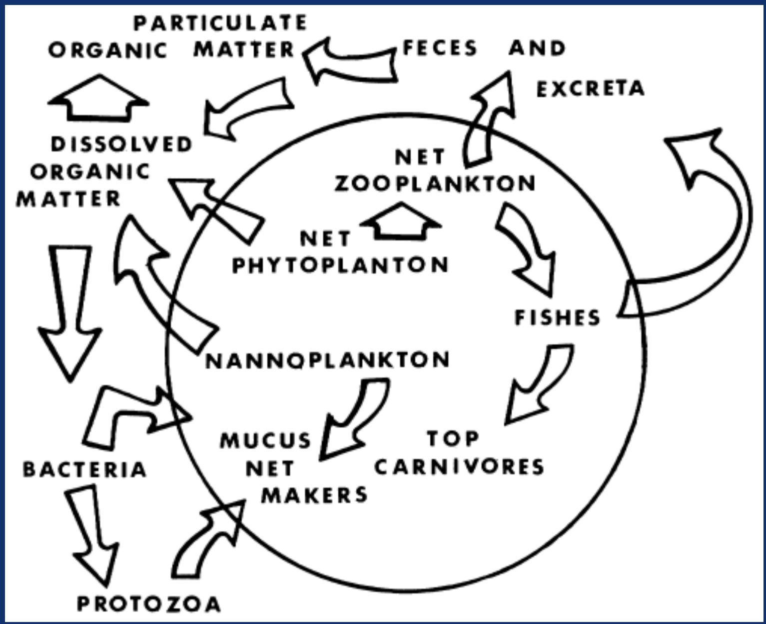
Microbial cycling of dissolved organic matter

MOG Lecture 8
March 1st, 2011

Microbial cycling of dissolved organic matter

- The inclusion of microbes in marine food webs
- Microbial production (from 2 perspectives)
- Microbial consumption (from 2 perspectives)
- Discuss Cottrell & Kirchman and Kujawinski review
- Recitation date/time

"I presume that the numerous lower pelagic animals persist on the infusoria, which are known to abound in the open ocean: but on what, in the clear blue water, do these infusoria subsist?"
- Charles Darwin (1845)

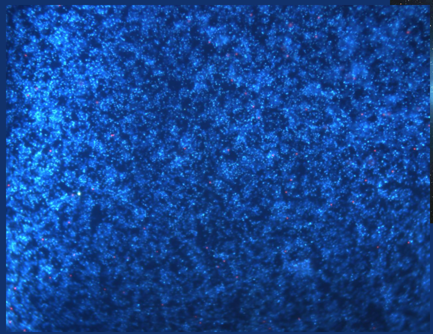


Pomeroy *Bioscience* 1974

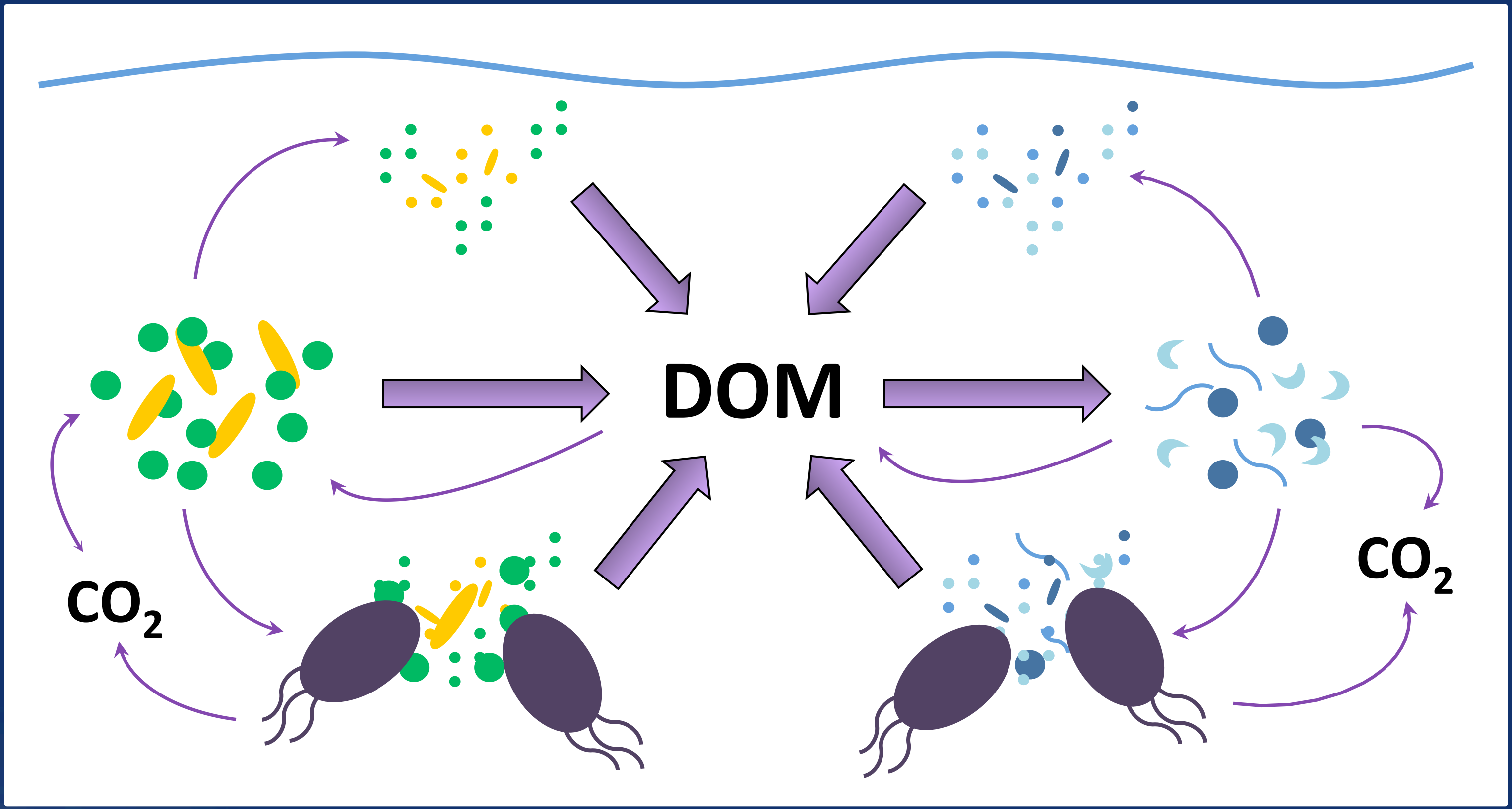
"Basic to the understanding of any ecosystem is knowledge of its food web, through which energy and materials flow. If microorganisms are major consumers in the sea, we need to know what kinds are the metabolically important ones and how they fit into the food web."
- Lawrence Pomeroy

Microbial Dominance in the Sea

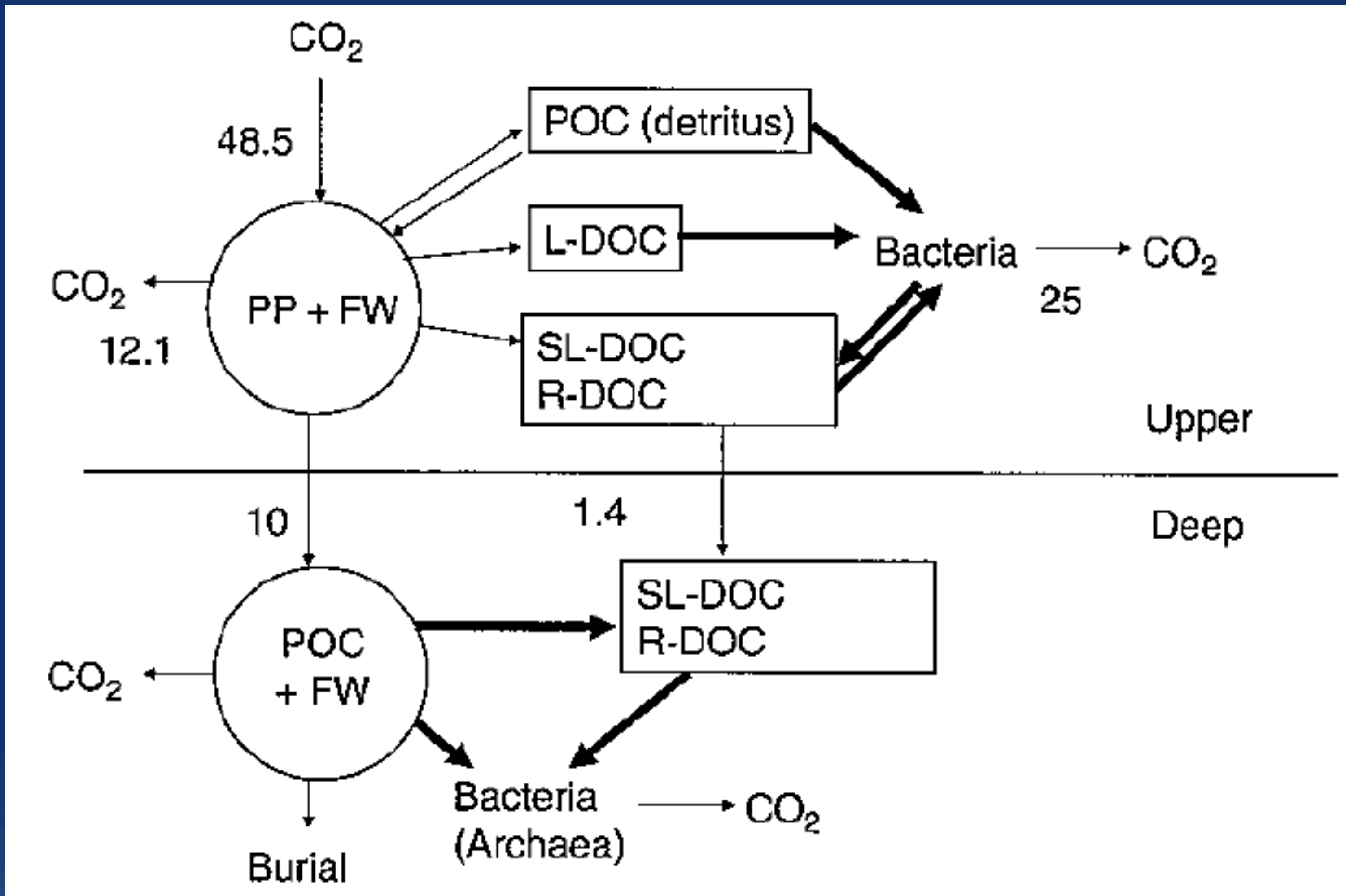
- Ca. 1 billion microbes per liter (includes viruses)
- More estimated bacteria in the ocean (10^{29}) than stars in the universe (10^{21})
- Total biomass of marine bacteria is greater than the combined mass of all zooplankton and fishes
- Metabolic rate of a 1um bacterium = 100,000 times that of a human
- Microbes dominate fluxes of energy and biologically-relevant chemical elements in the oceans



(simplified) Microbial Loop



Quantifying the microbial loop



Global fluxes in Gt C/year; Nagata *2ne ed Kirchman* 2008

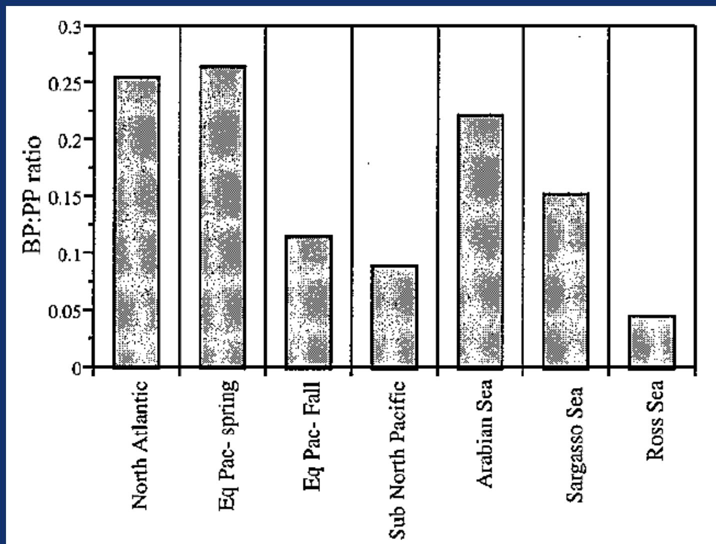
Bacterial carbon demand and growth efficiency

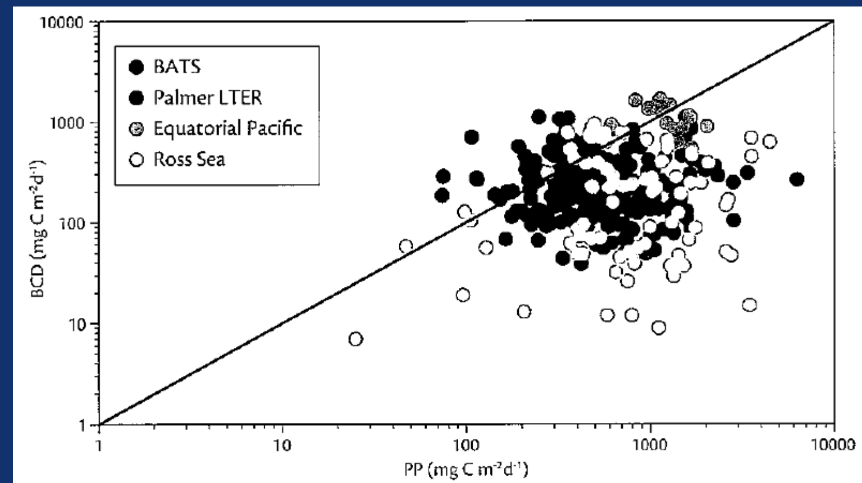
Bacterial Carbon Demand (BCD) =
Bacterial Production (BP) + Bacterial Respiration (BR)

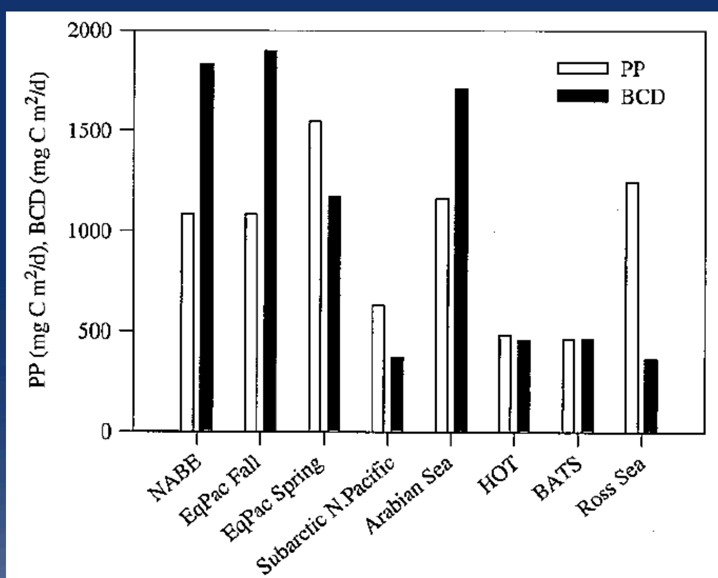
BP measured w/ incubation of ^{3}thymidine and/or ^{3}leucine
BR measured as either O_2 consumption or CO_2 production
-or calculated using an assumed BGE…

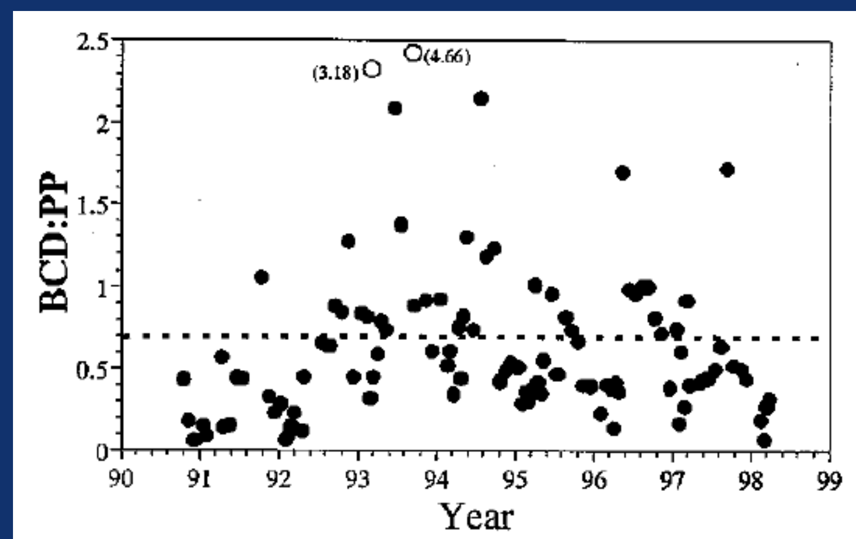
Bacterial Growth Efficiency (BGE) = BP/BCD

Bacterial carbon demand and growth efficiency



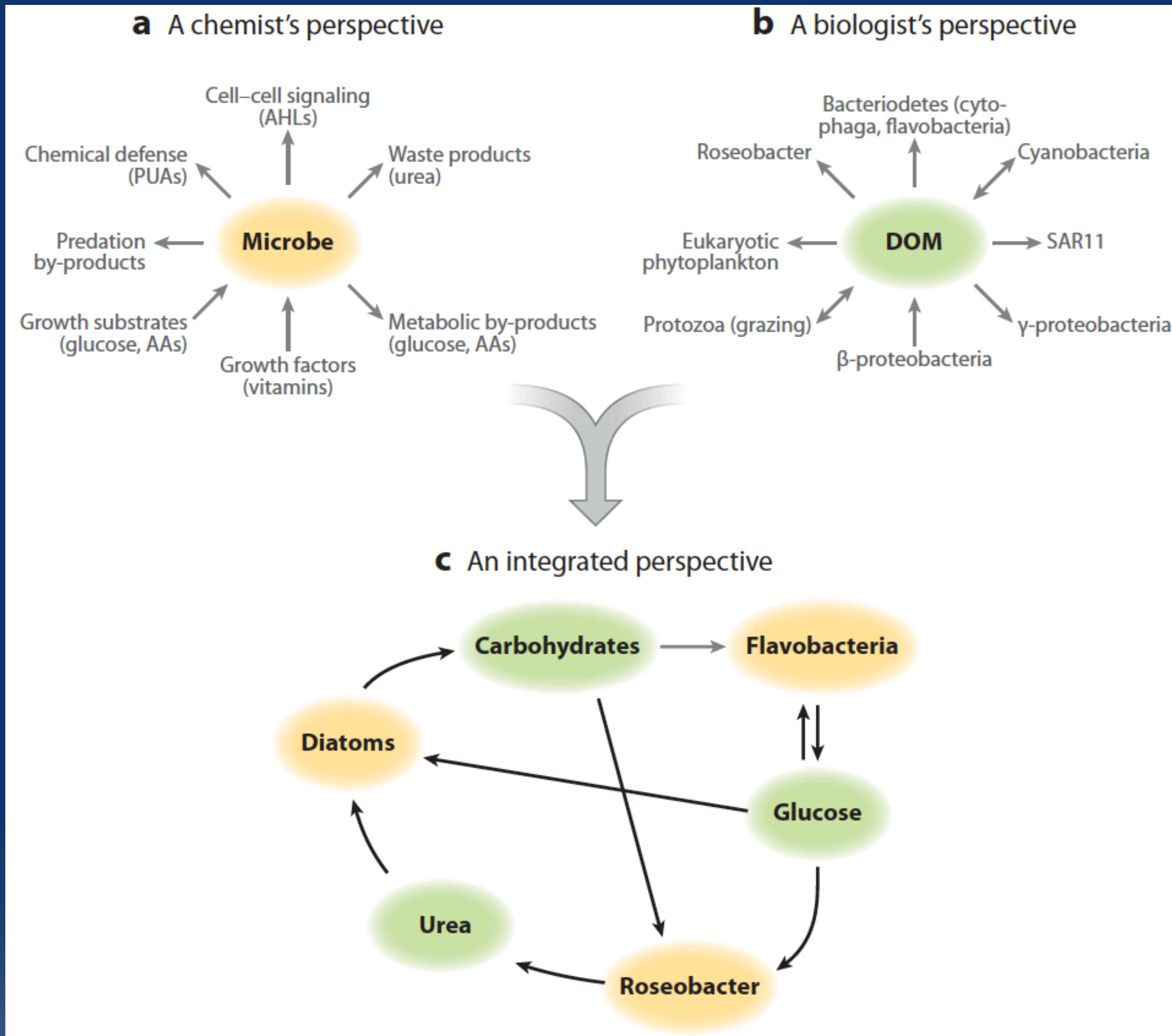






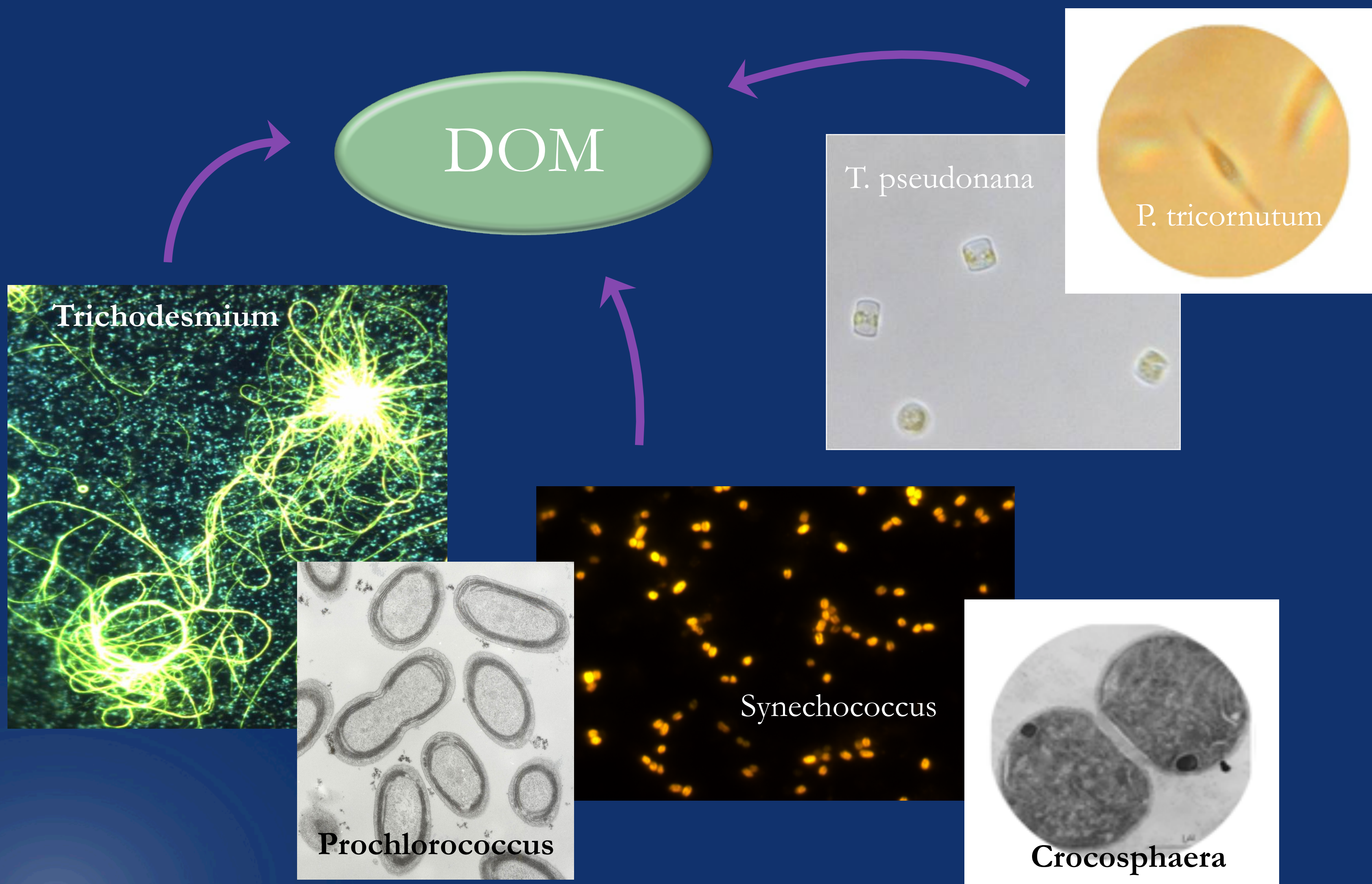
Church *2ne ed Kirchman* 2008

Carlson *BMDOM* 2002



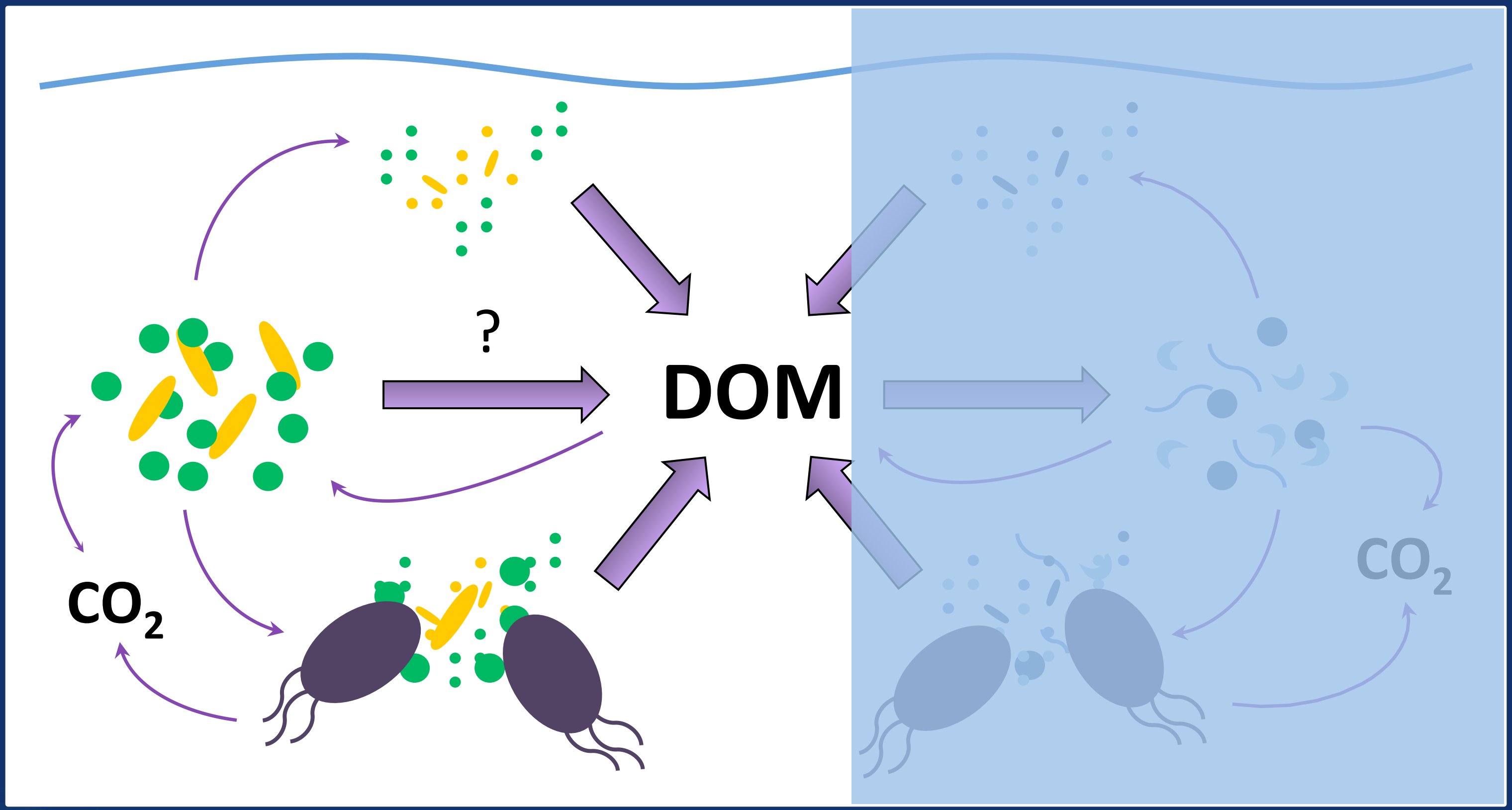
Kujawinski *Ann. Rev. Mar. Sci.* 2011

Microbial Production of marine DOM



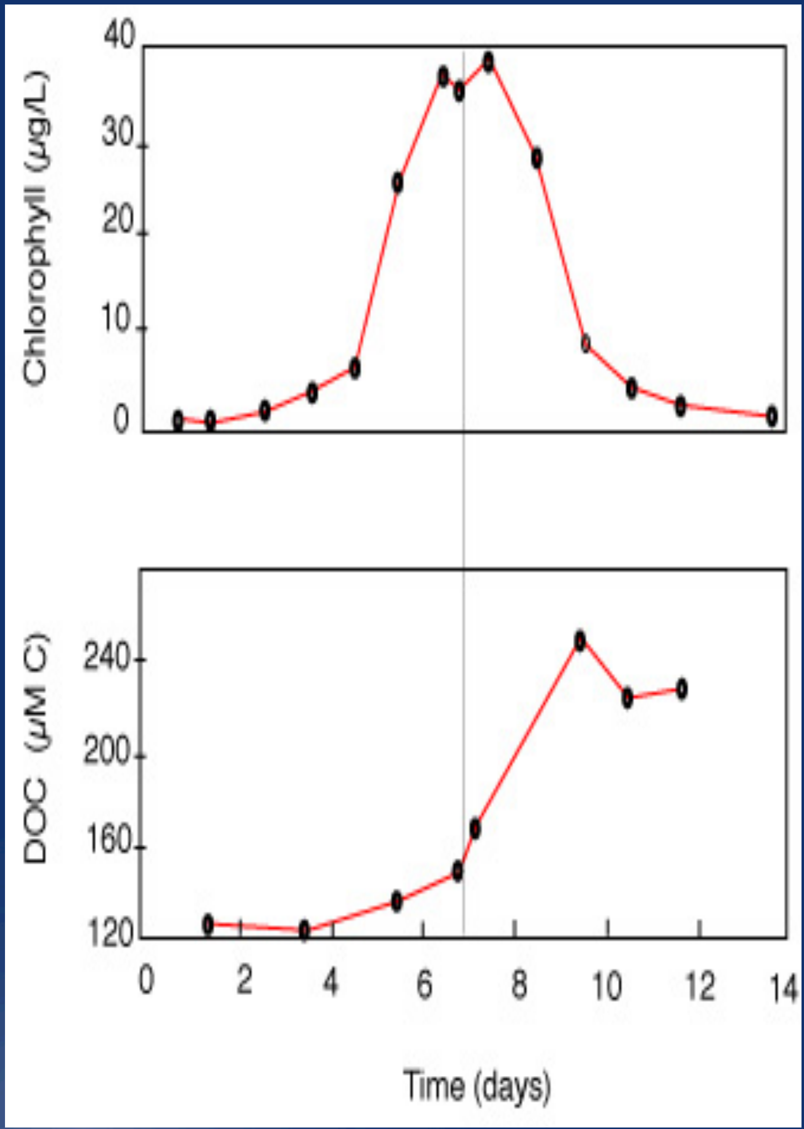
photos by J. Waterbury, C. Ting, A. Heithoff, and me

Microbial Production of marine DOM



?: passive diffusion, overflow release, ligands, communication, defense…

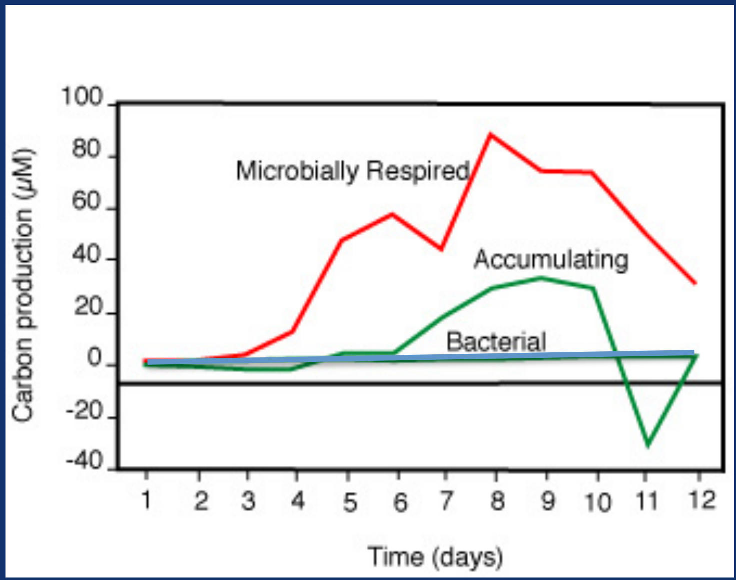
DOC dynamics in a simulated algal bloom



Most DOC accumulation occurs after nutrients are exhausted (bloom crashes)

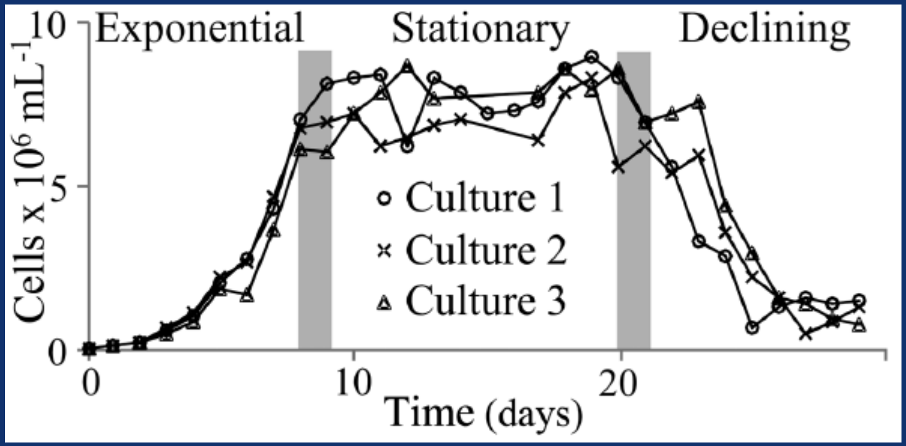
During early log phase growth DOC is being respired by bacteria

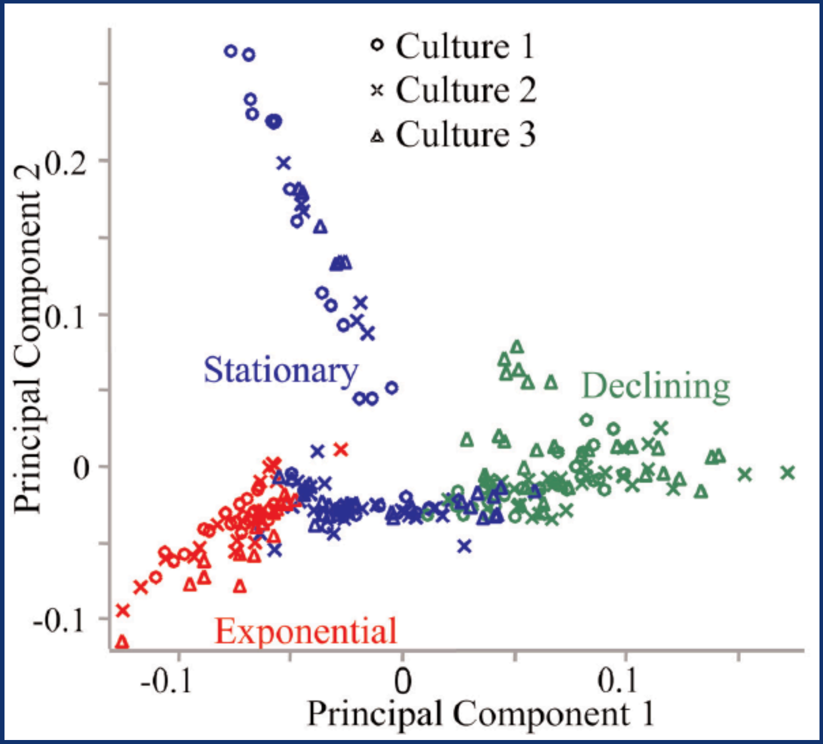
Two pools of DOC, reactive and non-reactive (timescale of exp!). Are they being produced by two different classes of microbes?



Norman et al *L&O* 1995

DOC dynamics in a diatom population



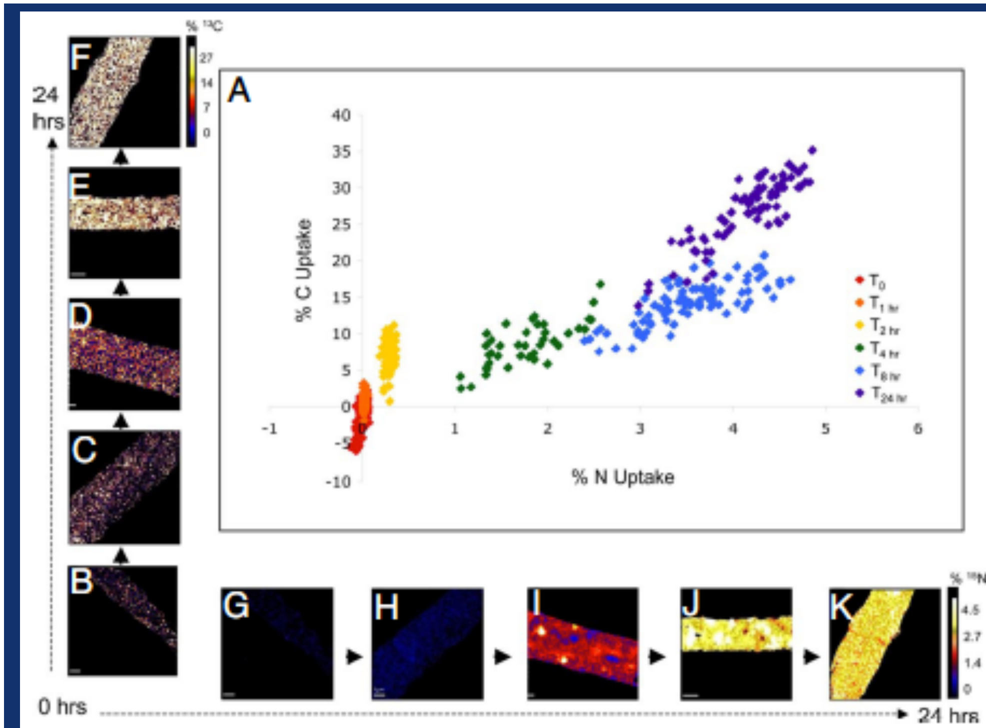


Barofsky et al *L&O Methods* 2009

Production and/or excretion of phytoplankton-derived DOM temporally dynamic

Composition of DOM changes with growth phase of producer

Potential metabolites for communication identified



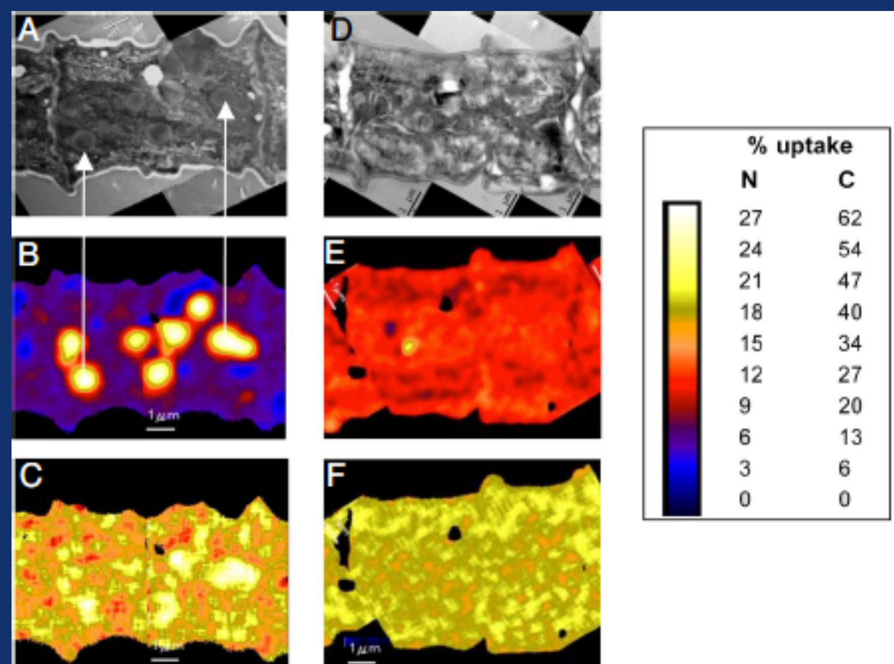
Intracellular Dynamics (Trichodesmium)

Finzi-Hart et al *PNAS* 2009

TEM

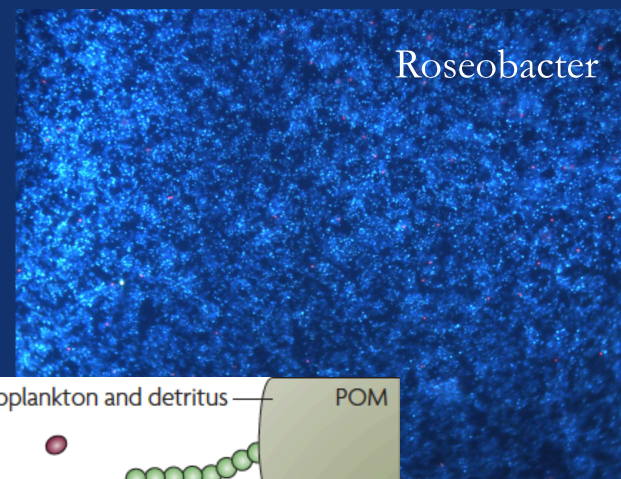
N-fix

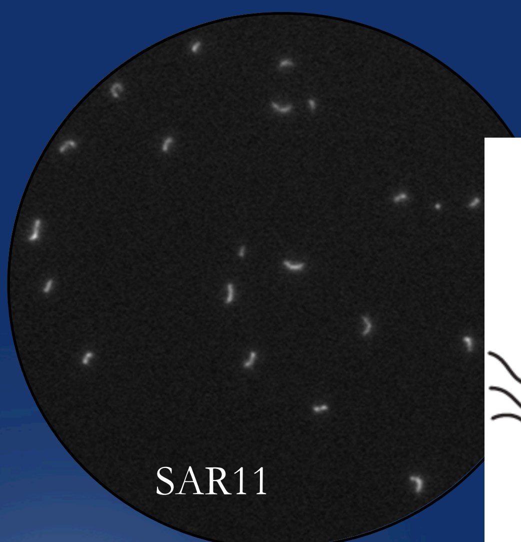
C-fix

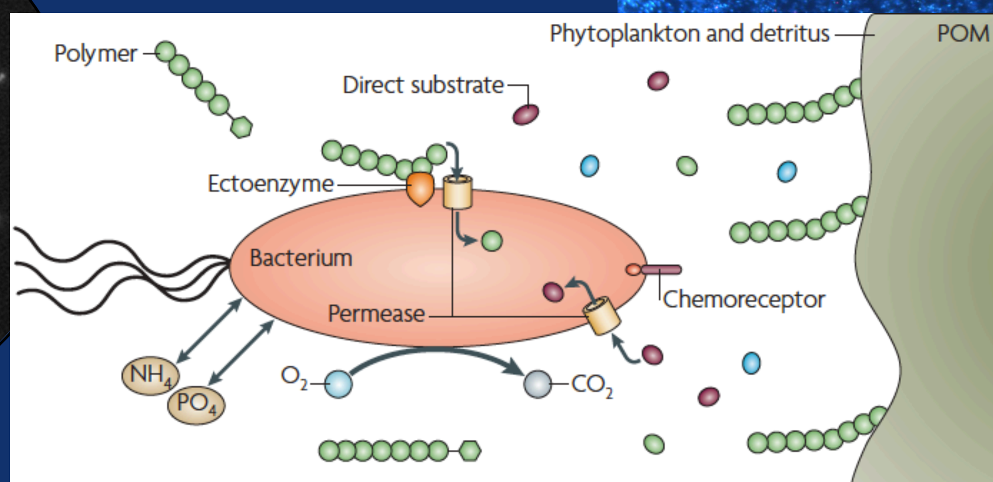


Microbial Consumption of marine DOM

DOM

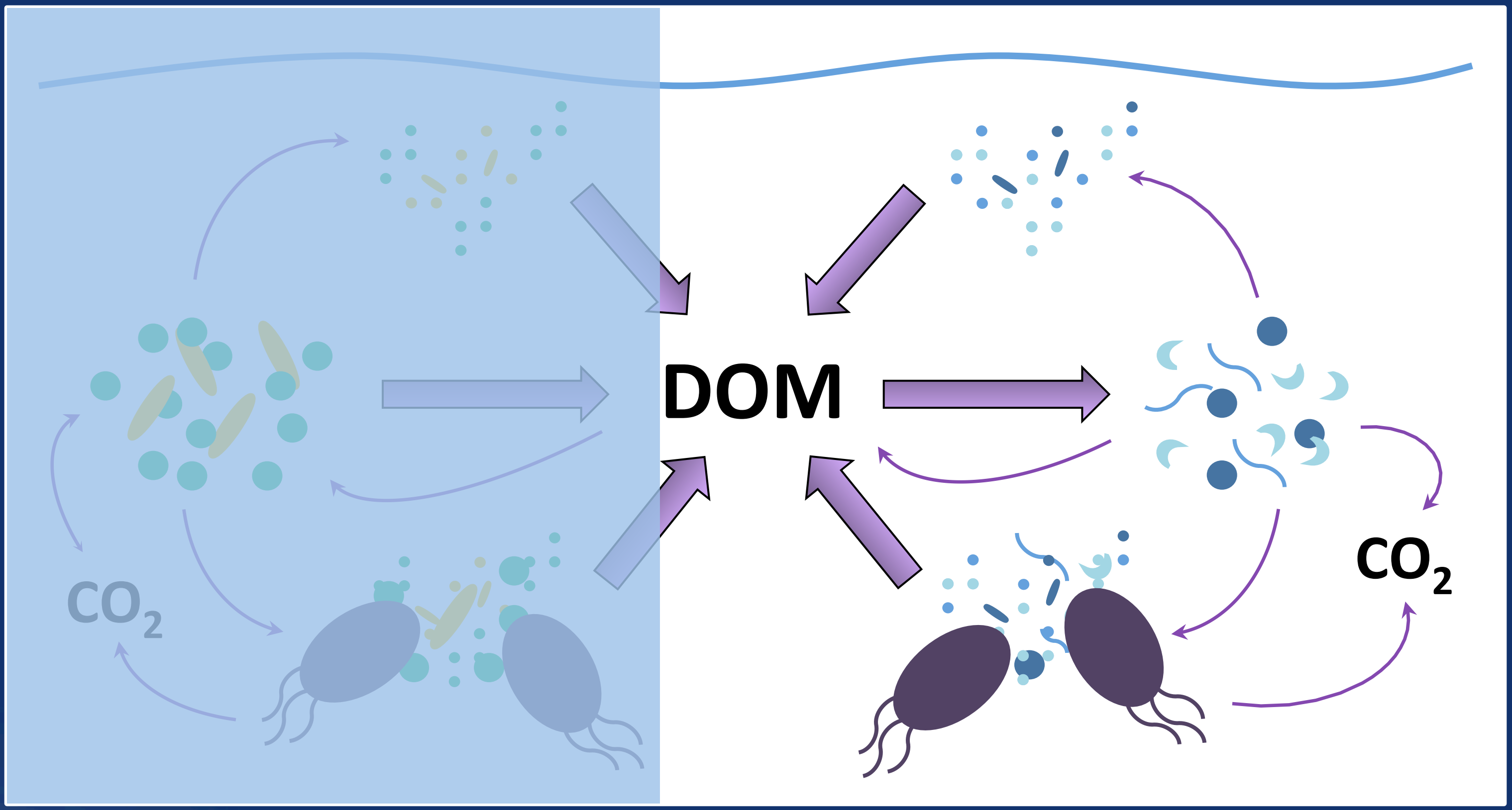




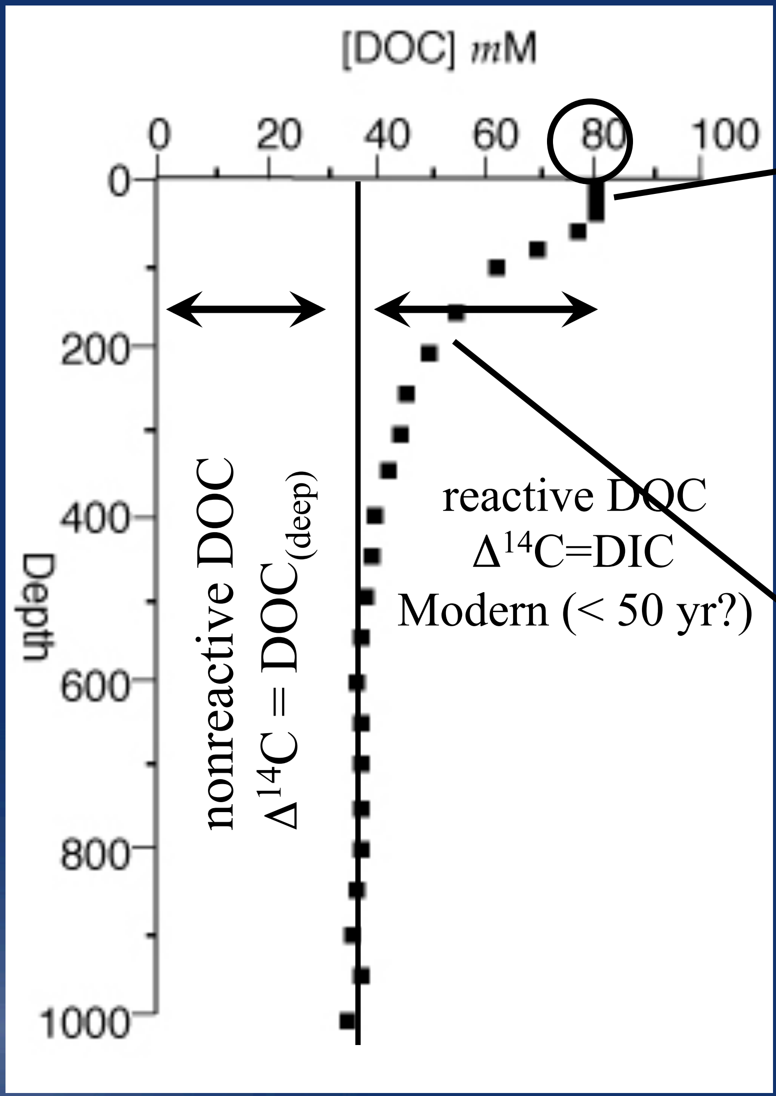


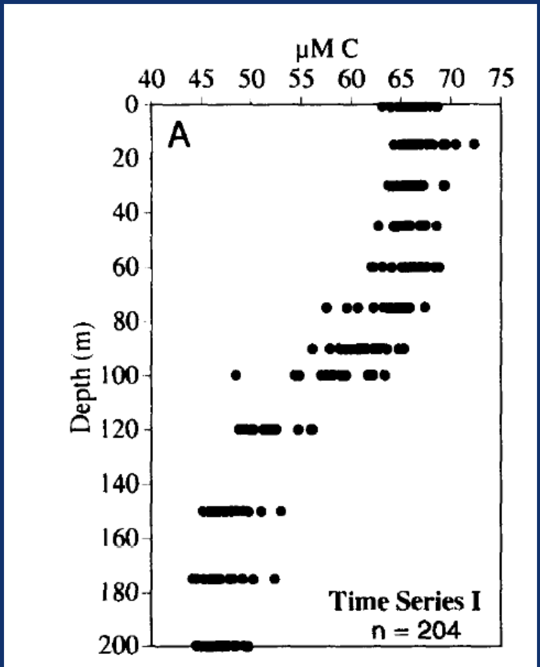
Azam *Nature Reviews* 2007

Microbial Consumption of marine DOM



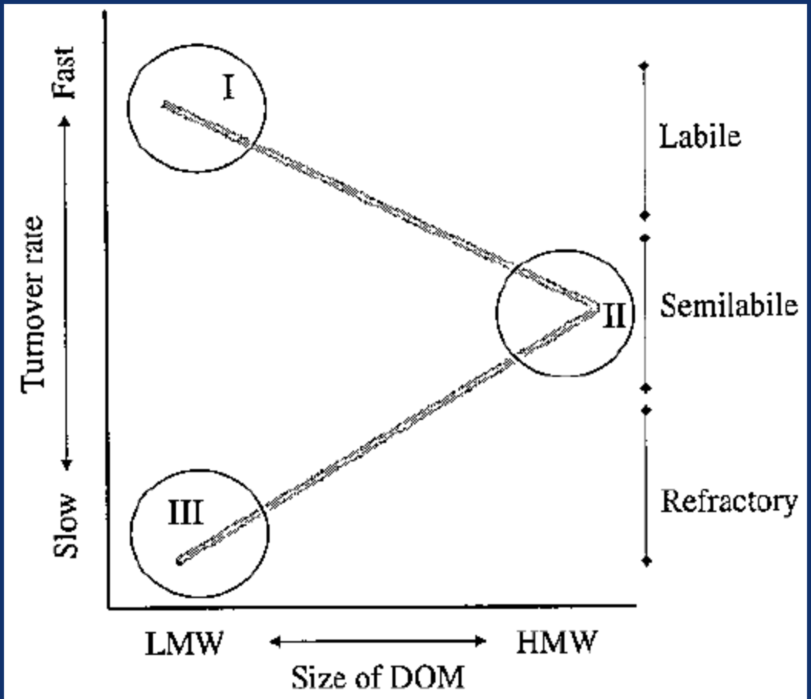
Three classes of reactive organic matter have been recognized through a combination of radiocarbon, Inventory, and microbial activity

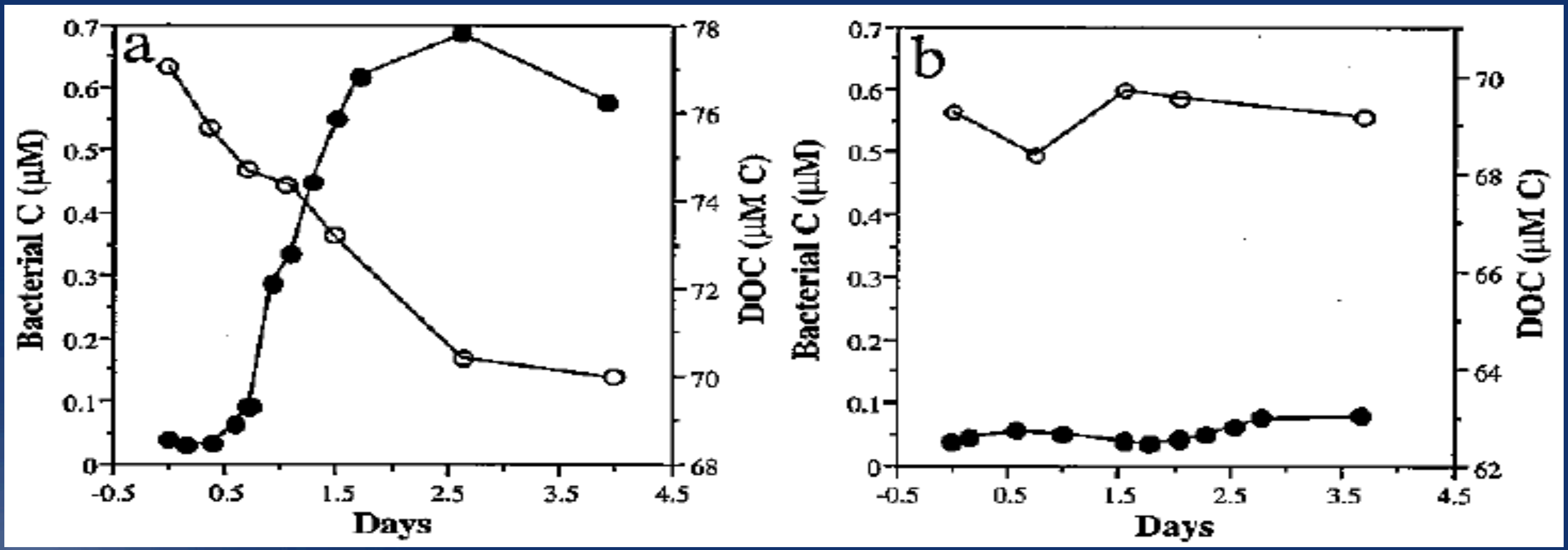




Nonreactive DOC = 650 GT C
Semi-reactive DOC = 30-50 GT C
Very reactive DOC = 1-3 GT C

Nagata *2ne ed Kirchman* 2008





Carlson *BMDOM* 2002

Proximate analysis of algal cells

Chlorophyceae (green algae)	Protein	Carbohydrate	Lipid	Ash
Tetraselmis maculata	72	21	7	(24)
Dunaliela salina	58	33	10	(8)
Chrysophyceae (golden brown algae)				
Monochrysis lutheri	53	34	13	(6)
Syracosphaera carterae	70	23	7	(37)
Bacillariophyceae (brown algae, diatoms)				
Chaetoceros sp.	68	13	16	(28)
Skeletonema costatum	58	33	10	(39)
Coscinodiscus sp.	74	16	10	(57)
Phaeodactylum tricornutum	49	36	14	(8)
Dynophyceae (dinoflagellates)				
Amphidinium carteri	35	38	23	(14)
Exuriella sp.	37	44	20	(8)
Average	**57**	**29**	**13**	

Most POM is protein, and this is probably a large fraction of reactive DOM
Dissolved "free" amino acids have been measured in seawater at 10's of nM

TABLE 7.2 Concentrations of Dissolved Free Amino Acids (DFAA) and Free Sugars in Marine Systems, Kinetic Parameters (Turnover Time and $K_m + S_n$) and Percentage Contributions of Uptake of These Compounds to Total Bacterial Production (%BP)

Location	Compounds	Conc (nmol/L)	Turnover Time (h)	$K_m + S_n$ (nmol/L)	% BP	Reference
			Open Ocean (Upper)/Coastal			
Sargasso Sea	DFAA (individual)	1.9 ± 3.0	31 ± 36 (7–144)	1.8 ± 1.5	23 ± 52	Suttle et al. (1991)
Sargasso Sea	DFAA (mixture)	1–10	3–4		1–4	Keil and Kirchman (1999)
Gulf of Mexico	DFAA (mixture)		0.4 ± 0.3 (0.1–0.8)	3.6 ± 2.5		Ferguson and Sunda (1984)
Arctic Ocean	DFAA	200	52–101		70–>100	Rich et al. (1997)
Atlantic coast	DFAA (individual or mixture)	2–33	0.4–1.2	1–38		Fuhrman and Ferguson (1986)
Gulf of Mexico	Glucose	2–15	2–5	4–9	1–30	Skoog et al. (1999)
Equatorial Pacific	Glucose	15–38	1.5–2.0		14–51	Rich et al. (1996)
Arctic Ocean	Glucose	42–90[a]	43–140		10–>100	Rich et al. (1997)
Pacific coast, USA	*N*-Acetyl-glucosamine		38–312	5		Riemann and Azam (2002)
			Estuary			
Chesapeake Bay, USA	4 DFAA	43 ± 26	1.4 ± 0.9 (0.8–2.7)		32 ± 22	Fuhrman (1990)
Kiel Fjord, Germany	Leu		3.5 ± 3.3 (0.2–12)			Hoppe et al. (1988)

Note that concentrations of monomeric pools are low (nmol/L level), but turnover time is high (days or even minutes in coastal waters), resulting in significant contributions to total bacterial production. Data are from the upper 100 m.

[a]Total dissolved neutral monosaccharides.

Nagata 2[ne] *ed Kirchman* 2008

Microbiologists view…..

If DFAA are about 20-40 nM (80-160 nM C) in the euphotic zone of the open ocean, and turnover times are about 0.5-1 per day; then this will support a bacterial carbon demand of 80-320 nM carbon.

We assume that there are other substrates (glucose, acetic acid, etc.) that are also metabolized very quickly and contribute to the "very reactive" fraction of DOM.

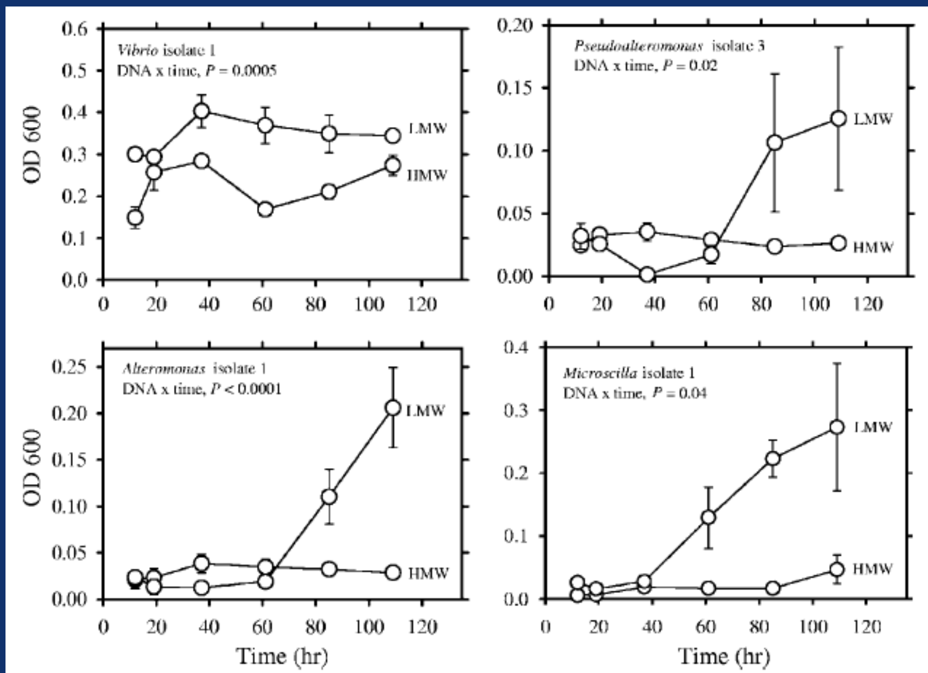
So,very reactive DOC supports most bacterial production in the ocean.

But……..

Geochemists view….

Semi-reactive DOC is 25-40 μM carbon, about 100x higher than DFAA. Does semilabile DOC contribute to bacterial carbon demand? If semi-reactive DOC turns over seasonally (every few months) this is 100x or so > than measured AA turnover times and it will support an equal amount of BCD.

Compound-specific studies

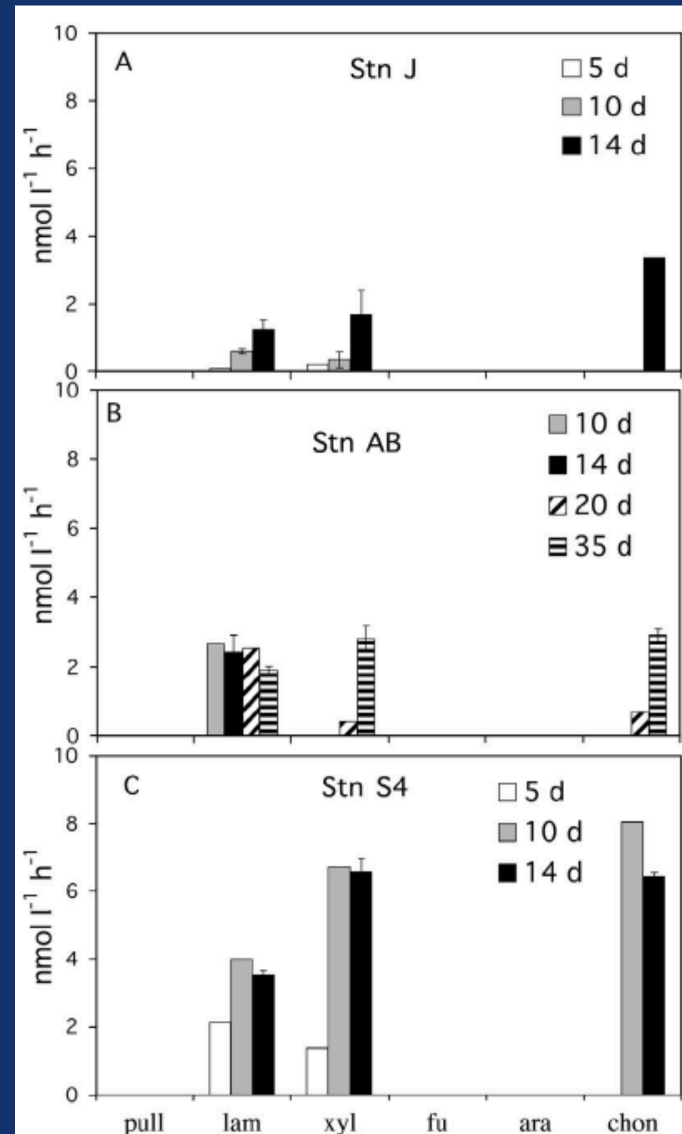


Lennon *AEM* 2007

Different preferences for HMW or LMW dissolved DNA substrate.

Same stoichiometry, so truly is a size issue

Extracellular nucleases to degrade HMW material



Arnosti et al *AME* 2005

Source-specific studies

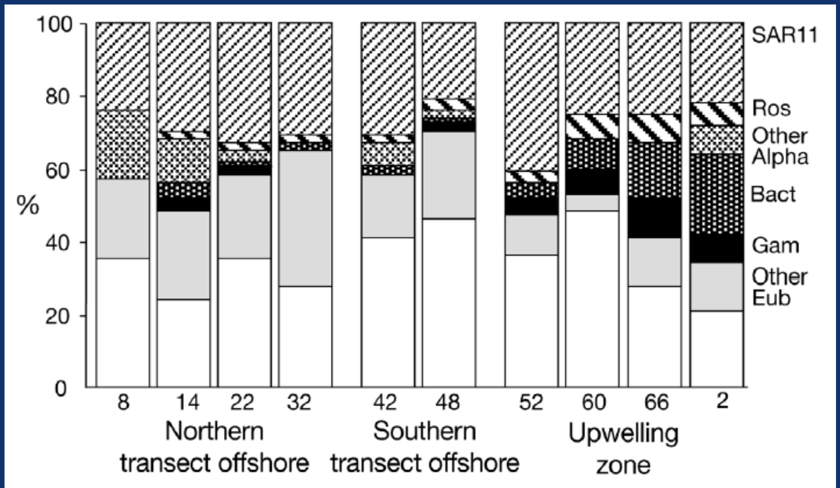


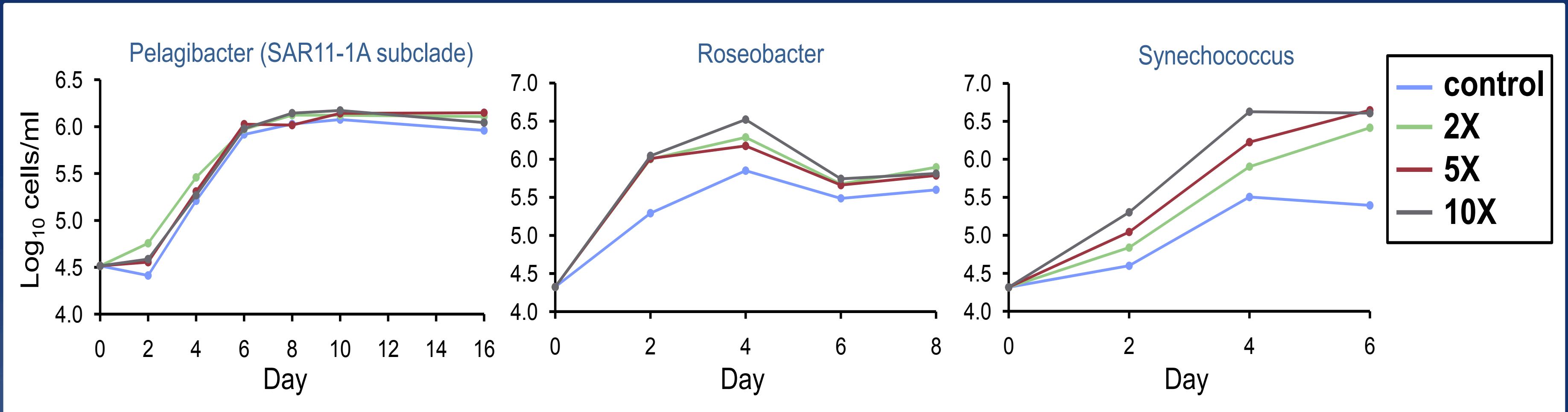
Fig. 4. Abundance (%) of bacterial groups detected by HRP-probes (CARD-FISH), scaled to DAPI counts. Ros: Roseobacter; Alpha: Alphaproteobacteria; Gam: Gammaproteobacteria; Bact: Bacteroidetes; Eub: Eubacteria

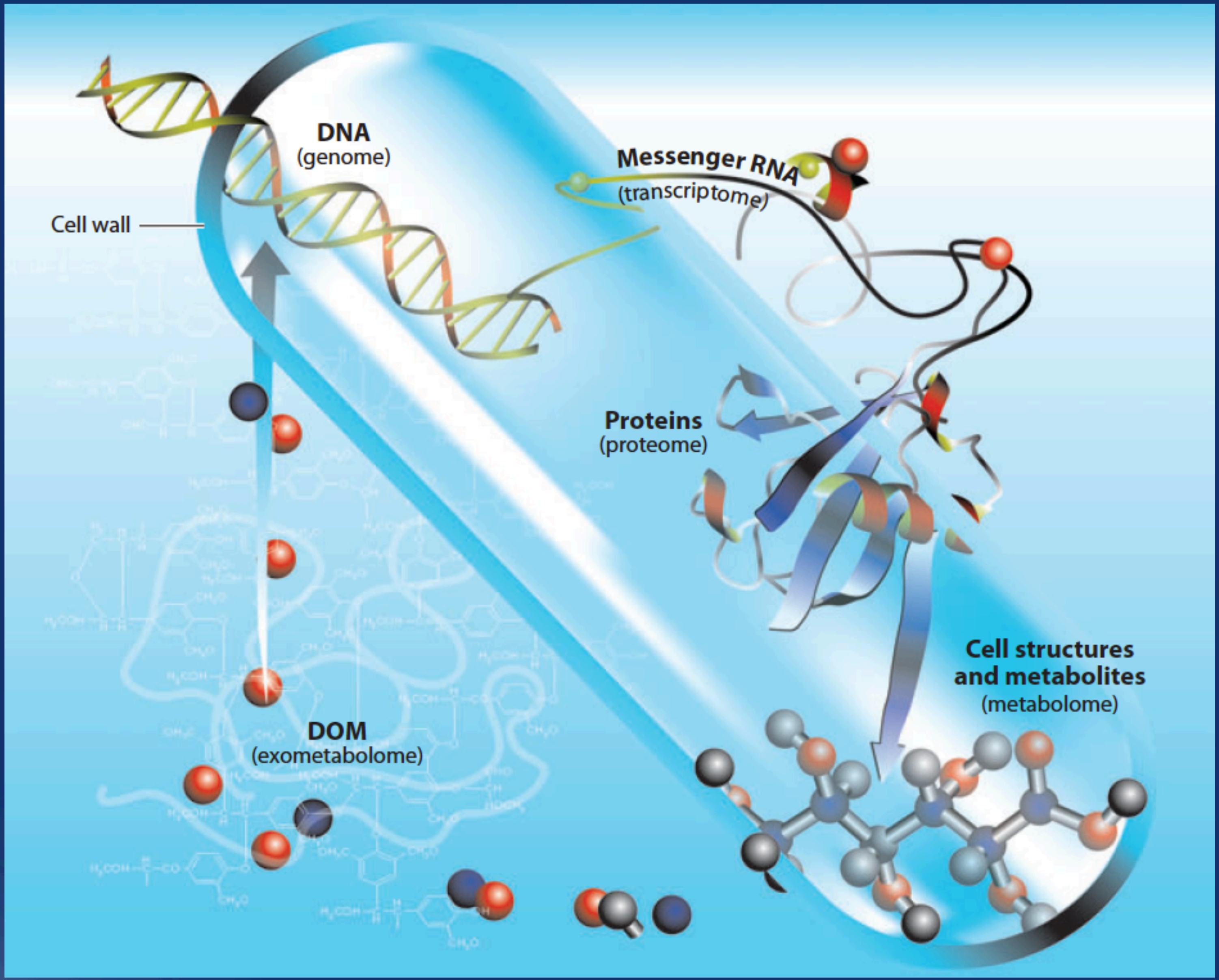
Alonso-Saez et al *AME* 2007

Different responses to productivity levels in-situ

SAR11 stays consistent

Roseobacter and Bacteroidetes prefer high productivity





Kujawinski *Ann. Rev. Mar. Sci.* 2011

Summary

Microbes are important members of marine food webs due to their great abundance/ total biomass and diverse metabolic capabilities

It is difficult to decouple DOM production and consumption processes

DOM is produced mainly by marine phytoplankton in the surface ocean but also by chemosynthetic, heterotrophic and viral activities in a variety of ways

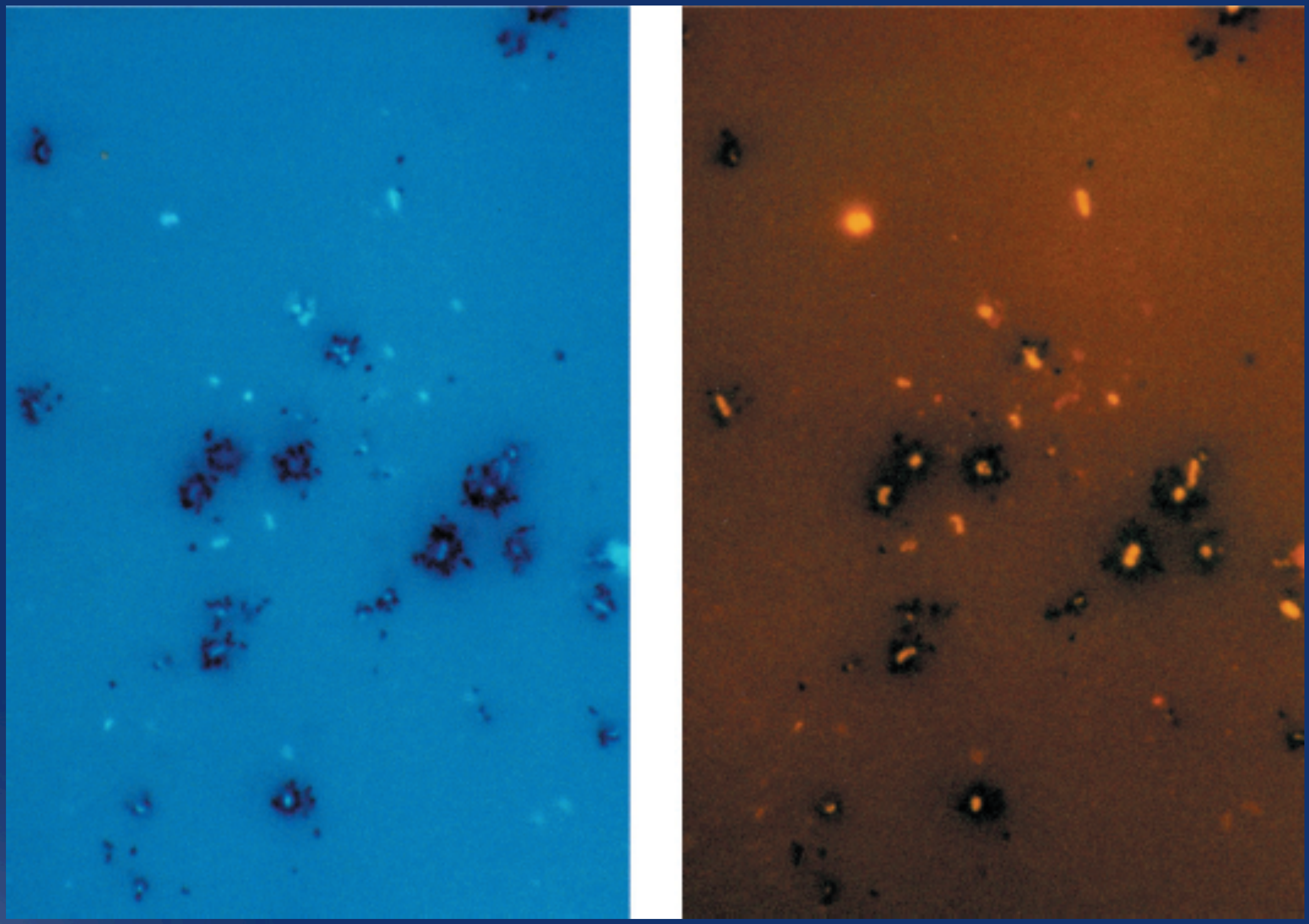
DOM serves as the main substrate for heterotrophic bacterial production in the ocean

On average, BCD = ca. 50% of PP, or about 25-35 GT C yr^{-1}. A large amount of carbon is processed through the microbial loop

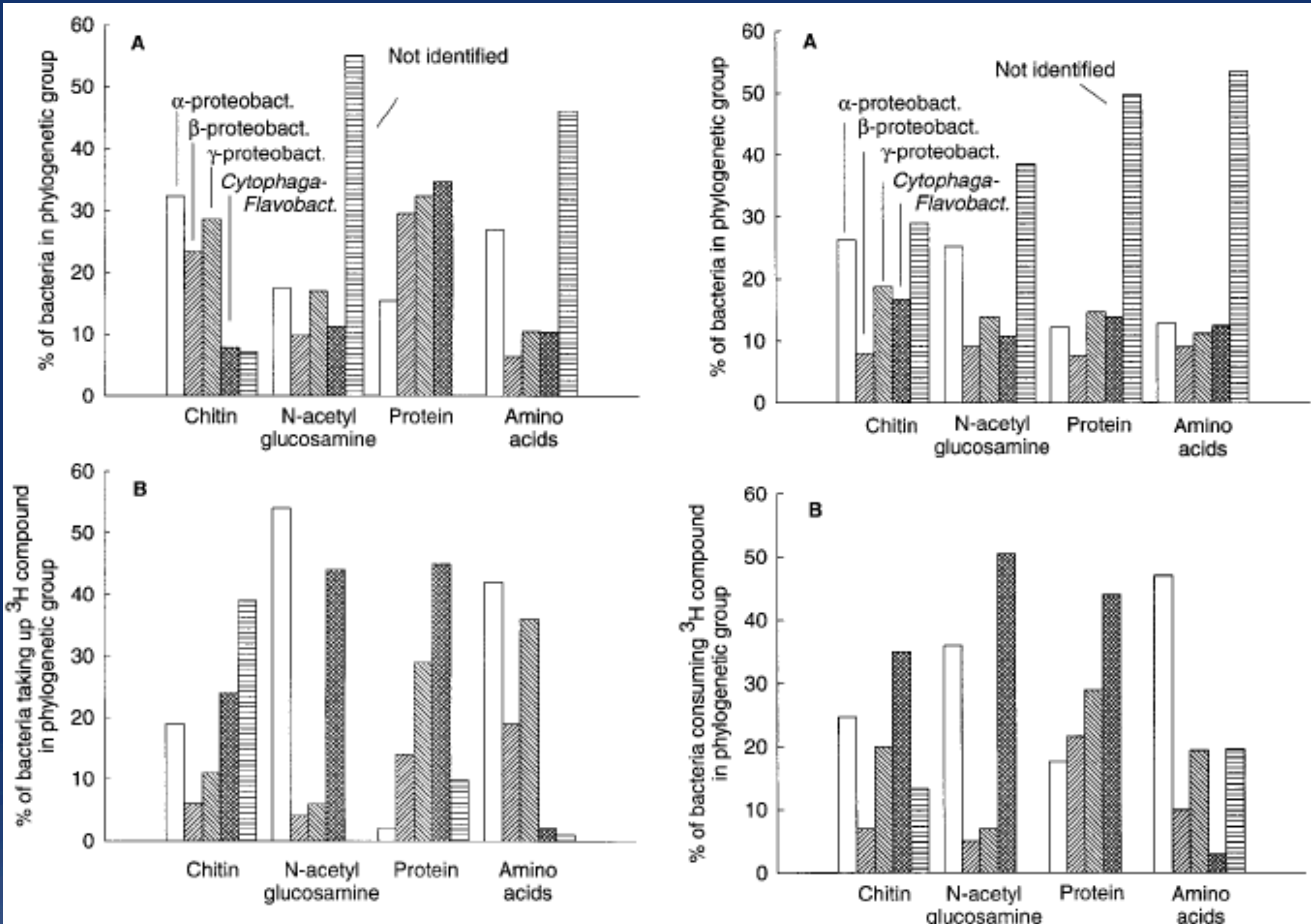
BP measurements are intimately coupled to protein synthesis, and it is believed that BP is fueled through the uptake of highly reactive DOM (free amino acids, dissolved DNA, peptides, small sugars, urea, etc.)

The role of semi-reactive DOM in BP production is not clear. We still don't know how quickly it is cycled, how it impacts bacterial diversity, or how it is degraded

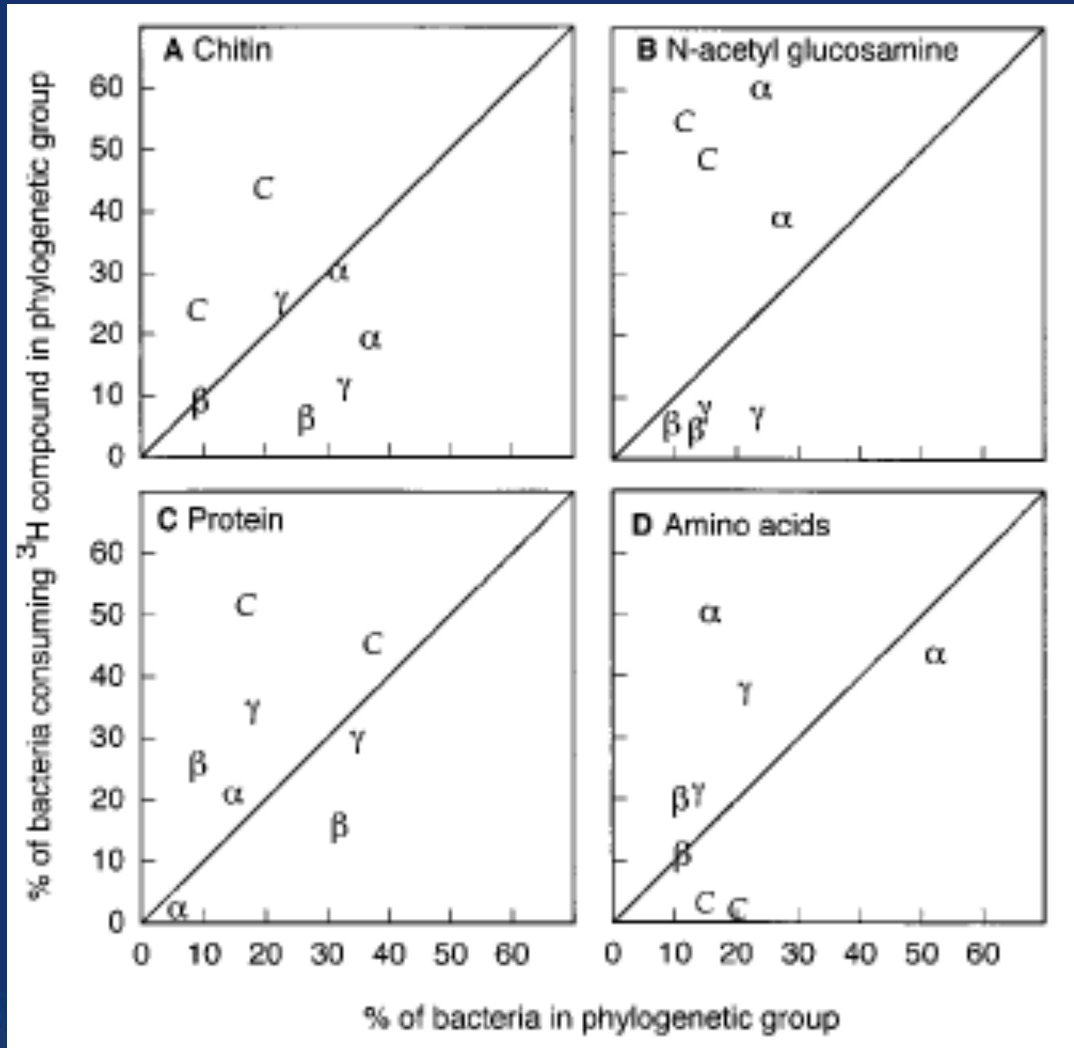
Natural Assemblages of Marine Proteobacteria and Members of the *Cytophaga-Flavobacter* Cluster Consuming Low- and High-Molecular-Weight Dissolved Organic Matter



Cottrell & Kirchman *AEM* 2000



Cottrell & Kirchman *AEM* 2000



Cottrell & Kirchman *AEM* 2000

The Impact of Microbial Metabolism on Marine Dissolved Organic Matter

Elizabeth B. Kujawinski

Recitation Date/Time