Aerosols and Trace Metal Toxicity

Or - It gets more interesting than just fertilization

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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

Diagram showing the impact of aerosols on the atmosphere, ocean, and land. The diagram includes arrows indicating the flow of dust Fe, CO₂, and the effects on temperature and organic carbon. A graph in the inset shows data over depth.
A source of nutrients (N, P) and trace metals (Fe) to the ocean.

<table>
<thead>
<tr>
<th>Element</th>
<th>Riverine(^a)</th>
<th>Atmospheric(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N (excluding N(_2) gas)</td>
<td>1500–3570</td>
<td>2140</td>
</tr>
<tr>
<td>Cd</td>
<td>0.0027</td>
<td>0.0036–0.0063</td>
</tr>
<tr>
<td>Cu</td>
<td>0.16</td>
<td>0.03–0.11</td>
</tr>
<tr>
<td>Ni</td>
<td>0.19</td>
<td>0.24–0.29</td>
</tr>
<tr>
<td>Fe</td>
<td>19.7</td>
<td>519</td>
</tr>
<tr>
<td>Pb</td>
<td>0.01</td>
<td>0.43</td>
</tr>
<tr>
<td>Zn</td>
<td>0.09</td>
<td>0.17–0.92</td>
</tr>
</tbody>
</table>

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

\(^b\) Total (dissolved + particulate) input.

Units = 10\(^9\) moles/yr

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

- Chlorophyll concentration (mg/m³)
- Iron dust

[World map showing distribution of chlorophyll concentration and iron dust]
Impact on Biology

Incubation Bioassay Experiments
Field Observations
4 fold increase in Chl $a$ with N+P additions $\rightarrow$ N+P co-limitation
3 fold increase with dust addition $\rightarrow$ Dust provides N + P
Different Responses

Coastal California

- Baseline
- Control
- Nitrate
- Aerosol

Barbados

- Baseline
- Control
- Phosphate
- Aerosol

Mackey et al., 2010

Chien et al., 2015
N:P = 170
(RFR = 16)

Oschlies & Garcon 1998
Impact on Biology

Paytan et al., 2009, PNAS
Impact on Biology

Nutrients higher in “toxic” aerosol… BUT some metals also higher.
Possible Cu toxicity !!

Toxicity threshold at 0.4 μg Cu μg Chl a⁻¹
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 at 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
Immediate decline in chl after aerosol addition could be due to toxicity.

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

Nagelkerken et al., 1997; Pathogen: soil fungus *Aspergillus sydowii.*

Walsh and Steidinger, 2001
Impact of Airborne Microbes – Limited Data
Foster et al., 2009
Viruses Dispersal

Sharoni et al., 2015
Change in Paradigm

Aerosols

Fires

Dust

Mist / Haze

Mineral Ballast

Dust

ATMOSPHERE

OCEAN MIXED LAYER

DEEP OCEAN

+ Primary Production

+ Organic C

+ Dust Fe

- CO₂ - Temp

+ Deserts

Land

OCEAN MIXED LAYER

DEEP OCEAN

+ Primary Production

+ Organic C

+ Dust Fe

- CO₂ - Temp

+ Deserts

Land

Chemistry
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