Phytoplankton ➔ Nutrients ➔ Zooplankton ➔ Phytoplankton

Nutrients

Phytoplankton ➔ Zooplankton

Zooplankton ➔ Phytoplankton

Nutrients ➔ Phytoplankton

Nutrients ➔ Zooplankton
Patterns of Productivity

- There is a large “Spring Bloom” in the North Atlantic (temperate latitudes… remember the Gulf Stream!)
What is a bloom?

- Analogy to terrestrial plants, referring to the “spring blooming” of flowers
- Typically short-lived, days to weeks (however, exceptions exist, such as the Texas Brown Tide, which lasted 7 years)
- Defined as a “significant” population increase... modeled after diatom blooms
Diatom Blooms

- Well studied—thought to be caused primarily by 1) increase in nutrients, and/or 2) decrease in grazing pressure, with 3) appropriate physical conditions
- Other (non-diatom) species often thought of as “rogue”, episodic, or inconsequential events
Modern Definition:

- **Non-Toxic species:**
  - A “significant” increase in biomass with time, relative to the mean
  - >100 μg Chl L\(^{-1}\) in coastal waters
  - Deep Chlorophyll Maximum (is this a bloom?)

- **Harmful species:**
  - Measurable harmful impacts, regardless of color, toxicity, cell abundance, etc.
Large-Scale Variability

- Upwelling
- Island Effect
- Domes
- Gyres
- Blooms
- Iron Fertilization
Definitions

Eutrophic: High Productivity
Mesotrophic: Moderate
Oligotrophic: Low Prod.
HNLC: High Nutrient, Low Chl
What controls the large scale patterns?

We would expect that it is some combination of Light, Temperature, Nutrients (bottom up control), and grazing (top down control)…..
Major Ocean Basins

Provides no information about the biology!
57 provinces on the basis of:

- Surface chlorophyll from CZCS
- Vertical distribution of Chl from 21,000 profiles
- Mixed layer depth from NOAA-NODC archive
- Surface nutrients
- Brunt-Vaisala

*Longhurst 1995*
Large Marine Ecosystems of the World
Patterns of Productivity

Barents Sea productivity

(a) Increase

Winter | Spring | Summer | Fall

Patterns of Productivity
Species Succession is embedded within the “bloom”

- can be different species of the same group (e.g. diatoms), or different groups (e.g. diatoms—>dinoflagellates) or even different “strains” of one species....
Patterns of Productivity

- Nutrient-depleted surface water
- Thermocline
- Nutrient-rich deep water

Depth (m)
Sources of Nutrients

1) Upwelling, Mixing
2) Vertical Migration
3) Direct Fixation
4) Exogenous Inputs
5) “Rogue Diatom” Hypothesis
Why is the Spring Bloom in the North Pacific “missing”?

N. Pacific--the Bering Sea blooms, but the rest of the North Pacific is low in biomass
N. Atlantic--widespread blooming of phytoplankton throughout the basin, not just near land
Latitudinal Effects

- Very High Lat, not enough light

- Very Low Lat, not enough variability

- N Atlantic, N Pacific, *should* get two blooms

Figure 3.17 Summary of annual cycles in plankton communities in different regions. The solid black lines represent changes in phytoplankton biomass; the dashed blue lines indicate changes in zooplankton biomass (arbitrary units).
(a)

- **Microscopic algae**
- **Grazers**
- **Sunshine**
- **Nutrients**

(b)

- **Phytoplankton**
- **Zooplankton**

- **Depth**
- **Isothermal**
- **Thermocline**
- **Strong Thermocline**

- **Sunlight**: Lowest (−)
- **Nutrients**: Highest (+)

- **WINTER**: Dec.
- **SPRING**: March
- **SUMMER**: June
- **FALL**: Sept.

- **Dec.**
- **Increasing (↑)**
- **Decreasing (↓)**
- **Highest (+)**
- **Lowest (−)**
- **Increasing (↑)**
Fig. 1.—The major current patterns of the subarctic North Pacific and North Atlantic oceans from 50° to 60°N. The positions of Ocean Weather Stations (OWS) B, I, J (Atlantic) and P (Pacific) are noted.

Fig. 2.—Temperature structure (°C) at OWS P (1957) from Tabata (1961), OWS I (1974) from Monthly Ice Charts (1974), and OWS B (1950) from Kielhorn (1952).
Fig. 3.—Average seasonal change in chlorophyll a (in mg·m$^{-2}$) at OWS P (1959–1970) from Anderson et al. (1977) and OWS I (1971–1975) from Robinson (unpubl. data).

Fig. 4.—Average seasonal change in primary productivity (0–50 m) at OWS P (1960–1966) from McAllister (1969) and OWS I (1971–1975) from Robinson (unpubl. data).
Behavior: Multiple Days

Migration by Growth Stage
Copepods produce eggs as a function of:
- Water Temperature
- Time of Year
- Availability of Prey

Egg production occurs mostly at night, when at depth

Development of early stages at depth is advantageous because:
- Fewer predators
- Can’t swim yet
- Minimizes advective losses

Figure 2.5 Copepods. (A) Typical copepod showing major anatomical features. (B) Outline of the typical life cycle of a copepod.
Figure 2.24 (A) The life cycle of *Calanus finmarchicus* in the North Atlantic Ocean. (B) The life cycle of *Neocalanus plumchrus* in the North Pacific Ocean.
What about Iron?

-The deep concentrations of iron are very similar in the North Pacific and North Atlantic (bottom panel), but the surface concentrations are very low in the North Pacific compared to the North Atlantic (top panel)

http://www-paoc.mit.edu/cmi/applications/biogeochemical.htm
Ecumenical Iron Hypothesis:

1) In the North Atlantic, Iron is not limiting, but in the North Pacific, Iron is limiting to diatoms--smaller cells are less iron limited, but are heavily grazed.

2) In the North Atlantic, there is very deep winter mixing (NADW forms); In the North Pacific, there is no deep water formation.

3) In the North Atlantic, zooplankton “bloom” after the phytoplankton, but in the North Pacific, zooplankton are present all year.

4) Iron limits diatom growth in the N. Pacific, and the macro- and micro-zooplankton control the limited diatom blooms and blooms of other organisms!