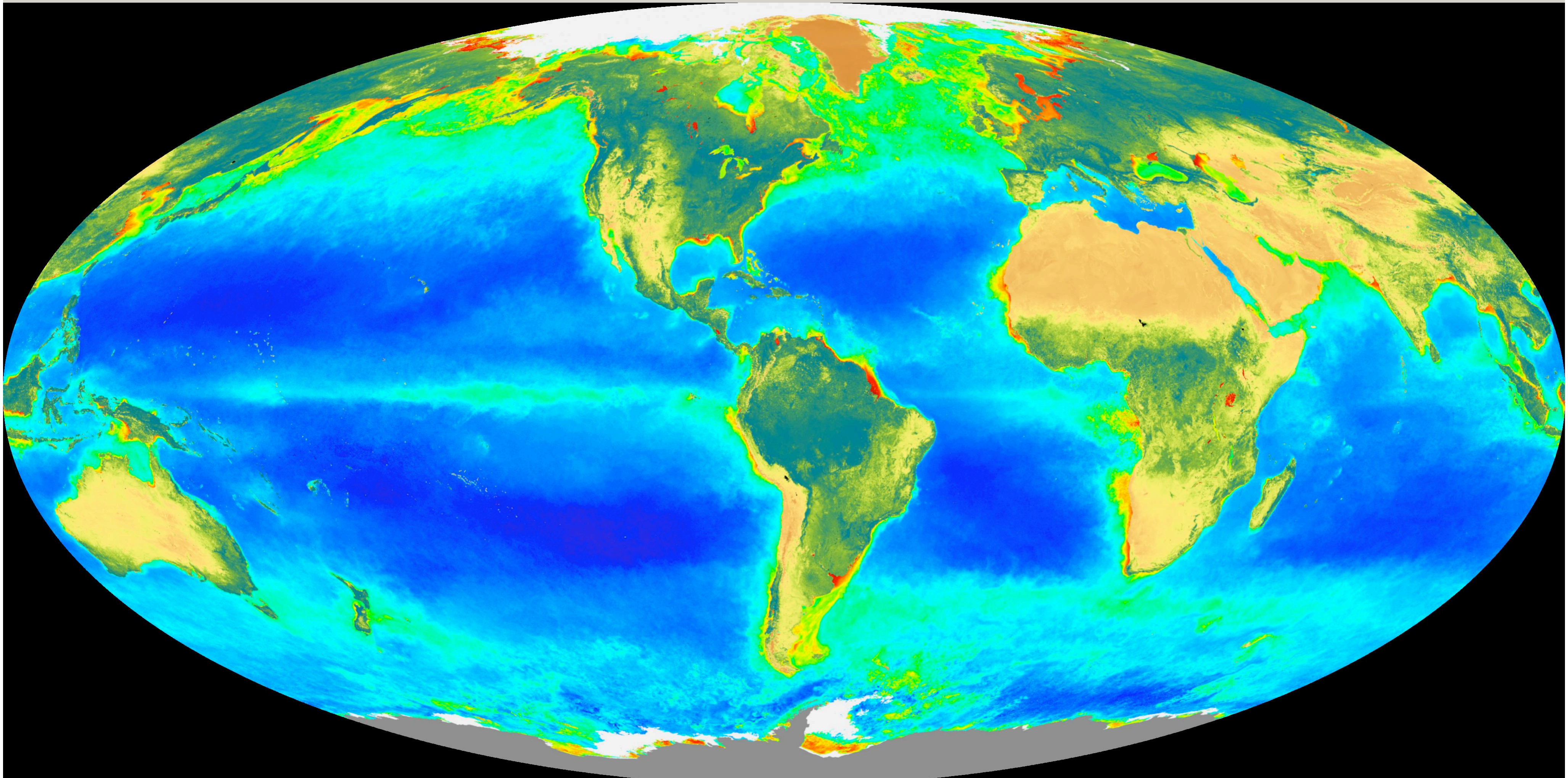
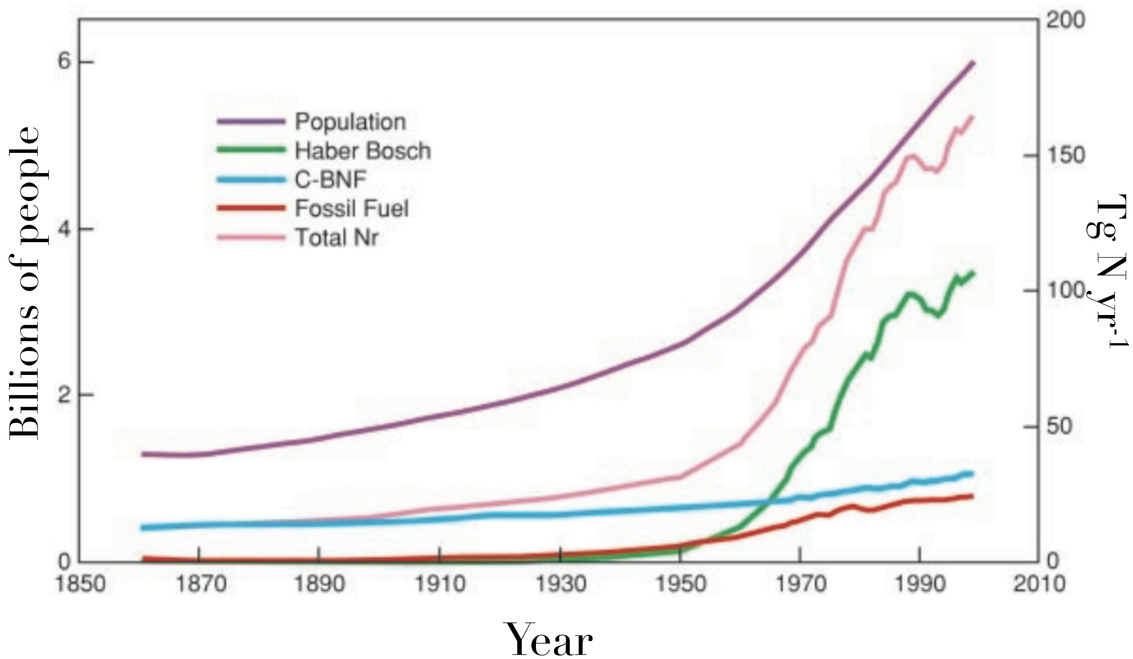
Stoichiometric controls over nitrogen and phosphorus accumulation from soils to the sea



Philip Taylor and Alan Townsend, INSTAAR and EEB, Univ. of CO.

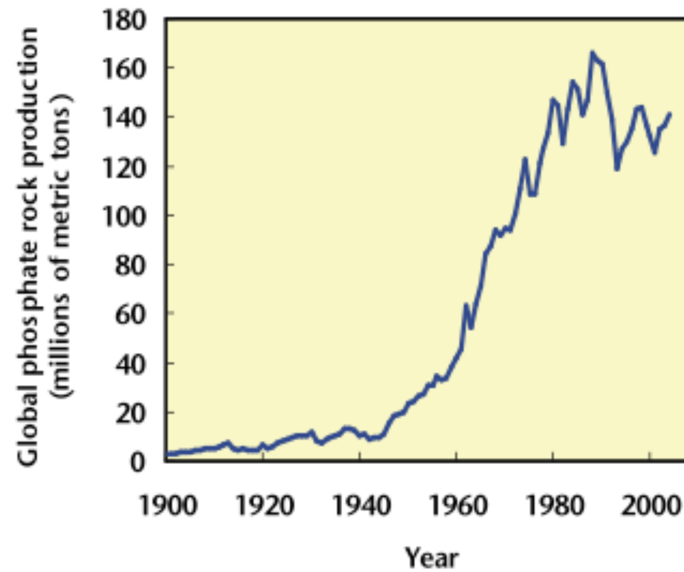
Unprecedented accumulation of bioavailable N and P

Population and Reactive N



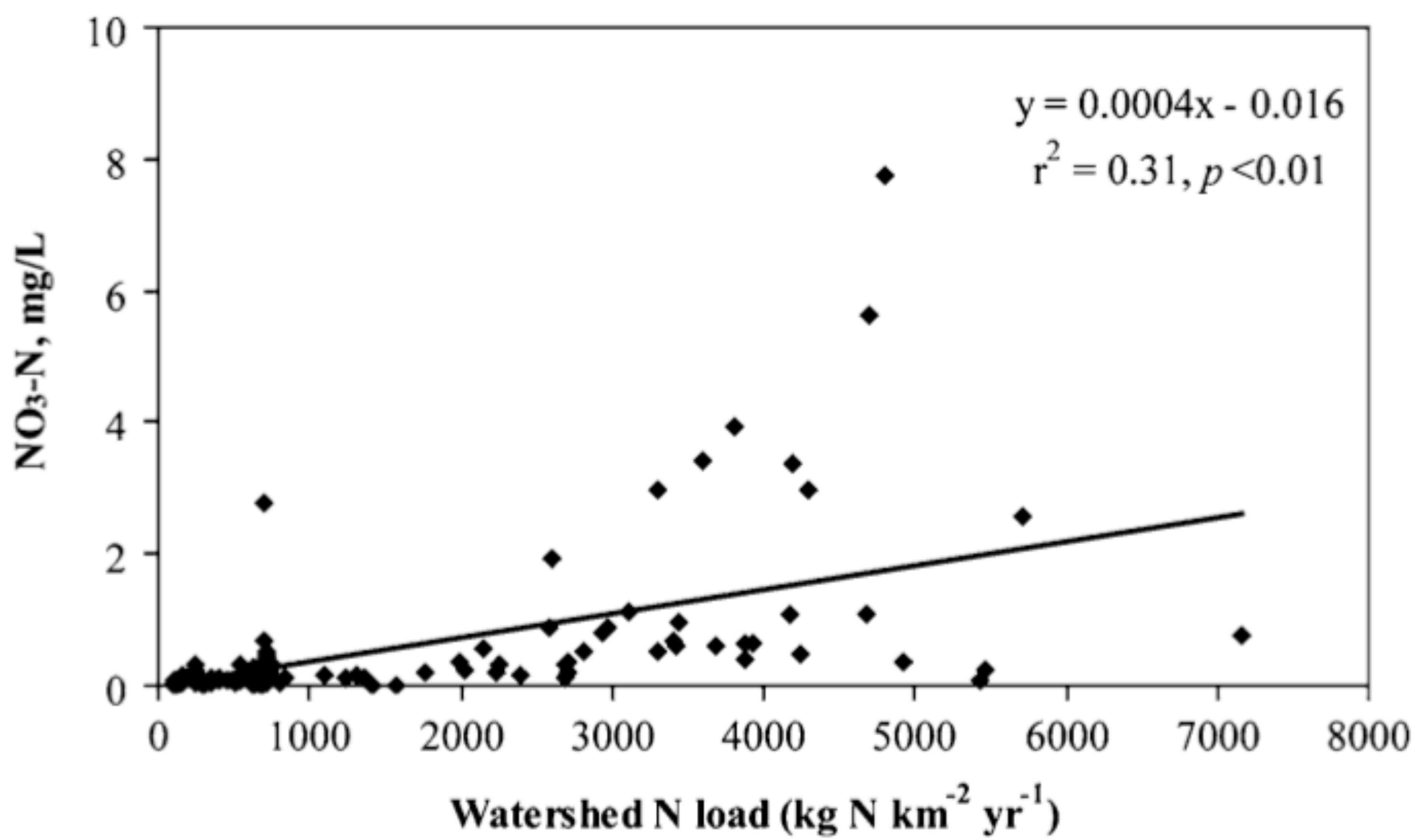
Galloway *et al.* 2003

Reactive P



Global Phosphate Production (USGS 2007)

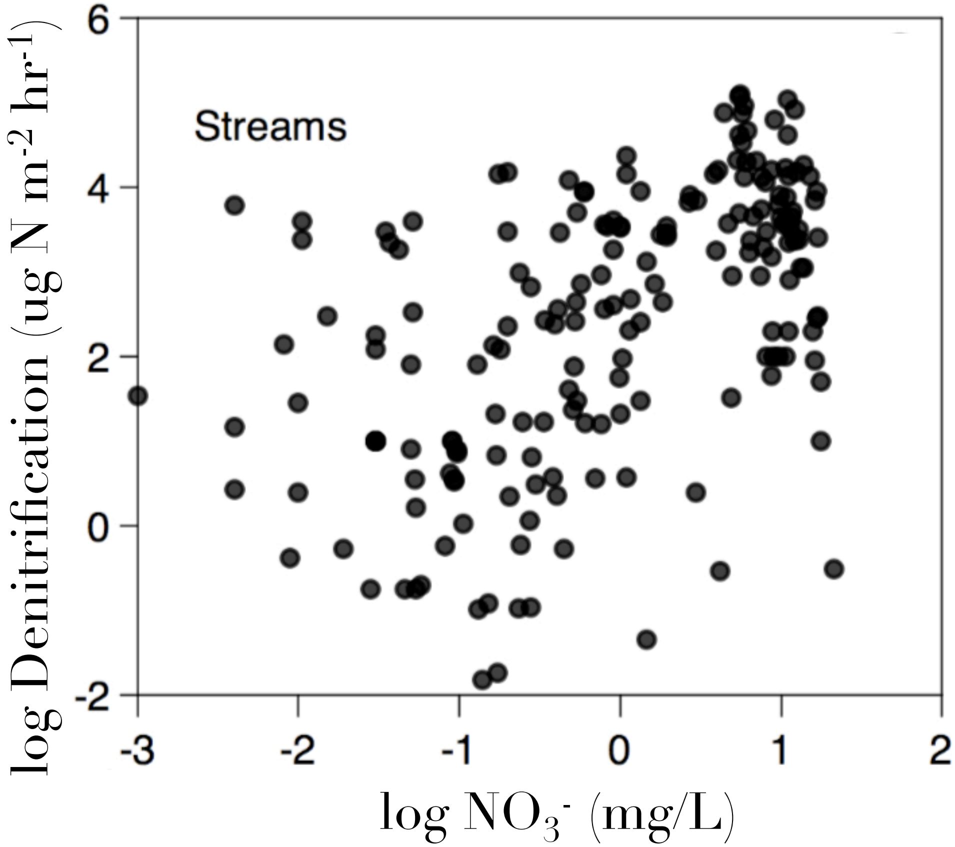
Impacts are concentration dependent, yet reactive N and P concentrations do not scale strongly with loading



Pellerin et al. 2006

And concentration is not a good predictor of key control processes

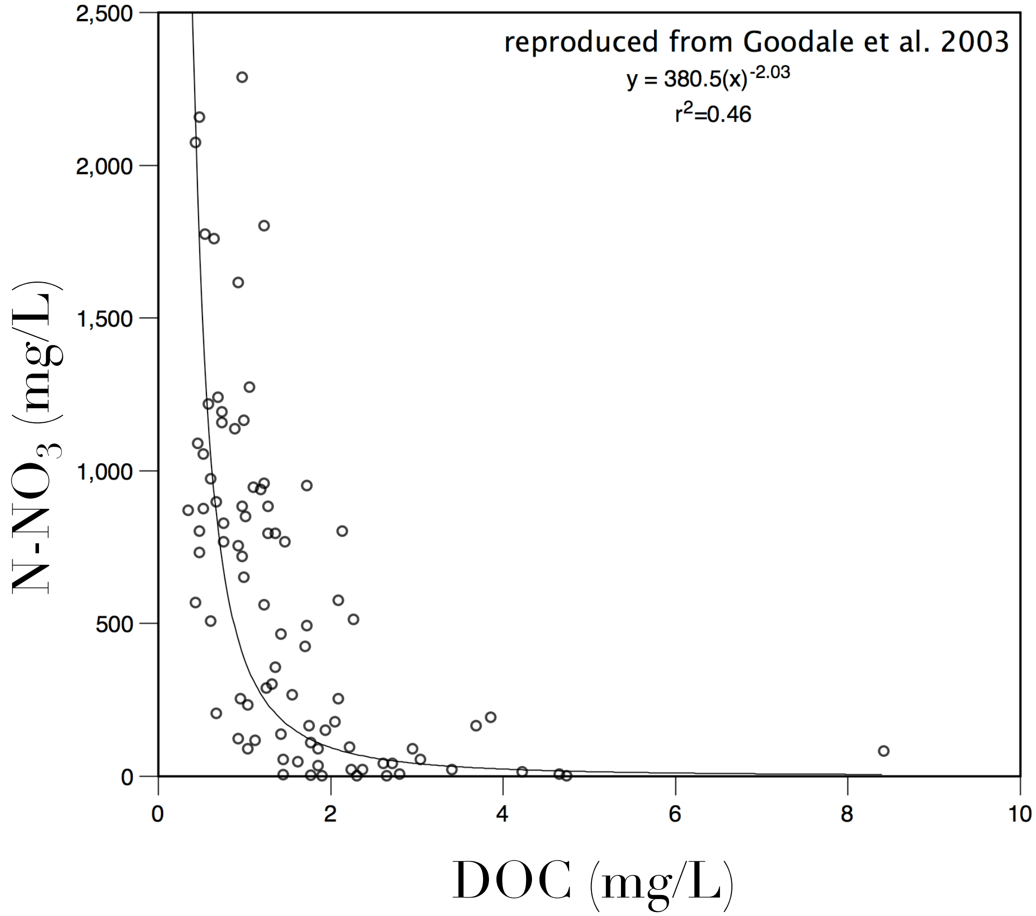
Denitrification across 230 streams and rivers
(conversion of NO_3^- to N_2 gas)



We need deeper insight.

Compelling pattern to work with

(seen in 6 other stream and groundwater systems, and many lakes and oceans)

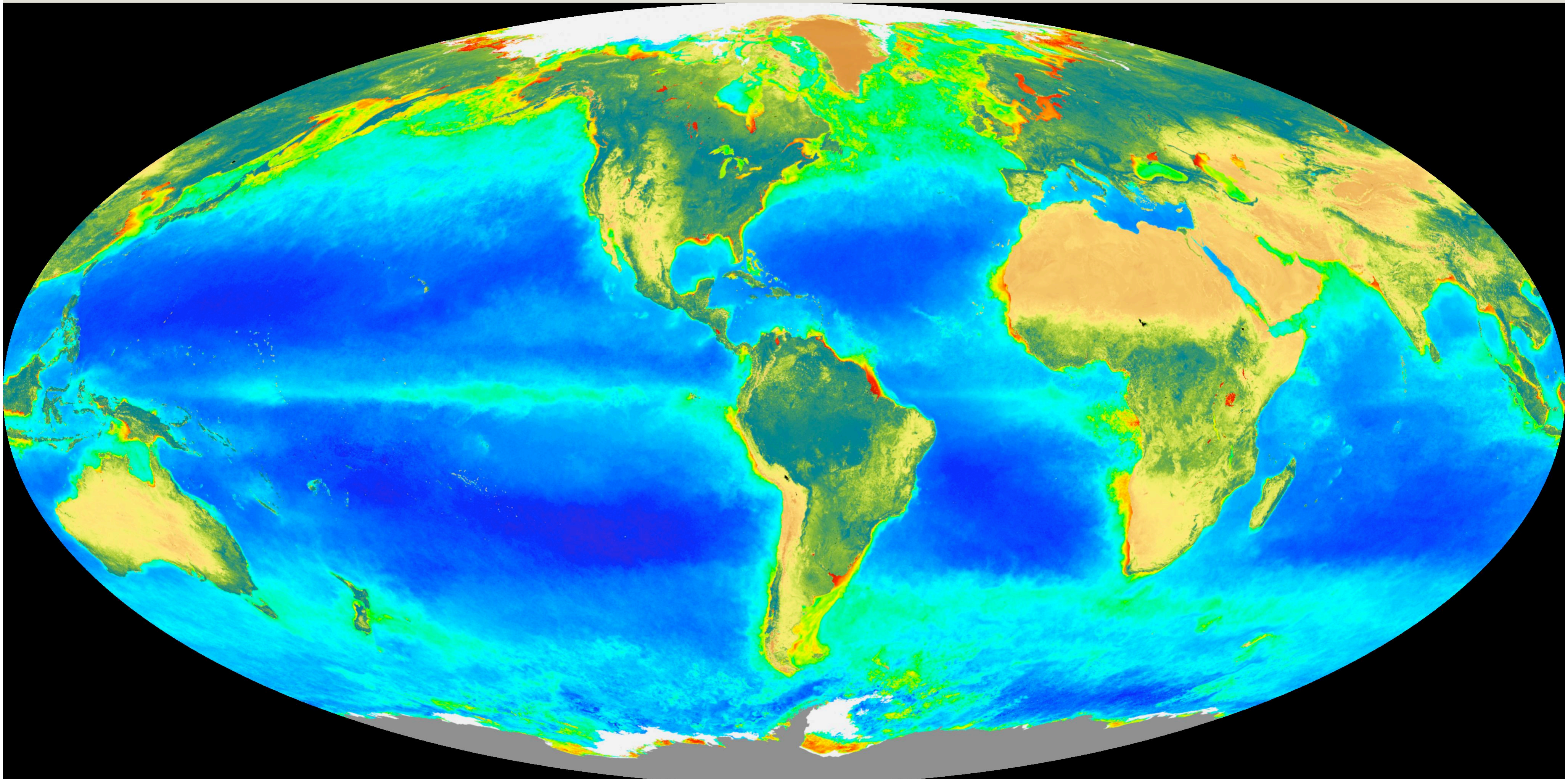


Outline

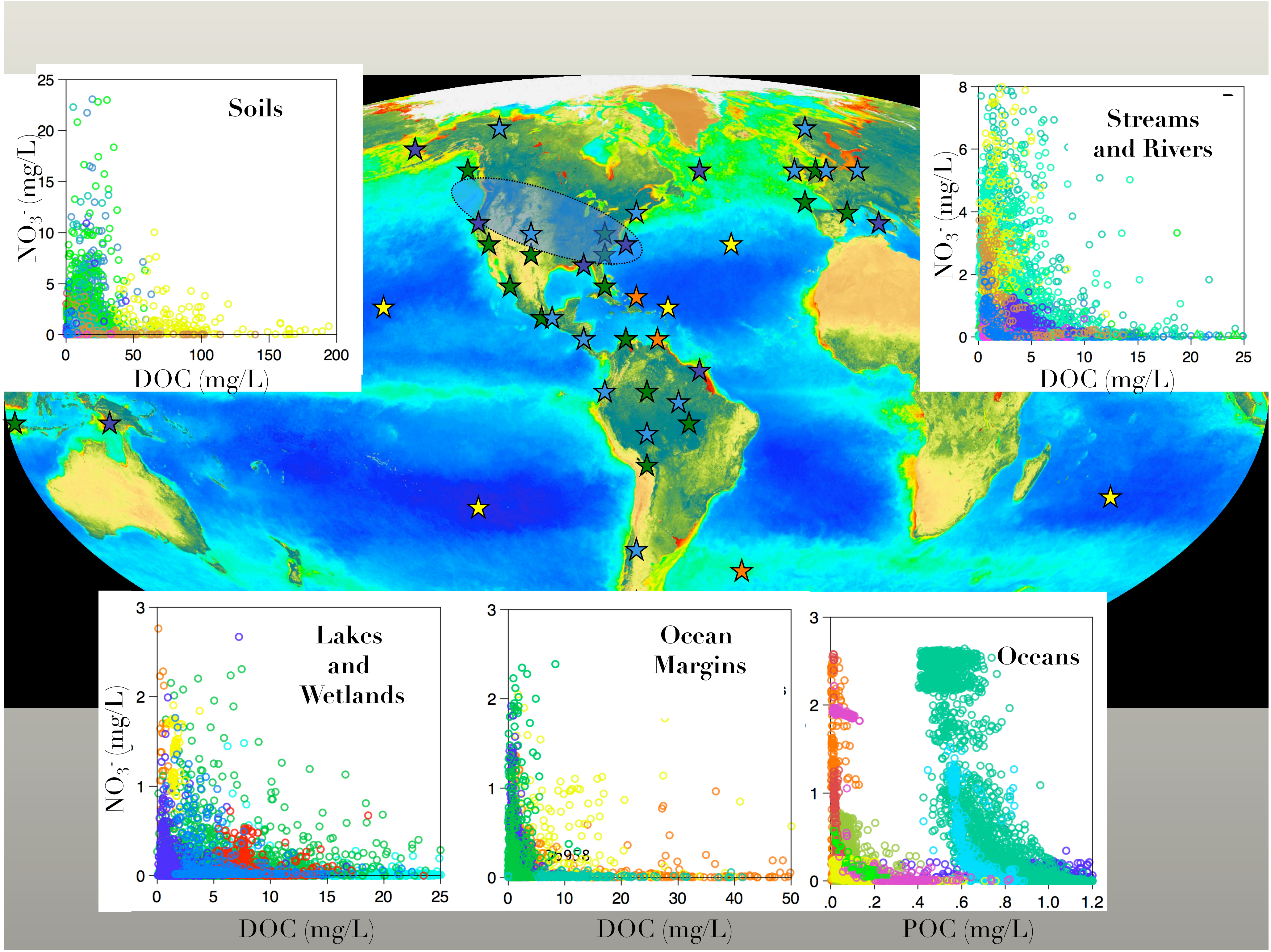
1) Are inverse patterns everywhere?

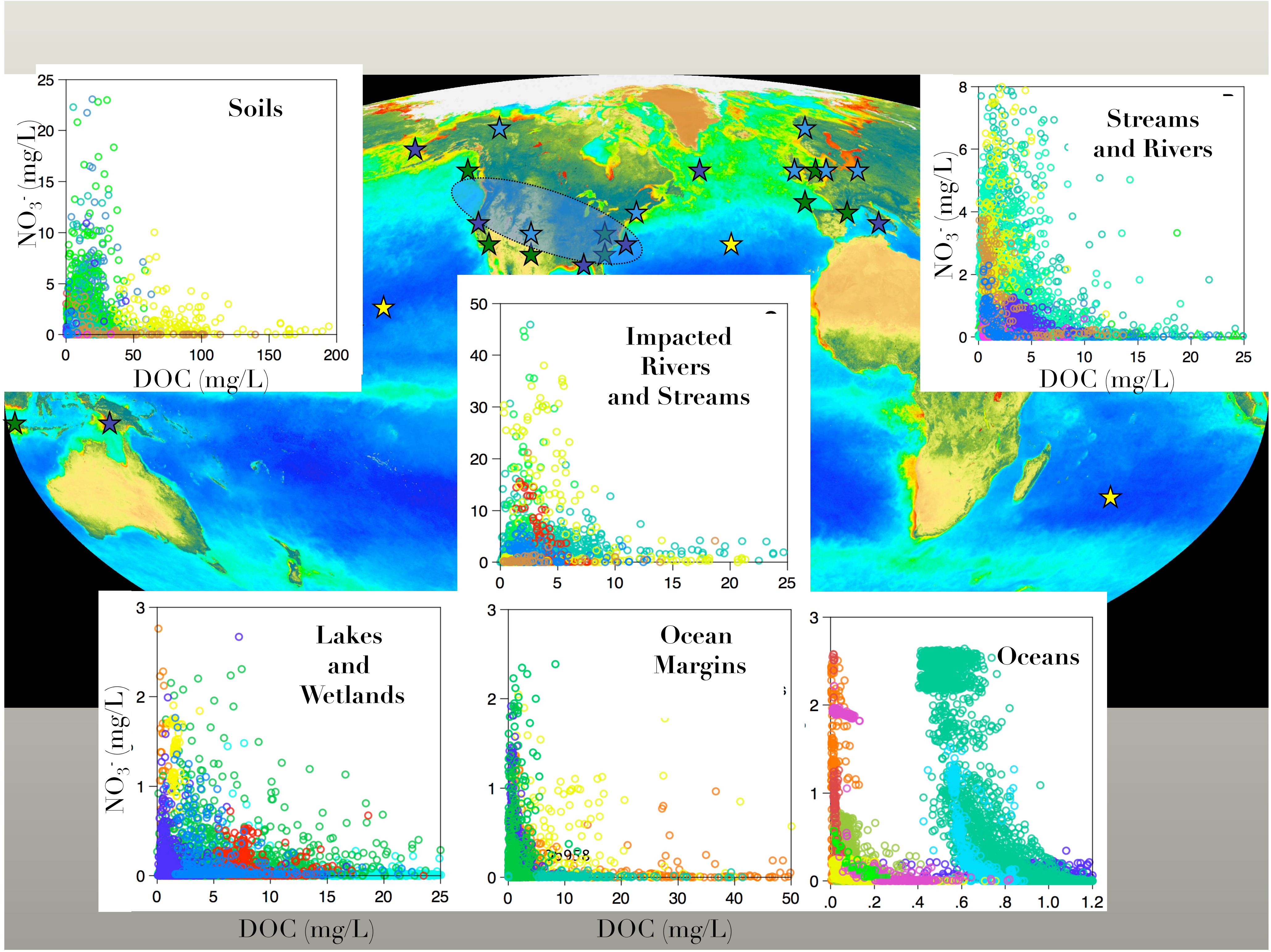
2) If so, what biological processes could underlie these patterns?

And, what data exist to test a conceptual model?



We explored DOC-NO_3 relationships in all of earth's major ecosystems.


Soils
NO_3^- (mg/L)
DOC (mg/L)
Streams and Rivers
NO_3^- (mg/L)
DOC (mg/L)
Lakes and Wetlands
NO_3^- (mg/L)
DOC (mg/L)
Ocean Margins
DOC (mg/L)
Oceans
POC (mg/L)



Soils
NO_3^- (mg/L)
DOC (mg/L)
Streams and Rivers
NO_3^- (mg/L)
DOC (mg/L)
Impacted Rivers and Streams
Lakes and Wetlands
NO_3^- (mg/L)
Ocean Margins
Oceans
DOC (mg/L)
DOC (mg/L)

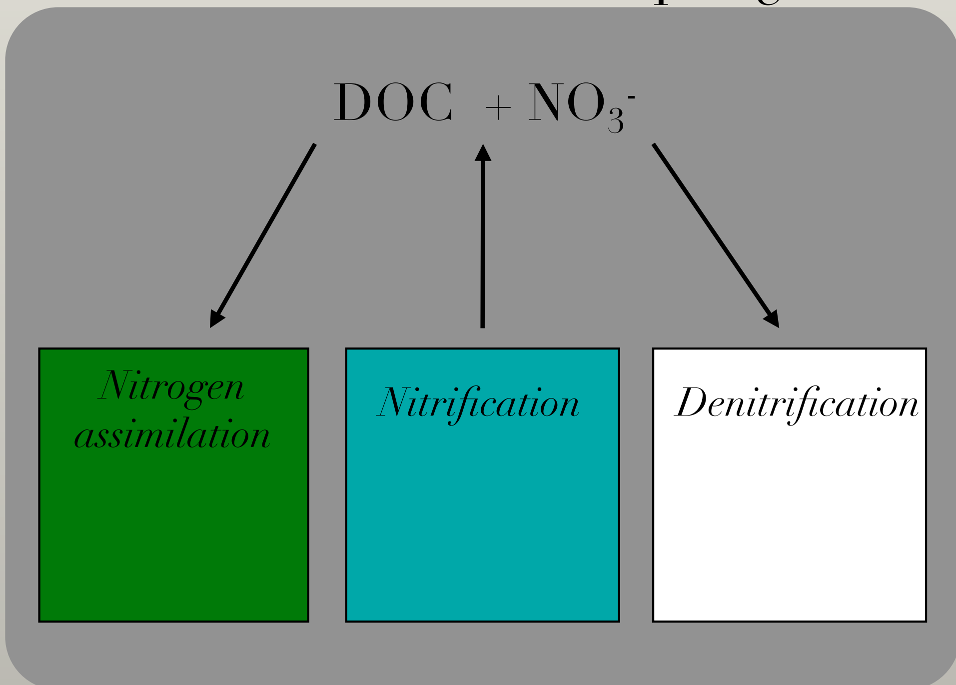
Outline

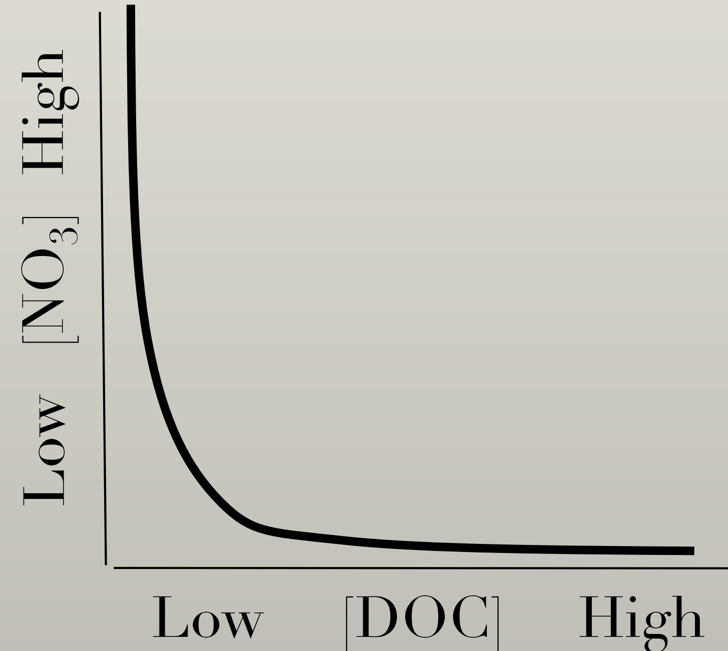
1) Are inverse patterns everywhere? **YES**

2) If so, what biological processes could underlie these patterns?

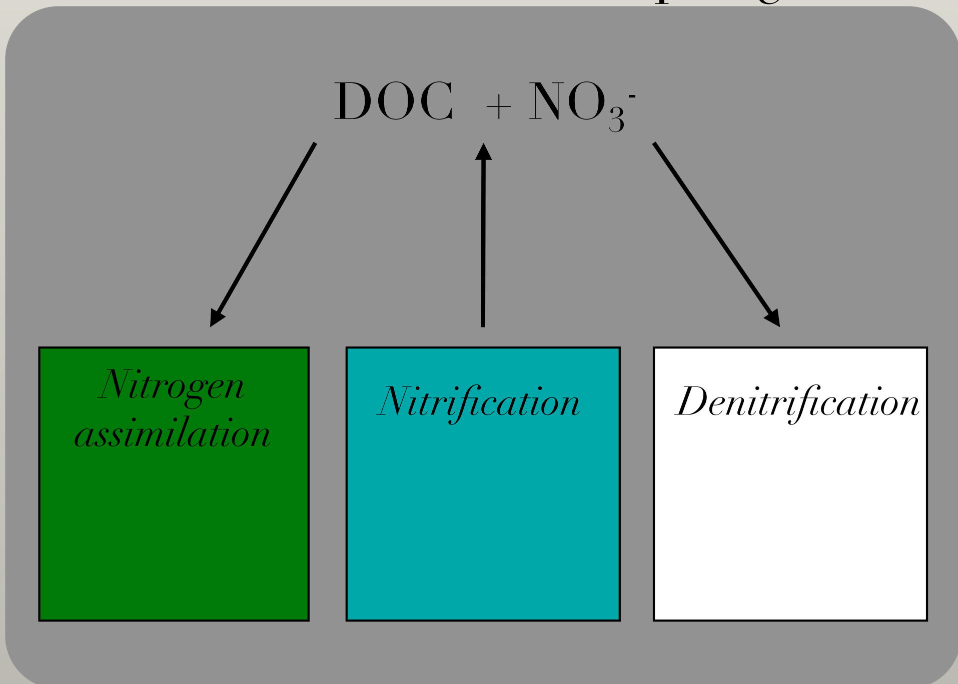
And, what data exist to test a conceptual model?

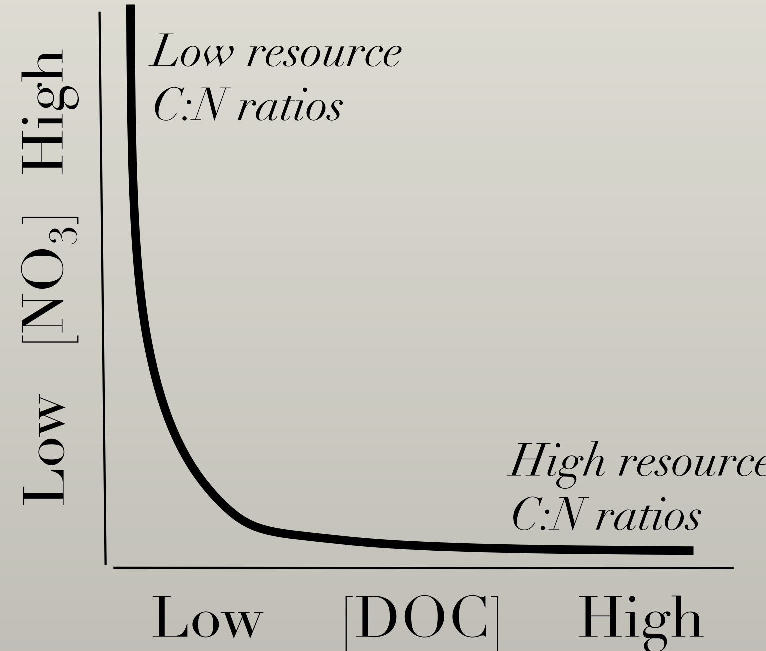
Stoichiometry of microbial C-N coupling





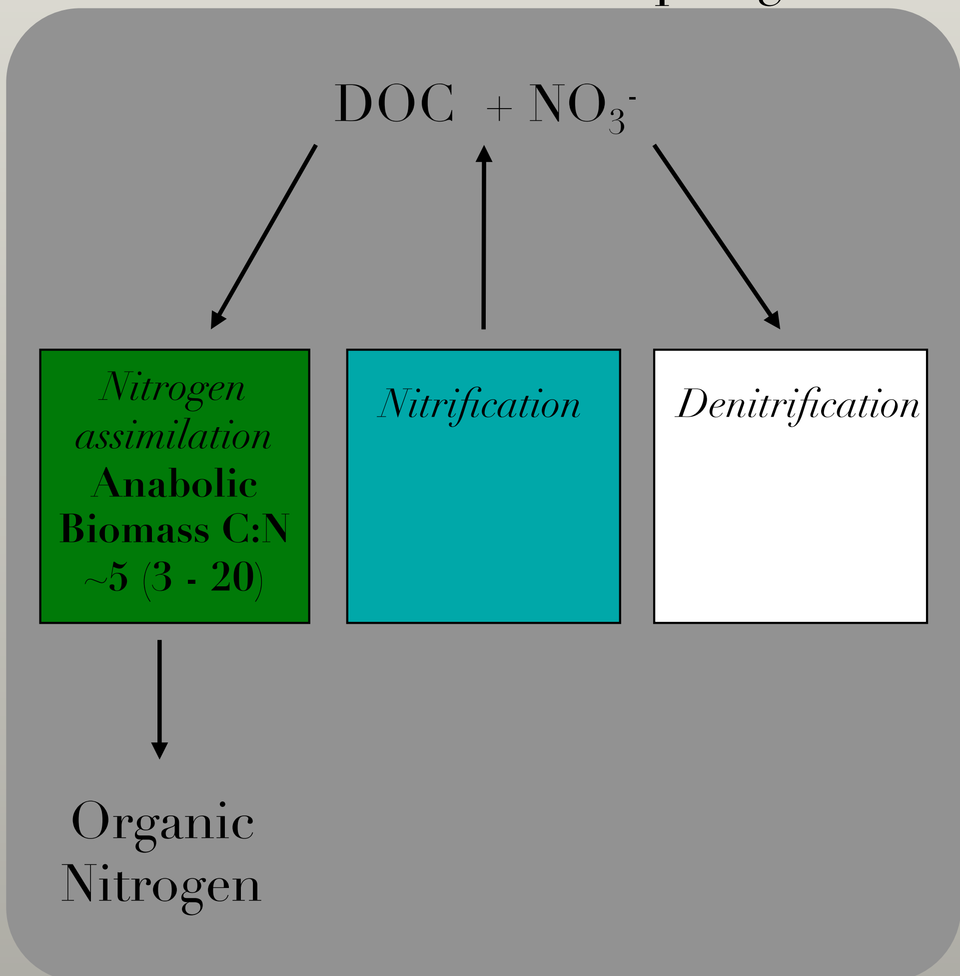
Stoichiometry of
microbial C-N coupling

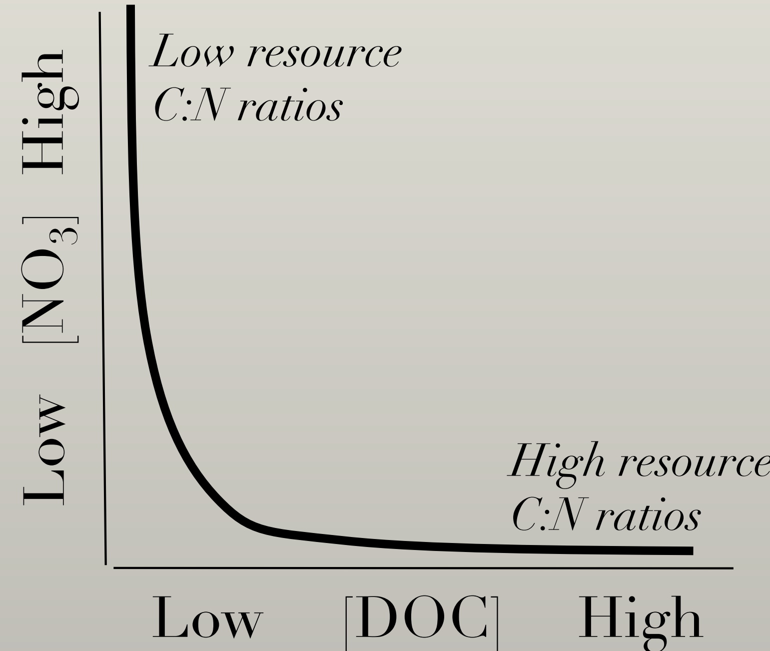




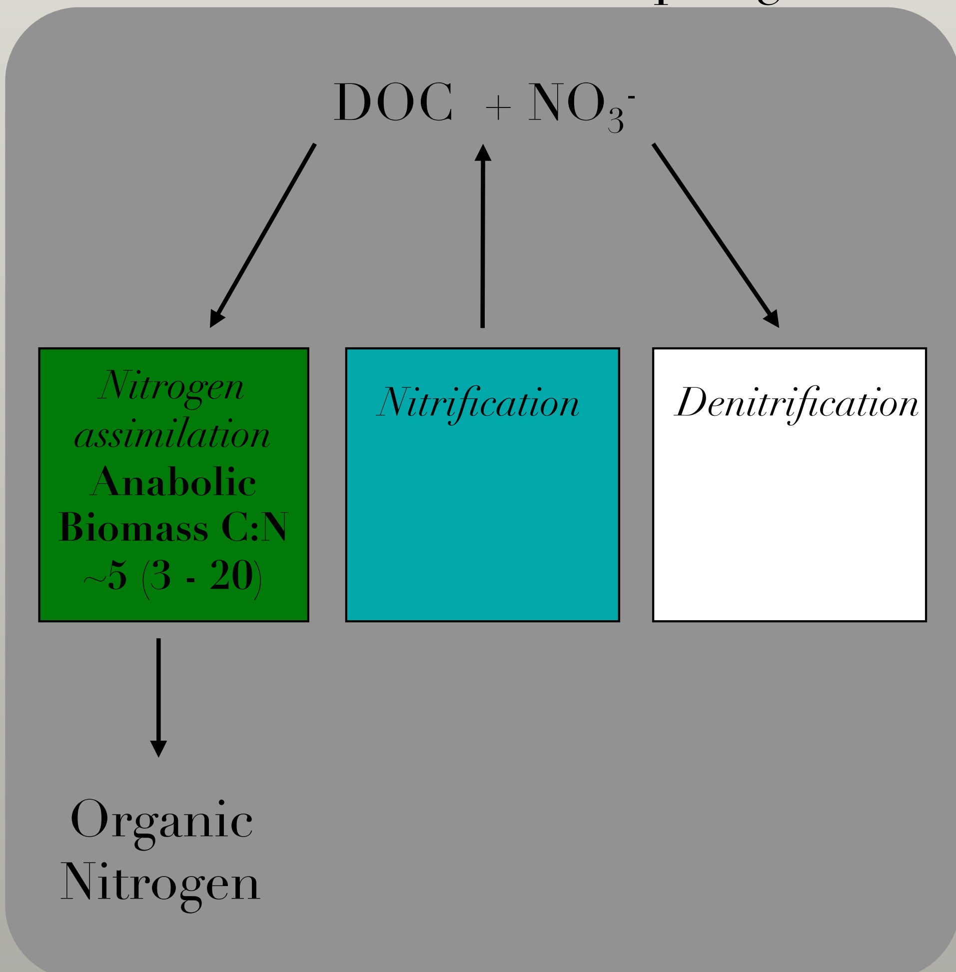
How may shifts in resource $C:NO_3^-$ stoichiometry govern these three processes?

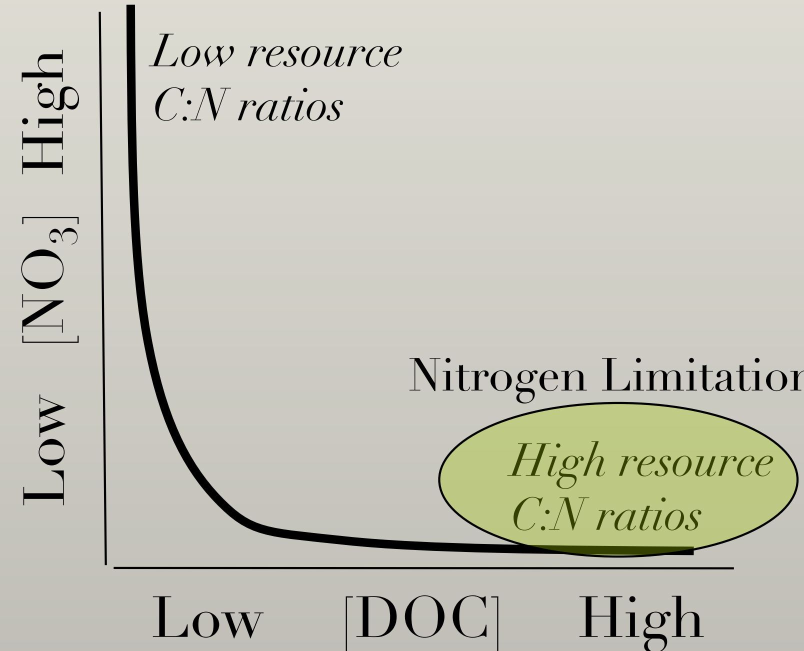
Stoichiometry of microbial C-N coupling



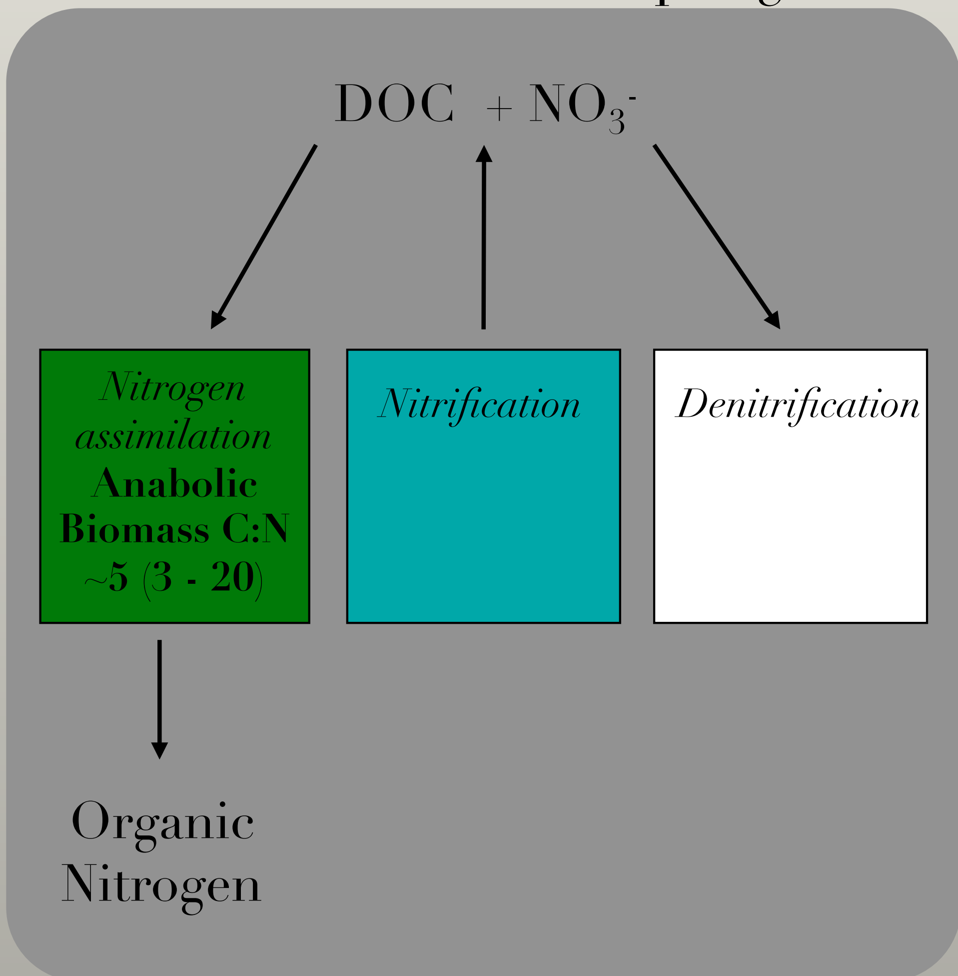


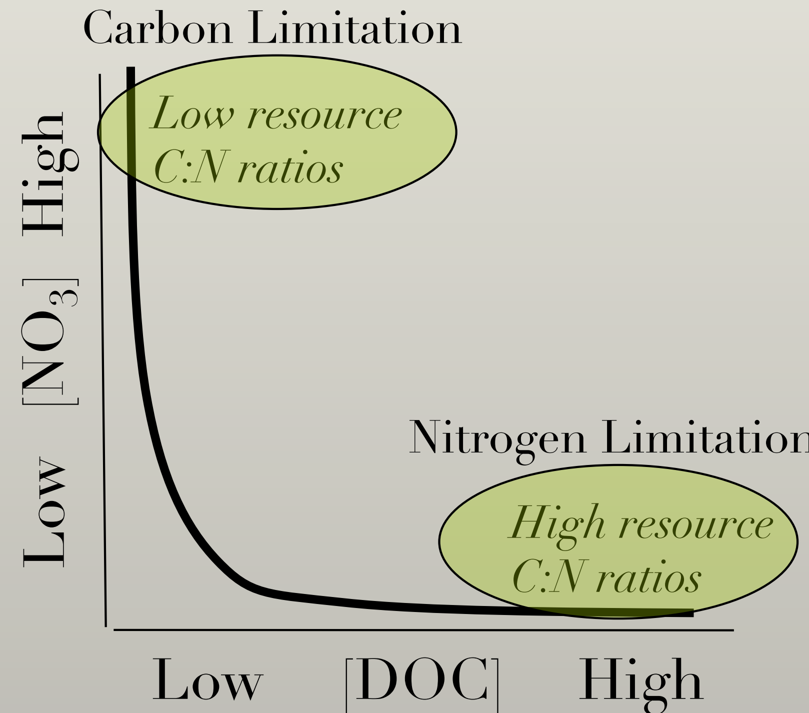
Stoichiometry of microbial C-N coupling



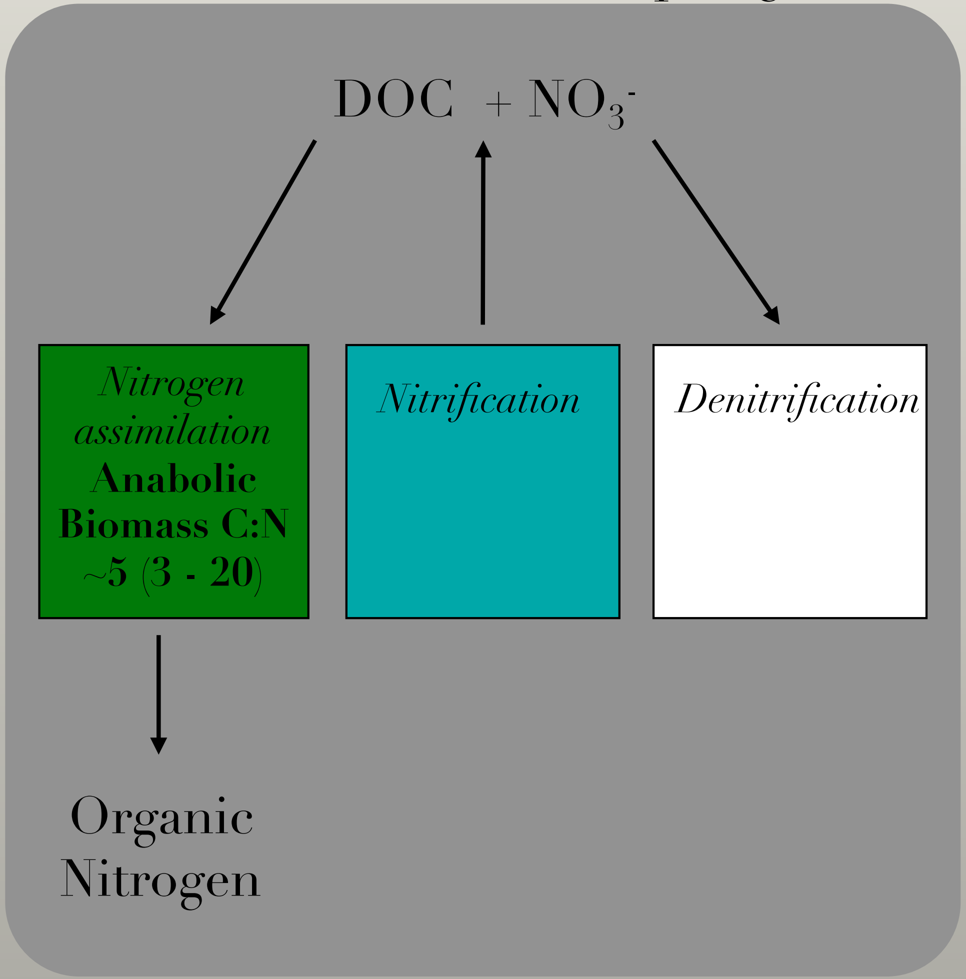


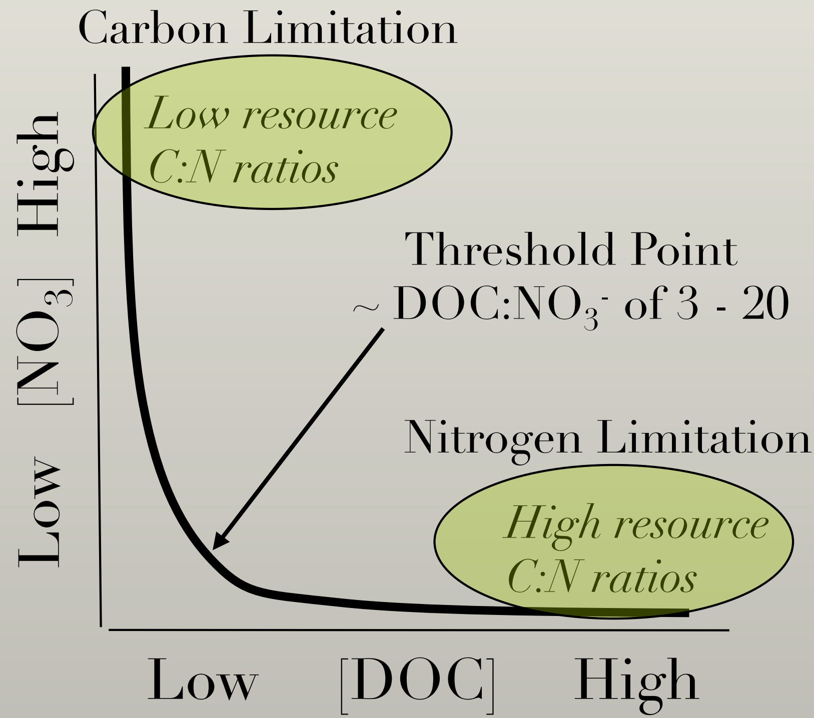
Stoichiometry of microbial C-N coupling



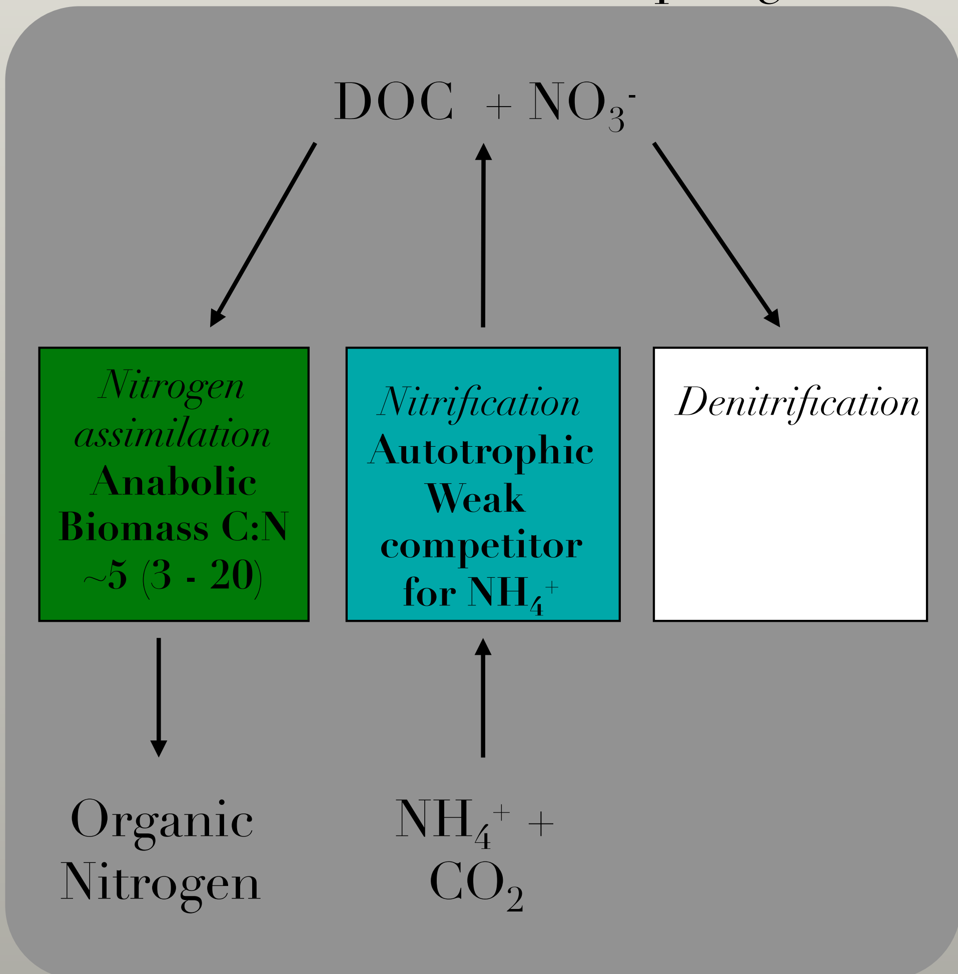


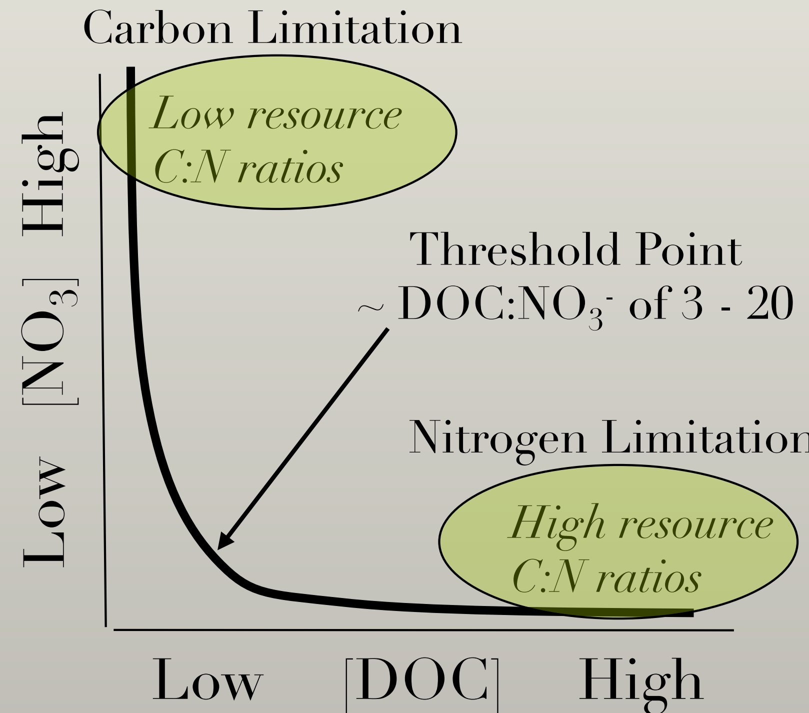
Stoichiometry of microbial C-N coupling



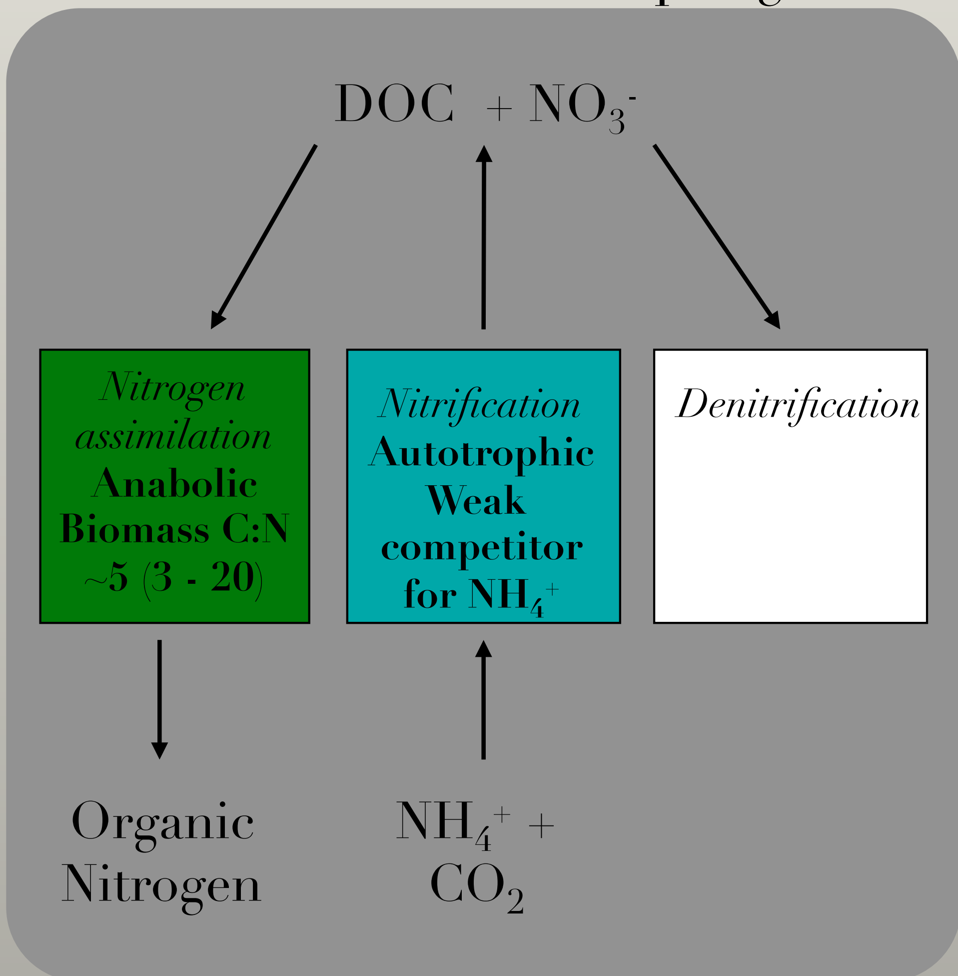


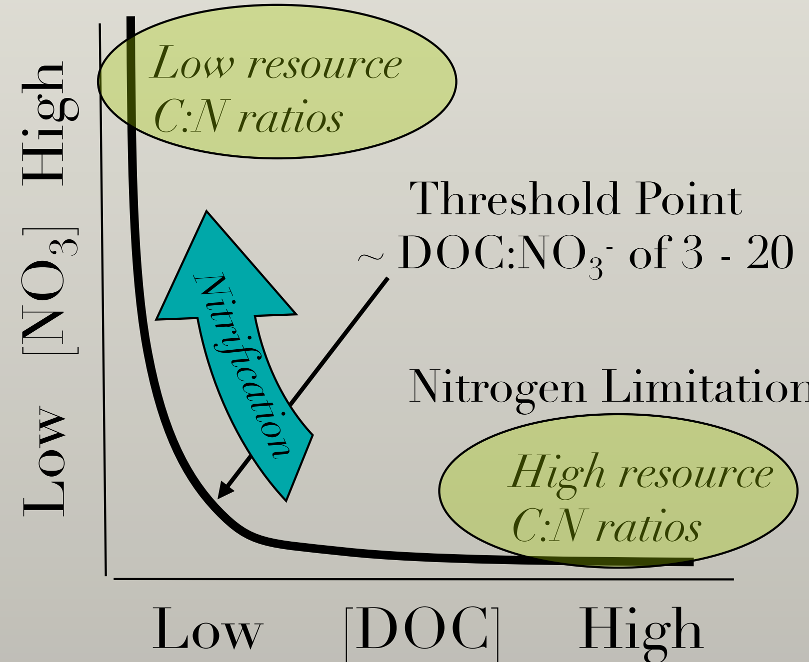
Stoichiometry of microbial C-N coupling



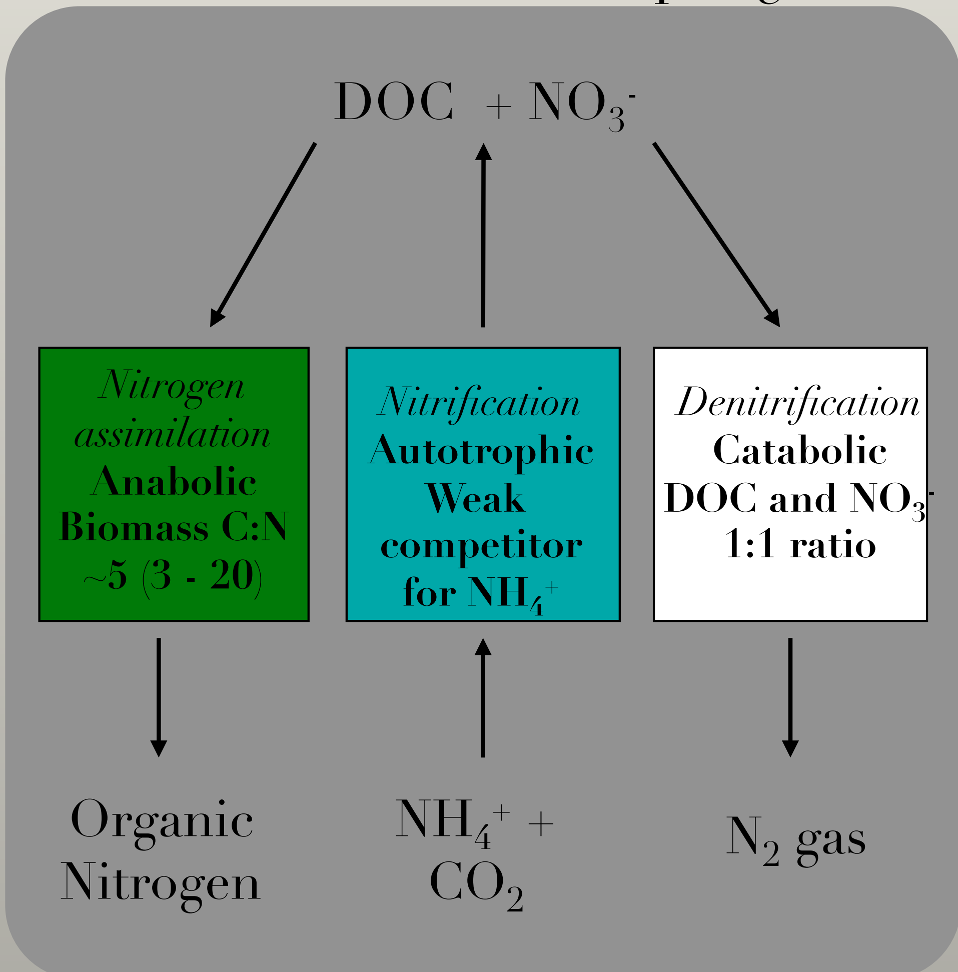


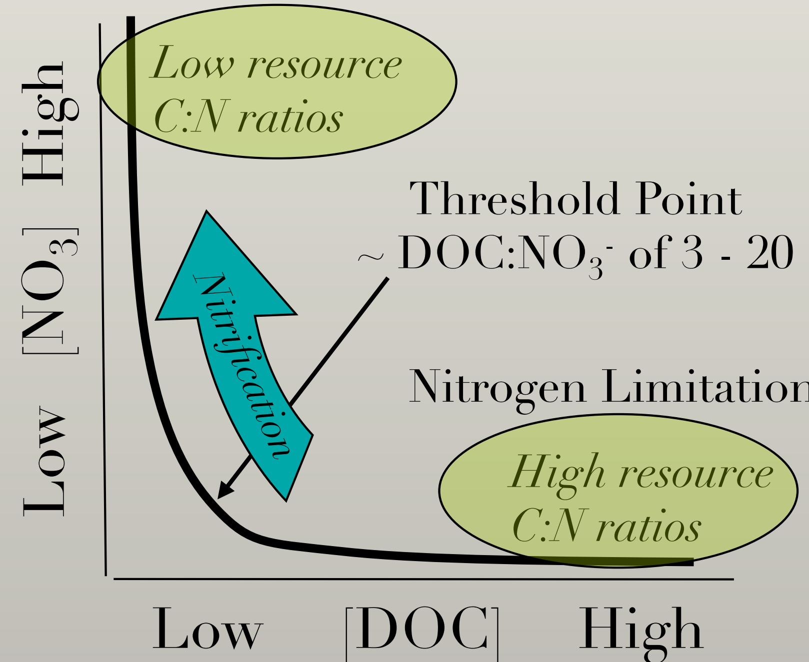
Stoichiometry of microbial C-N coupling



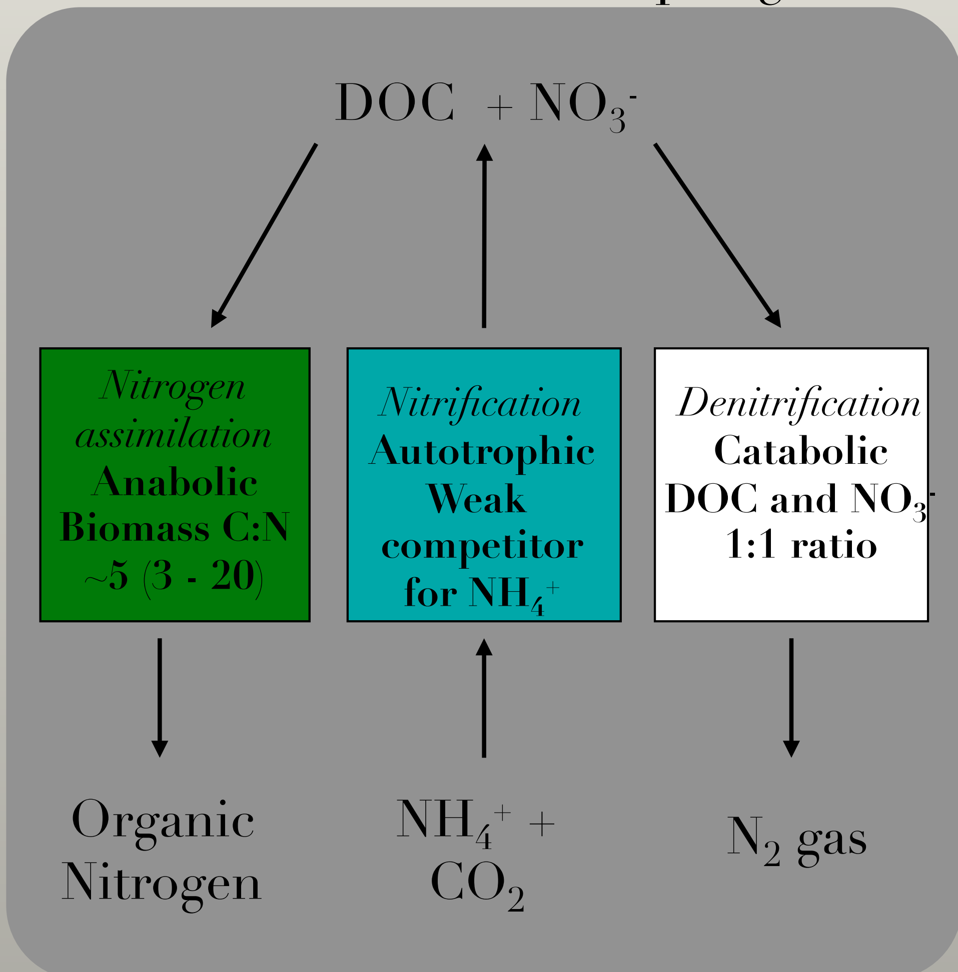


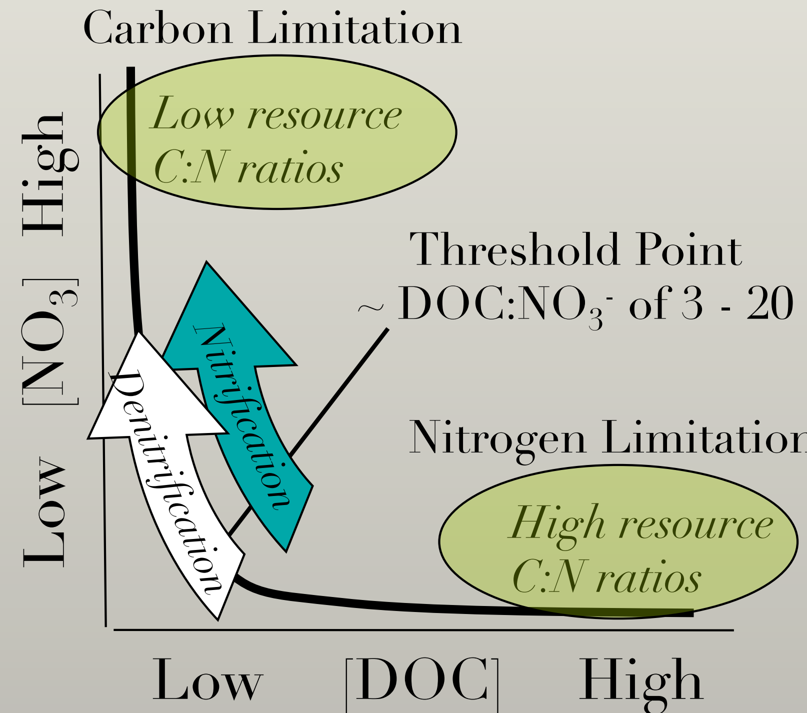
Stoichiometry of microbial C-N coupling



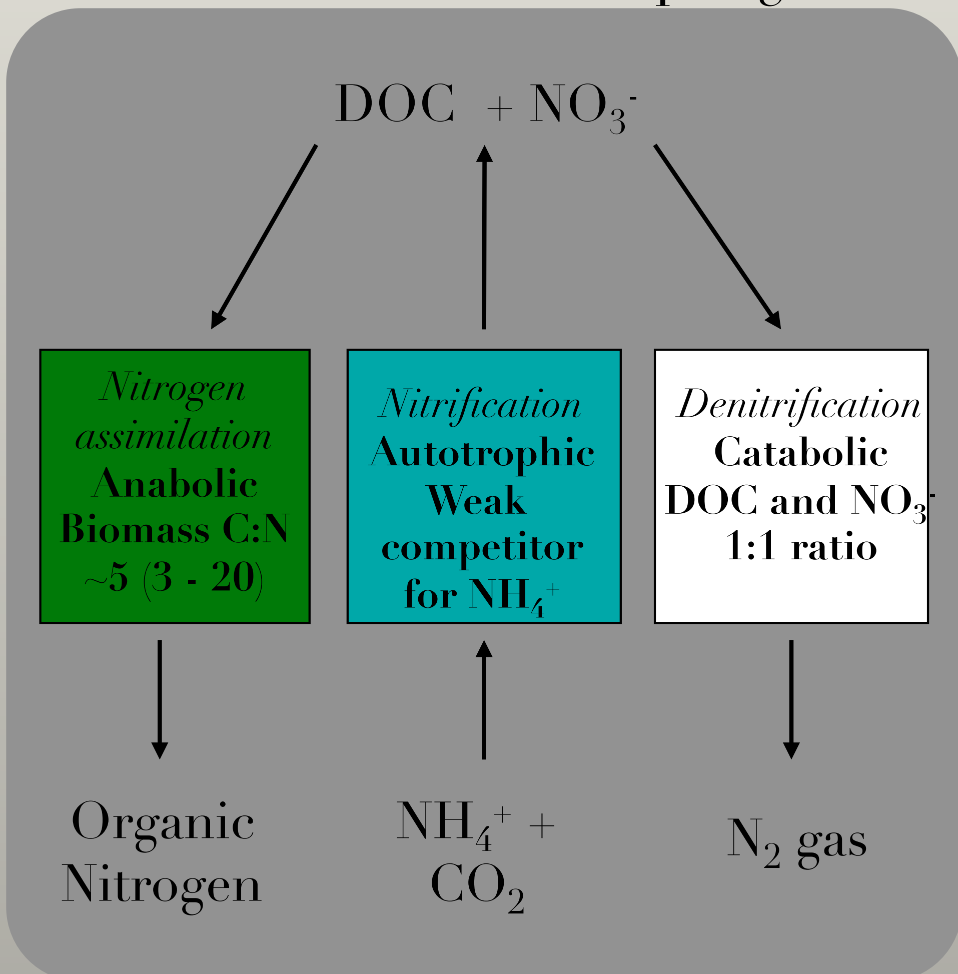


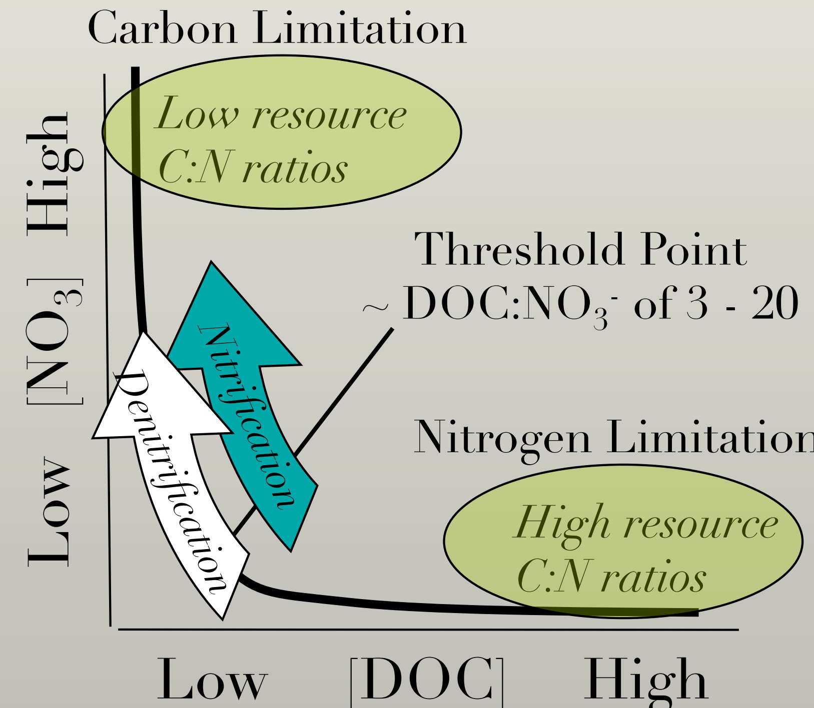
Stoichiometry of microbial C-N coupling

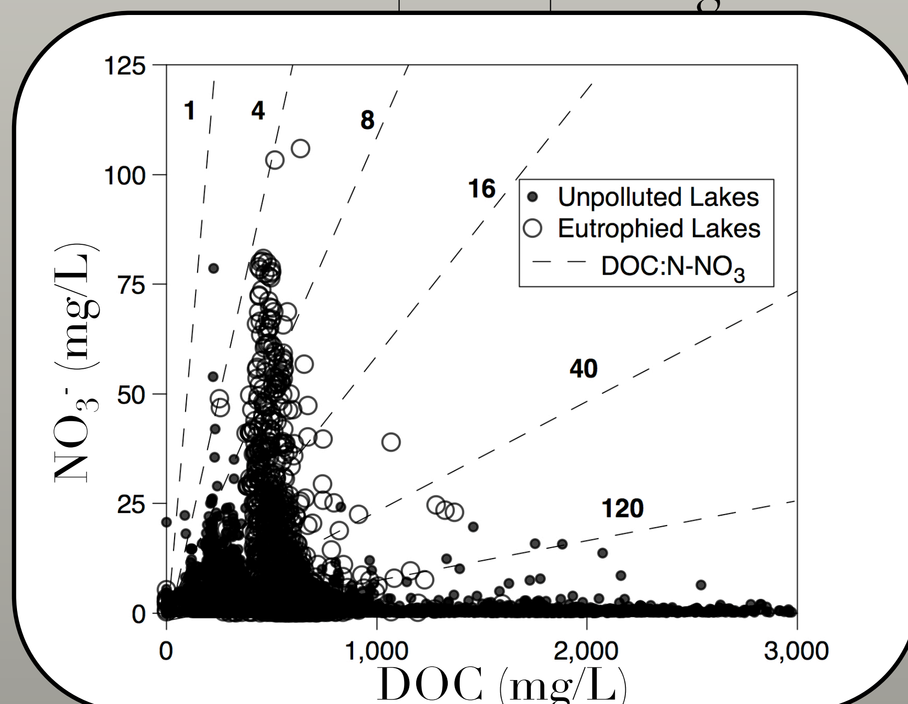




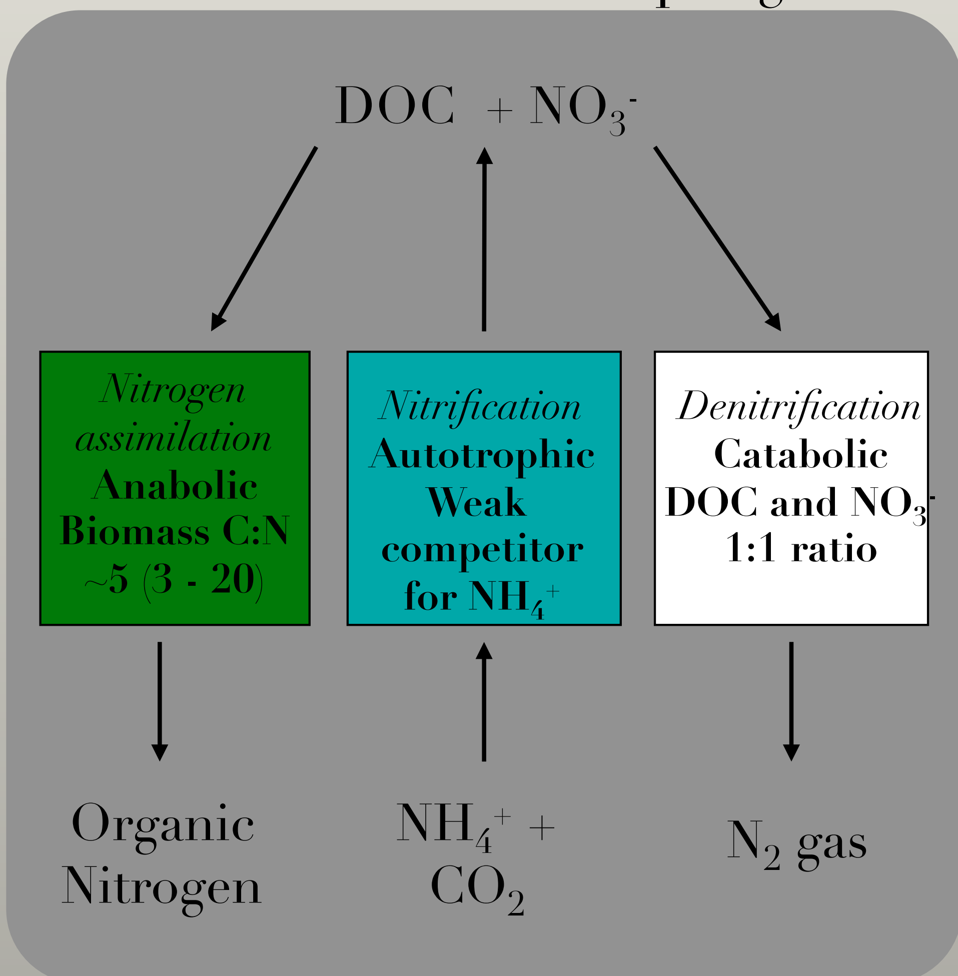
Stoichiometry of microbial C-N coupling



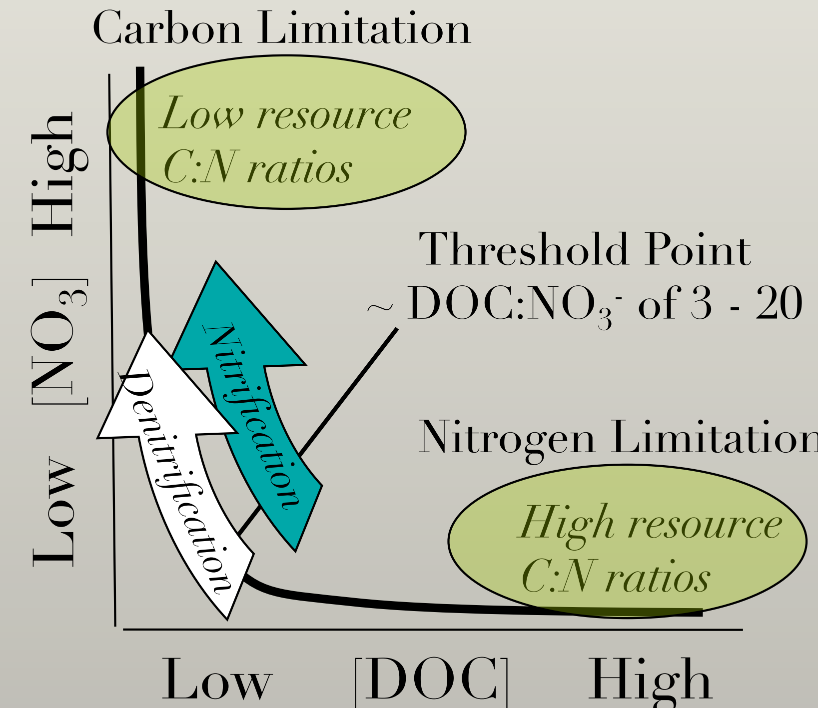


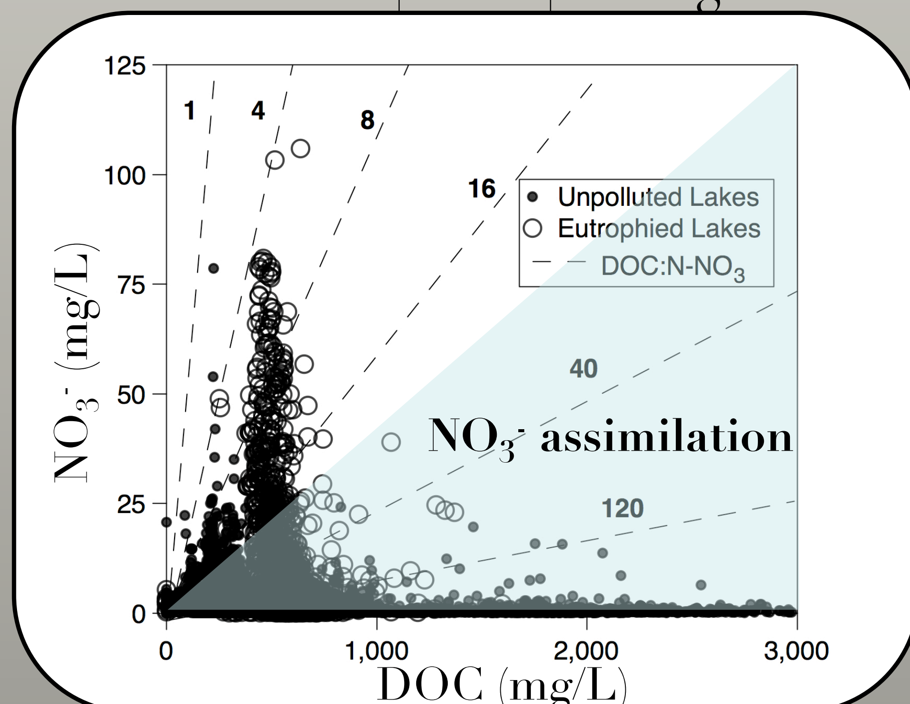


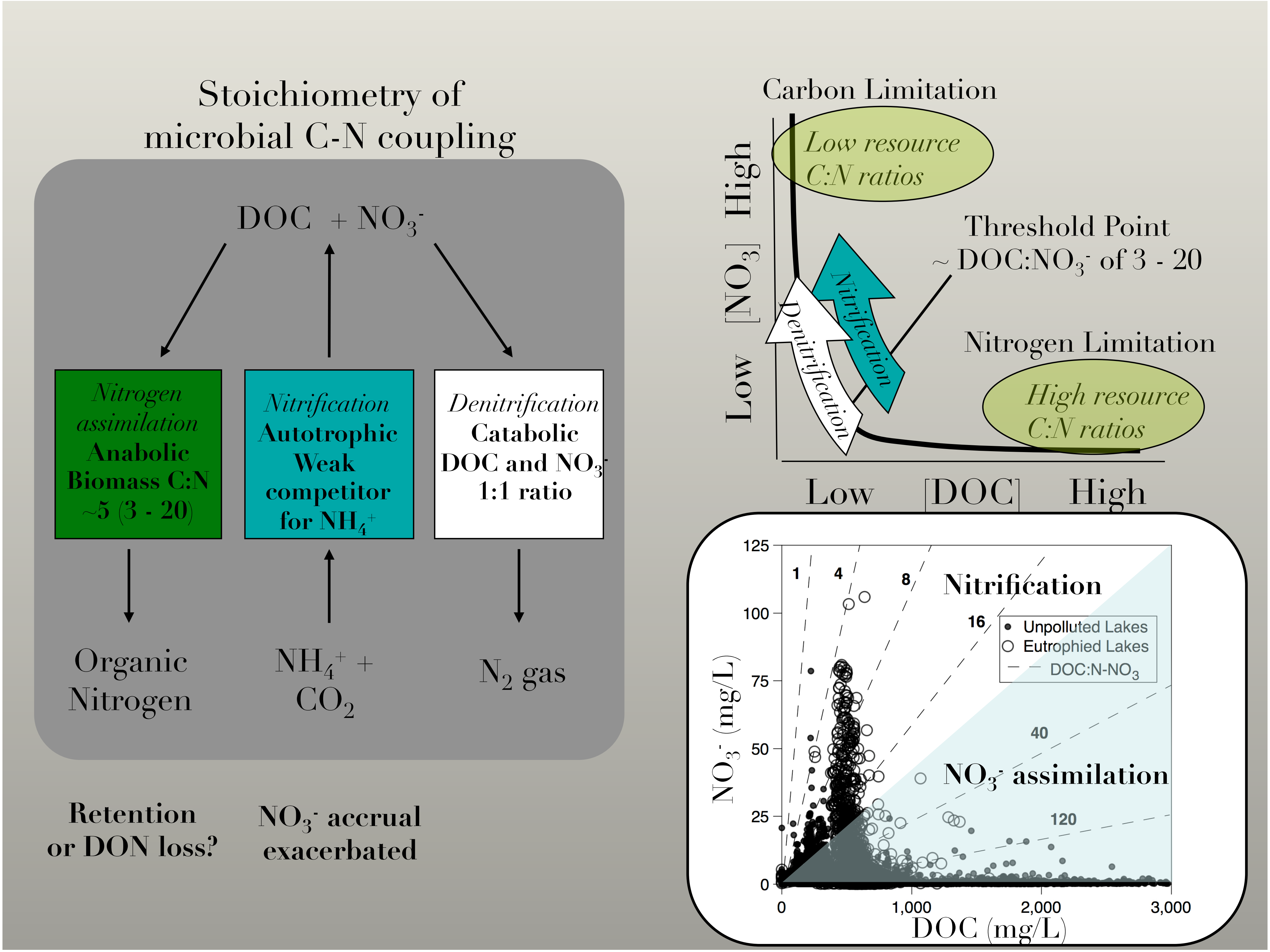
Stoichiometry of microbial C-N coupling



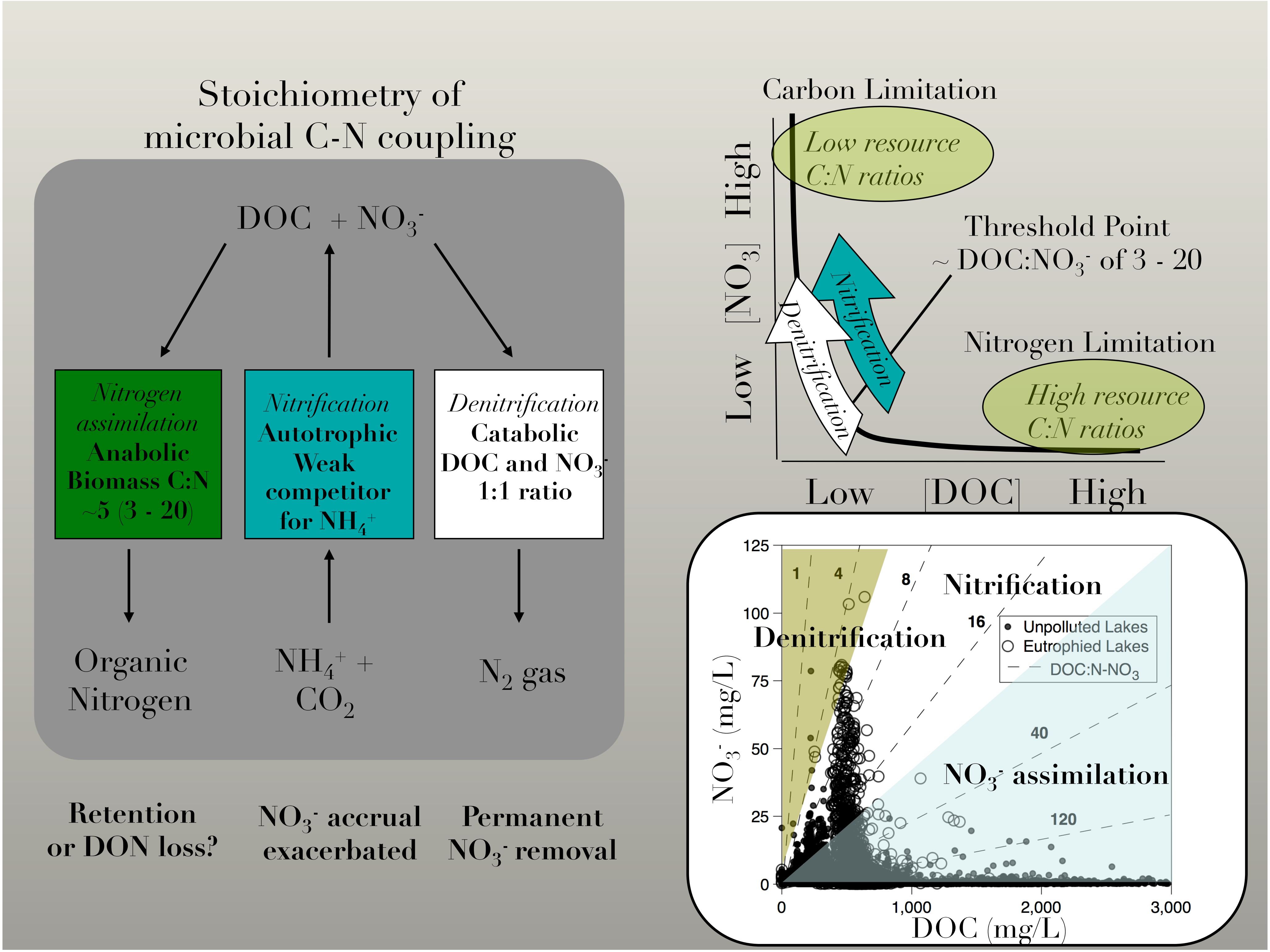
Retention or DON loss?





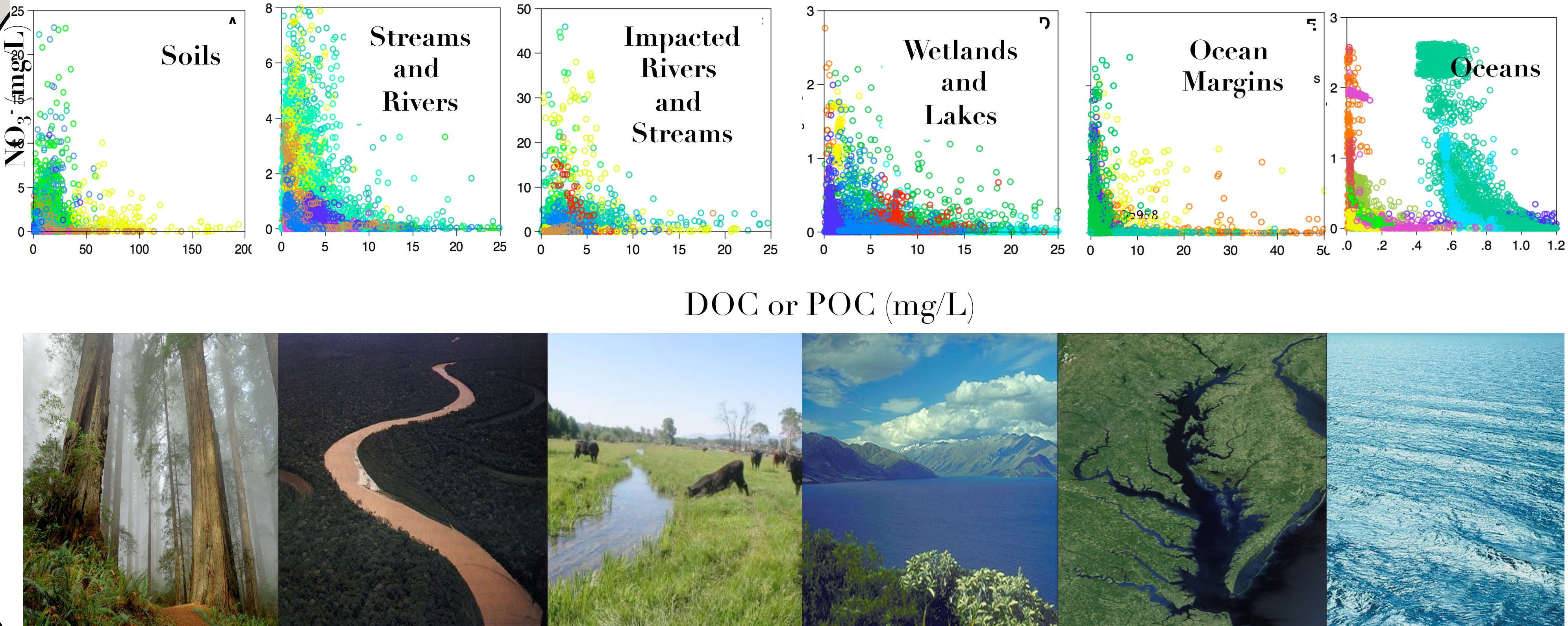


Stoichiometry of microbial C-N coupling
DOC + NO3-
Nitrogen assimilation
Anabolic
Biomass C:N
~5 (3 - 20)
Nitrification
Autotrophic
Weak competitor for NH4+
Denitrification
Catabolic
DOC and NO3-
1:1 ratio
Organic Nitrogen
NH4+ + CO2
N2 gas
Retention or DON loss?
NO3- accrual exacerbated
Carbon Limitation
Low resource C:N ratios
Threshold Point
~ DOC:NO3- of 3 - 20
Nitrification
Denitrification
Nitrogen Limitation
High resource C:N ratios
Low [NO3] High
Low [DOC] High
Nitrification
NO3- assimilation
Unpolluted Lakes
Eutrophied Lakes
DOC:N-NO3
1
4
8
16
40
120
NO3- (mg/L)
DOC (mg/L)
0
25
50
75
100
125
0
1,000
2,000
3,000


Stoichiometry of
microbial C-N coupling
DOC + NO3-
Nitrogen assimilation
Anabolic
Biomass C:N
~5 (3 - 20)
Nitrification
Autotrophic
Weak competitor for NH4+
Denitrification
Catabolic
DOC and NO3-
1:1 ratio
Organic Nitrogen
NH4+ + CO2
N2 gas
Retention or DON loss?
NO3- accrual exacerbated
Permanent NO3- removal
Carbon Limitation
Low resource C:N ratios
Threshold Point
~ DOC:NO3- of 3 - 20
Nitrification
Denitrification
Nitrogen Limitation
High resource C:N ratios
Low [NO3] High
Low [DOC] High
125
100
75
50
25
0
1
4
8
16
40
120
Nitrification
Denitrification
NO3- assimilation
Unpolluted Lakes
Eutrophied Lakes
DOC:N-NO3
NO3- (mg/L)
0
1,000
2,000
3,000
DOC (mg/L)

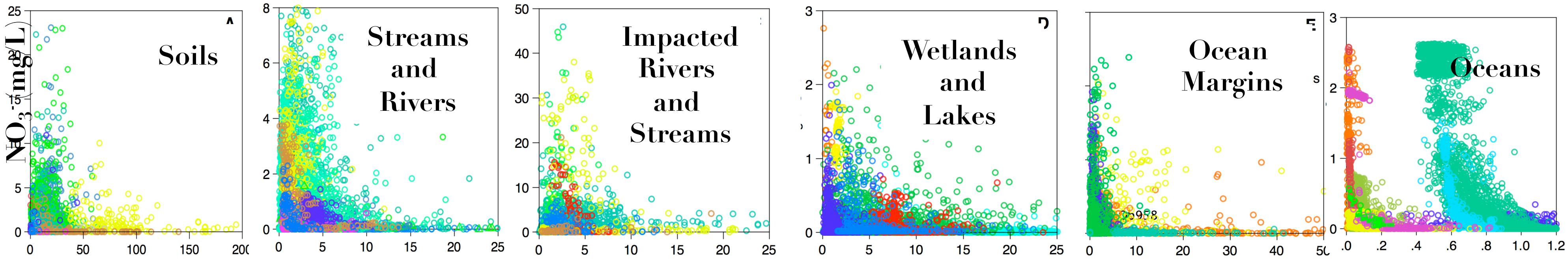
Examine critical threshold ratios at inflection point

$(y = a + b^{-k(x)})$



Examine critical threshold ratios at inflection point

$(y = a + b^{-k(x)})$



DOC or POC (mg/L)

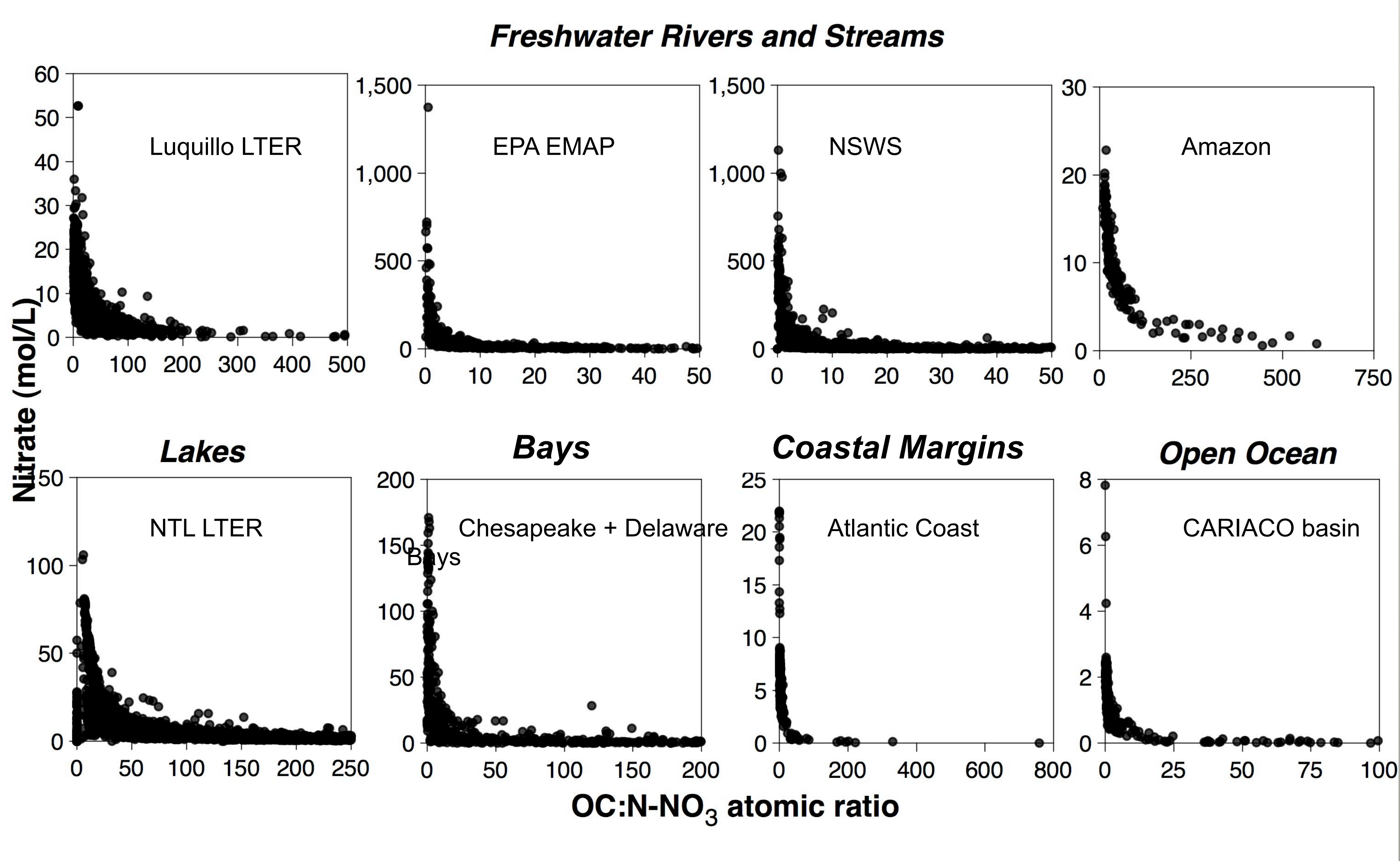
Global mean inflection point ratio, DOC:N-NO_3 = 3.54

	Soils	Streams/ Rivers	Impacted Streams	Wetlands/ Lakes	Ocean Margins	Low C Seas	High C Seas
Inflection C:N-NO_3	5.22	3.29	3.12	4.76	2.19	2.67	3.79
r^2	.25	.32	.24	.42	.39	.47	.50

Global inflection points for each of earth's major ecosystems rests between the optimal resource stoichiometries for denitrification and heterotrophic NO_3^- assimilation.

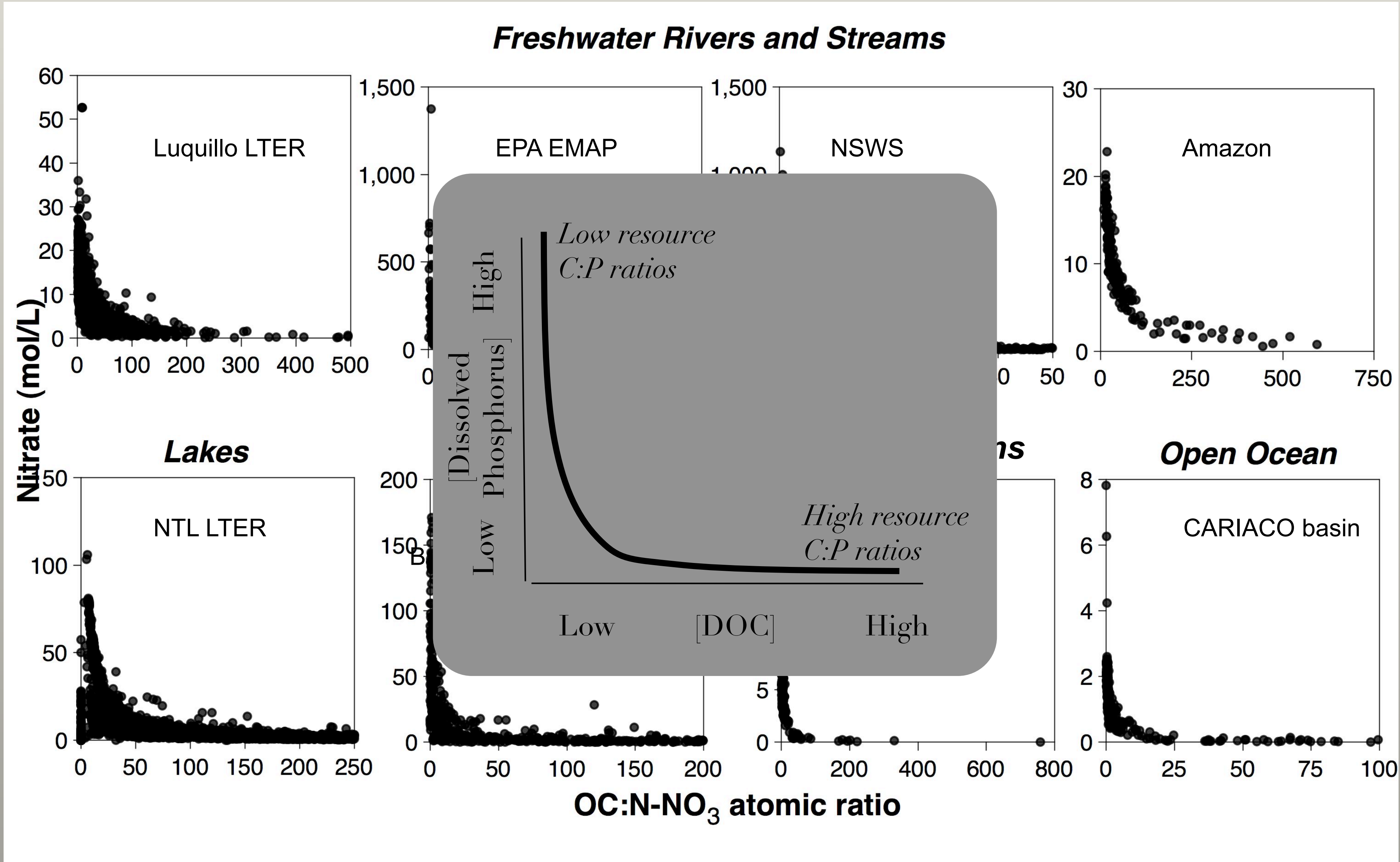
System-specific scenarios for NO_3^-

Inflection Points range from 3 to 20, except Amazon



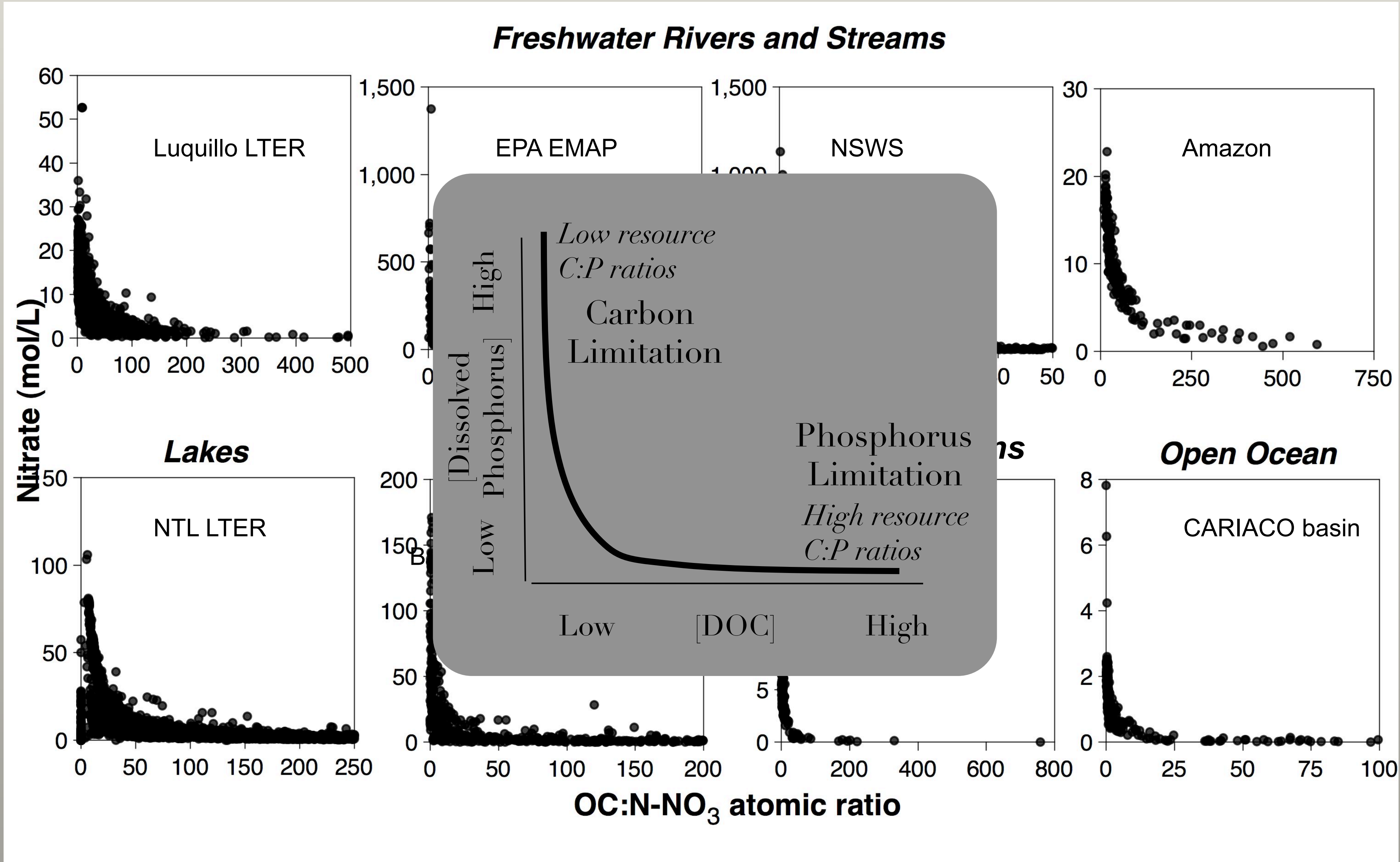
How about for phosphorus?

Inflection Points range from 3 to 20, except Amazon



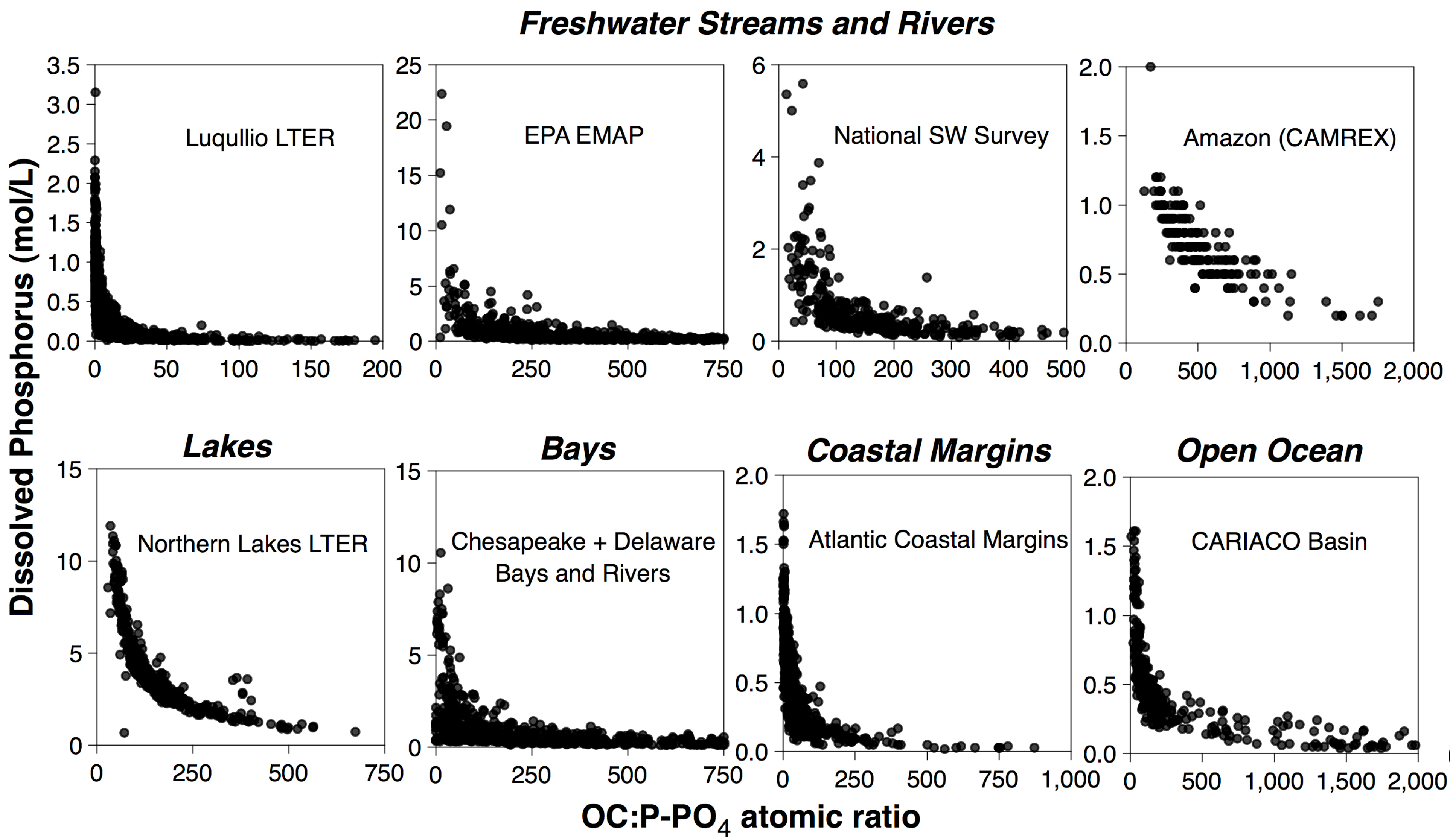
How about for phosphorus?

Inflection Points range from 3 to 20, except Amazon



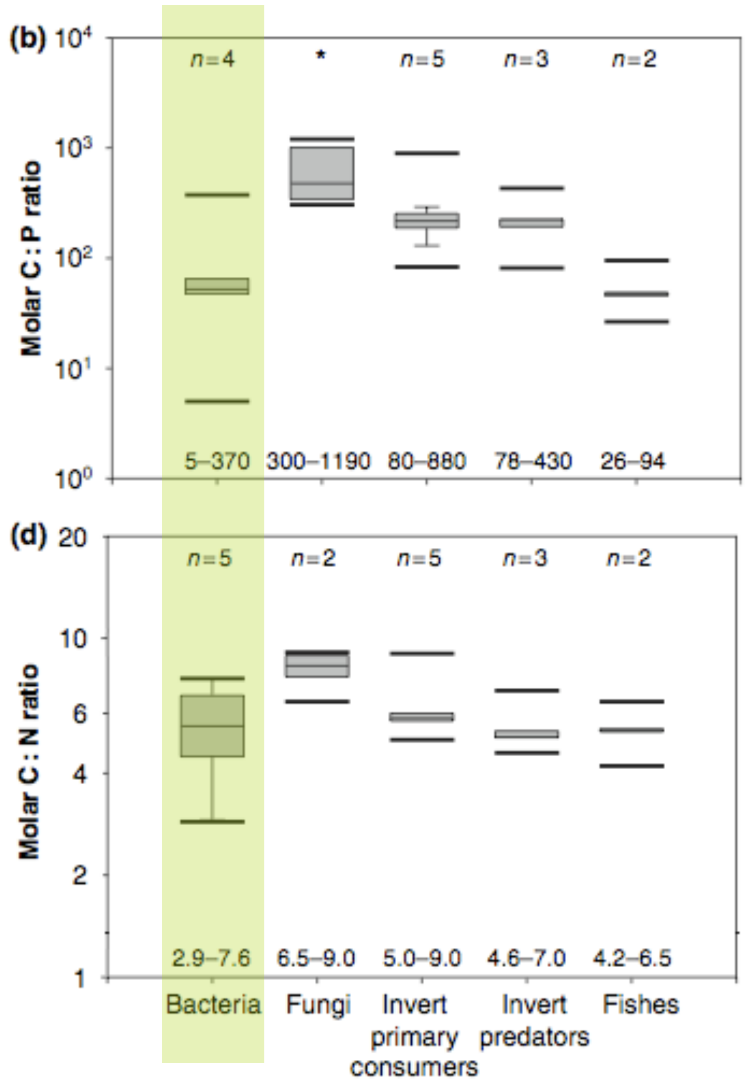
Emerges with C:P ratios too!

Inflection Points range from 20 to 300, except Amazon



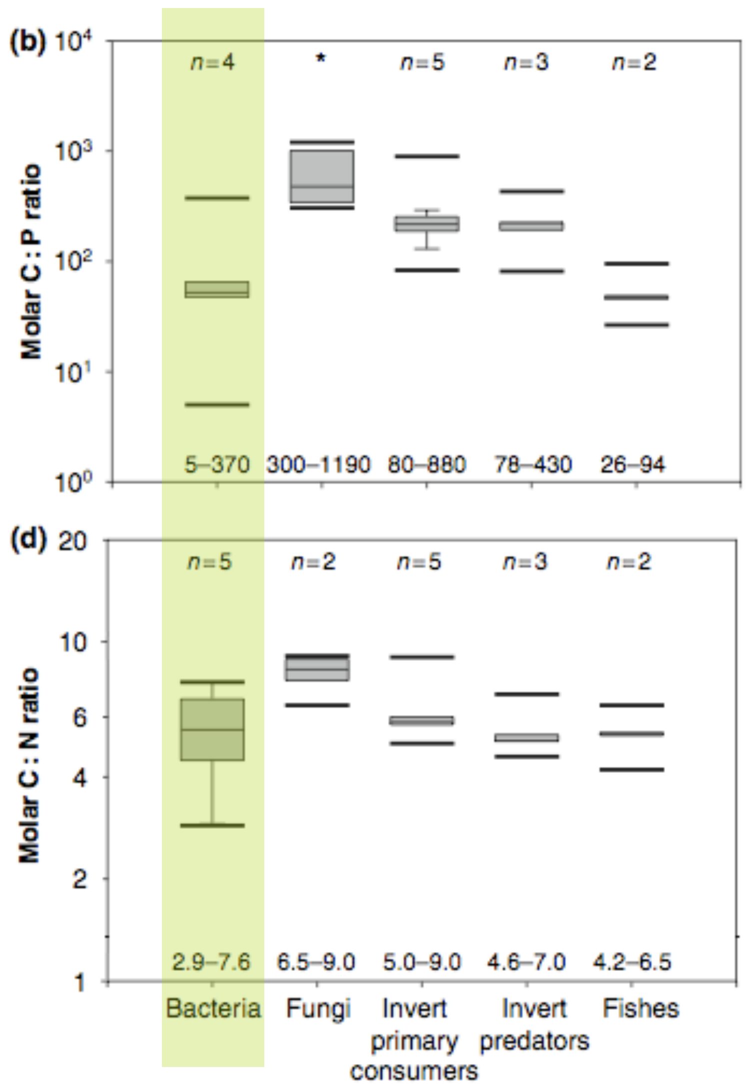
Why is C:P much more variable?

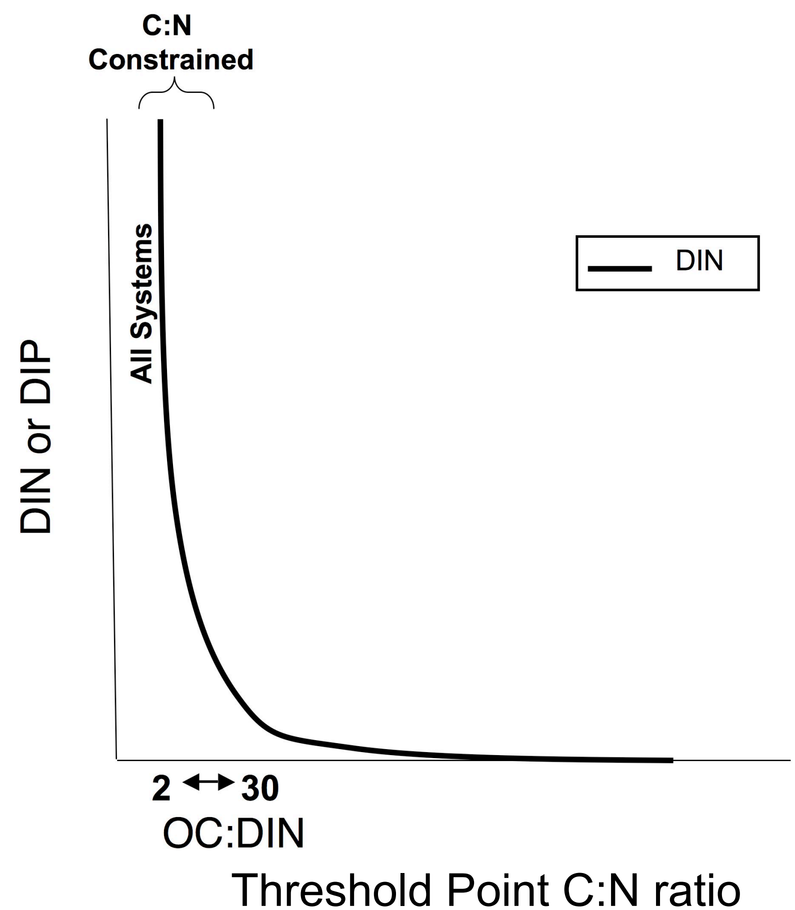
Greater bacteria C:P plasticity



Frost et al. 2004

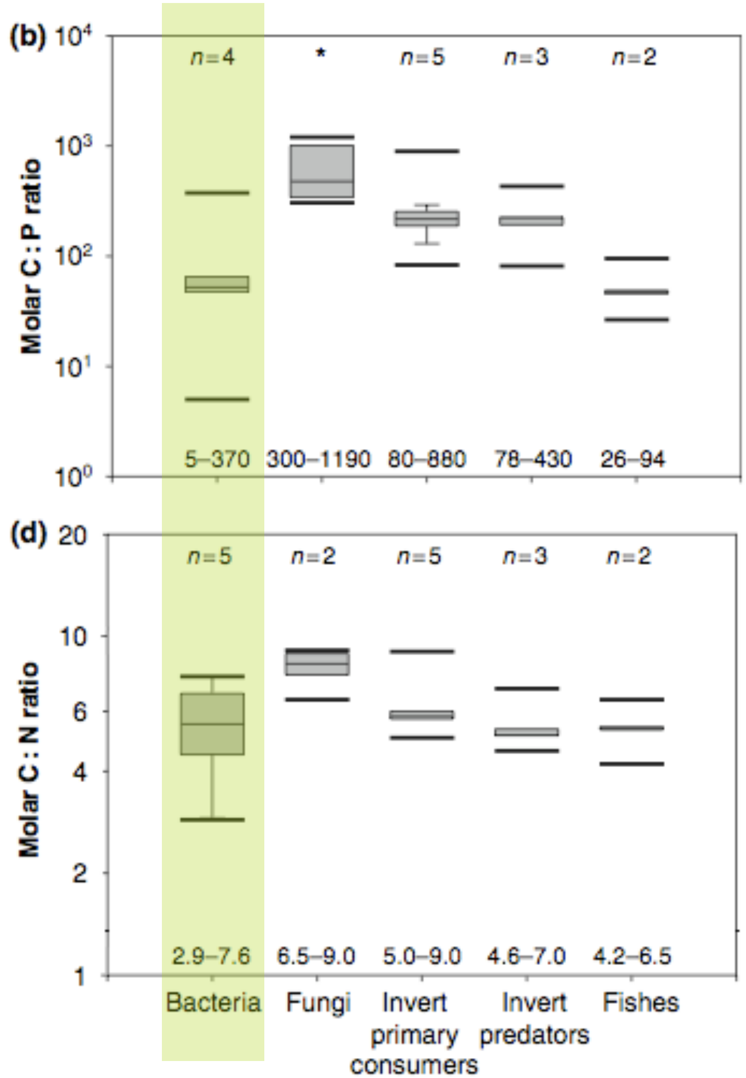
Why is C:P much more variable?
Illustrative Model

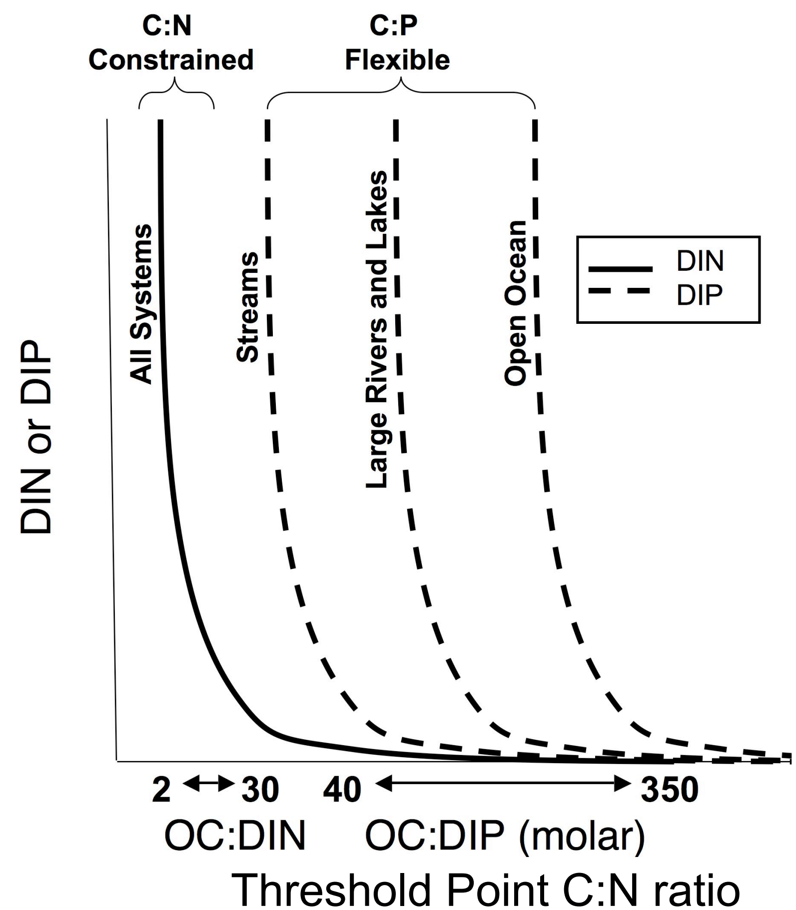




Frost et al. 2004

Why is C:P much more variable?
Illustrative Model



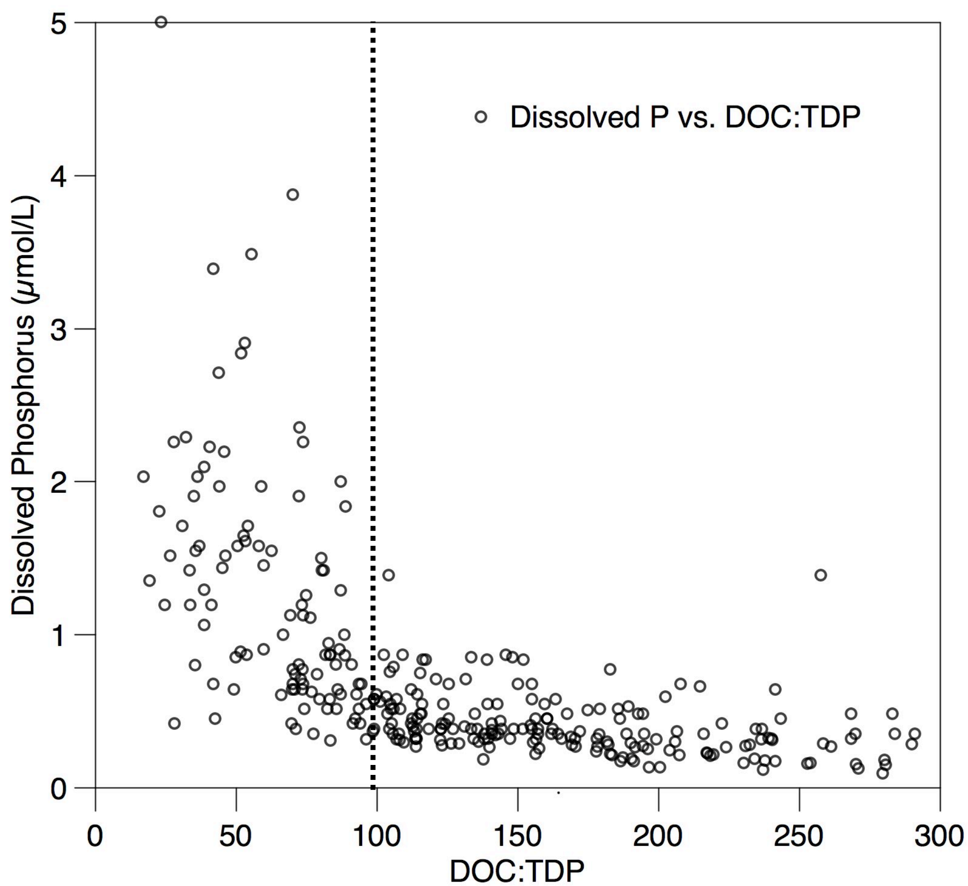


Frost et al. 2004

System-specific scenarios

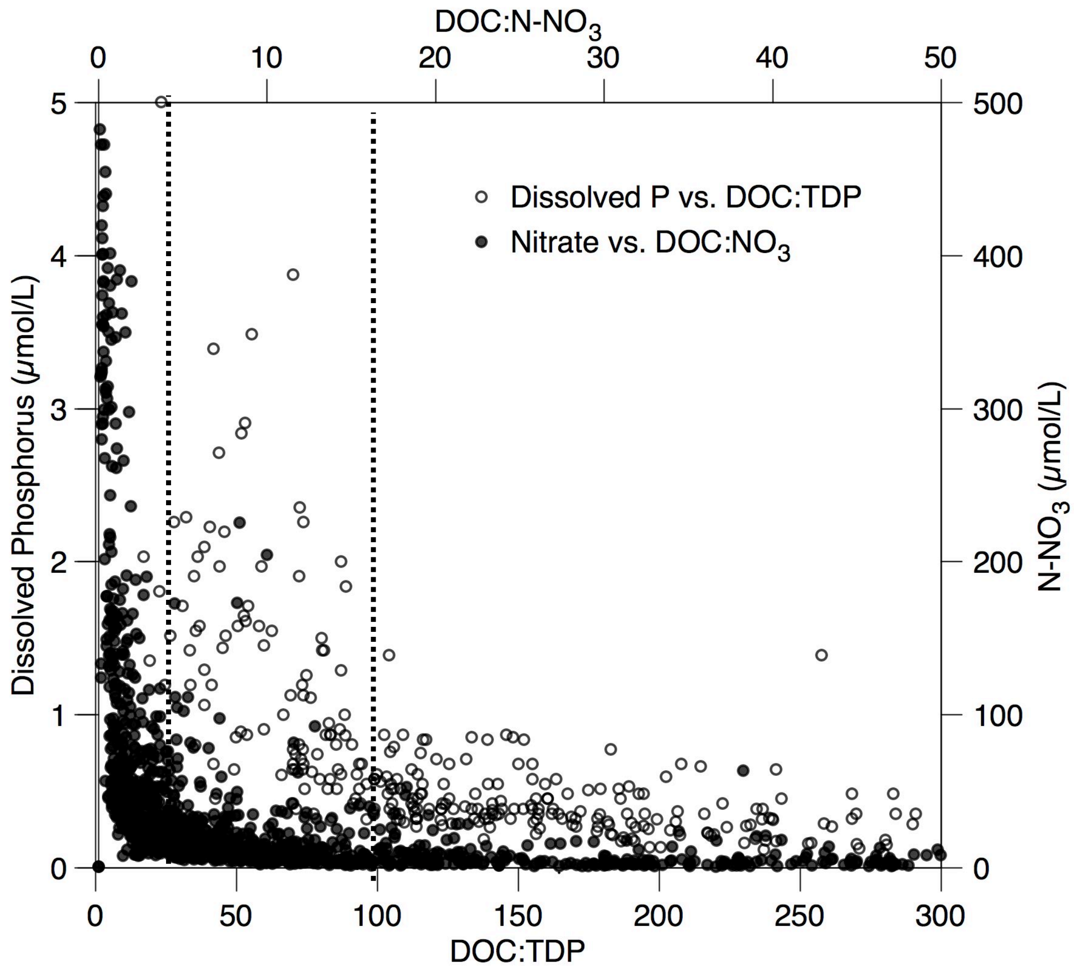
(eastern USA streams and rivers)

Bioavailable N and P accumulates only when resource conditions of favor heterotrophic carbon limitation



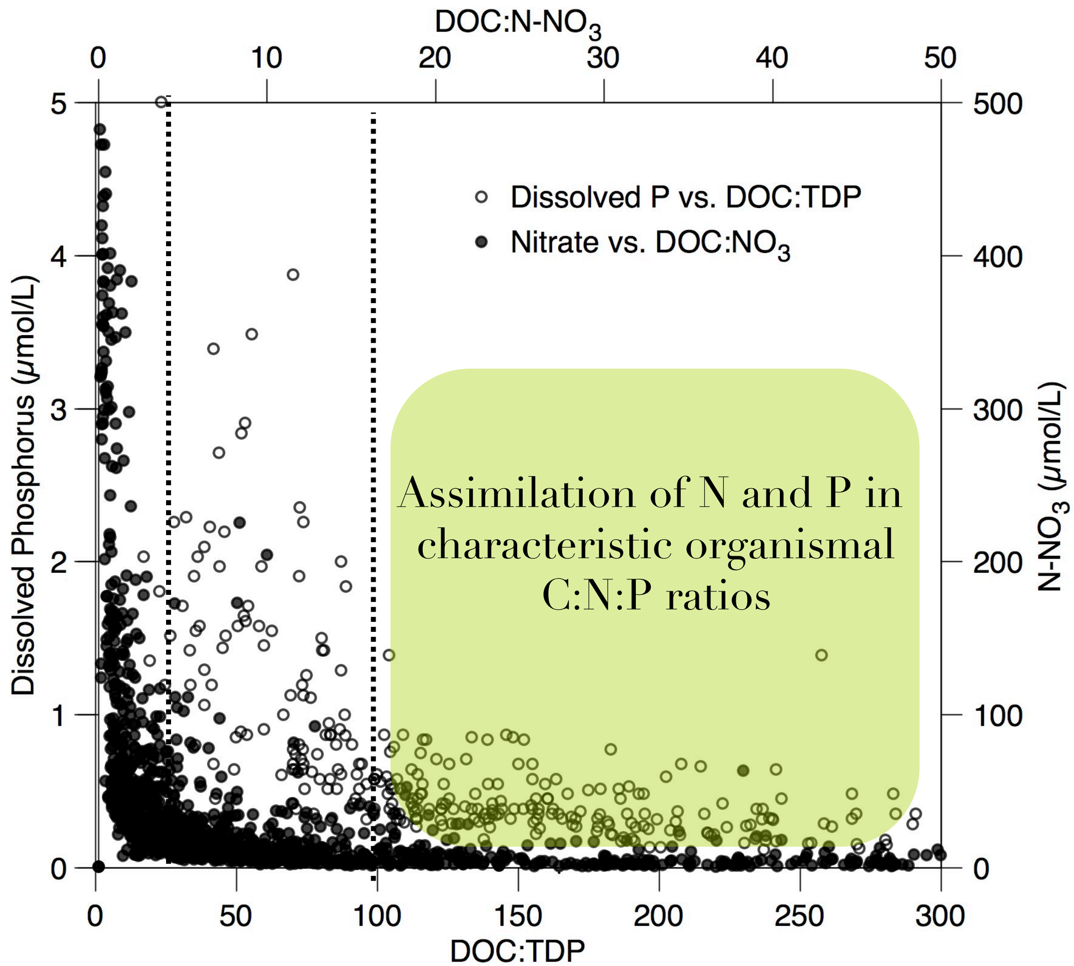
System-specific scenarios
(eastern USA streams and rivers)

Bioavailable N and P accumulates only when resource conditions of favor heterotrophic nutrient limitation

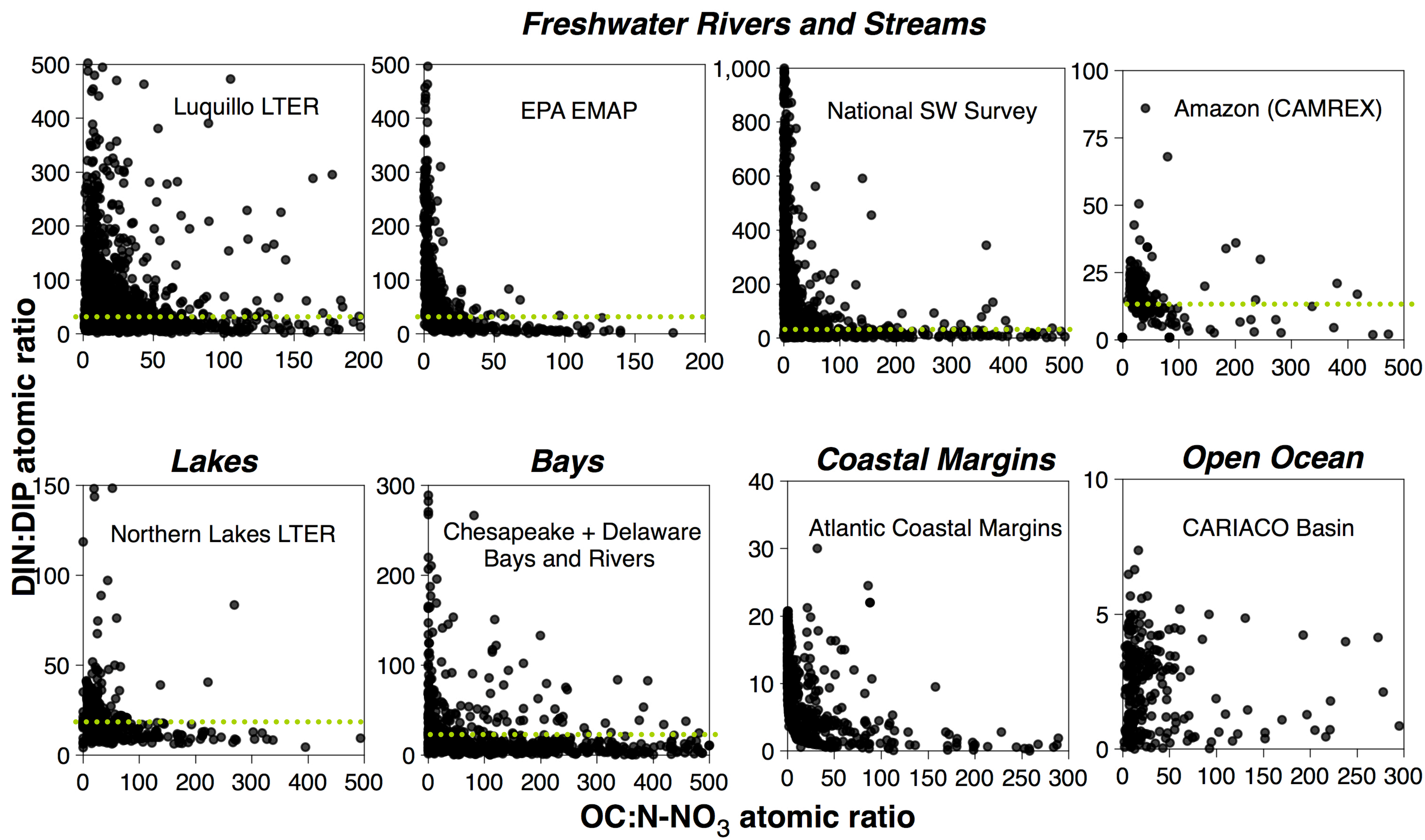


System-specific scenarios
(eastern USA streams and rivers)

Bioavailable N and P accumulates only when resource conditions of favor heterotrophic nutrient limitation

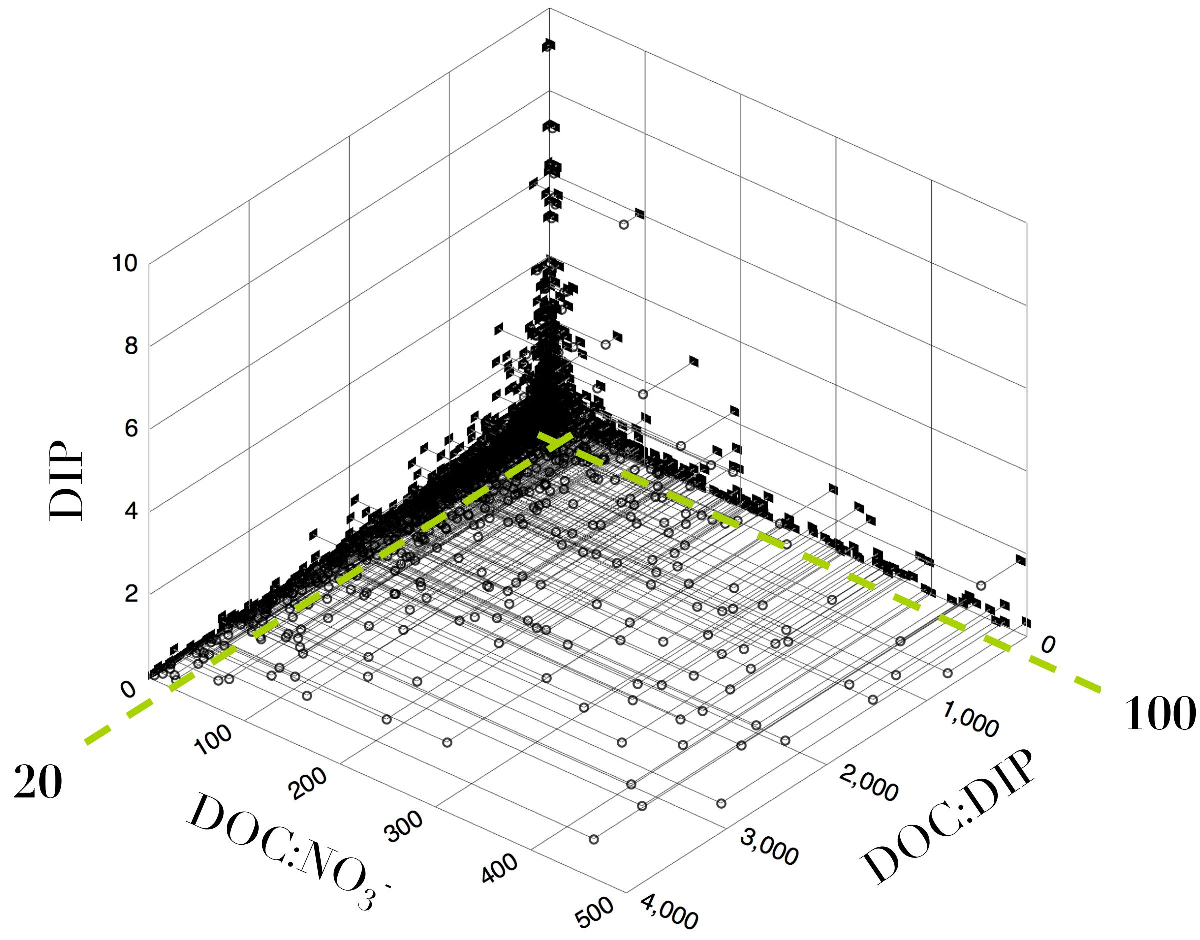


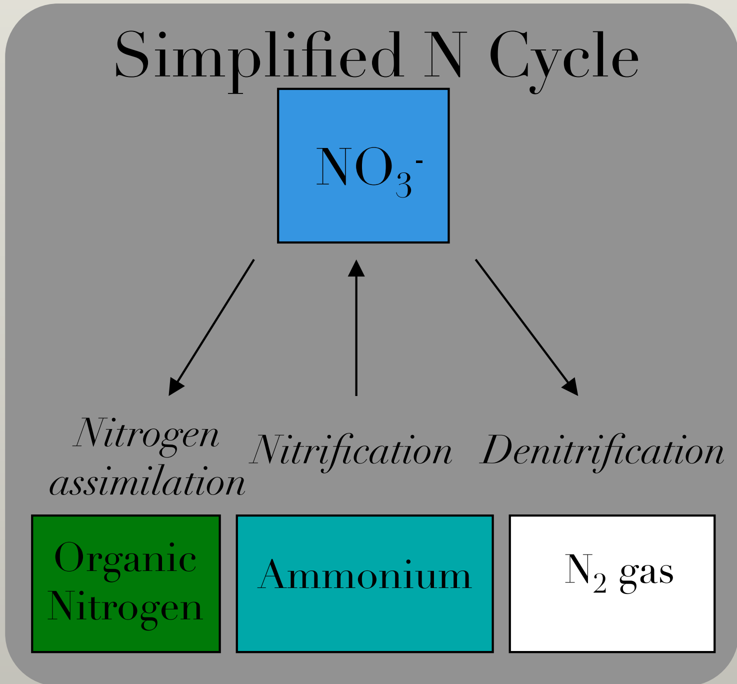
Stronger relative NO_3^- accumulation shifts ecosystem N:P ratios across magic 16:1; role for nitrification?



System-specific scenarios
(eastern USA streams and rivers)

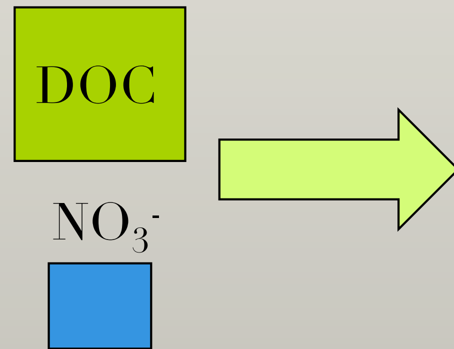
Bioavailable P accumulates only when resource conditions of favor heterotrophic nutrient limitation



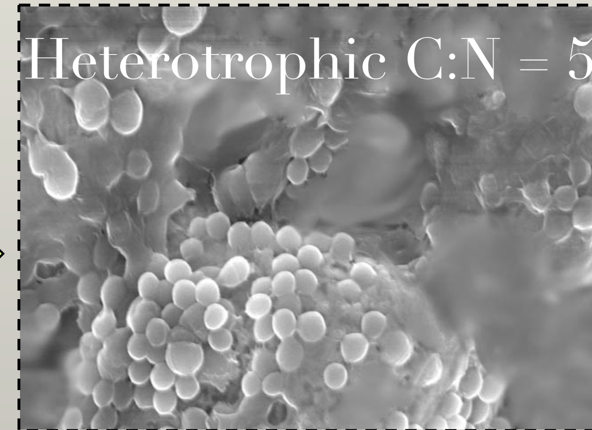


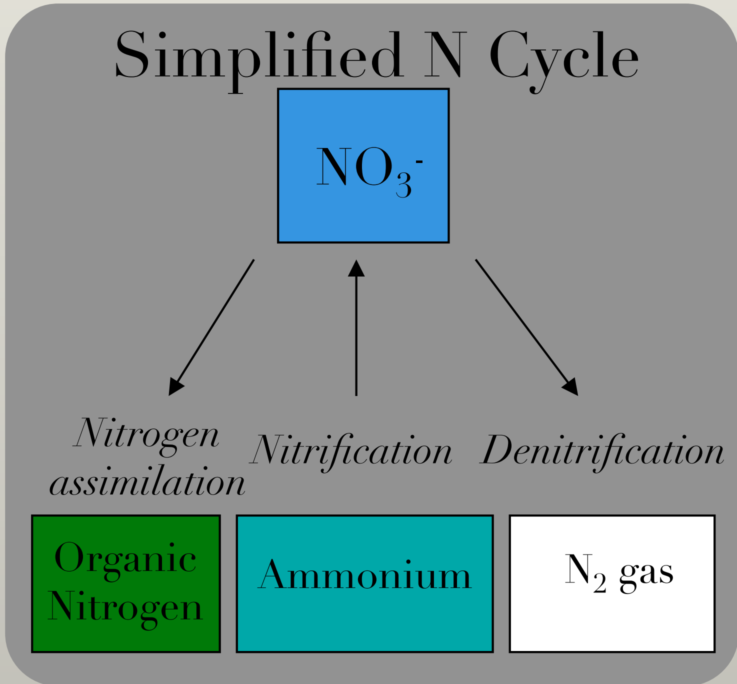
Resource

3) Denitrification



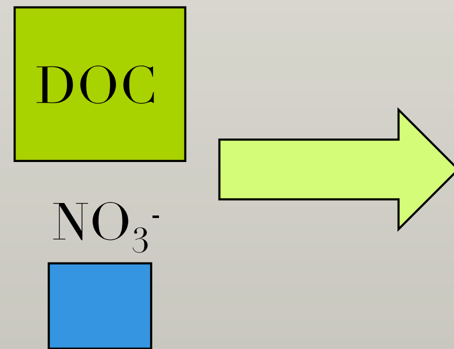
Microbial Community



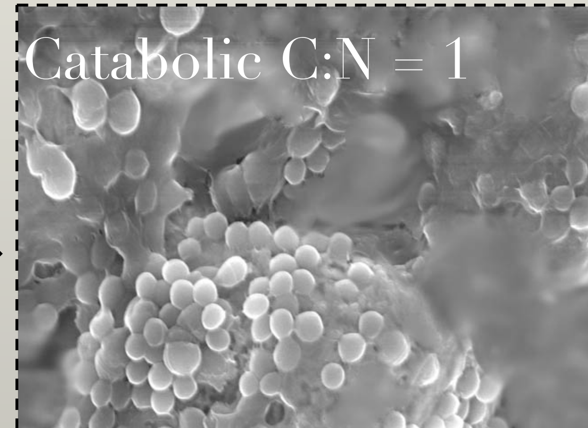


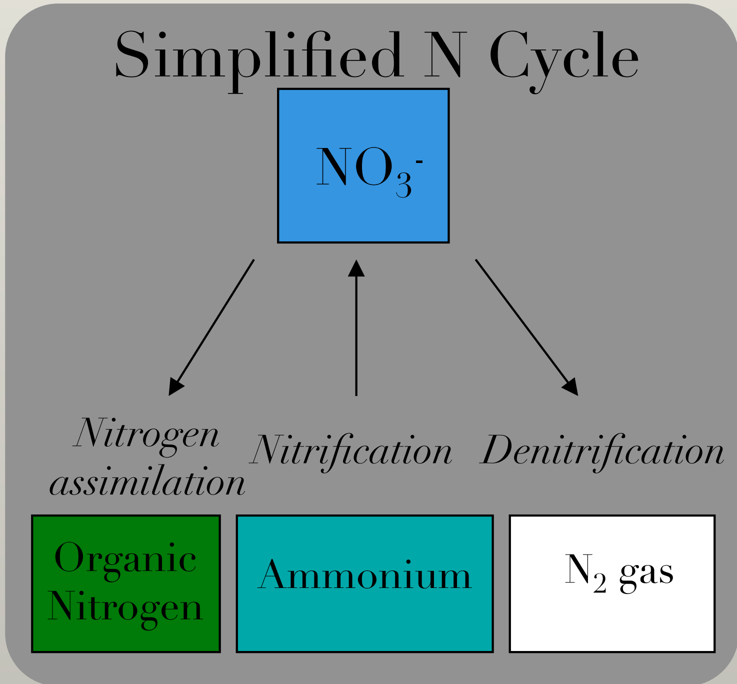
Resource

3) Denitrification



Microbial Community

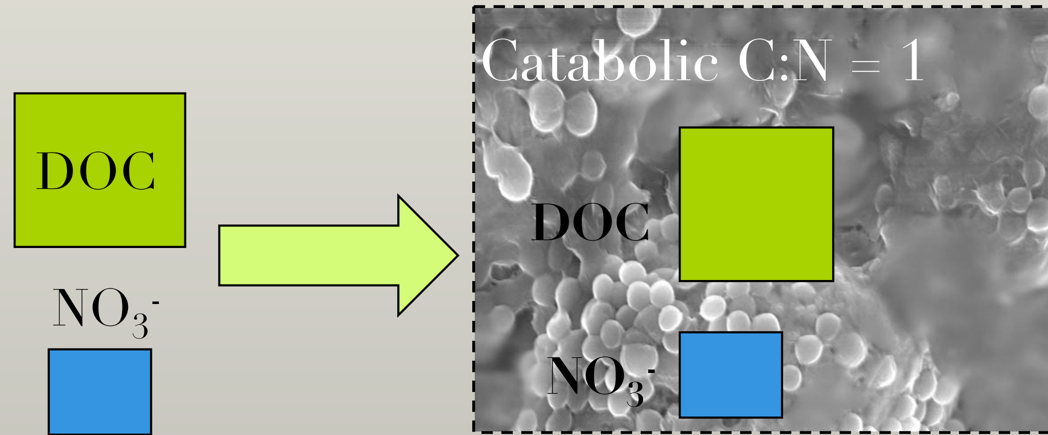


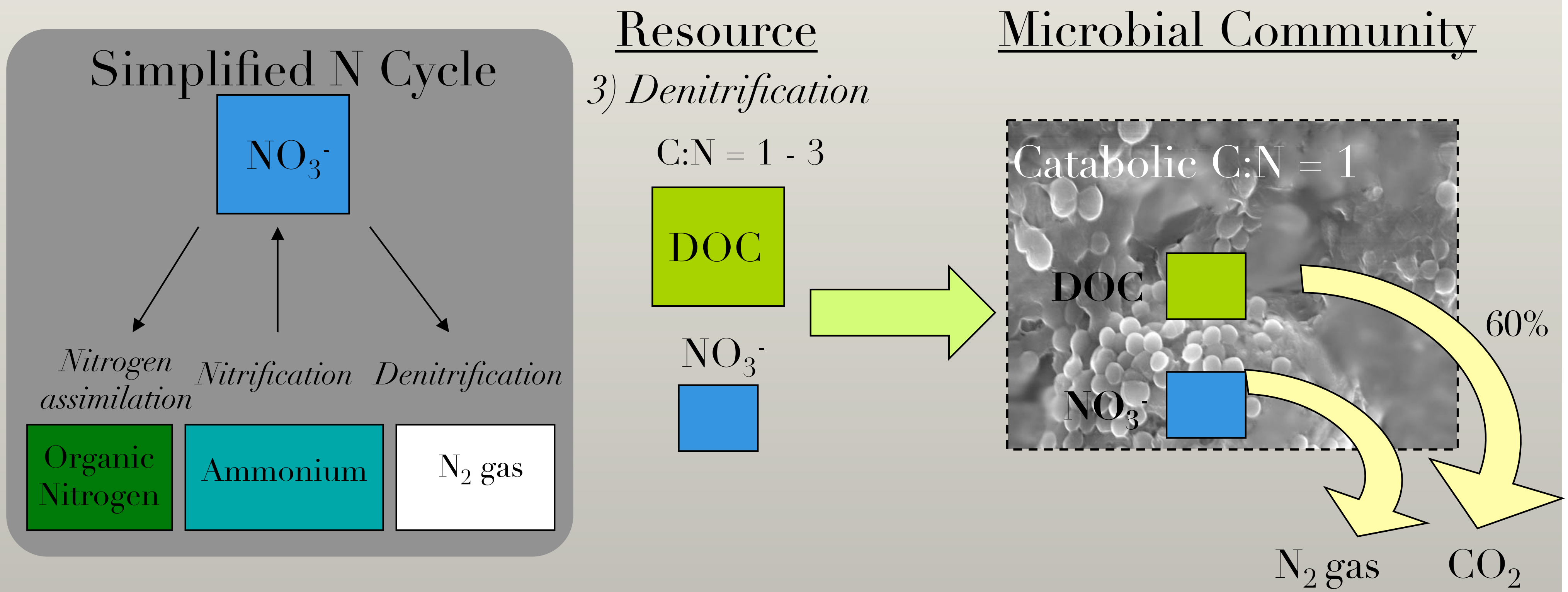


Resource

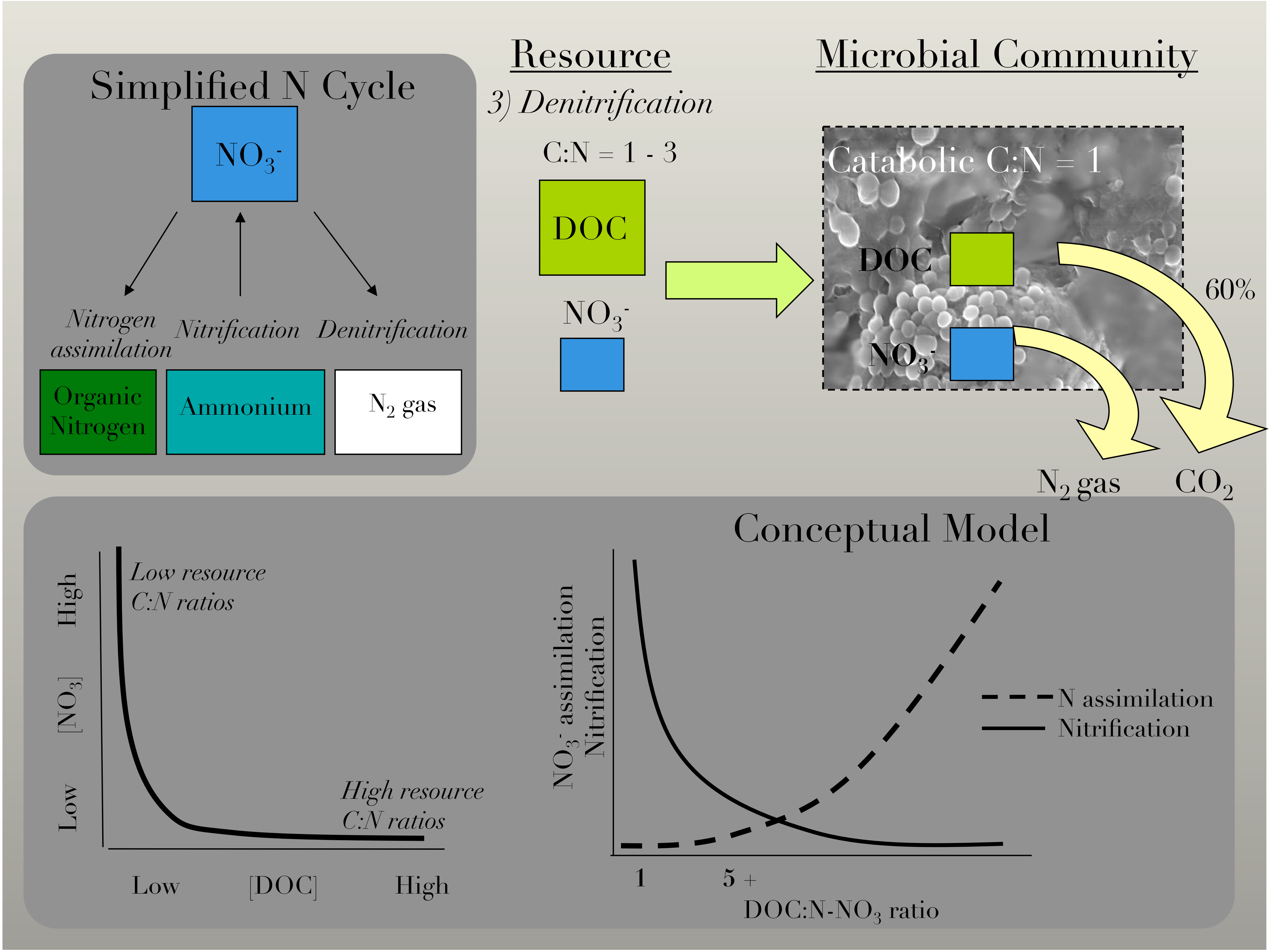
3) Denitrification

Microbial Community

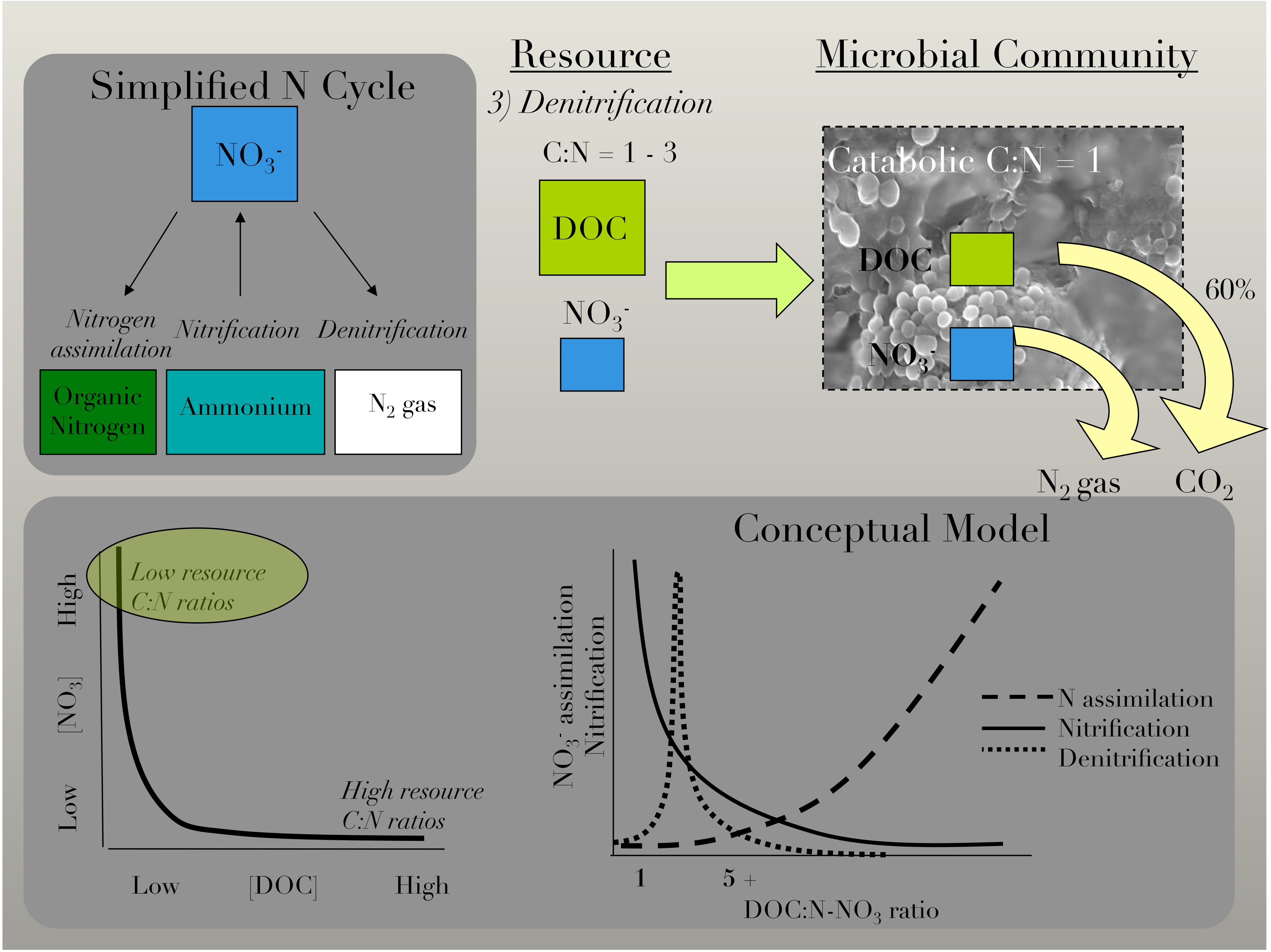




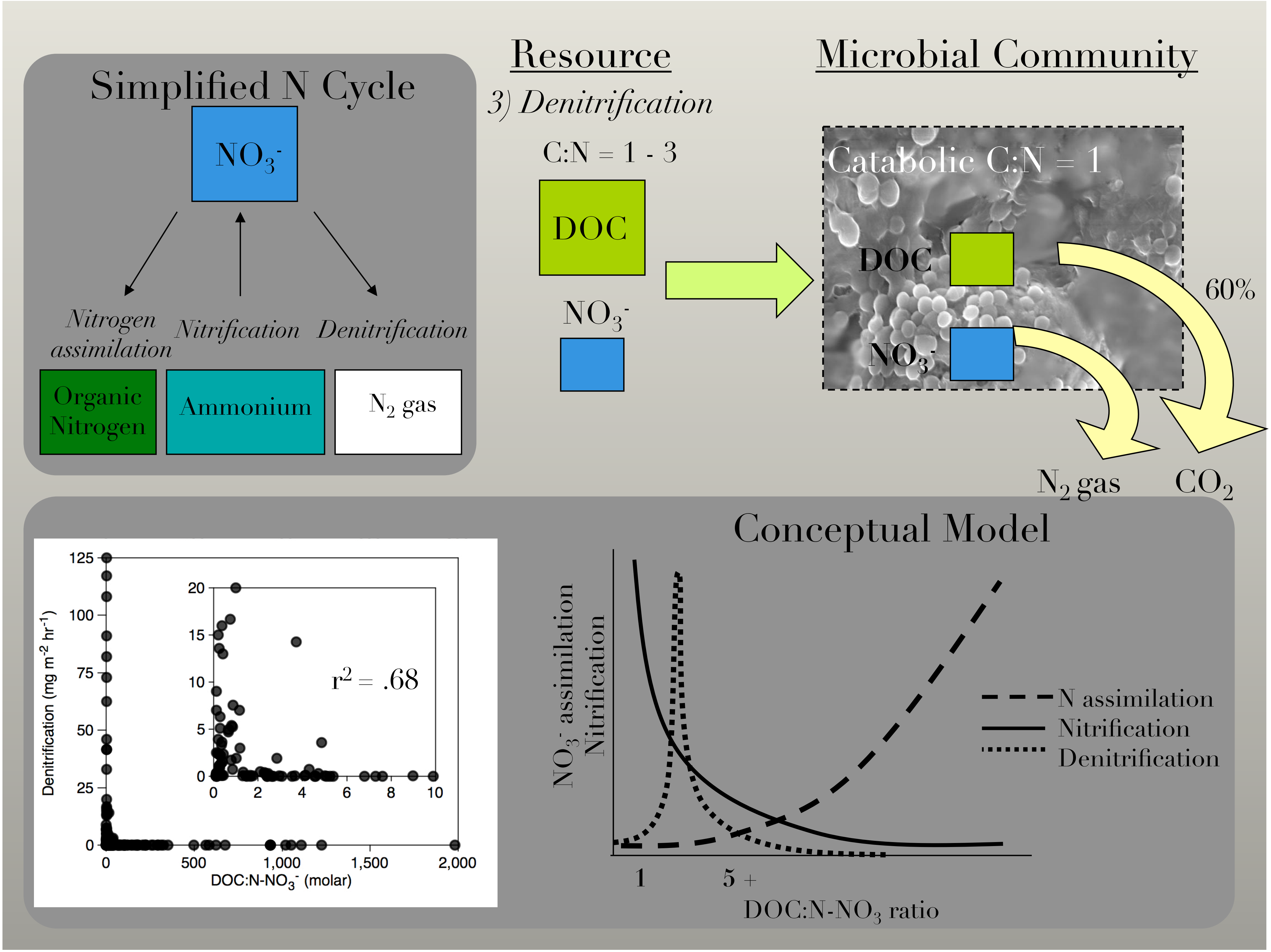
Simplified N Cycle
NO3-
Nitrogen assimilation
Nitrification
Denitrification
Organic Nitrogen
Ammonium
N2 gas
Resource
3) Denitrification
C:N = 1 - 3
DOC
NO3-
Microbial Community
Catabolic C:N = 1
DOC
NO3-
60%
N2 gas
CO2



Simplified N Cycle
NO3-
Nitrogen assimilation
Nitrification
Denitrification
Organic Nitrogen
Ammonium
N2 gas
Resource
3) Denitrification
C:N = 1 - 3
DOC
NO3-
Microbial Community
Catabolic C:N = 1
DOC
NO3-
60%
N2 gas
CO2
Conceptual Model
High
[NO3]
Low
Low resource C:N ratios
High resource C:N ratios
Low
[DOC]
High
NO3- assimilation
Nitrification
N assimilation
Nitrification
1
5 +
DOC:N-NO3 ratio



Simplified N Cycle
NO3-
Nitrogen assimilation
Nitrification
Denitrification
Organic Nitrogen
Ammonium
N2 gas
Resource
3) Denitrification
C:N = 1 - 3
DOC
NO3-
Microbial Community
Catabolic C:N = 1
DOC
NO3-
60%
N2 gas
CO2
Conceptual Model
High
[NO3]
Low
Low resource C:N ratios
High resource C:N ratios
Low
[DOC]
High
NO3- assimilation
Nitrification
N assimilation
Nitrification
Denitrification
1
5 +
DOC:N-NO3 ratio

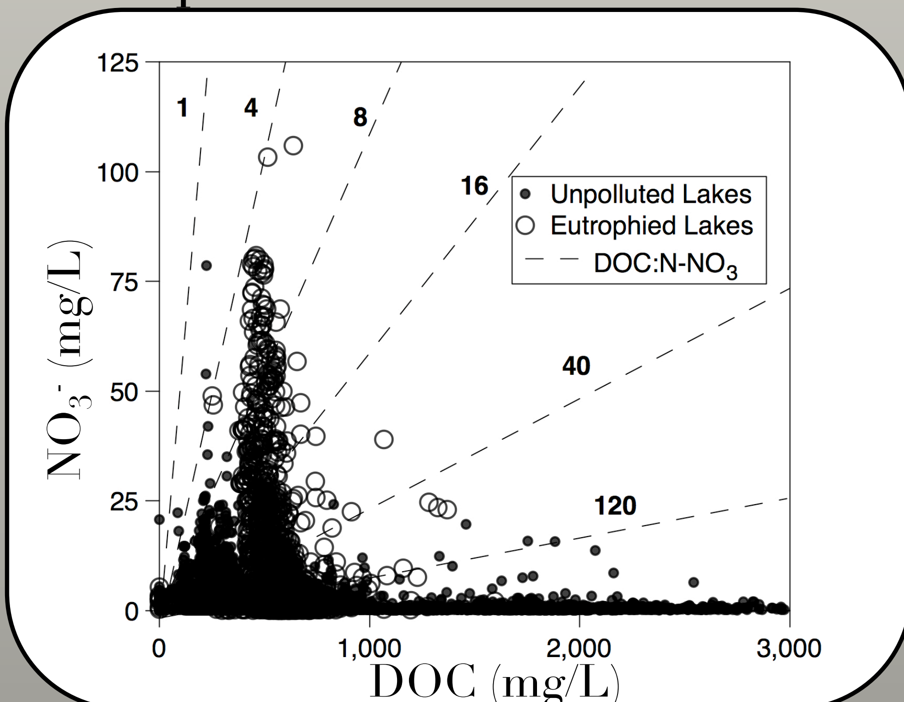

Simplified N Cycle
NO3-
Nitrogen assimilation
Nitrification
Denitrification
Organic Nitrogen
Ammonium
N2 gas
Resource
3) Denitrification
C:N = 1 - 3
DOC
NO3-
Microbial Community
Catabolic C:N = 1
DOC
NO3-
60%
N2 gas
CO2
Denitrification (mg m-2 hr-1)
DOC:N-NO3- (molar)
r2 = .68
Conceptual Model
NO3- assimilation
Nitrification
N assimilation
Nitrification
Denitrification
1
5 +
DOC:N-NO3 ratio

Implications

1. Ecological stoichiometry is a fundamental control over bioavailable nitrogen and phosphorus accumulation among earth's major ecosystems (not simply kinetic or thermodynamic).

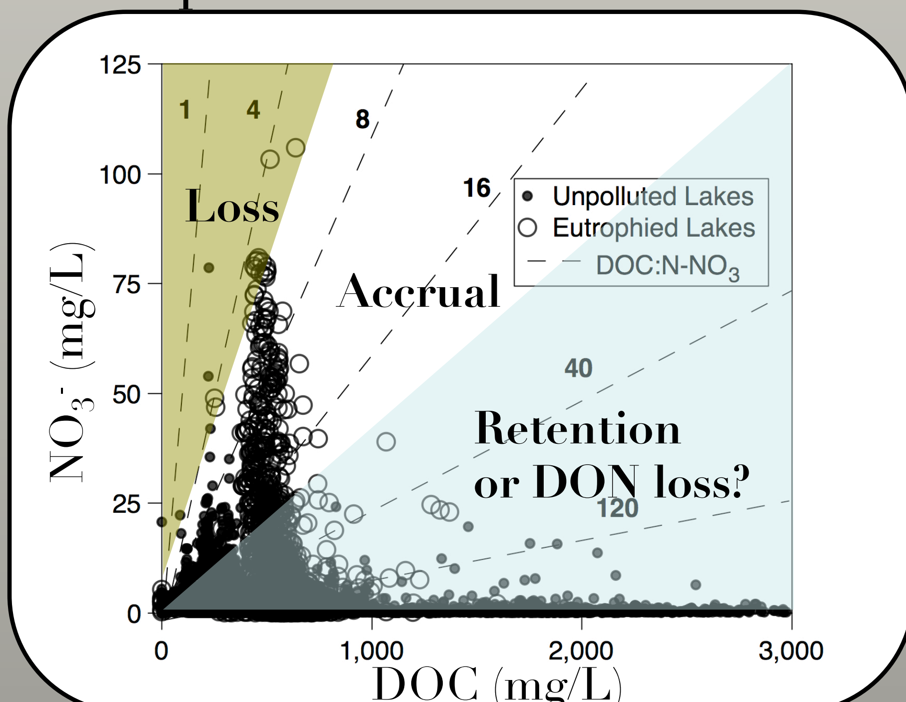
Implications

1. Ecological stoichiometry is a fundamental control over bioavailable nitrogen and phosphorus accumulation among earth's major ecosystems (not simply kinetic or thermodynamic).
2. Major role for heterotrophic microbes in N and P retention, accrual and loss.



Implications

1. Ecological stoichiometry is a fundamental control over bioavailable nitrogen and phosphorus accumulation among earth's major ecosystems (not simply kinetic or thermodynamic).
2. Major role for heterotrophic microbes in N and P retention, accrual and loss.

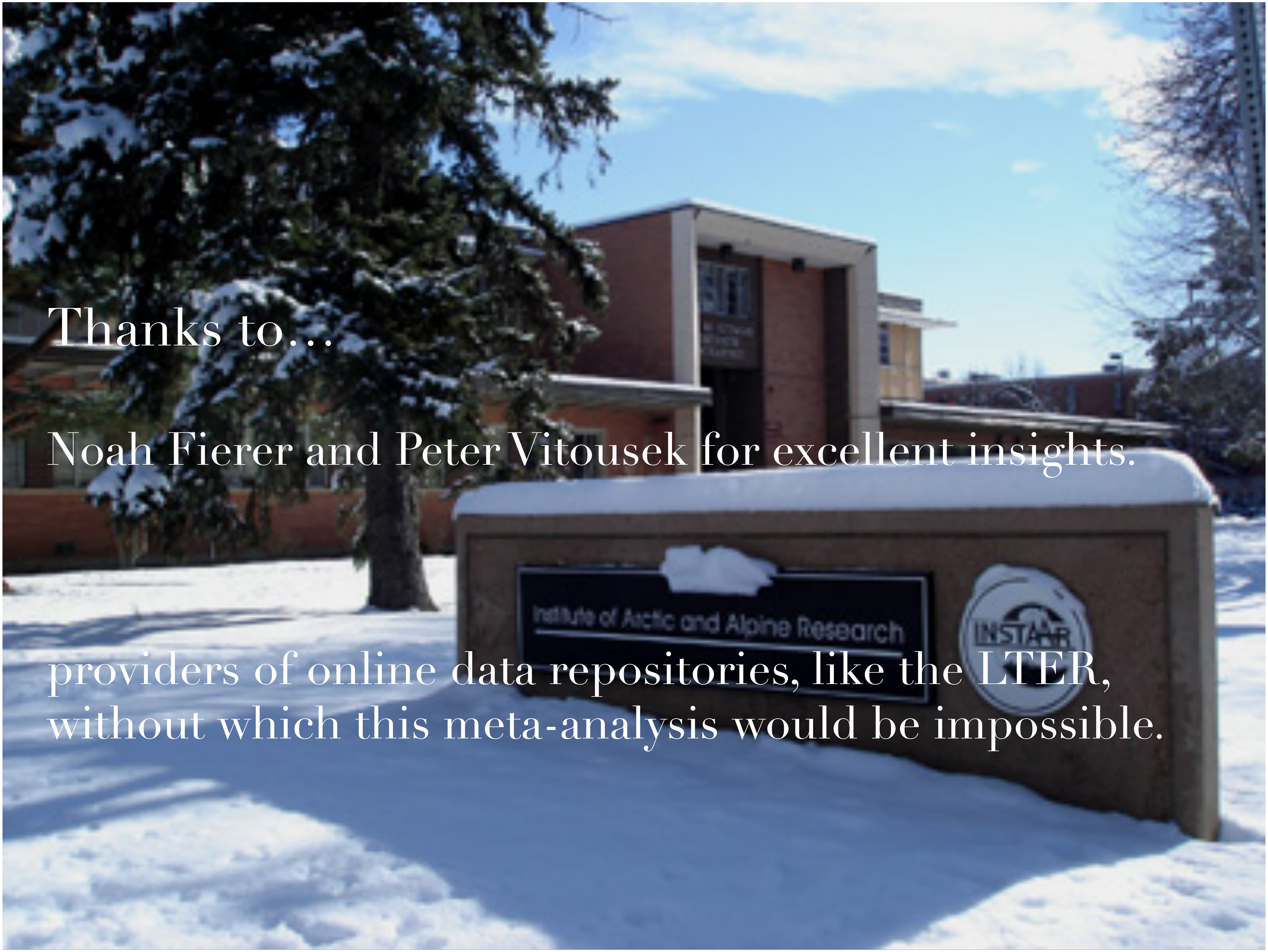


Implications

1. Ecological stoichiometry is a fundamental control over bioavailable nitrogen and phosphorus accumulation among earth's major ecosystems (not simply kinetic or thermodynamic).
2. Major role for heterotrophic microbes in N and P retention, accrual and loss.
3. Argues for explicit stoichiometric considerations in both diagnostic and prognostic modeling.

Implications

1. Ecological stoichiometry is a fundamental control over bioavailable nitrogen and phosphorus accumulation among earth's major ecosystems (not simply kinetic or thermodynamic).
2. Major role for heterotrophic microbes in N and P retention, accrual and loss.
3. Argues for explicit stoichiometric considerations in both diagnostic and prognostic modeling.
4. Offers a unique theoretical framework to explore similarities and differences in patterns (strength, breakpoints, etc.) between systems.



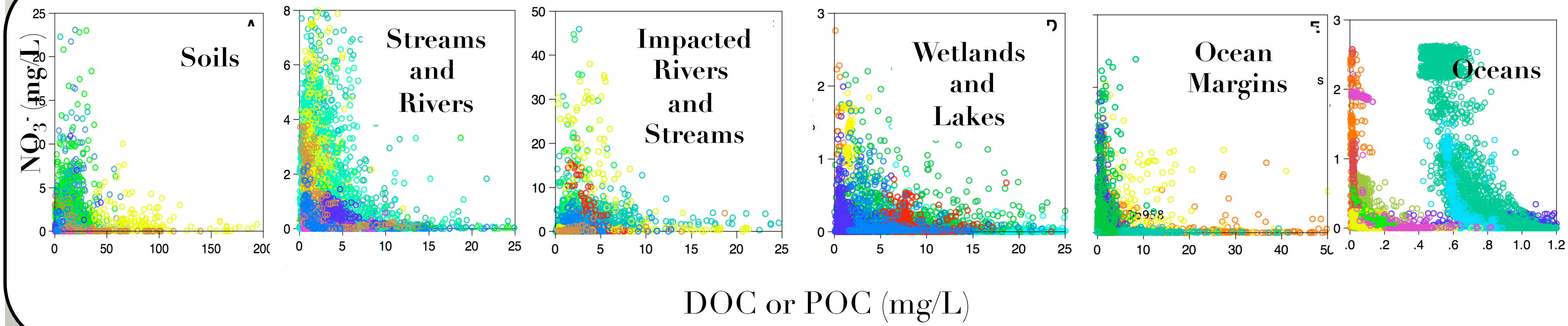
Thanks to…

Noah Fierer and Peter Vitousek for excellent insights.

providers of online data repositories, like the LTER, without which this meta-analysis would be impossible.

Threshold behavior reveals role for C quality

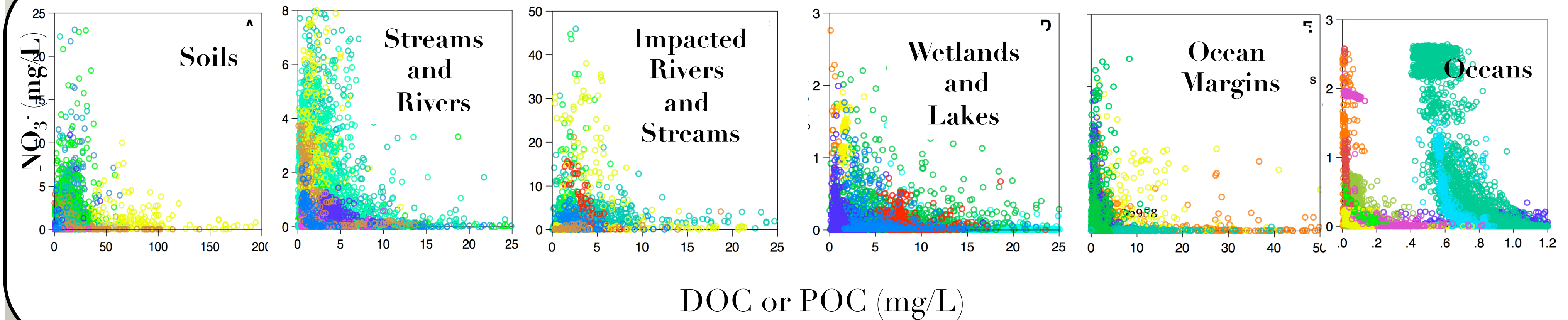
$$(y = a + b^{-k(x)})$$



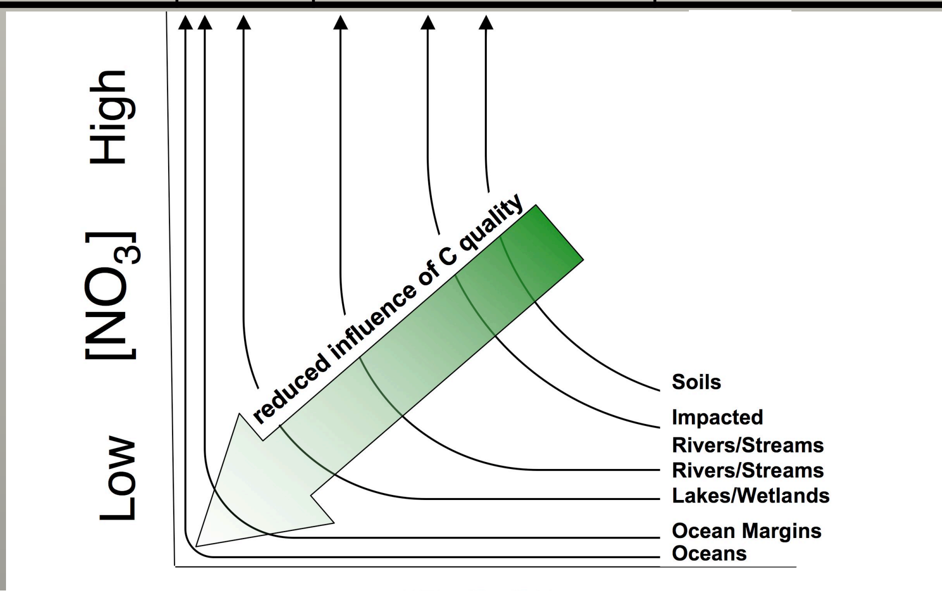
Inflection C:N-NO_3	5.22	3.29	3.12	4.76	2.19	2.67	3.79
r^2	**.25**	**.32**	**.24**	**.42**	**.39**	**.47**	**.50**
k	**.13**	**.40**	**.14**	**1.39**	**3.55**	**4.86**	**8.15**

Threshold behavior reveals role for C quality

$(y = a + b^{-k(x)})$

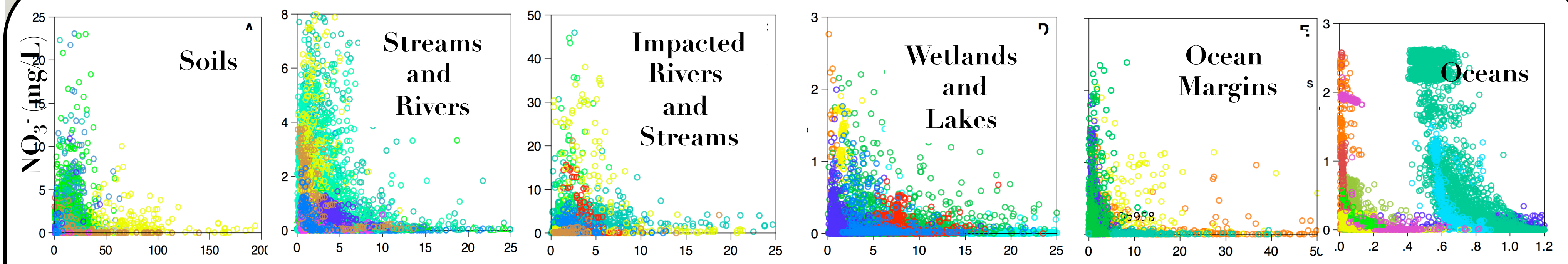


Inflection $C:N-NO_3$	5.22	3.29	3.12	4.76	2.19	2.67	3.79
r^2	**.25**	**.32**	**.24**	**.42**	**.39**	**.47**	**.50**
k	**.13**	**.40**	**.14**	**1.39**	**3.55**	**4.86**	**8.15**

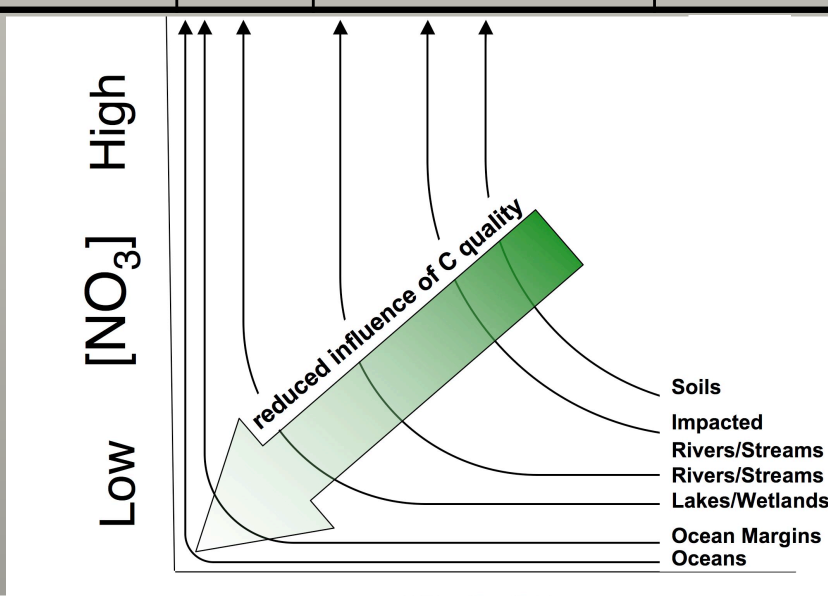


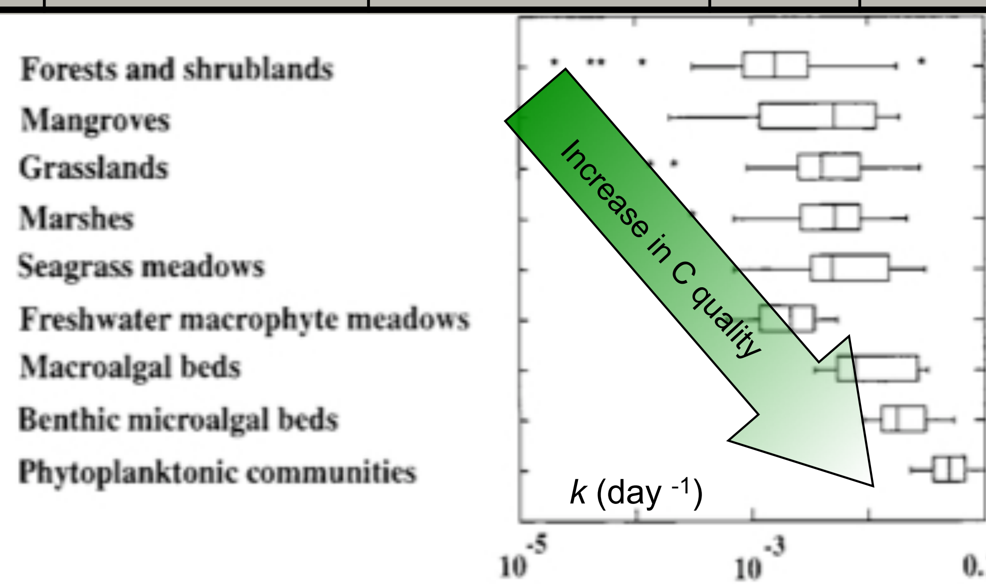
Threshold behavior reveals role for C quality

$(y = a + b^{-k(x)})$



Inflection C:N-NO_3	5.22	3.29	3.12	4.76	2.19	2.67	3.79
r^2	**.25**	**.32**	**.24**	**.42**	**.39**	**.47**	**.50**
k	**.13**	**.40**	**.14**	**1.39**	**3.55**	**4.86**	**8.15**





Same idea for phosphorus!

Inflection Points range from 3 to 30, except Amazon