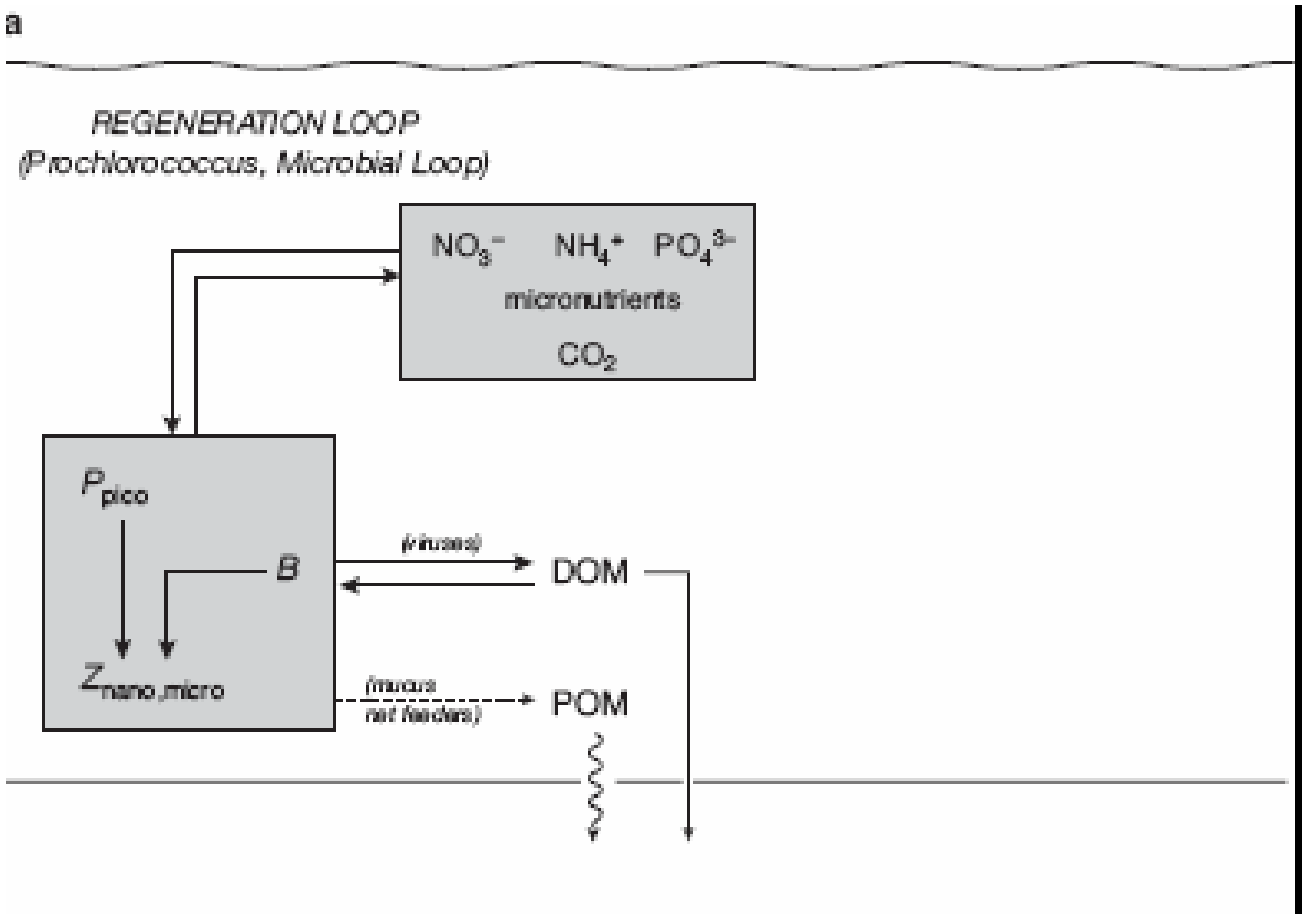
Overall we find that

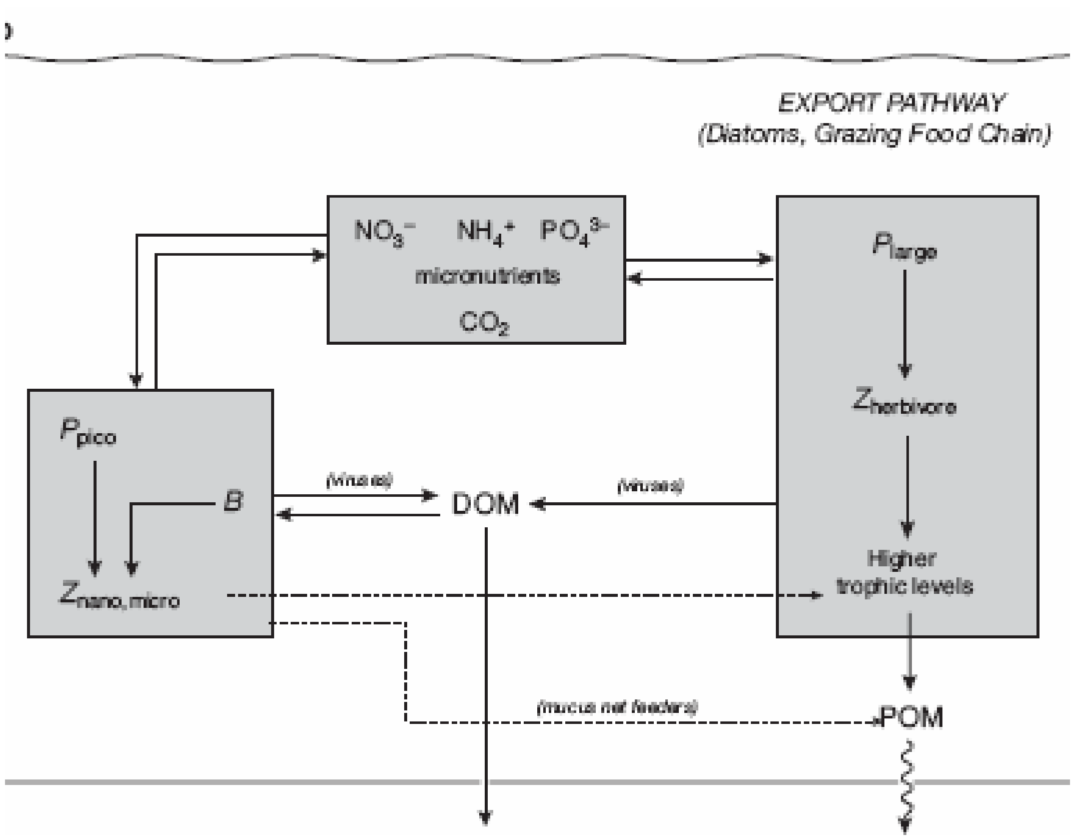
- Marine ecosystems can be bottom-up and top-down limited, with the first being the case for the ecosystem as whole and top-down limitation for individual P-Z components
- The NPZ component based on diatoms is at the base of the food chain for higher trophic levels
- On the other ‘size-end’ are picophytoplankton and nano-micro-zooplankton (top-down)
- The microbial loop (mainly heterotrophic bacteria) is important for recycling organic matter in the system. They produce (and consume) DOM and ammonium
- Iron is important in determining whether diatoms are also present in the system
- Nitrogen fixation in tropical and subtropical areas (next week)

Regeneration loop: picophytoplankton based ecosystem

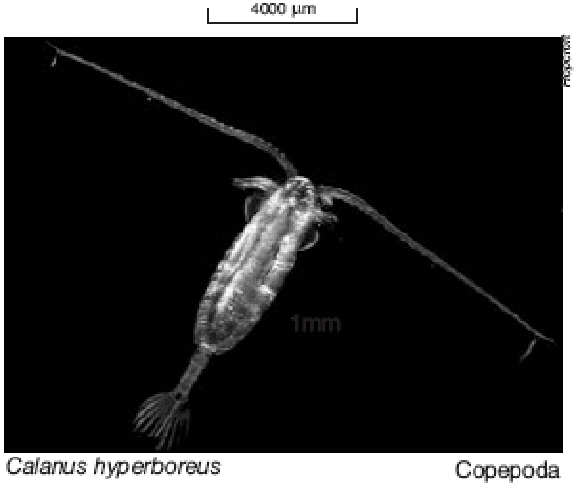


- Picophytoplankton (many of which are not able to uptake nitrate or nitrite)
- Fueled by ammonium produced by recycling (bacteria!)
- Top-down limited by zooplankton (also small and fast growing). Fast response to any perturbation of the system → quick return to steady state
- The regeneration loop includes the microbial one
- Export of organic matter by downward transport and sinking of large particles produced by zooplankton
- Iron is required, but picophytoplankton is well fit in iron limited environments (large surface area/volume)
- Abundant everywhere, more in warm waters (more bacteria)

The export pathway
diatoms and grazing food chain



- Diatom based
- Involves the regeneration loop
- Bottom-up or top-down limited (depends on situation)
- Kicks off in response to perturbations (iron supply, deep wintertime mixing, upwelling for example): it is opportunistic → take advantage of perturbations
- Large zooplankton (copepods) have slow growth rate: they respond slowly, but once they do the bloom usually dies out (the export pathway is not resilient)
- Perturbations have to be large enough (or localized enough) to sustain diatom growth over a sufficient long time (IRONEX I vs IRONEX II)



IRON

- Redox transformation: Fe is transformed between reduced - Fe(II)- and oxidized -Fe(III)- form in presence of oxygen and H_2O_2 in sea water with half life of seconds to few hours.
- Btw Fe(II) is toxic and can limit plant growth

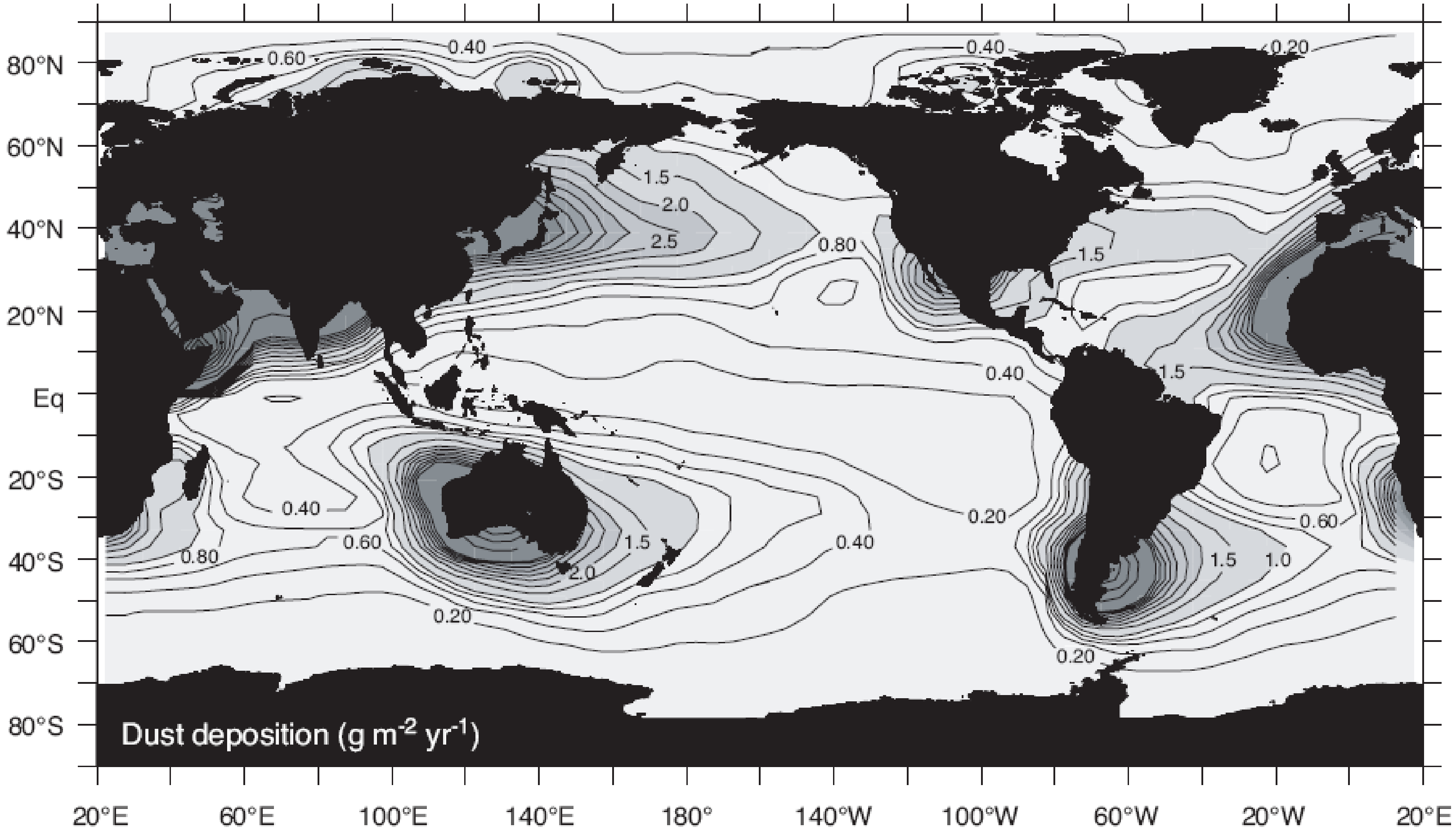
- Inorganic Fe(III) can be found in the ocean in hydrolyzed form as $Fe(OH)^{+}_{2}$ and $Fe(OH)^{-}_{4}$ with solubility of ~ 0.1μmol m^{-3} but in large percentage bound to ligands with overall solubility of 0.2μmol m^{-3} at the ocean surface and 0.6μmol m^{-3} in deep waters (thanks to low temperatures and humic-type organic matter)

- Models can fit iron observations (not many and not so precise! See Doney et al paper on Science, 2007) by simulating iron in both free and complexed form available for uptake and remineralization. In reality the utilization of ligand-bound iron by phytoplankton requires an intermediate reduction step
- Fe:C for phytoplankton ranges between

  ~ 2 (iron limited) and 25 (iron rich, coastal regions) μmol Fe / (mol C). Using 5 μmol Fe/(mol C) as average →

  Fe:N gives ~ 40 μmol Fe / (mol N) for phytoplankton to be able to use all N. In the ocean given the averaged concentrations of Fe and N Fe:N is ~ 20 μmol Fe / (mol N)
- Btw Nitrogen fixers needs several times more Fe:N to function

Why some regions are more limited than others?



- Iron is supplied by rivers, dust deposition and dissolution in continental margin sediments.
- The river input on the overall ocean budget is negligible because is used ‘in-loco’ in estuaries and shelfs
- The contribution of iron from continental margin sediments where ~ anoxic conditions due to high organic carbon contents favor iron reduction from Fe(III) to the soluble Fe(II) is still a matter of debate. Recent estimates give values up to three time the amount by dust deposition (Elrod et al., 2004; check out Doney et al., 2007 for a study in the N. Pacific)

Eolian dust contribution:

- Total amount: 2.5 - 5.7 x 10^{11} mol Fe/yr
- Percentage of this amount soluble in seawater: anything from 1% (from model tuning) to 30% (for wet deposition), passing for 17% (atmospheric observations + model tuning).
- In general ocean models use soluble fractions comprised between 2% and 10%. Likely on average <~ 2%, for a total ocen inventory of soluble iron of 3 x 10^{11} mol Fe/yr
- From sediments Elrod et al. (2004) ~ 9 x 10^{11} mol Fe/yr
- Relative short residence time (~<100ys) relative to deep ocean circulation (>~1000ys): the distribution of iron reflects the one of dust deposition

- In the water column depleted at surface and more abundant at depth below the euphotic zone
- On a global scale about ¾ of iron supply comes from advection and mixing of iron below the mixed layer into the euphotic zone (Moore et al., 2002) (if interested check out his web page (http://www.ess.uci.edu/~jkmoore/)

What does control productivity?

- N distribution (large scale circulation vertical and horizontal transport)
- Iron limitation (dust distribution gives an indication of global scale patterns)
- In the southern ocean likely a combination of iron and light limitation

What does control the recycling efficiency?

$$\text{Recycling efficiency} = \frac{\text{Regenerated production}}{\text{Primary Production}} = \left(1 - \frac{\text{New Production}}{\text{Primary Production}}\right) = (1 - f)$$

Overall understanding this implies understanding the ef-ratio (export to f ratio)
This is somehow related to production and it does increase with increasing primary productivity because of the shift from the regeneration loop (small -pico-phytoplankton and zooplankton groups) to the export pathway (diatoms)

- The ef-ratio also increases with T (more efficient recycling of organic matter thanks to bacteria in warm waters)