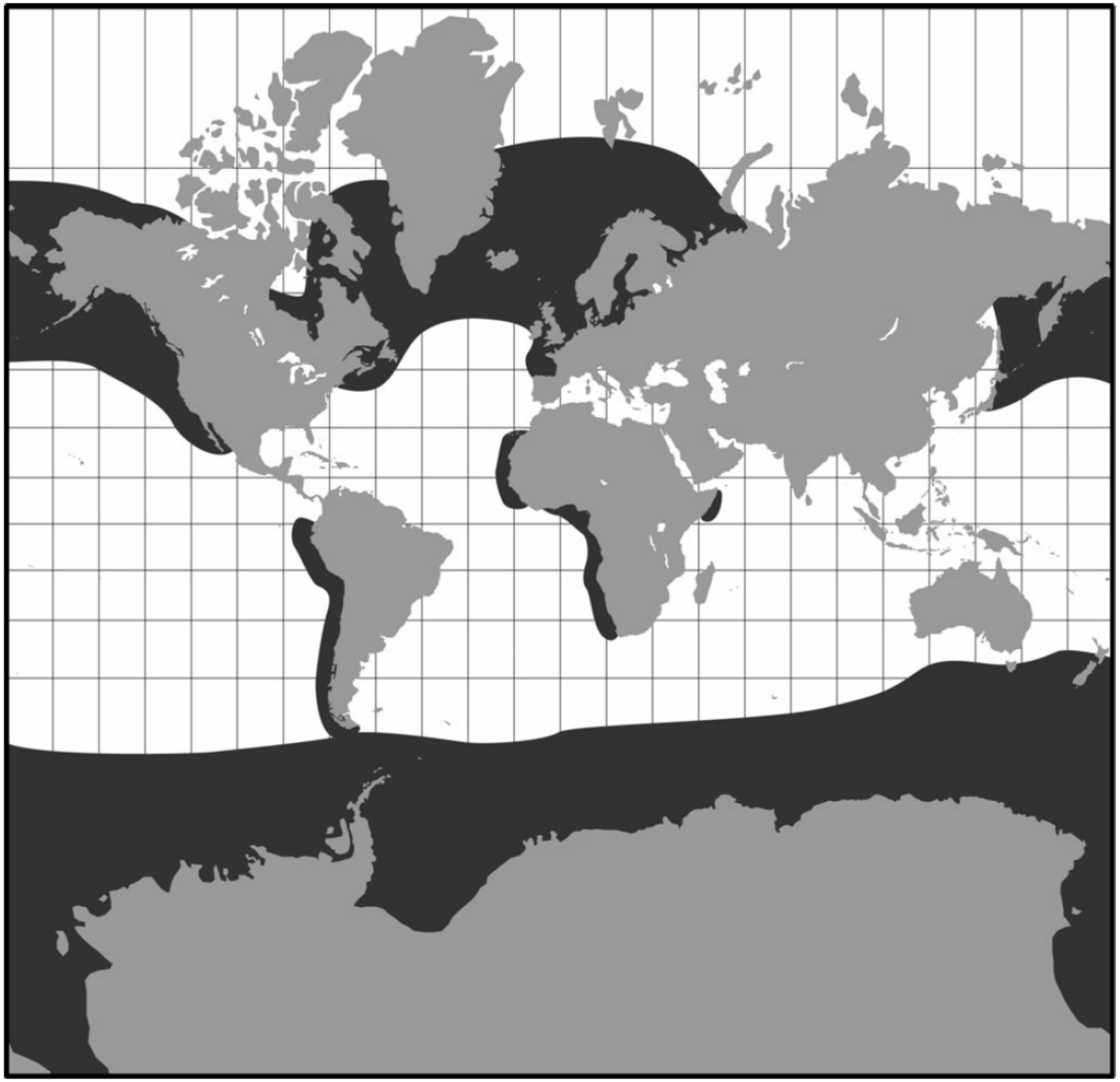




ca 80 kT C/yr



Calanus finmarchicus and *C. hyperboreus*
Mortality flux
DTU
Passive N&P flux
Active N&P flux
Active N&P flux - LP
0 m
150 m
300 m
500 m
1000 m
Particle
$C_{187}N_{22}P_1$
1.6 mmol N /m² /day
0.011 mmol P /m² /day
$C_{294}N_{21}P_1$
0.8
0.004
$C_{376}N_{22}P_1$
0.45
0.002
0.22
Sequestration depth
Zooplankton
$C_{58}N_{14}P_1$
0.11
0.006
DVM
$C_{58}N_{14}P_1$
0.11
0.006
Calanus
$C_{57}N_{20}P_1$
mid-water depths
$C_{57}N_{20}P_1$
0.01
0.002
Aubert et al 2013



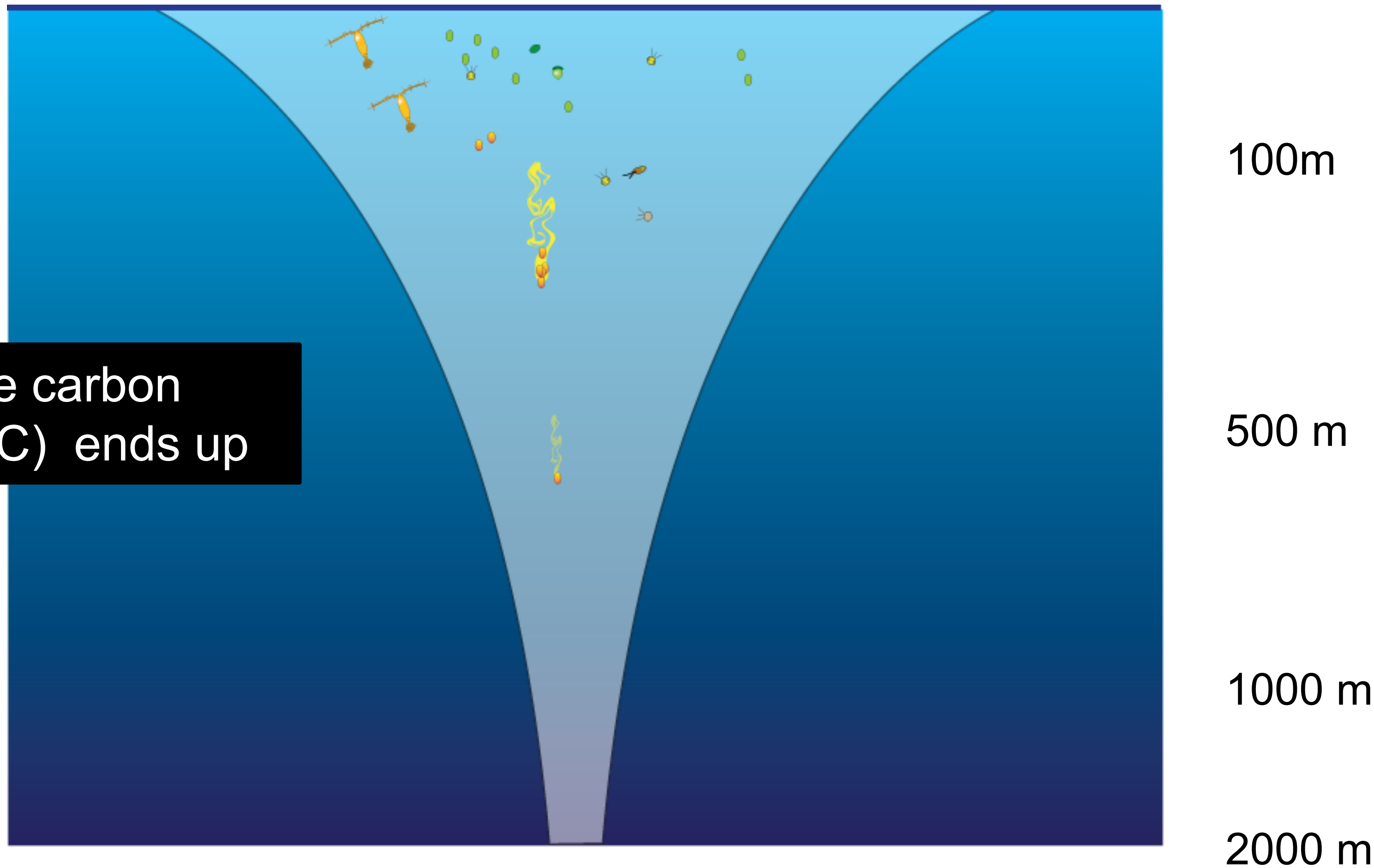
Calanus finmarchicus
hyperboreus
glacialis
pacificus
helgolandicus
carinatus
acutus
australis
sincus
marshalle
chilensis
Neocalanus tonsus
plumchrus
cristatus
flemingeri
Calanoides carinatus
acutus

Rhincalanus gigas
Eucalanus bungii
californicus

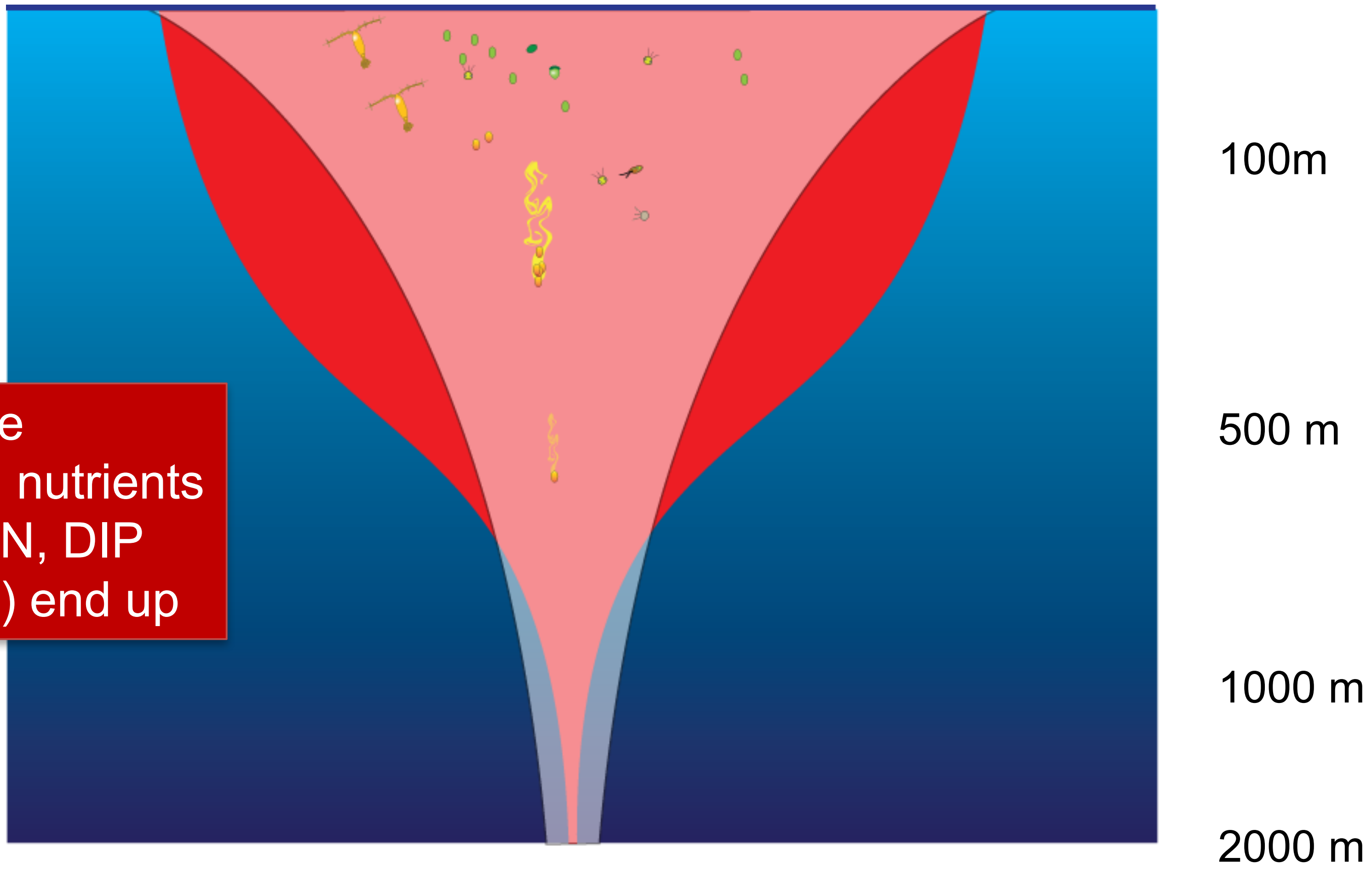
SUMMARY

Biological pump: particle flux and microbial mineralization

Where the carbon (DOC+DIC) ends up

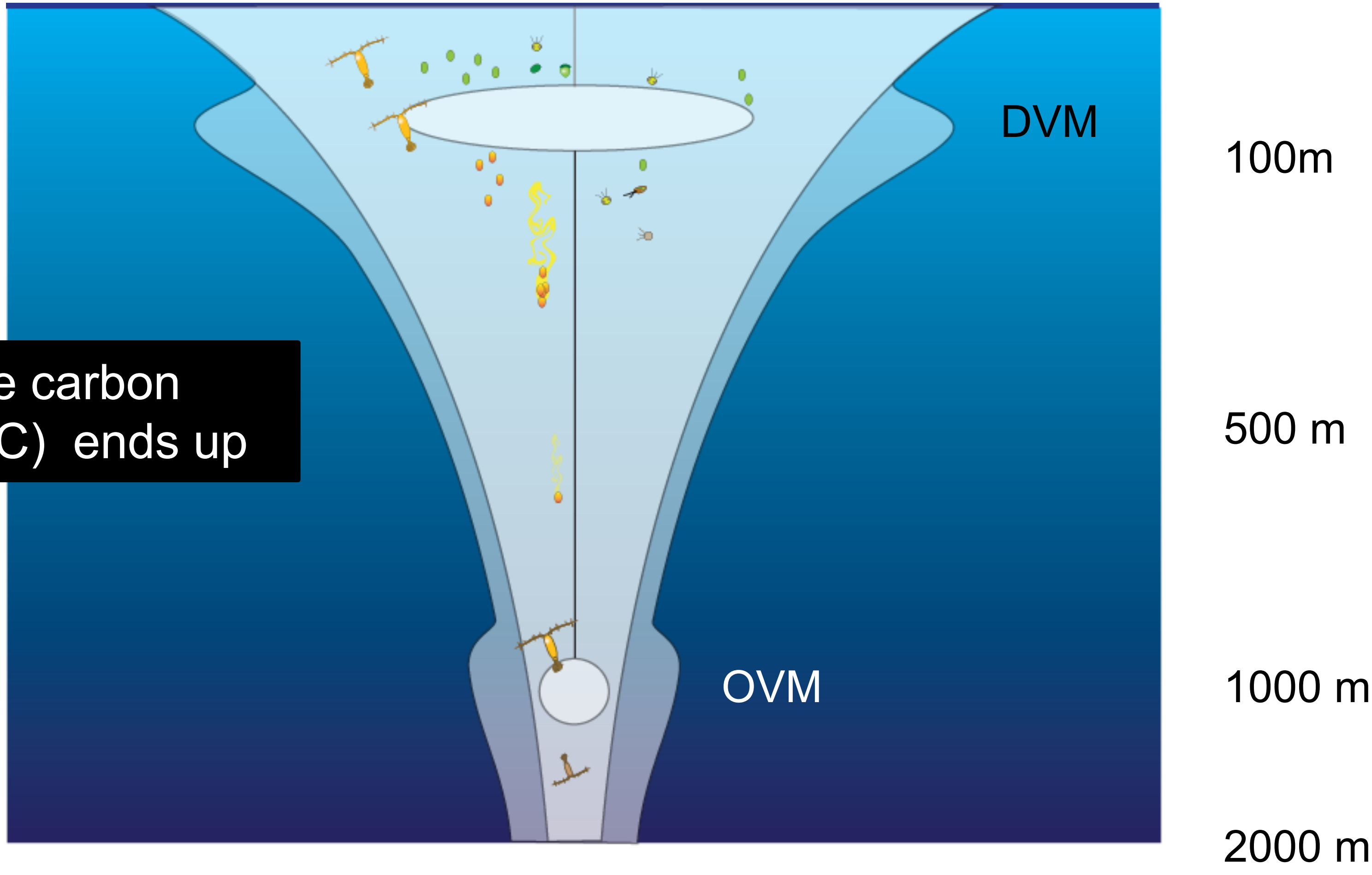


Biological pump: particle flux and microbial mineralization



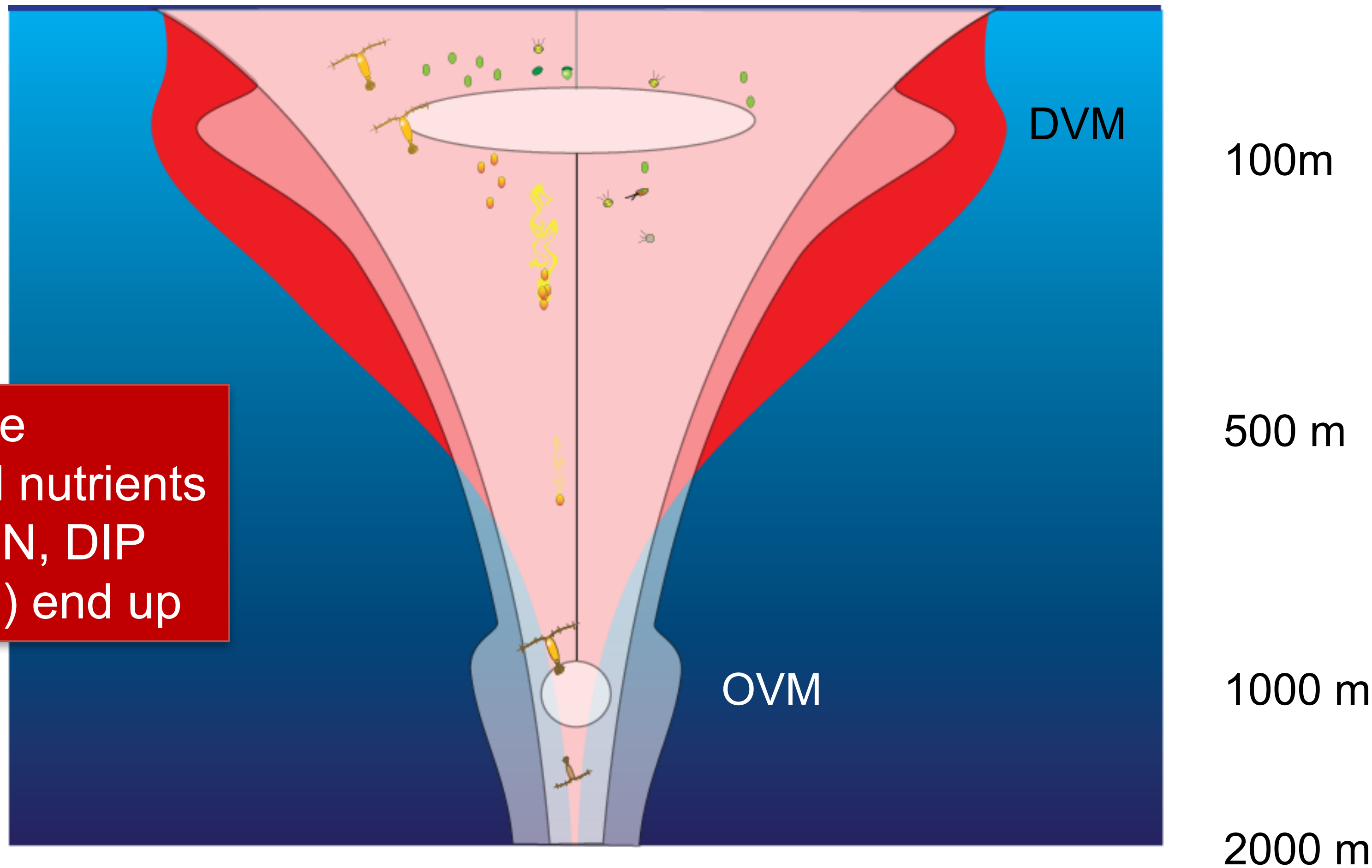
Where the dissolved nutrients (DIN, DON, DIP and DOP) end up

Biological pump: particle flux and microbial mineralization + zooplankton migration, both DVM and OVM



Where the carbon (DOC+DIC) ends up

Biological pump: particle flux and microbial mineralization + zooplankton migration, both DVM and OVM



Where the dissolved nutrients (DIN, DON, DIP and DOP) end up

Conclusion

- **Zooplankton play a significant role in transporting nutrients and carbon to intermediate and deep ocean.**
- **There is a decoupling between carbon and nutrient flux through microbial processes and the "lipid shunt"**
- **OVM is particularly effective in transporting carbon, with only a small removal of surface nutrients.**

Where the dissolved nutrients (DIN, DON, and DOP) end up

100m

500 m

1000 m

2000 m