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Aerosols and Trace Metal Toxicity

Or - It gets more interesting than just fertilization

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OCB

2015

Saudi Arabia



Red Sea

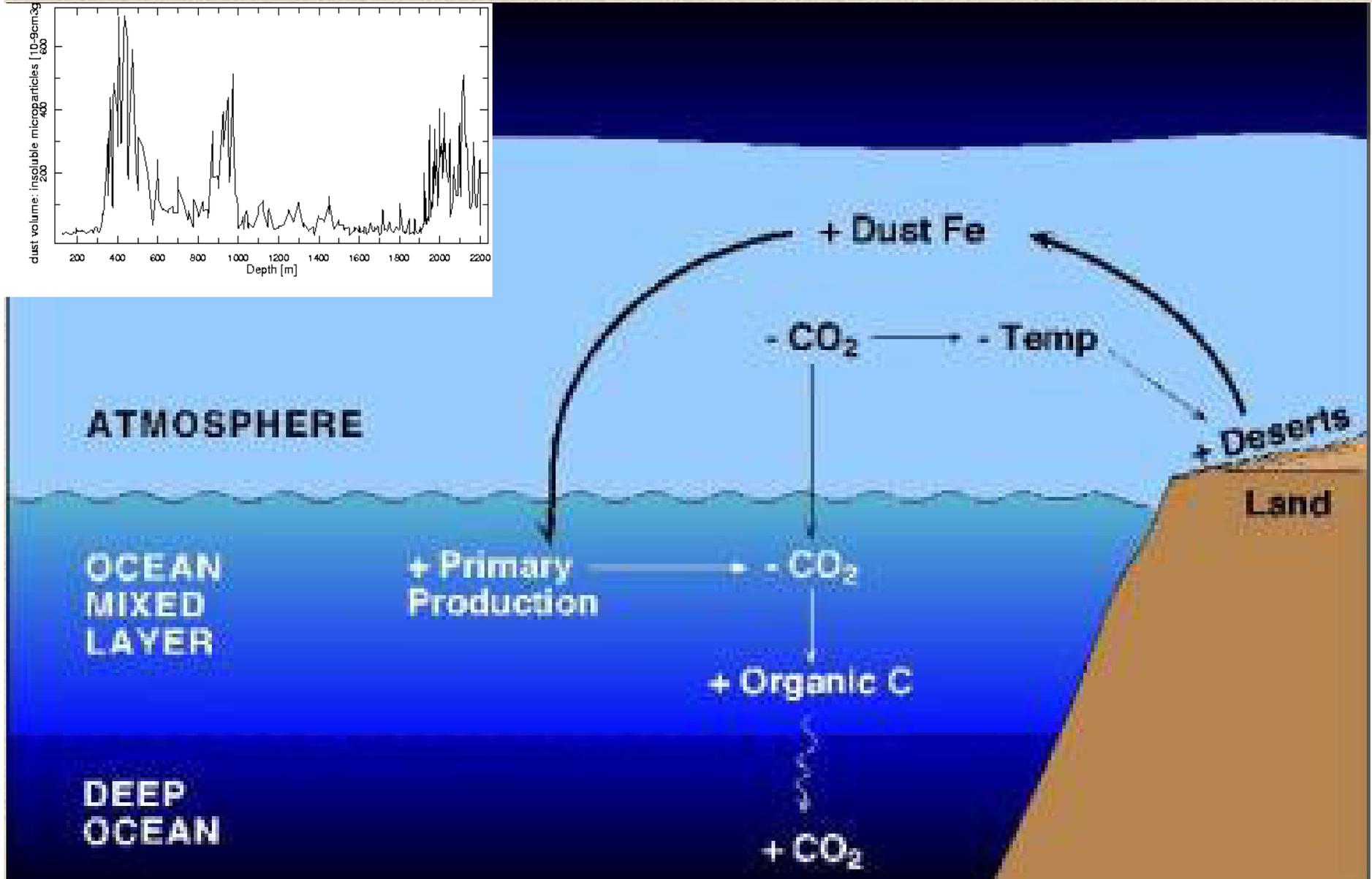
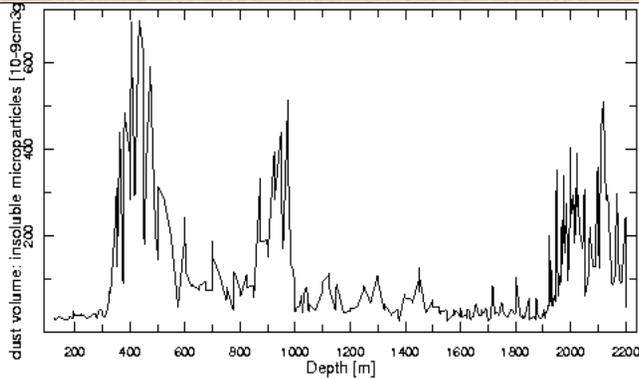


Why Study Aerosols ?

- **Affect radiative properties of the atmosphere,**
(light scattering, light absorption, indirect effect on cloud albedo)
- **Serve as reactive surfaces for atmospheric gases,**
(condensation nuclei, photochemical reactions, heterogeneous catalysis)
- **Affect air quality, visibility and human health**
(allergy, asthma)
- **Add minerals, nutrients, and MANY other things. to the ocean (and land) directly impacting ecosystems.**

Direct and indirect effects on climate (cooling, precipitation, C)

Aerosol Impacts Paradigm



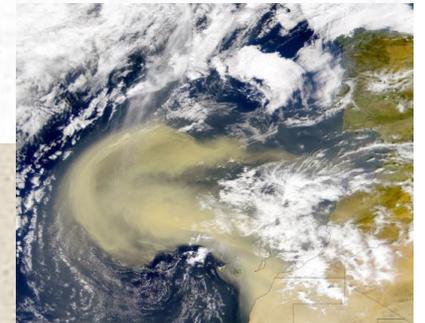
A source of nutrients (N, P) and trace metals (Fe) to the ocean.

Element	Riverine ^a	Atmospheric ^b
N (excluding N ₂ gas)	1500–3570	2140
Cd	0.0027	0.0036–0.0063
Cu	0.16	0.03–0.11
Ni	0.19	0.24–0.29
Fe	19.7	519
Pb	0.01	0.43
Zn	0.09	0.17–0.92

^a Dissolved input, particulate components are assumed to be deposited in coastal areas.

^b Total (dissolved + particulate) input.

Units = 10⁹ moles/yr
Jickells, 1995.



SeaWiFS February 26, 2000

Santa Maria (Azores)

Conclusions

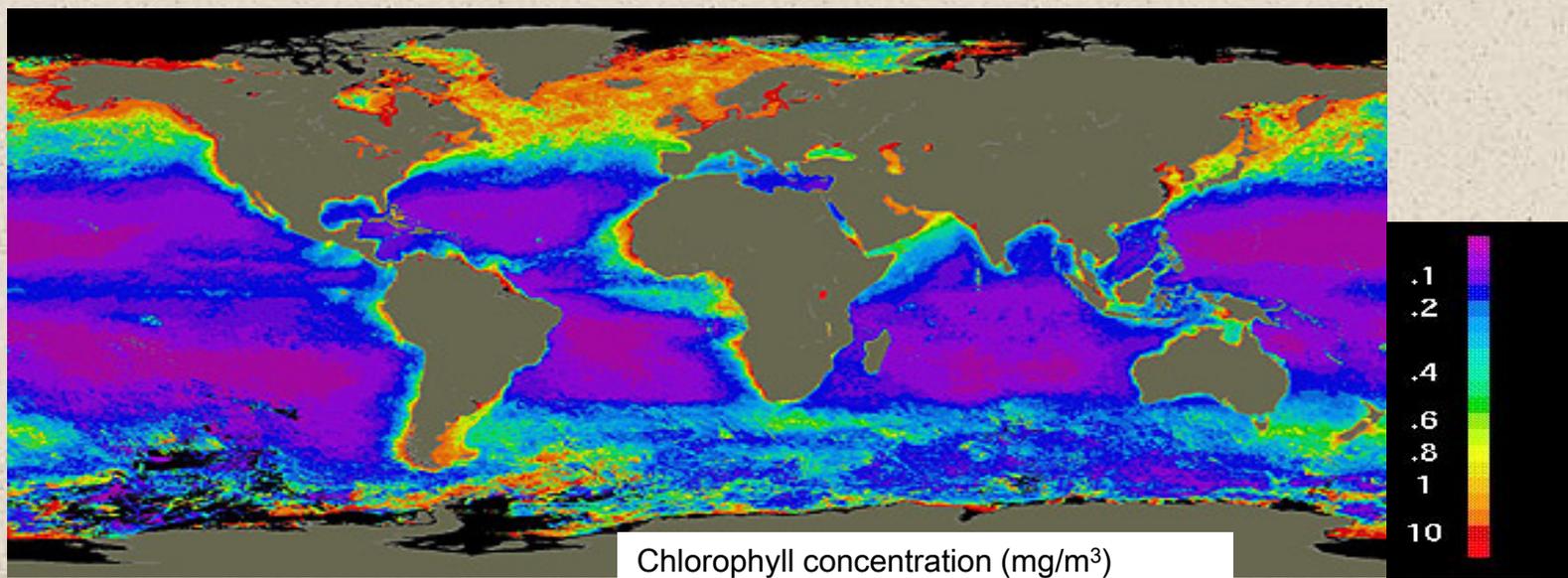
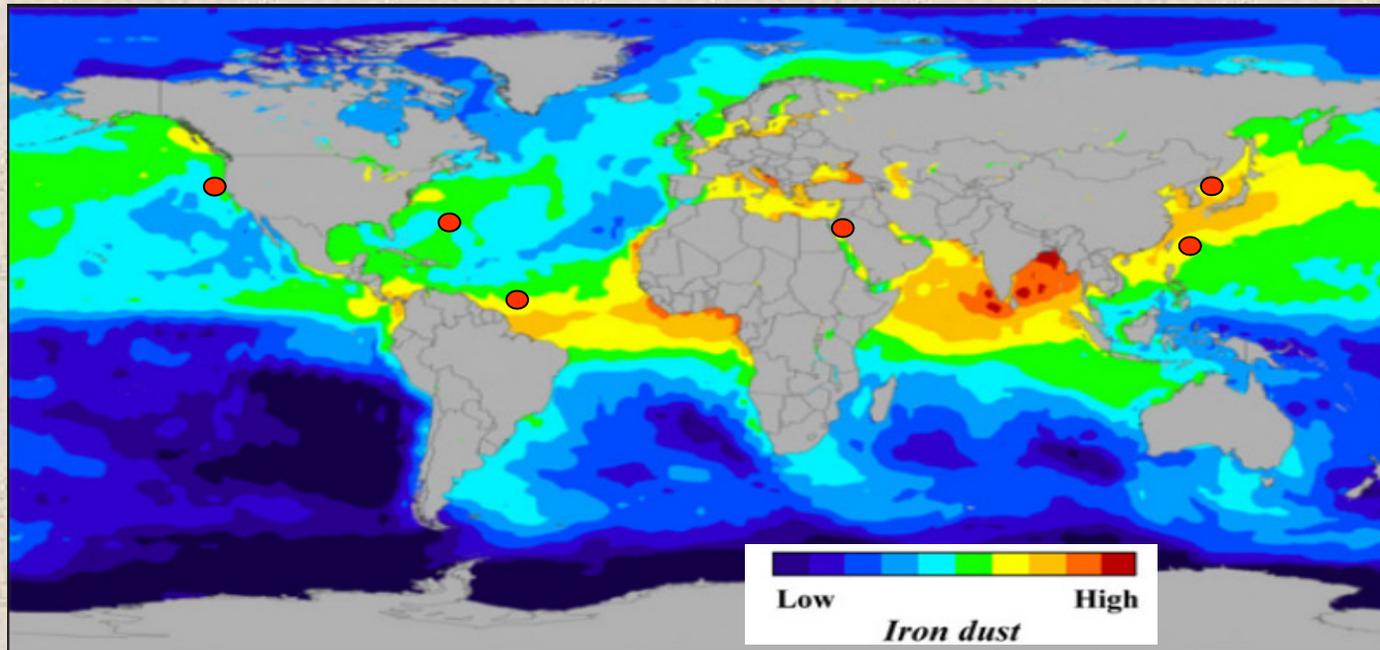
- Aerosols (atmospheric deposition) are not just dust!
- Aerosols have profound effects on ocean chemistry and biology with implications to global biogeochemical cycling and climate,
BUT - not all aerosols are created equal.
- Different organisms/ecosystems are affected differently by aerosol deposition,
Not all organisms respond equally.

Examples from direct experiments demonstrating these impacts.



- Which components in the aerosols affect phytoplankton at the individual species or the community level?
- Do all aerosols have the same impact?
- How do different taxa within the community respond to distinct aerosol deposition events?
- What are the effects on other organisms?

Different Sites and Settings

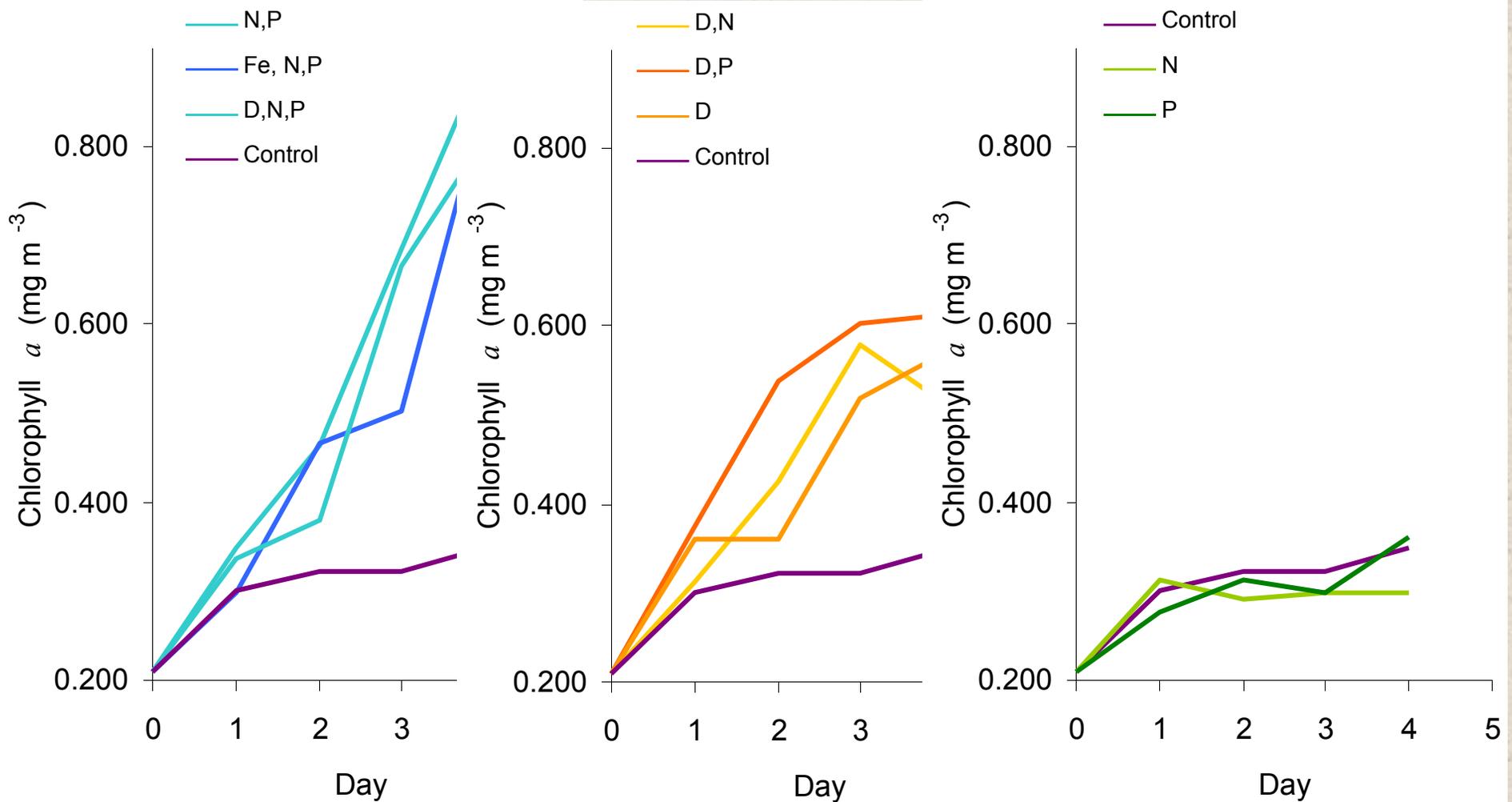


Impact on Biology

Incubation Bioassay Experiments
Field Observations

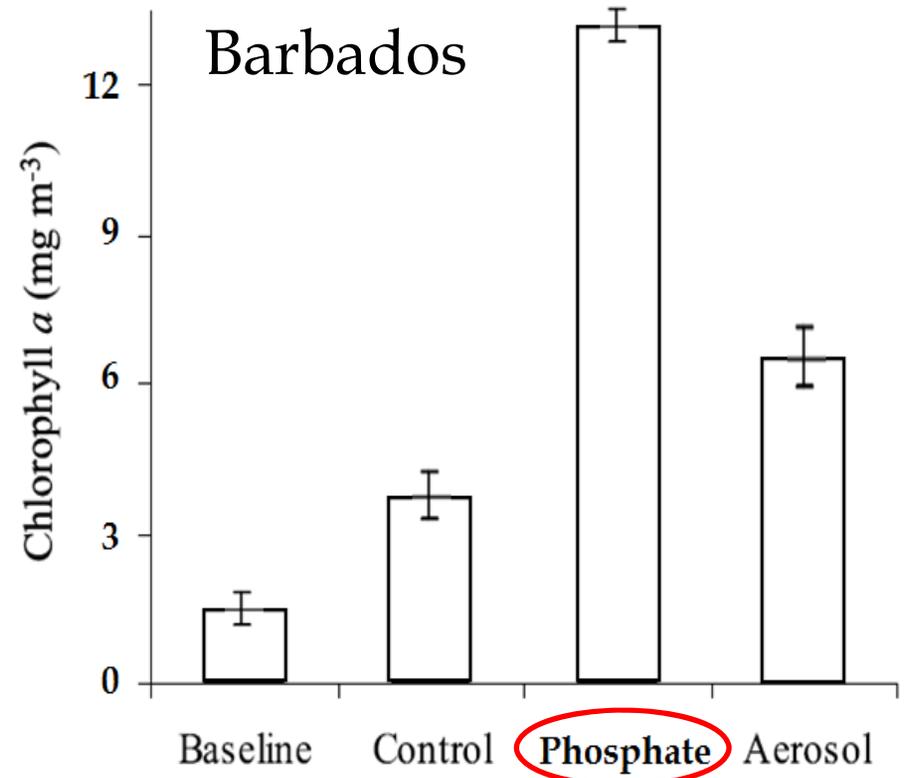
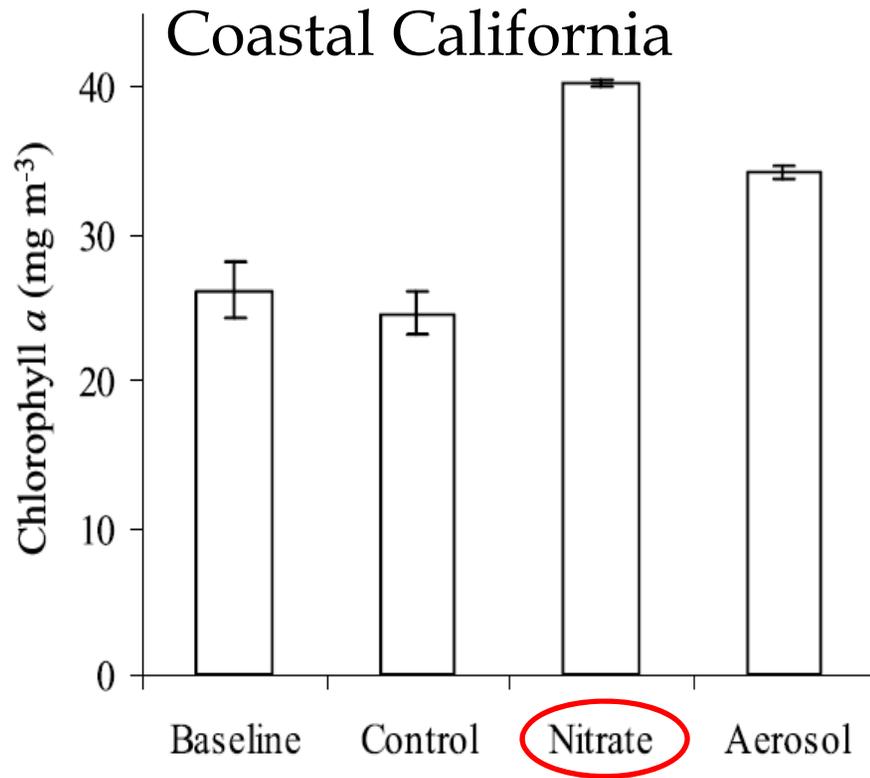
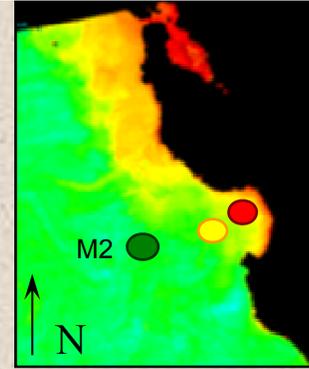


Gulf of Aqaba – Oligotrophic System



4 fold increase in Chl *a* with N+P additions → N+P co-limitation
3 fold increase with dust addition → Dust provides N + P

Different Responses



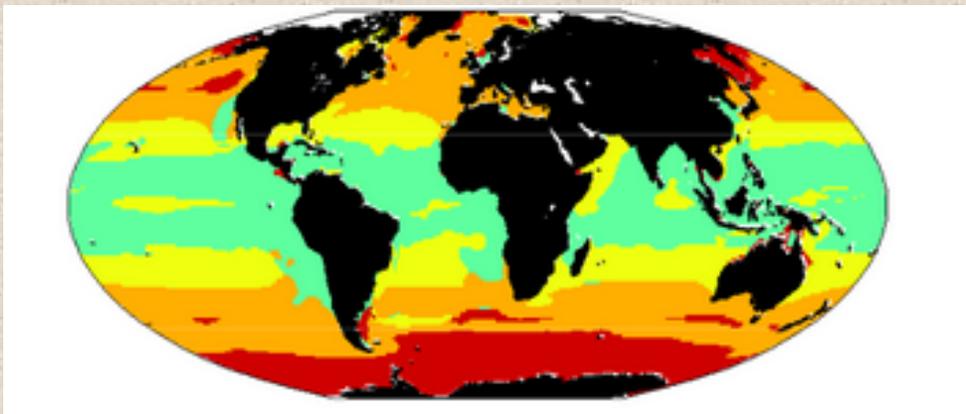
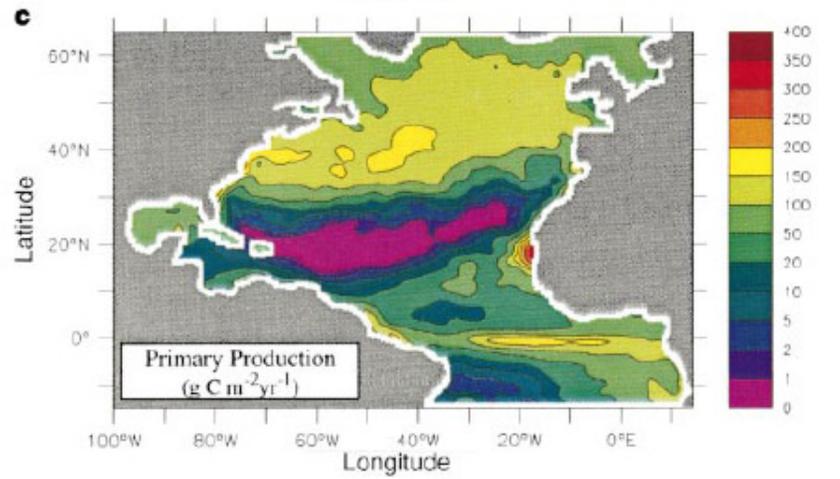
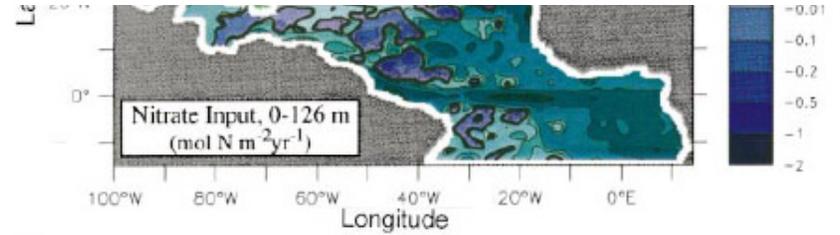
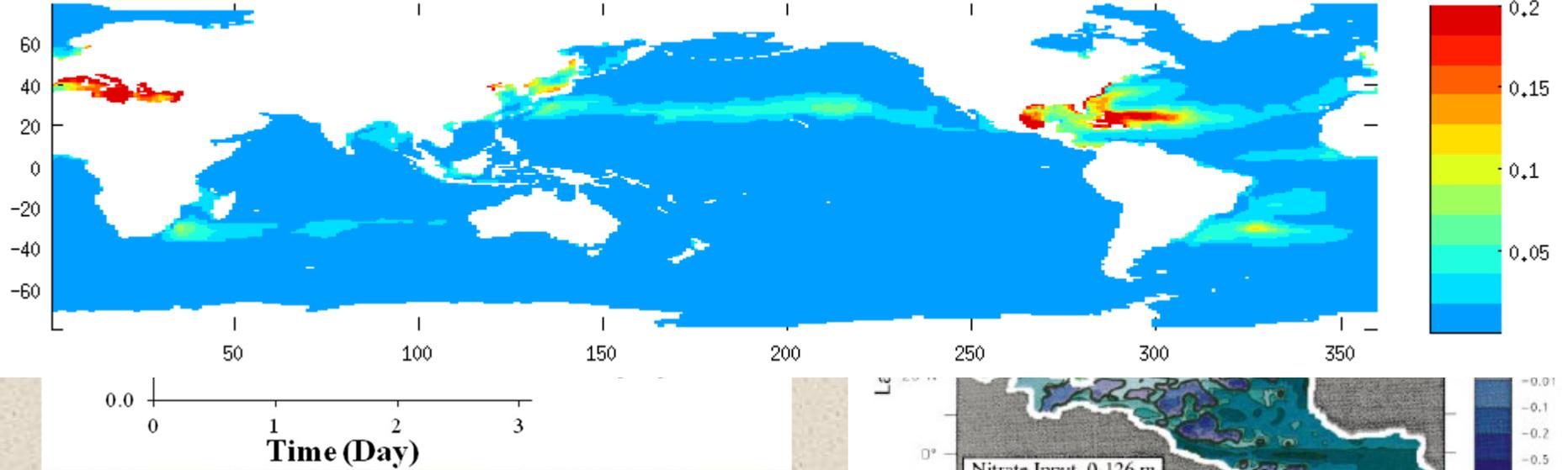
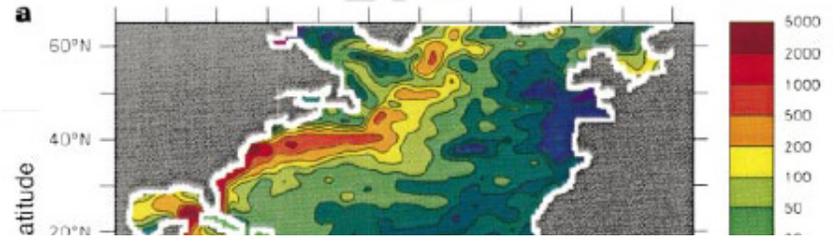
Mackey et al., 2010

Chien et al., 2015

$N:P = 170$
(RFR = 16)

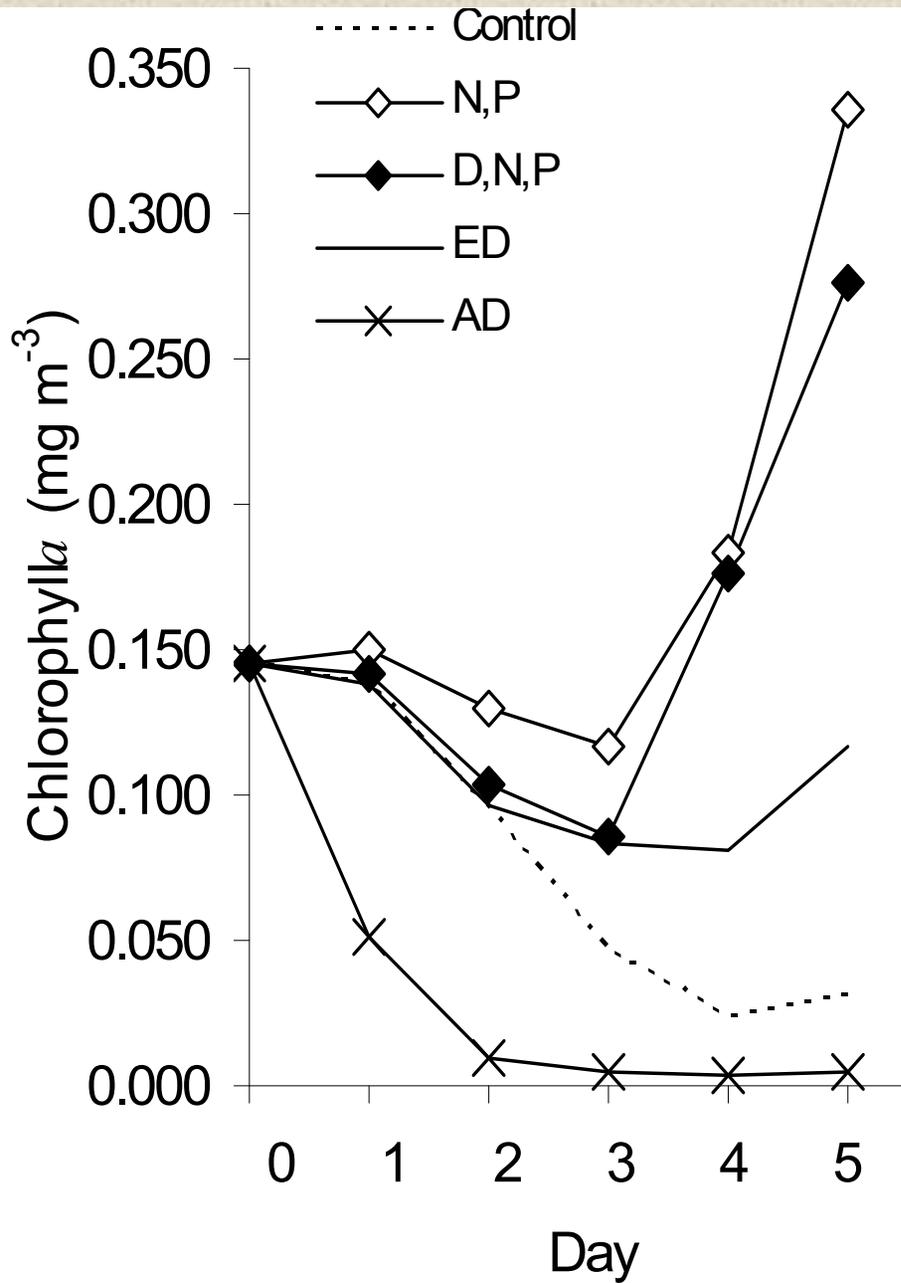
($\mu\text{g/L}$)

◆ $\text{NO}_3 + \text{NH}_4 + \text{PO}_4$
◆ PO_4
◆ Spring dust high
DIN ratio

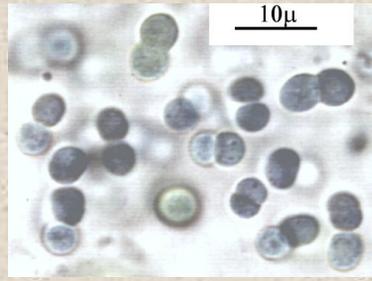
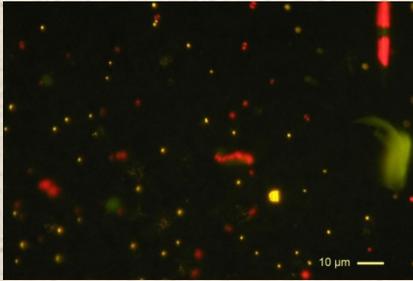


Oschlies & Garcon 1998

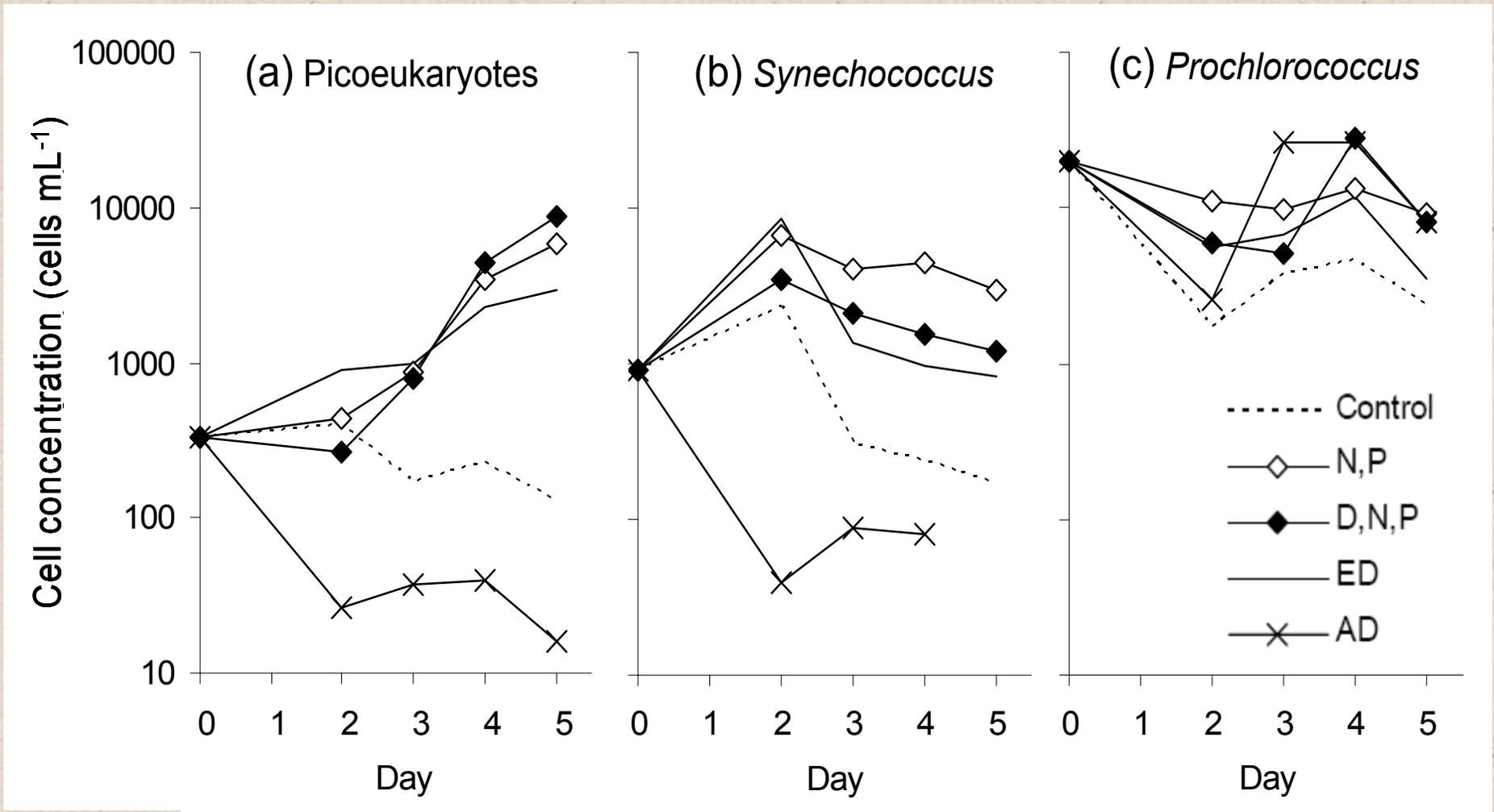
Impact on Biology



Paytan et al., 2009, PNAS



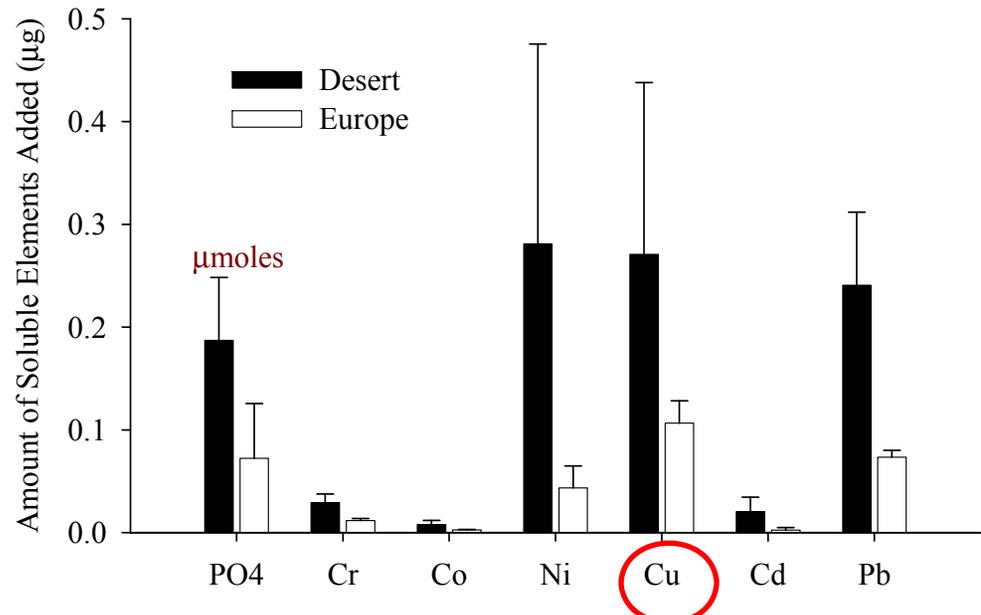
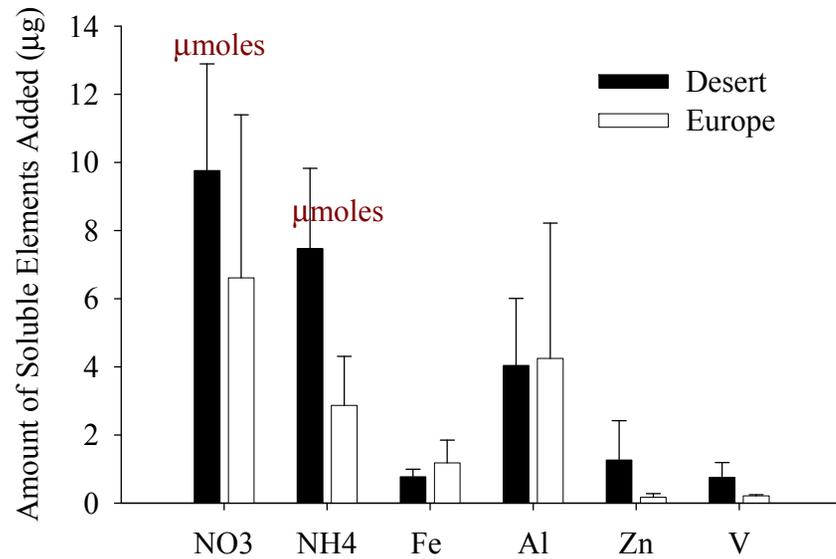
Impact on Biology



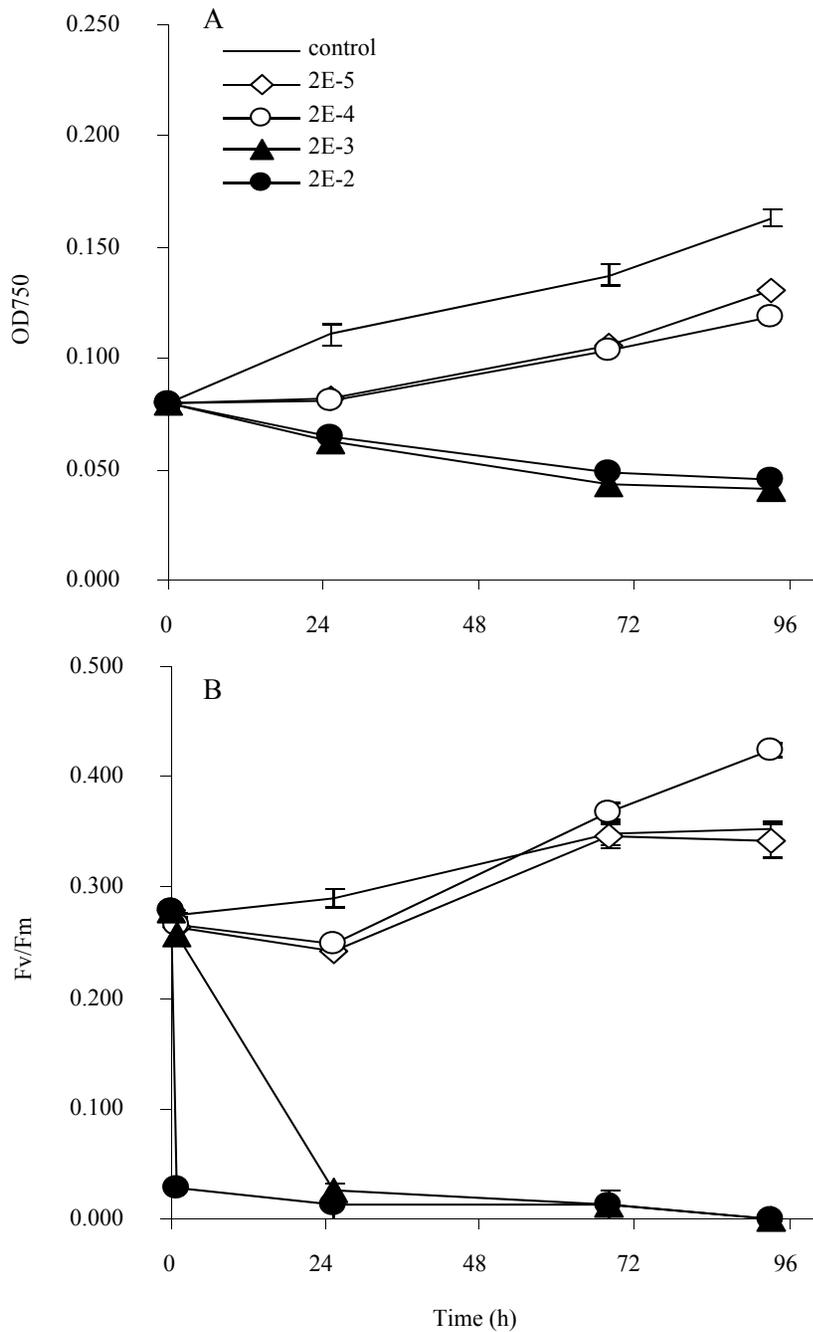
Impact on Biology



Nutrients higher in
“toxic” aerosol...
BUT some metals
also higher.

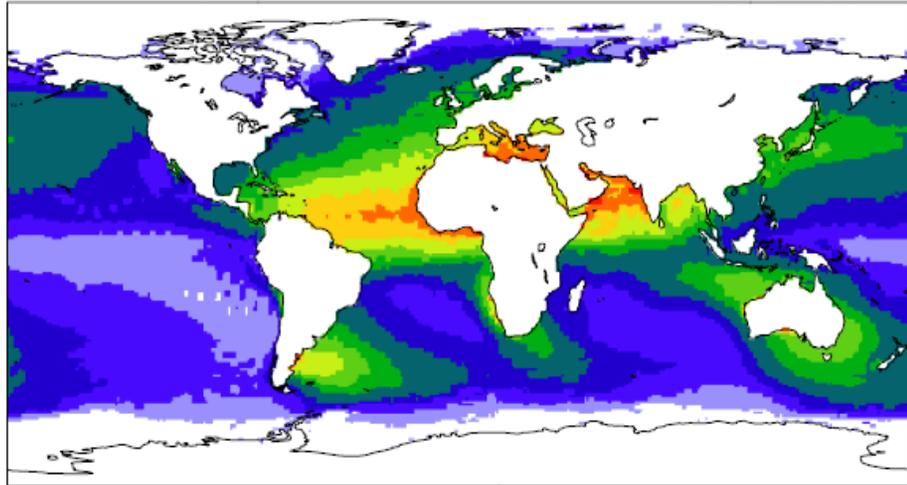


Possible Cu toxicity !!



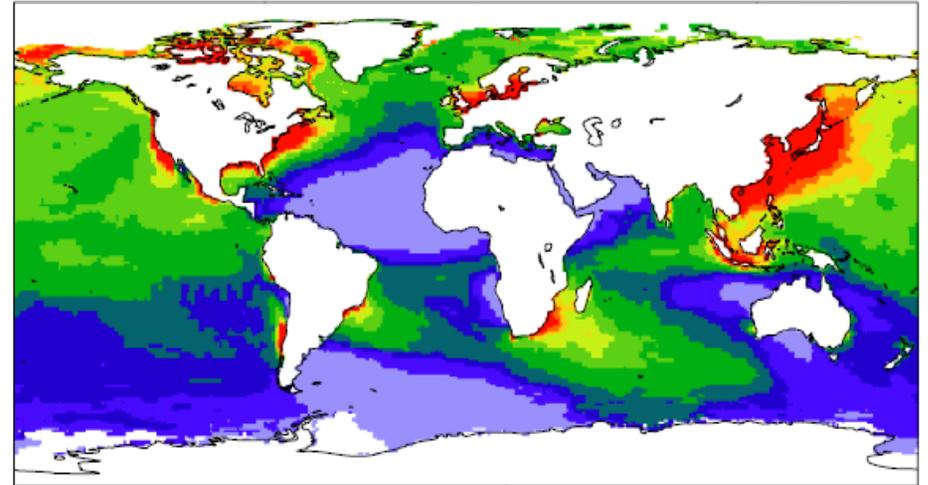
Toxicity threshold at $0.4 \mu\text{g Cu } \mu\text{g Chl } a^{-1}$

Annual Cu deposition Pre-Industrial



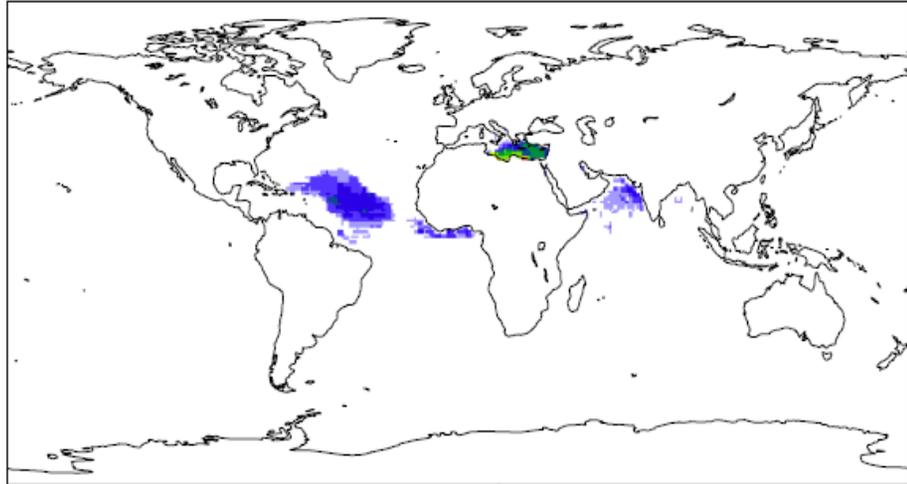
0.002 0.005 0.01 0.02 0.05 0.1 0.2 0.5 1 2
mg m⁻² y⁻¹

Modern/Pre-Industrial annual deposition ratio Modern



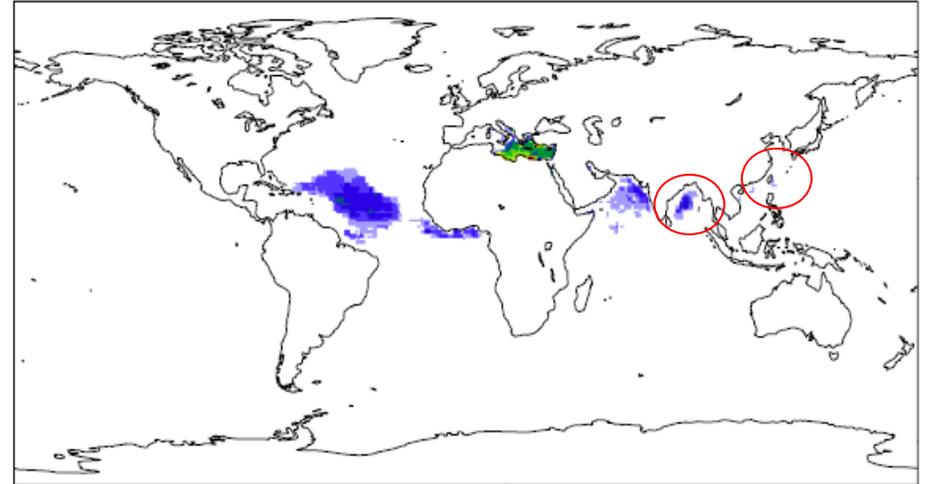
1 1.1 1.2 1.3 1.5 2 2.5 3 3.5 4

Number of months with toxic Cu Pre-Industrial

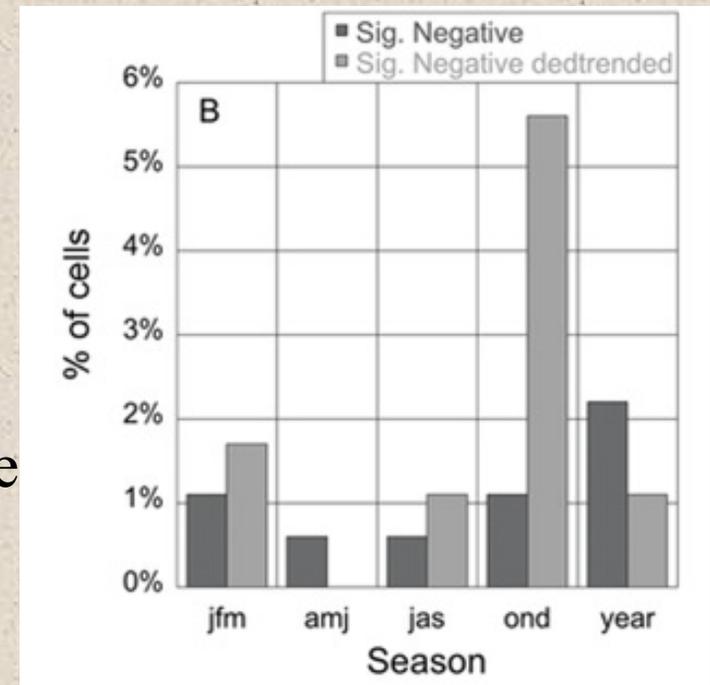
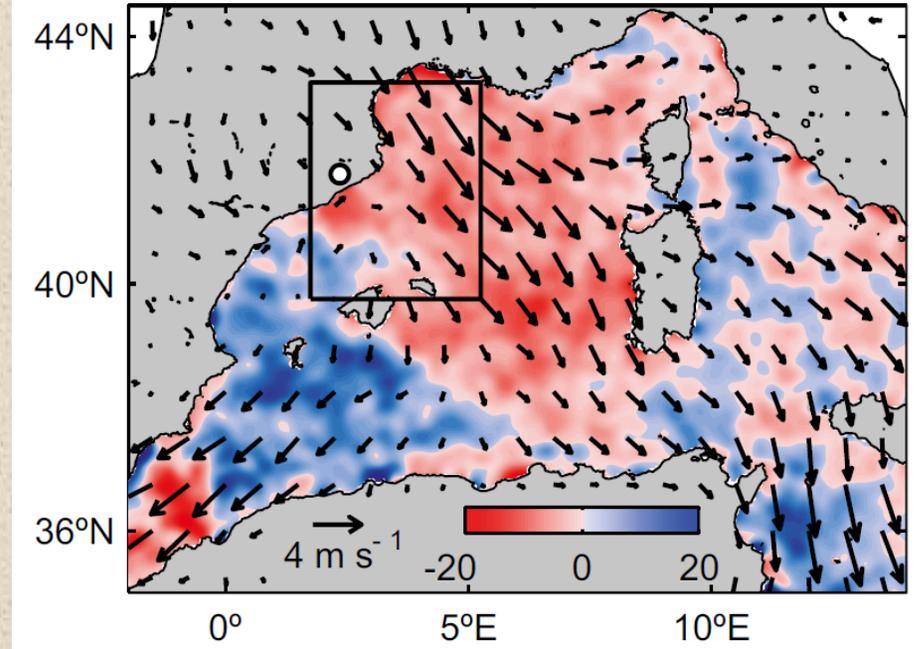
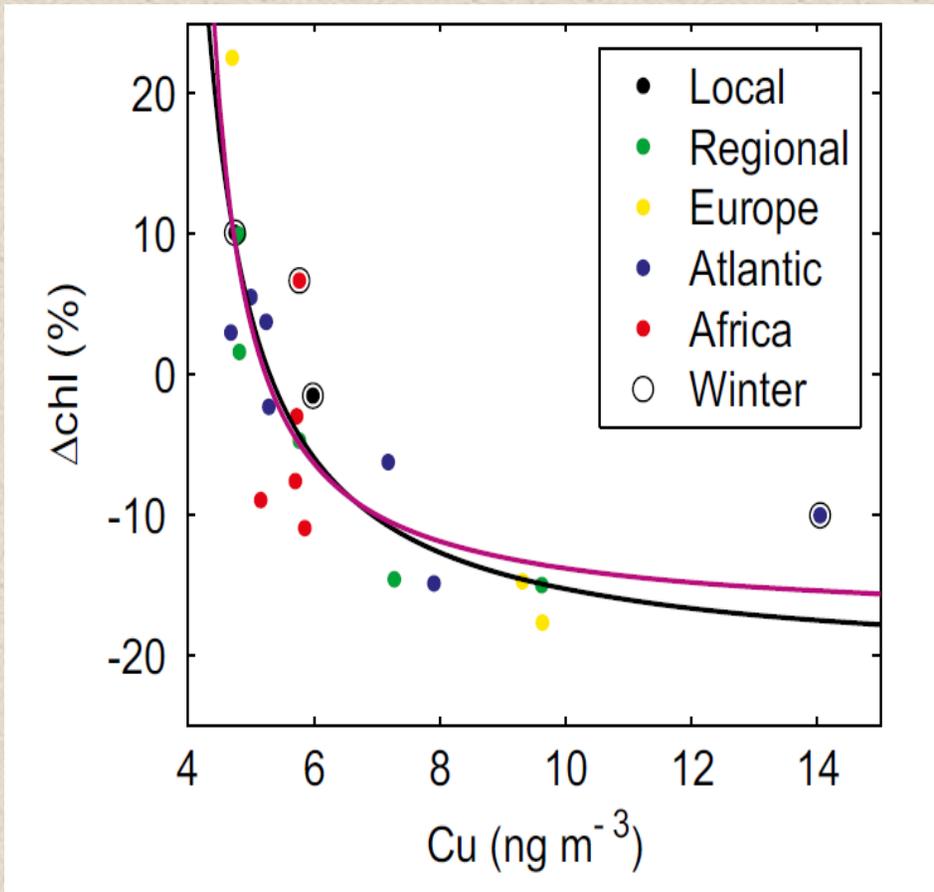


1 2 3 4 5 6 7 8 9 10 11

Number of months with toxic Cu Modern

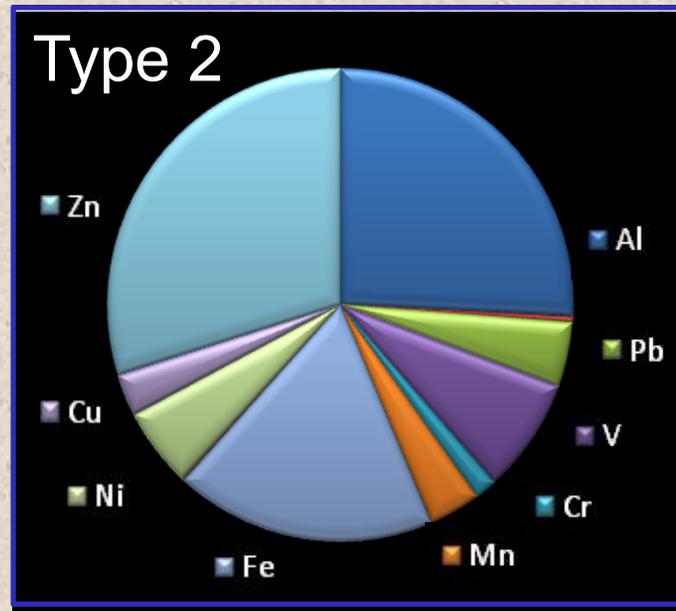
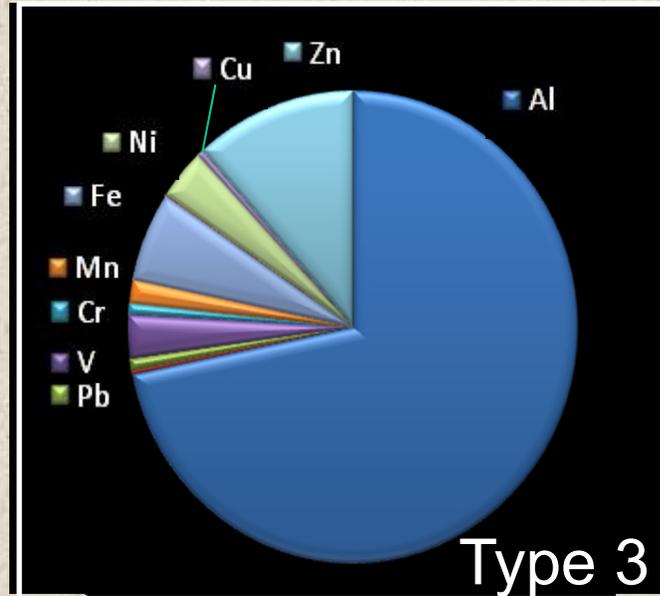
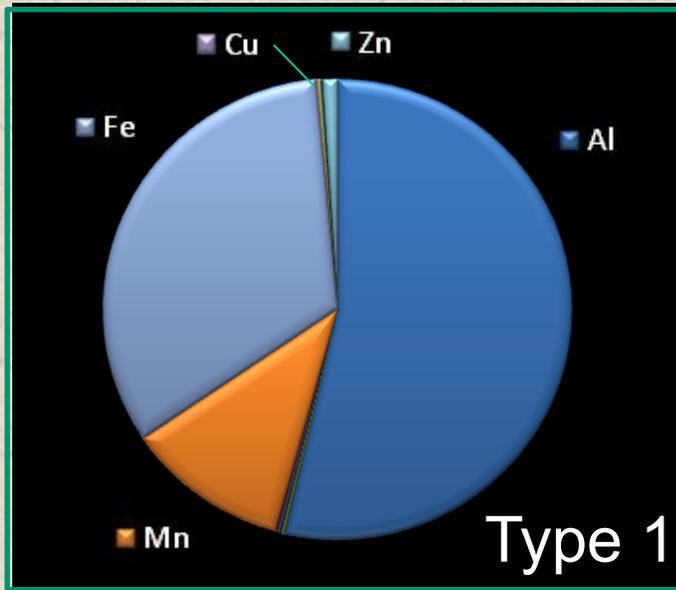


1 2 3 4 5 6 7 8 9 10 11



Some areas in the Mediterranean show negative effects of dust deposition on chlorophyll, specifically regions under a large influence of aerosols from European origin (Jordi et al., 2012; Gallisai et al., 2014)

Bermuda

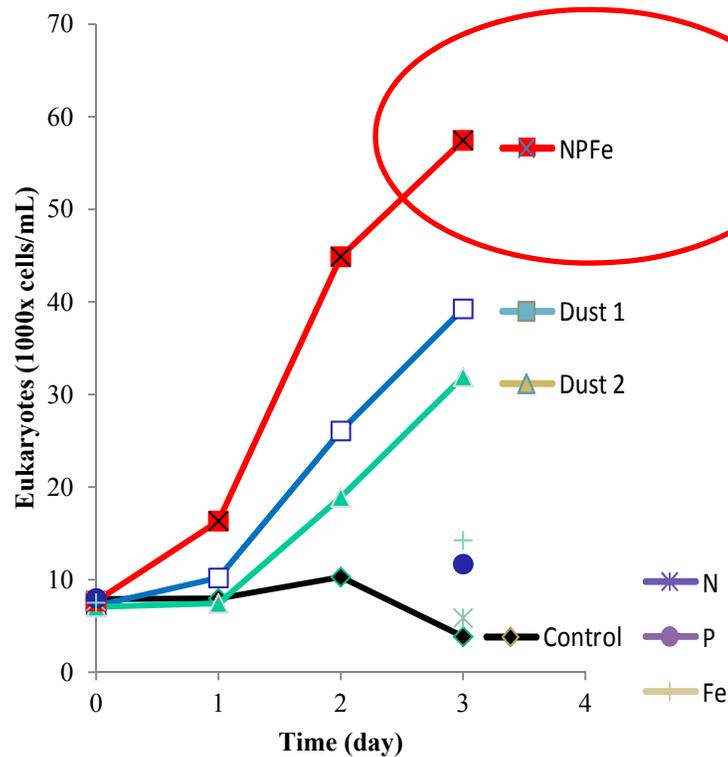


Different Responses for Different Taxa

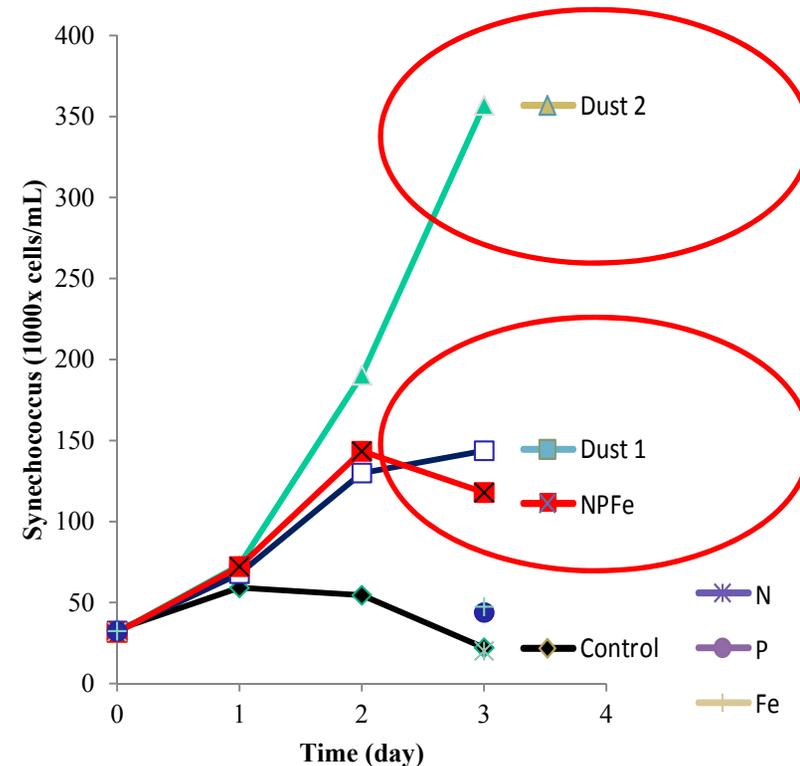
Bermuda



Oceanic picoeukaryotes

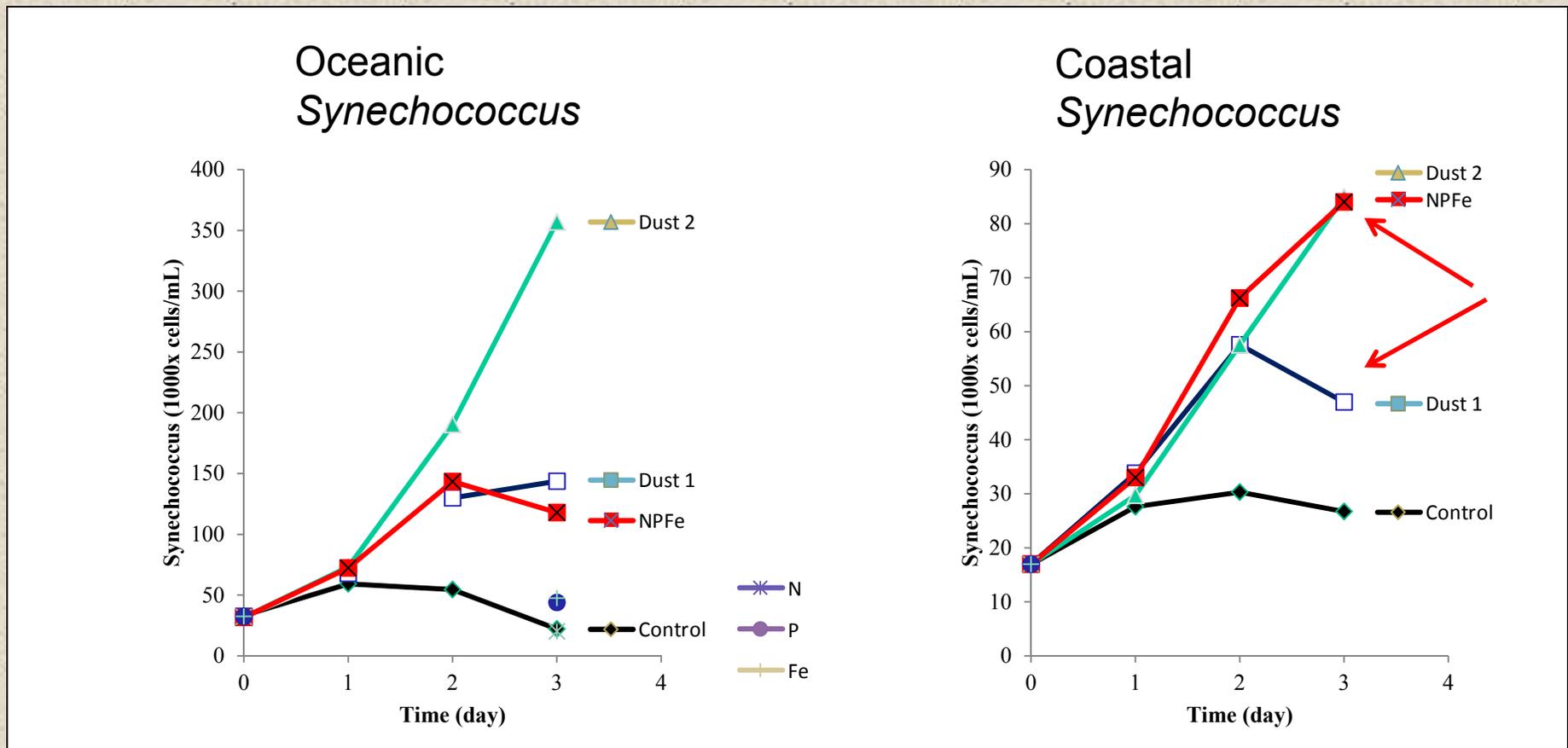


Oceanic *Synechococcus*



Mackey et al., 2011

Oceanic vs. Coastal *Synechococcus* Populations



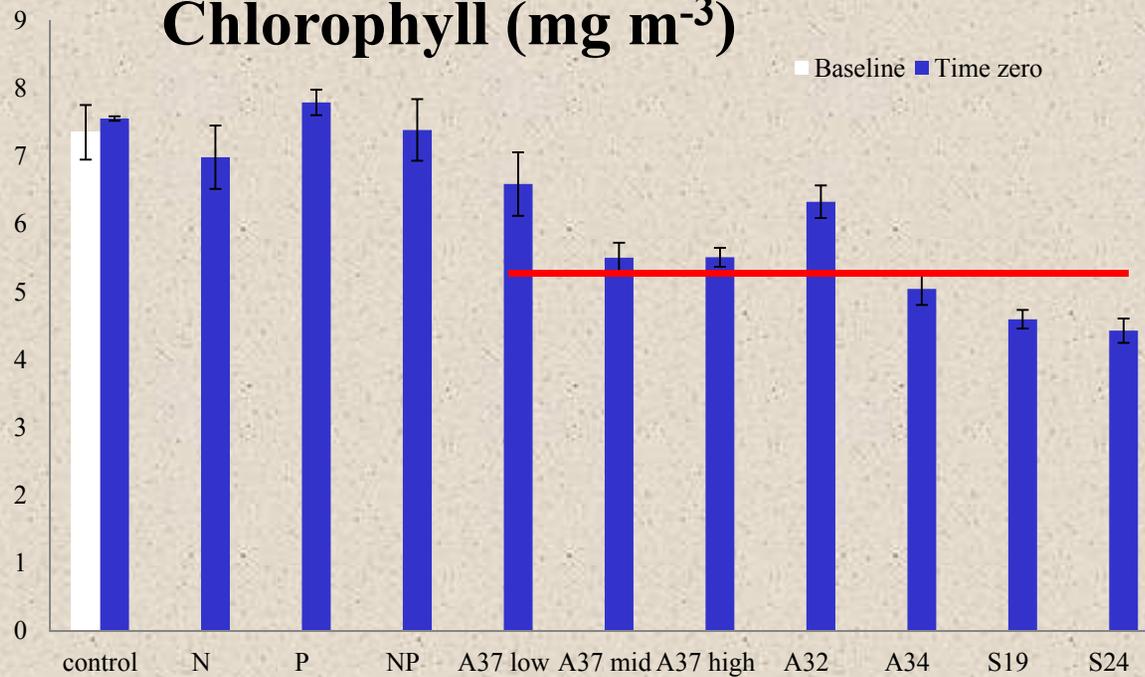
- Oceanic *Synechococcus* limited by unidentified metal (Zn?)
- Coastal *Synechococcus*:
 - Co-limited for N+Fe, *or*
 - More than one strain with different nutrient statuses



April 2011 – Shensi
Huaniao Island, China

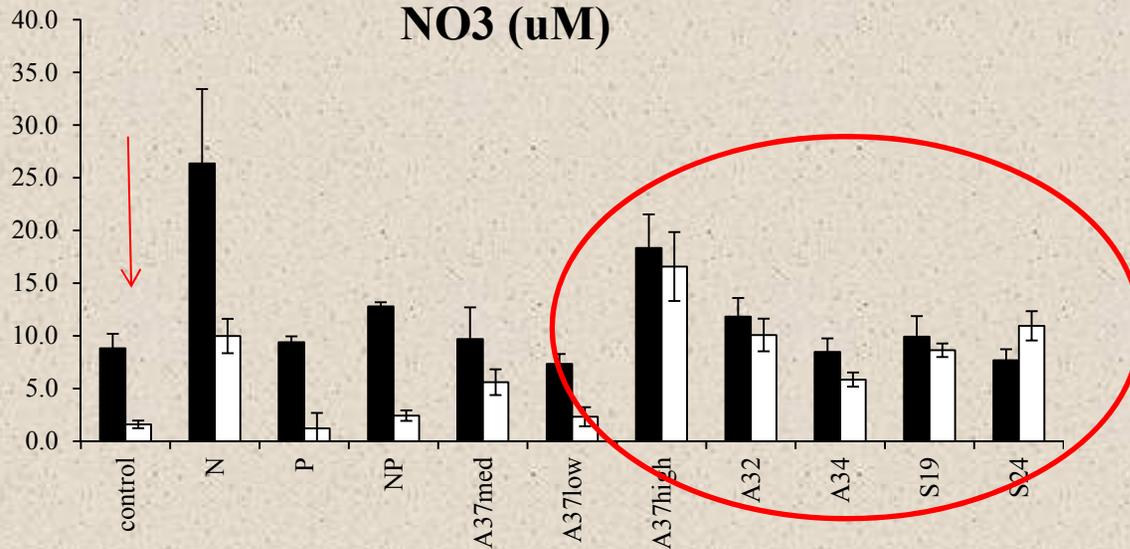


Chlorophyll (mg m⁻³)



Immediate decline in chl after aerosol addition could be due to toxicity

NO₃ (uM)

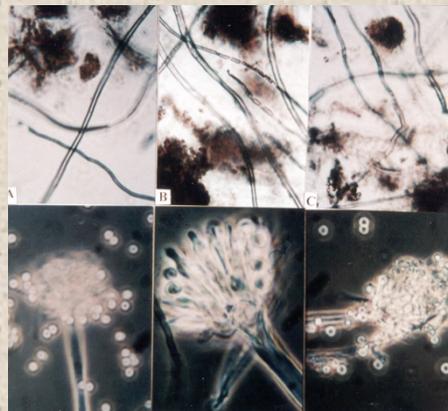


N was not drawn down in aerosol samples, further suggesting toxicity

Other Impacts



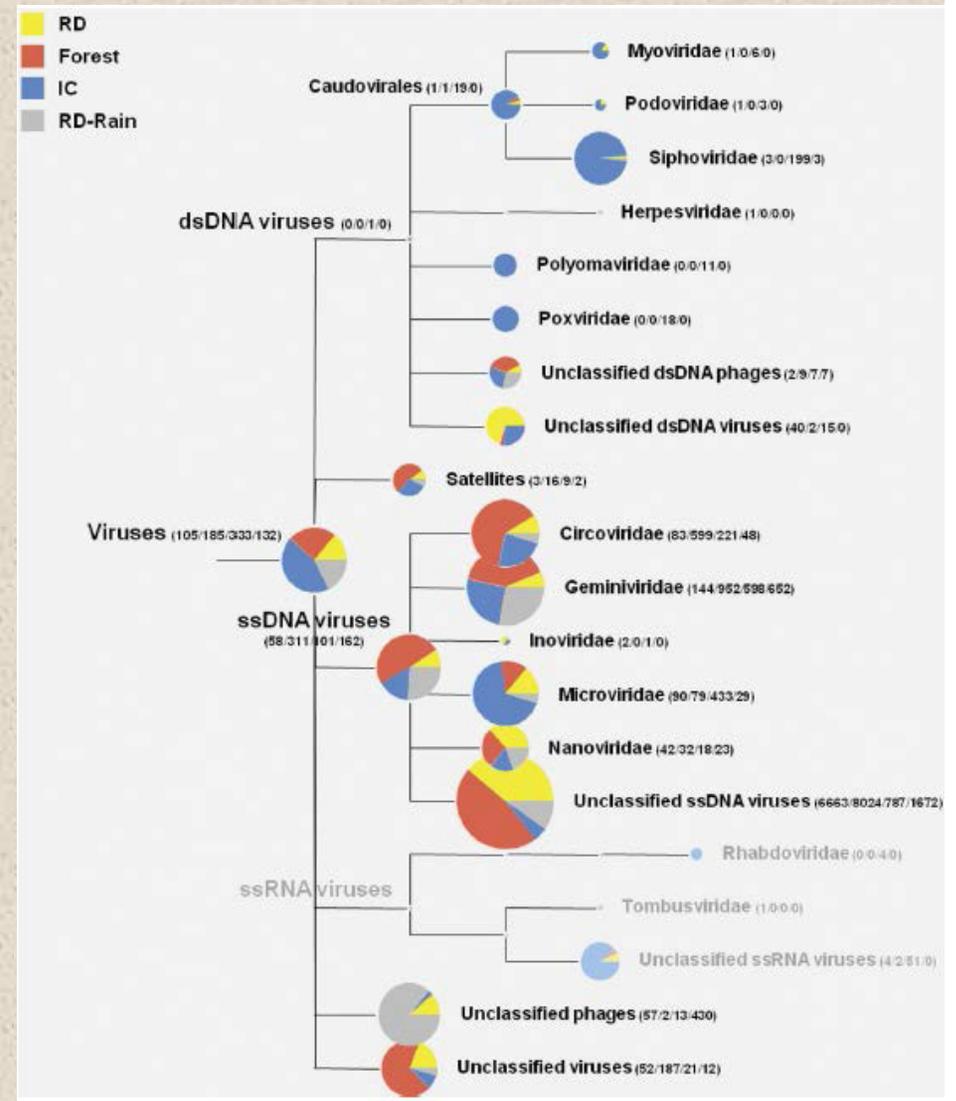
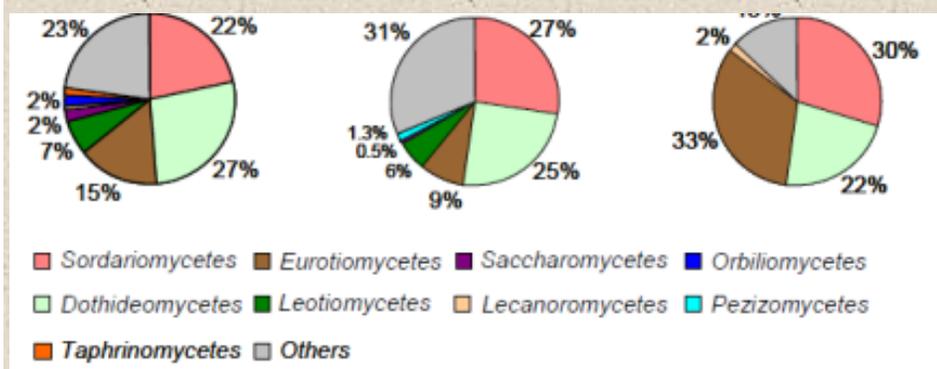
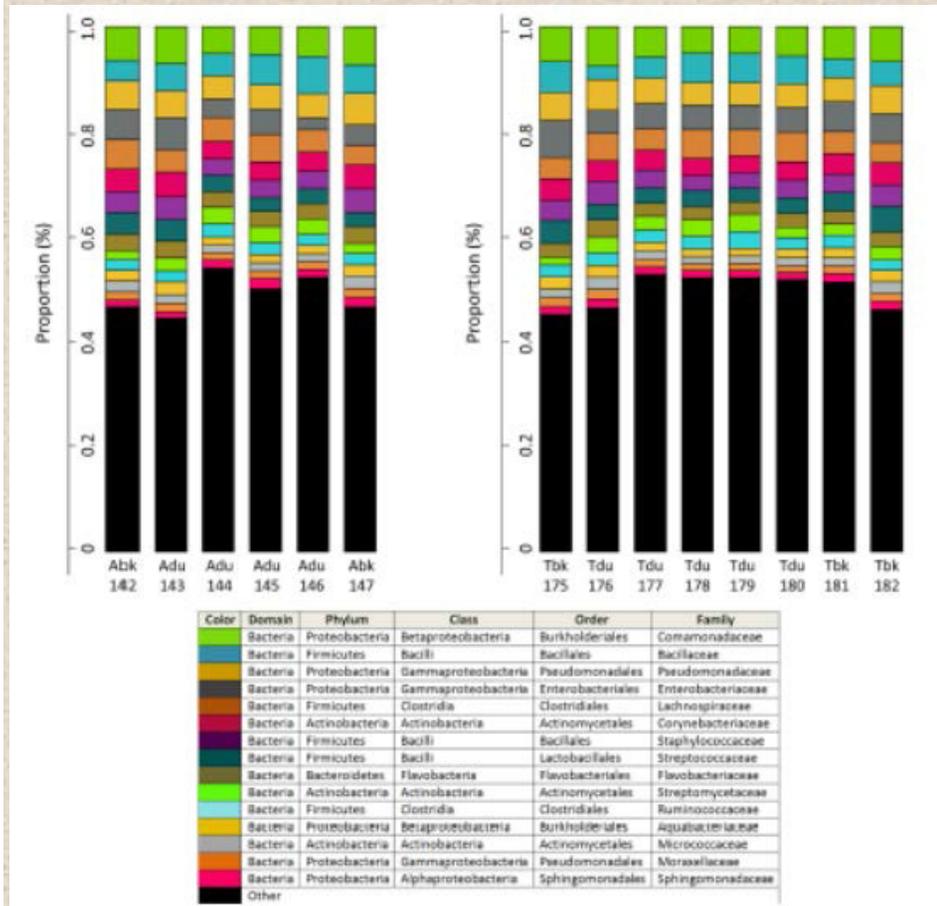
- Adverse effects:
 - Aspergillosis of sea fans (gorgonian corals)
 - Red tides in the Gulf of Mexico



Dust
Iron
Trich.
DON
Gymno.
Red tide

Gymnodinium breve

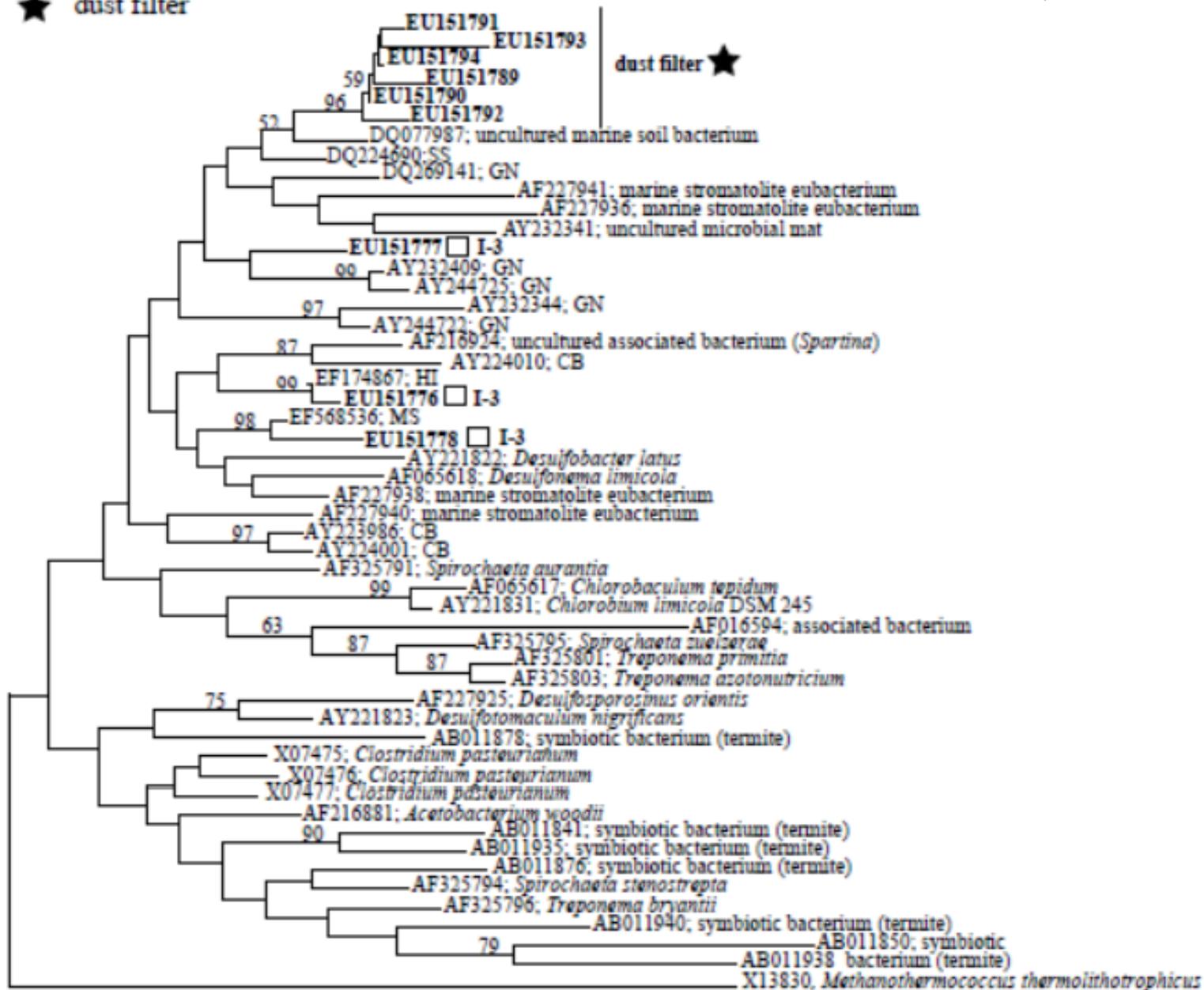
Impact of Airborne Microbes – Limited Data



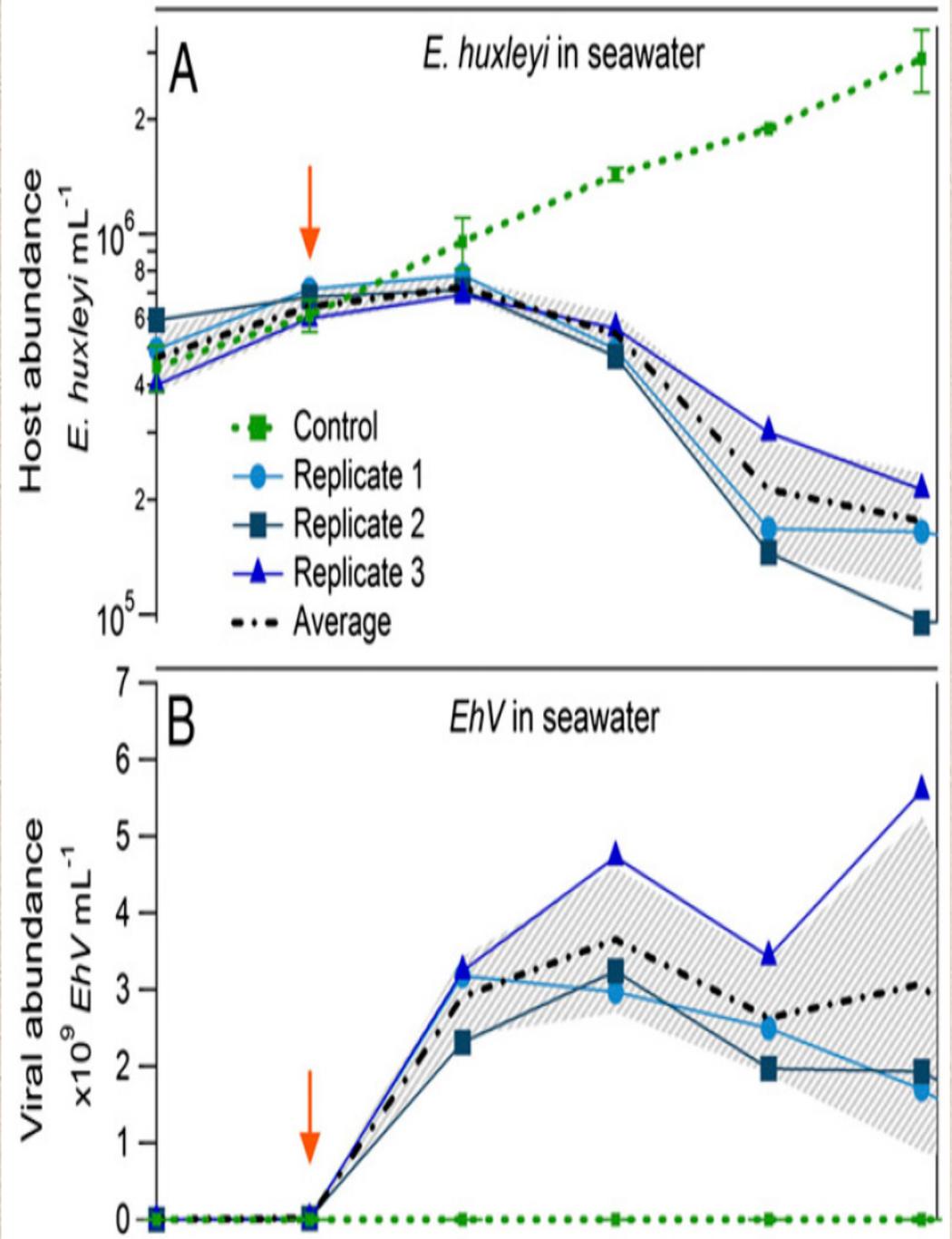
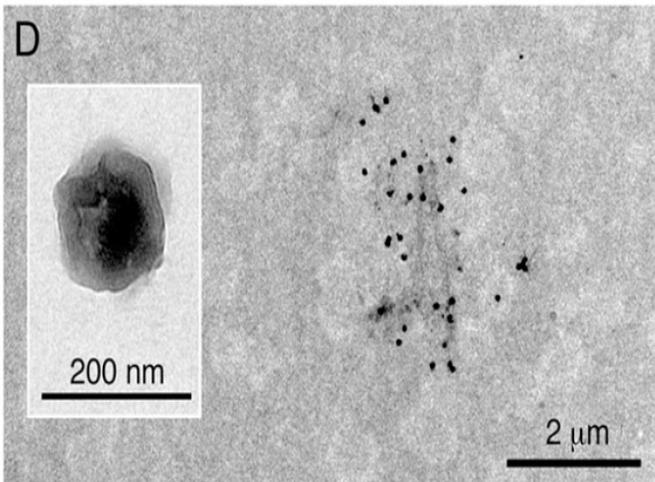
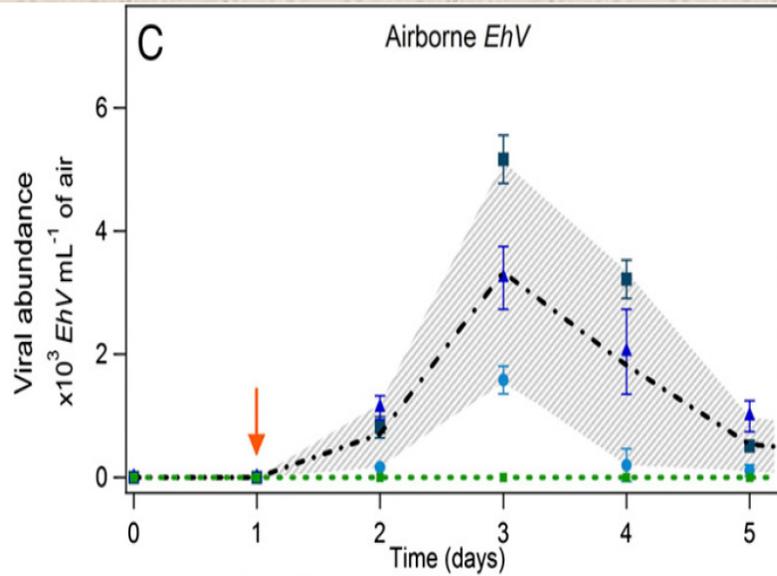
Fall 2006

- 0 m
- ★ dust filter

Foster et al., 2009

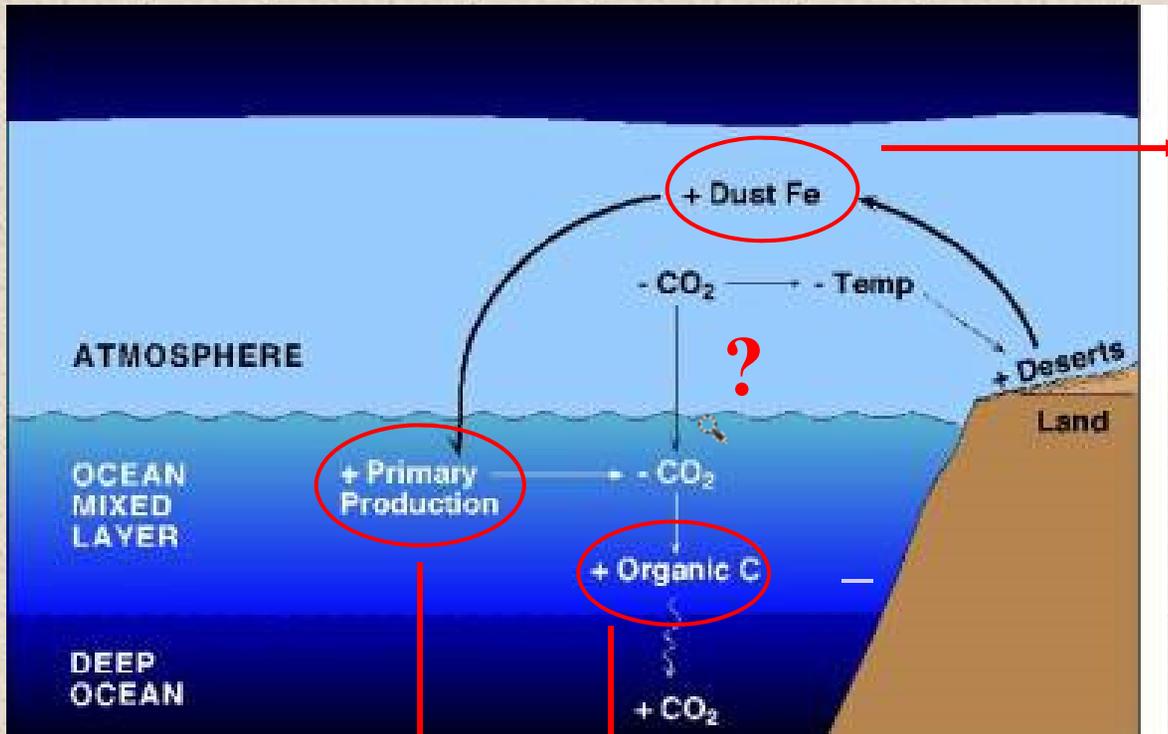


Viruses Dispersal



Change in Paradigm

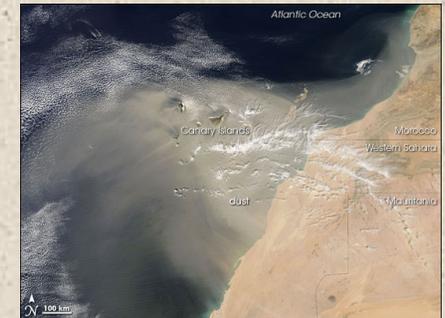
Aerosols



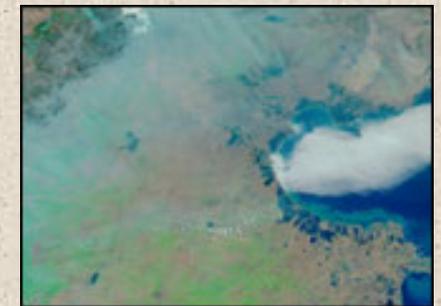
Fires



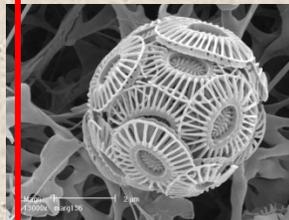
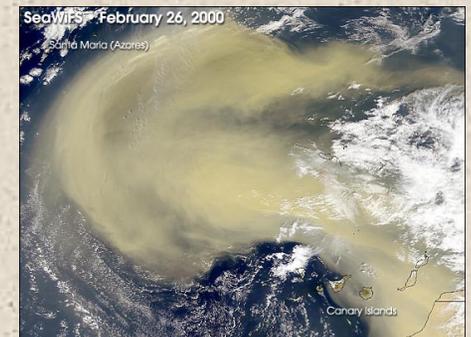
Dust



Mist / Haze



Dust



Mineral Ballast

Acknowledgements

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NATO - Science for Peace
NSF - BIO OCE



Thank you

