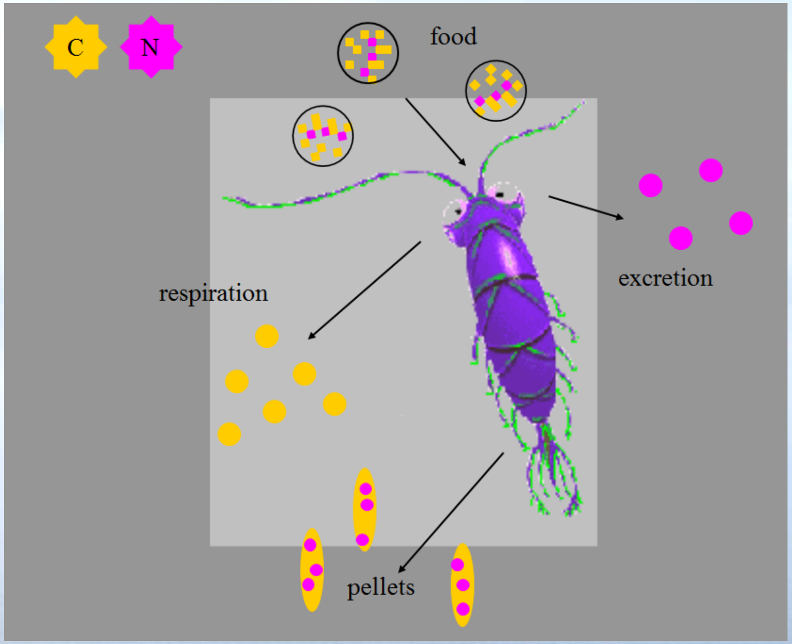
Stoichiometry of mesopelagic zooplankton and carbon sequestration in the ocean

Tom Anderson

National Oceanography Centre, Southampton, UK



Ocean Carbon & Biogeochemistry workshop, Woods Hole, 28 June 2017

Talk outline

- Introduction to zooplankton stoichiometry
- Zooplankton and ocean C sequestration
- Mesopelagic zooplankton: a stoichiometric analysis
- Microbial gardening
- Conclusions

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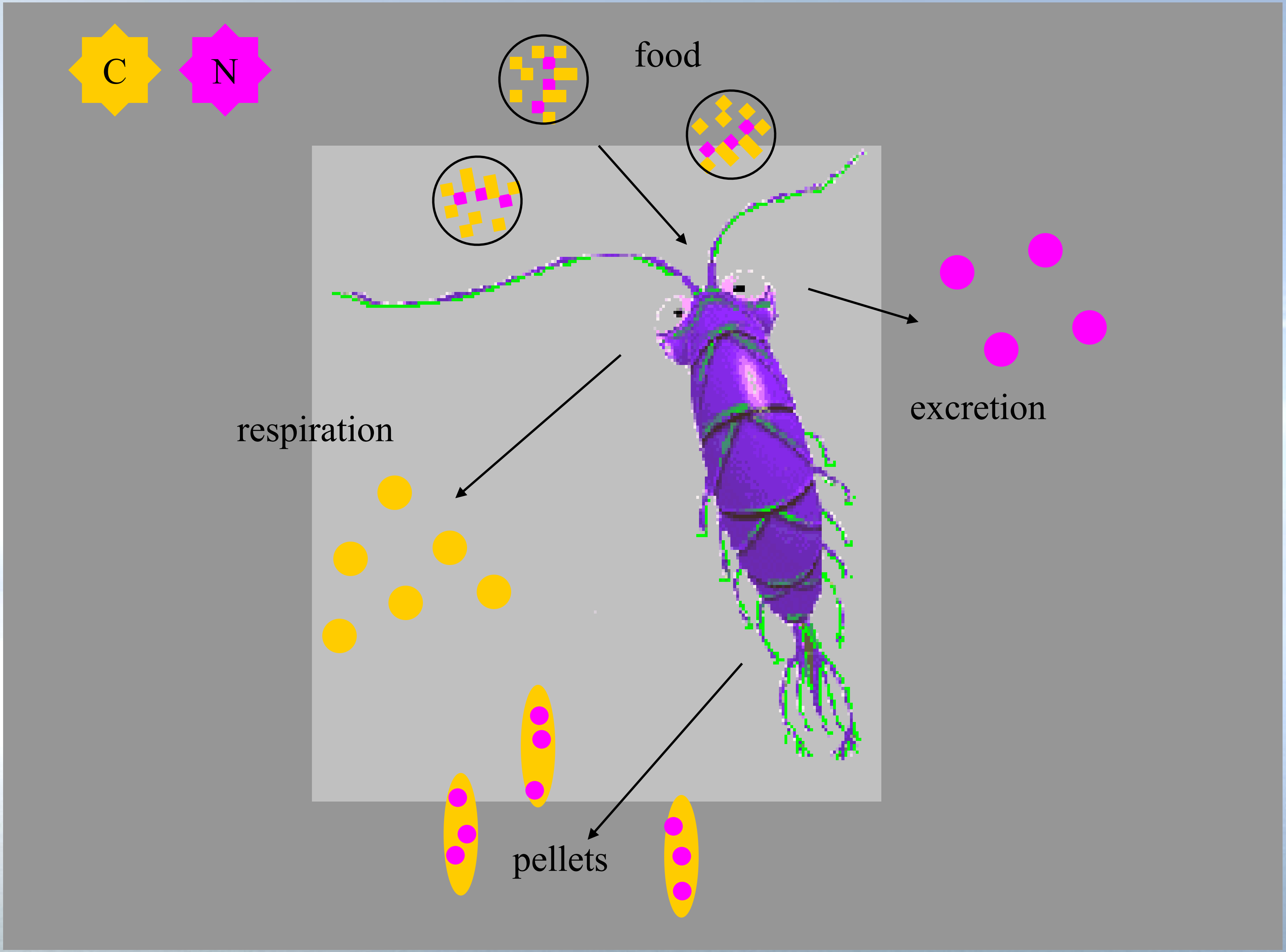

C
N
food
respiration
excretion
pellets

C:N = 5.5

growth

C	N	C

C:N = 5.5

maintenance

C	N	C

C:N = 5.5

C:N = 5.5

growth 

C	N	C

C:N = 5.5

maintenance 

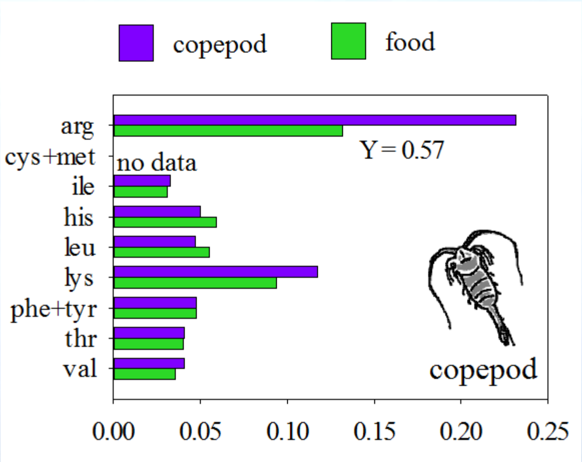
C	N	C	+	C

C:N = 5.5

biomass

maintenance

lability



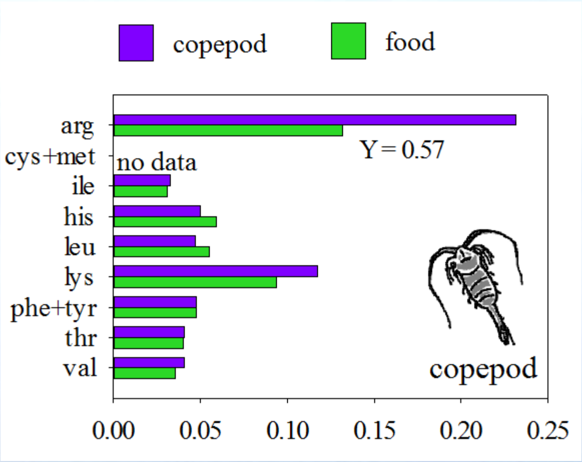
micronutrients

food quantity

biomass

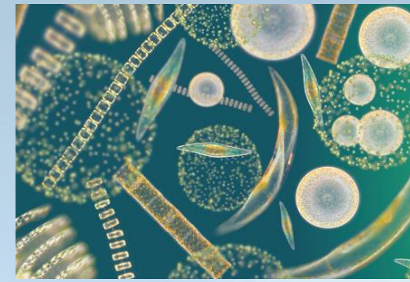
maintenance

lability



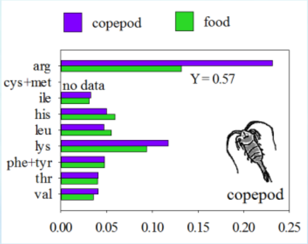
micronutrients

food quantity



C:N = 5.5

C:N = 8.0



Threshold Elemental Ratio (TER)

excess C or N has to be disposed of

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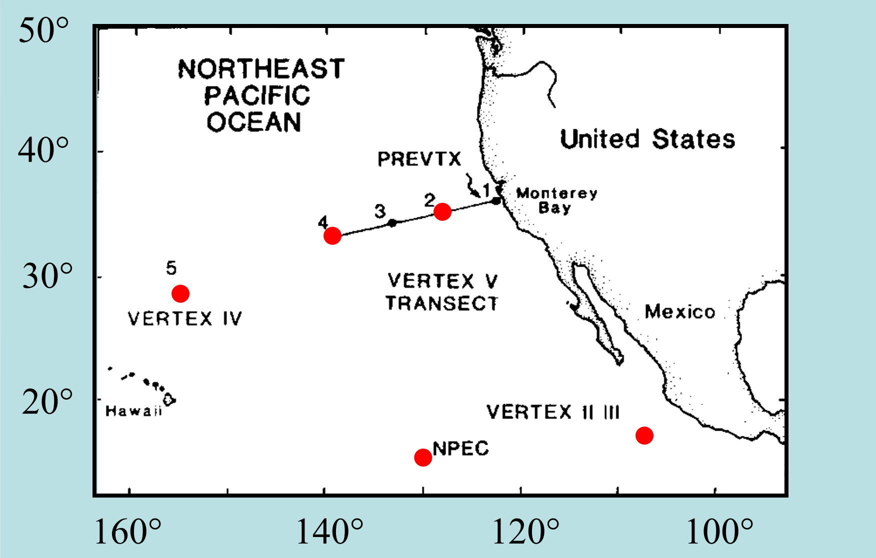
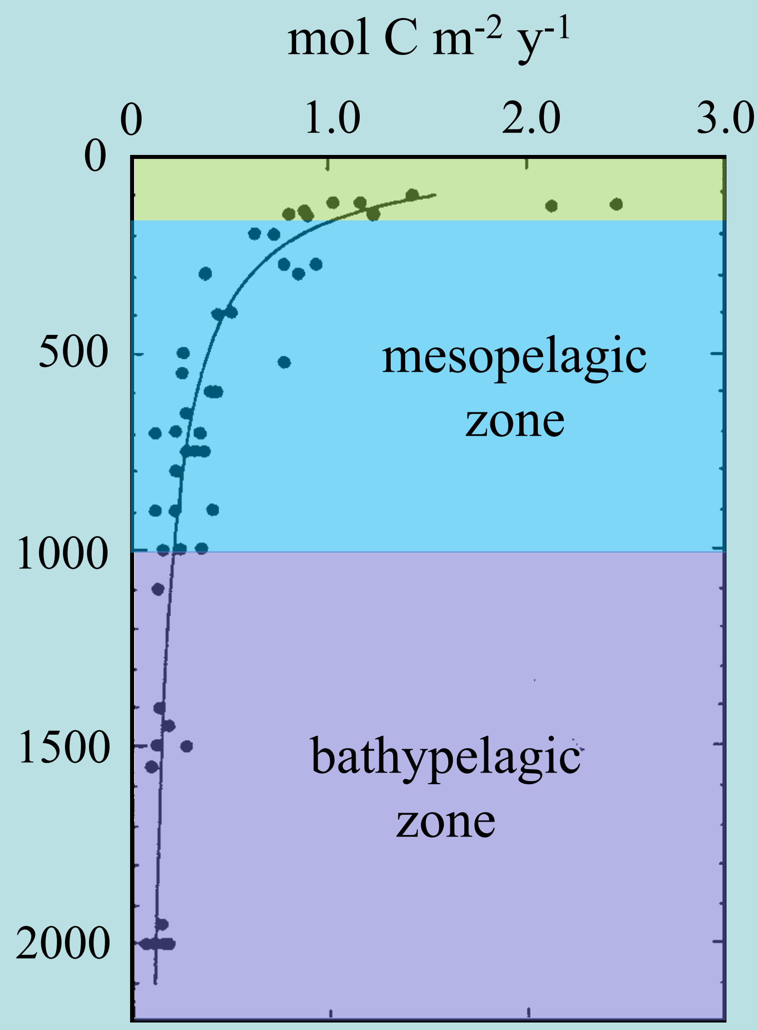
VERTEX: C cycling in the NE Pacific





$$F_Z = 1.53 F_{100} \left(\frac{z}{100}\right)^{-0.858}$$

(Martin et al. 1987: Deep-Sea Res 34, 267-285)

A balanced budget for the twilight (mesopelagic) zone

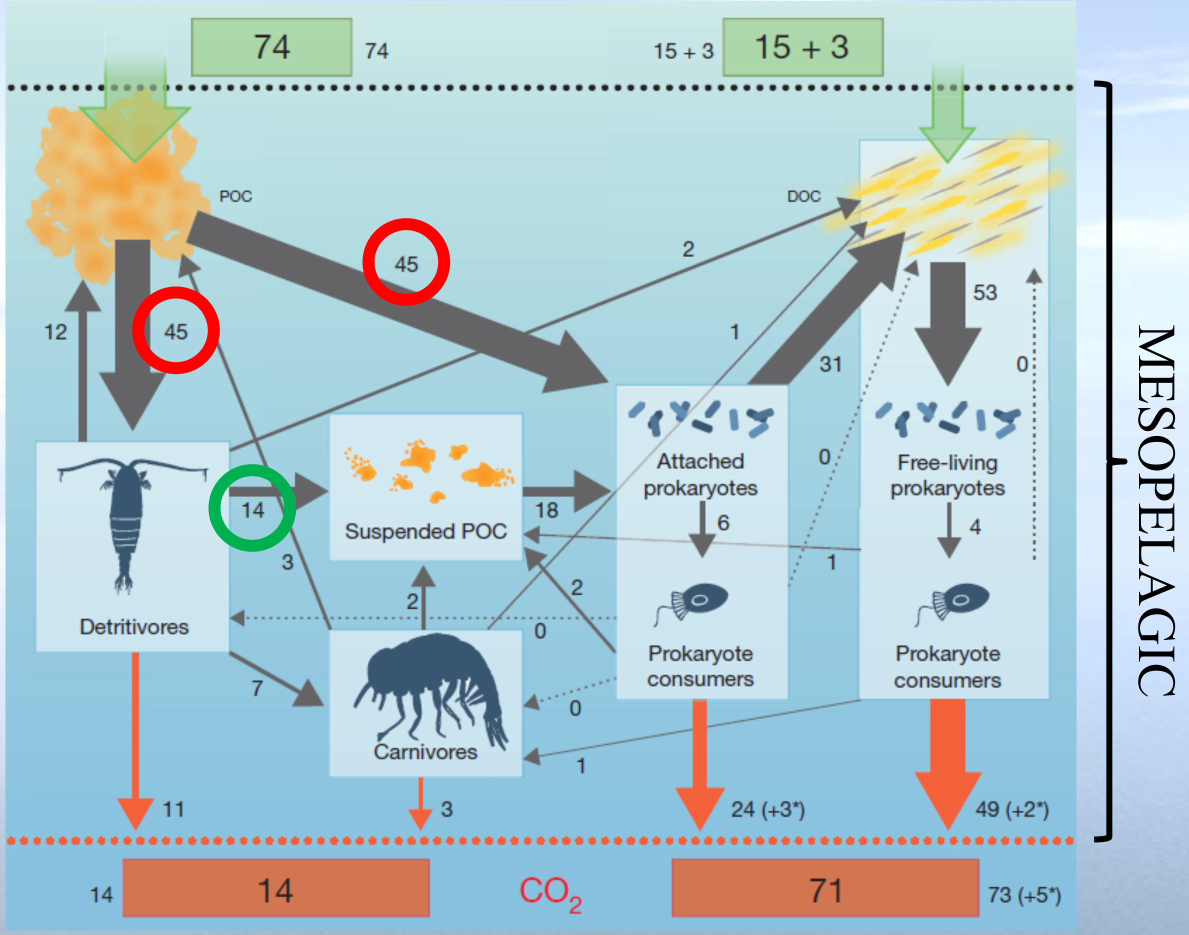
Reconciliation of the carbon budget in the ocean's twilight zone

doi:10.1038/nature13123

Giering et al., 2014

50% of sinking POC is processed by detritivorous zooplankton, remainder by prokaryotes

>30% of POC encountered by zooplankton is fragmented to smaller particles that fuel prokaryotic production



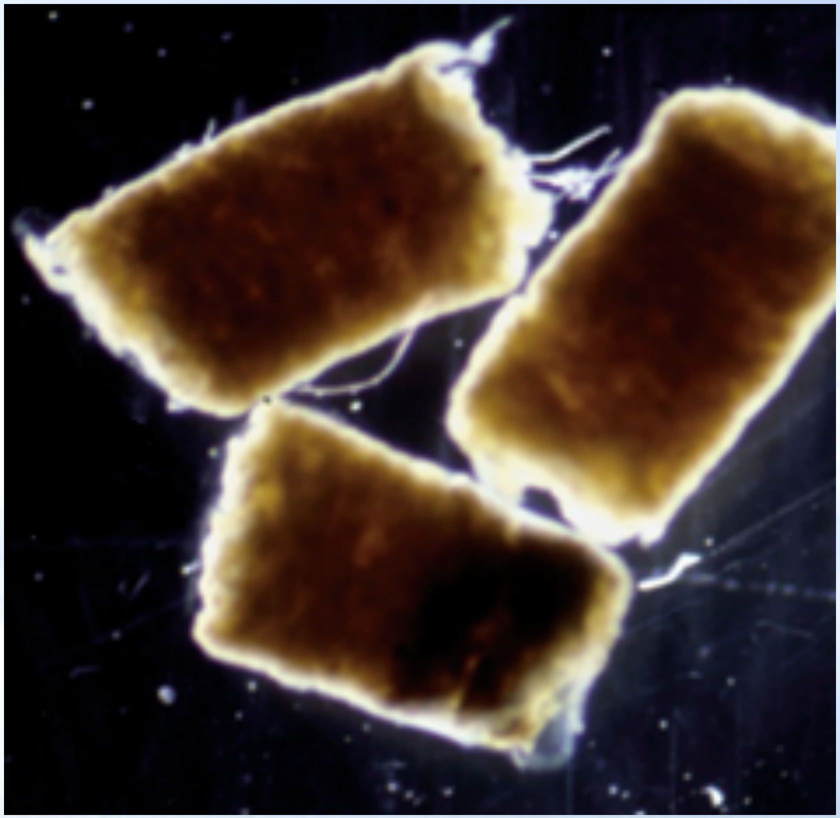
Steady state model analysis, units = mg C m^{-2} d^{-1}

photo: Debbie Steinberg

photo: Debbie Steinberg




Peanut butter – cracker hypothesis




17.52 µm


17.52 µm

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frontiers in Microbiology

ORIGINAL RESEARCH
published: 04 January 2017
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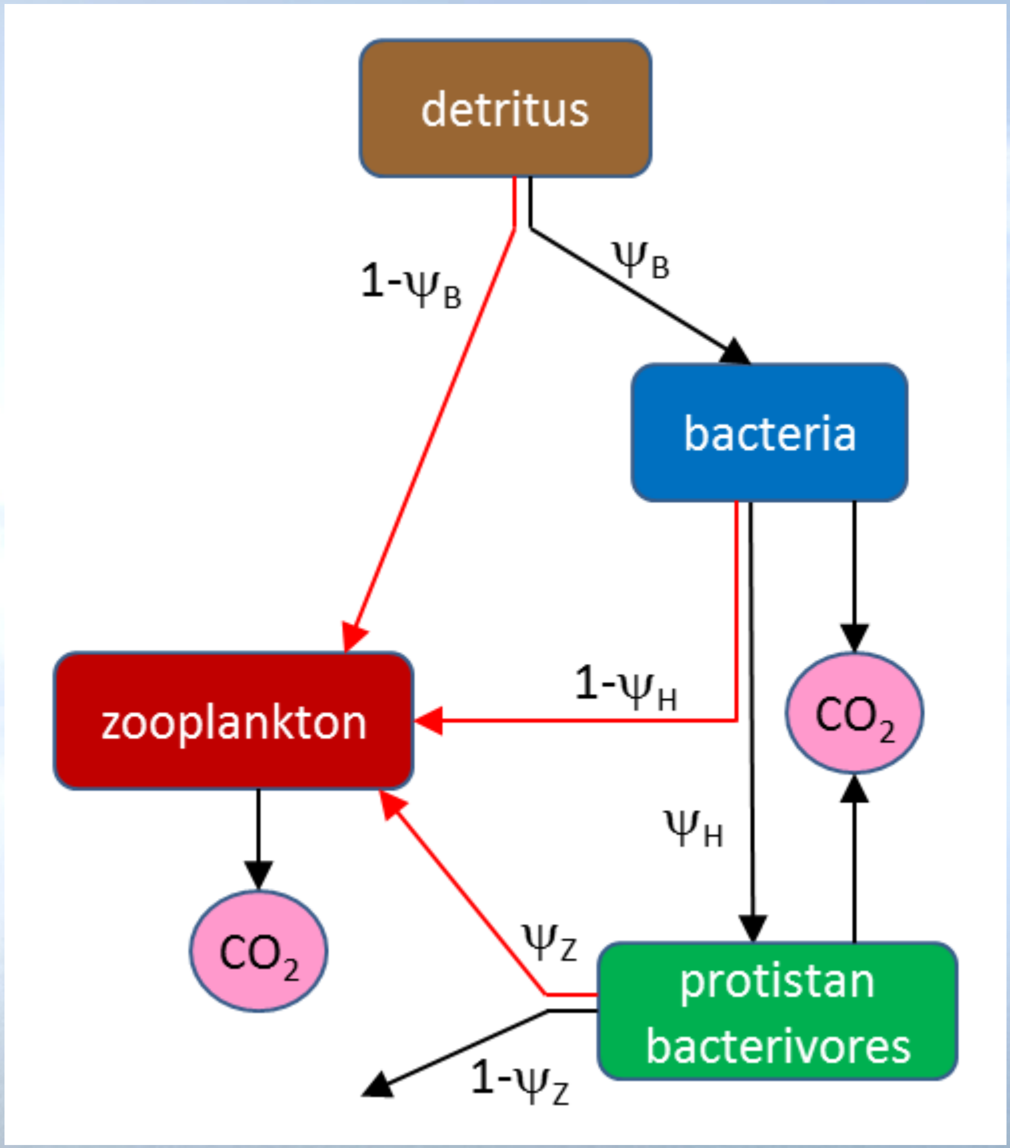
Check for updates

The Role of Microbes in the Nutrition of Detritivorous Invertebrates: A Stoichiometric Analysis

Thomas R. Anderson[1]*, David W. Pond[2] and Daniel J. Mayor[1]*

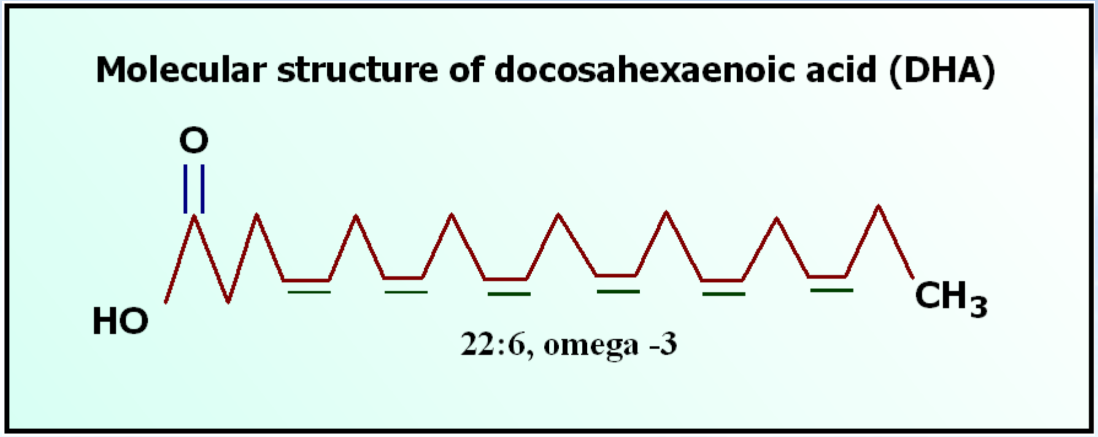
[1] National Oceanography Centre, Southampton, UK, [2] Scottish Association for Marine Science, Natural Environment Research Council, Oban, UK

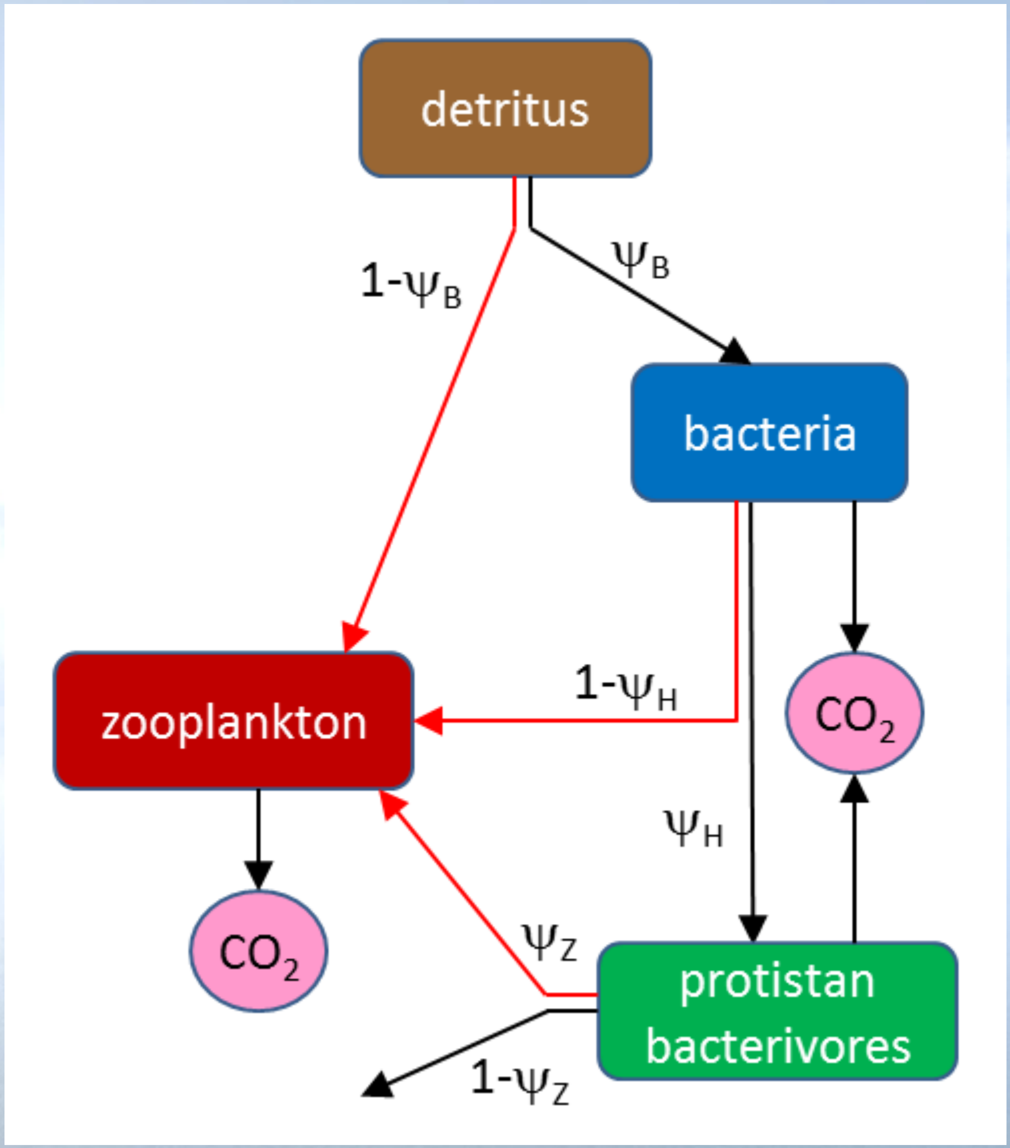
Frontiers in Microbiology 7 (2017), art. 2113



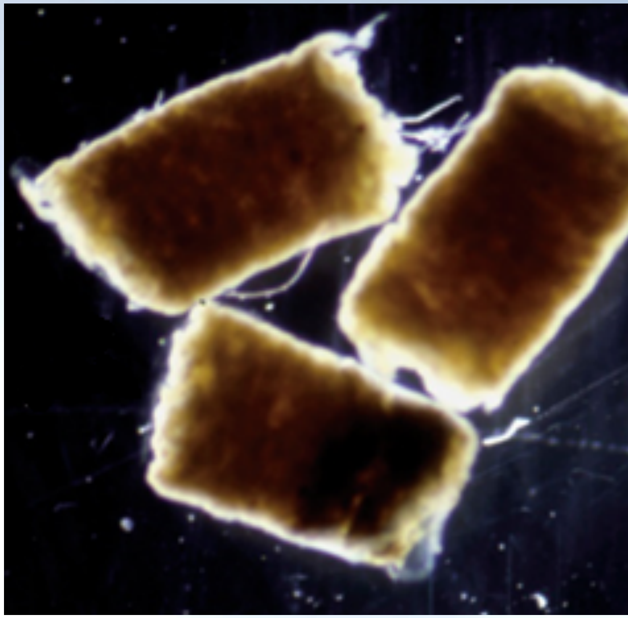
detritus
1-ψB
ψB
bacteria
zooplankton
1-ψH
CO2
ψH
CO2
ψZ
protistan bacterivores
1-ψZ

Model currencies: C and DHA





detritus
1-ψB
ψB
bacteria
zooplankton
1-ψH
CO2
ψH
CO2
ψZ
protistan bacterivores
1-ψZ



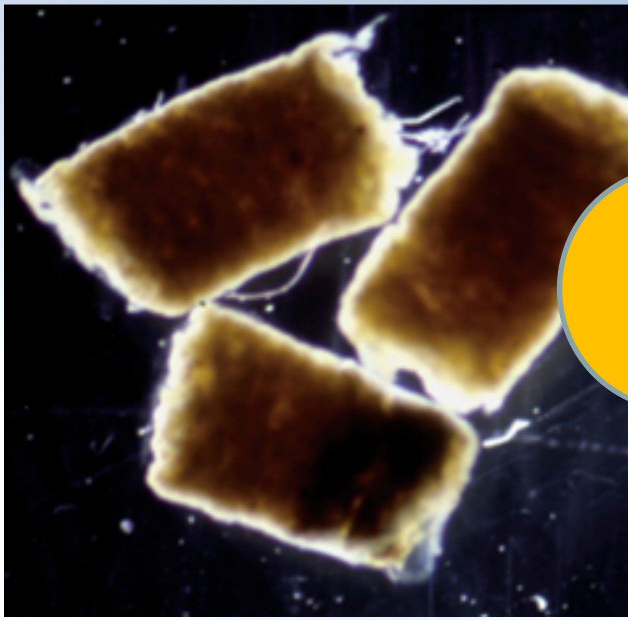
high in C, low in DHA

DHA:C = 0.21 mmol mol^{-1}

high in DHA, low in C

DHA:C = 1.40 mmol mol^{-1}

DHA:C = 1.76 mmol mol^{-1}



AE
0.1

AE
0.72

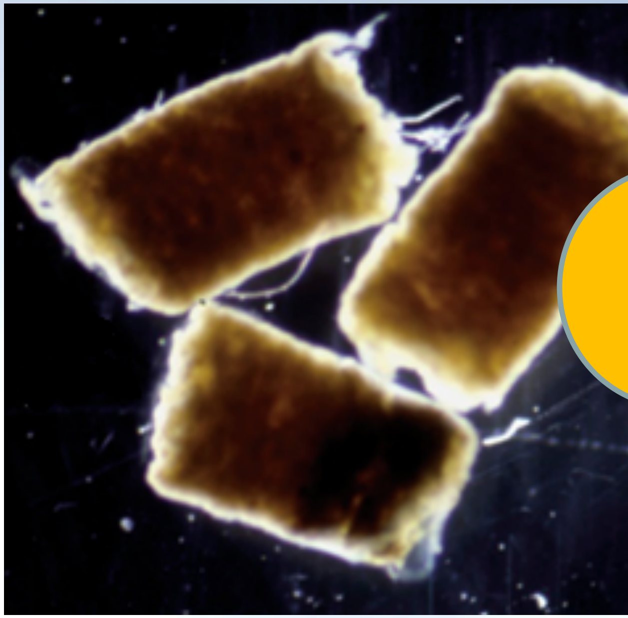
high in DHA, low in C

DHA:C = 1.40 mmol mol^{-1}

high in C, low in DHA

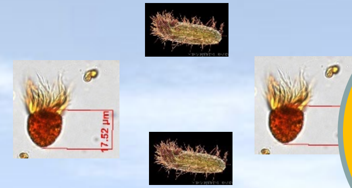
DHA:C = 0.21 mmol mol^{-1}

DHA:C = 1.76 mmol mol^{-1}



AE
0.1

BGE
0.12



AE
0.72

high in DHA, low in C

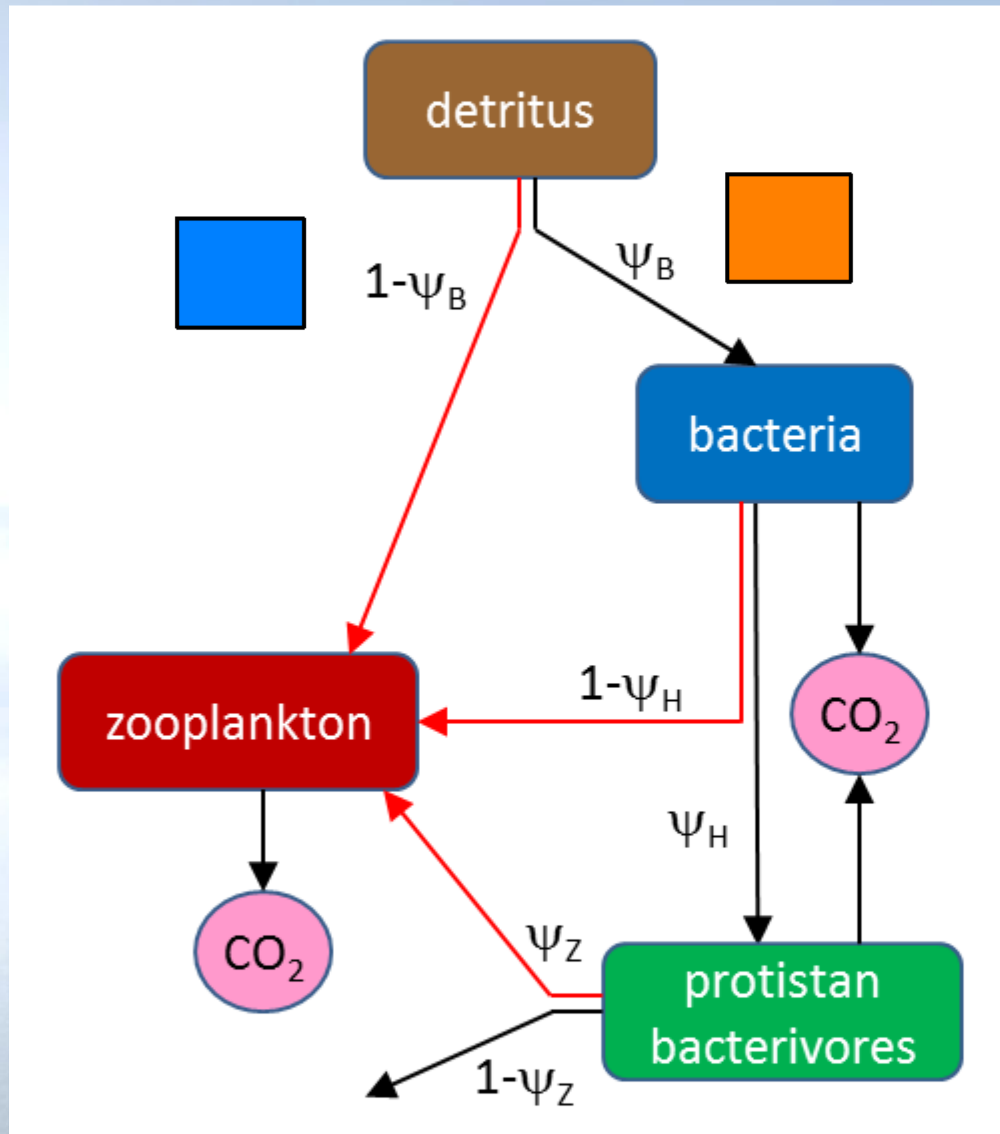
DHA:C = 1.40 mmol mol^{-1}

high in C, low in DHA

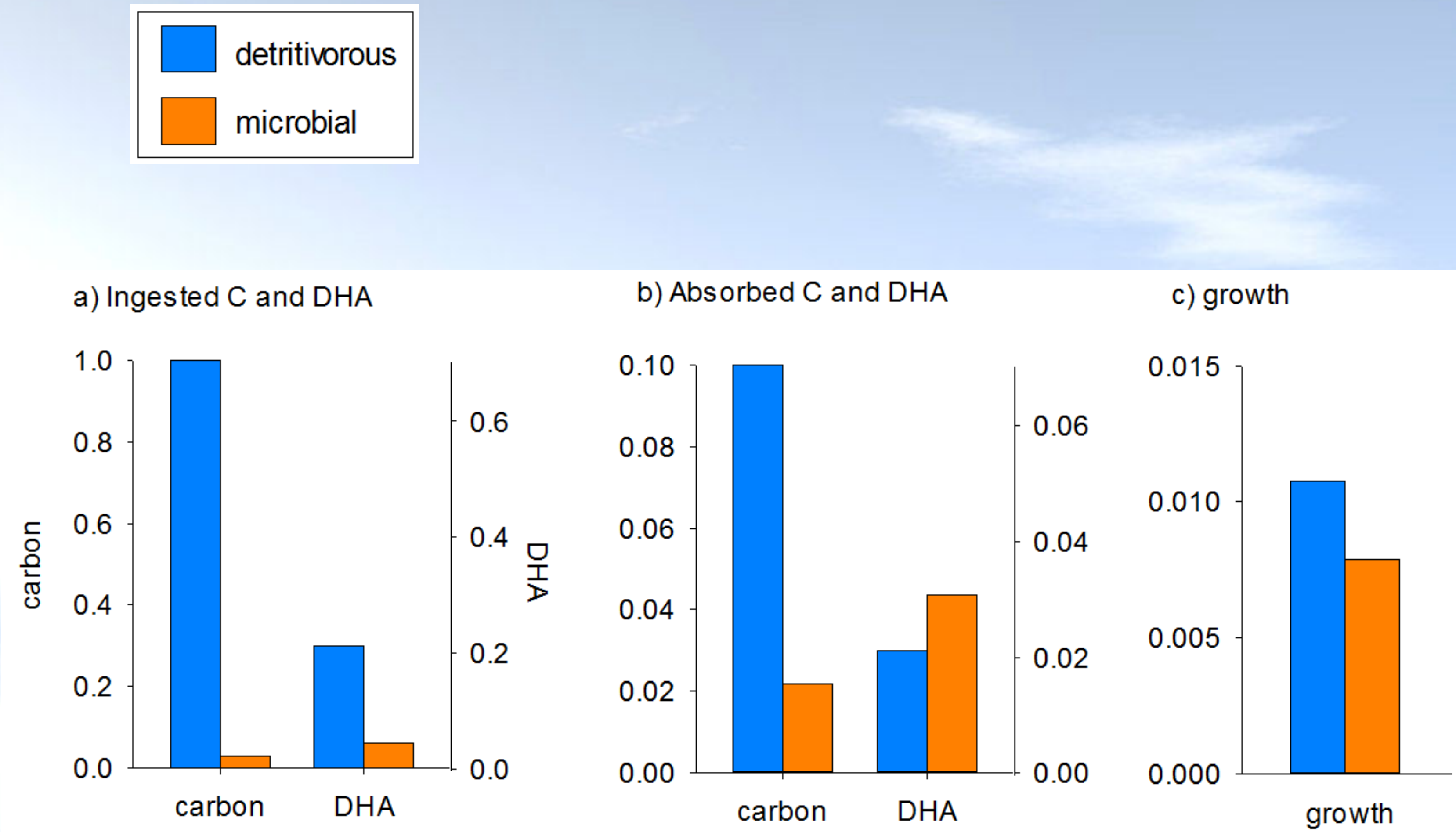
DHA:C = 0.21 mmol mol^{-1}

DHA:C = 1.76 mmol mol^{-1}

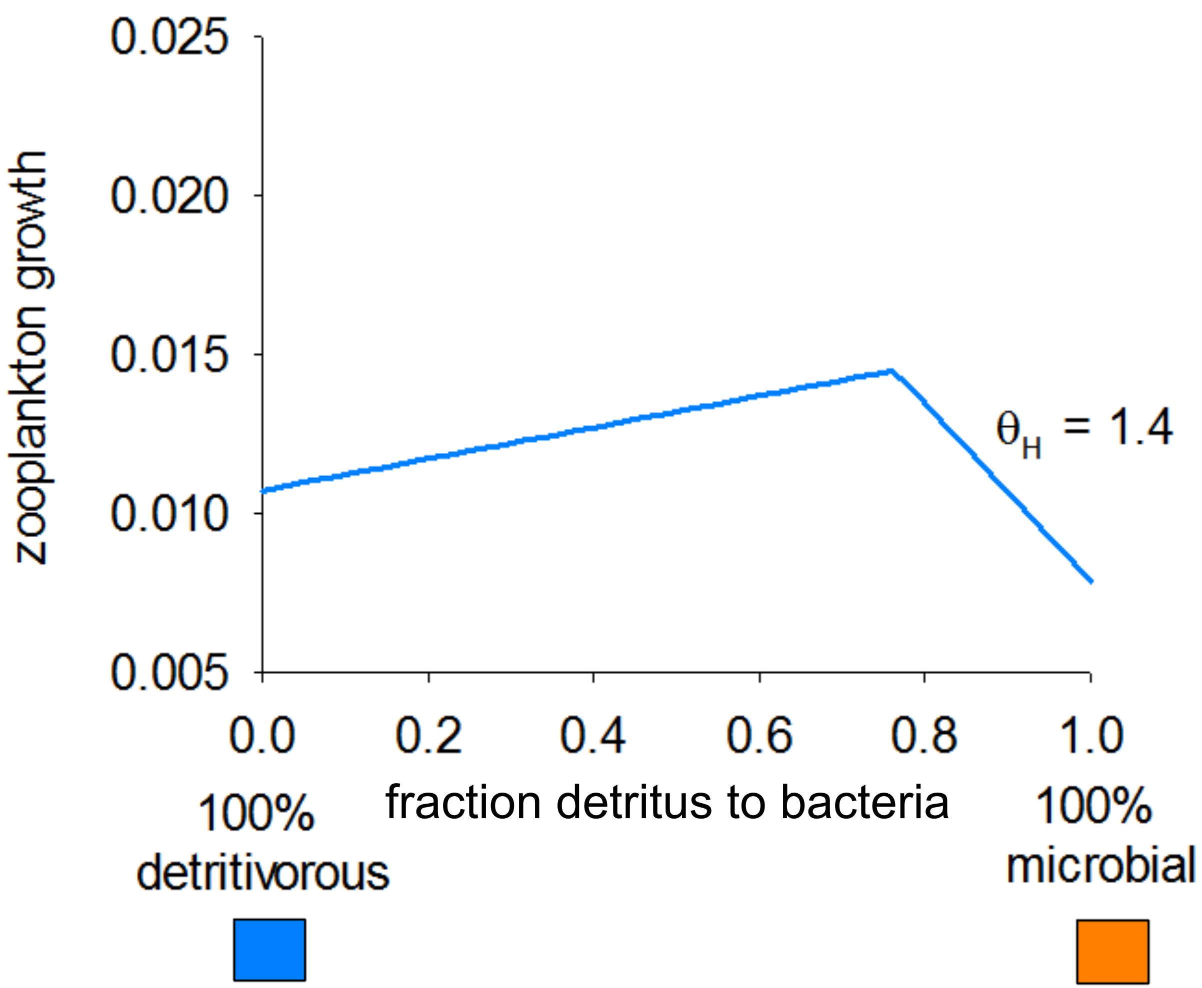
detritivorous pathway
$\psi_B = 0$

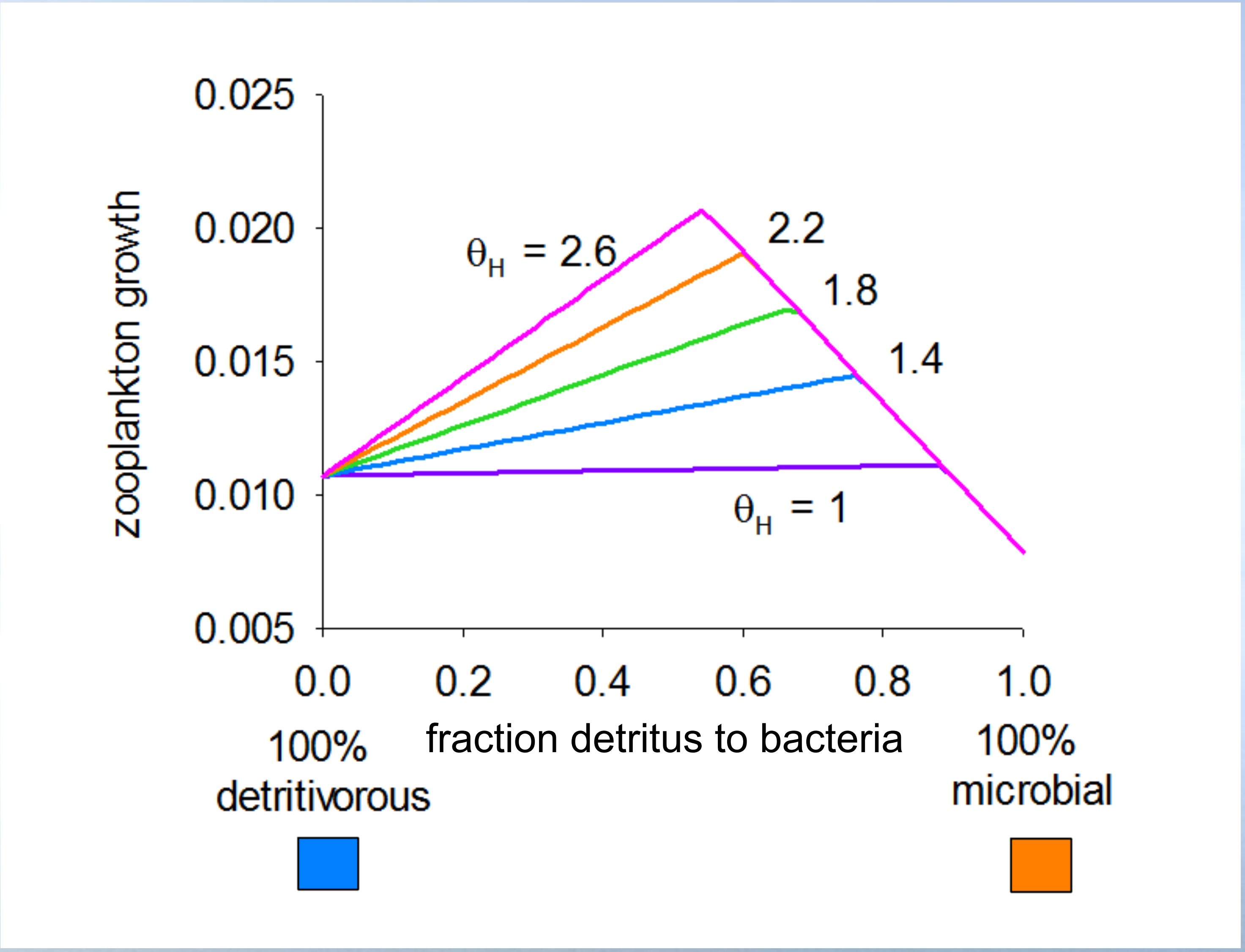


microbial pathway
$\psi_B = 1$



detritivorous
microbial
a) Ingested C and DHA
carbon
DHA
1.0
0.8
0.6
0.4
0.2
0.0
0.6
0.4
0.2
0.0
carbon
DHA
b) Absorbed C and DHA
0.10
0.08
0.06
0.04
0.02
0.00
0.06
0.04
0.02
0.00
carbon
DHA
c) growth
0.015
0.010
0.005
0.000
growth


0.025
0.020
0.015
0.010
0.005
zooplankton growth
0.0
0.2
0.4
0.6
0.8
1.0
fraction detritus to bacteria
θ_H = 1.4
100%
detritivorous
100%
microbial



0.025
0.020
0.015
0.010
0.005
zooplankton growth
θ_H = 2.6
2.2
1.8
1.4
θ_H = 1
0.0
0.2
0.4
0.6
0.8
1.0
fraction detritus to bacteria
100% detritivorous
100% microbial

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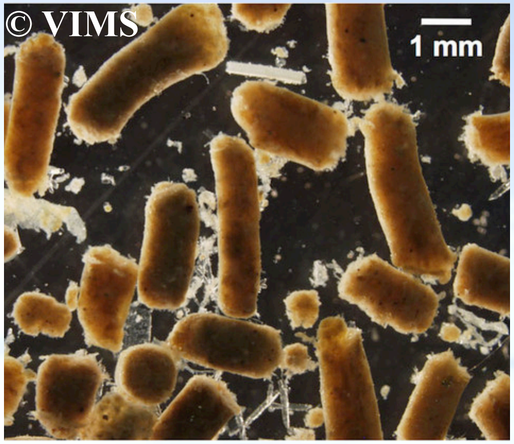
Why are detritivorous zooplankton so wasteful in a food-poor environment?



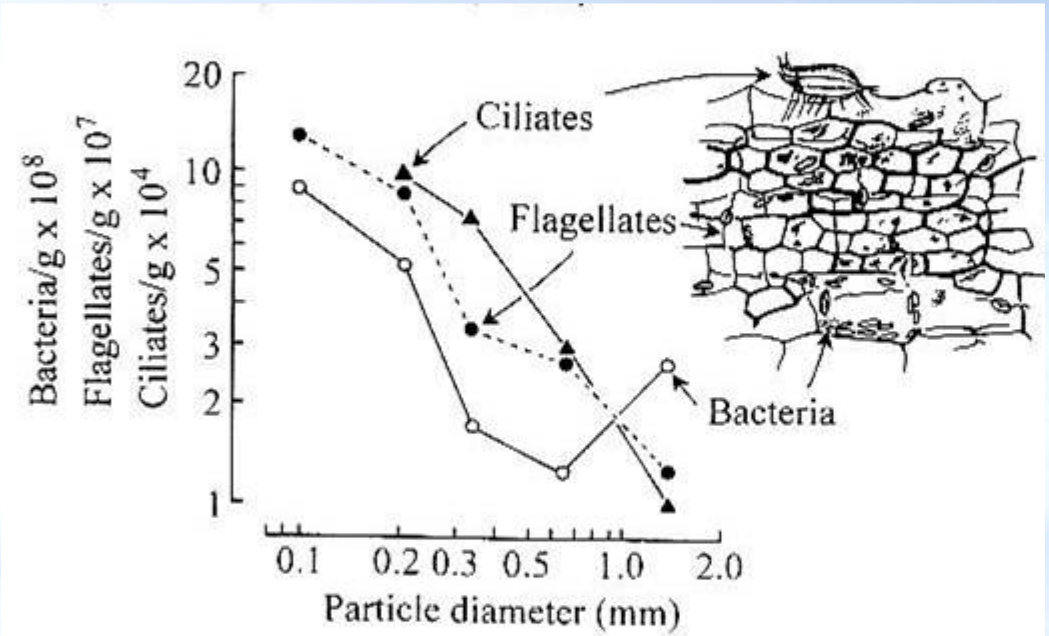
Faecal pellets – large, fast-sinking POC

Oithona sp., a typical mesopelagic detritivore

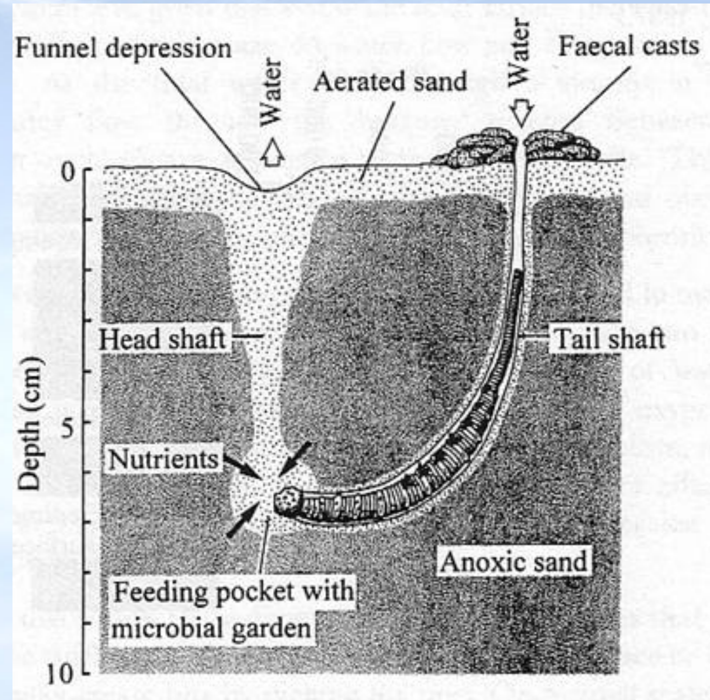
Are the sinking particles simply too big?

Or is sinking detritus not really their food after all?

Fragmentation may increase the lability and nutritional content of sinking POC



Fenchel, 1970

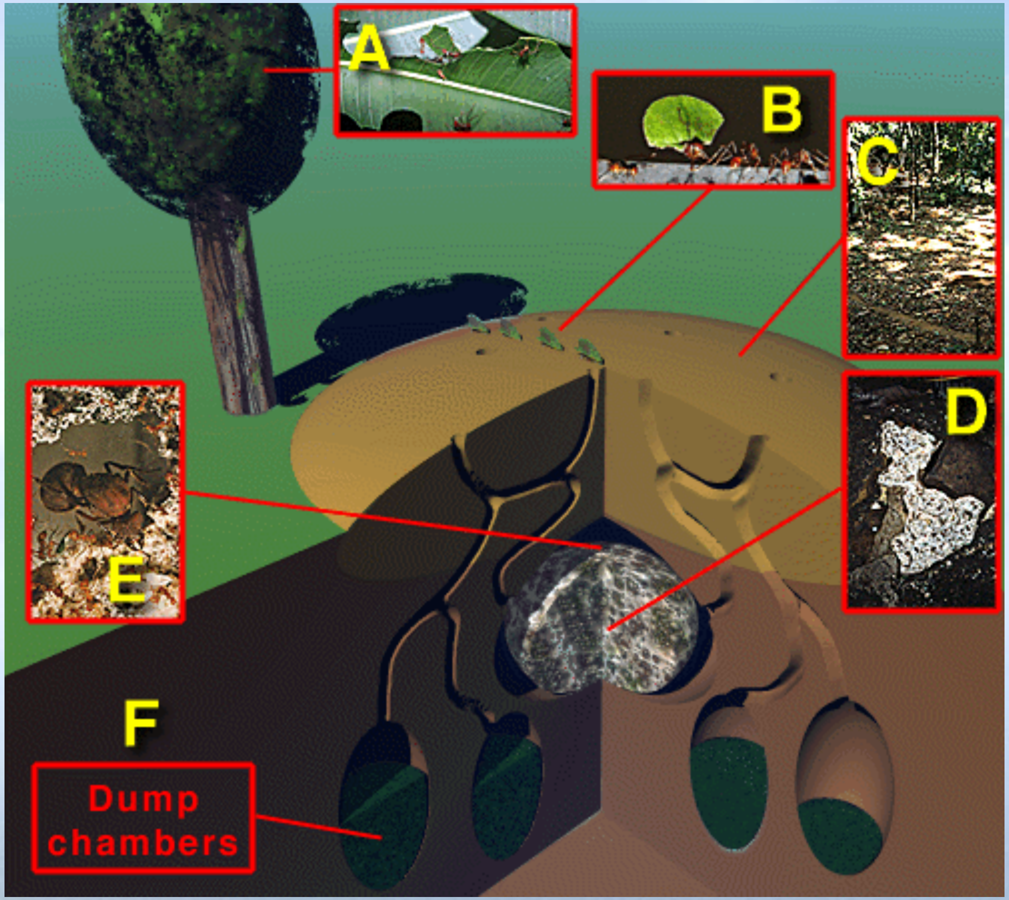


Hylleberg, 1975

Intertidal ‘detritivores’ fragment detritus to stimulate the proliferation of nutritious microbial biomass: **‘microbial gardening’**

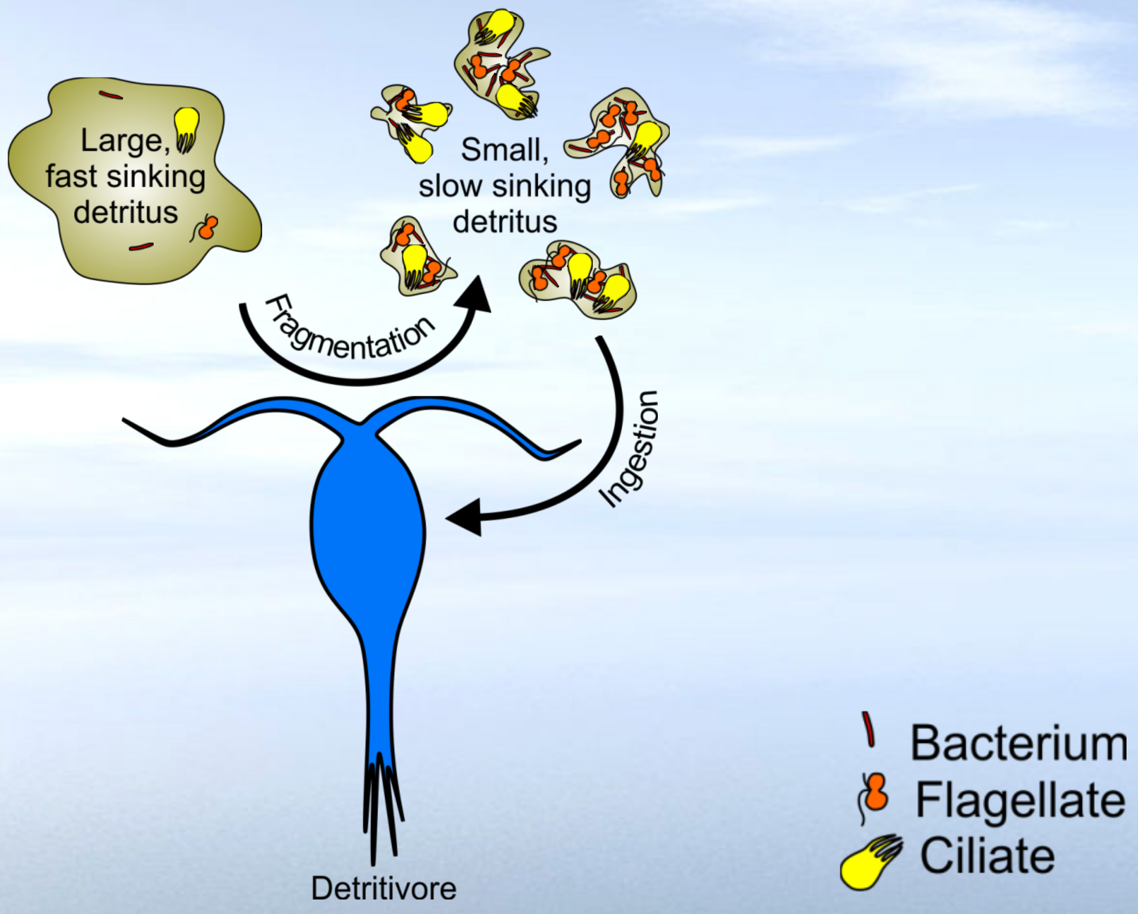
Plant fragments are ingested, but only microbes are digested

Leaf cutter ants



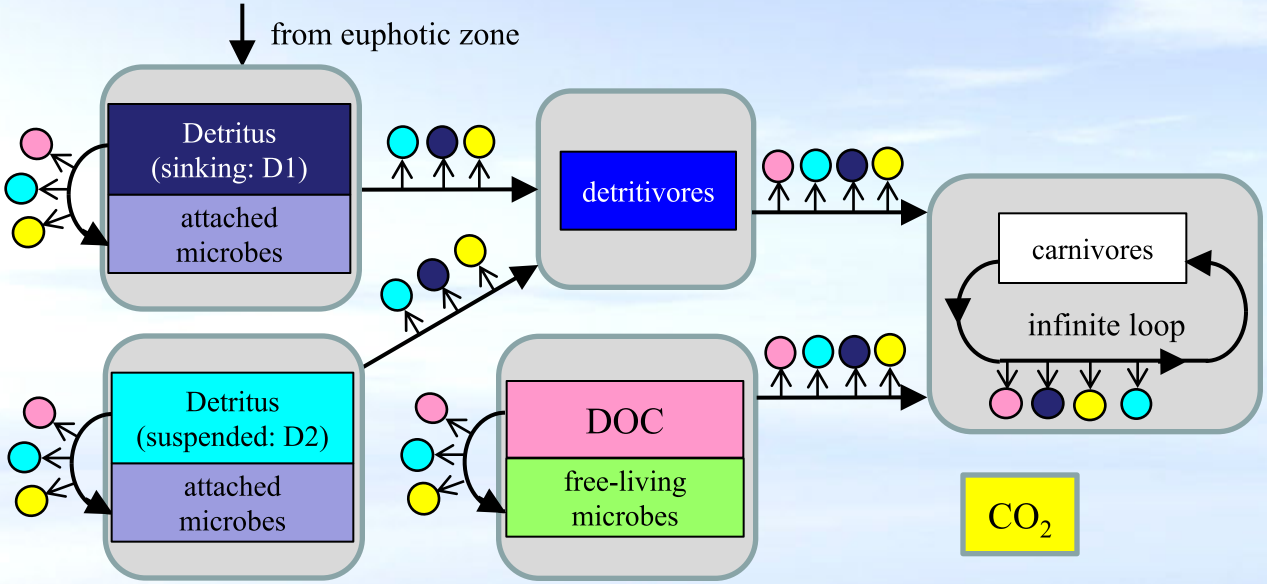
http://bioold.science.ku.dk/drnash/atta/pages/leafcut.html

Microbial gardening in the twilight zone?



Mayor et al. (2014)

Mesopelagic zone model



Mayor et al. (2014)

Large detritus

low accessibility to microbes

detritivore AE = 0.1

Small detritus

high accessibility to microbes

detritivore AE = 0.5

BGE = 0.12

Large detritus

low accessibility to microbes

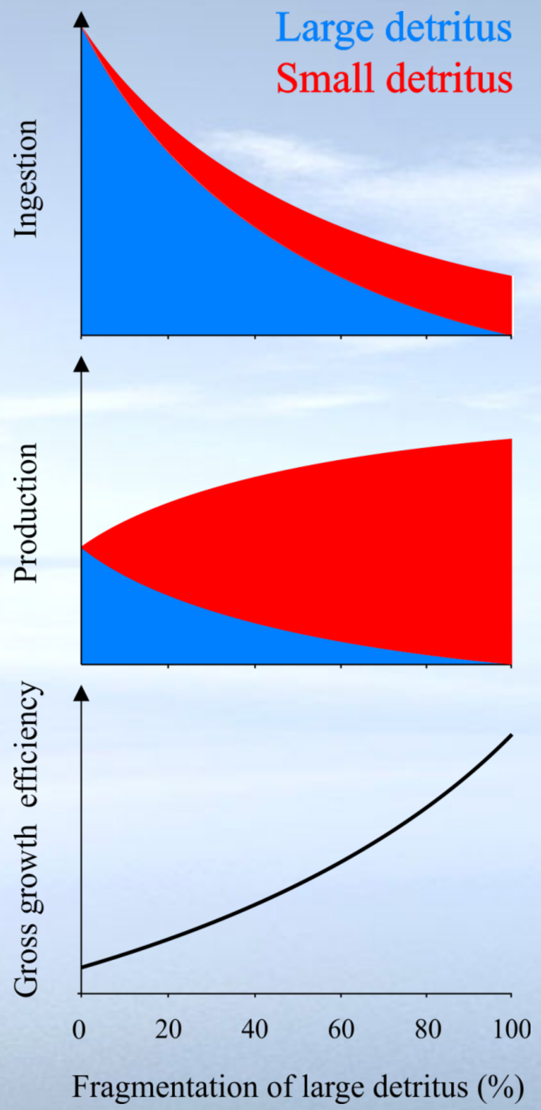
detritivore AE = 0.1

Small detritus

high accessibility to microbes

detritivore AE = 0.5

BGE = 0.12



Insights & Perspectives

Ideas & Speculations

Microbial gardening in the ocean's twilight zone: Detritivorous metazoans benefit from fragmenting, rather than ingesting, sinking detritus

Fragmentation of refractory detritus by zooplankton beneath the euphotic zone stimulates the harvestable production of labile and nutritious microbial biomass

Daniel J. Mayor[1)], Richard Sanders[2)], Sarah L. C. Giering[1)] and Thomas R. Anderson[2)]*

BioEssays 36 (2014), 1132-1137

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Conclusions

- Optimal diet (TER) depends on requirements for growth and maintenance, food quantity and quality (absorptive properties)
- Detritivorous zooplankton may obtain their nutrition from microbes associated with detritus, rather than the non-living substrate
- Zooplankton may fragment particles as a means of "microbial gardening", i.e., to promote growth of microbes
- The extent to which zooplankton ingested versus fragment detritus influences detritus sinking rate and carbon sequestration
- There are many uncertainties in the stoichiometry of detrital ecosystems. We need to know far more about the physiology and ecology of mesopelagic organisms and their interaction with detritus