Ultrafiltration high molecular weight DOM (HMWDOM)

>1000 D
DOM fraction
30-35% TOC

membrane filter

< 1000 D
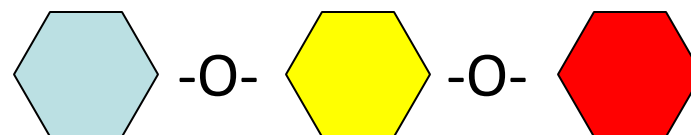DOM fraction
65-70% TOC
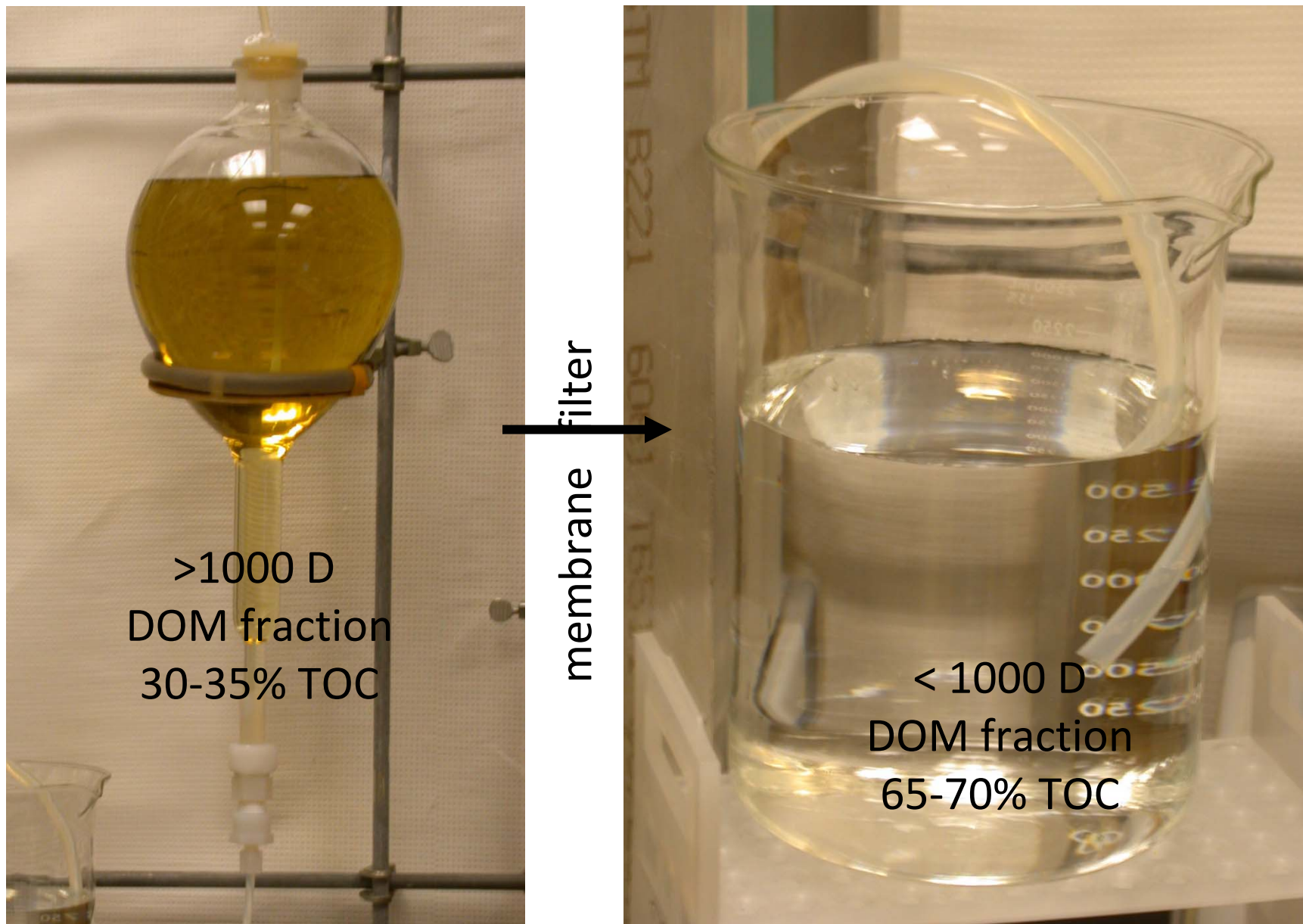
Photos from Dan Repeta

**Final product
30-35% of total DOC**

Spectral and chemical analyses of HMWDOC

Carbohydrate
50-70% of HMWDOC

^{13}CNMR

Acid
hydrolysis
→

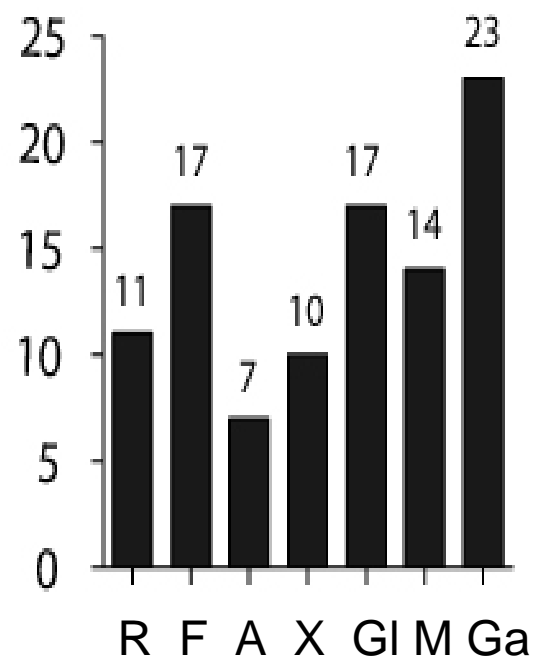-O- -O-

Acid hydrolysis followed by
Monosaccharide analyses
yields 7 major neutral sugars
that represent 5-10% of surface water DOM

200   150   100   50   0
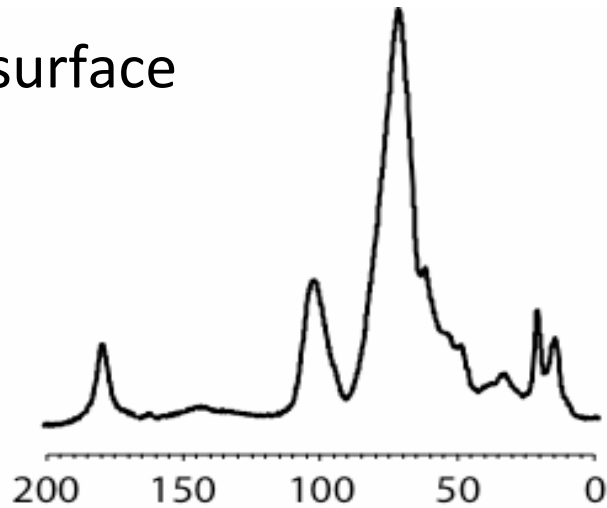
25
23
20
17   17
11   14
15   10
10   7
5
0

R F A X Gl M Ga
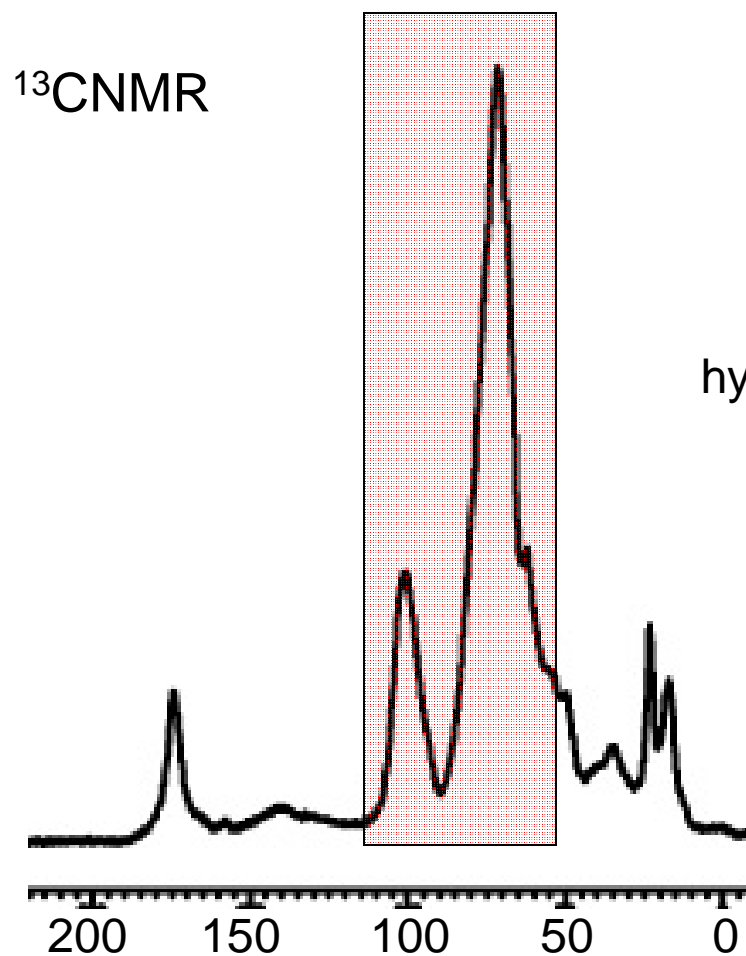
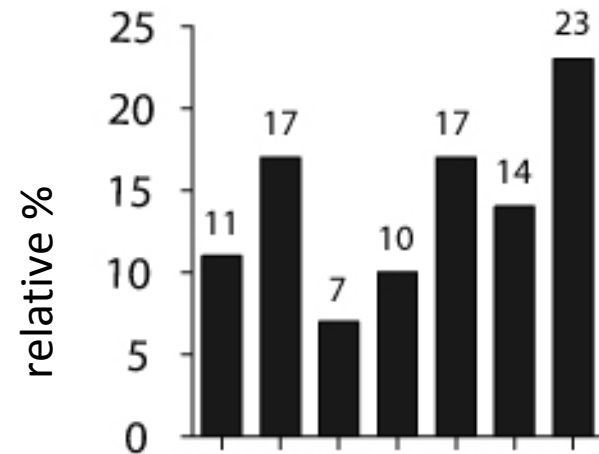# NMR and carbohydrate analyses of deep sea HMWDOC

monosaccharide distribution

surface

deep

Bomb ^{14}C

Cosmogenic ^{14}C production

Fossil fuel dilution

Atmosphere

Air-Sea Exchange

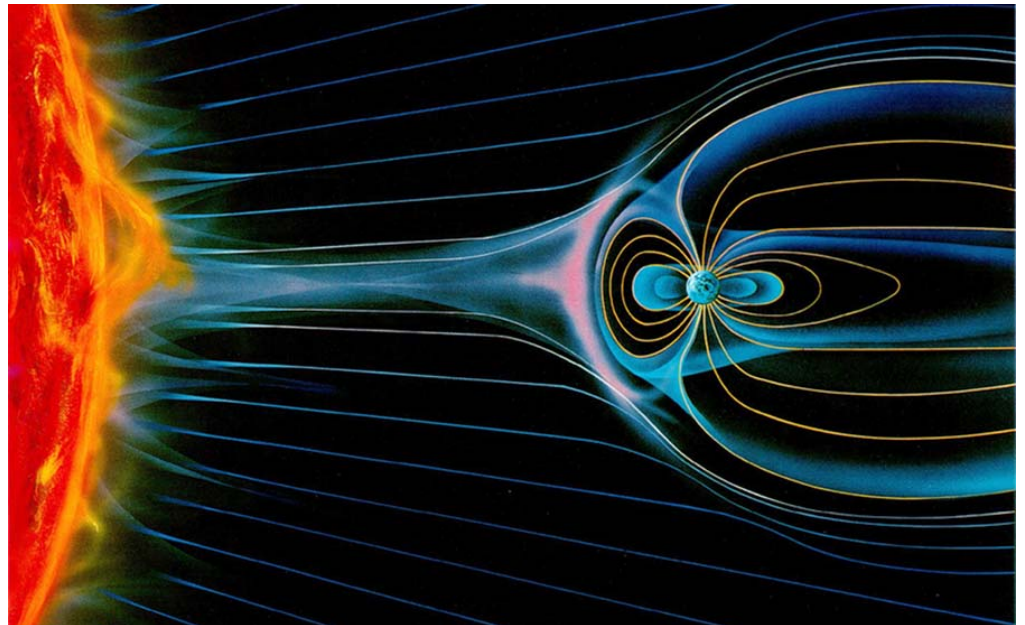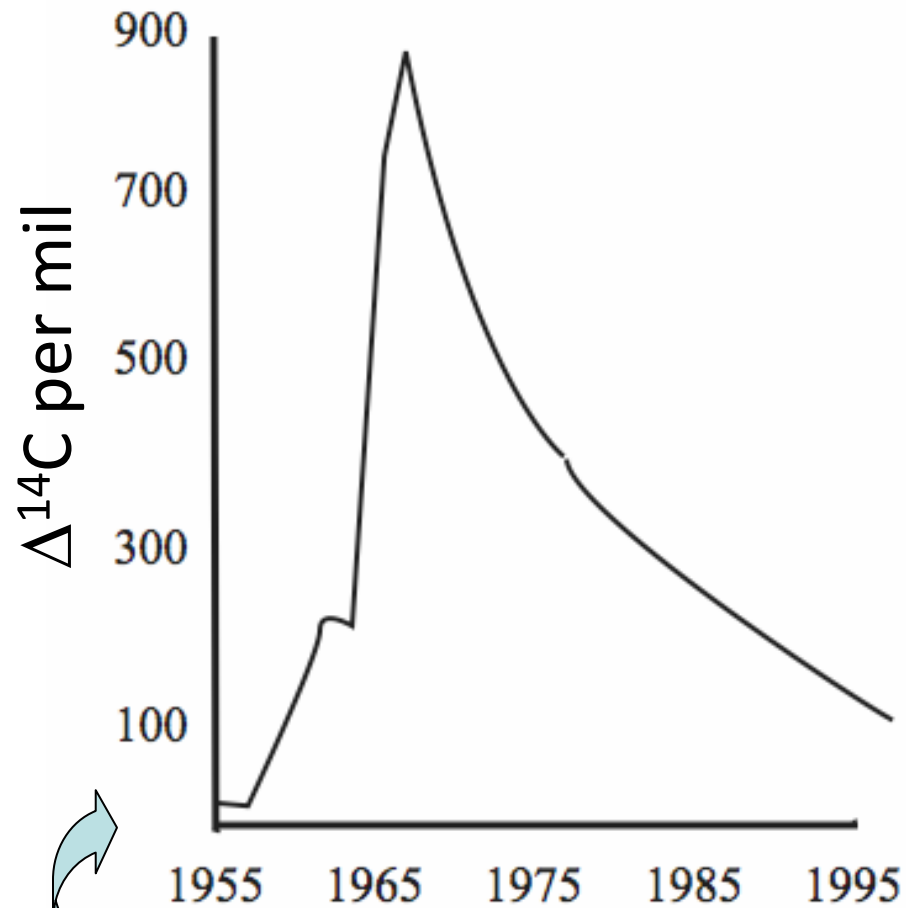Surface Ocean

Deep Ocean
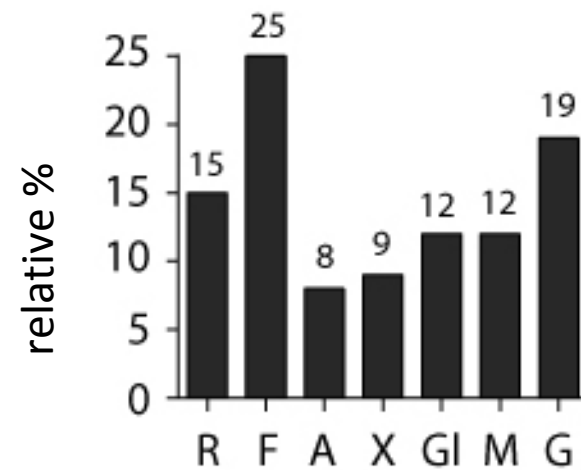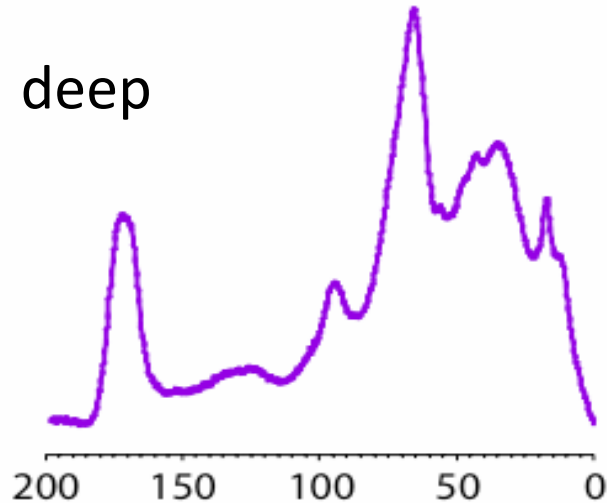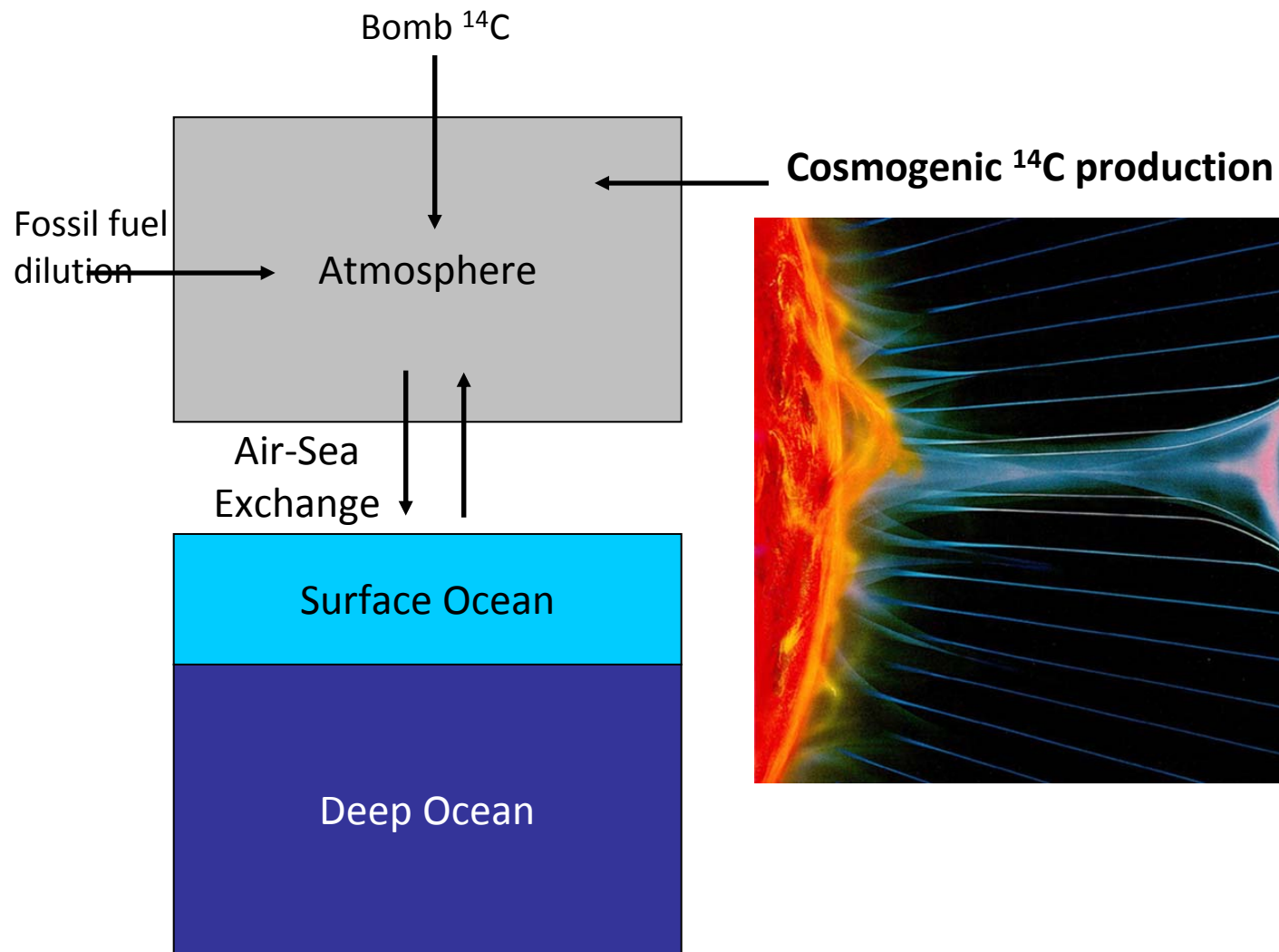
Factors controlling ^{14}C in atmospheric and oceanic reservoirs

^{14}C half-life is 5730 years

History of radiocarbon in the Atmosphere and ocean

$\Delta^{14}C$ per mil

900
700
500
300
100

1955   1965   1975   1985   1995

Prebomb value of -80 per mil

Frigate shoals

200
150
100
50
0
-50
-100

1960   1970   1980   1990

Fiji

Galapagos
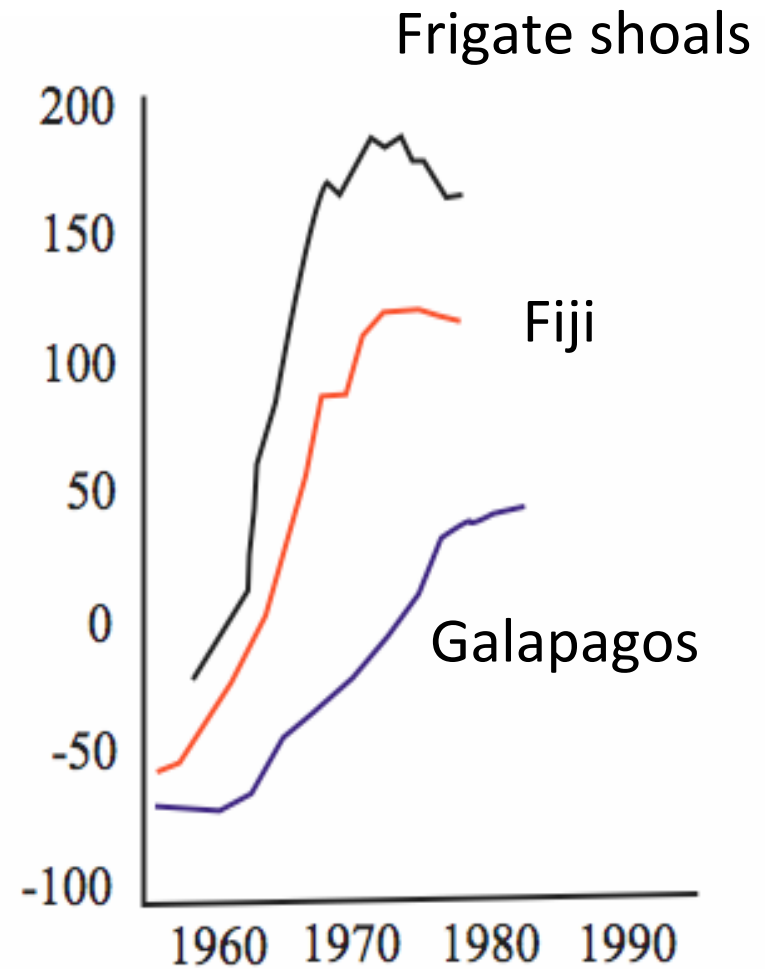
DOC cycling via DO^{14}C

Williams, Oeschger, and Kinney; Nature v224 (1969)

Natural Radiocarbon Activity of the Dissolved Organic Carbon in the North-east Pacific Ocean

THE "age" of the dissolved organic matter in the deep sea relative to its origin in the euphotic zone has been a matter of conjecture for some time[1-3]. Photosynthetic fixation of carbon dioxide into plant carbon by phytoplankton and subsequent biochemical oxidation or solubilization of organic carbon takes place primarily in the upper 0–300 m of the sea. A small, as yet unknown, fraction of this organic carbon is transferred into the deep water by physical processes such as turbulent mixing and sinking of surface water at high latitudes. In addition, particulate organic carbon which sinks from the surface may be converted into dissolved organic matter at depth. In order to determine how "old" this dissolved organic carbon is, its natural radiocarbon activity has been measured for two deep-water samples taken off southern California.
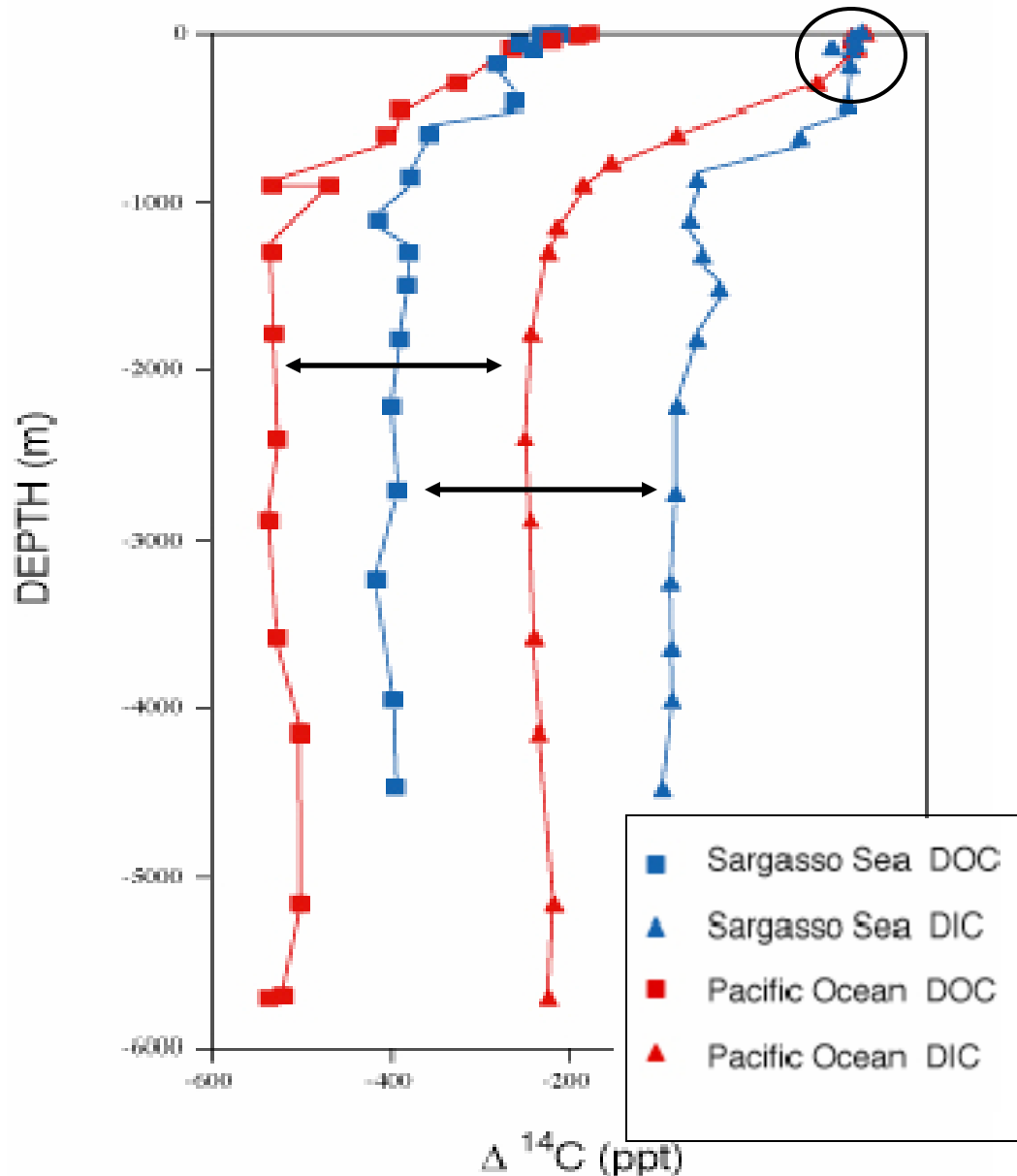
The dissolved organic carbon was converted to carbon dioxide (and subsequently to methane for radiocarbon counting) by photo-oxidation with high energy ultraviolet radiation[4] (Fig. 1). Seawater was collected with a 100 l. stainless steel sampler and stored in 200 l. pre-leached steel drums lined with polythene (no increase in organic carbon was detected during the storage period before analysis). Pre-filtration to remove particulate organic matter was not necessary because its concentration was less than 5 µg/l. The seawater was acidified to pH 2 with hydrochloric acid, sparged free of inorganic carbon (99–97 per cent) with oxygen gas and irradiated in 60 l. batches for 20 h. using a 1,200 W mercury-arc lamp (Hanovia Engelhardt '189 A'). The carbon dioxide so formed was sparged from the seawater with oxygen gas and trapped in strontium hydroxide as strontium carbonate. Complete oxidation was ascertained by comparison of the carbon dioxide in the irradiated seawater (detected by a Beckman model 15 infrared analyser) with the amount of carbon dioxide resulting from the wet combustion of the organic carbon in the seawater before oxidation[5,4]. The strontium carbonate was collected by filtration, washed with water in a nitrogen atmosphere and then dried in vacuo.

UV photooxidation
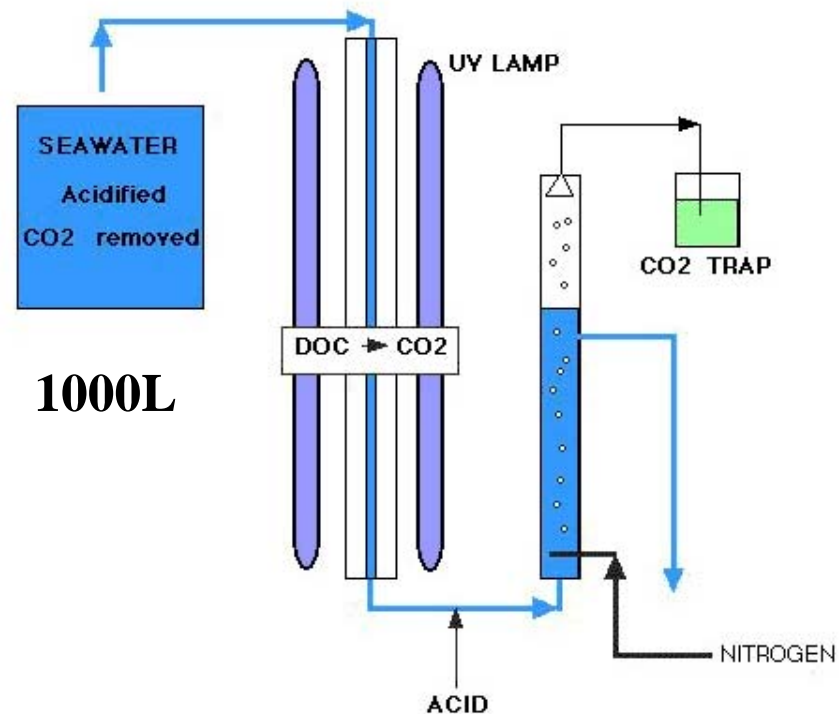
Depth	Δ14C(‰)	Age
1880m	-351 ‰	-3470±330 ybp
1920m	-341 ‰	-3350±300 ybp

Radiocarbon in the Atlantic and Pacific Oceans

Peter M. Williams and Ellen Druffel; Nature 1987, JGR 1992

DEPTH (m)

0
-1000
-2000
-3000
-4000
-5000
-6000

-600   -400   -200

■ Sargasso Sea DOC
▲ Sargasso Sea DIC
■ Pacific Ocean DOC
▲ Pacific Ocean DIC

Δ ^{14}C (ppt)

DIC ^{14}C in surface waters of the Atlantic and Pacific has the same isotopic value.

DOC is always older than DIC (by 4 kyrs in surface water)

Deep ocean values of DOC are equal to a radiocarbon age of 4000-5000 yrs

Either there is a source of "old" DOC, or DOC persists for several ocean mixing cycles

- Very difficult to directly measure the flux of carbon from primary producers into the microbial loop.
  - The microbial loop is mostly run on labile (recently produced organic matter) - - very low concentrations (nM) turning over rapidly against a high background pool (μM).
  - Unclear exactly which types of organic compounds support bacterial growth.

Bacterial Production

•**Bacterial production (BP) is the rate that bacterial biomass is produced. It is the net movement of organic matter from a nonliving pool (DOM) to a living pool (bacterial biomass).**

•**Mathematically**

$P = \mu B$

μ = specific growth rate (time^{-1})

B = bacterial biomass (mg C L^{-1})

P= bacterial production (mg C L^{-1} d^{-1})

•**Note that** μ = P/B

•**Thus, P has units of mg C L^{-1} d^{-1}**

Bacterial production provides one measurement of carbon flow into the microbial loop

Heterotrophic bacteria

??

Dissolved organic matter
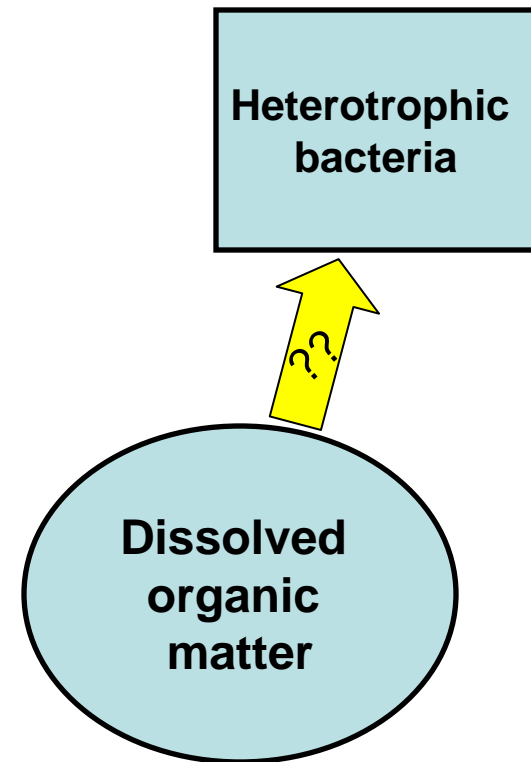
Production

(Δ biomass/time)

(mg C L^{-1} d^{-1})

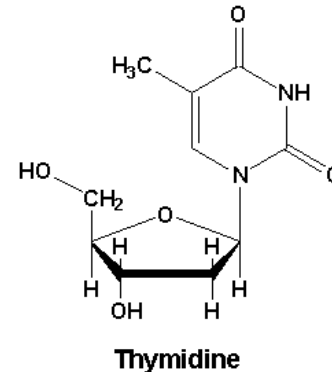- **^{3}H-thymidine**
- **^{3}H or ^{14}C-leucine**

Note: these are NOT direct measures of biomass production (i.e. carbon)

Bacterial Production –
Advantages and Disadvantages of selected methods

- **Thymidine** nucleoside of thymine; DNA precursor (see Fuhrman and Azam 1980). Measures DNA production rates.

  Pros: specific to heterotrophic bacteria

  —**Cons:** difficult to measure intracellular dilution, undergoes catabolism
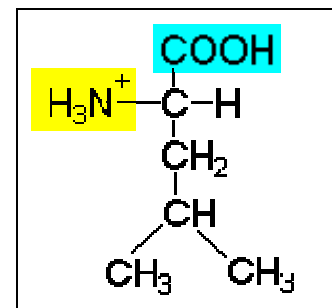

Thymidine

- **Leucine-** amino acid; incorporated into protein (see Kirchman et al. 1992). Measures Protein production rates.

  —**Pros:** more sensitive than thymidine (intracellular protein>>DNA)

  —**Cons:** some cyanobacteria can utilize; difficult to measure isotope dilution.

Leucine

Measuring Bacterial Production

^{3}H-thymidine or leucine

SW + isotope

Whole SW

SW + isotope

Incubate at *in situ* temperature, typically in the dark (if interested in heterotrophic production)

Concentrate plankton or nucleic acids

Extract DNA and protein.
Count radioactivity and convert to rate of production (ng C L^{-1} d^{-1})
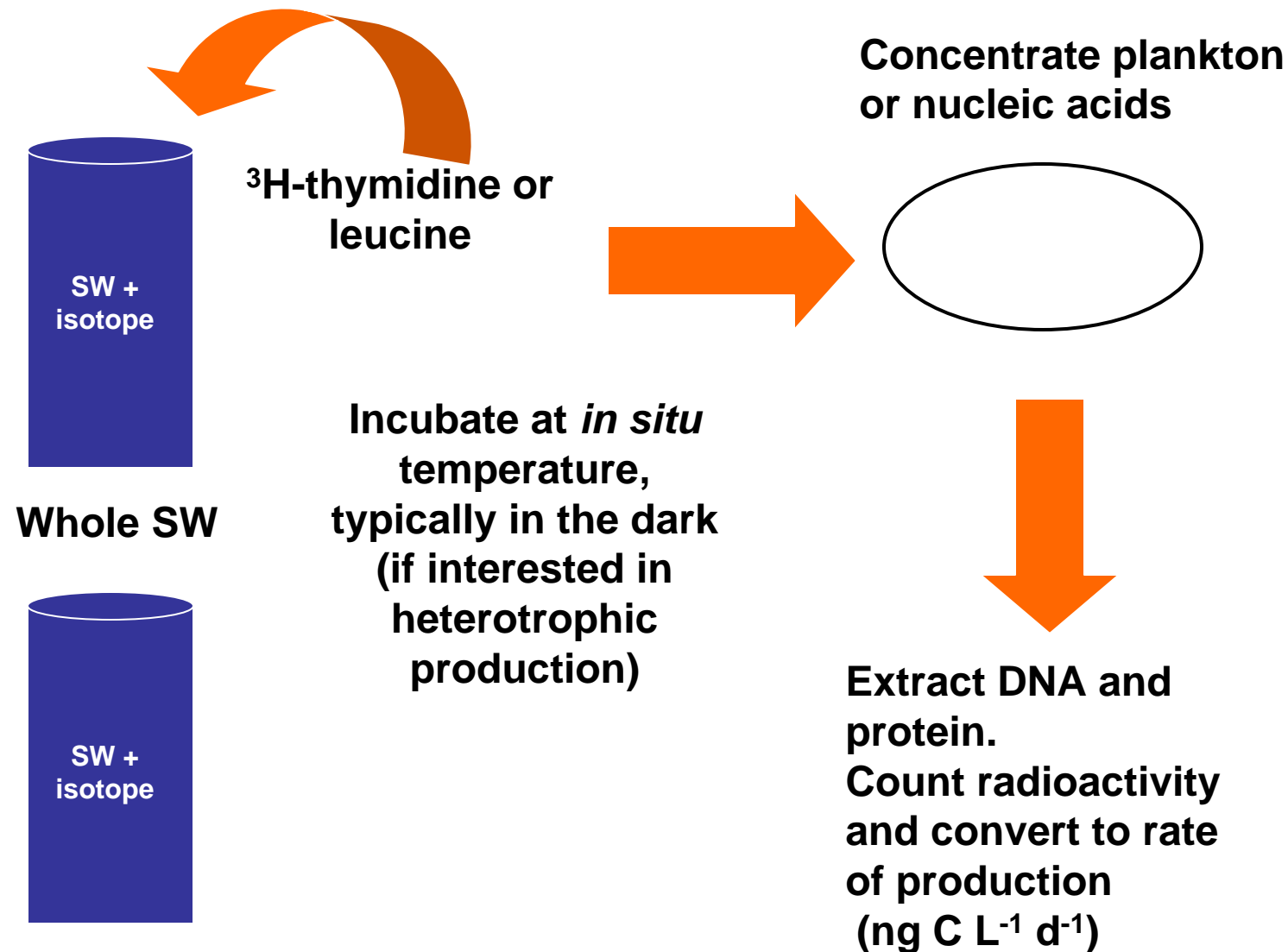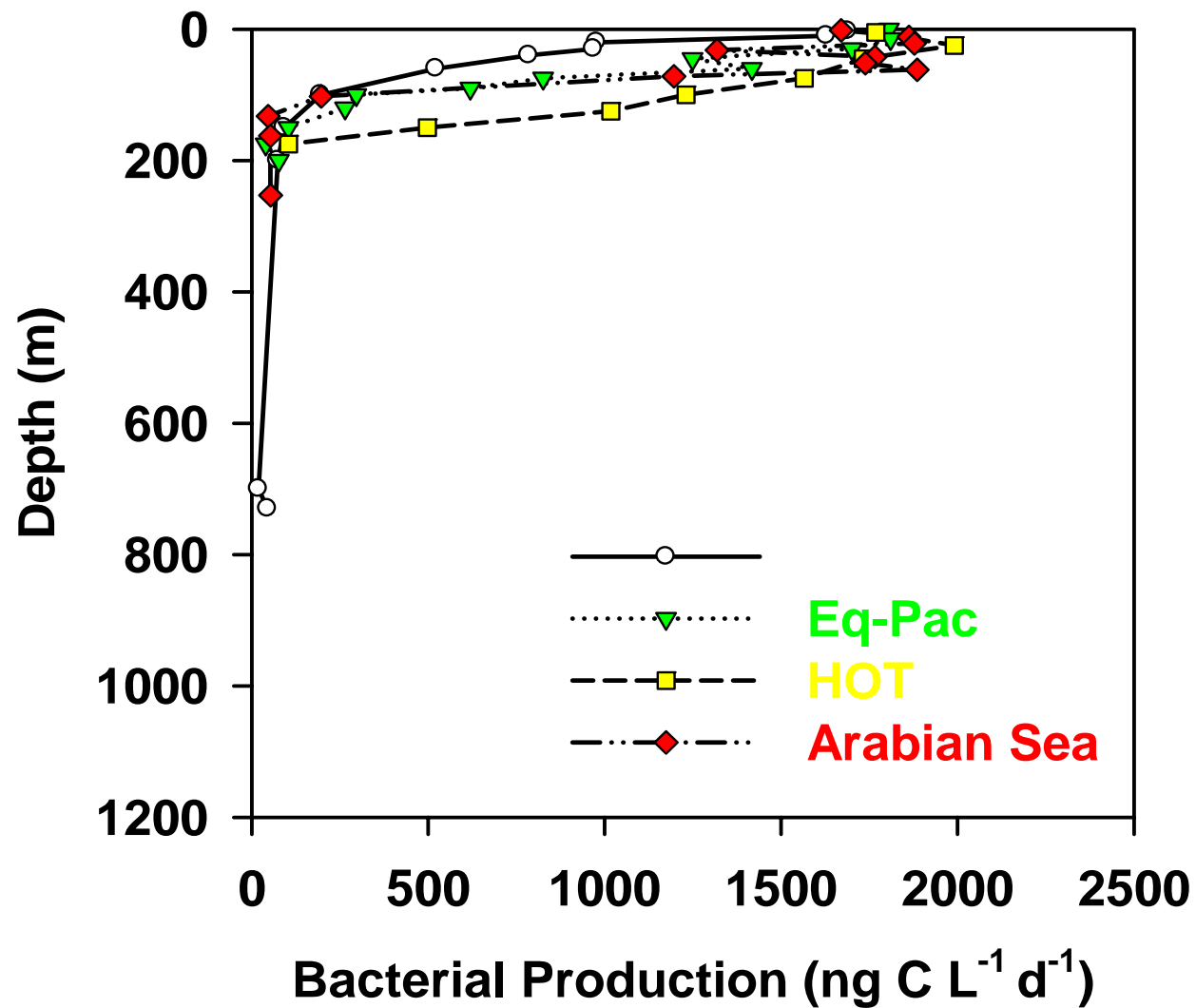
Phytoplankton and bacterial biomass, production and growth in various ocean ecosystems

Location	Bact. Biomass (mg C m⁻²)	Phyto. Biomass (mg C m⁻²)	BactB: PhytoB	BactP (mg C m⁻² d⁻¹)	1° Pro (mg C m⁻² d⁻¹)	1° Pro: PhytoB (d⁻¹)	BactP: BactB (d⁻¹)	1° Pro: BactP
Sargasso Sea	659	573	1.2	70	465	0.8	0.1	0.15
North Atlantic Bloom	500	4500	0.1	275	1083	0.2	0.6	0.25
Subarctic North Pacific	571	447	1.2	56	629	1.4	0.1	0.09
Station ALOHA	750	447	1.7	106	486	1.1	0.1	0.22
Arabian Sea	724	1248	0.6	257	1165	0.9	0.4	0.22
Average Stand dev. CV (%)	641 105 16	1443 1741 121	1.0 0.6 65	153 105 69	766 334 44	0.9 0.4 48	0.3 0.2 79	0.19 0.07 35

Bacterial biomass, growth and production in the oceans

- Bacterial **biomass** is typically 50-100% of phytoplankton **biomass**. In oligotrophic ecosystems, bacterial biomass can exceed phytoplankton biomass.

- Bacterial **production** typically ranges ~10-30% of primary **production**.

- Bacterial growth rates range 0.1 to 0.5 d^{-1} (equivalent to doubling times of ~1 to 7 days).

- Top down pressures control biomass, bottom up factors control growth.

Quantifying fluxes of carbon/nutrients through bacteria also requires knowledge of bacterial respiration

DOM

CO_2, NH_4^+, PO_4^{3-}

Bacterial Biomass

Regeneration of nutrients

BP ~10-30% PP

Available to food web

Higher trophic levels