Chapter 8
Primary Productivity - Chemical Tracers (4/18/01)

This week we start a discussion of the production and destruction of organic matter by photosynthesis and respiration. Much of this may have been covered in biological oceanography but here we talk about biological oceanography from a chemical oceanography perspective, with an emphasis on chemical tracers and feedbacks.

The topic is important for three key reasons:
1. One cannot understand the chemistry of the oceans without considering biological influences.
2. To understand the limits on biological production in the oceans, we need to understand the underlying chemical constraints (especially the macro (e.g. N and P) and micro (e.g. Fe and Zn) nutrients).
3. The balance between ocean productivity and respiration is called export production. Export production is the flux of biologically produced organic carbon from the surface ocean to the deep ocean and is also referred to as the biological pump. This biological pump is a primary control on atmospheric CO_2 . Changes in the magnitude of the biological pump are one of the main explanations for why atmospheric CO_2 was lower during glacial times than during interglacials. It is important for us to understand how the biological pump might change in response to increases in anthropogenic CO_2 and global warming.

Units

Many different units are used for primary production. The most common are mmolC m^{-2} d^{-1}, mgC m^{-2} d^{-1} , gC m^{-2} y^{-1}, and Gt C y^{-1}. This can be very confusing, especially at meetings where in successive talks each speaker uses different units. Chemical Oceanographers always recommend that moles be the preferred unit, i.e. mmol C m^{-2} d^{-1}. Use of moles makes comparison of stoichiometric ratios between nutrients and carbon easier.

Global view of primary production:
A map of the distribution of primary production in the global ocean is shown on the following page (**Fig 8-1**). This version was prepared by Berger et al (1989) and is based on literature data.

Note the **general patterns**:

central gyres	low
equatorial zones	high especially toward the eastern boundaries
coastal regions	high
Arabian Sea	high!
circumpolar region (>50°S)	mostly no data but moderatly high when available

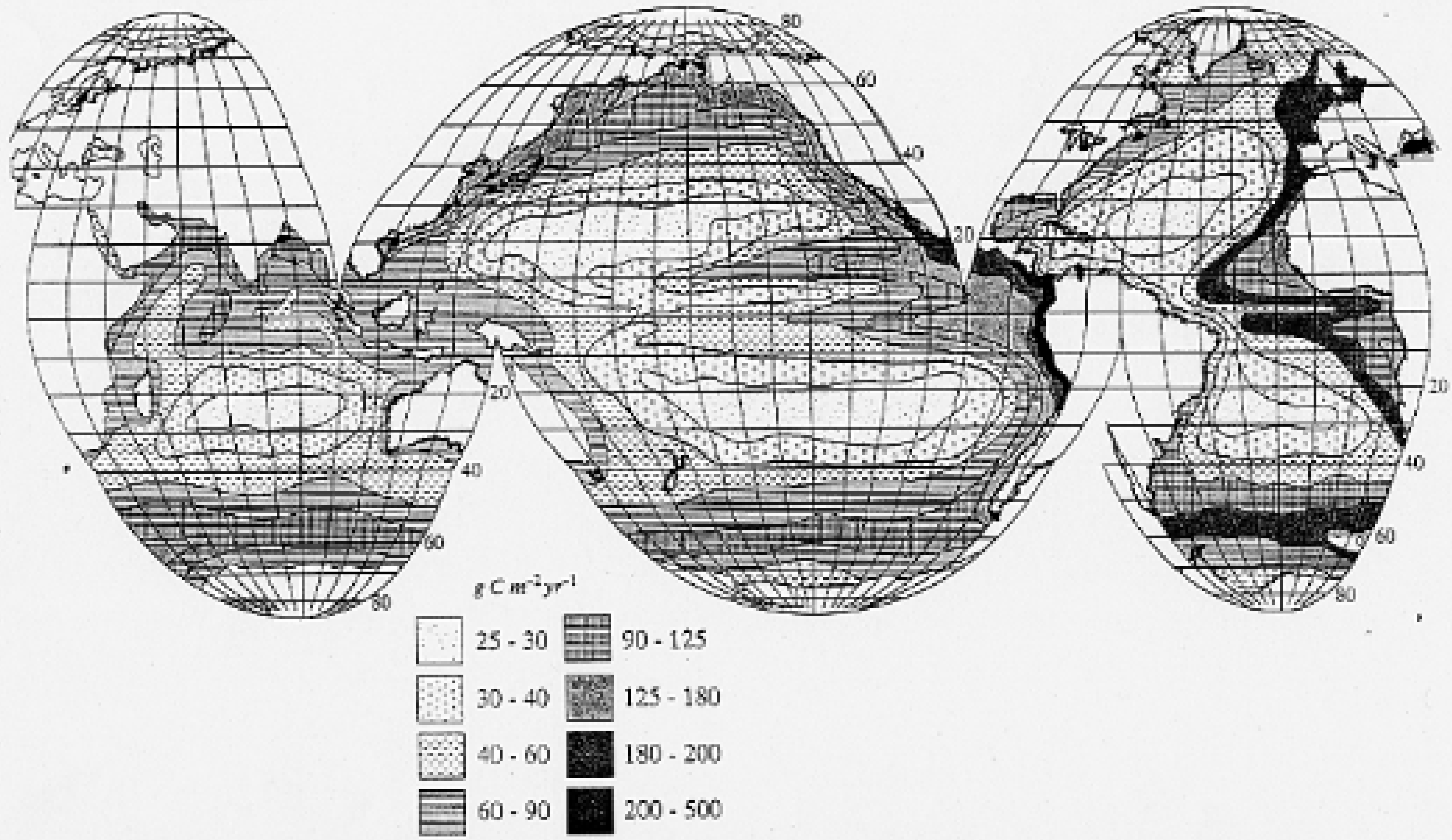

Figure 11.1 *Map of the distribution of net primary production in the world ocean, combining about 9000 measurements, mostly by the ^{14}C method, with estimates based on the phosphate concentration in regions without productivity data. From these data Berger et al. (1988, 1989) estimated the world total to be 27 Gt per year, expressed as carbon.* (Berger et al. 1989, with the coding key from Berger et al. 1988.)

(From Pilson 1998)

There have been many different estimates of the **total amount of primary production** in the ocean. A few examples are listed here. It is interesting to note that the estimates of the total have doubled in the past decade since satellite data have been available and there is general consensus that the correct value is about 50 Gt C y^{-1}. Pilson (1998) also supports the larger value (see attached table).

Table 8-1 Historial estimates of ocean primary production

	Value (Gt C y^{-1})	
Koblents-Mishke et al (1968)	23	
Ryther (1969)	20	
Eppley and Peterson (1979)	19.1	
	23.7	**The best value
Romankevich (1984)	25	appears to be about
Martin et al (1987)	51	50 Gt C y^{-1}**
Berger et al (1987)	26.9	
Field et al (1998)	48.5	

Note: 1 Gt = 1Pg = 10^9 tons = 10^{12} kg = 10^{15} gms

The total (marine plus terrestrial) global annual net primary production (NPP) has recently been estimated to be 104.9 Pg of C per year (Field et al., 1998), with similar contributions from the terrestrial (56.4 Pg of C (53.8%)) and oceanic (48.5 Pg of C (46.2%)) regimes. NPP is defined as the amount of photosynthetically fixed carbon available to the first heterotrophic level in an ecosystem. It can be expressed as the difference betwen autotrophic photosynthesis and respiration. This estimate was made using satellite date and the co-called CASA-VGPM biosphere model. In general NPP for both land and ocean models is determined from the absorbed photosynthetically active (400 to 700 nm) solar radiation (APAR) and an average light utilization efficiency (ε).

$$NPP = APAR \times \varepsilon$$

Models based on this approach are diverse in detail but they are all connected to global-scale satellite observations.

A color map of net primary production (NPP) for the terrestrial and marine biosphere is shown in **Fig 8-2** (from Field et al , 1998).

Even though the total amounts are about equal the amounts per area are greater on land than in the ocean. Average NPP on non-ice covered land is 426 g C m^{-2} yr^{-1} while in the ocean it is 140 gC m^{-2} yr^{-1}. The lower NPP per unit area of the ocean largely results from competition for light between phytoplankton and their strongly absorbing medium, seawater. Only about 7% of the incident radiation as photosynthetically active radiation (PAR) is absorbed by the phytoplankton, with the remainder absorbed by water and dissolved organic matter. In contrast terrestrial plants absorb about 31% of the PAR incident on land. Even though primary producers in the ocean are responsible for nearly half the total NPP, they represent only 0.2% of the global producer biomass. Thus, the