Just how much phosphorus does a bacterium need?

Jim Cotner (cotne002@umn.edu)
University of Minnesota- Twin Cities

What we will discuss...

- How much P is in a (real and not so real) bacterium and how little can they get by on, i.e., how low can they go?
- Homeostasis: How variable is bacterial C and P content? How does a bacterium and a bacterial community respond to changes in its their environment?
- The future of Phosphorus?

Why are we interested in P?

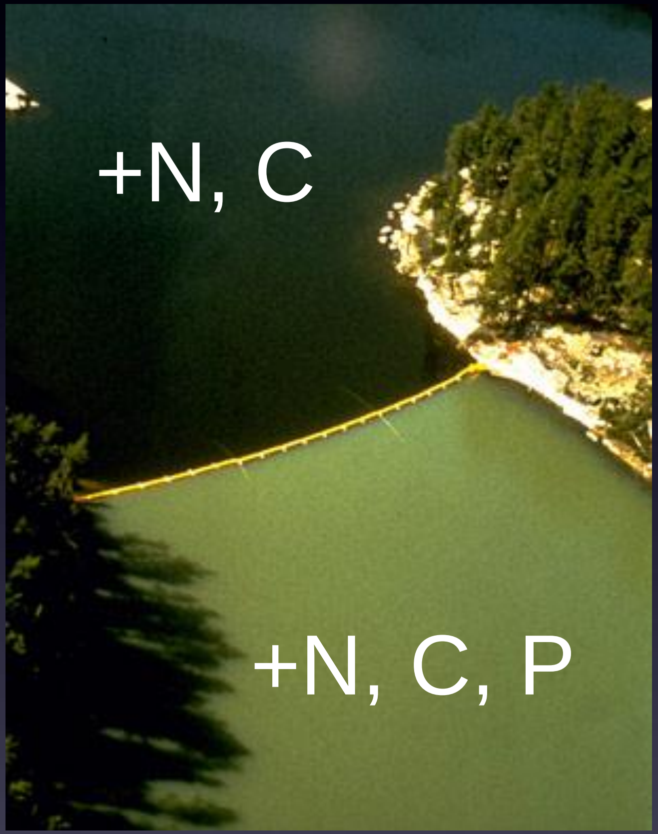
- It's part of the basic composition of organisms (RNA, DNA, P-lipids)
- It is often a limiting nutrient
- We are releasing too much of it into the environment
- We are running out of it!

photo: J. Williamson

Human perturbations to different biogeochemical cycles

Table 2. Examples of human intervention in the global biogeochemical cycles of carbon, nitrogen, phosphorus, sulfur, water, and sediments. Data are for the mid-1900s.

Element	Flux	Magnitude of flux (millions of metric tons per year)		% change due to human activities
		Natural	Anthropogenic	
C	Terrestrial respiration and decay CO_2	61,000		
	Fossil fuel and land use CO_2		8,000	+13
N	Natural biological fixation	130		
	Fixation owing to rice cultivation, combustion of fossil fuels, and production of fertilizer		140	+108
P	Chemical weathering	3		
	Mining		12	+400
S	Natural emissions to atmosphere at Earth's surface	80		
	Fossil fuel and biomass burning emissions		90	+113
O and H (as H_2O)	Precipitation over land	111×10^{12}		
	Global water usage		18×10^{12}	+16
Sediments	Long-term preindustrial river suspended load	1×10^{10}		
	Modern river suspended load		2×10^{10}	+200



Falkowski, P. G., Scholes, R. J., Boyle, E., Canadell, J., Canfield, D., Elser, J., Gruber, N., Hibbard, K., Högberg, P., Linder, S., Mackenzie, F. T., Moore, B. I., Pedersen, T., Rosenthal, Y., Seitzinger, S., Smetacek, V. & Steffen, W. (2000). The global carbon cycle: a test of our knowlege of Earth as a system. *Science* **290**, 291-296.

Ecological stoichiometry

P

How organisms deal with variability in resource

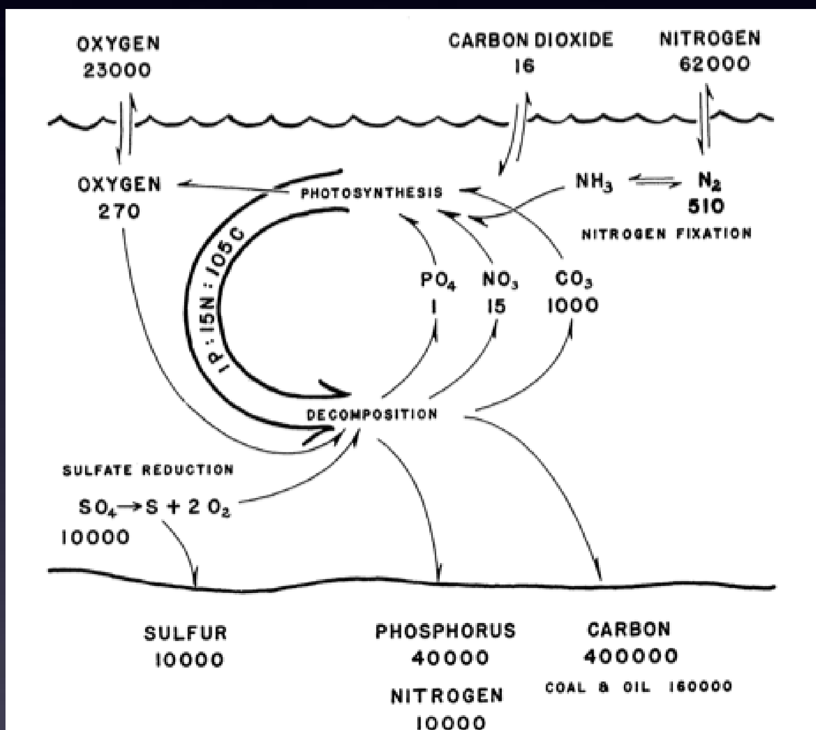
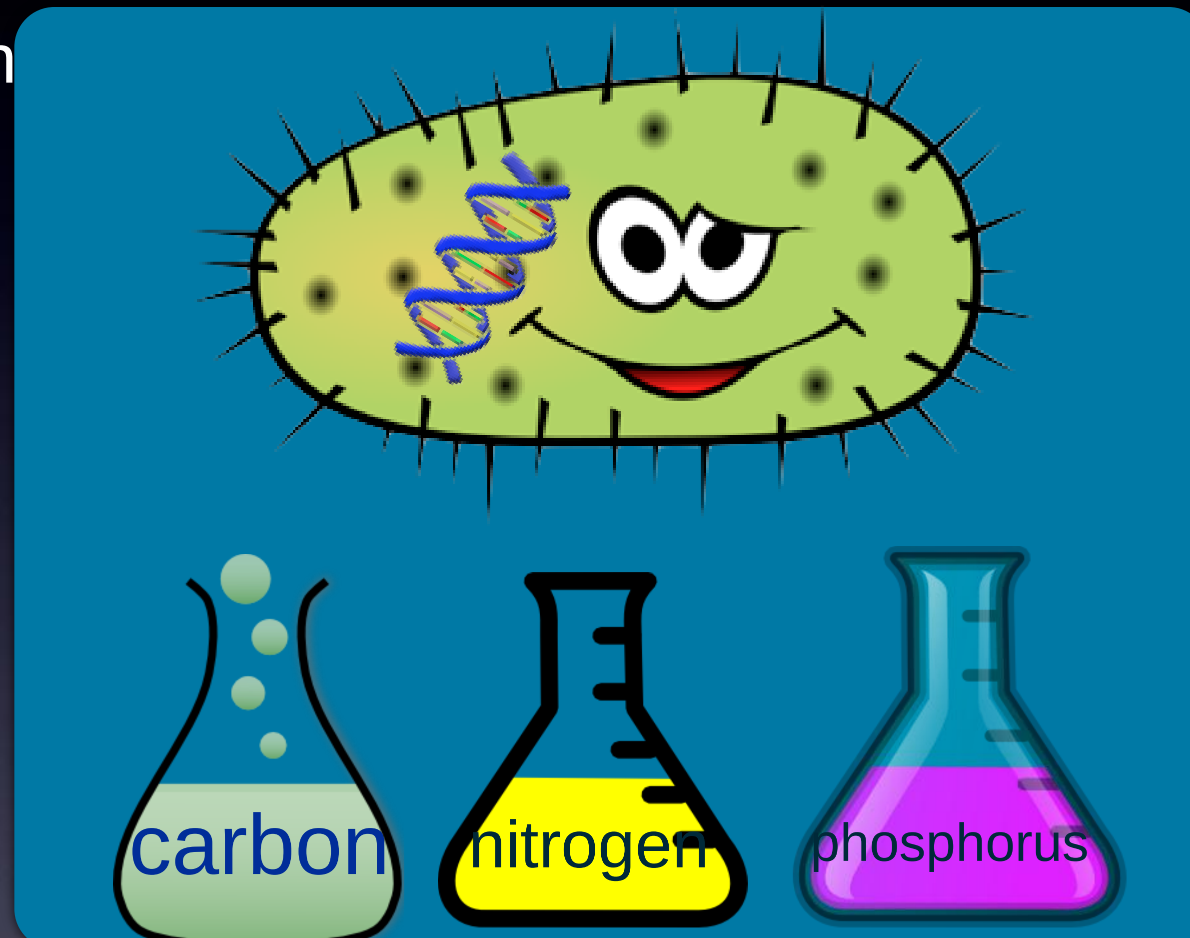


FIG. 3. The Biochemical Cycle. Numbers represent quantities of respective elements present in the atmosphere, the ocean, and the sedimentary rocks, relative to the number of atoms of phosphorus in the ocean.

Redfield 1958



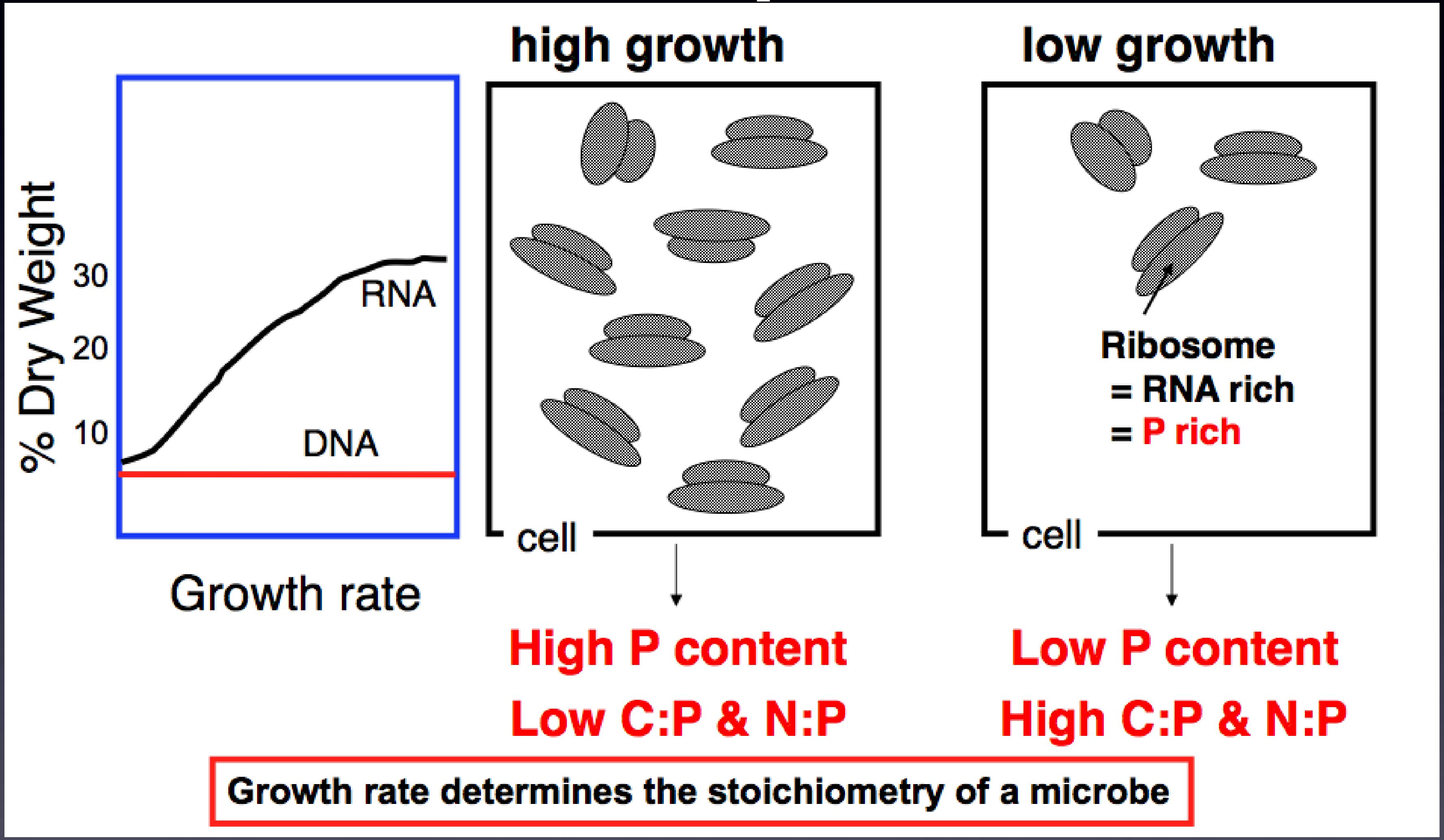
osmotrophs vs. phagotrophs,
heterotrophs vs. autotrophs

What determines the biomass composition of microbial communities?

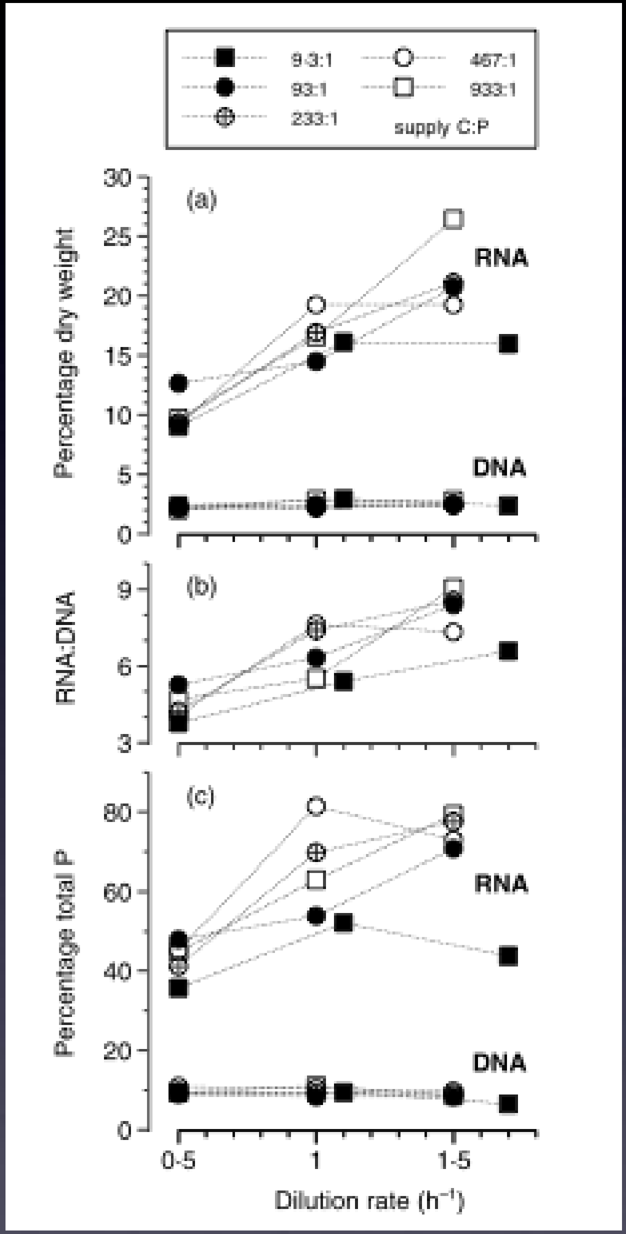
P

- Growth rate (the 'growth rate hypothesis')
- Substrate stoichiometry
- Temperature
- Community composition (prokaryotic vs. eukaryotic; unicellular vs. multi-cellular, autotrophs vs. heterotrophs)

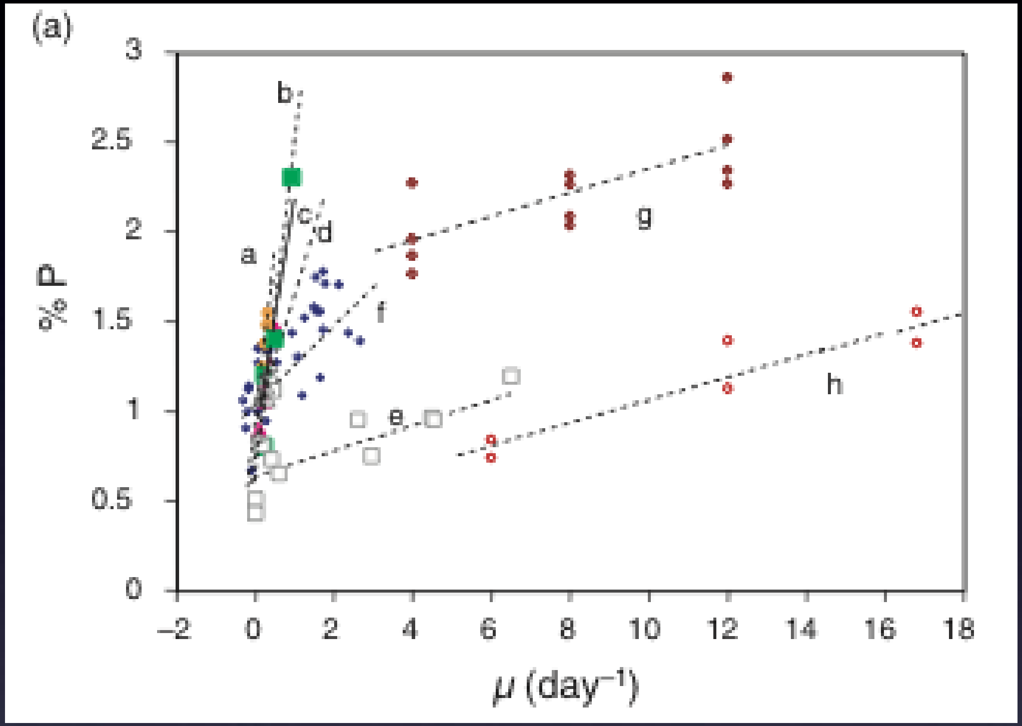
Growth rate, RNA and P



P and growth: The growth rate hypothesis



P

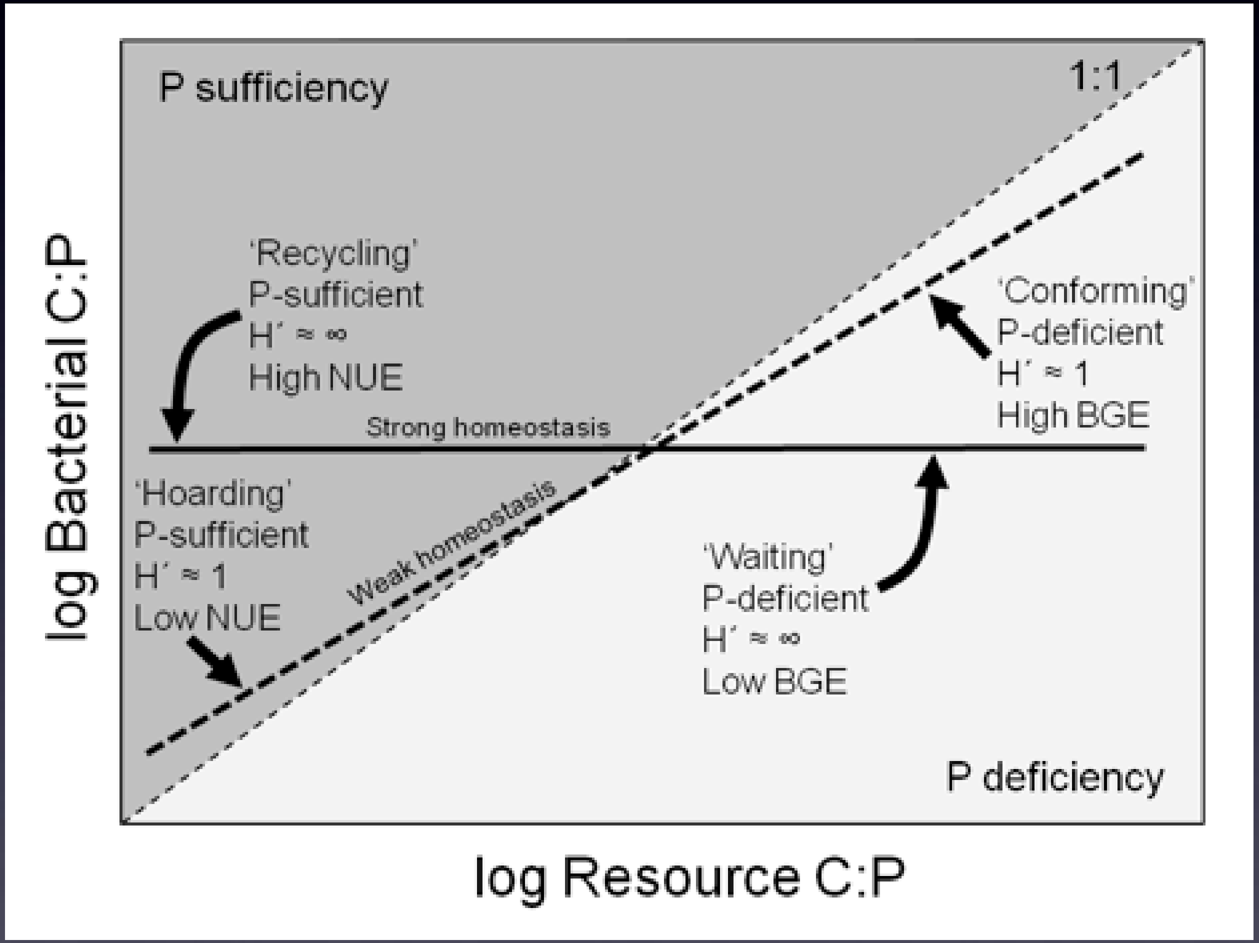


...where's the rest of the P?

Makino et al. 2003; Elser et al. 2003

Substrate stoichiometry and homeostasis

P



P

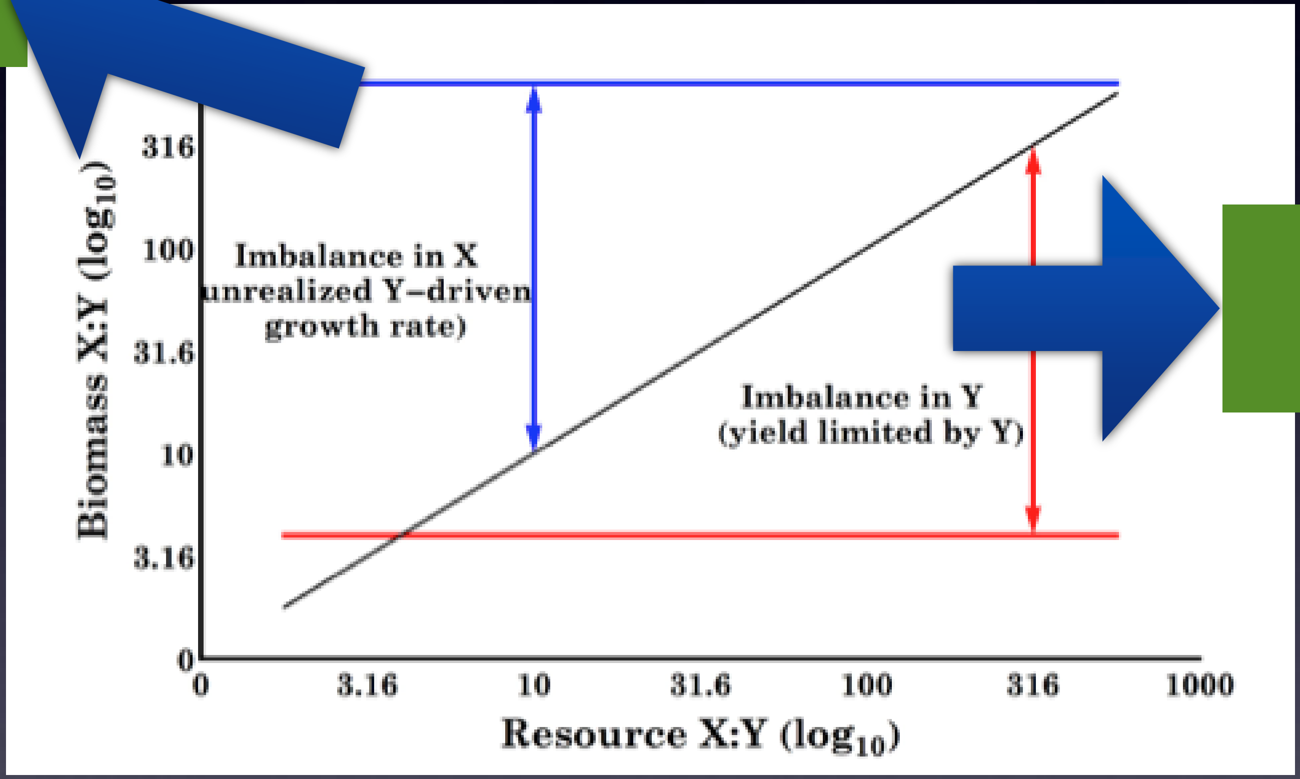
How much P is there in a bacterium?….

...and how low can they go?

...and why should we care

Positive feedbacks

P



Unrealized production

..How much P does a bacterium have? We used to think a lot...

Redfield ratio 106C: 16N: 1P

P

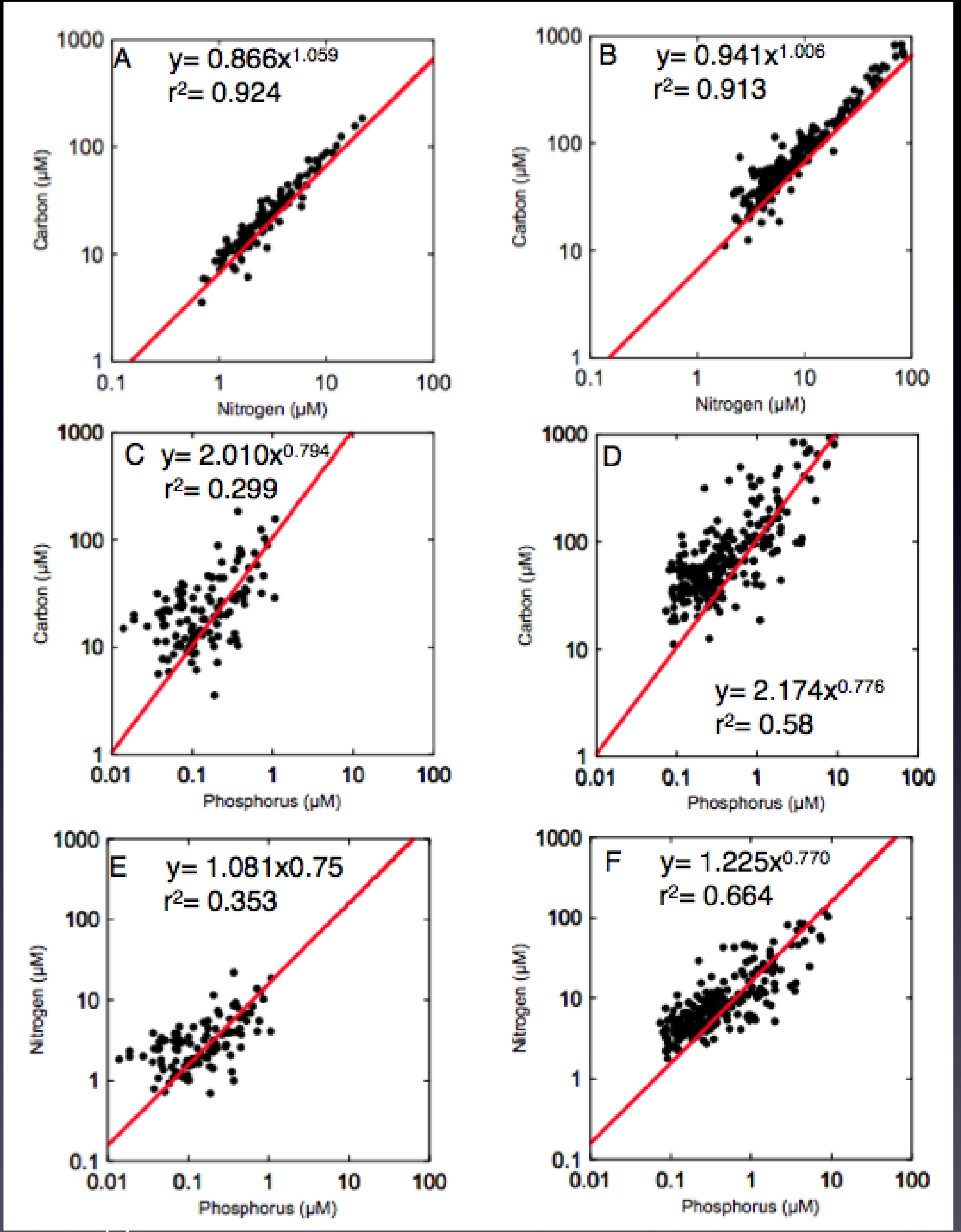
Most studies assume that bacteria are P-rich with C:P ratios about 50:1

But are they really that nutrient rich? Bratbak 1985

TABLE 1. Comparison of cell composition, carbon per cell, estimates of cell volume obtained with different methods, and carbon per unit of estimated cell volume for six different cultures of bacteria

Inoculum	Limiting nutrient	Cell composition (C:N:P molar ratio)	g of C per cell ($\times 10^{-13}$)	Cell vol (μm^3) by: SEM	Cell vol: Epifluorescence microscopy, Eyepiece graticule	Cell vol: Epifluorescence microscopy, Photographs	Cell vol: Electronic sizing	C per unit of cell vol (10^{-13} g of C μm^{-3})[a] by: SEM	C per unit of cell vol: Epifluorescence microscopy, Eyepiece graticule	C per unit of cell vol: Epifluorescence microscopy, Photographs
P. putida	C	100:22:6.2	1.29	0.30	0.28	0.29	ND[b]	4.2	4.6	4.4
P. putida	N	100:19:5.1	1.69	0.39	0.66	0.71	0.74	4.4	2.6	2.4
P. putida	P	100:18:0.2	3.12	0.34	0.57	0.63	0.66	9.3	5.5	5.0
Mixed	C	100:21:13	1.06	0.14	0.11	0.19	ND	7.7	8.0	5.8
Mixed	N	100:15:4.9	2.14	0.24	0.30	0.48	ND	9.0	7.2	4.5
Mixed	P	100:16:1.8	1.91	0.32	0.27	0.55	ND	6.0	7.1	3.5

Bacterial and seston stoichiometry



Cotner et al. 2010

Mean among lakes: C:N:P 102:12:1

Strains: 875:179:1

Community in a lake: 259:69:1

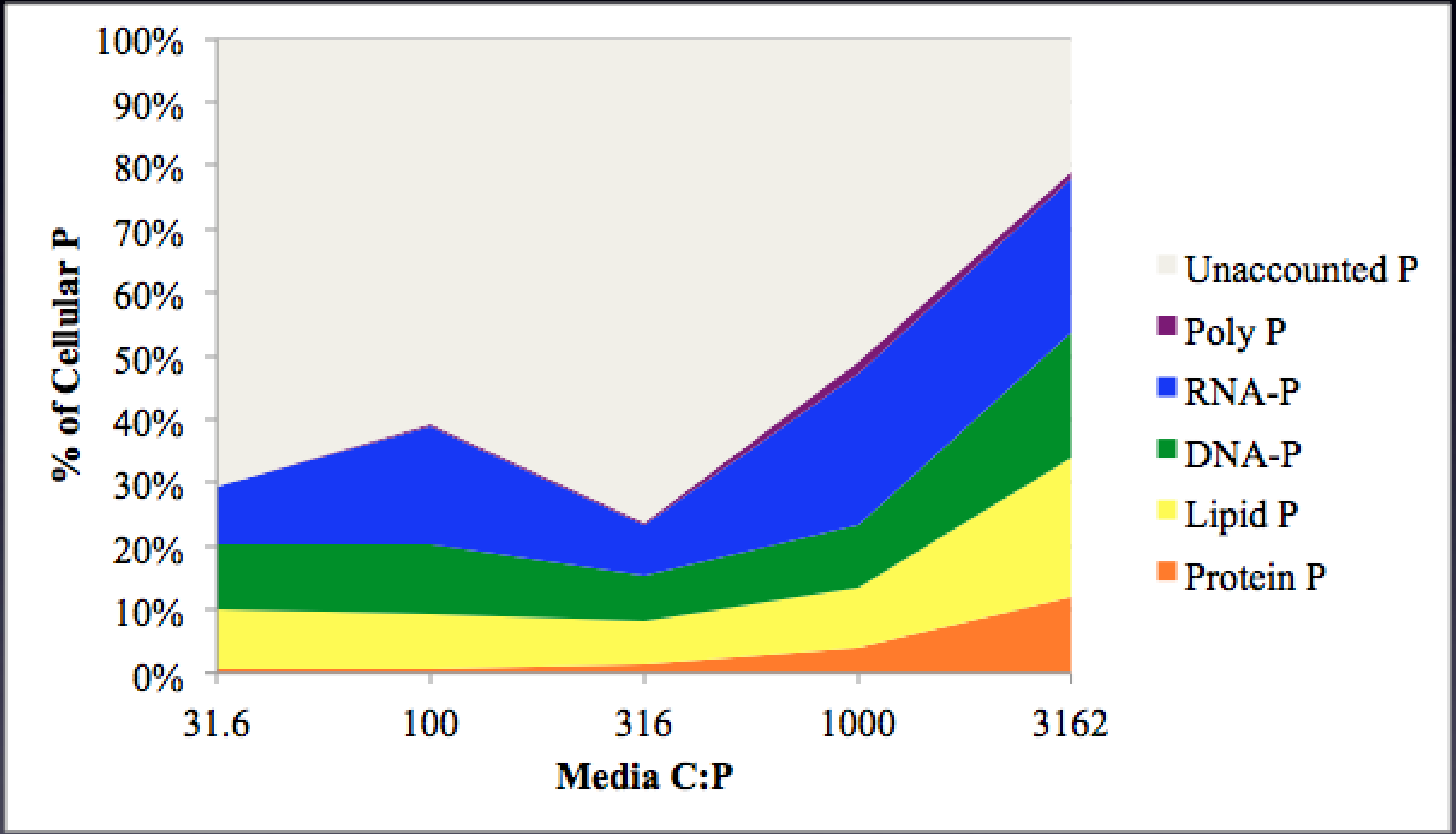
P

Chemostats

P

Where's the P? (lake communities)

P

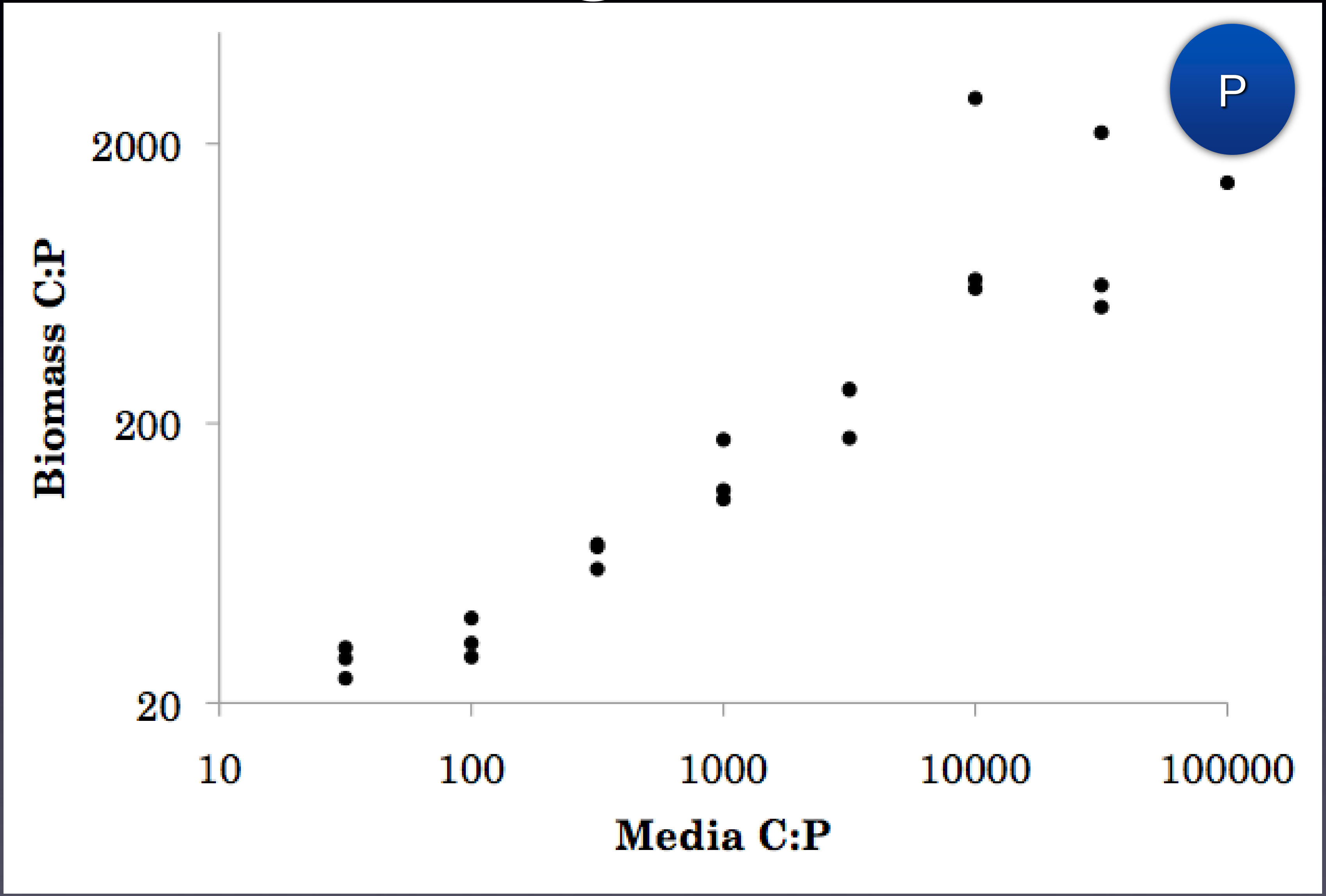


Growth rates 0.2-0.3 per day

How low can they go (and how flexible are they)?

P

How high can the C:P go?



How low can they go? Can a bacterium have P content of 0.02% dw?

P

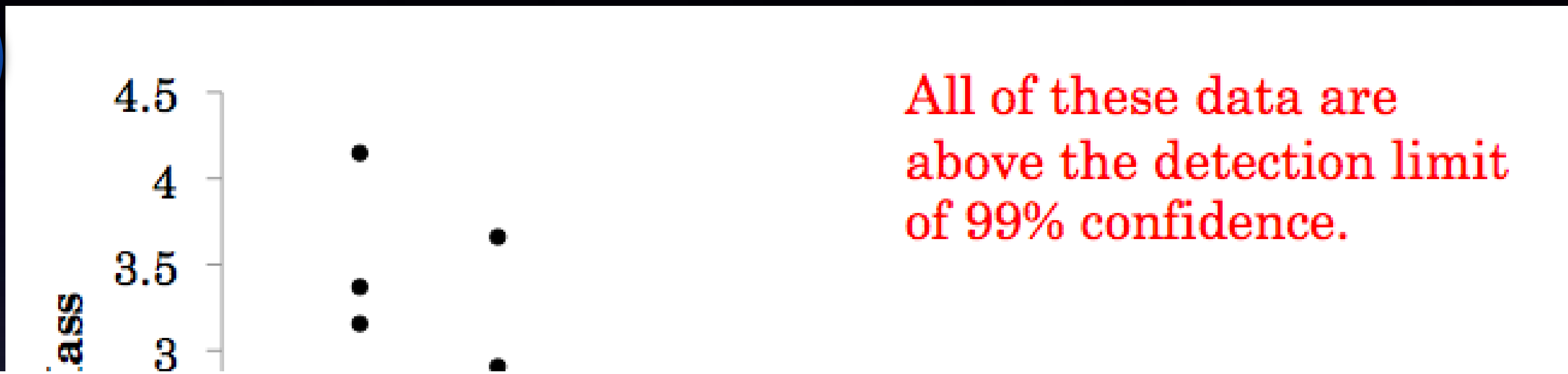
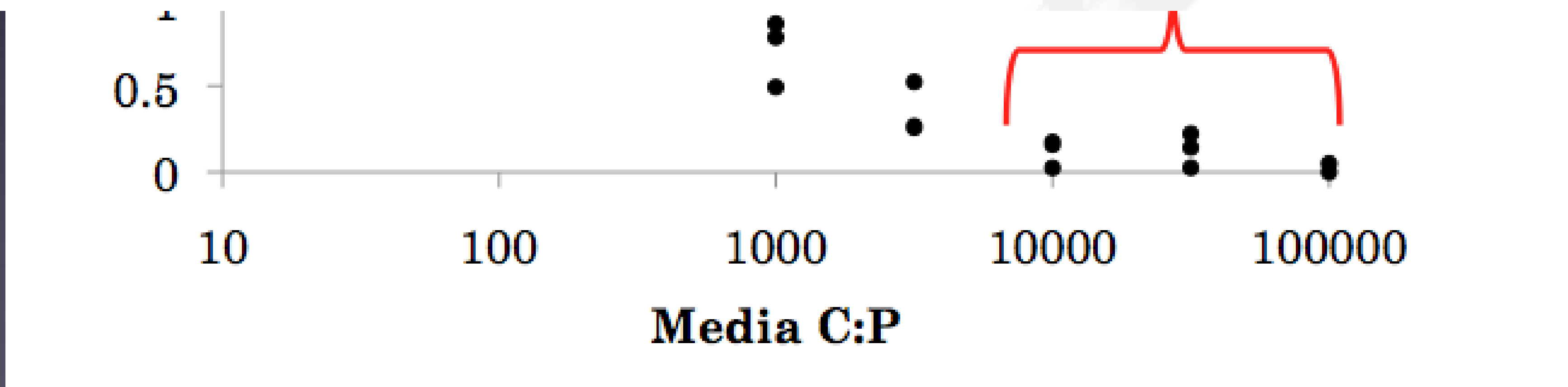


Table 1. Bulk intracellular elemental profile of strain GFAJ1.*

	(% dry weight)		
Condition (n)	As	P	As:P
+As/-P (8)	0.19 ± 0.25	0.019 ± 0.0009	7.3
-As/+P (4)	0.001 ± 0.0005	0.54 ± 0.21	0.002

*Cells grown and prepared with trace metal clean techniques (*11*). Number in parentheses indicates replicate samples analyzed.



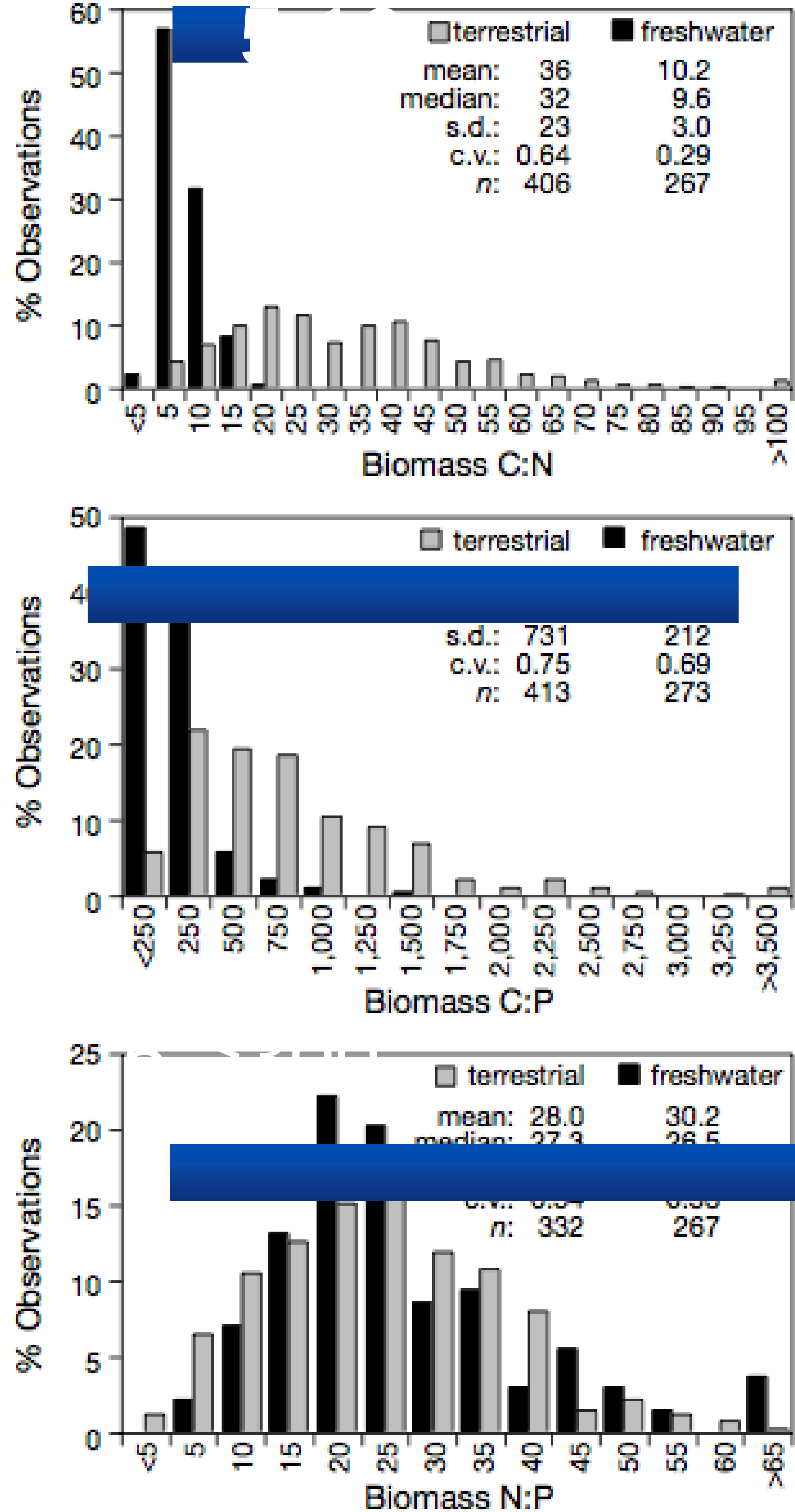
H

Homeostasis

How flexible are bacteria?

How flexible?Comparison with autotrophs

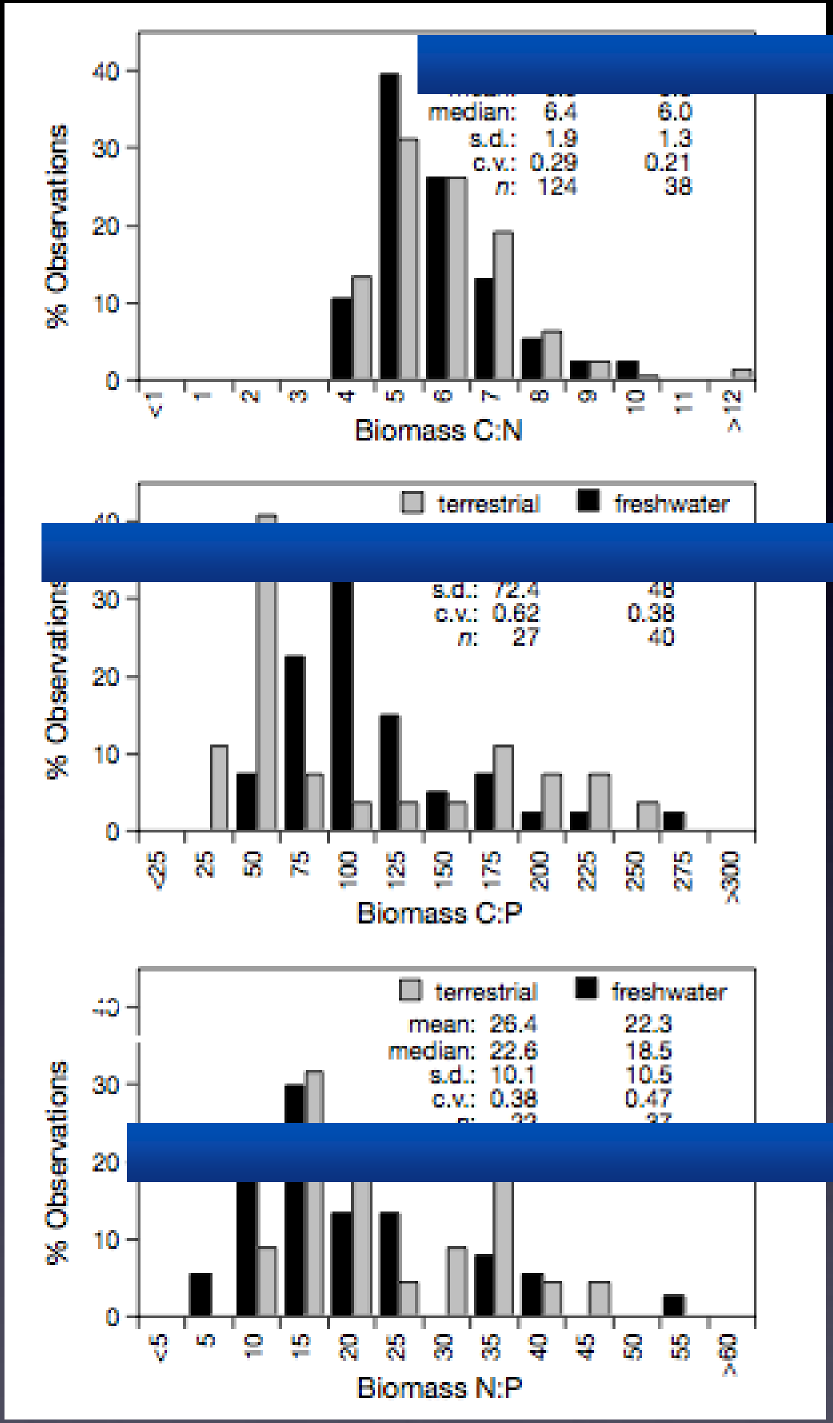
H



Elser et al. 2007

Comparison with heterotrophs

Heterotrophic bacteria are the most stoichiometrically diverse organisms on the planet!



H

Homeostasis and ecological theory

H

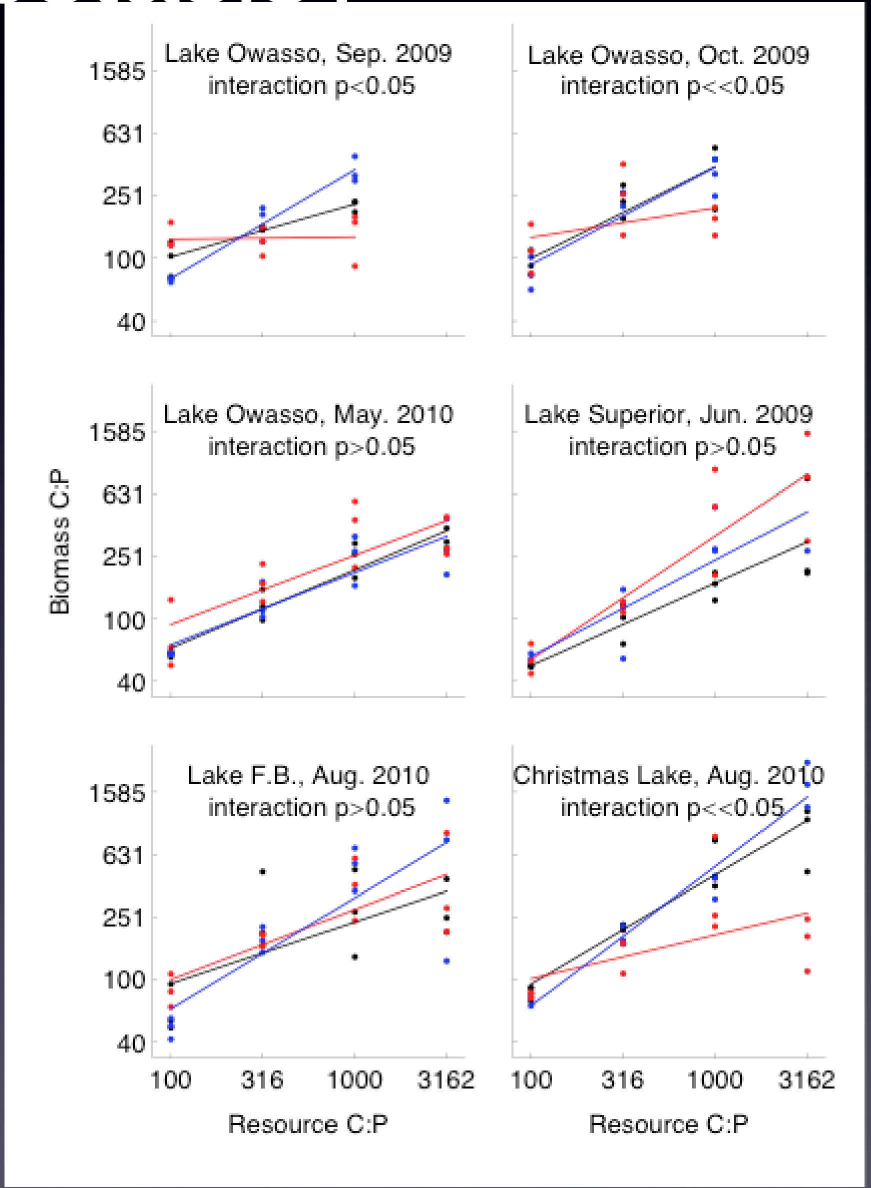
	r-Selected [3,4], Competitive Specialists [2], Velocity Strategy [1,5], Strong Homeostasis, 'Homeostoichs' [6]	K-Selected [3,4], Stress-Tolerant [2], Affinity-Adapted [1,5], Non-Homeostasis, 'Heterostoichs' [6]
μ max	high	low
'Storage capacity'	small	large
Nutrient content	high	low / variable
Nutrient requirement	high	low
Strength of Regulation (H)	high	low
Biomass C:X	low / less variable	high / variable
TER	low	high

[1] Crowley 1975; [2] Grime 1977; [3] Jannasch 1974; [4] MacArthur and Wilson 1967; [5] Sommer 1985; [6] Jim Cotner

Godwin and Cotner In prep.

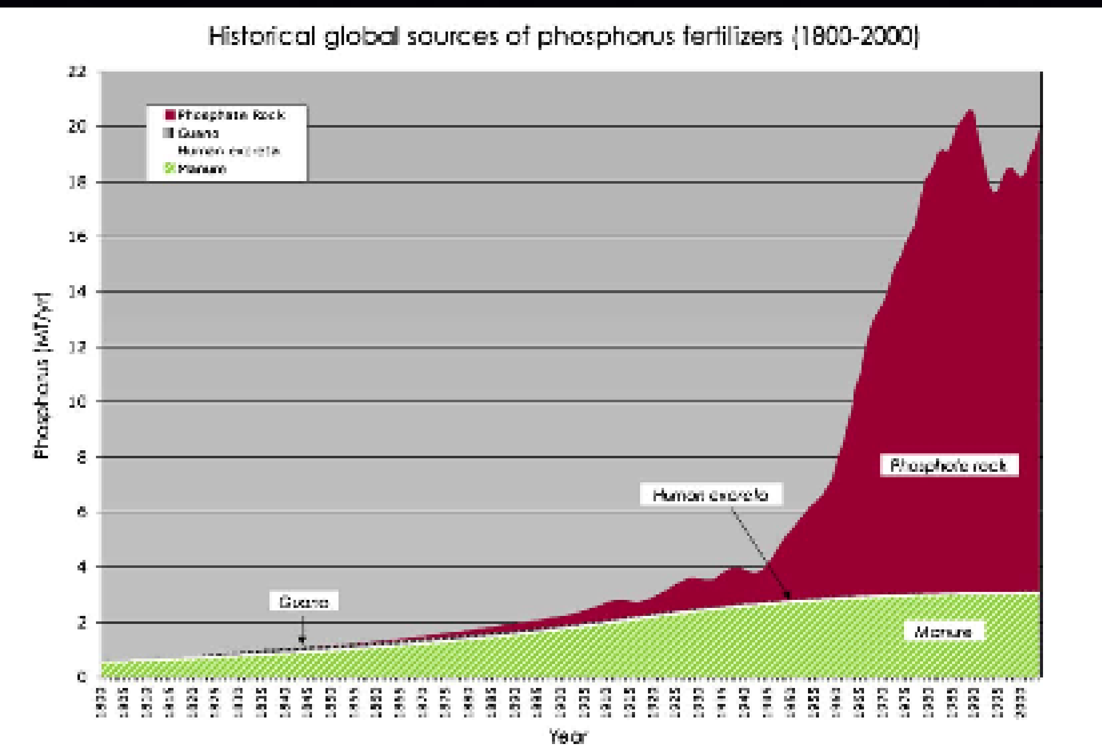
Homeostasis and communities: Do P rich conditions select for homeostasis?

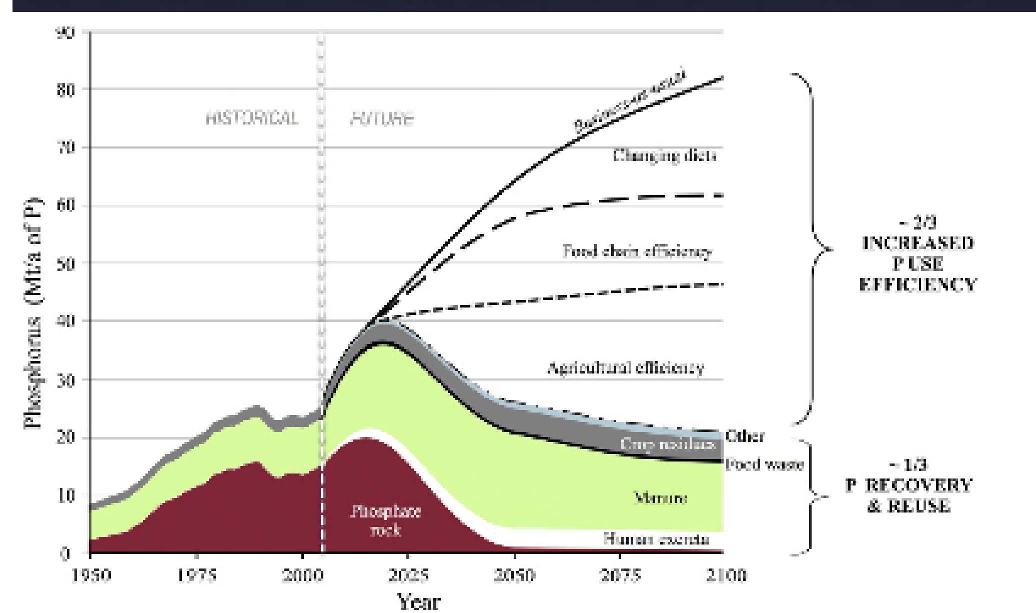
H



Black-Initial assemblage
Red-High P
Blue-Low P

Running out of P





Cordell et al. 2010; 2011

Conclusions

- bacteria are extremely stoichiometrically flexible with respect to P and they don't need a lot of it
- there are two main stoichiometric 'behaviors' that parallel r and K-selected species and our evidence suggests that 'K' selected species rule the day
- we're running out of P but we also have too much, i.e., eutrophication

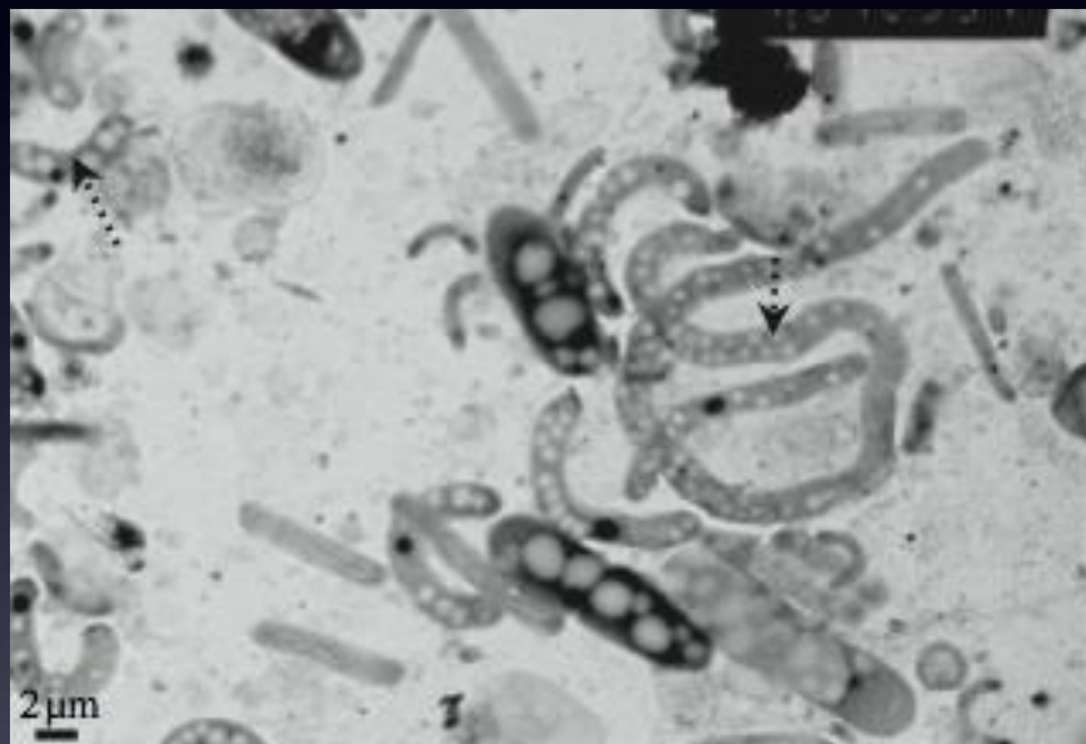
Acknowledgments

- Graduate students: Ed Hall, Casey Godwin, Seth Thompson
- Andrea Little- lab manager
- Post docs: Wataru Makino, Thad Scott
- Mikal Heldal and Frede Thingstad
- Funding: NSF, University of Minnesota (IonE/IREE)

National Science Foundation
WHERE DISCOVERIES BEGIN

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

Non-homoestasis: Using carbon to get phosphorus



Thingstad et al. 2005

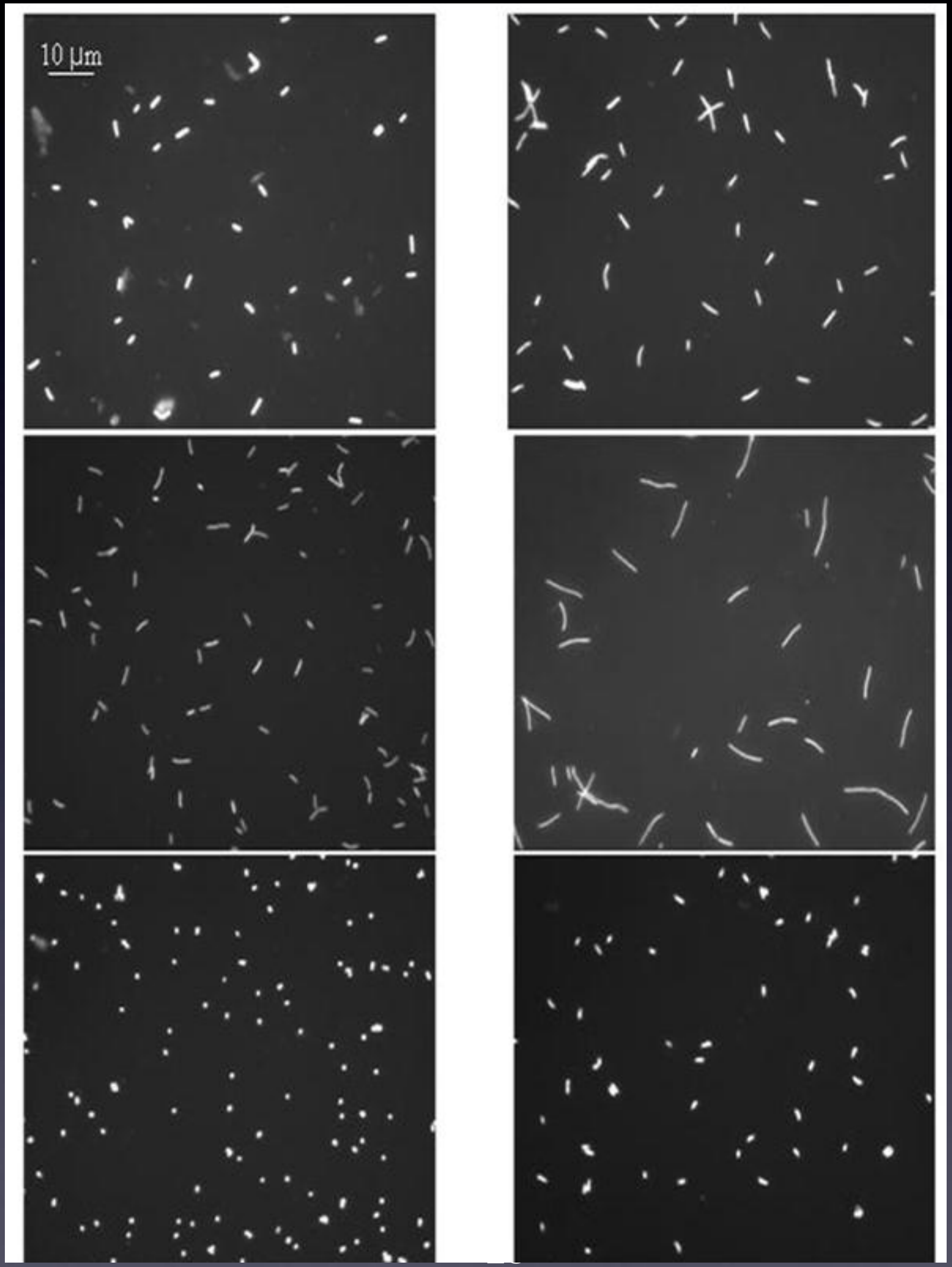
Morphometric changes under P limitation

+P

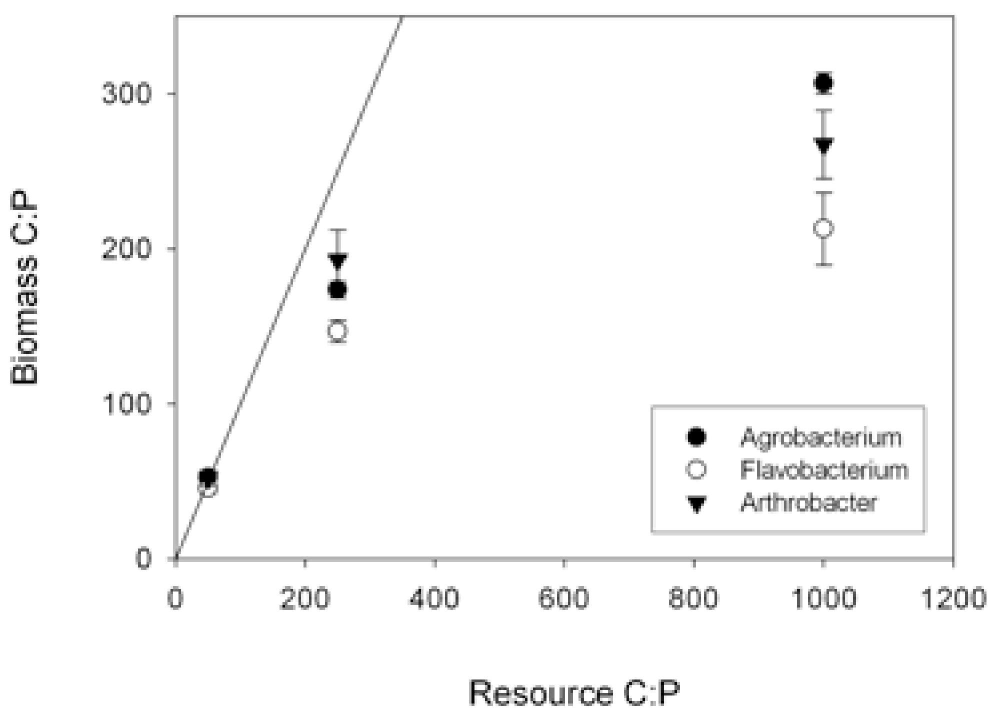
Agrobacterium

Flavobacterium

Arthrobacterium



-P



Biomass C:P
300
200
100
0
0
200
400
600
800
1000
1200
Resource C:P
Agrobacterium
Flavobacterium
Arthrobacter

More info on the As:P controversy

http://www.sciencemag.org/content/332/6034/1163