Global Patterns of Phytoplankton Dynamics in Coastal Ecosystems: Utilizing long-term data to distinguish human from climatic drivers of ecological change

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(http://wg137.net)
Coastal Ocean: <10% of world's ocean >30% of global marine primary production
Environmental Factors Impacting Coastal Phytoplankton Communities

Positive

- Adequate N & P (low N:P for N\textsubscript{2} fixing taxa)
- Low turbulence (benefits mobile/buoyant taxa, e.g., flagellates, cyanobacteria)
- High (adequate) light
- Elevated temperature (except for low temperature adapted diatoms, chlorophytes)
- Long residence time (benefits slow-growers)
- High DOM high DIC
- Sufficient Fe (+ traces)?
- Low grazing rates (although some fast growers might benefit due to nutrient recycling)?

Negative

- Low N & P (except for N\textsubscript{2} fixers)
- High turbulence (takes away advantage for motile taxa, benefits diatoms)
- Low temperatures
- Low light (for most taxa)
- Short residence time
- Low DOM
- Low Fe (+ trace metals)?
- High grazing rates? (although fast growers will benefit from enhanced nutrient recycling)?
The challenge: Use long-term comparative phytoplankton community structure/function and environmental data sets to identify and “tease apart” key anthropogenic & climatic drivers of ecological change

Key interactive drivers discussed here

• Nutrients: N, P, Si, Fe
• Climatic: temperature, precipitation/FW discharge, circulation/stratification
• Light (transparency, color)
• Top-down: Grazing, predation, trophic interactions
Anthropogenic nutrient (N) inputs & Eutrophication: Atmospheric N Deposition in the Yellow Sea

**CHL\(_{SD}\) (APR-OCT) in the eastern YS**

(Yoo, in preparation)

(Kim et al., 2011)

Fig. 1. (A) Rate of change (µM decade\(^{-1}\)) of N\(^*\) in surface waters (<50 m) of the study area. The red and yellow boxes indicate regions in which the N\(^*\) values tended to increase, and the blue box indicates a region in which N\(^*\) decreased. Boxes with statistically significant N\(^*\) trends are marked with an asterisk (*). (B) 1980-2010 mean rate of change (µM decade\(^{-1}\)) of N\(^*\) at the Yellow Sea and East China Sea.

Fig. 4. Time series of the 3-year mean N\(^*\) (µM) for various depth ranges in (A) the East China and Yellow seas, (B) the East Sea (Sea of Japan), and (C) the Pacific coast of Japan. The colors indicate the N\(^*\) values derived from the data collected at the indicated depth ranges. The dotted lines correspond to N\(^*\) = 0 µM. The error bars are confidence intervals of the resulting N\(^*\), for p = 0.05. The colored lines in (C) not indicated in the legend correspond to the depths indicated in (A) and (B).
The forms of N and P enrichment matter: Effects of DIN, DON and P on HABs in the New River Estuary, NC

Dinoflagellate (Peridinin) biomass and Cyanobacteria (multiple) indicator pigment responses

Karlodinium sp
Scrippsiella trachoides
Anabaenopsis sp
Heterocysts: site of N-fixation

Altman & Paerl 2012.
The Interactive effects of Climate Change (warming & hydrology) on phytoplankton communities

Positive proof of global warming.
Increasing CPR-Chl-a in North Sea

Eutrophication or climate?

Data sources: Continuous plankton recorder (CPR), Europ. Environ. Agency
Nutrients

- Signif. decrease of nutrients in coastal waters and rivers
- Coastal nutrients decrease significantly and negatively correlated with Chl-a
- Open nutrients not correlated with Chl-a

North Sea


Climate

- SST, wind & winter water trans correlated with Chl a
- Open Chl a correlated with SST, NAO, inflow, wind = climate driving phyto-biomass
Phyto. Community changes

Edwards et al. (2006) L&O
Marsdiep tidal inlet (southern North Sea). Sudden Shifts in Phytoplankton Species Composition (1977/1978 & 1987/1988) This is coincident with climatic (precipitation/FW discharge) changes Timing is remarkably “in tune” with larger-scale (North Atlantic) shifts in phytoplankton dynamics

1974-1976
low chl-a
P-limited

1978-1987
high chl-a
N-limited

1988-1994
high chl-a
P-limited

Philippart et al. (2000)
Limnol. Oceanography
45: 131–144.
Changes in abundance/seasonality

Guinardia delicatula Thalassionema nitzschioides Odontella aurita

Helgoland Roads, Germany

Guinardia delicatula is broadening its range

O. aurita: cell numbers decreasing

Reason? In the case of Guinardia, preference for warmer temperatures

Wiltshire et al. 2010
US Mid-Atlantic Coastal Waters: The Neuse-Pamlico Sound System, The US’s Largest Lagoon/Key Fishery: Recent increase in cyanobacterial dominance

Is it solely due to eutrophication????
Seasonal patterns of Chl $a$ and cyanobacterial biomass (zeaxanthin) in the Neuse River Estuary, NC

Gaulke et al. 2010
Relationship of unicellular diazotroph abundances [log10 (nifH copies per liter)] and temperature for *Crocosphaera*. $f = 5.13 - 0.1754x + 0.0638x^2 - 0.0124x^3$.

Moisander et al. 2010 (Science 327: 1512-114).
Temperature affects growth rates influences dominance by various phytoplankton groups

Freshwater discharge (flushing) interacts with temperature to impact phytoplankton composition: Effects on diatom (fucoxanthin) & cyanobacterial (zeaxanthin) dominance in the Neuse R. Estuary, NC.

Diatoms like it cool & fast

Cyanos like it hot & slow

Paerl et al. 2011
Chesapeake Bay: Remotely sensed chl-a from SeaWiFS Aircraft Simulator (SAS II) during low flow ('95) and high flow ('96) years

spring '95, low flow

spring '96, high flow

Harding et al. 2009
Chesapeake Bay CHEMTAX – contrasting flow years

Low

Diatoms
Dinoflagellates
Cryptophytes
Cyanophytes
Chlorophytes
Prasinophytes
Haptophytes

High

Diatoms

Cyanos

Harding et al. 2009
32°S: Patos Lagoon, Brazil

- The world largest choked lagoon
  Area: 10.227 km²
  Hydrographic basin:
  - 201.626 km²

- Main Cities
  North: Porto Alegre Pop.: 1.5 million.
  South: Rio Grande+Pelotas Pop.: ~400,000.
  Rio Grande Harbor
Anthropogenic (Nutrient)- climatic interactions determine phytoplankton community composition and function

*Thau Lagoon, Mediterranean Coast, France*
Climate change and oligotrophication: Thau lagoon, France

- SRP (Soluble Reactive Phosphorus) decreases
- Temperature increases
- Picocyanobacteria increase
- *Alexandrium catenella* increases
Decadal-Scale Changes of Dinoflagellates and Diatoms in the Anomalous Baltic Sea Spring Bloom

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- From 1995-2004, dinoflagellates have increased in the northern and eastern Baltic Sea.

- Shift has mostly been linked to climate variability and changes in the physical environment, since nutrients are not limiting at the beginning of the spring bloom.

- Wintertime mixing and resuspension of benthic cysts, followed by proliferation in stratified thin layers under melting ice favors motile dinoflagelates over sinking diatoms. Motility enables dinoflagellates compete with faster growing, but sinking diatoms.

- Shifts in dominant spring bloom algal groups can have significant effects on ecosystem biogeochemical cycling and trophodynamics.

Figure 5. Shifts in the proportion of dinoflagellates over the period of ten years (1995 to 2004). The predictions were made by geographically weighted linear regression and interpolated with ordinary kriging. Positive and negative values represent the areas of increasing and decreasing dinoflagellate proportion, respectively. Thick contour lines denote boundary between areas of increasing and decreasing trend. doi:10.1371/journal.pone.0021567.g005
Long-term changes in phytoplankton composition in the Gulf of Riga (1976-2008)

Jurgensone et al. (2011) Estuaries & Coasts

Spring composition (Apr - May)

Summer composition (Jun - Sep)

Cyanobacteria  Diatoms  Dinoflagellates  Chlorophytes
The biomass of the summer phytoplankton community was mainly controlled by pelagic grazing, which has declined over the period due to overfishing.

Low DIN:DIP ratios favors cyanobacteria and increasing temperatures cause a shift from dinoflagellates to chlorophytes.
Climatically-driven Changes on Coastal Upwelling due to shifts in North Pacific Gyre Oscillation Effects on San Francisco Bay, CA

Biological ramifications?
A Climate-Driven Trophic Cascade in San Francisco Bay

NE Pacific shifted to its cool phase (+NPGO/ -PDO) after 1998

Intensified upwelling and primary productivity in coastal waters adjacent to SF Bay

Immigration of record-high numbers of marine shrimp, juvenile flatfish & crabs (benthivores)

Disappearance of bivalve suspension feeders

Increased phytoplankton biomass

Cloern & Jassby 2012
Through a Trophic Cascade

PRIMARY PRODUCERS

HERBIVORES

PREDATORS
Scaling up to the Ecosystem

**Nutrient and Hydrologic drivers**

**PHYTOPLANKTON COMMUNITY**

FORM of Limiting Nutrient (NO₃⁻, NH₄⁺, DON)
Nutrient Ratios, Residence Time

**Grazed Phytoplankton Species**

**Nuisance / Toxic Phytoplankton Species**
Some Dinoflagellates Cyanobacteria

**Grazing and Water Column Carbon Recycling**

**Carbon Deposition (POC)**

**DECREASED**
O₂ Depletion Potentials

**INCREASED**
O₂ Depletion Potentials

**OXIC CONDITIONS**

**HYPOXIA ANOXIA**

Linkages Between Nutrient Inputs, Hydrology, Phytoplankton Community Composition, Grazing, Hypoxia and Fisheries Habitat

Nutrient Regeneration
Decomposition of POM

Mixing
Stratification
Conclusions (for now)

- Strong interactions between climatic, nutrient and “top down” factors control coastal ocean phytoplankton dynamics.
- Residence time and ocean-estuary exchange (flushing, transport) determines sensitivity to eutrophication, biogeochemical/trophic changes.
- Nutrient input-phytoplankton growth & bloom thresholds need to incorporate effects of climate change (warming, precip., stratification).

http://wg137.net/
• The bulk of WG137’s data is being managed with the COPEPOD Interactive Time-series Explorer (COPEPOTIDE) data system.

• The data handling process involves the transformation of hundreds of raw data files into a common format, common units, and indexing via a standardized variable identity set.

• WG137 (in cooperation with ICES-WGPME) has assembled a database of over 150 phytoplankton sites.
The WG137 web site ([http://WG137.net](http://WG137.net)) features an interactive map and searching tool that provides data and site contact information as well as a detailed graphical and text summary for each site participating in the WG137 study.

As they become available, this site will also link to research results and publications.