The versatility of diversity: understanding ecological functions provided by complex mussel communities

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The versatility (or headache) of diversity: understanding ecological functions provided by complex mussel communities

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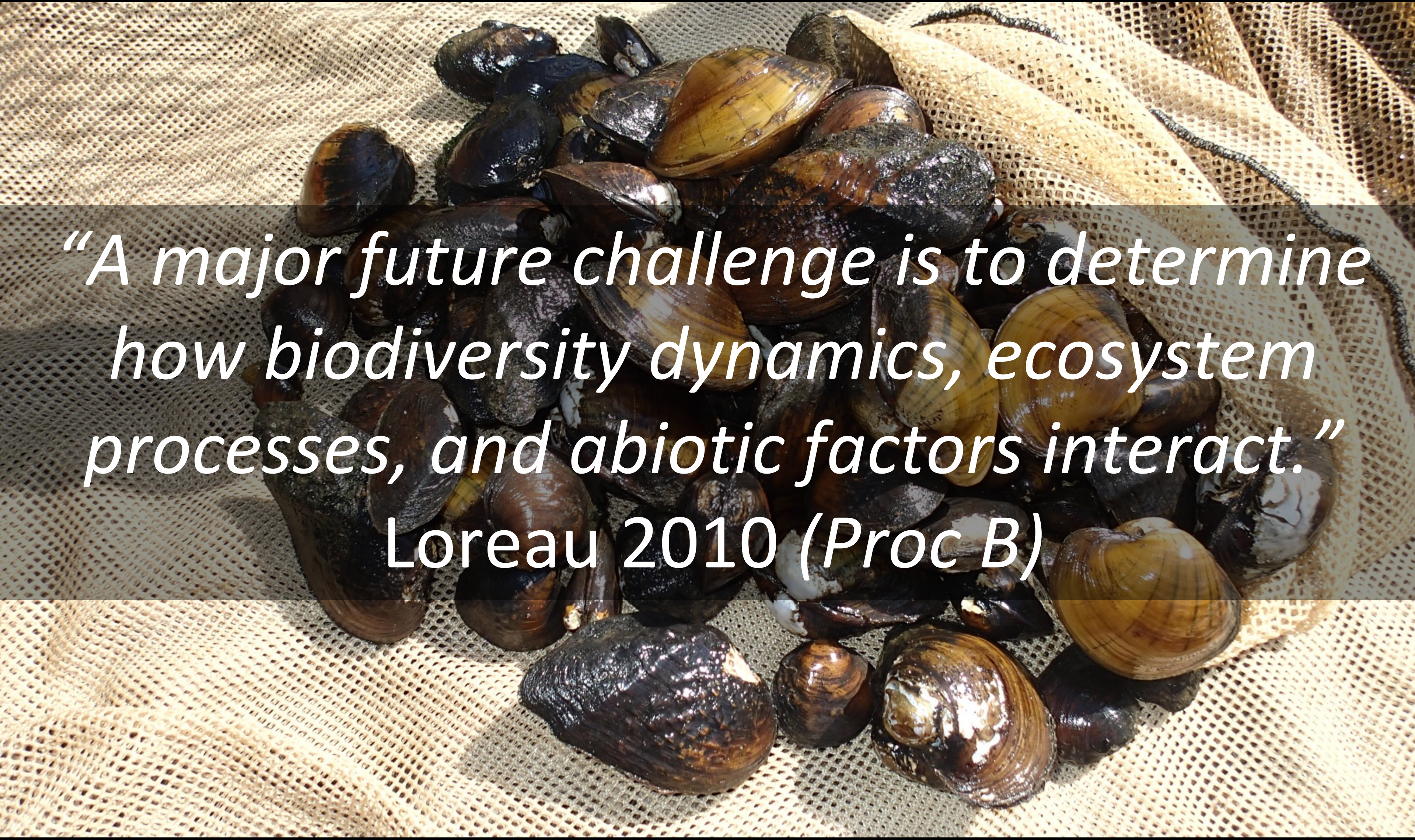
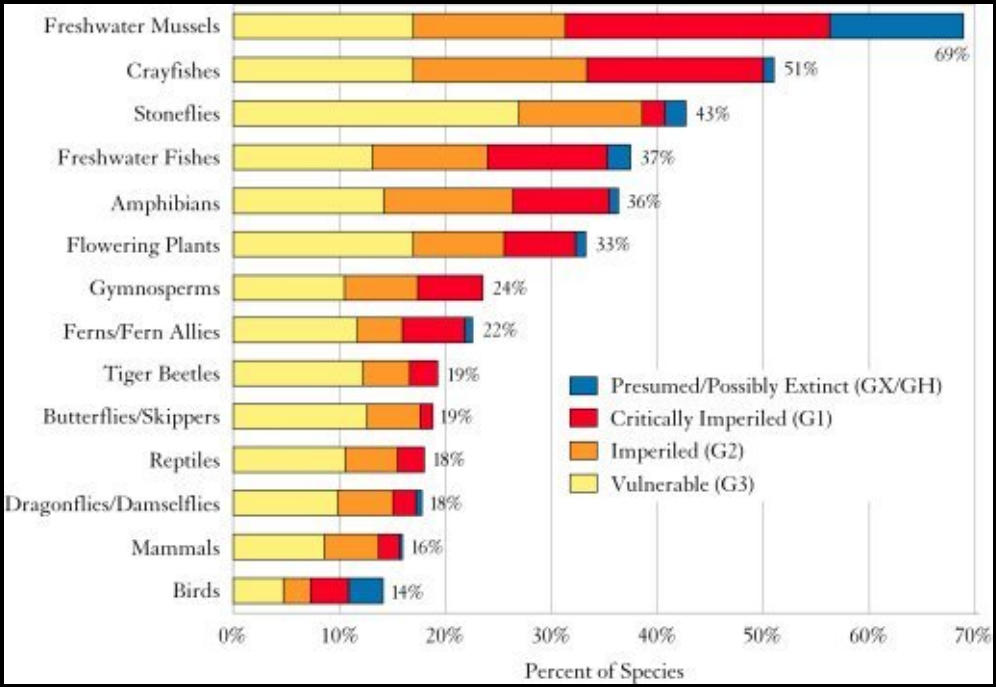
How does ecosystem context shape Ecosystem Services?



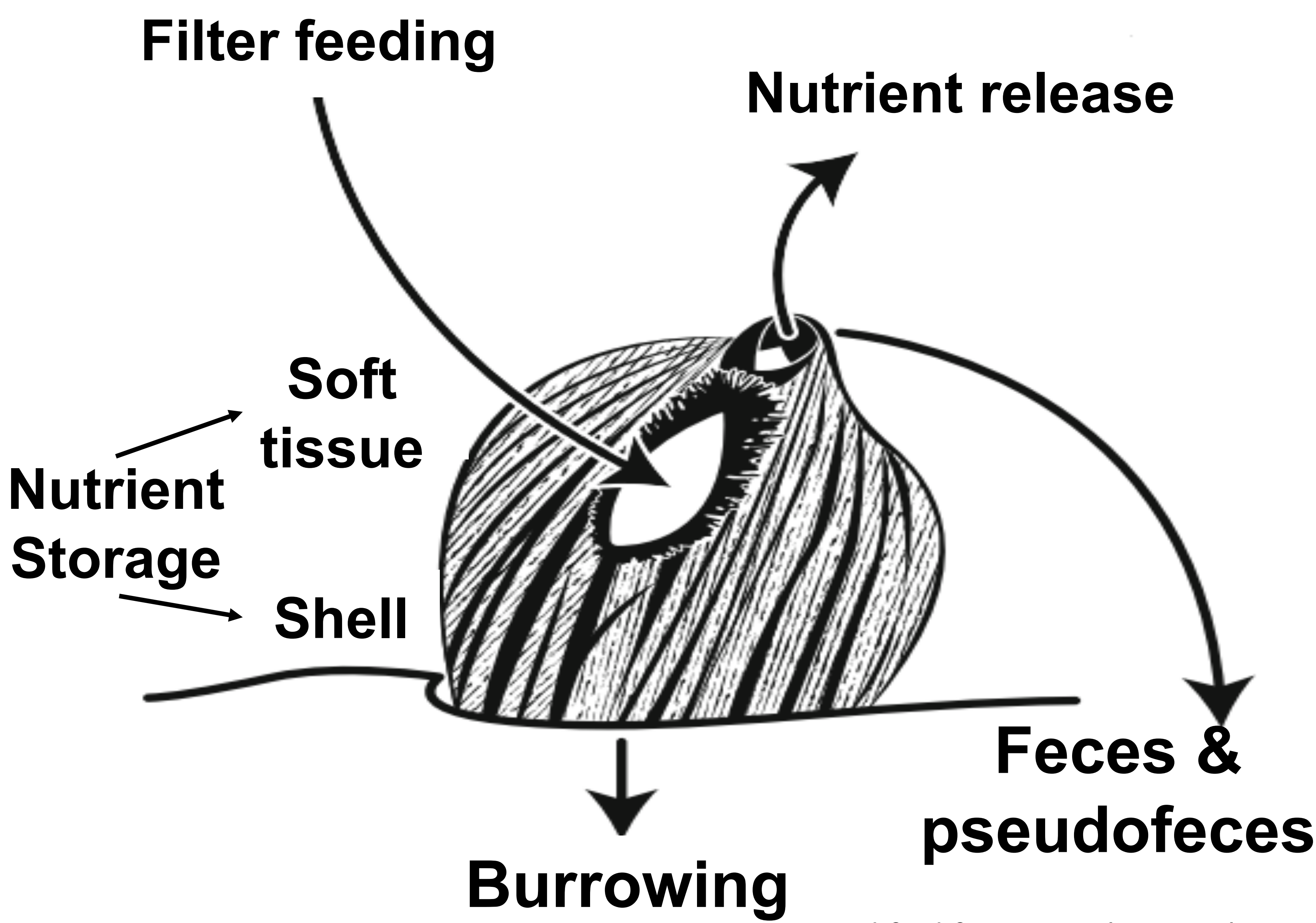
How does community assembly shape Ecosystem Services?

Freshwater Mussels

- Diverse group (~300 species)
- Occur in dense aggregates
- Powerful filter-feeders

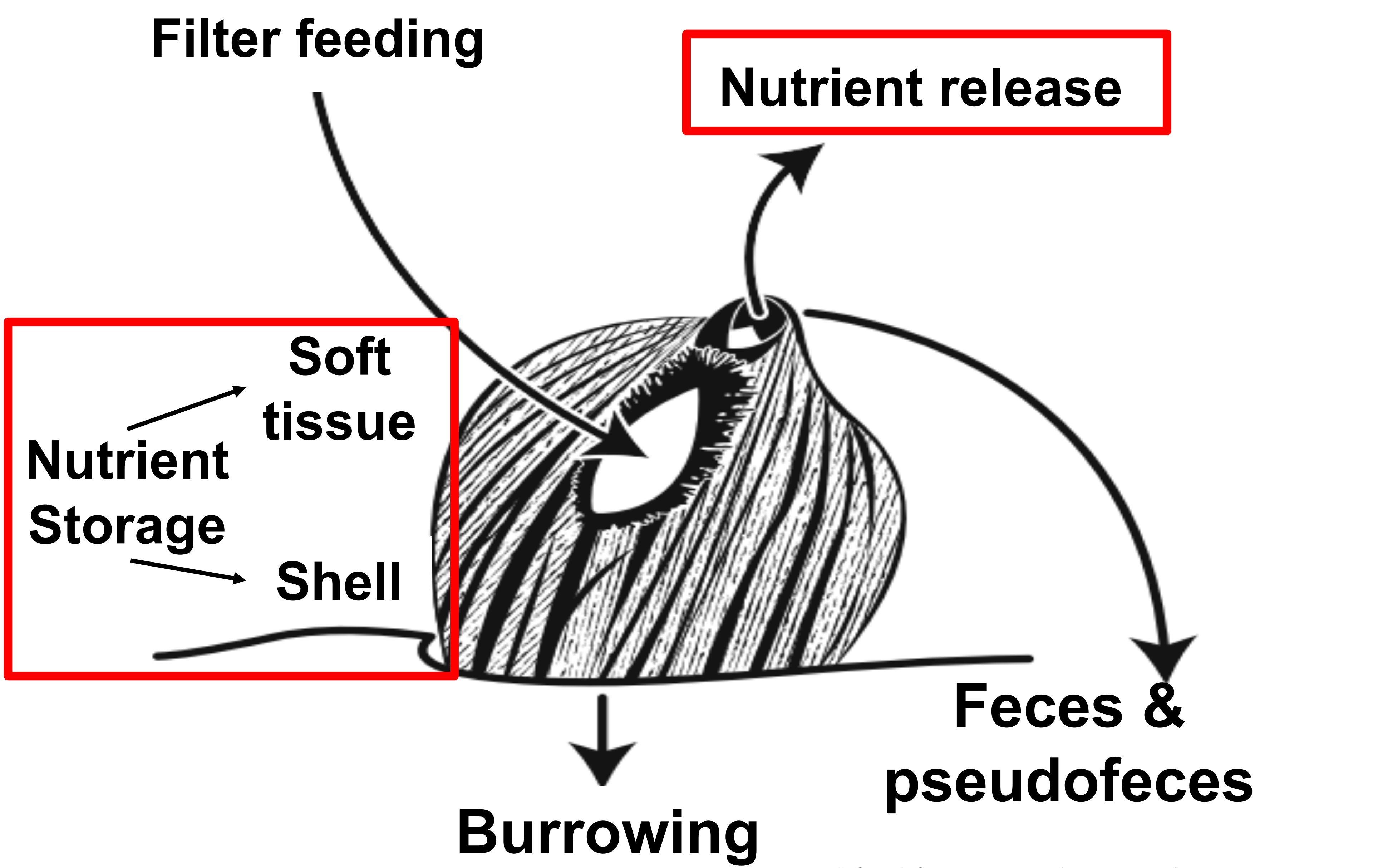


Freshwater Mussels = Important Functions



Modified from Vaughn & Hakencamp 2001

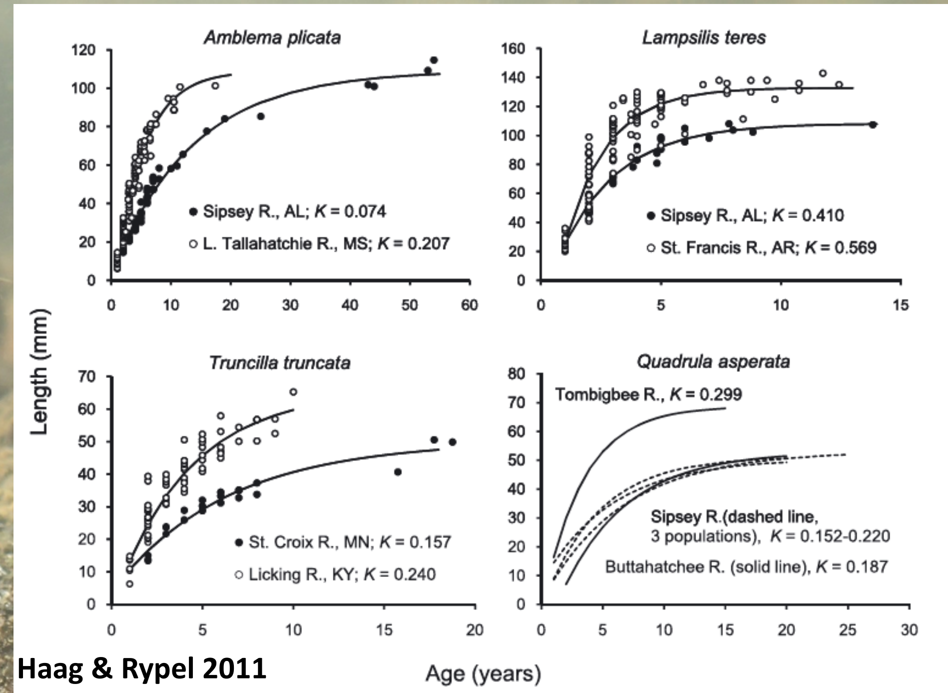
Freshwater Mussels = Important Functions



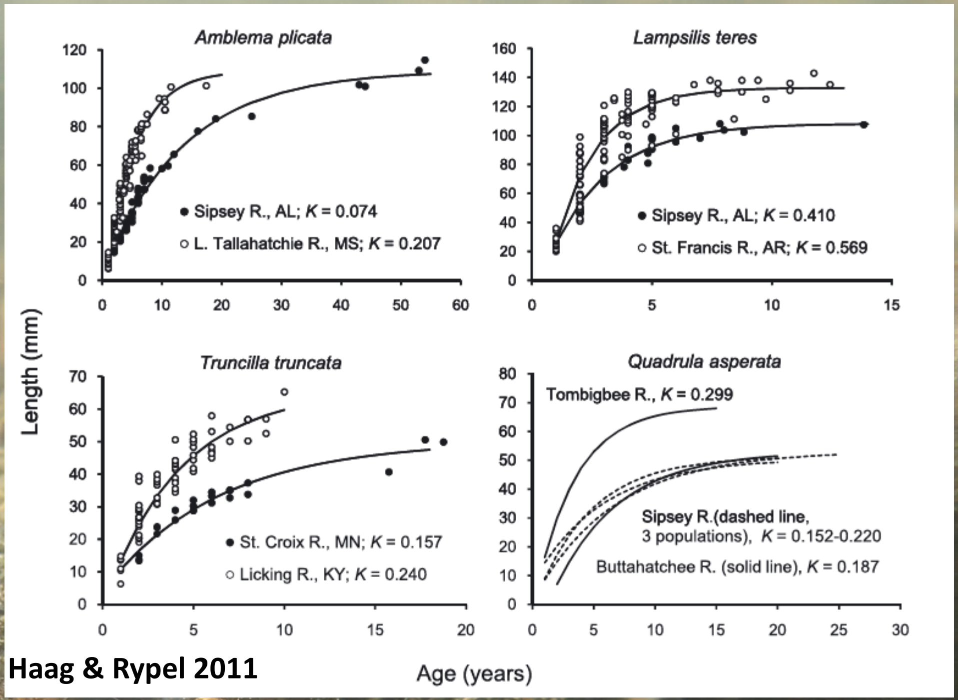
Modified from Vaughn & Hakencamp 2001

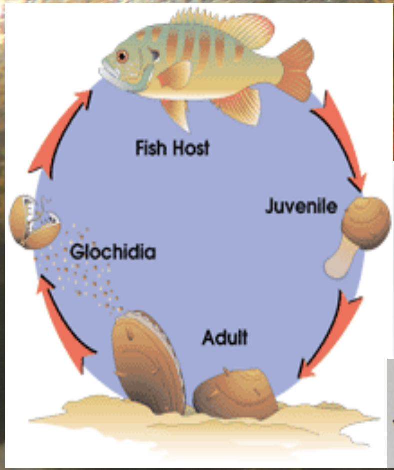
Freshwater Mussels

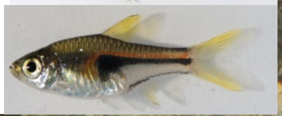
Freshwater Mussels



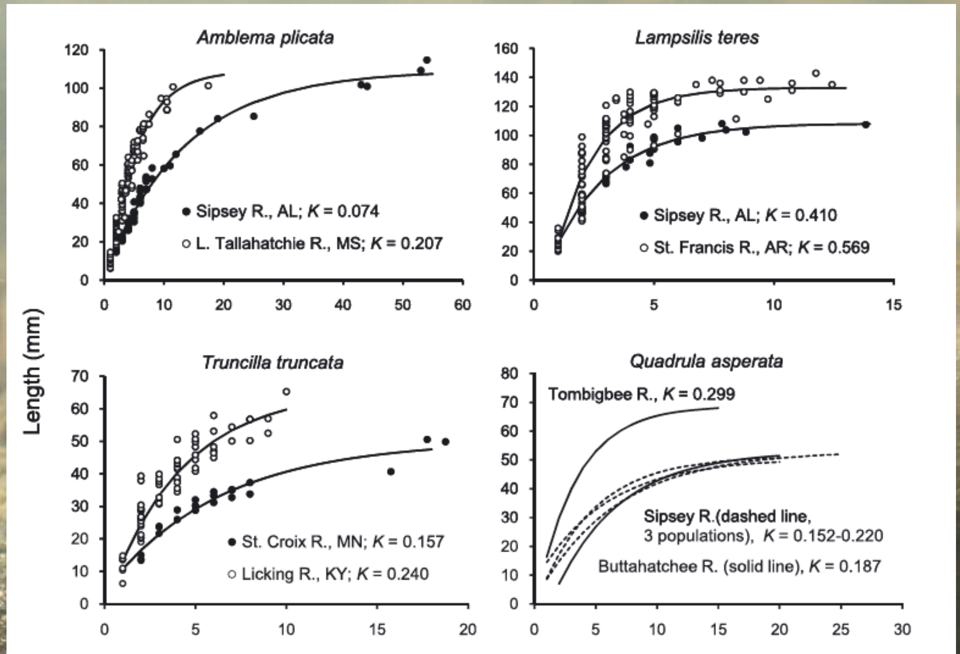
Freshwater Mussels



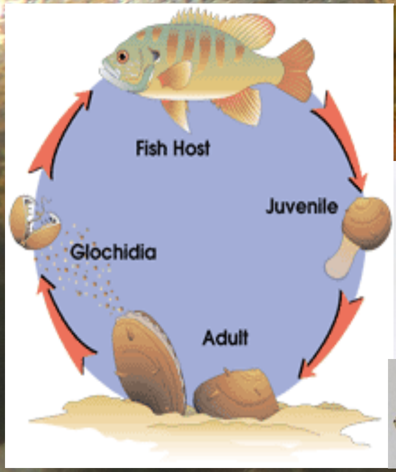


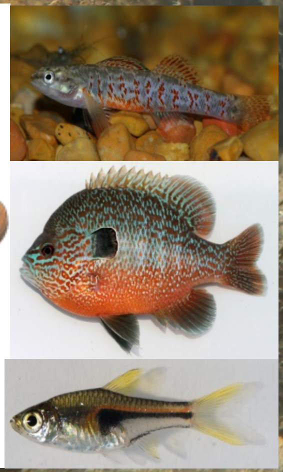


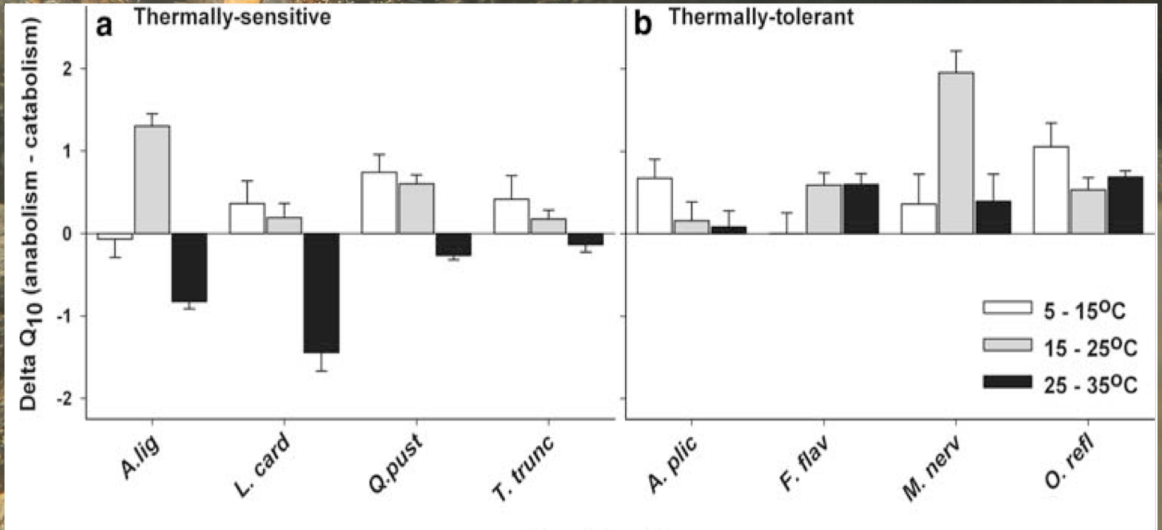
Freshwater Mussels



Haag & Rypel 2011

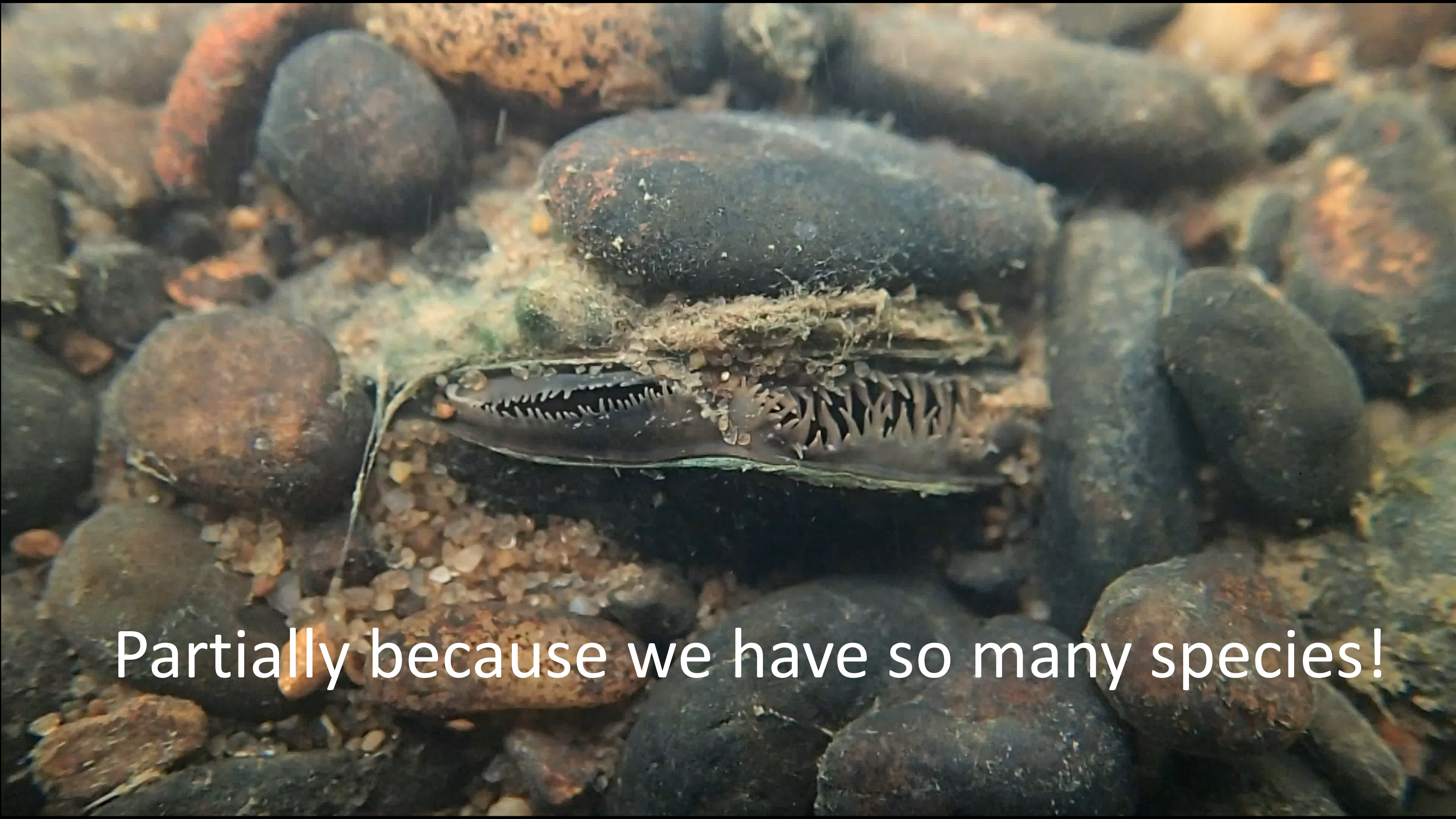






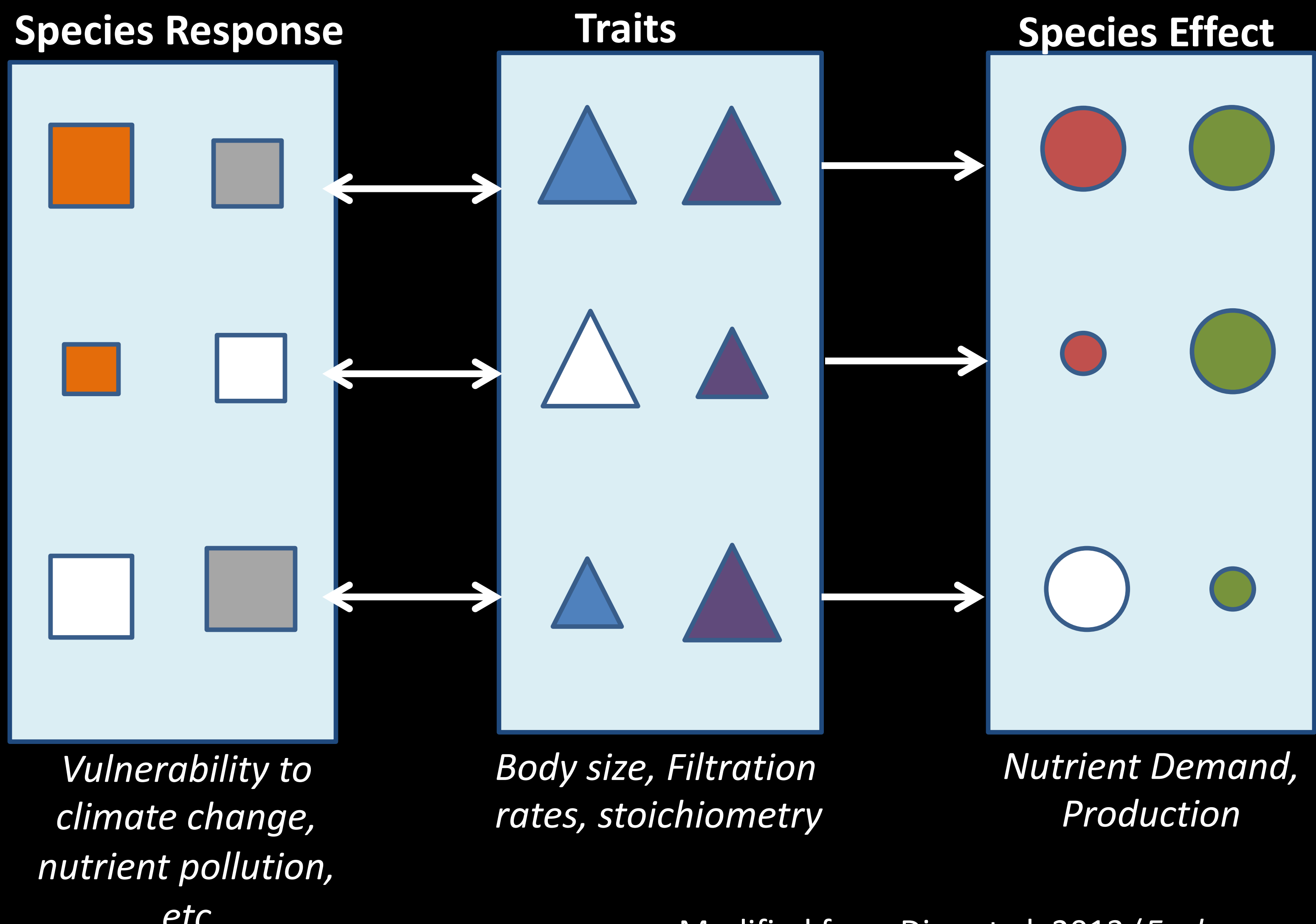
Spooner & Vaughn 2008, *Oecologia*

The ecological functions of mussels



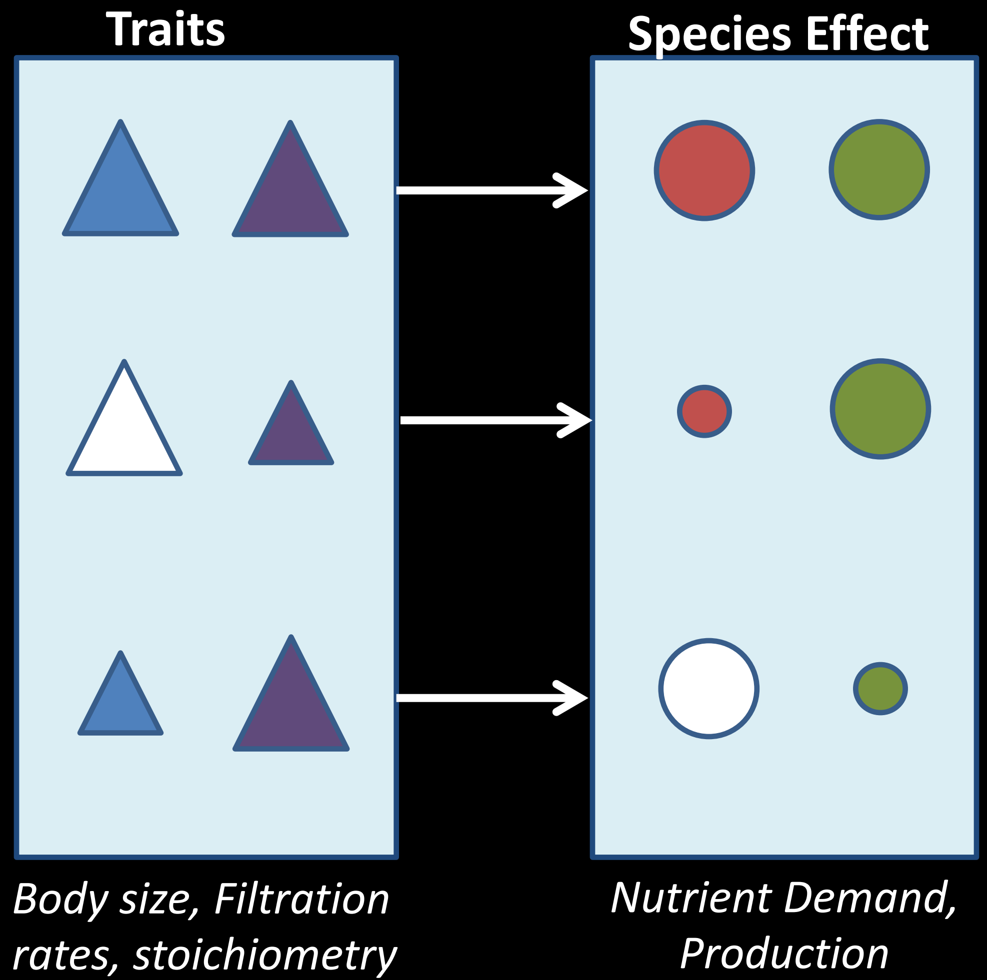
We are lacking in basic information on the ecological roles of mussels.

Can we link species traits to species responses to abiotic conditions to understand ecosystem vulnerability and predict ecosystem services provided and their resiliency?



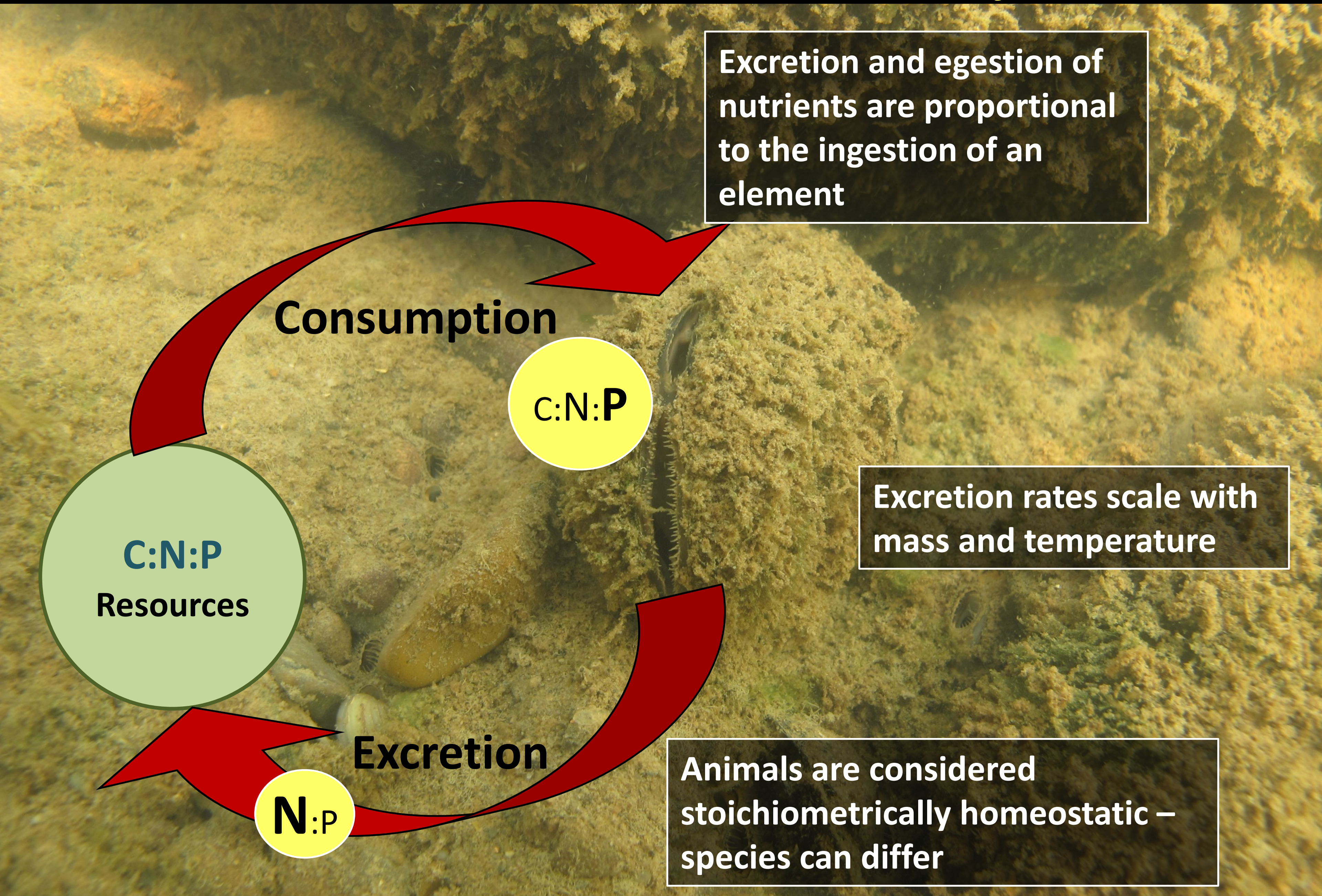
Modified from Diaz et al. 2013 (*Ecology and Evolution*)

Can we link species traits to species responses to abiotic conditions to understand ecosystem vulnerability and predict ecosystem services provided and their resiliency?



Modified from Diaz et al. 2013 (*Ecology and Evolution*)

Consumer-driven nutrient dynamics



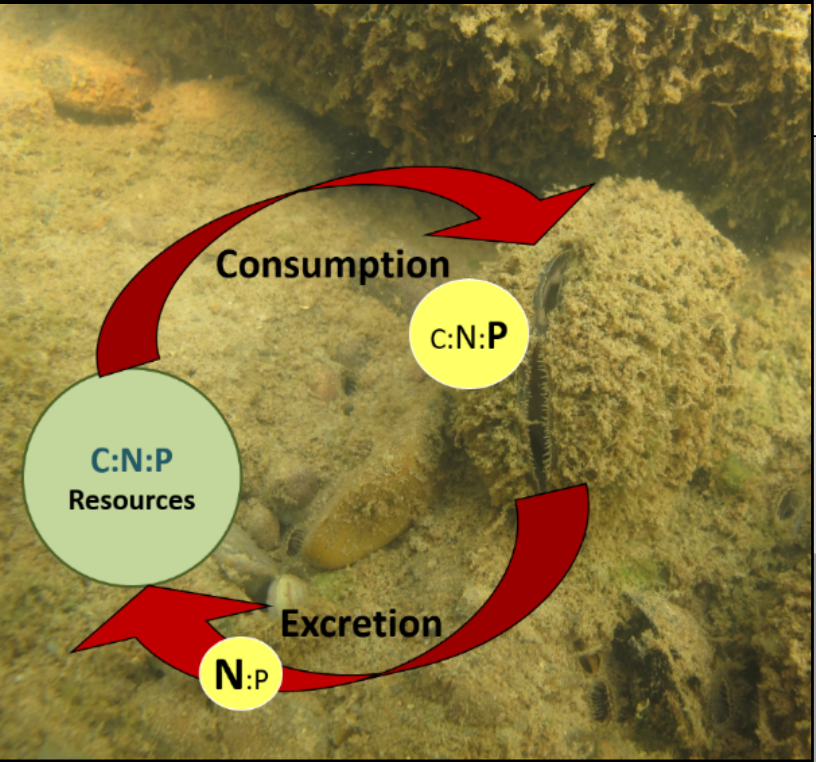
Excretion and egestion of nutrients are proportional to the ingestion of an element

Excretion rates scale with mass and temperature

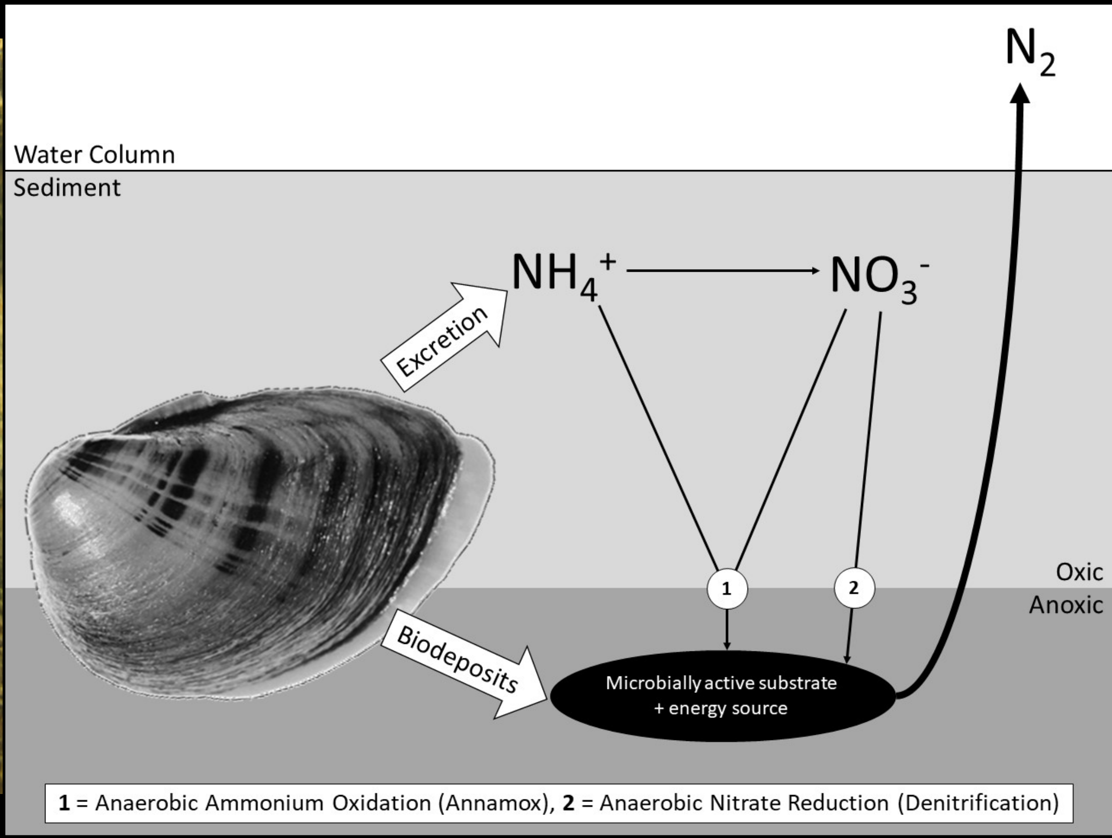
Animals are considered stoichiometrically homeostatic – species can differ

Consumer-driven nutrient dynamics

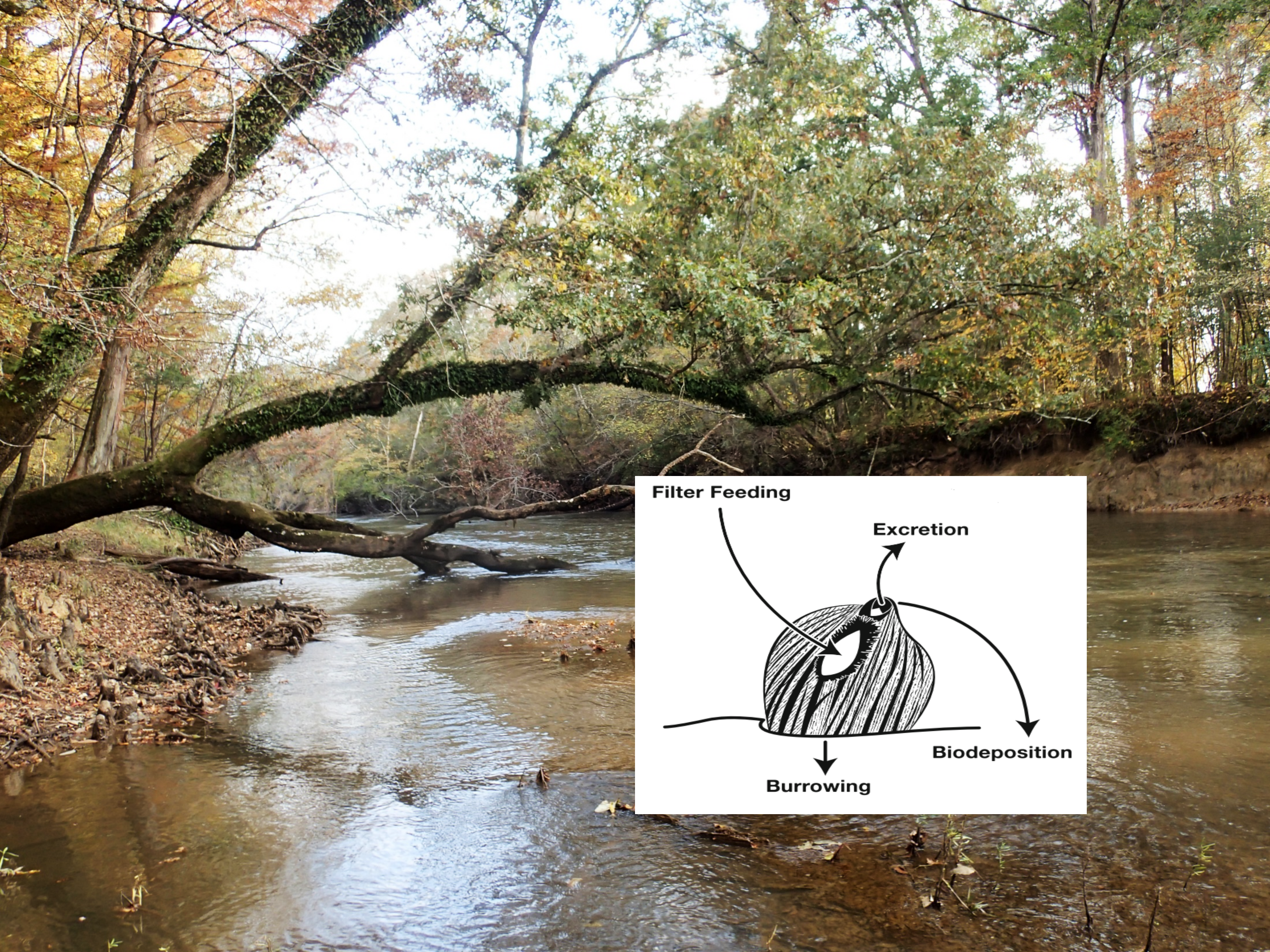
Direct Effects

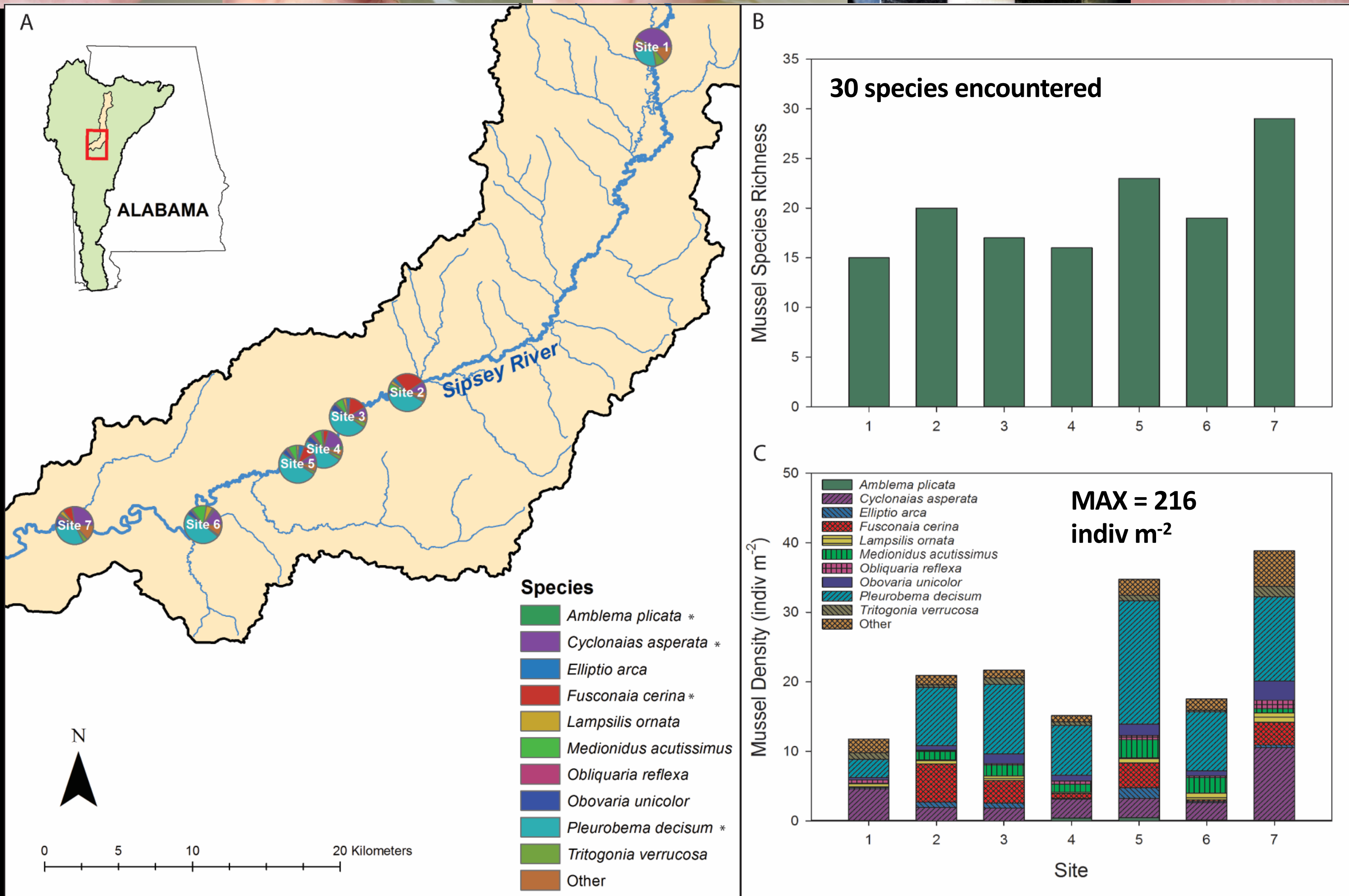


Indirect Effects



Both contribute to indirect-use values


Filter Feeding
Excretion
Biodeposition
Burrowing



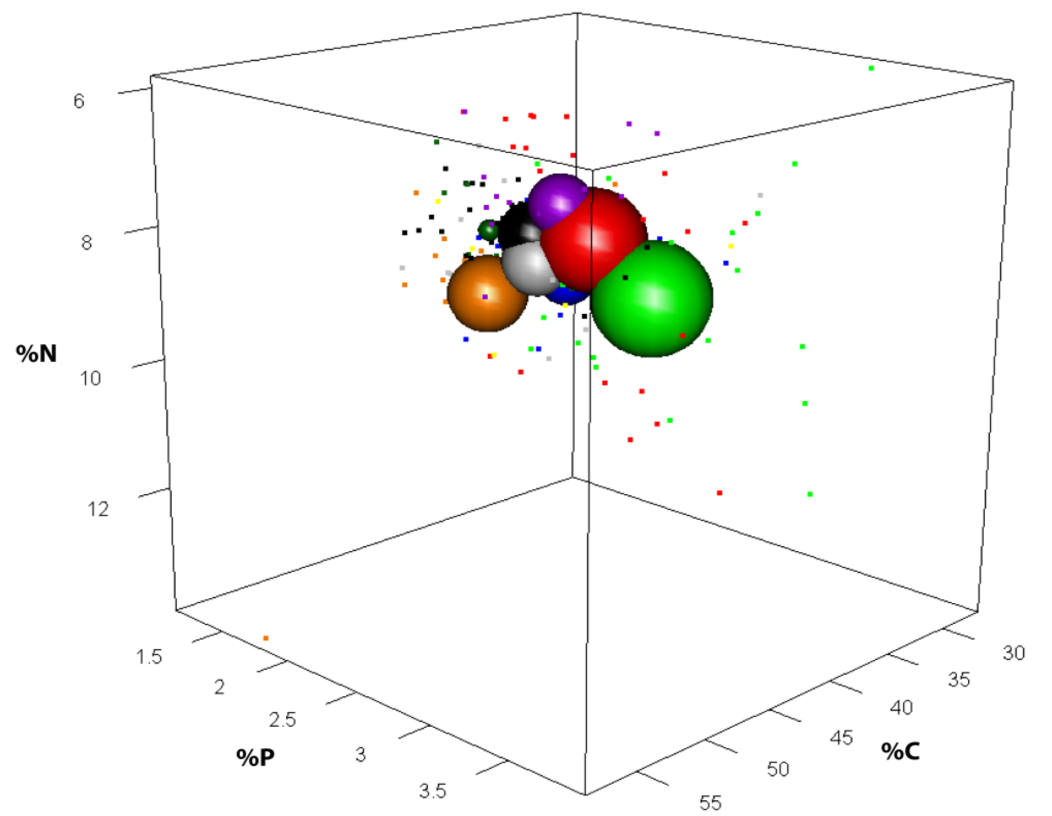
A
ALABAMA
Site 1
Site 2
Site 3
Site 4
Site 5
Site 6
Site 7
Sipsey River
N
0
5
10
20 Kilometers
Species
Amblema plicata *
Cyclonaias asperata *
Elliptio arca
Fusconaia cerina *
Lampsilis ornata
Medionidus acutissimus
Obliquaria reflexa
Obovaria unicolor
Pleurobema decisum *
Tritogonia verrucosa
Other
B
30 species encountered
Mussel Species Richness
0
5
10
15
20
25
30
35
1
2
3
4
5
6
7
C
MAX = 216
indiv m-2
Mussel Density (indiv m-2)
0
10
20
30
40
50
Amblema plicata
Cyclonaias asperata
Elliptio arca
Fusconaia cerina
Lampsilis ornata
Medionidus acutissimus
Obliquaria reflexa
Obovaria unicolor
Pleurobema decisum
Tritogonia verrucosa
Other
1
2
3
4
5
6
7
Site

Species store nutrients differently

Niche volumes

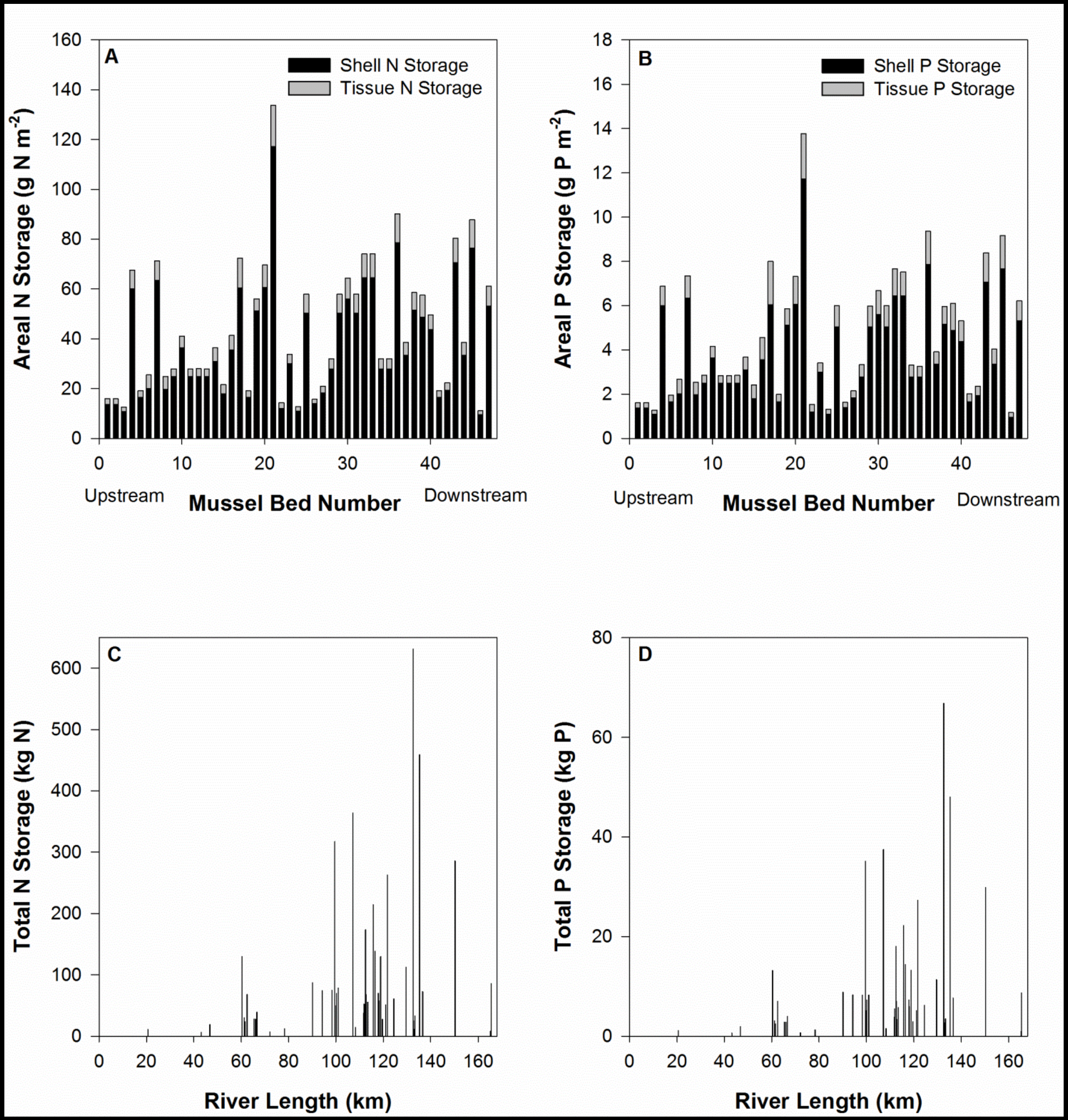
- Lampsilis ornata
- Obovaria unicolor
- Obliquaria reflexa
- Tritagonia verrucosa
- Cyclonaias asperata
- Fusconaia cerina
- Pleurobema decisum
- Elliptio arca
- Amblema plicata

Soft Tissue Storage



Atkinson, van Ee, and Pfeiffer, *In review*

Nutrient Storage by Mussels can be Significant



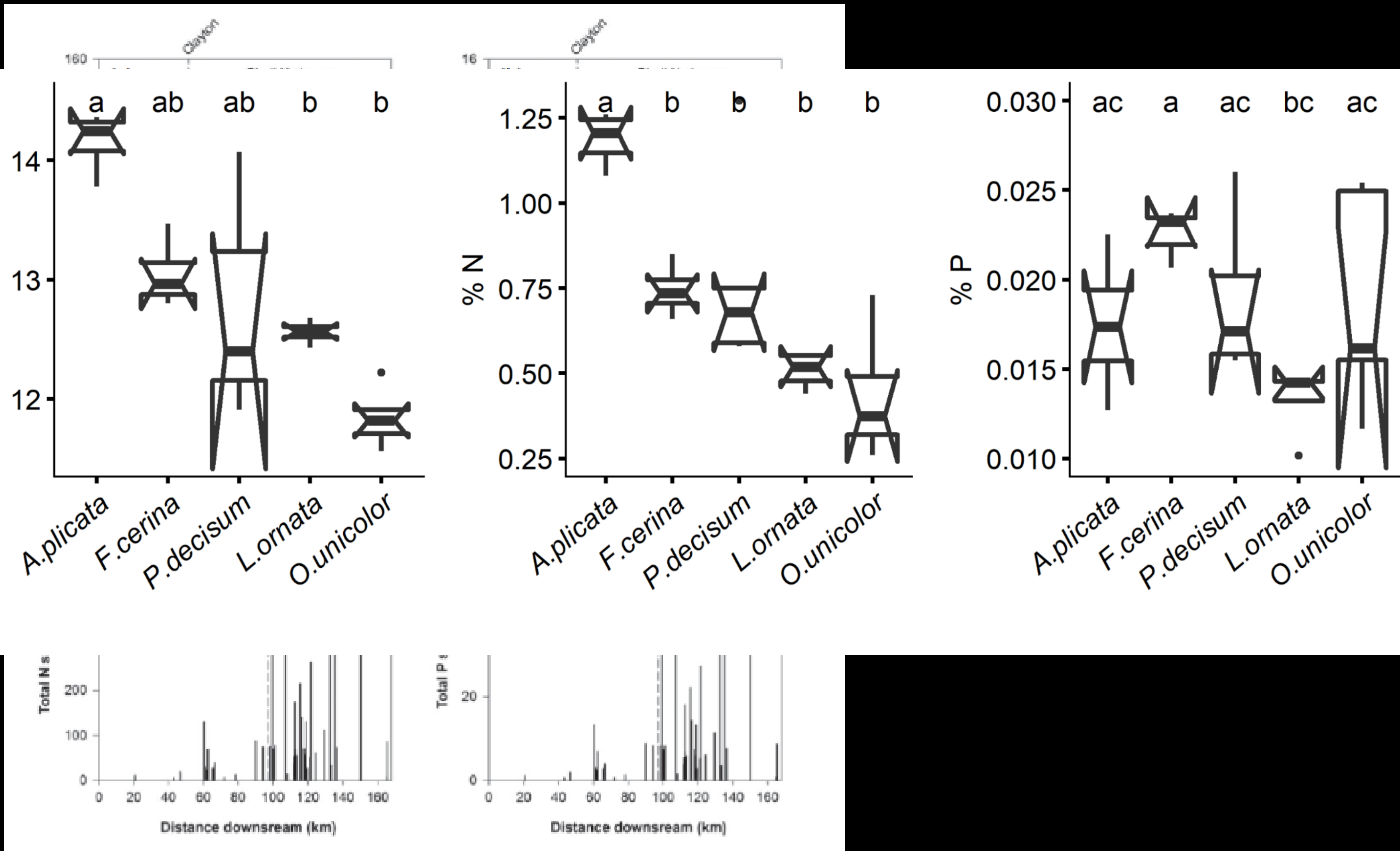
Sequestration

Mussels live 5 to >50 years

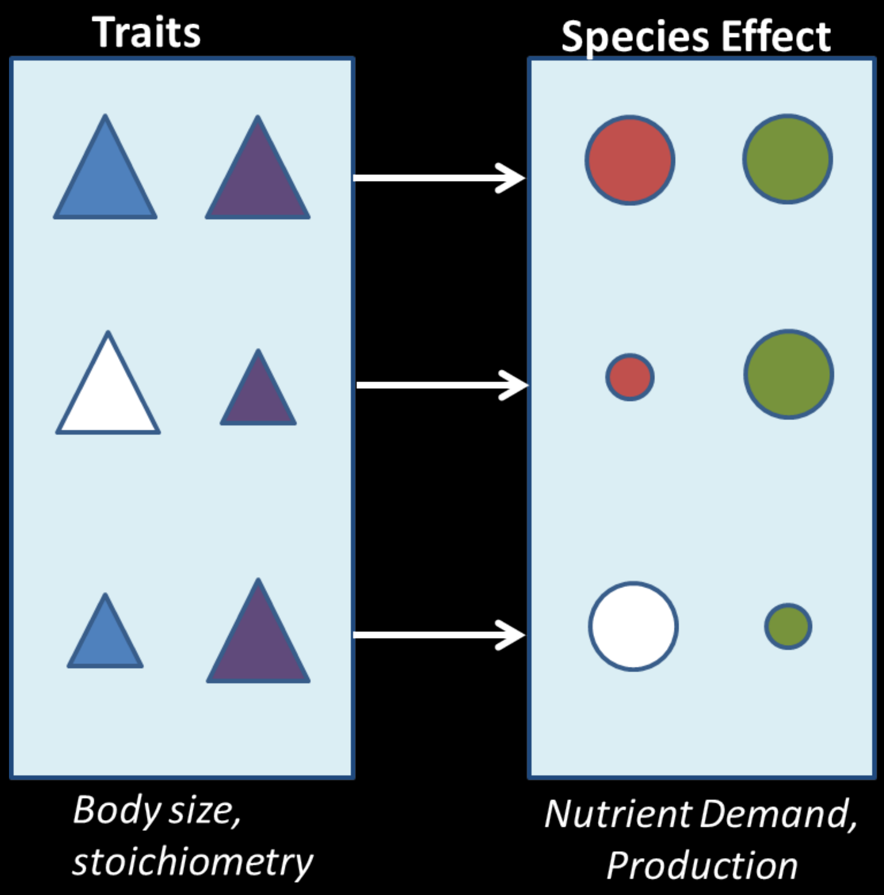
Shell = long term store, "nutrient sink"

Atkinson and Vaughn 2015

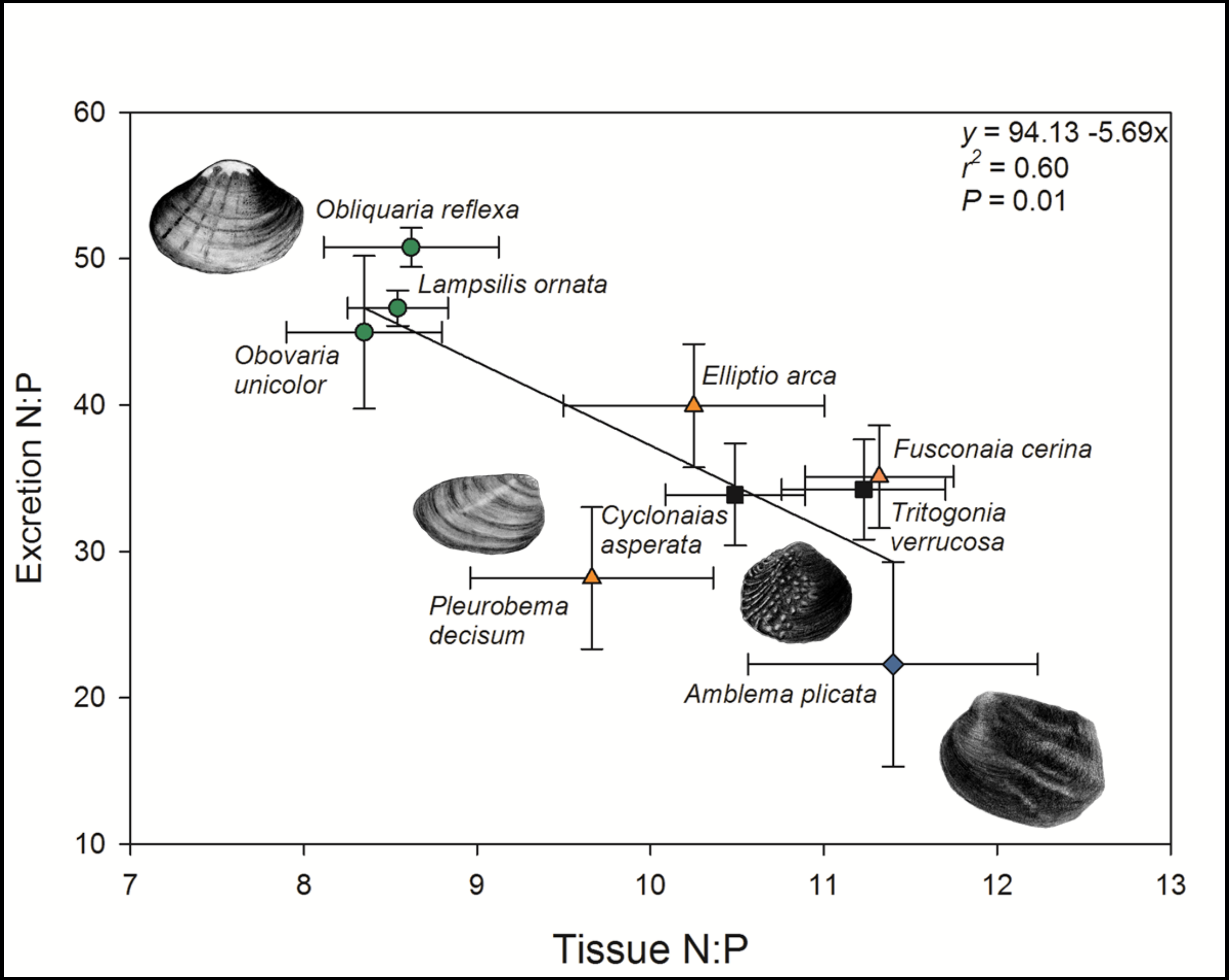
Nutrient Storage in Mussels can be Significant



Is body stoichiometry dictating ecosystem effect traits?



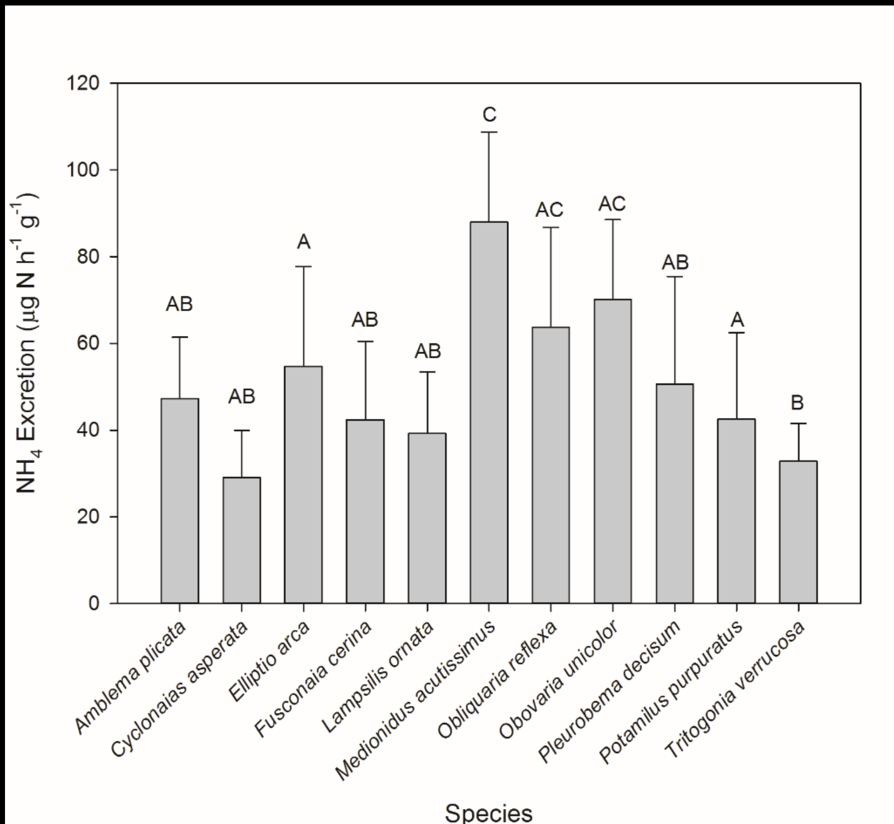
Concordance between Tissue Storage and Nutrient Recycling Stoichiometry



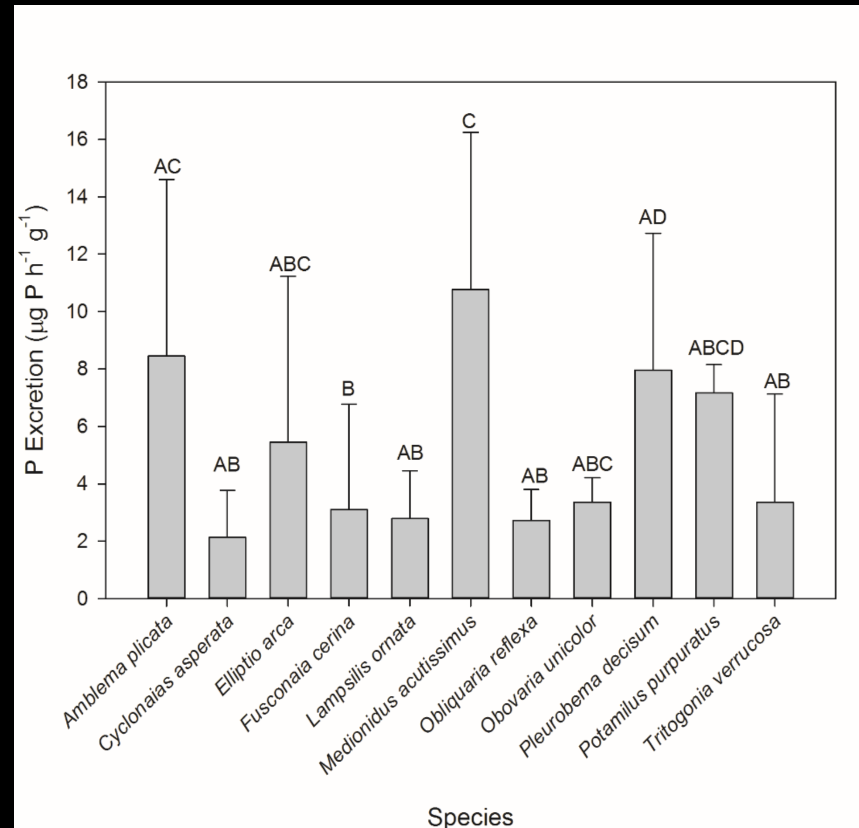
Meets the expectations of ecological stoichiometry

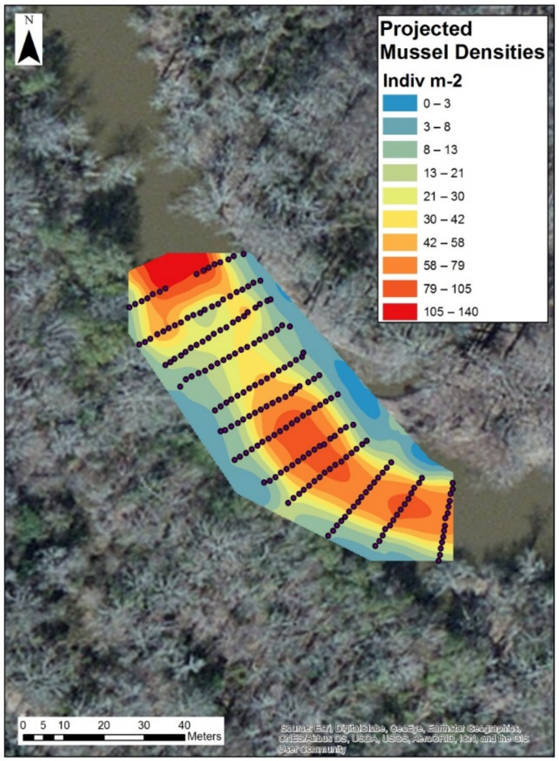
Ecosystem Effect

N Excretion Rates

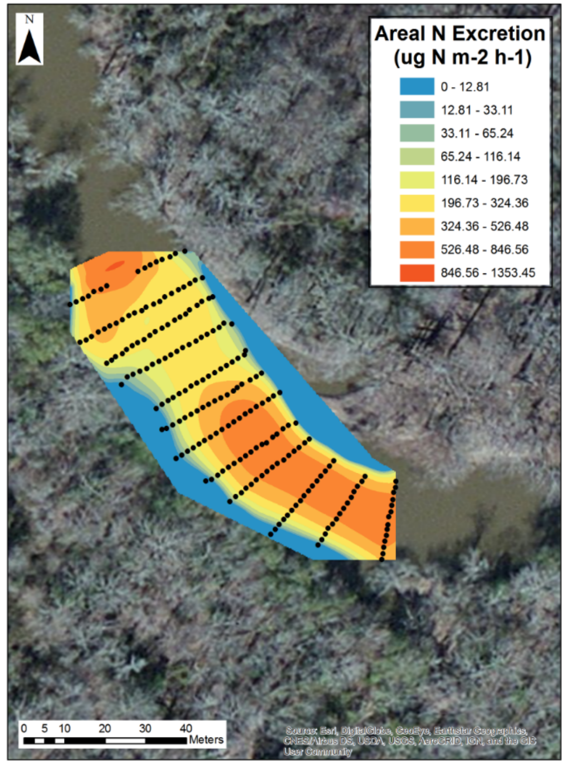


P Excretion Rates

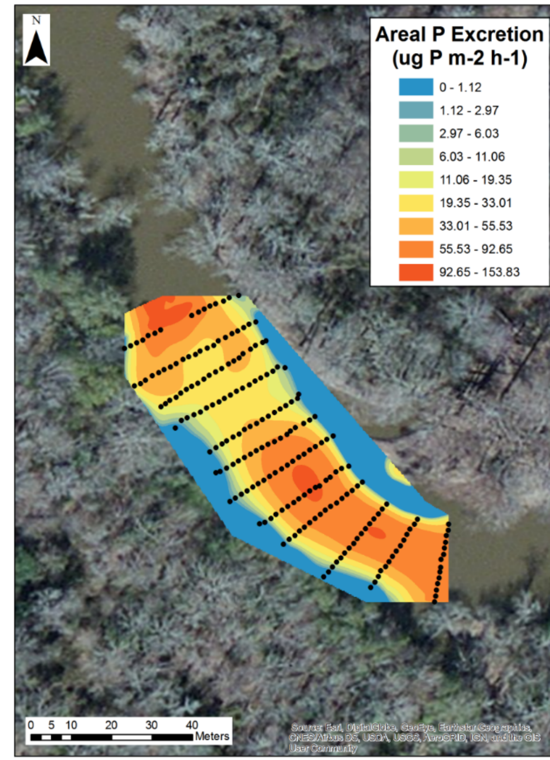




Densities



Areal N Excretion



Areal P Excretion

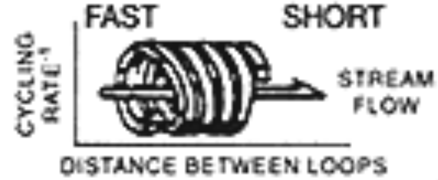
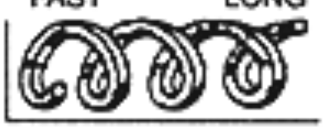
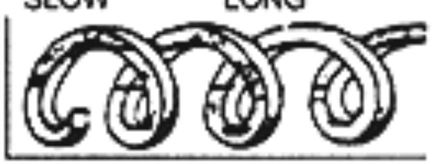
Average = 35 indiv m^{-2}

Average = 369 μg N m^{-2} h^{-1}

Average = 44.9 μg P m^{-2} h^{-1}

Atkinson et al. *In prep*

Mussels likely enhance ecosystem stability as they tighten nutrient spirals enhancing retention

	Mechanism: Retention	Mechanism: Biological Activity	Effect on Nutrient Cycling: Rate of Recycling	Effect on Nutrient Cycling: Distance Between Spiral Loops		Ecosystem Response to Nutrient Addition	Ecosystem Stability
A.	HIGH	HIGH	FAST	SHORT		CONSERVATIVE (I>E)	HIGH
B.	HIGH	LOW	SLOW	SHORT		STORING (I>E)	HIGH
C.	LOW	HIGH	FAST	LONG		INTERMEDIATELY CONSERVATIVE < A but > D	LOW
D.	LOW	LOW	SLOW	LONG		EXPORTING (I=E)	LOW

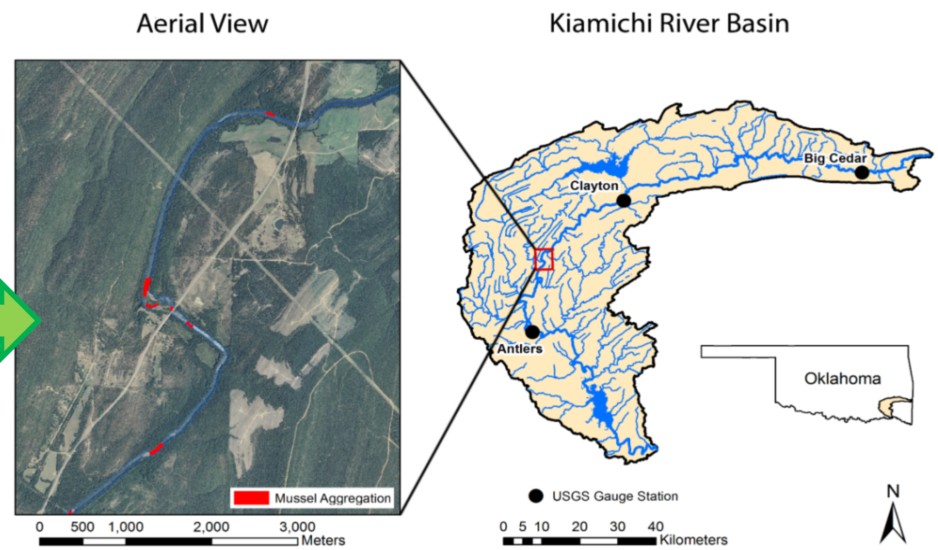
Minshall et al. 1983



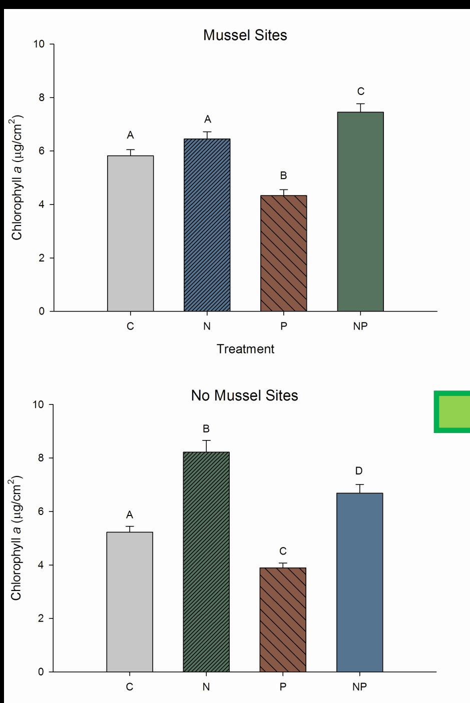


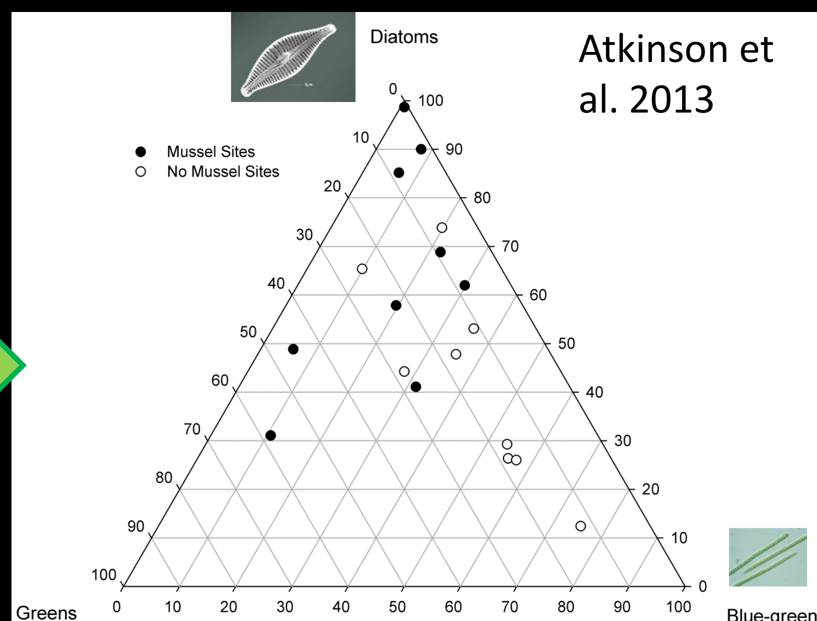
What does this mean for ecosystem structure and function?



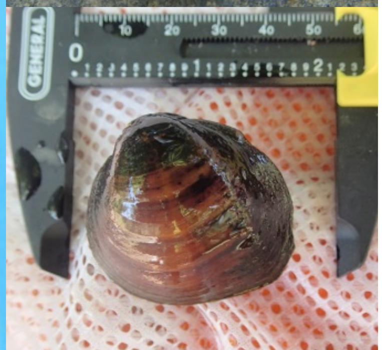
Atkinson and Vaughn 2015

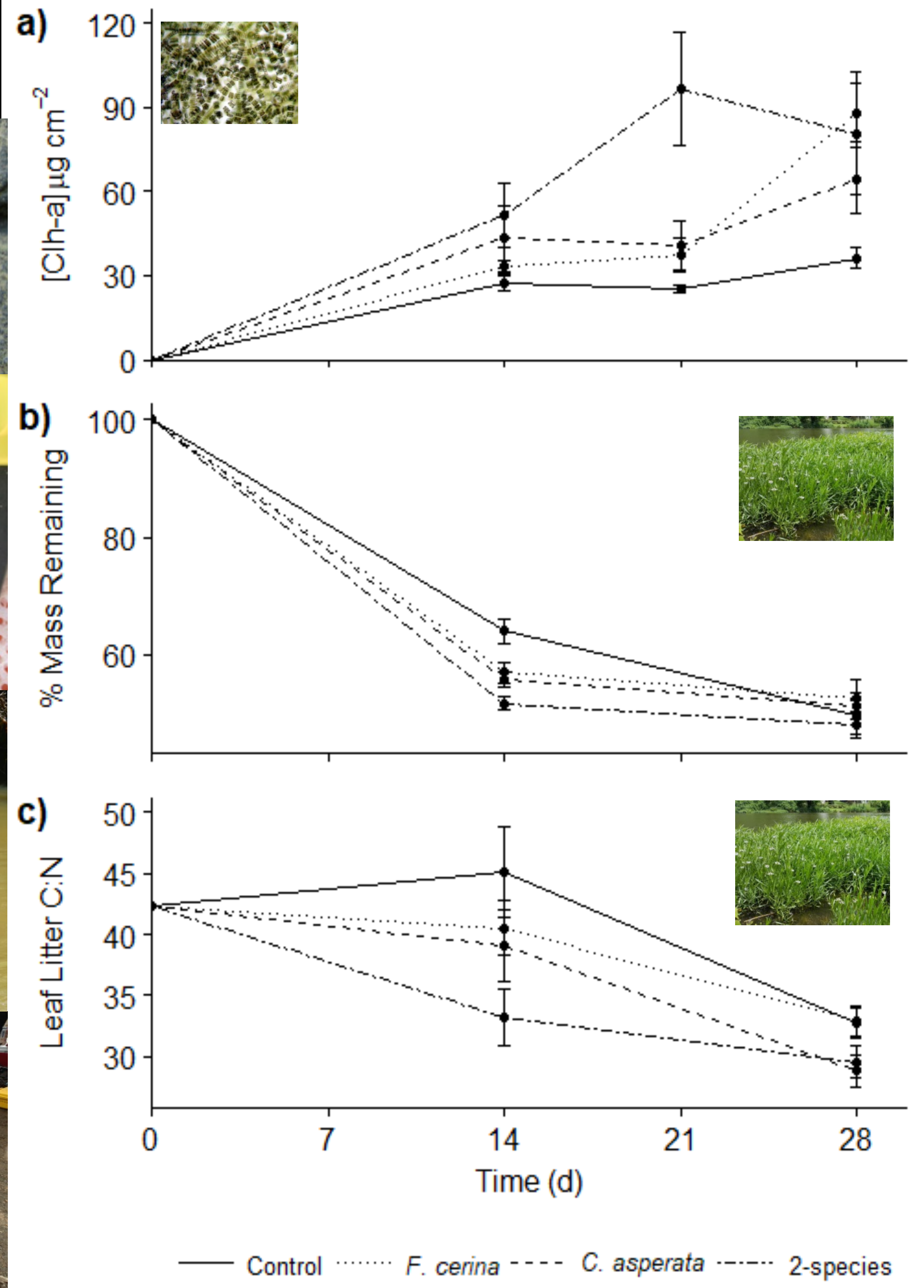




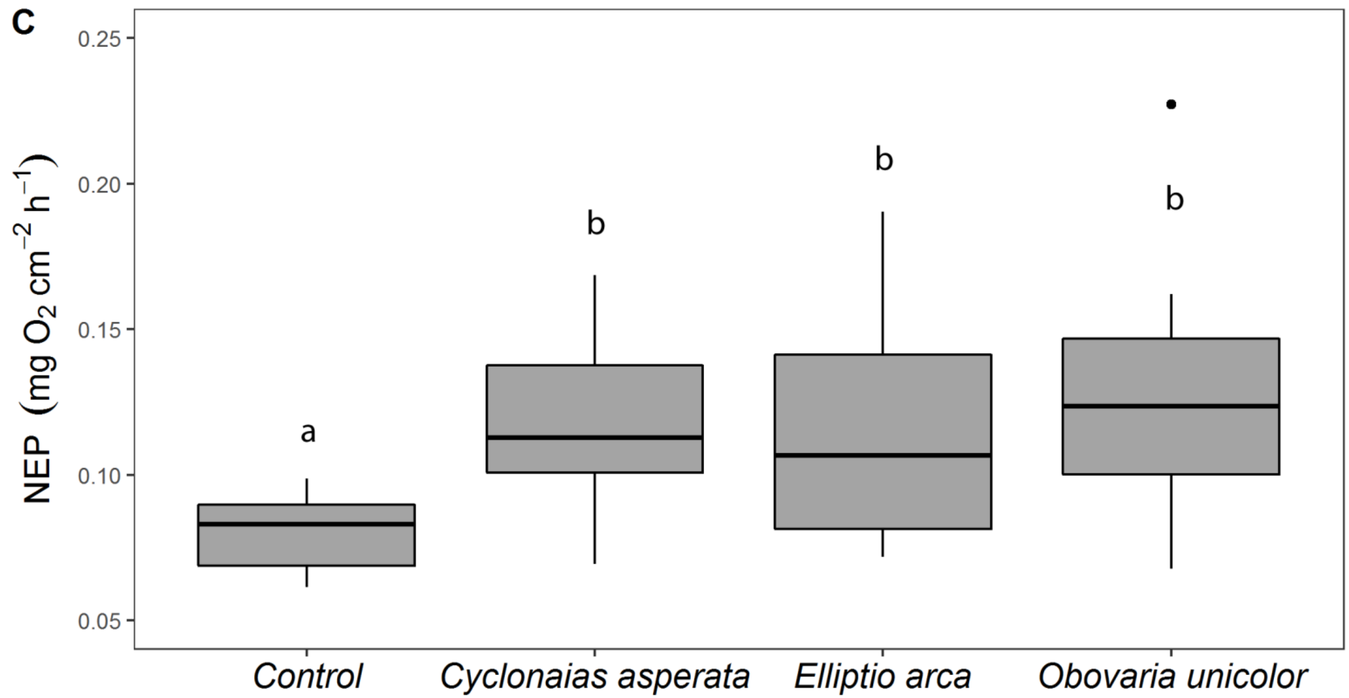
Atkinson et al. 2013

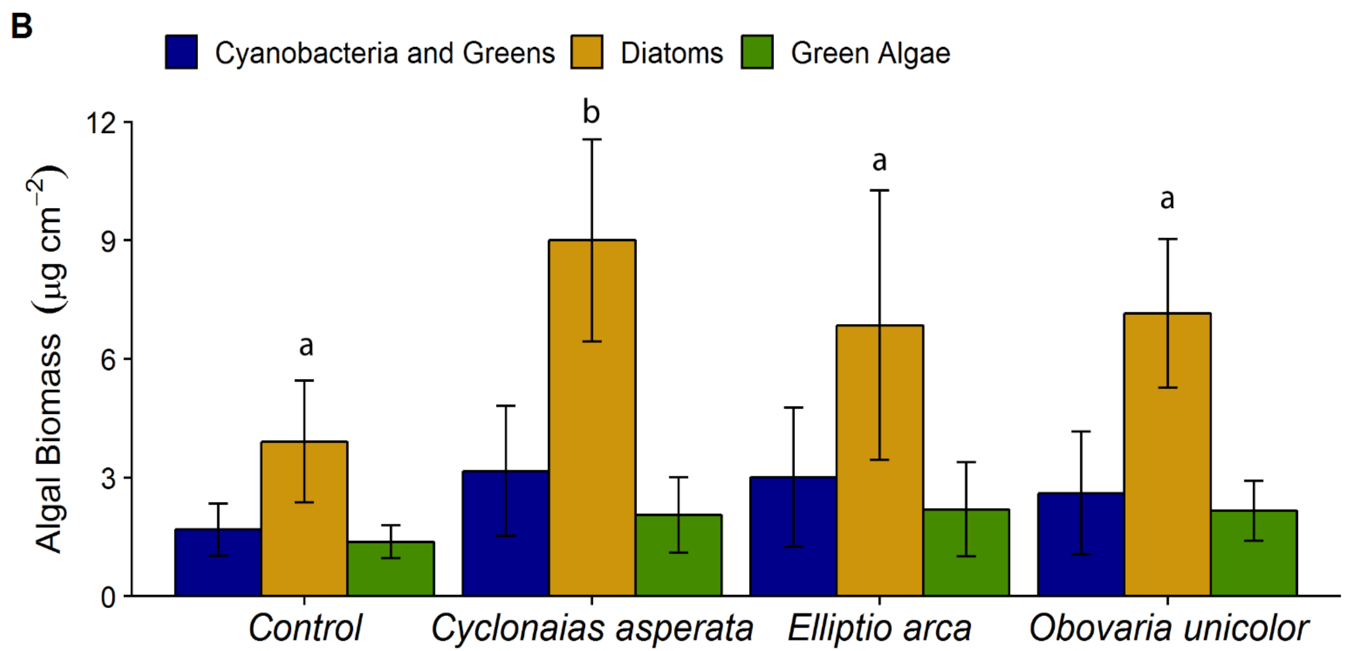
Mesocosm Experiments





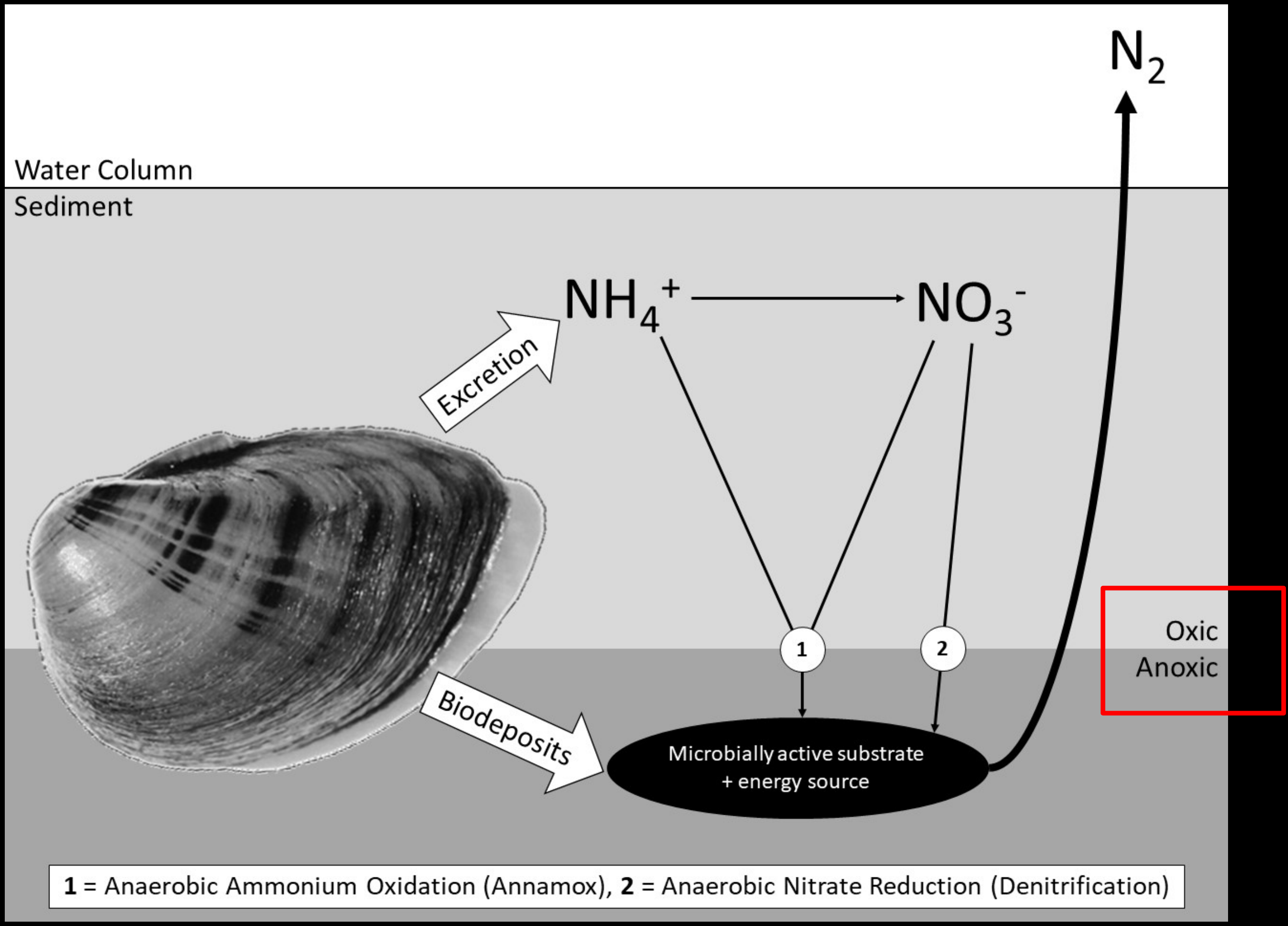
Nickerson et al. *In review*





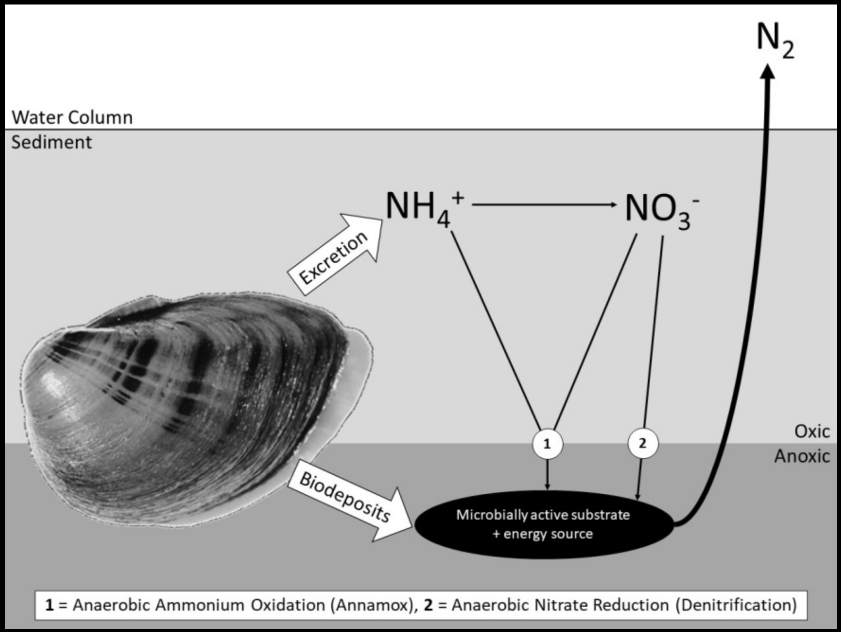
Atkinson et al. *In prep*

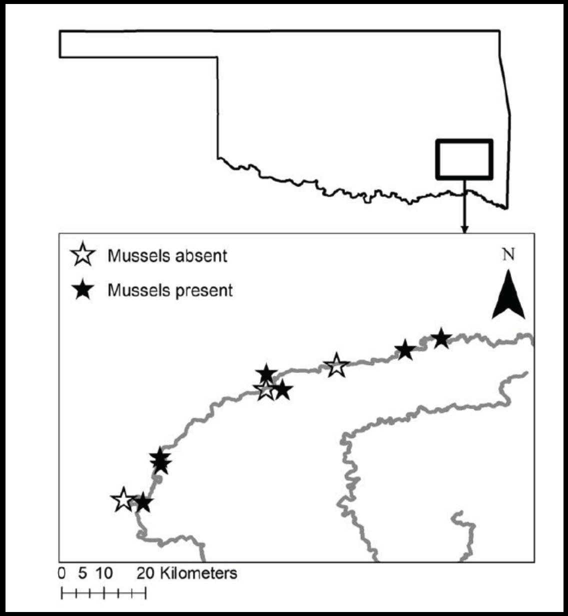
Indirect Effects

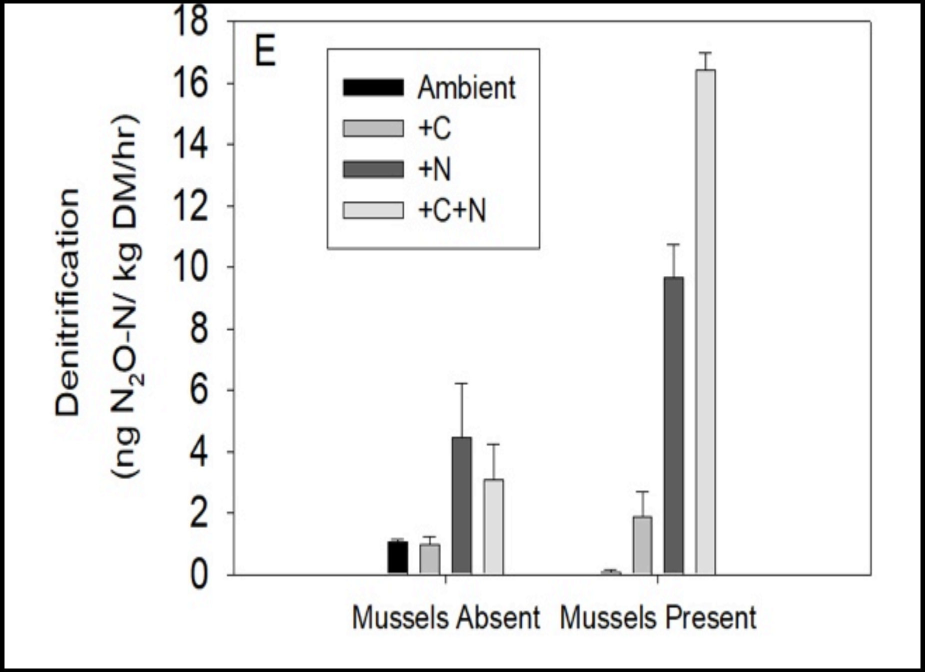


Nickerson 2018

Implications for Removal of N -> Denitrification

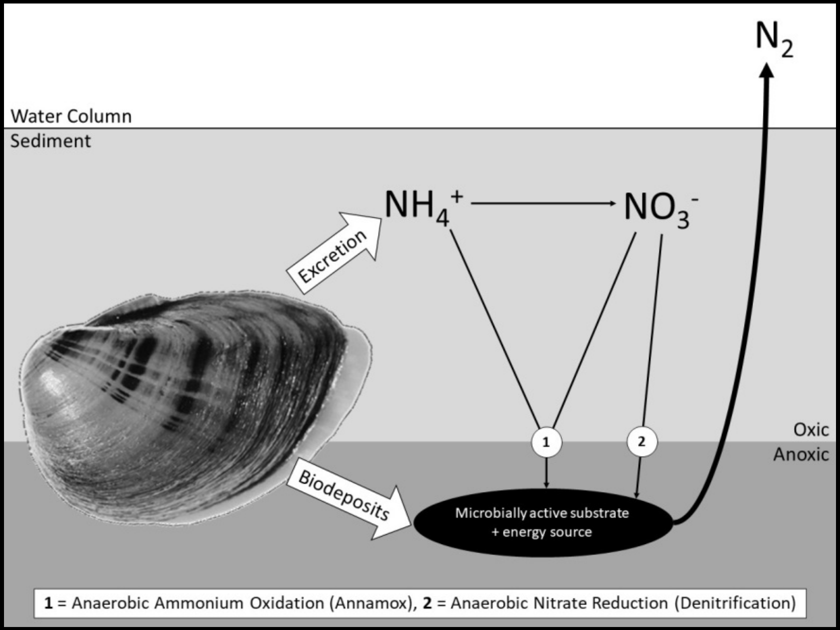




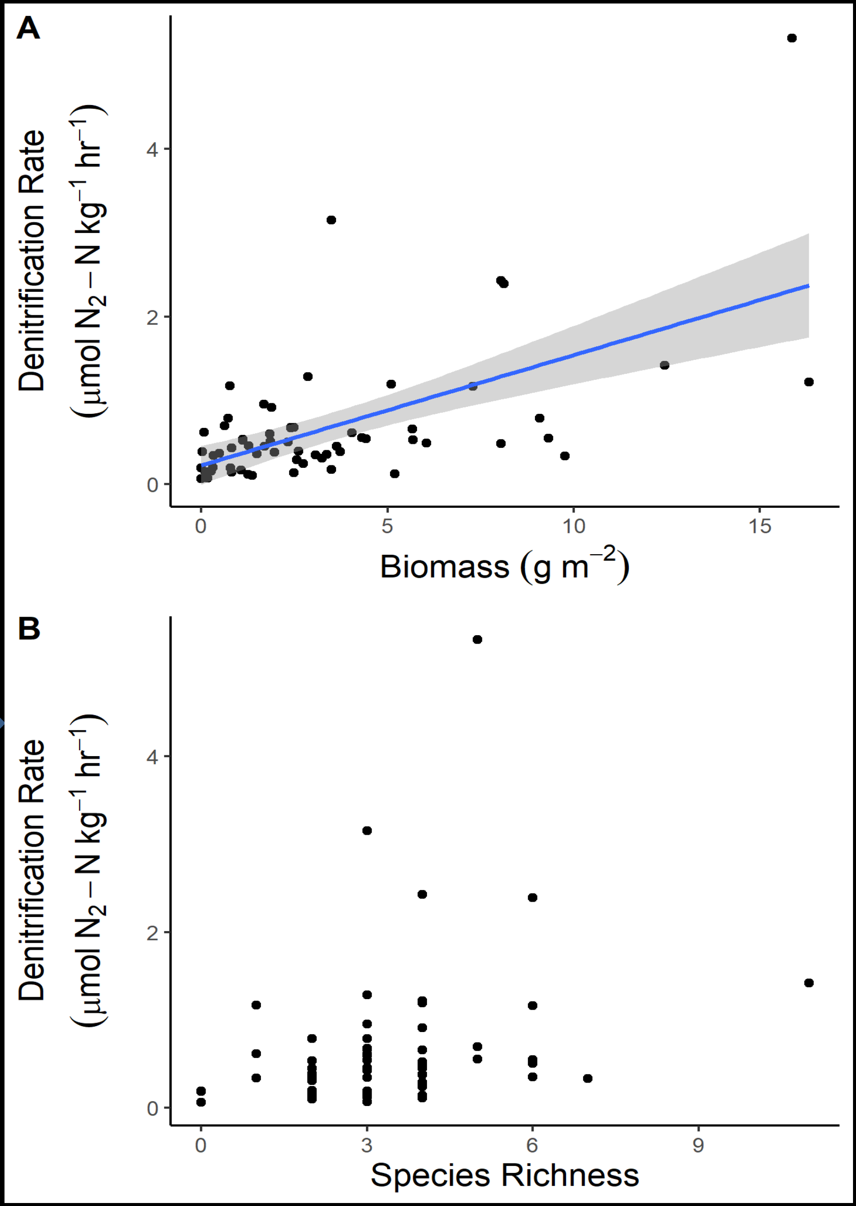


Trentman et al. 2018

Implications for Removal of N -> Denitrification



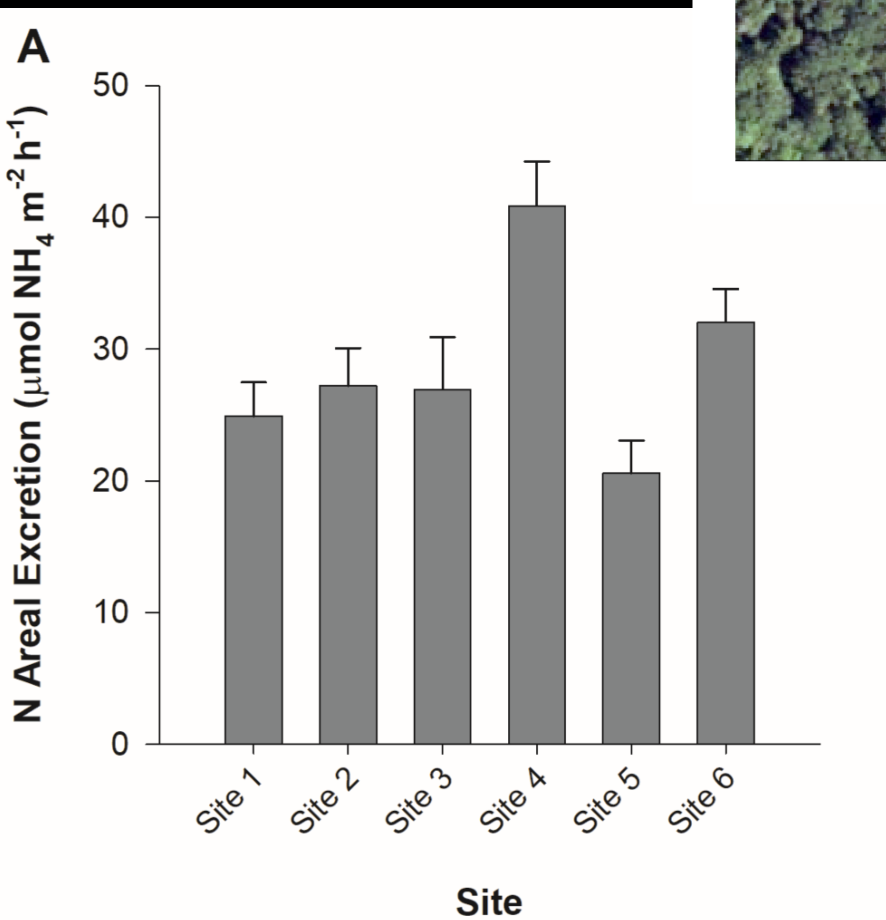
Field study

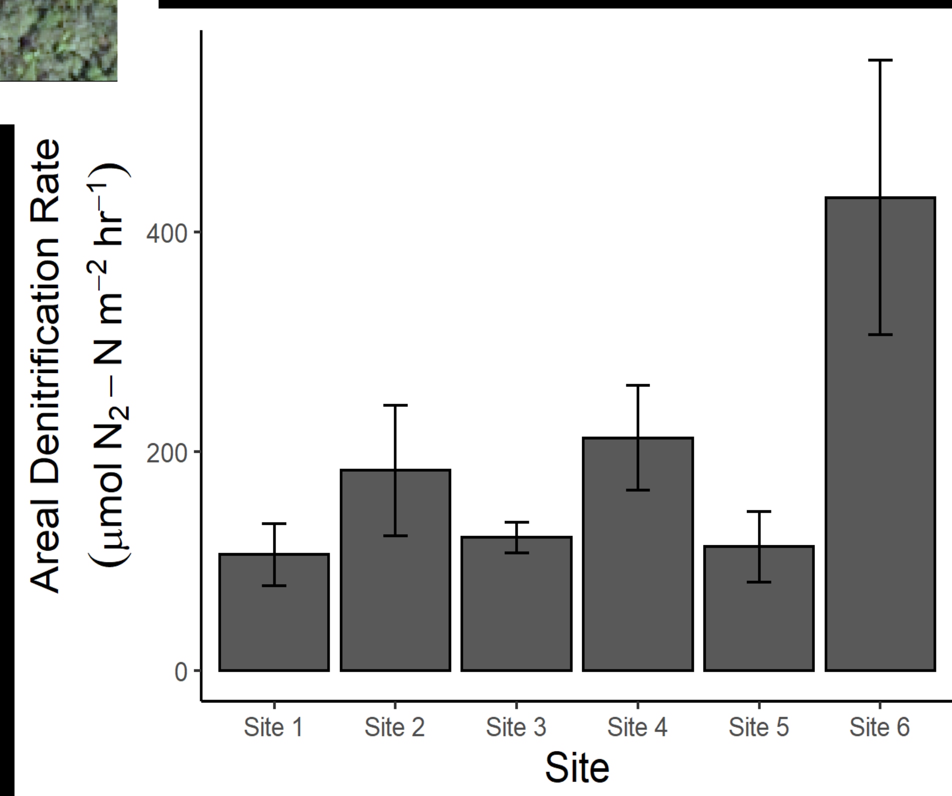


Want to better understand functional trait effects

Atkinson et al., *In prep*

Implications for Removal of N -> Denitrification

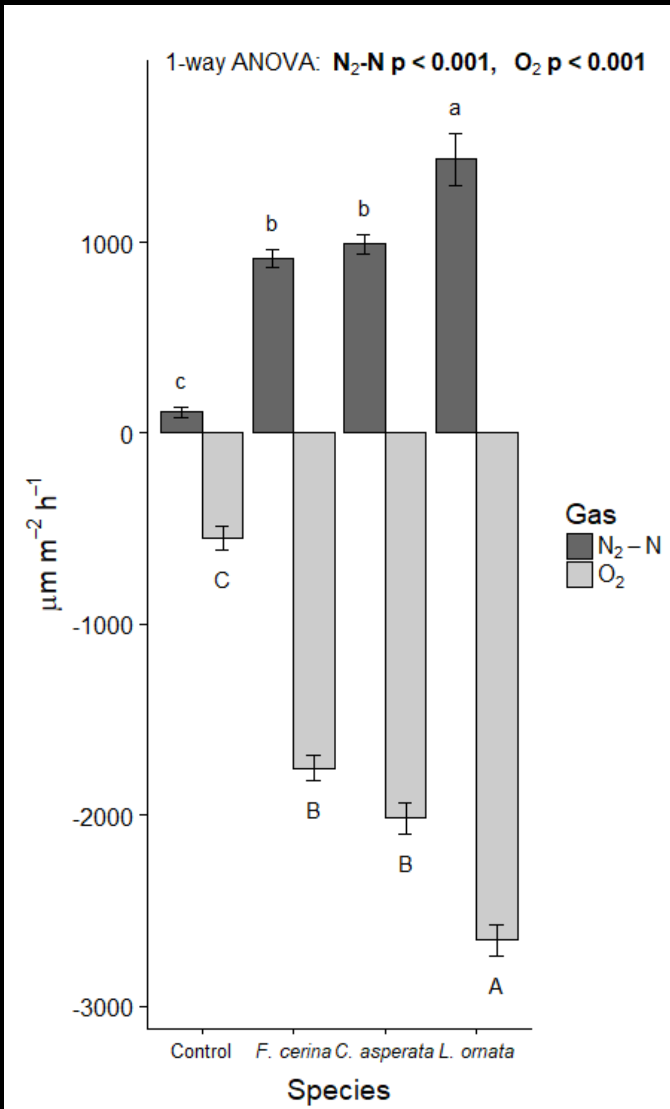


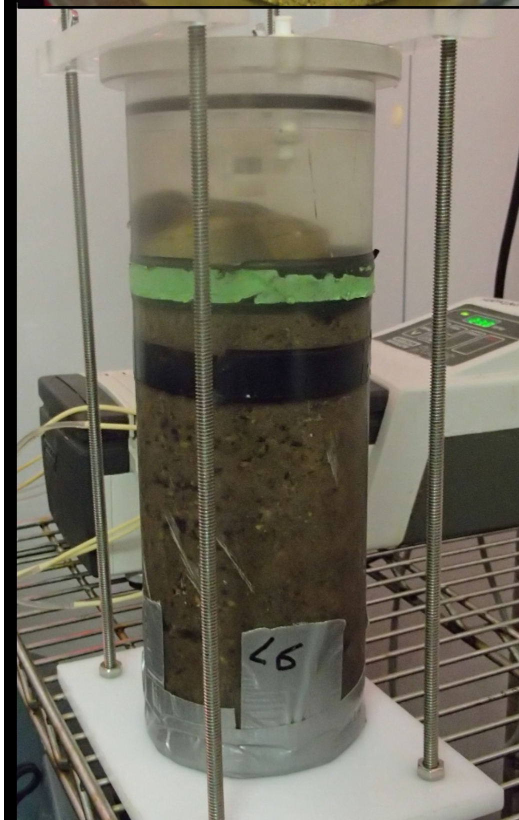


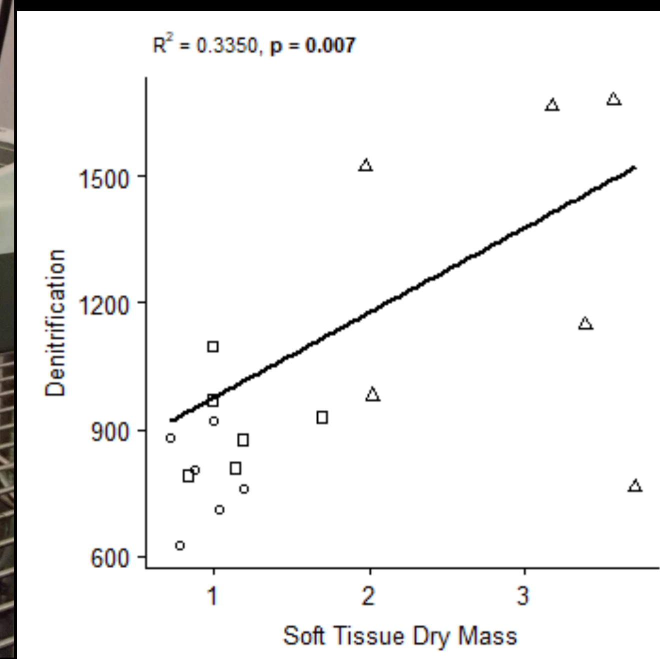
Atkinson et al., *In prep*

Lab Experimental Approach: Chamber Incubations

Gas Flux

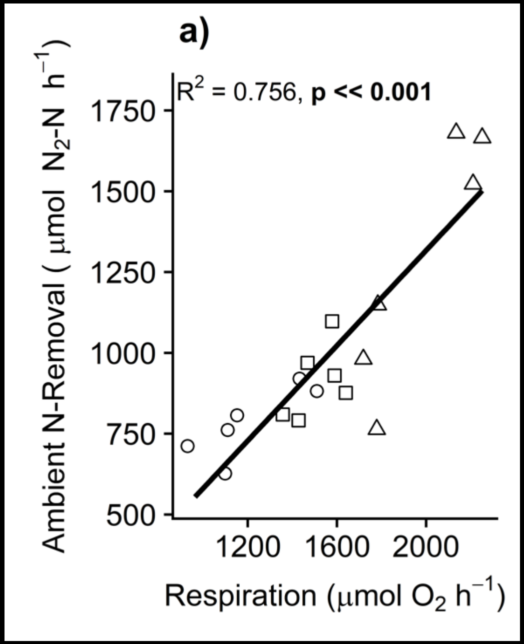






Nickerson, Mortazavi, Atkinson, 2019 *(Biogeochemistry)*

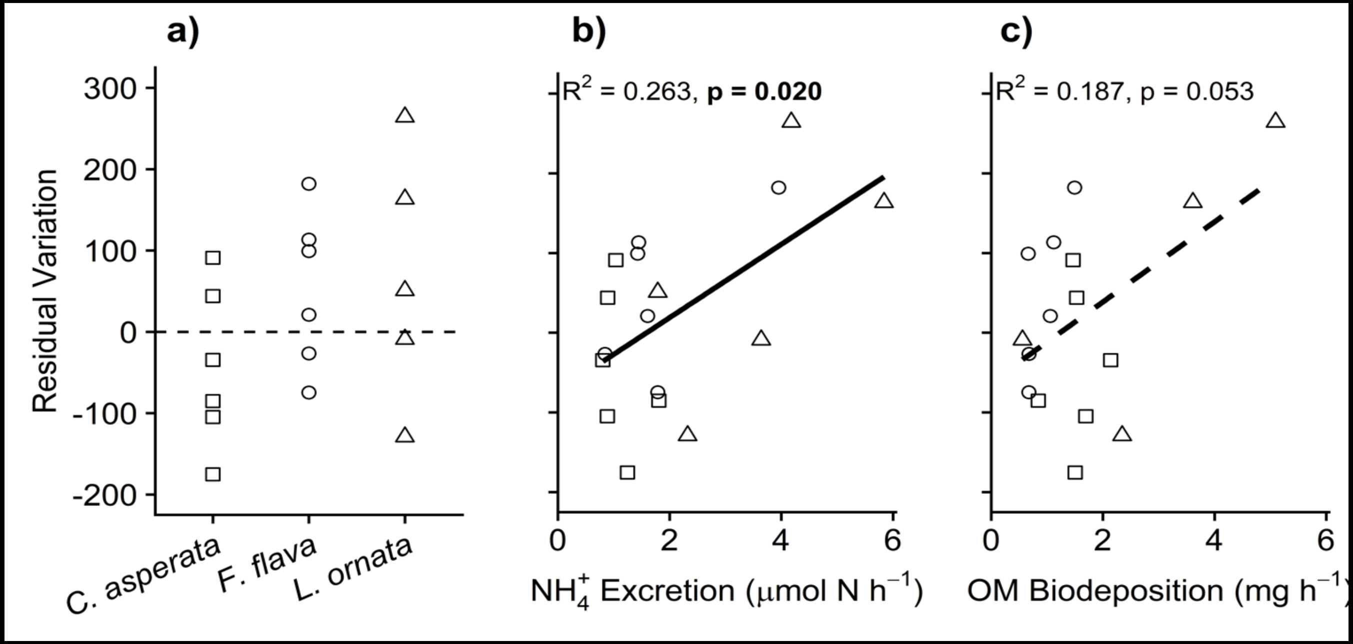
Lab Experimental Results: Chamber Incubations



After accounting for respiration….

Nickerson, Mortazavi, Atkinson, 2019 *(Biogeochemistry)*

Lab Experimental Results: Chamber Incubations

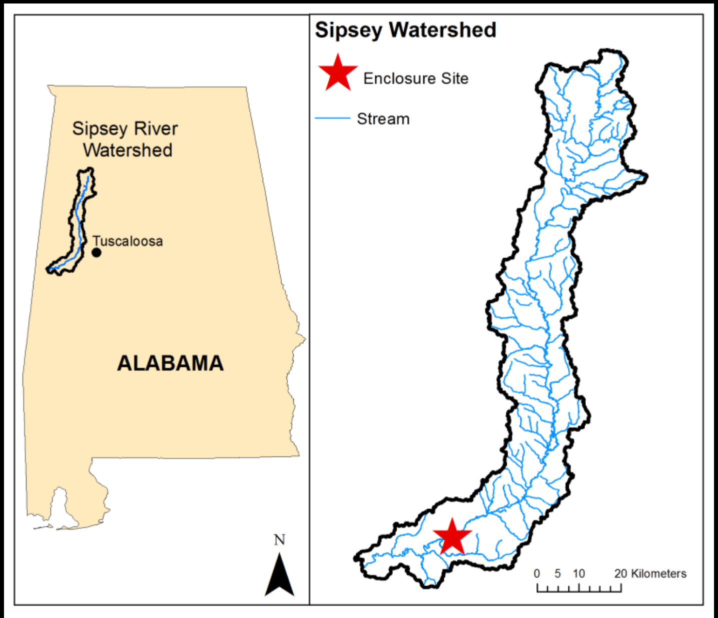


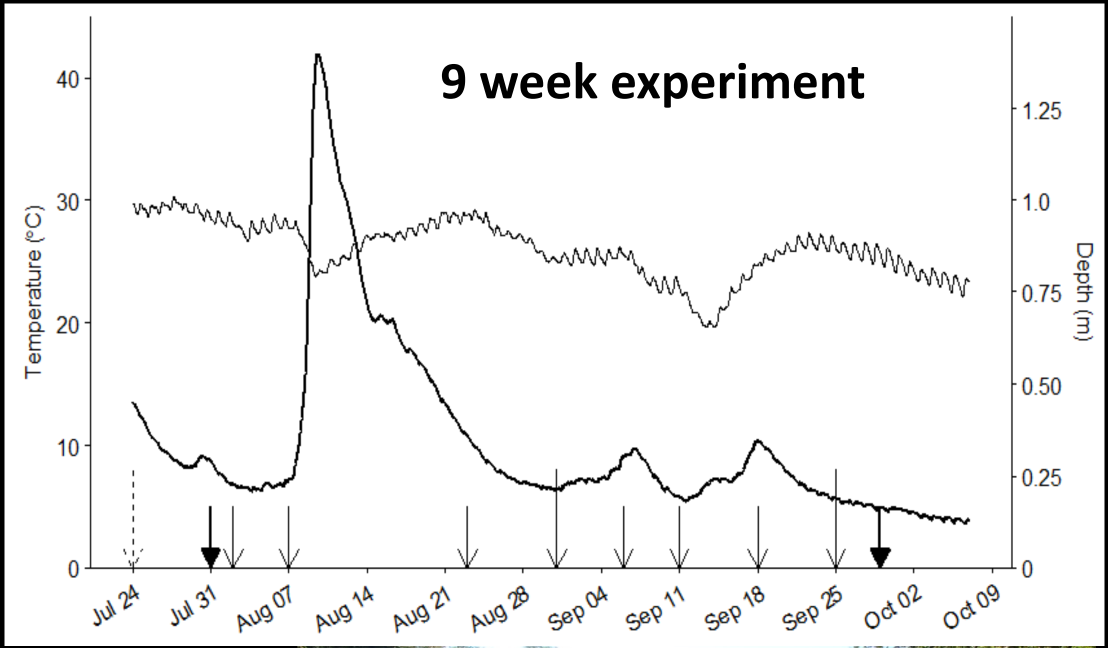
<u>Conclusions</u>:

- Significant positive relationship between NH_4^+ excretion (↑ reactive N) and denitrification
- Moderate positive relationship between OM biodeposition (↑ substrate) and denitrification

Nickerson, Mortazavi, Atkinson, 2019 *(Biogeochemistry)*

Field Experimental Approach

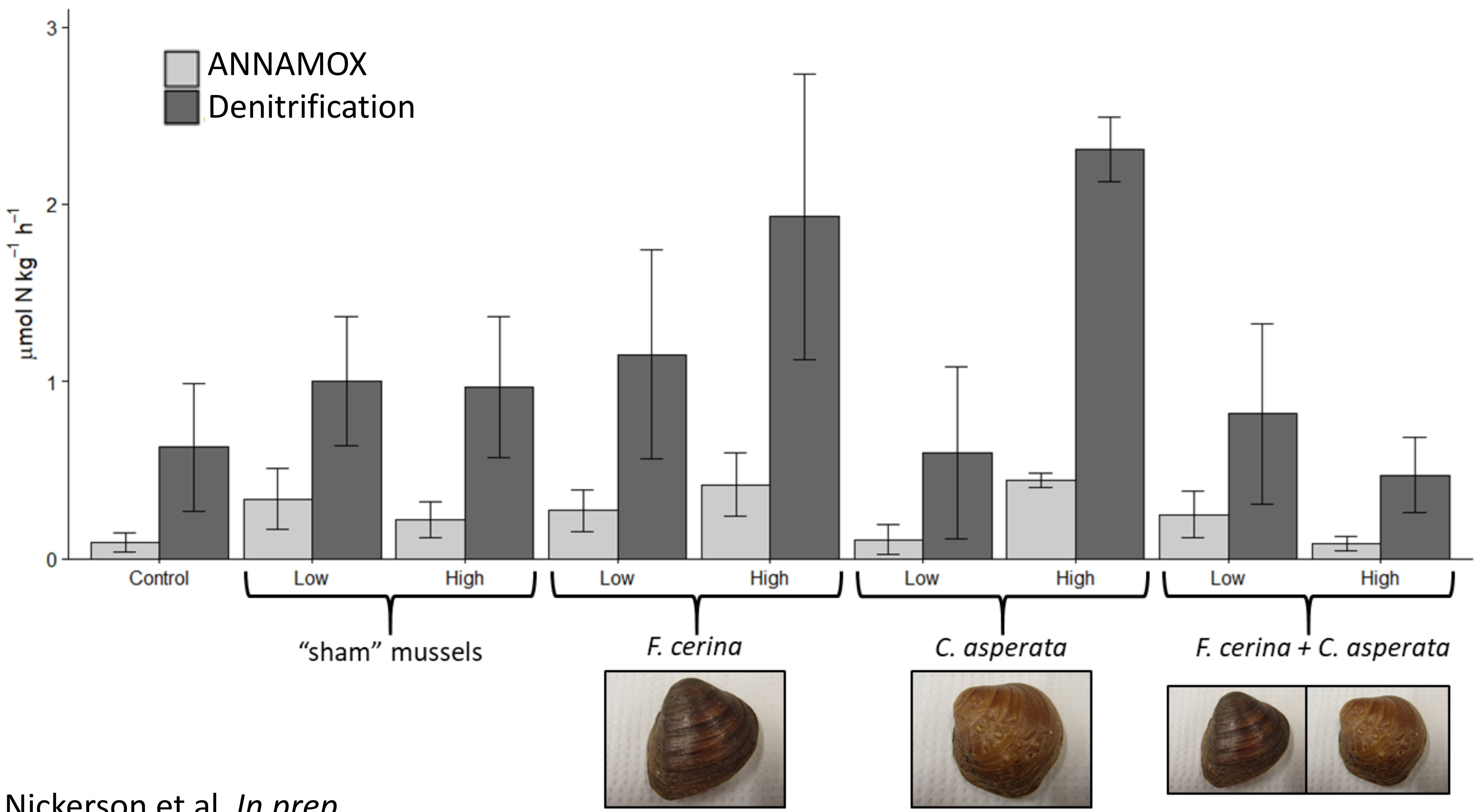




Field Experimental Results

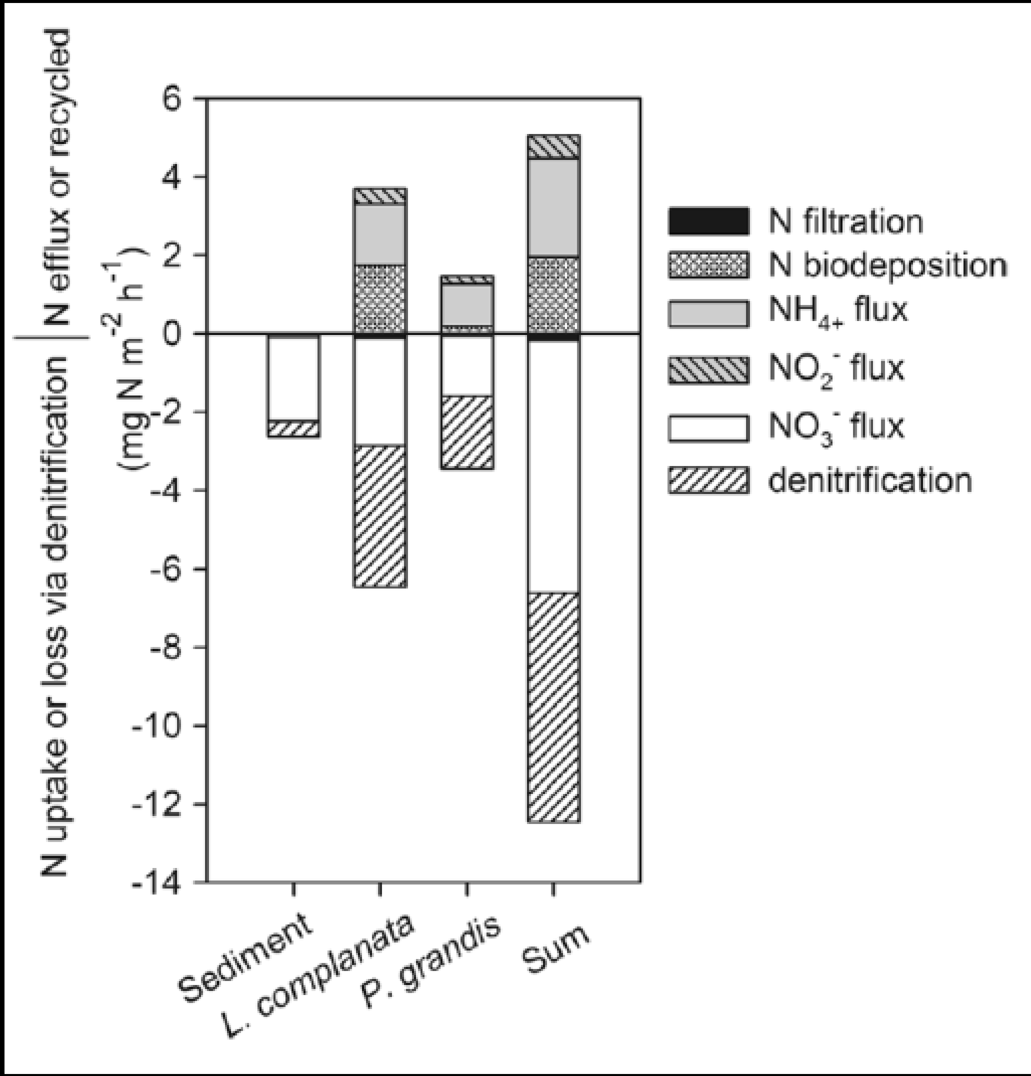
Results of 2-Way ANOVA

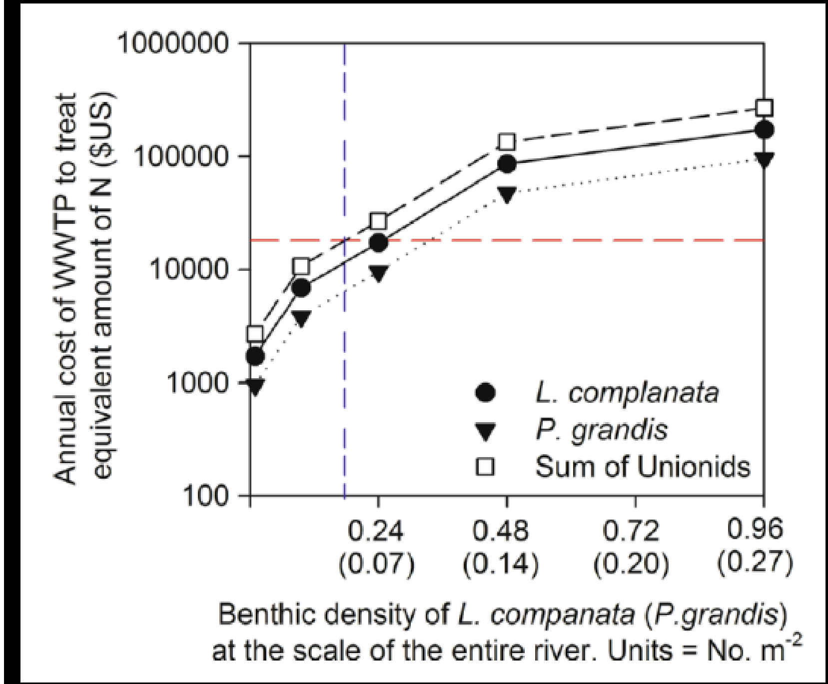
- Denitrification
  - Mussel Density ($F_{2,31}$ = 2.494, p = 0.1)
  - Species Diversity ($F_{1,31}$ = 4.806, **$p < 0.05$**)
  - Interaction ($F_{1,31}$ = 4.180, **$p < 0.05$**)
- ANNAMOX
  - Mussel Density ($F_{2,31}$ = 0.811, p > 0.4)
  - Species Diversity ($F_{1,31}$ = 2.167, p > 0.1)
  - Interaction ($F_{1,31}$ = 4.386, **$p < 0.05$**)



Nickerson et al. *In prep*

Implications for Removal of N -> Denitrification

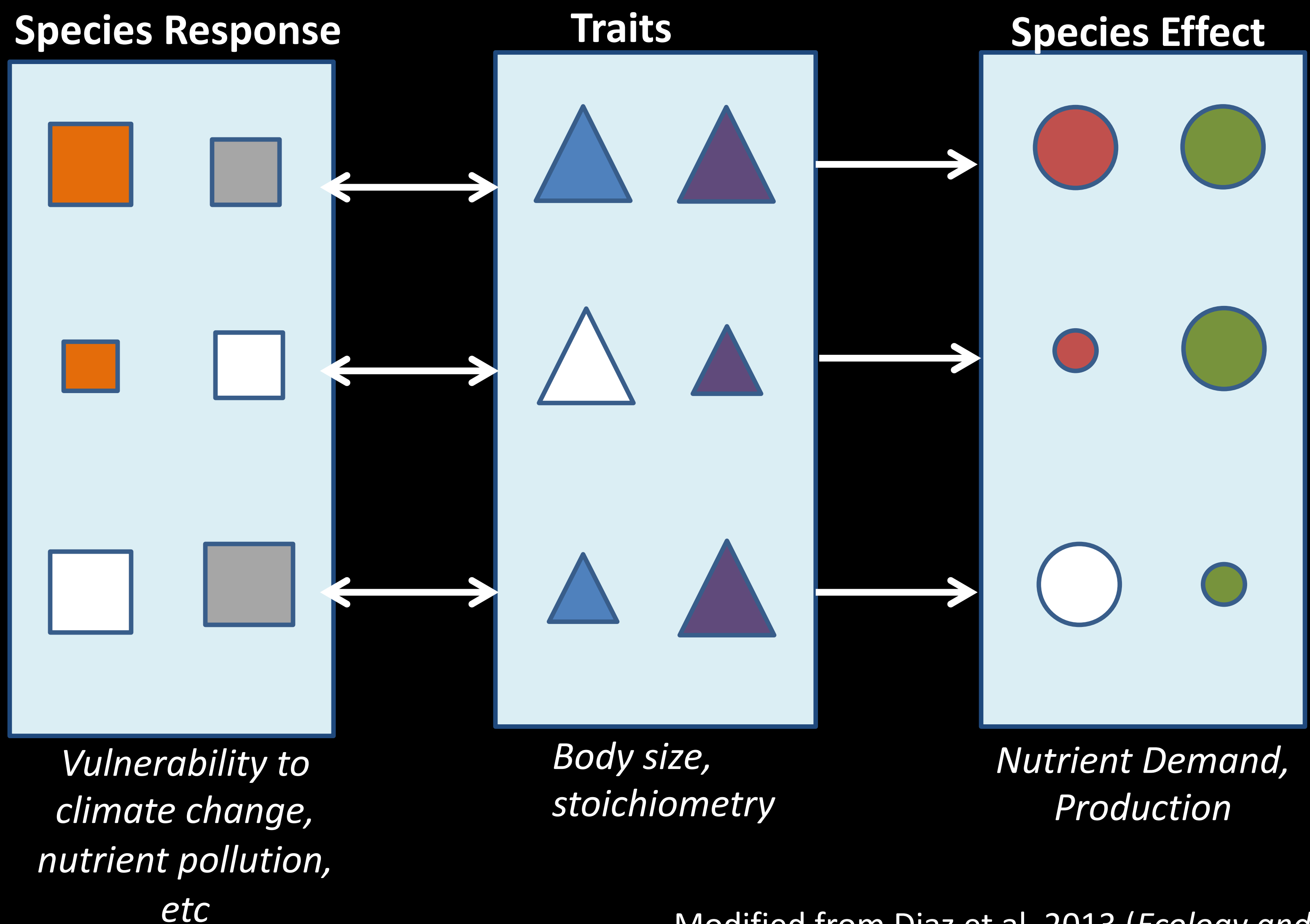




Contribute ~$266k of N loss per year in the East Branch DuPage River.

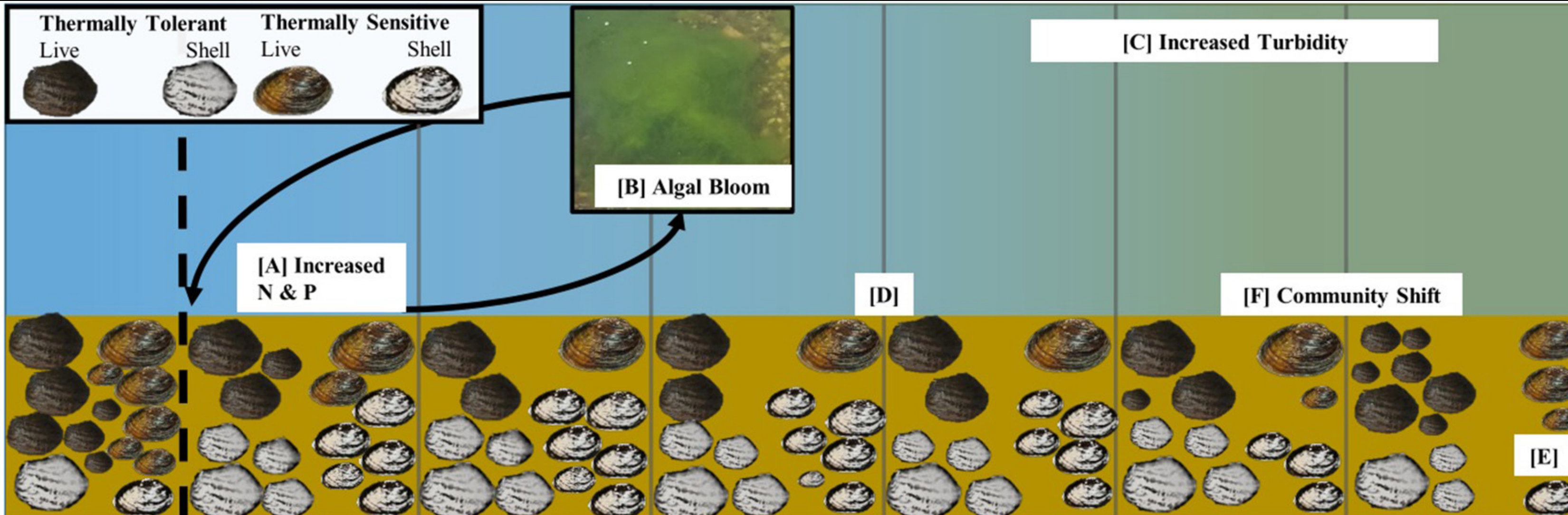
Hoellein et al. 2017 (*Biogeochemistry*)

Can we link functional traits to species' responses to abiotic conditions to understand ecosystem vulnerability and predict species losses and consequential declines in ecosystem function?



Modified from Diaz et al. 2013 (*Ecology and Evolution*)

Mussel decline leads to long-term loss in function

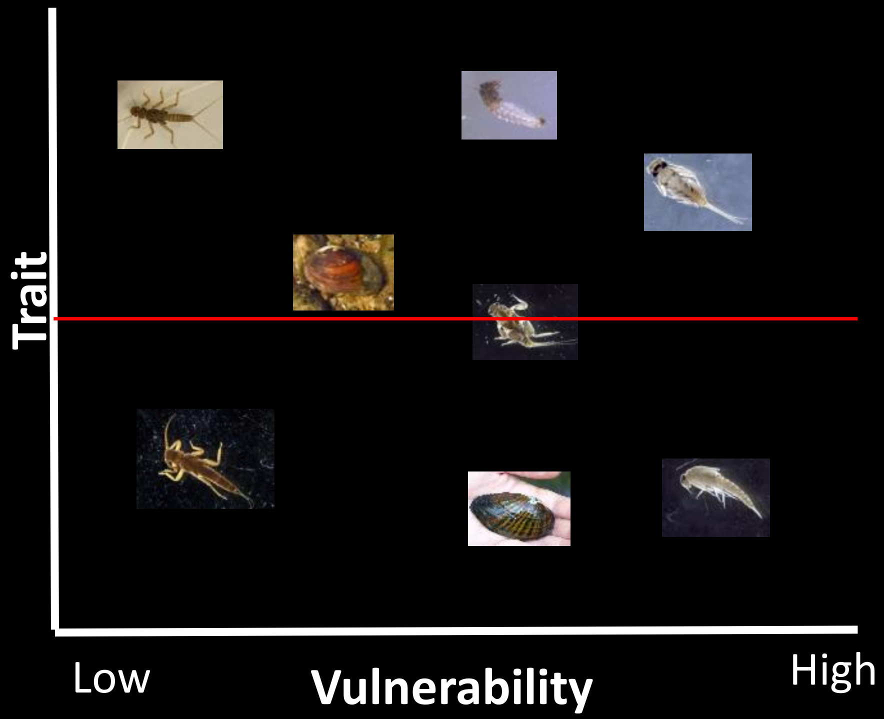


	PRE MASS MORTALITY[a,b]	HOURS	DAYS	WEEKS	MONTHS	YEARS	DECADES
BIOFILTRATION	~5,200 L h^{-1} m^{-2}	Reduced	[B] Reduced biofiltration, paired with increased nutrients, lead to algal blooms[a,c,d]		[C] Potentially altered biofiltration capacity & timing, due to community change		
NUTRIENT REGENERATION	~345 µmol N m^{-2} h^{-1} ~26 µmol P m^{-2} h^{-1}	[A] Increased N & P in the water column[e] & the interstitial space[f]	Increased N & P in the interstitial space[f]			Loss of nutrient capacitance* & shift of excretion stoichiometry because of the homogenized community and reduced biomass	
			[D] Loss of nutrient capacitance, due to individuals lost[g]				
NUTRIENT STORAGE	~47 g N m^{-2} ~4.8 g P m^{-2}	Soft tissue storage reduced while shell is stable[g]			[E] Shells begin dissolving, slowly releasing nutrients into the water column[h]		Storage reduced until biomass completely rebounds
HABITAT	~28 ind. m^{-2} ~5 species m^{-2}	Increased interstitial spaces from shells without tissue			[E] Decreased habitat heterogeneity of mussels & mussel shells[i]		More homogenous benthos

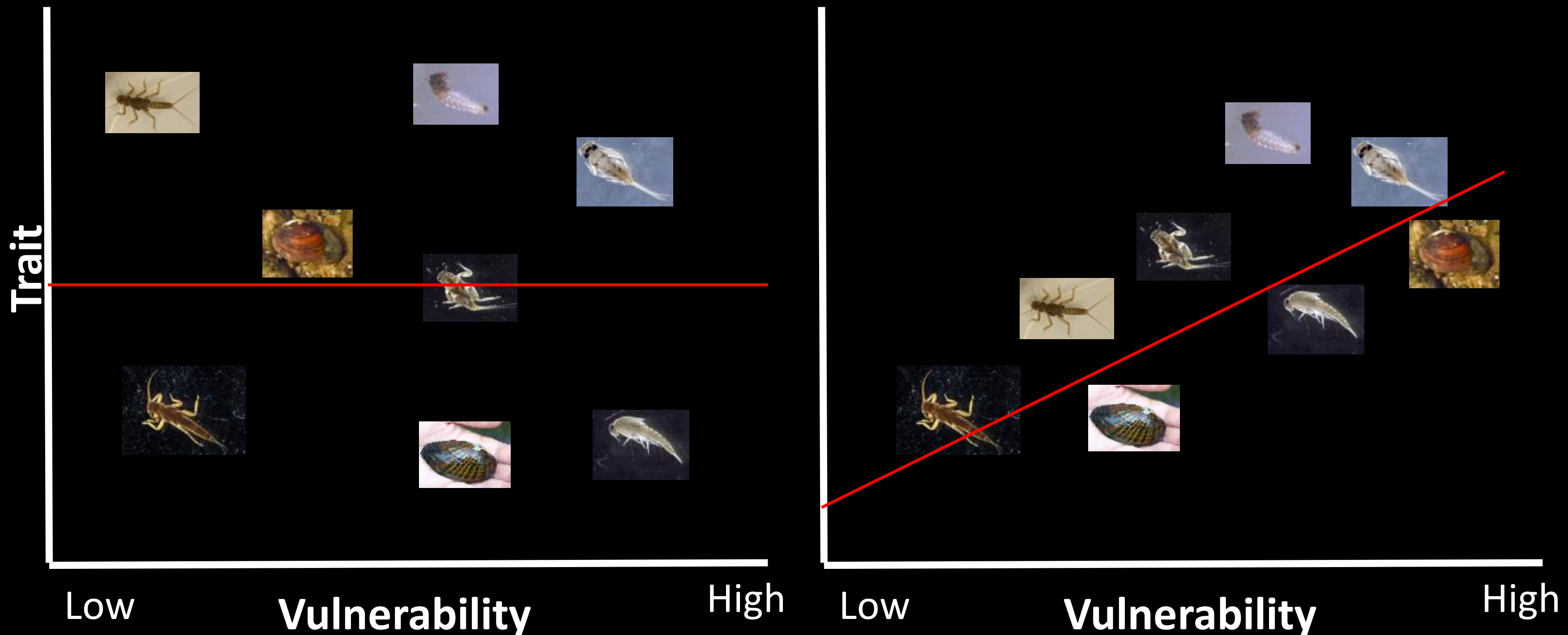
What is the cost?

DuBose, Atkinson, Vaughn, & Golladay, 2019 (*Front. Ecol. Evol.*)

Can we link functional traits to species' responses to abiotic conditions to understand ecosystem vulnerability?



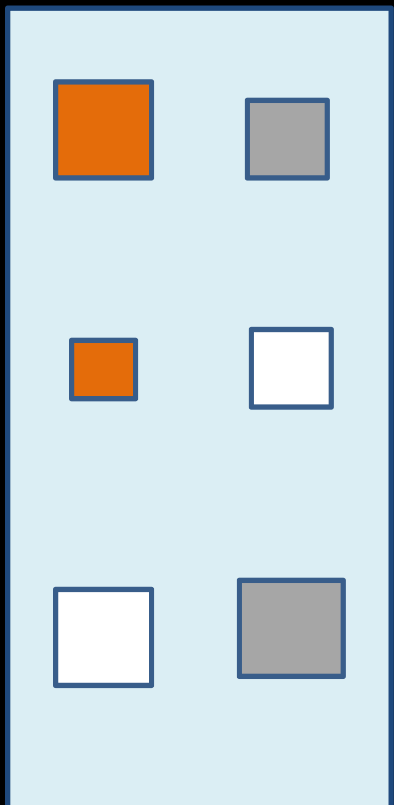
Can we link functional traits to species' responses to abiotic conditions to understand ecosystem vulnerability?



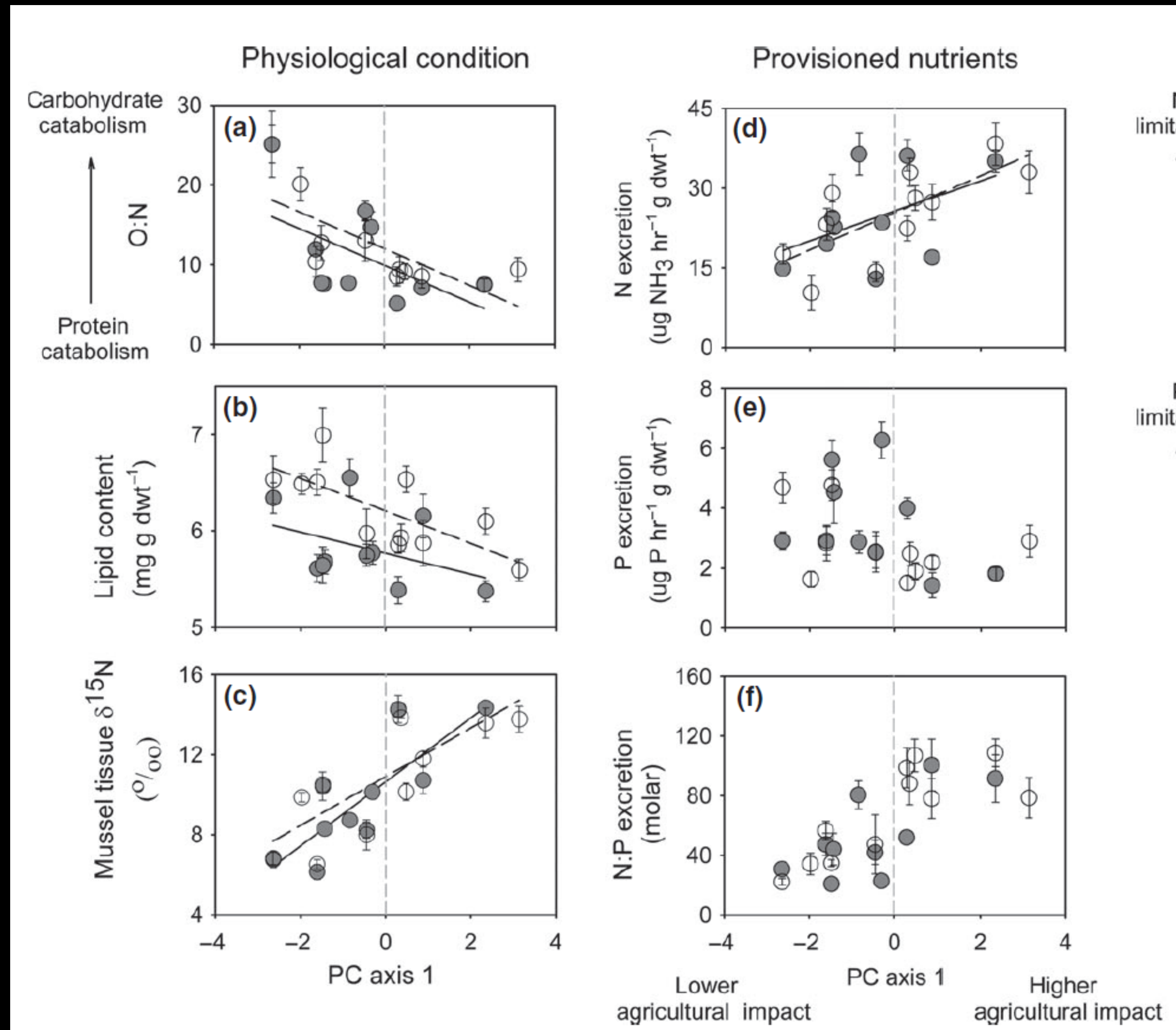
Essential to determine for future management strategies.

Vulnerable to Land Cover Alteration

Species Response



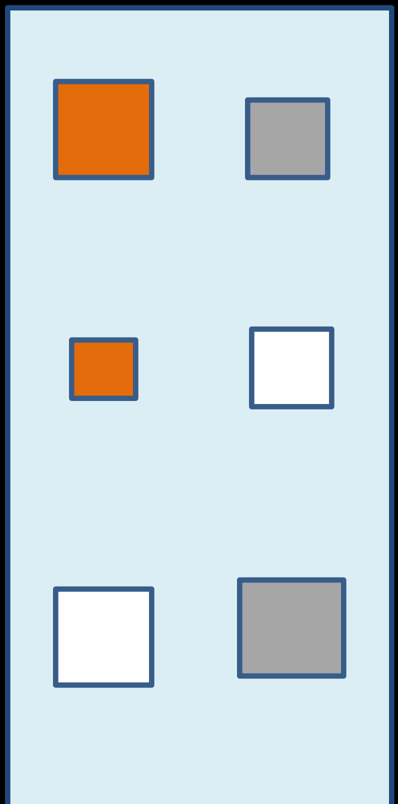
Vulnerability to climate change, nutrient pollution, etc



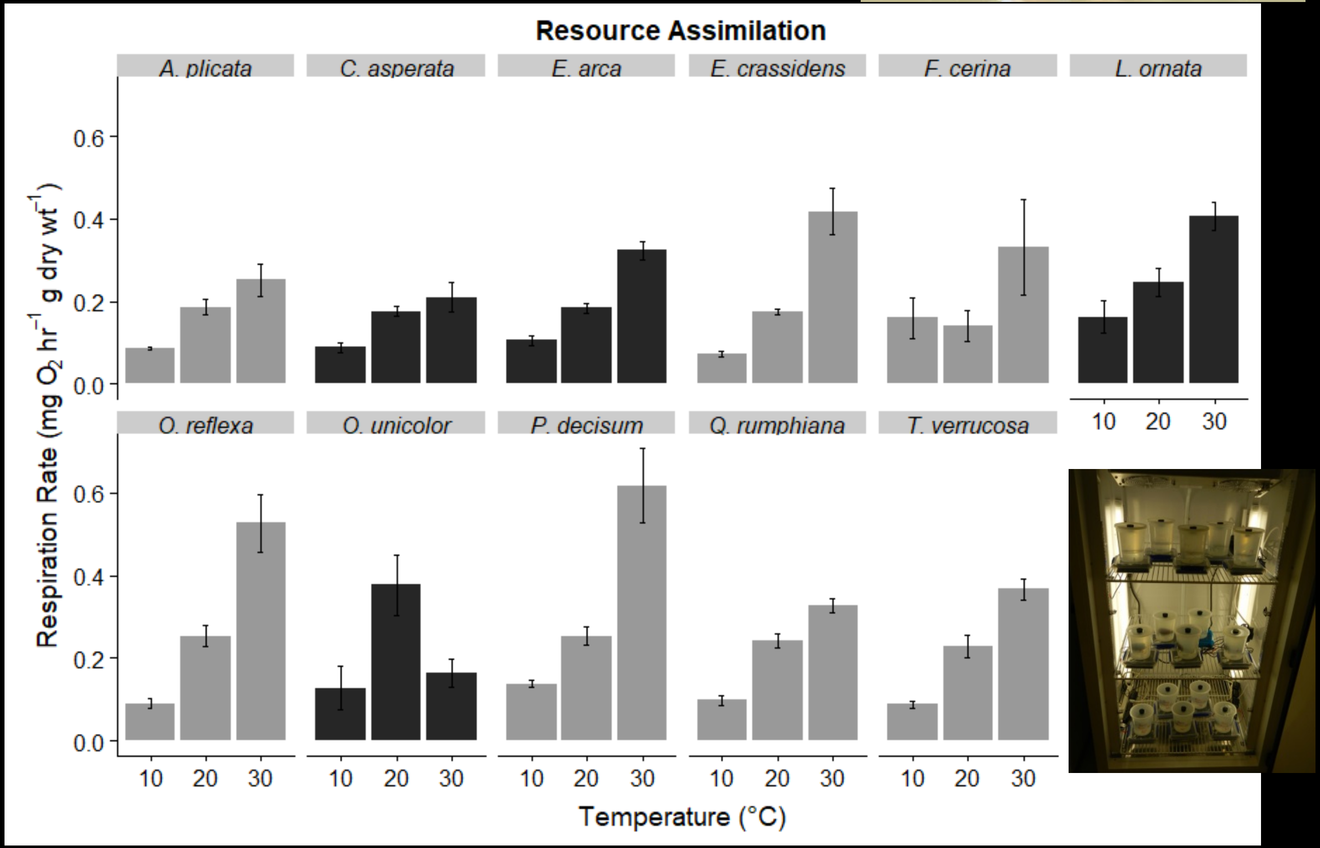
Spooner et al. 2013 (*Ecology Letters*)

Can we link traits to species responses to abiotic conditions to understand ecosystem vulnerability?

Species Response



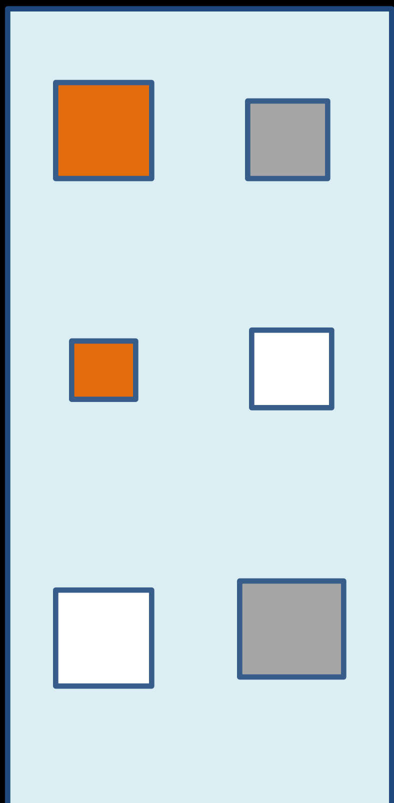
Vulnerability to climate change, nutrient pollution, etc



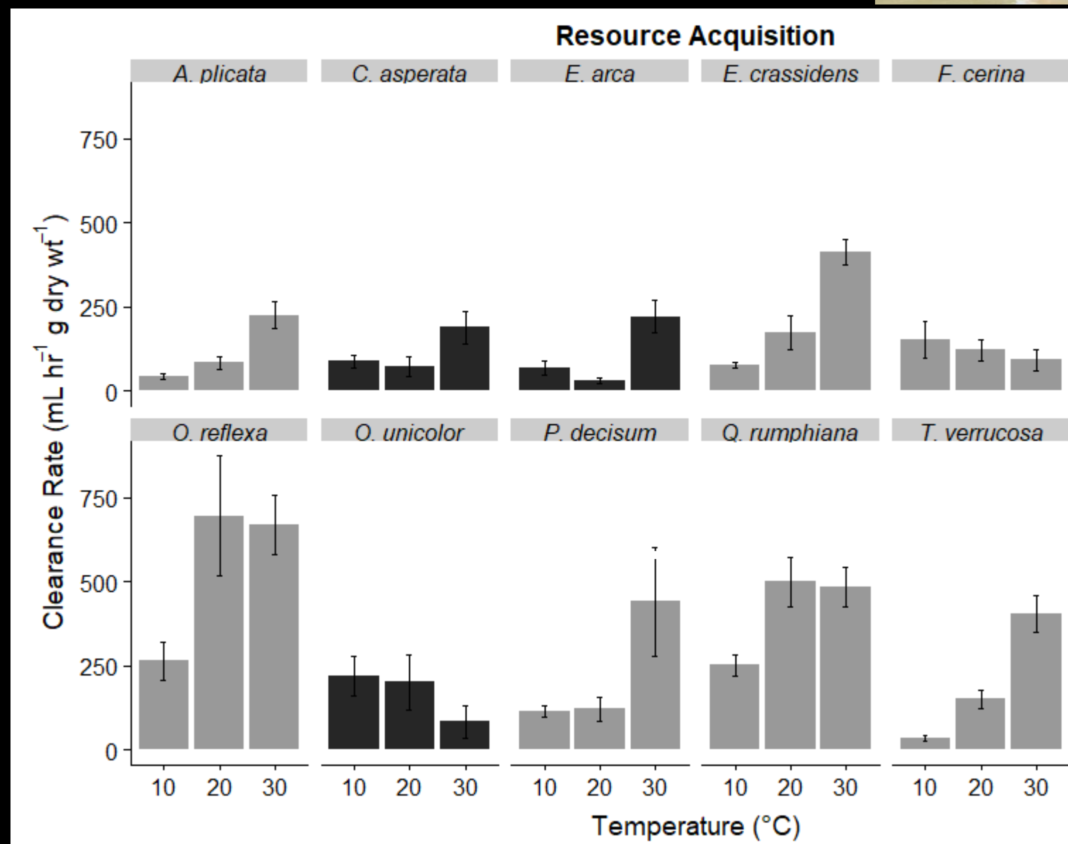
van Ee, Johnson, Atkinson, *In prep*

Can we link traits to species responses to abiotic conditions to understand ecosystem vulnerability?

Species Response



Vulnerability to climate change, nutrient pollution, etc



van Ee, Johnson, Atkinson, *In prep*

Closing Thoughts

Despite mussels occupy the same family and functional feeding group, there are distinct species-specific differences.

Mussels, through both direct and indirect effects, enhance nutrient retentiveness in streams

Strategies employed for using them as tools for management and ecosystem services provisioning will be need to be diverse.

Also, need to consider genetic variation as management strategies move forward.

Acknowledgements - collaborators

And a bunch of others!

Acknowledgements – the lab crew

ANY QUESTIONS?

More info

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Website: https://atkinsonlab.ua.edu

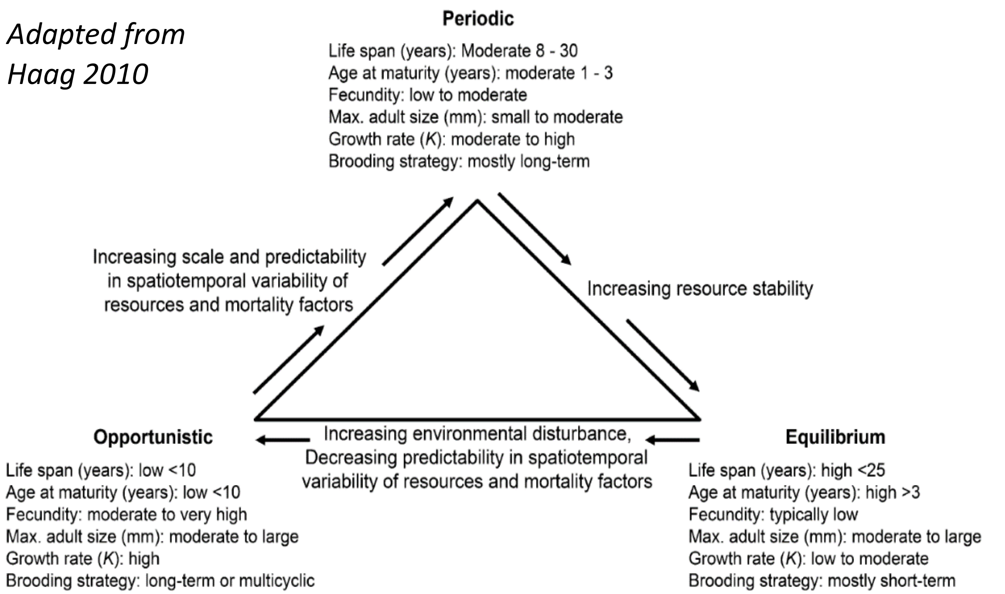
"Mussels are not dismissible, even by those who have little interest in the natural world. Their presence is a signature of healthy aquatic ecosystems, to which they contribute as living water filters."

- E.O. Wilson

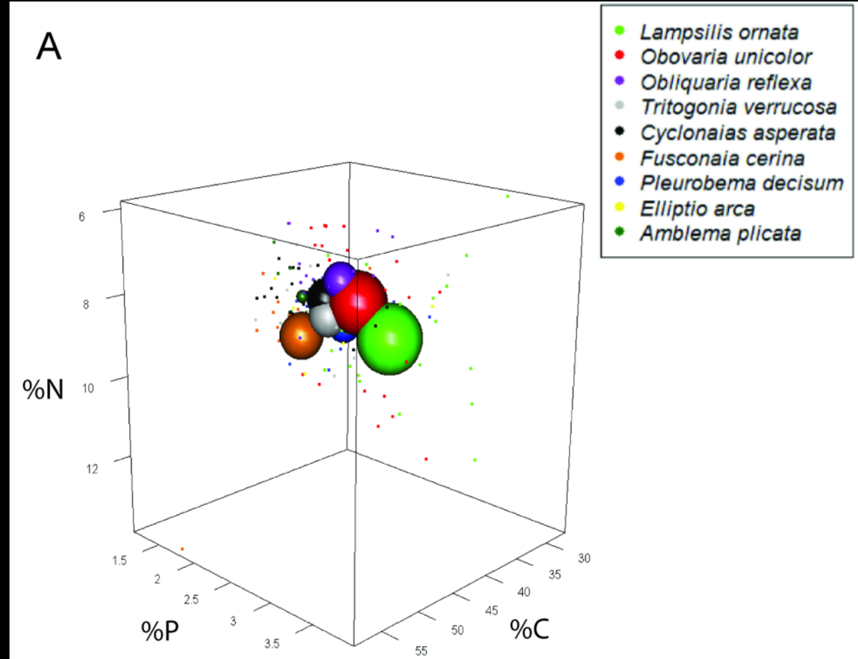
What's the mechanism?

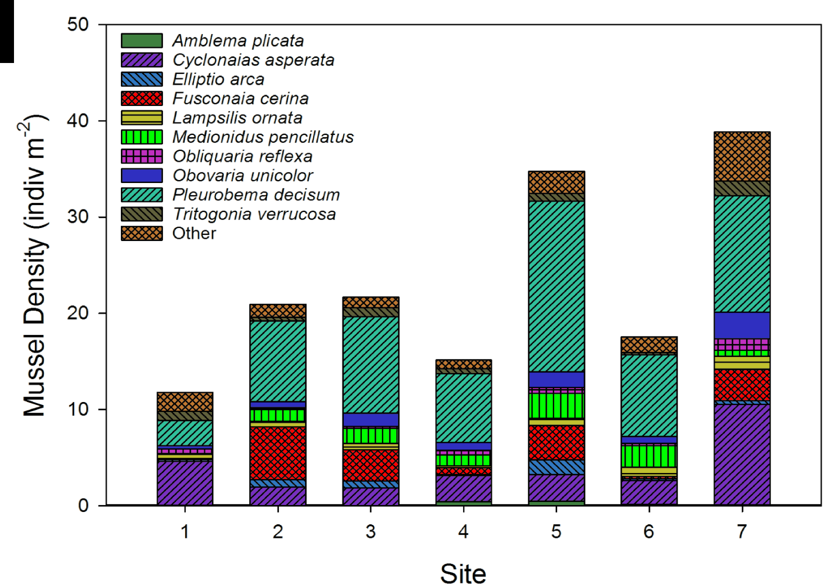
Dominant species are "equilibrium species" -> small niche volumes -> high niche partitioning. Suggests directional selection

Fast growing species – "periodic strategy" – large niche volumes



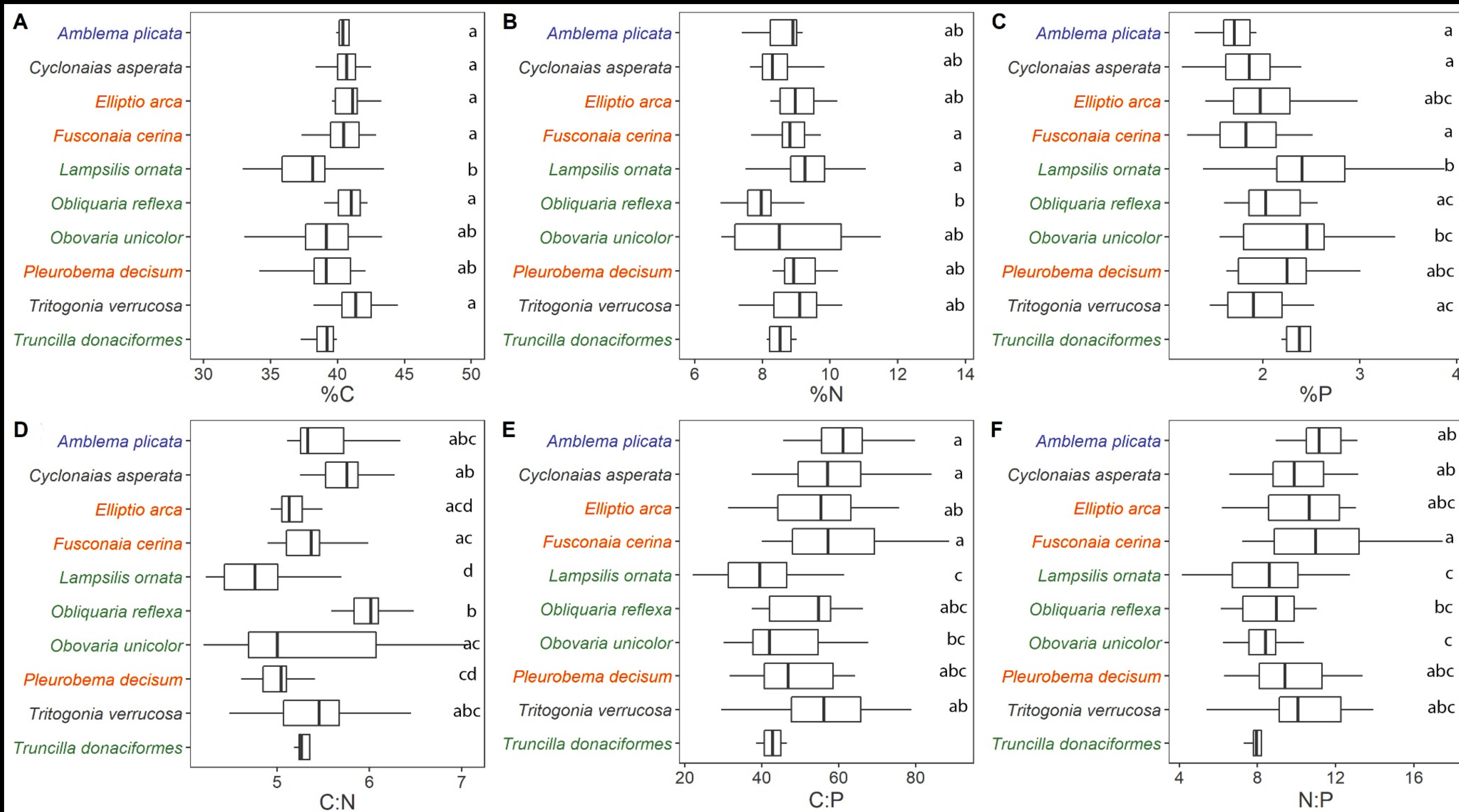
Adapted from Haag 2010





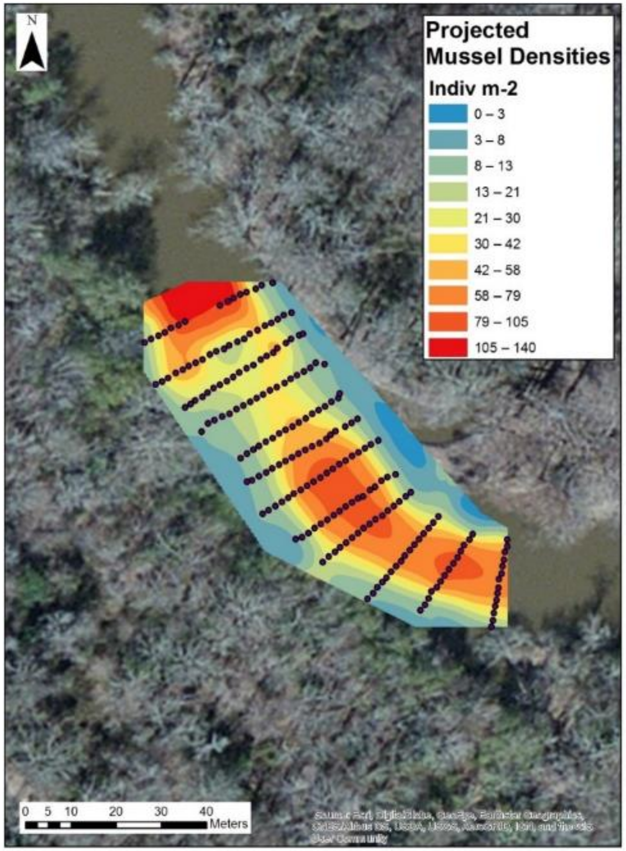
Atkinson, van Ee, Pfeiffer *In review*

Are species exhibiting storing nutrients differently?

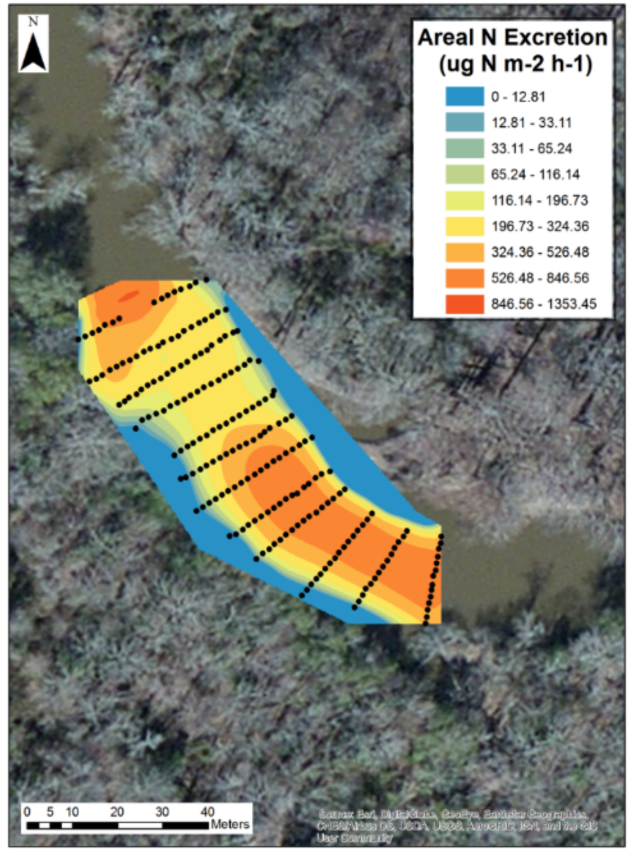








Densities



Areal N Excretion

Average = 35 indiv m^{-2}

Average = 369 $\mu g\ NH_4\text{-}N\ m^{-2}\ h^{-1}$

Biomass-corrected average N:P of Excretion = 18.2; Background water column N:P ~8.9

Some species doing more than what their biomass would suggest

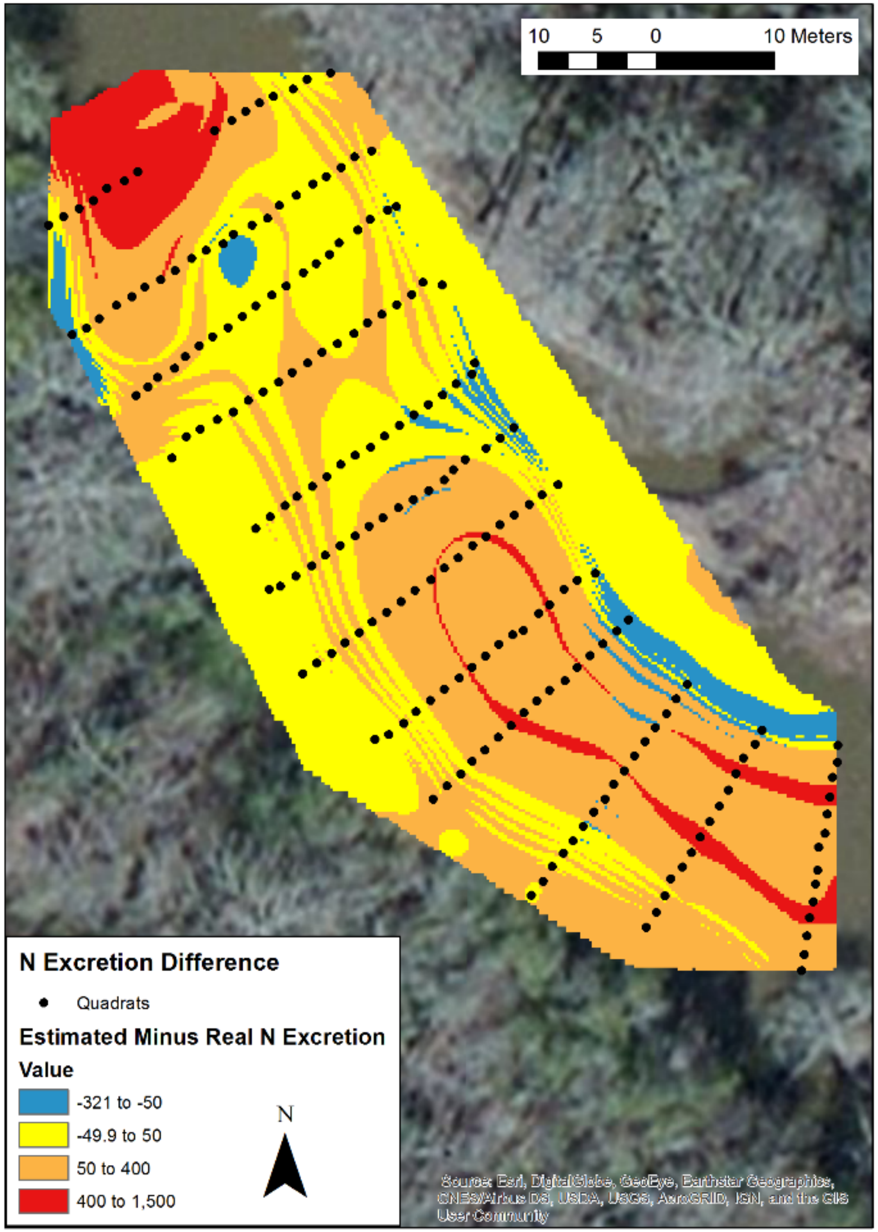
- Big contributors:
  - *Pleurobema decisum*
  - *Obovaria unicolor*

Do species matter?

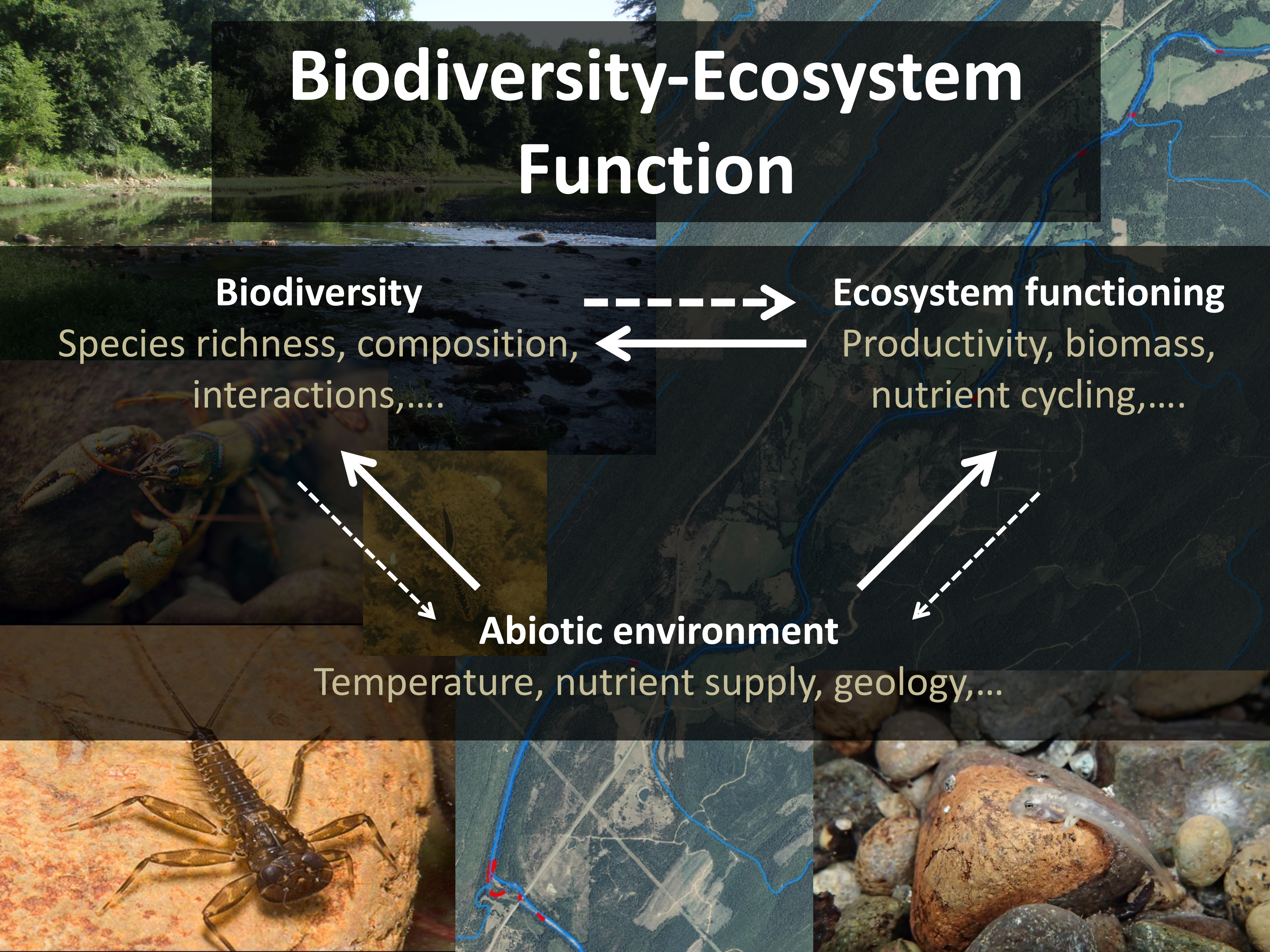
Applying a Average Excretion value versus the Species-Weighted

N Excretion

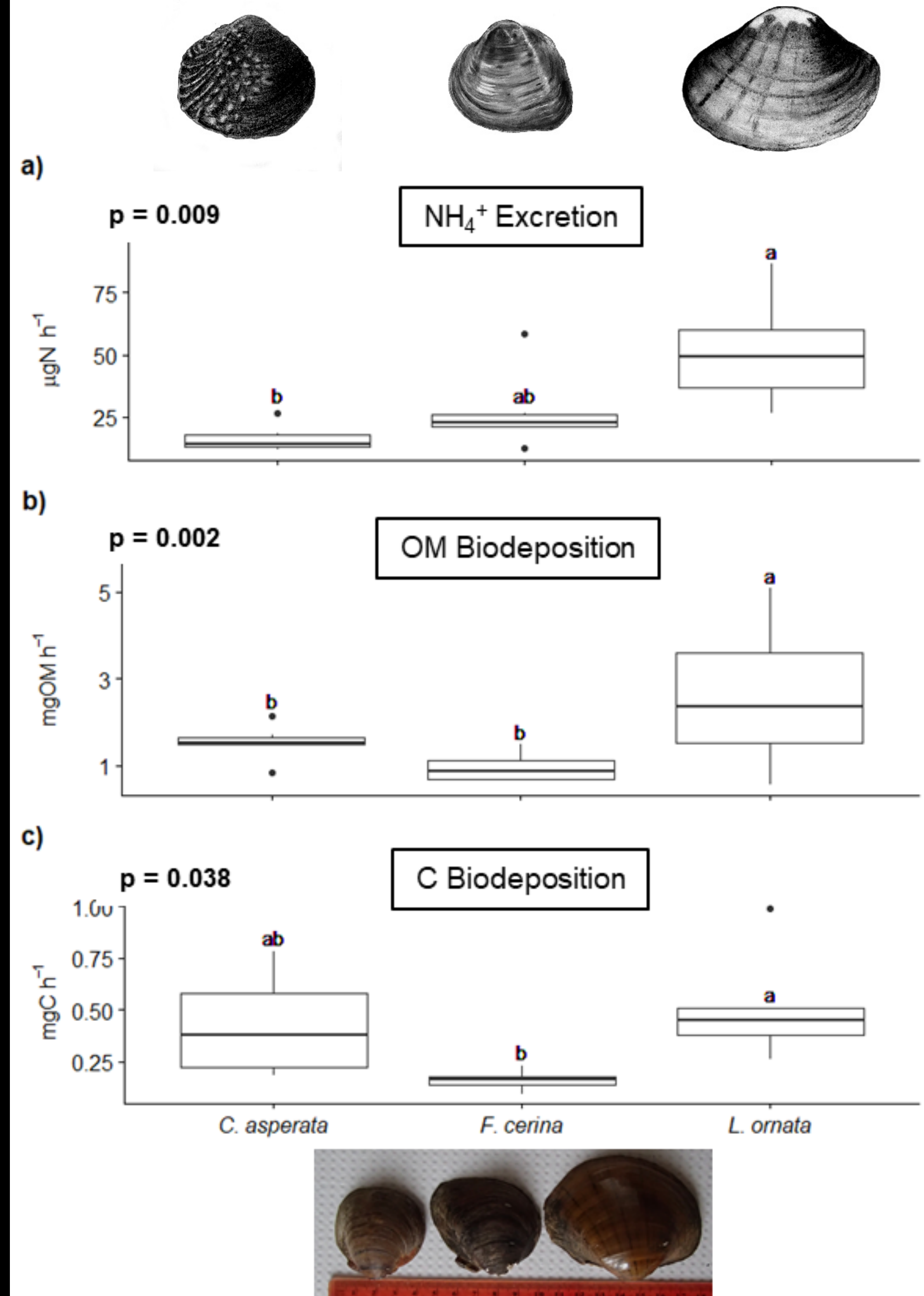
Accuracy	Percent Coverage
Underestimate	2.6
Good	43.2
Small Overestimate	46.5
High Overestimate	7.7



Mussel Species in Order of Relative Abundance	Phylogenetic Tribe	Conservation Status	Shell Morphology	Max Shell Length (mm) / Category	Max Age (years) in Sipsey[1]	Burial Preference	Thermal Sensitivity above 25°C
Pleurobema decisum	Pleurobemini	Federally endangered	Smooth	87 / Medium	45	High	unknown
Cyclonaias asperata	Quadrulini	stable	Pustules	64 / Medium	40	Medium	tolerant
Fusconaia cerina	Pleurobemini	stable	Smooth	74 / Medium	45	Medium	sensitive
Obovaria unicolor	Lampsilini	stable	Smooth	51 / Small	44	High	sensitive
Medionidus acutissimus	Lampsilini	Federally threatened	Ridged	44 / Small	5	High	unknown
Lampsilis ornata	Lampsilini	stable	Smooth	107 / Large	18	High	sensitive
Elliptio arca	Pleurobemini	AL state threatened	Smooth	112 / Large	32	High	unknown
Tritagonia verrucosa	Quadrulini	stable	Ridged	121 / Large	35	Low-Medium	tolerant
Obliquaria reflexa	Lampsilini	stable	Pustules	64 / Medium	20	Medium	OK - tolerant
Amblema plicata	Amblemini	stable	Ridged	110 / Large	55	Medium	OK - tolerant


Biodiversity-Ecosystem Function
Biodiversity
Species richness, composition, interactions,….
Ecosystem functioning
Productivity, biomass, nutrient cycling,….
Abiotic environment
Temperature, nutrient supply, geology,…

Species Traits Play a Role



Nickerson, Mortazavi, Atkinson, 2019
(Biogeochemistry)