# The Redfield or "RKR" Equation (A Model)

The mean elemental ratio of marine organic particles is given as:

P : N : C = 1 : 16 : 106

- The average ocean photosynthesis (forward) and aerobic ( $O_2$ ) respiration (reverse) is written as:

106 $CO_2$ + 16 $HNO_3$ + $H_3PO_4$ + 122 $H_2O$ + trace elements (*e.g. Fe, Zn, Mn…*) →

$(CH_2O)_{106}(NH_3)_{16}(H_3PO_4)$ + 138 $O_2$

- Reduction half reactions:

$$CO_2 + 4H^+ + 4e^- \rightarrow CH_2O + H_2O$$

$$NO_3^- + 9H^+ + 8e^- \rightarrow NH_3 + 3H_2O$$

- Oxidation half reaction:

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$$

- From plankton tows
- $O_2$ production was estimated theoretically, assuming 1 mol of $O_2$ released for every atom of carbon converted into biomass and 2 moles of $O_2$ for every atom of nitrogen.
- Assumes all OM is carbohydrates (and represents OM as an average "molecule")

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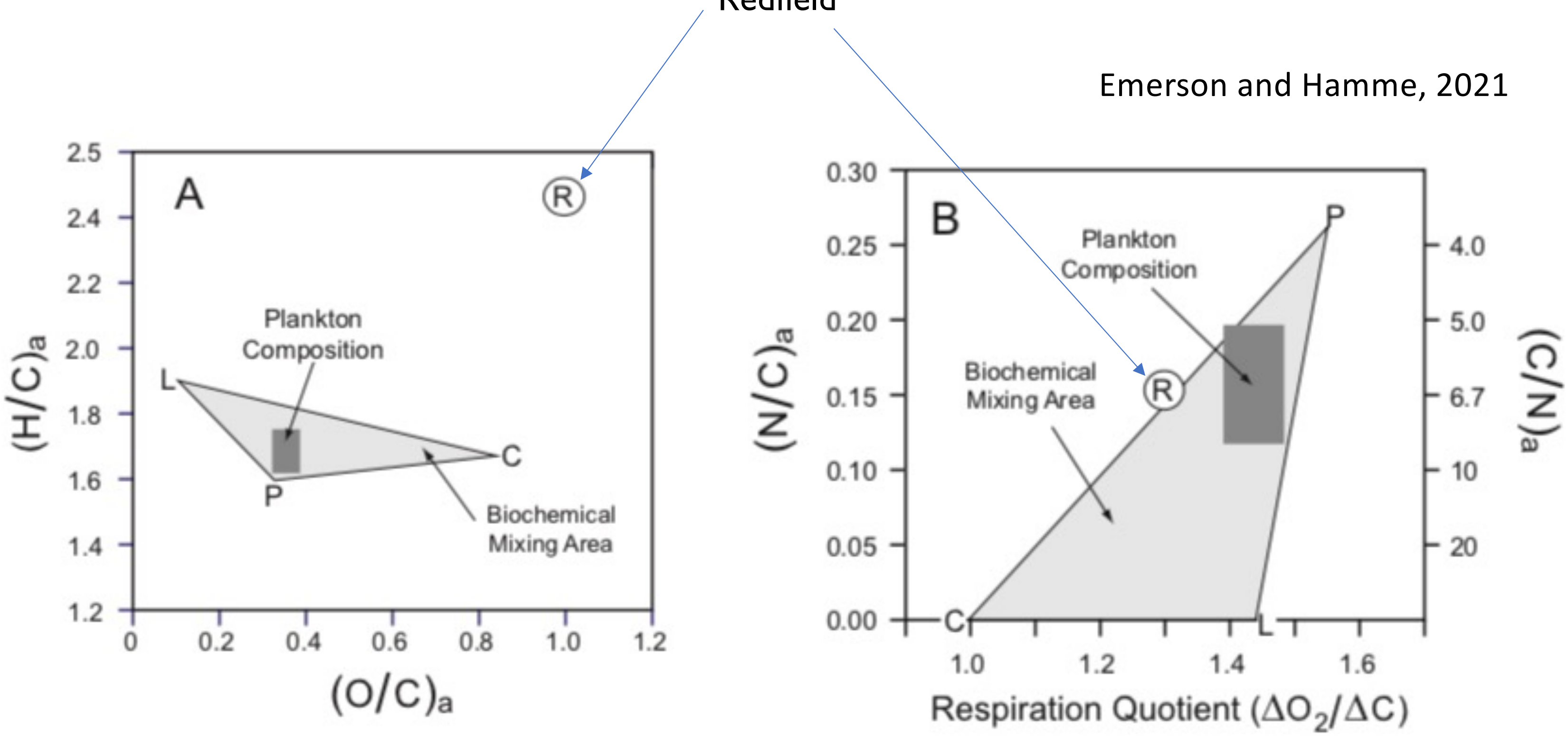
Actual ratios of C/N/P/O vary considerably

C – Carbohydrates
P – Proteins
L - Lipids

Redfield

Emerson and Hamme, 2021



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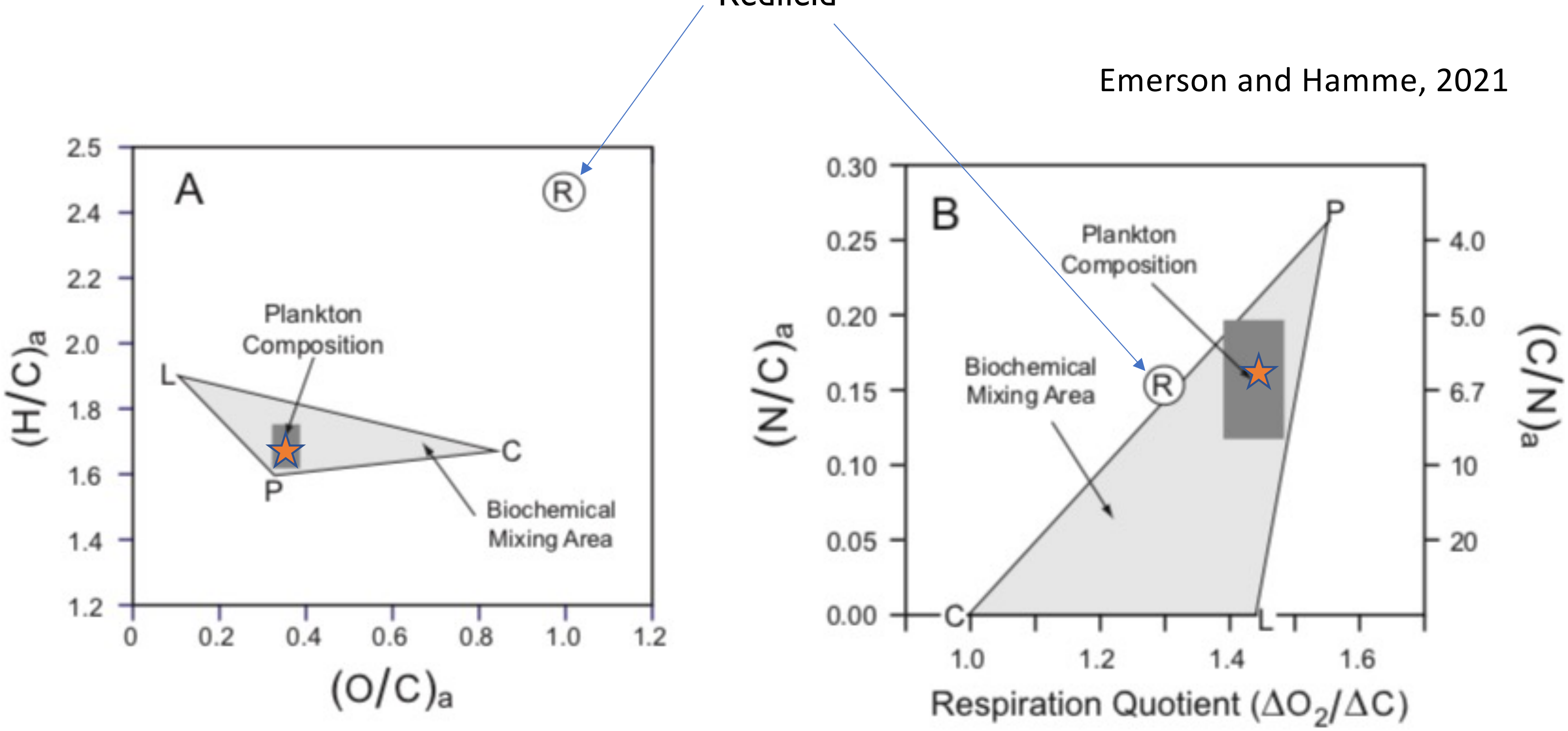



Modified RKR using actual stoichiometry of plankton:

$$106CO_2 + 16HNO_3 + H_3PO_4 + 80H_2O \rightarrow C_{106}H_{179}O_{38}N_{16}P\ (OM) + 153O_2$$

# Biological production: limitations

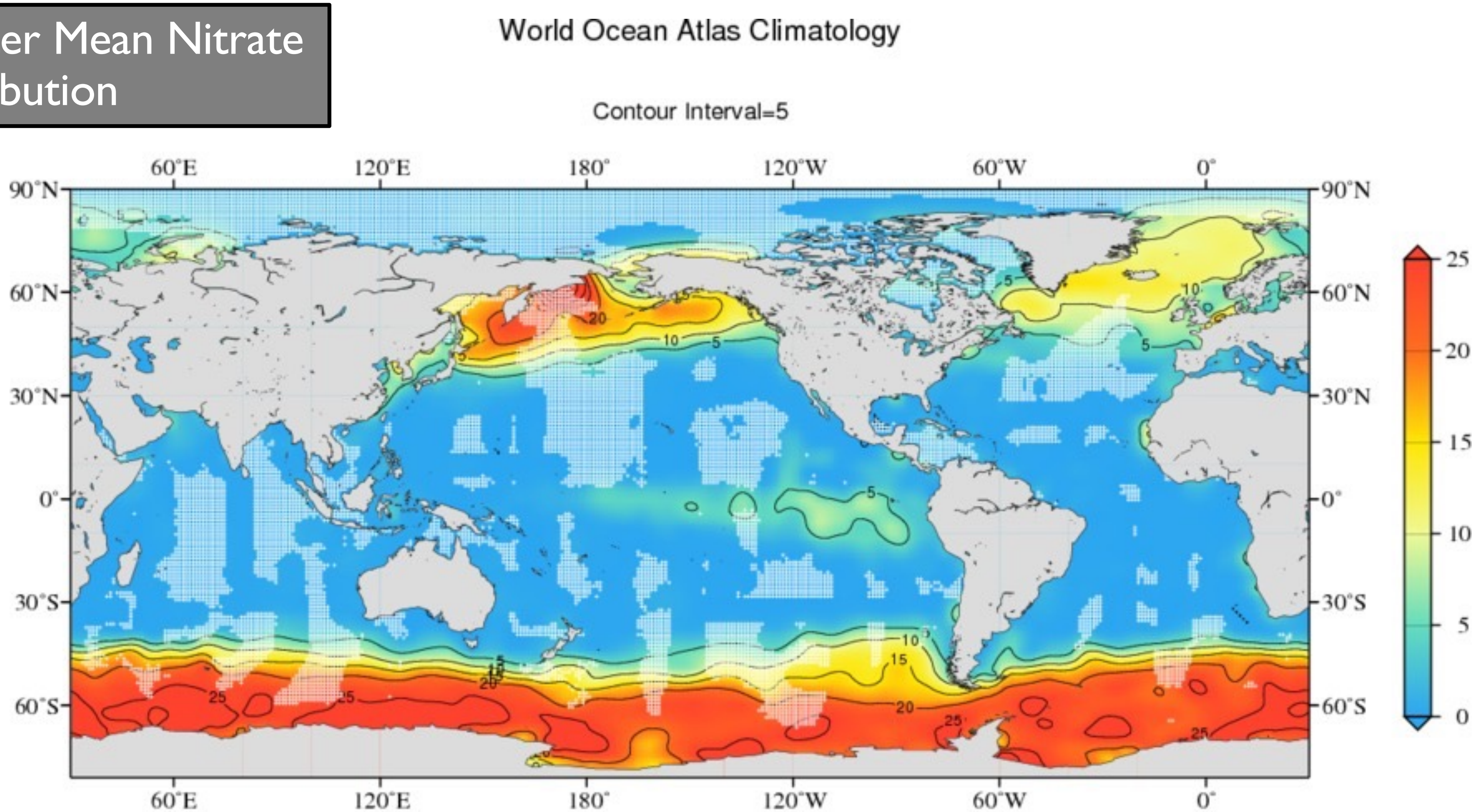
$$CO_2 + N + P + H_20 \underset{R}{\overset{P}{\rightleftharpoons}} \text{Organic matter} + O_2$$

"*inorganic nutrients*": N, P and Si

They are also called "*biolimiting elements*" -- Why?

1. Small reservoir size in oceans
2. Fast turnover time
3. Required for many kinds of biological activity

# Winter Mean Nitrate distribution




Winter (Jan.-Mar.) nitrate [umol/kg] at the surface (one-degree grid)

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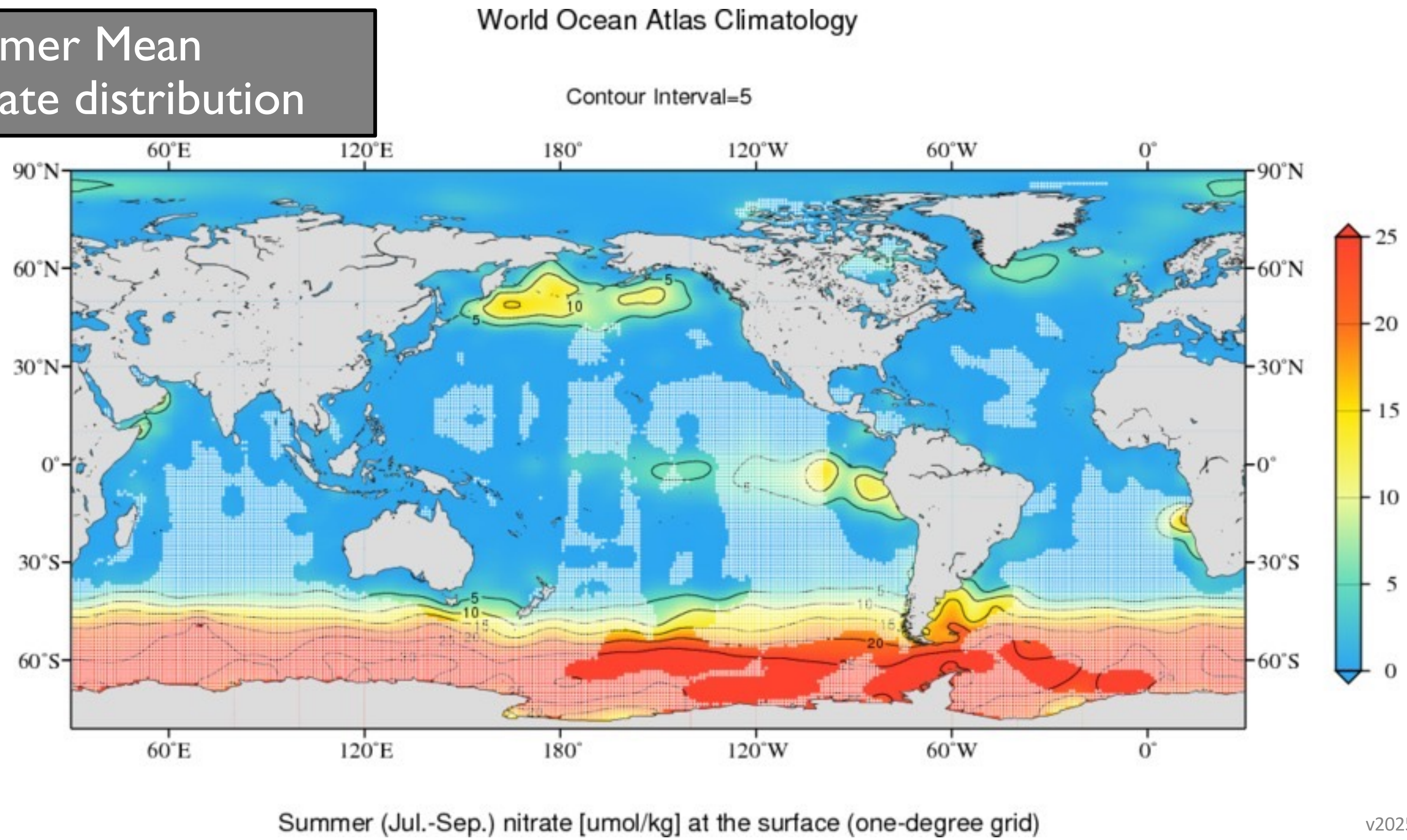
# Summer Mean Nitrate distribution



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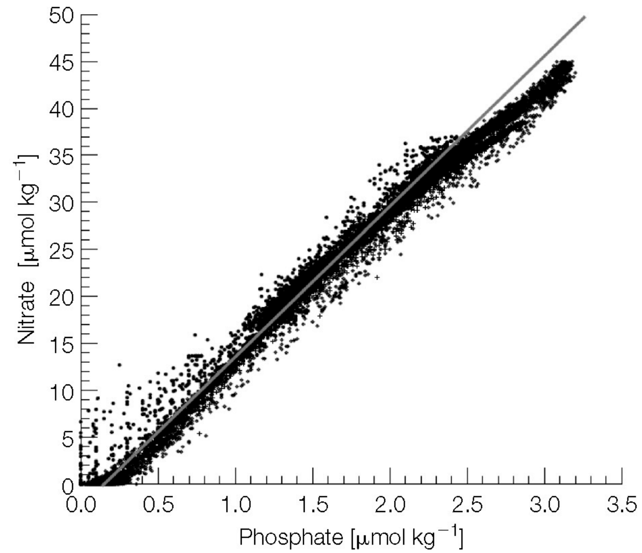
"*inorganic nutrients*": N, P and Si – macronutrient limitation

Global DIN:DIP



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Trace metal needs:

Fe (photosynthesis, uptake of $NH_4^+$, $N_2$ fixation)

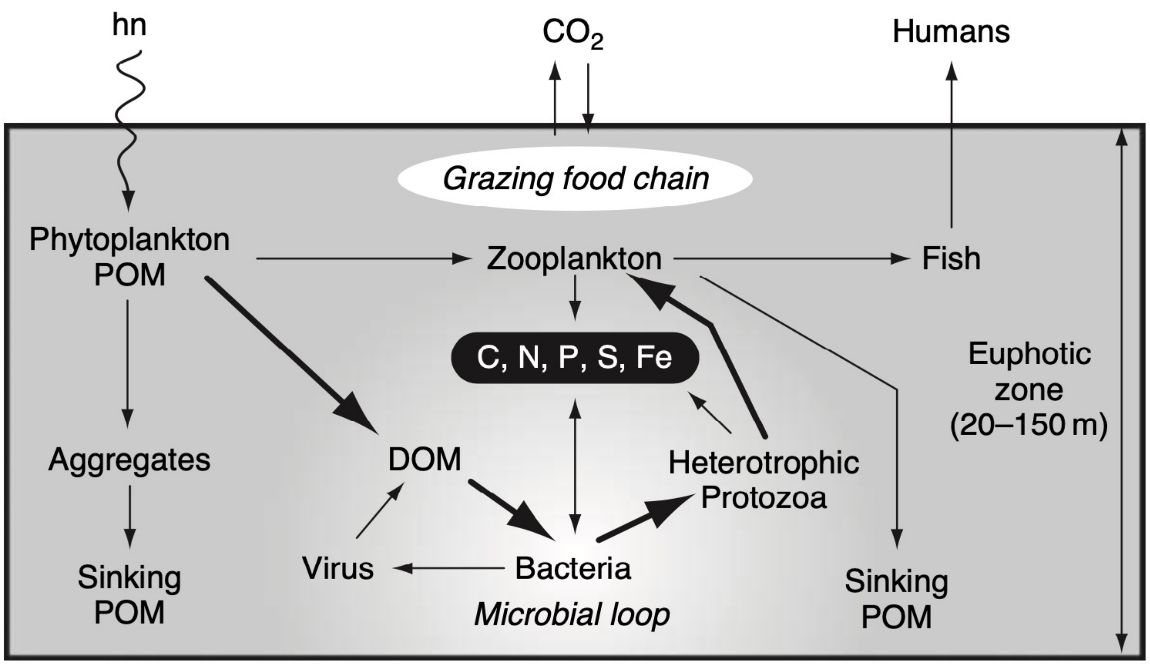
Mn (phtoynthesis)

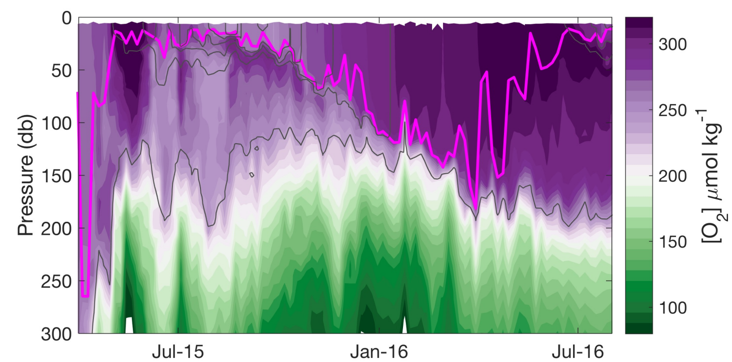
Zn (carbonic anhydrase, enzyme that catalyses $HCO_3^-$ to $CO_2$)

Cu, Co, Ni

Can be limiting: High-Nutrient, Low Chlorophyll regions (HNLC)

# What happens to that primary production?



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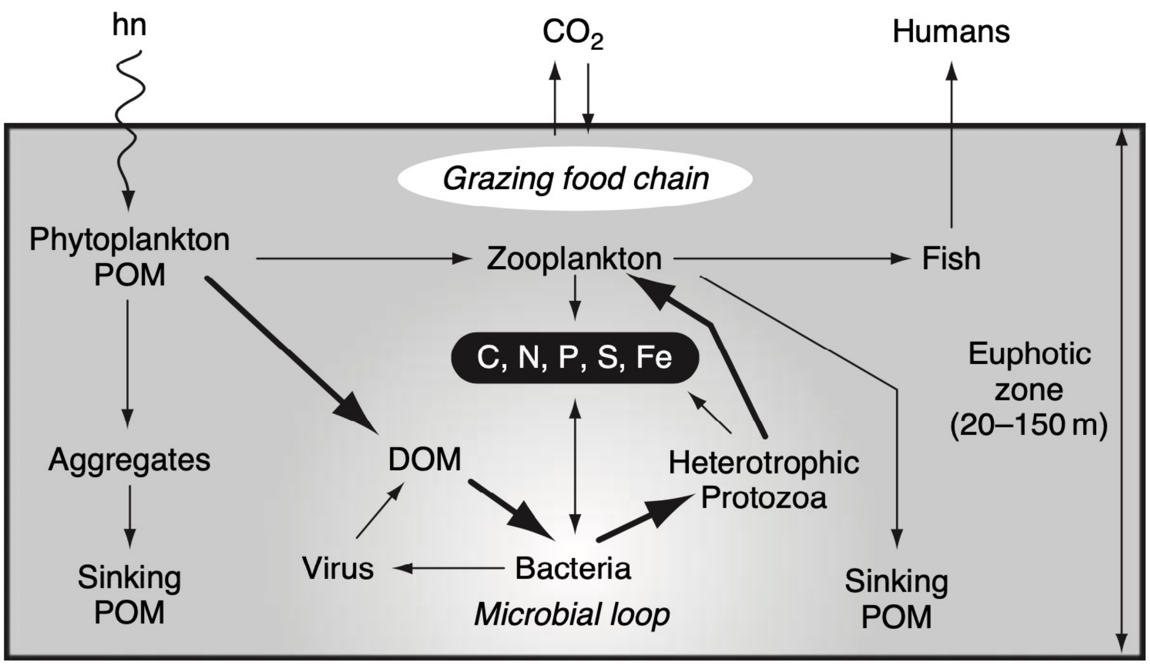
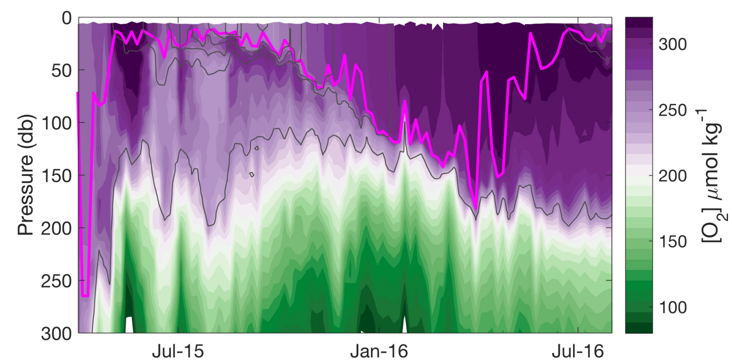
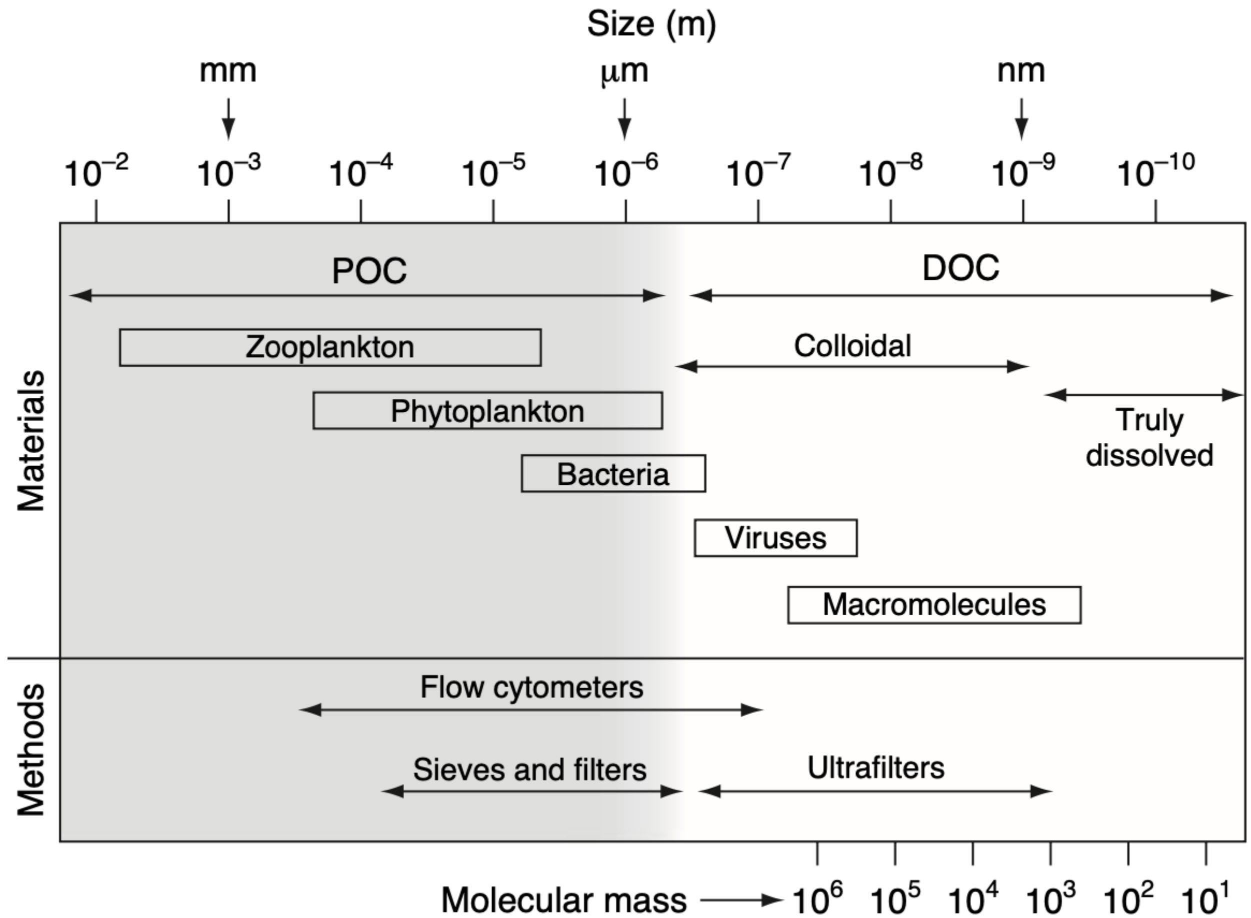



- **Primary production**: autotrophic production
- **Net primary production**: PP minus respiration by autotrophs
- **Net community production**: PP minus all respiration (auto and heterotrophic)
- **Annual net community production**: The amount of organic matter that is produced but is removed from contact with the upper ocean on time scales >1yr

# Dissolved vs. Particulate: Operational definition




Emerson and Hedges 2008

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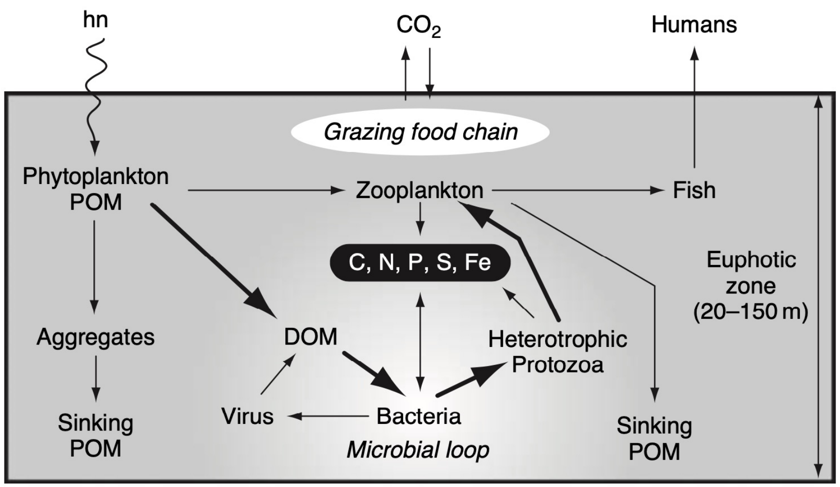
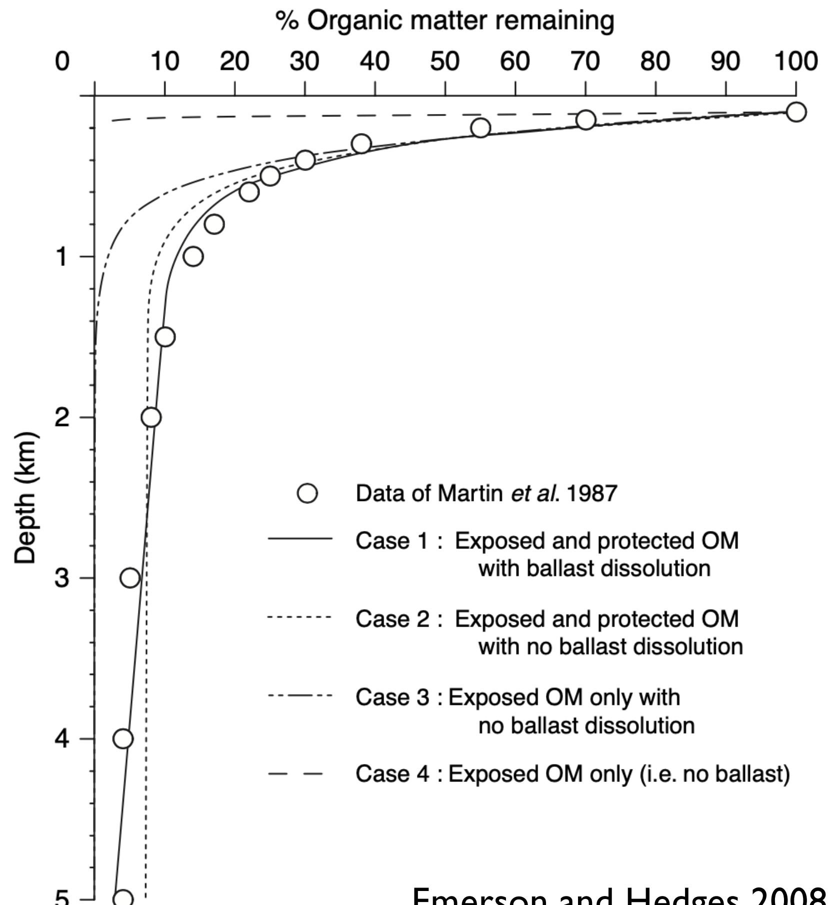
# The Martin Curve: How much OM sinks out of the upper ocean?




- Carbon leaving upper ocean is a mix of soft (OM) and hard parts (silica and calcium carbonate shells)
- ~6% of carbon leaving upper ocean is $CaCO_3$
- $SiO_2$ is often ~2x the $CaCO_3$
- Weights down OM, also can protect from grazing

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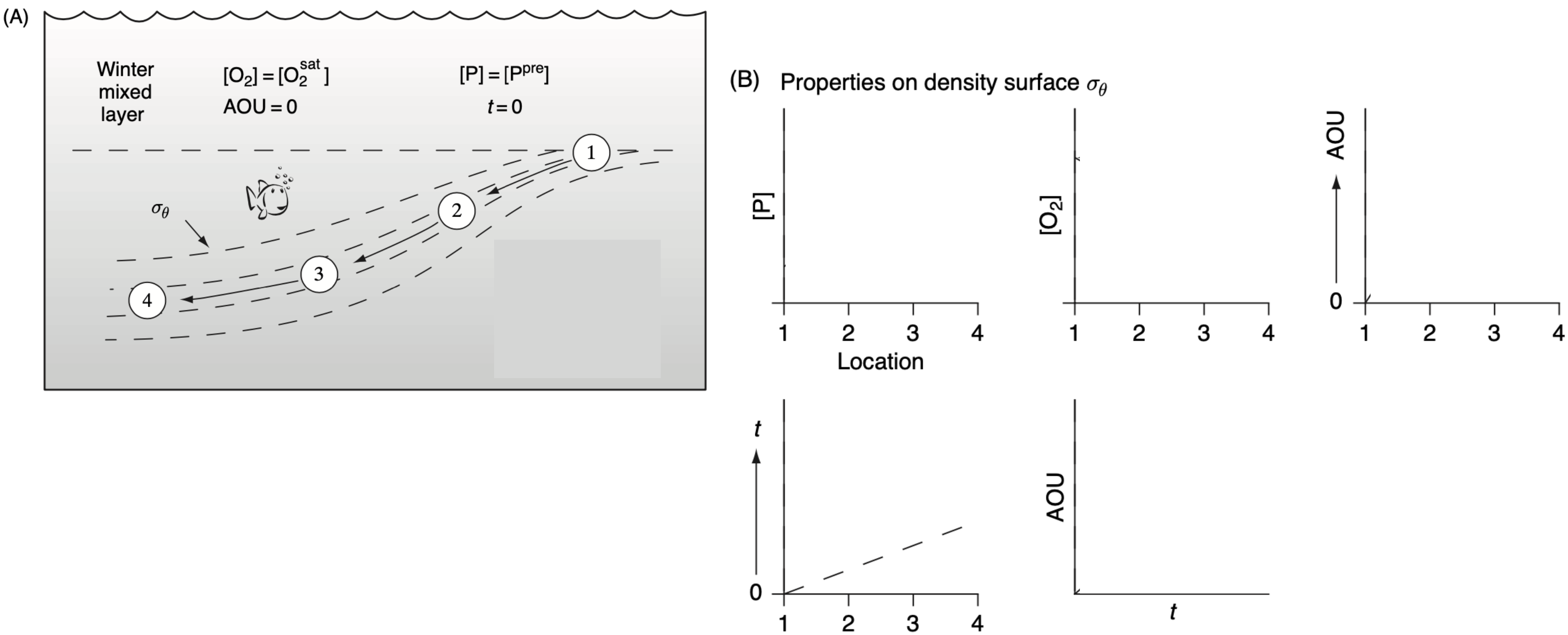
# Property evolution after a water parcel leaves the surface

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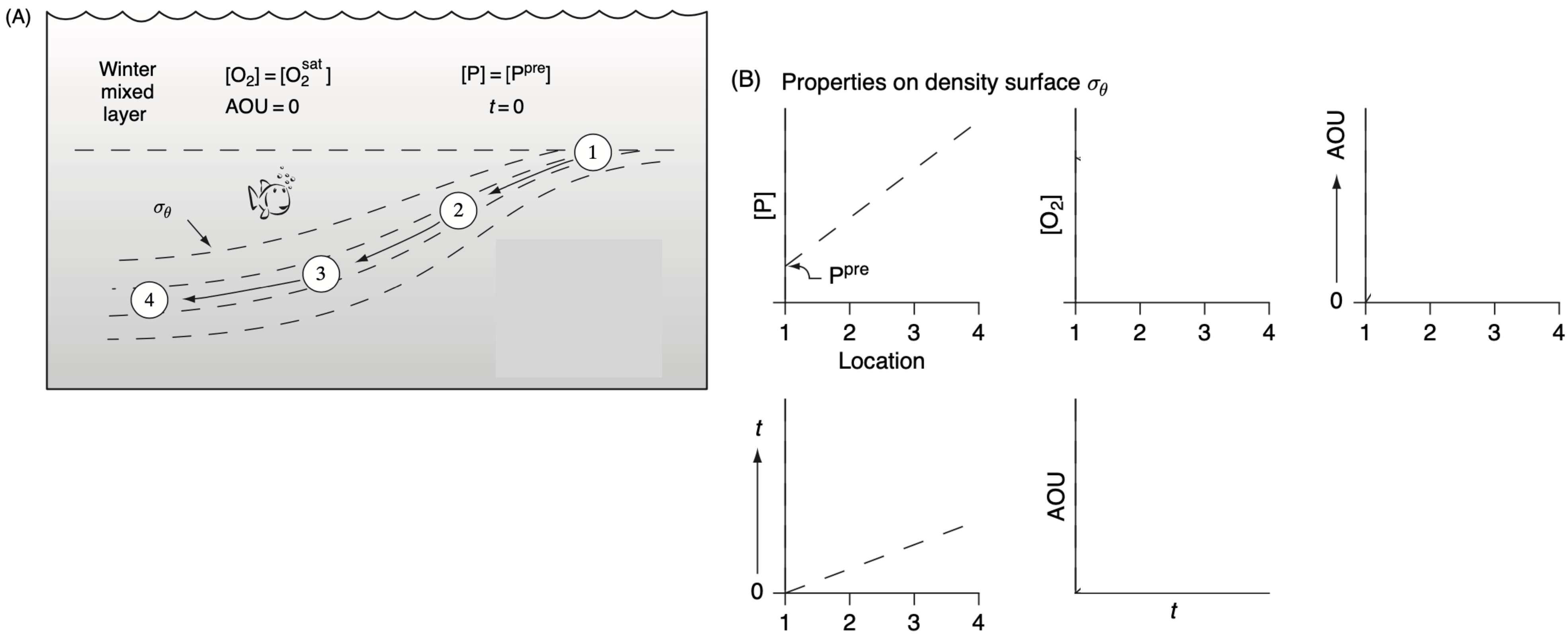

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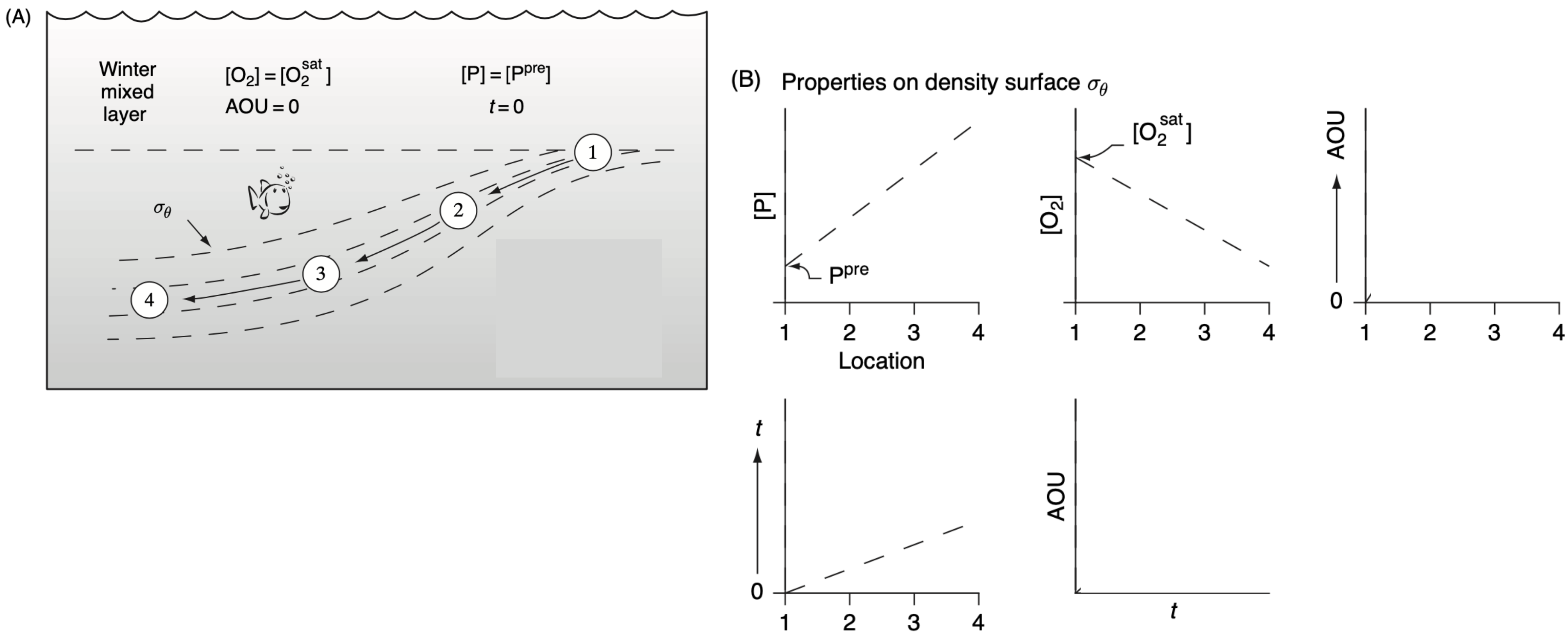


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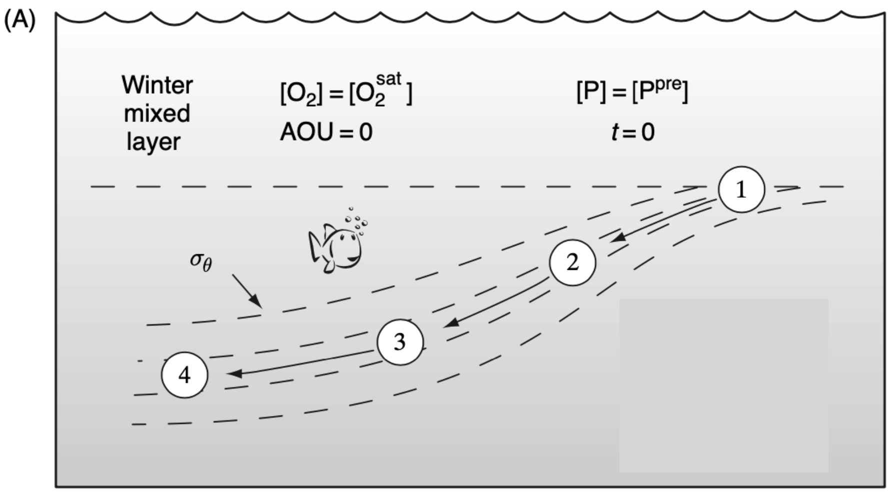


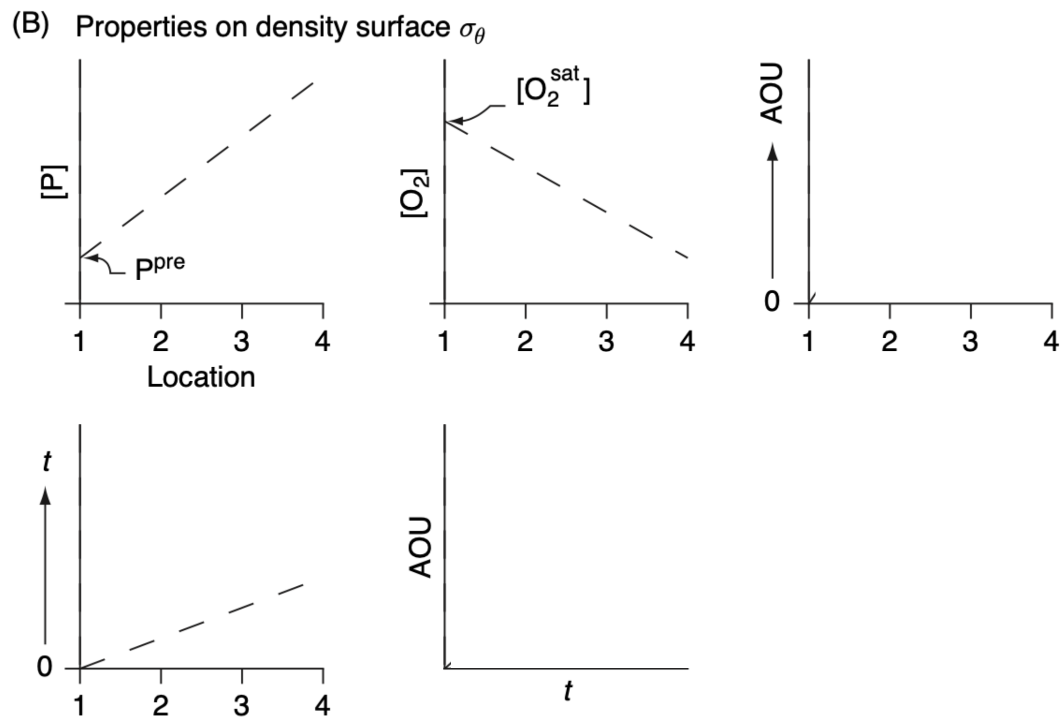


Apparent Oxygen Utilization:
$AOU = [O_2]_{sat} - [O_2]_{measured}$

Oxygen Utilization Rate:
OUR = AOU/t

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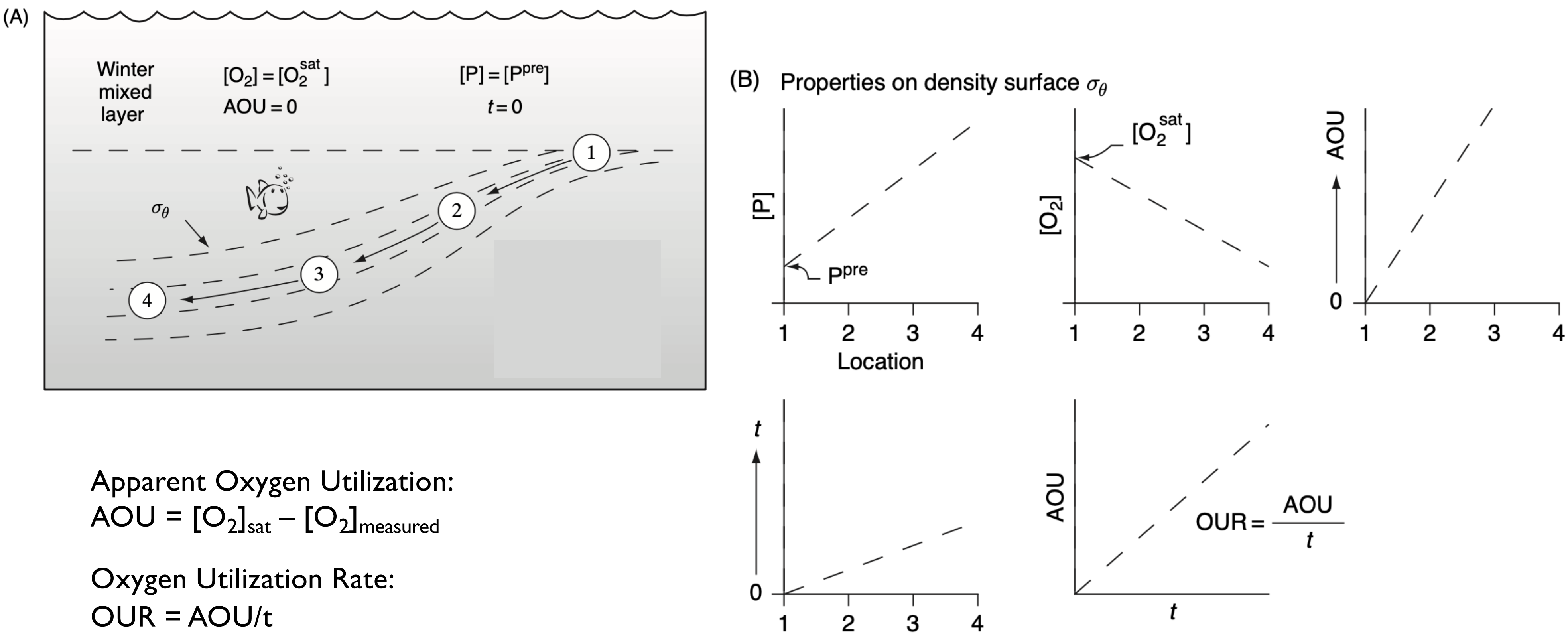


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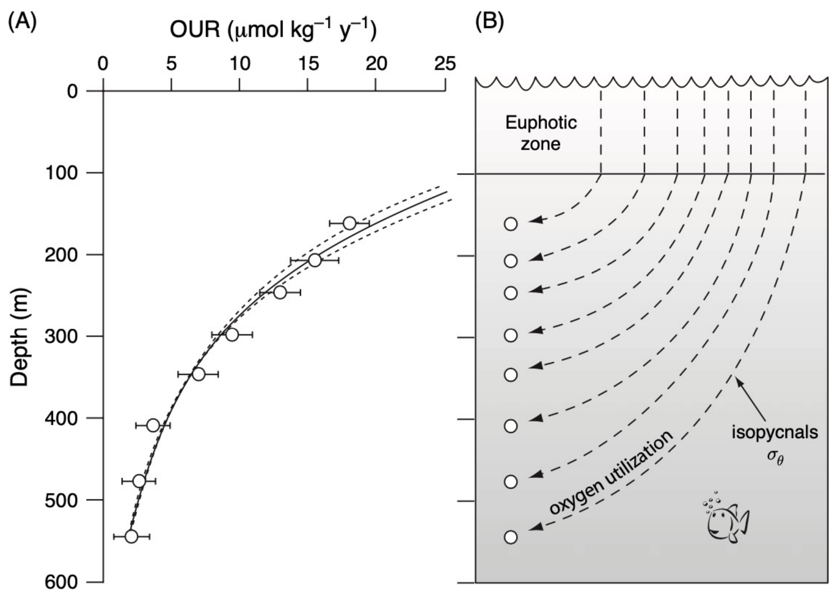


- Why does OUR decrease with depth?

- Most of the organic matter that crosses 100m is respired by 200m (1/e remains at ~165 m)

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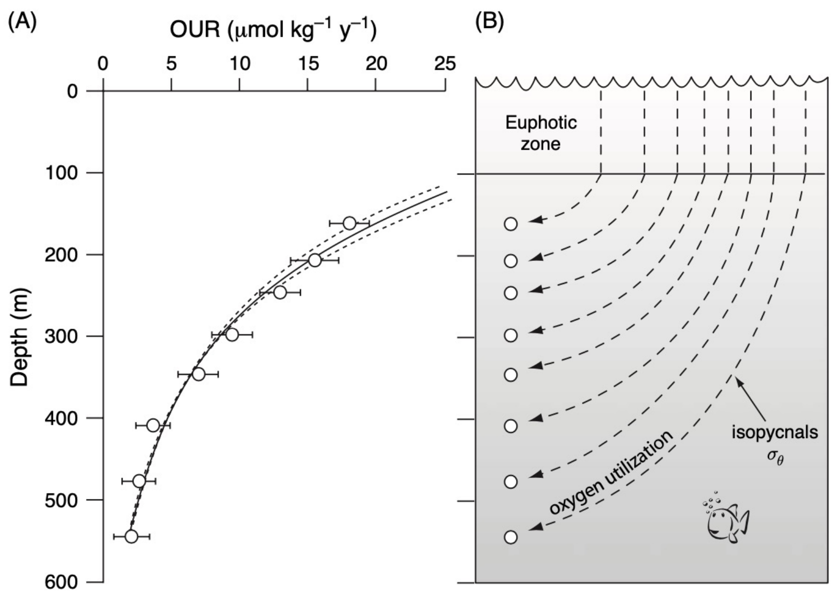


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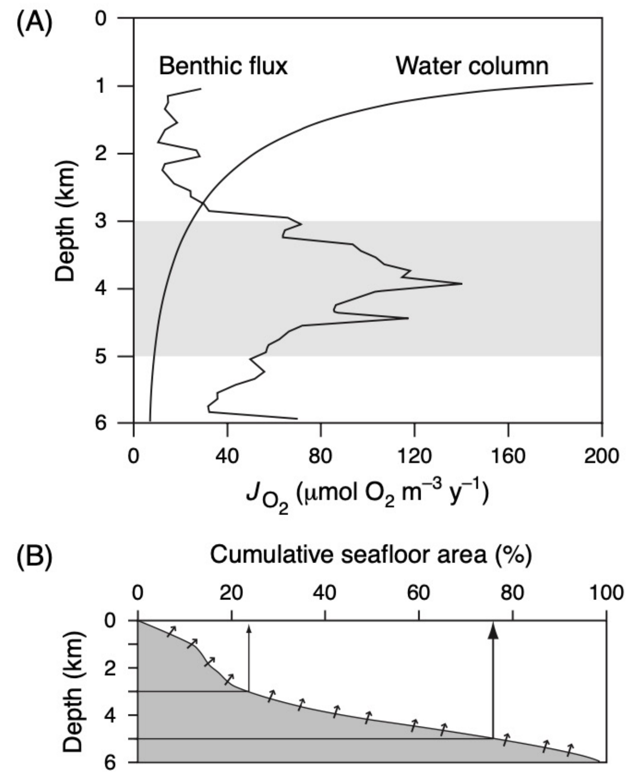


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