Exploring the role of bottom-up provisioning by consumers across ecosystems

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Ocean Carbon and Biogeochemistry Workshop
28 June 2017

Acknowledgements

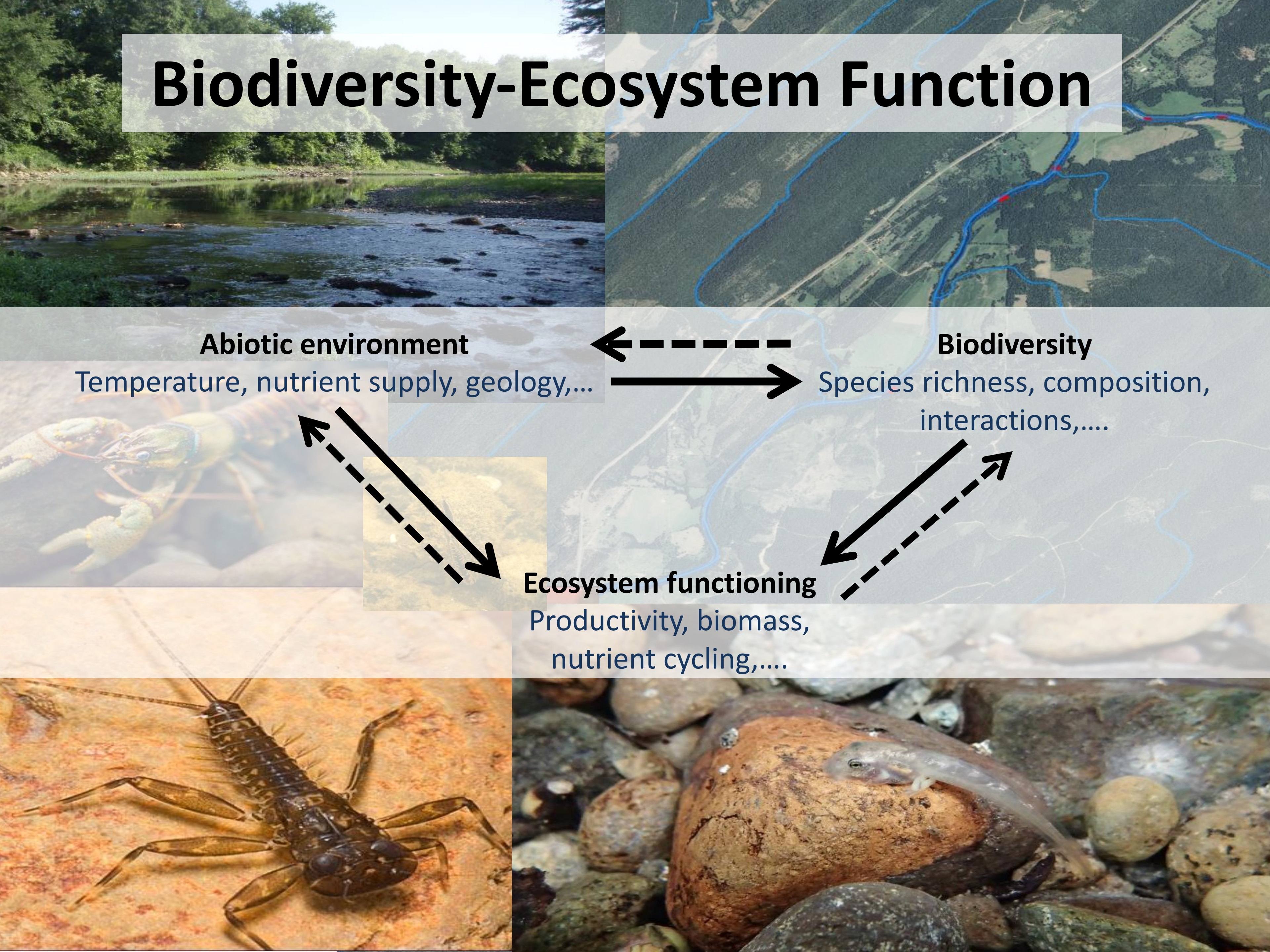
PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Linking biodiversity and ecosystems: towards a unifying ecological theory

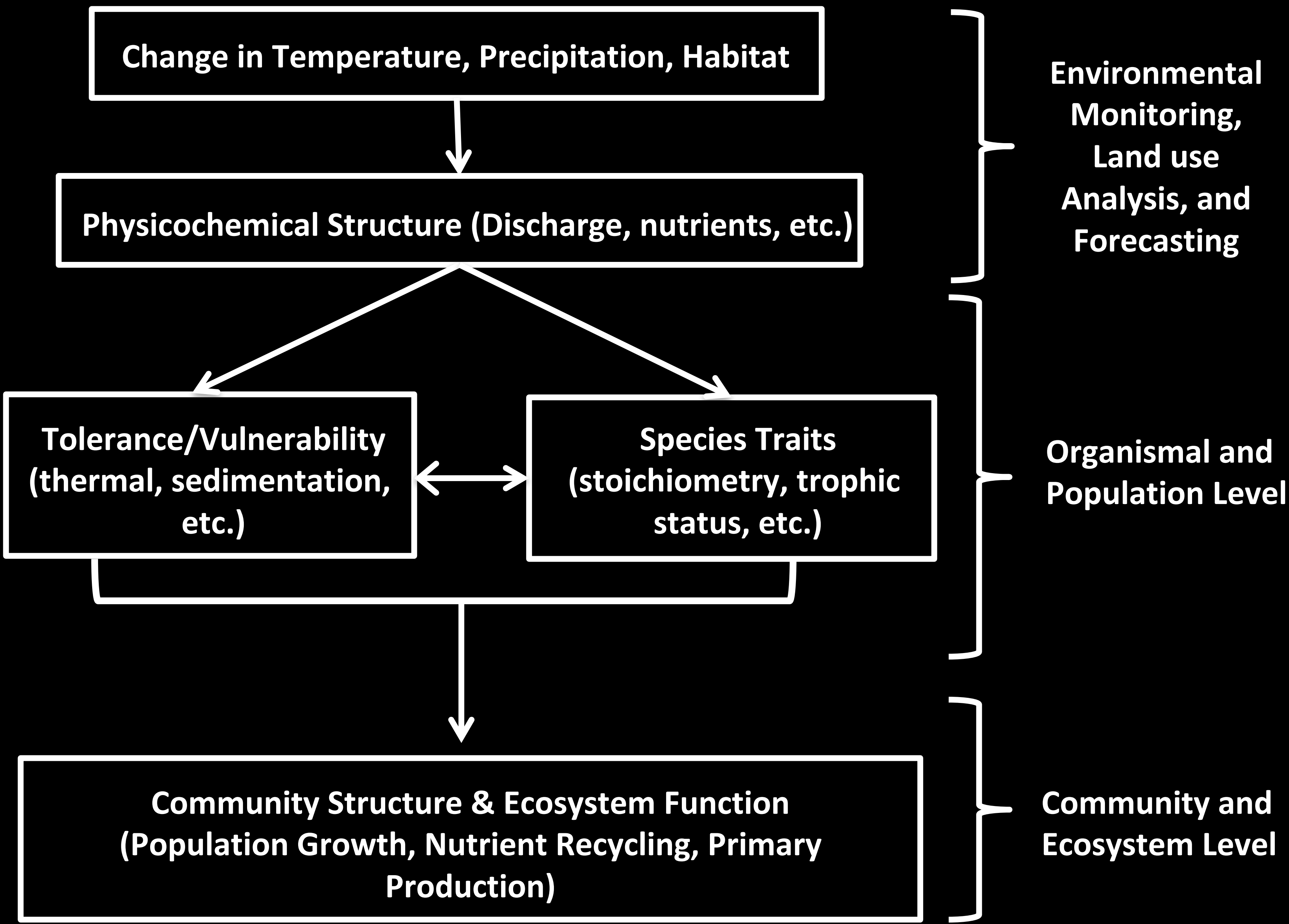
Michel Loreau

Phil. Trans. R. Soc. B 2010 **365**, 49-60

"A major future challenge is to determine how biodiversity dynamics, ecosystem processes, and abiotic factors interact."

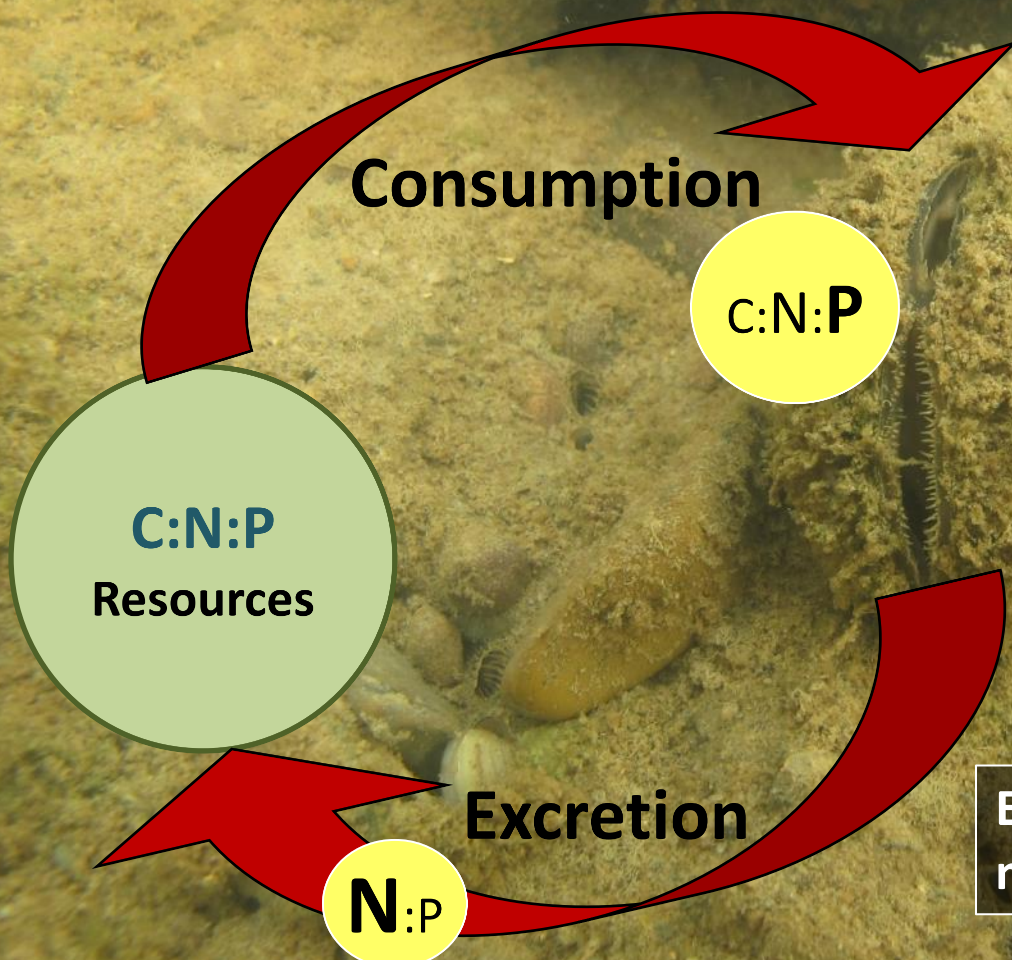

Biodiversity-Ecosystem Function
Abiotic environment
Temperature, nutrient supply, geology,…
Biodiversity
Species richness, composition, interactions,….
Ecosystem functioning
Productivity, biomass, nutrient cycling,….

Conducting ecological research across scales



Consumer-driven nutrient dynamics

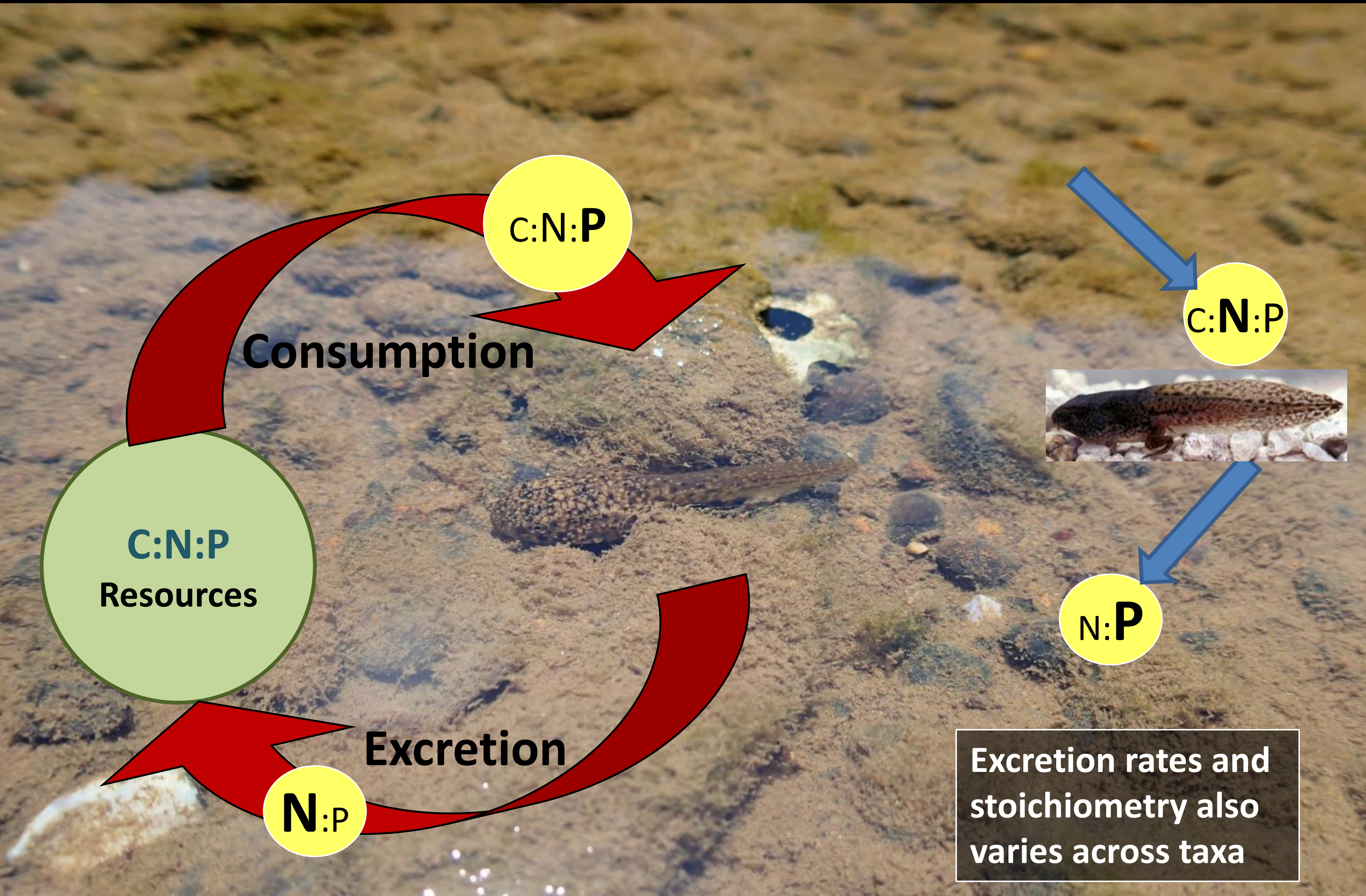
Excretion and egestion of nutrients are proportional to the ingestion of an element



Animals are considered stoichiometrically homeostatic and are storing nutrients.

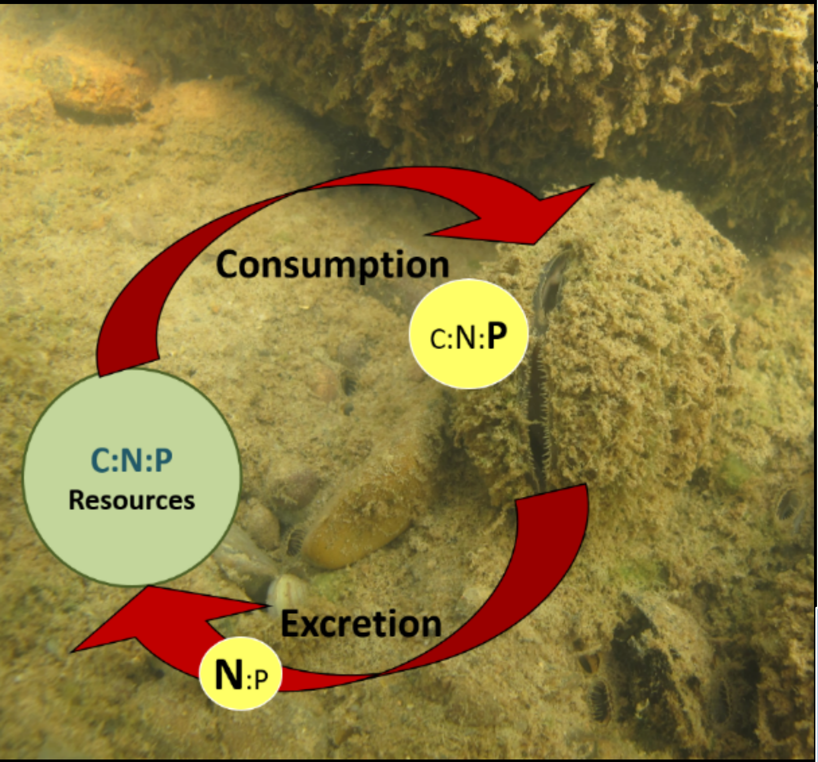
Excretion rates scale with mass and temperature

Consumer-driven nutrient dynamics

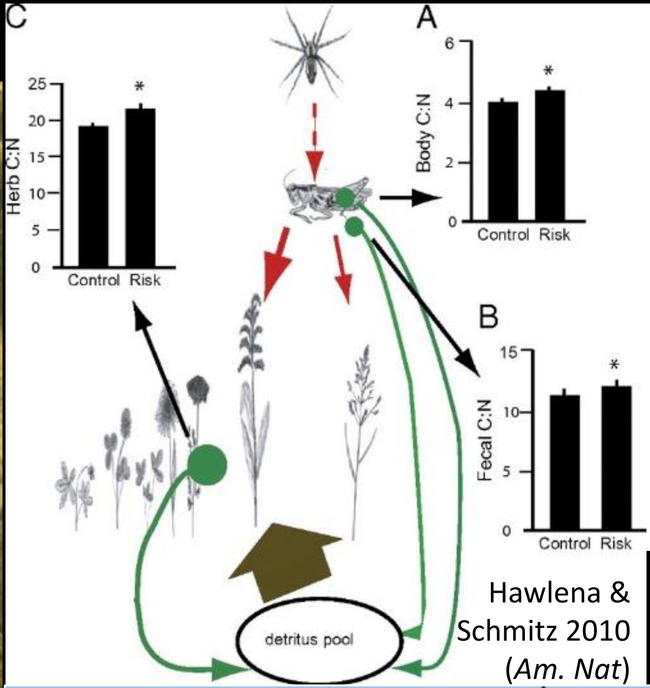


Consumer-Driven Nutrient Dynamics

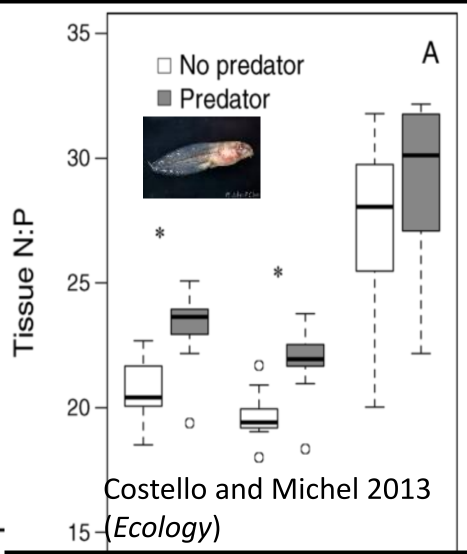
Direct Effects



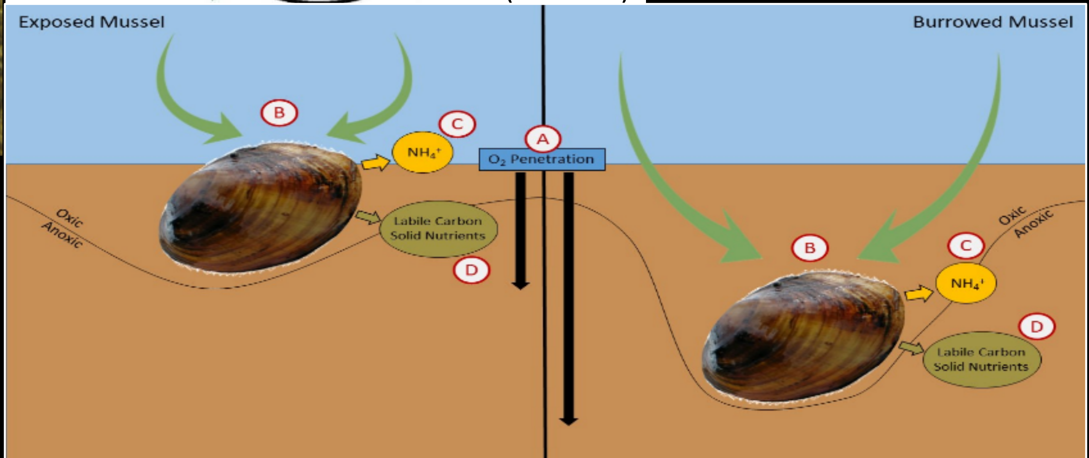
Indirect Effects



Hawlena & Schmitz 2010 (*Am. Nat*)

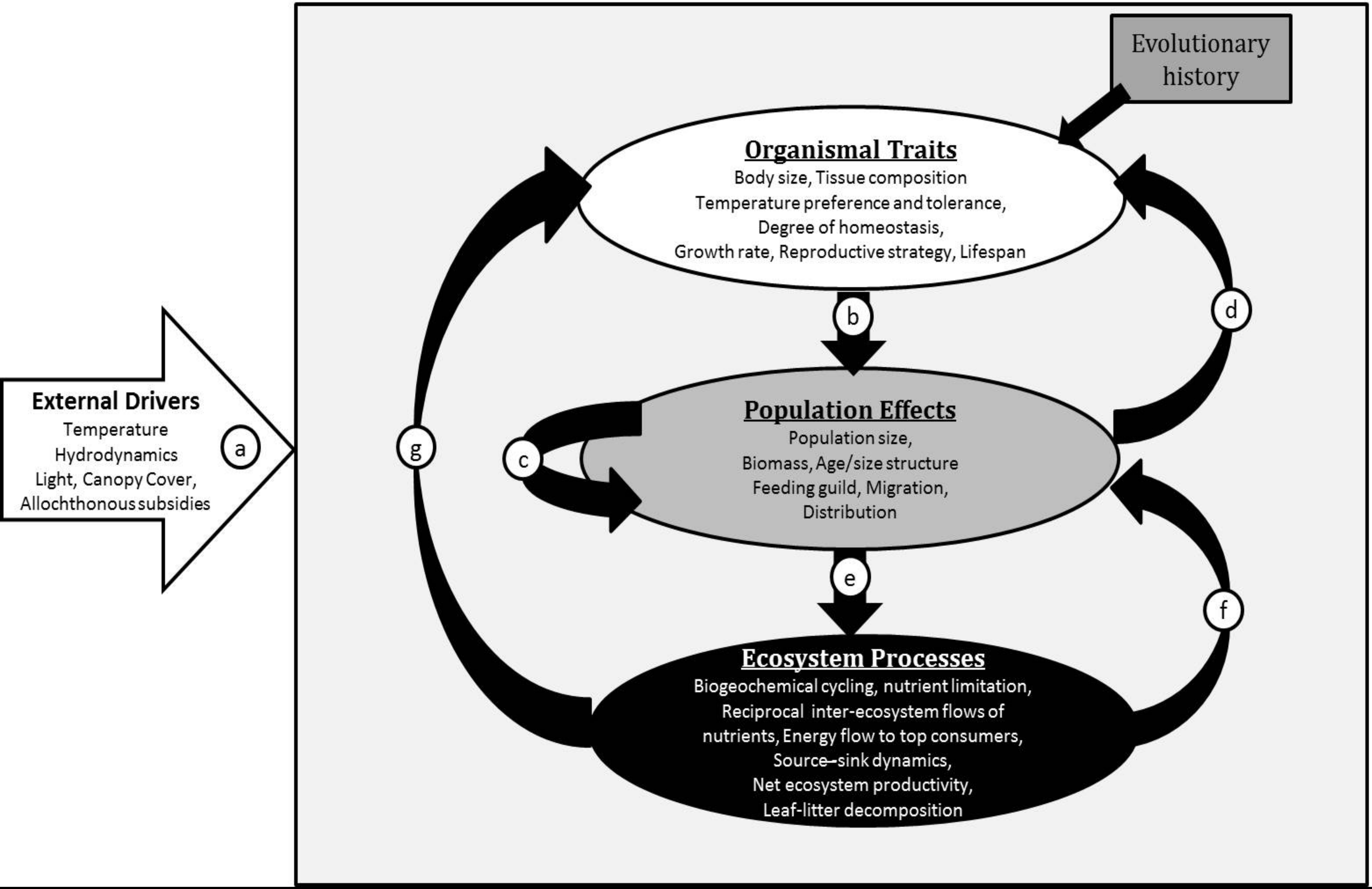


Costello and Michel 2013 (*Ecology*)



How do we examine if consumer effects are important for higher trophic levels and ecosystem function?

Consumer-Driven Nutrient Dynamics



Atkinson et al. *In press, Biological Reviews*

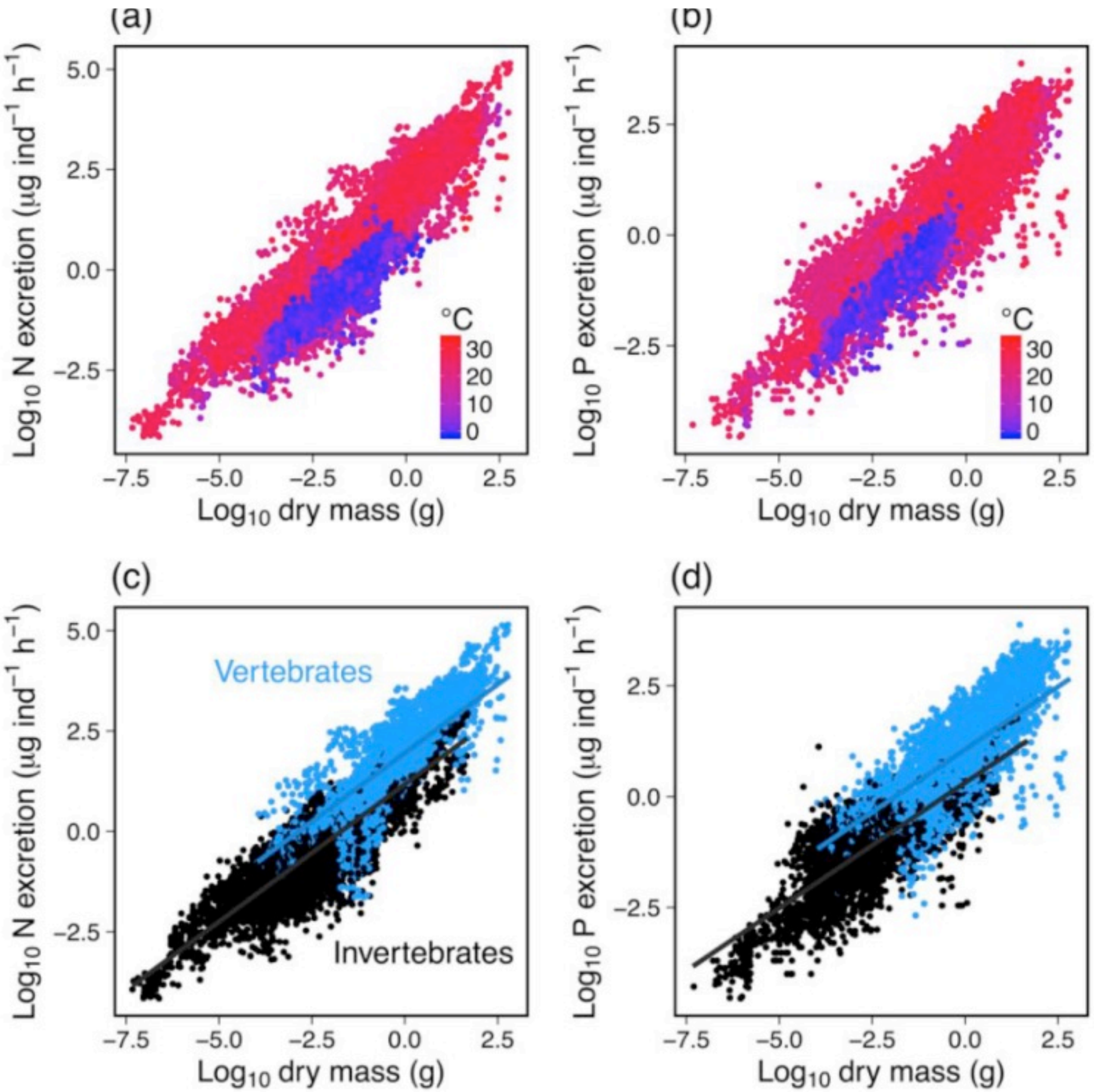
Organismal Traits

Tissue composition, Body size, Feeding guild, Temperature preference, Growth rate, Reproductive strategy, Lifespan, Evolutionary history

Ecology, 97(12), 2016, pp. 3460–3471
© 2016 by the Ecological Society of America

Predicting nutrient excretion of aquatic animals with metabolic ecology and ecological stoichiometry: a global synthesis

Michael J. Vanni[1,3] and Peter B. McIntyre[2]



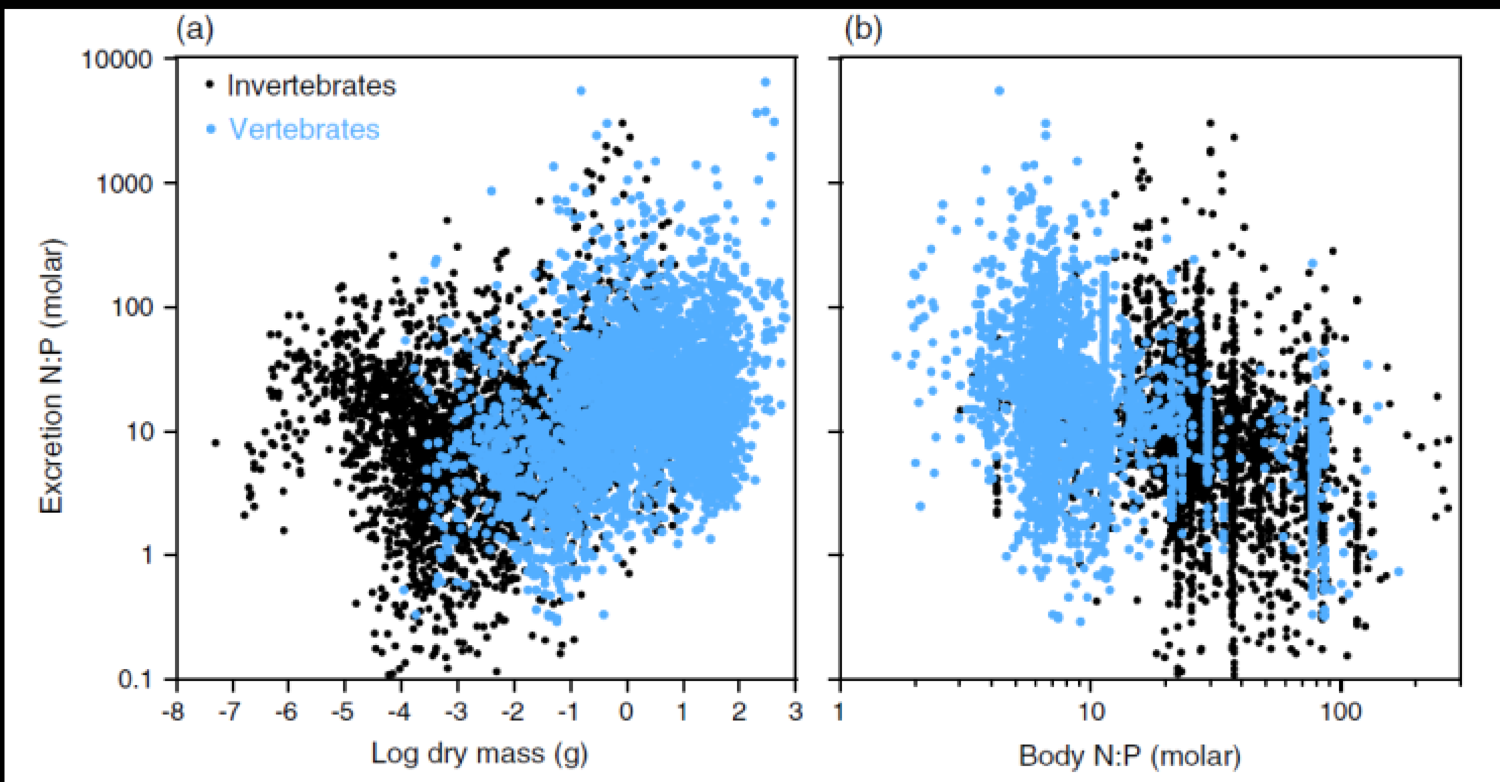
Rates vary due to body mass, temperature, and vertebrates vs invertebrate (Vanni and McIntyre 2016)

Ecology, 97(12), 2016, pp. 3460–3471
© 2016 by the Ecological Society of America

Predicting nutrient excretion of aquatic animals with metabolic ecology and ecological stoichiometry: a global synthesis

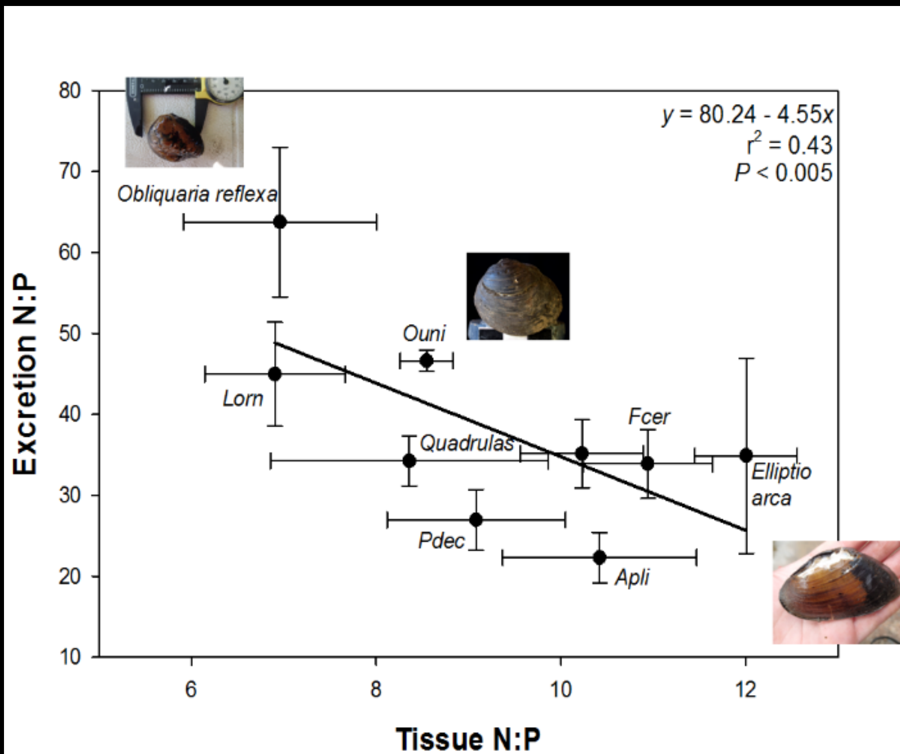
Michael J. Vanni[1,3] and Peter B. McIntyre[2]

Excretion N:P most strongly driven by body size in this data set (Vanni and McIntyre 2016)



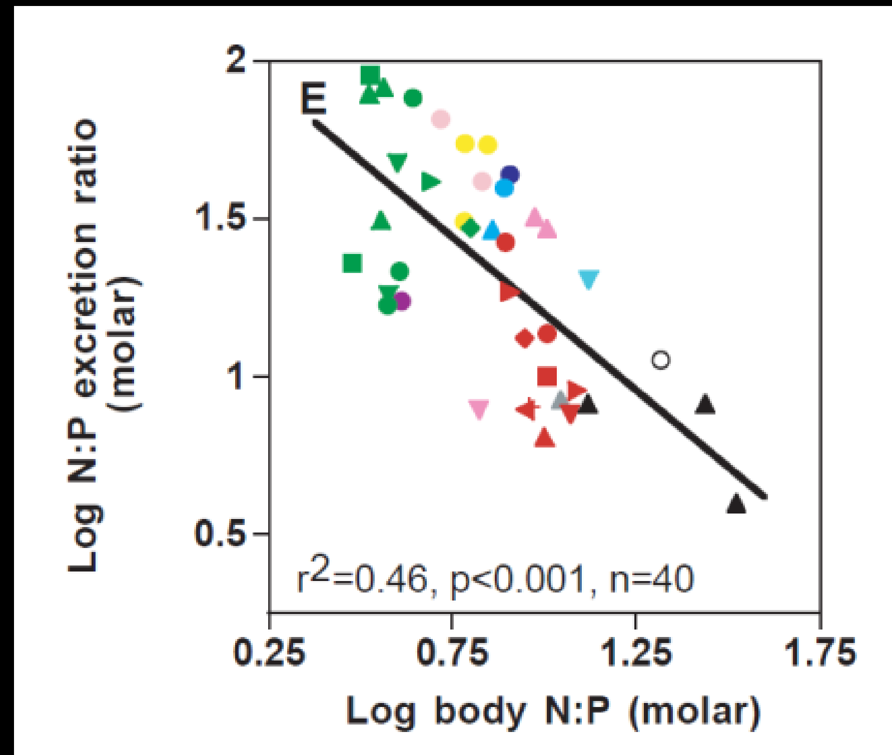
Stoichiometric Traits

Alabama, Atkinson, *unpublished*





Vanni et al. 2002



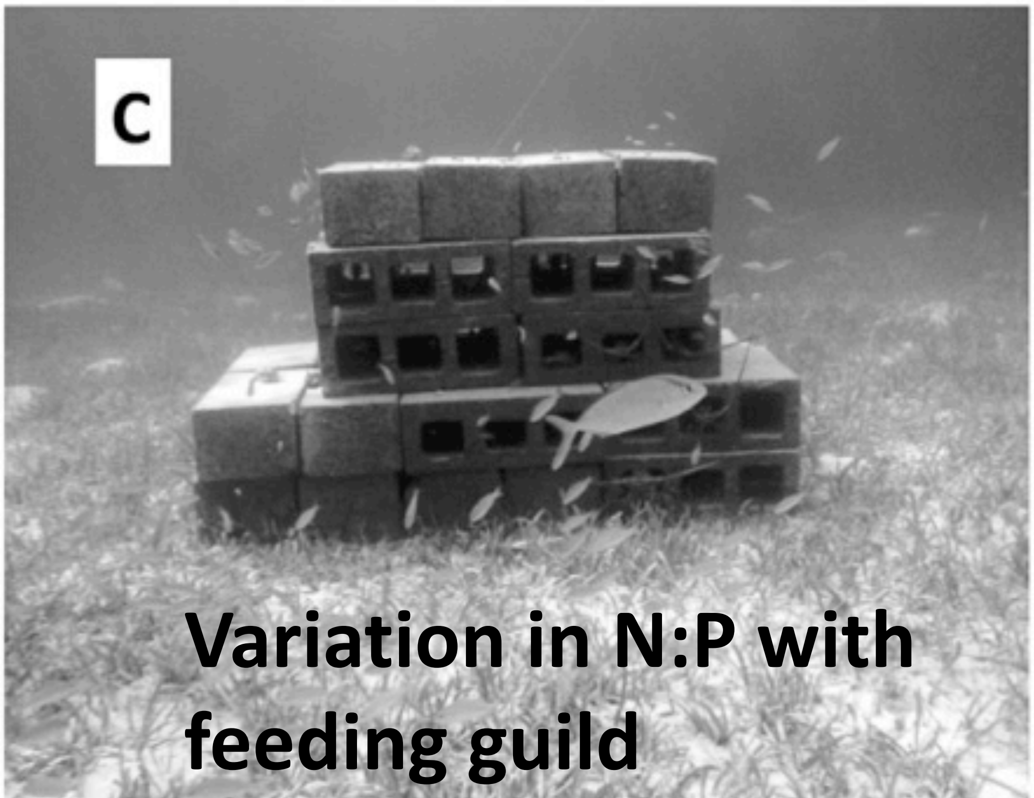


Also, variation in N:P due to age and phylogenetic grouping

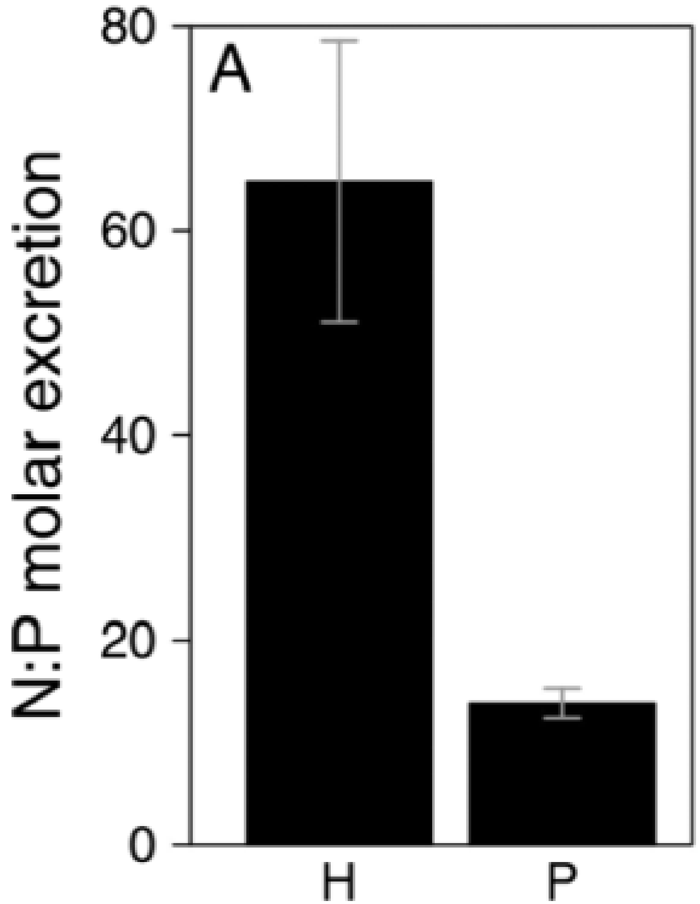
Ecology, 94(2), 2013, pp. 521–529
© 2013 by the Ecological Society of America

Consumers regulate nutrient limitation regimes and primary production in seagrass ecosystems

Jacob E. Allgeier,[1,3] Lauren A. Yeager,[2] and Craig A. Layman[2]



Variation in N:P with feeding guild



Allgeier et al. 2013 (*Ecology*)

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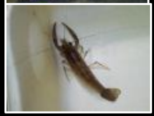
Population Effects

Population size, Age/size structure, Distribution, Migration, Biomass

N Areal Excretion

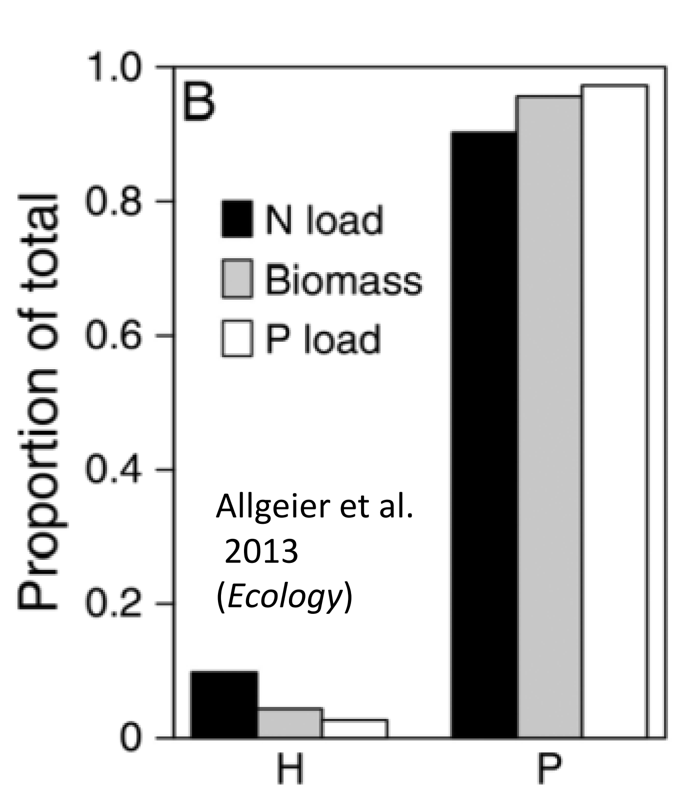


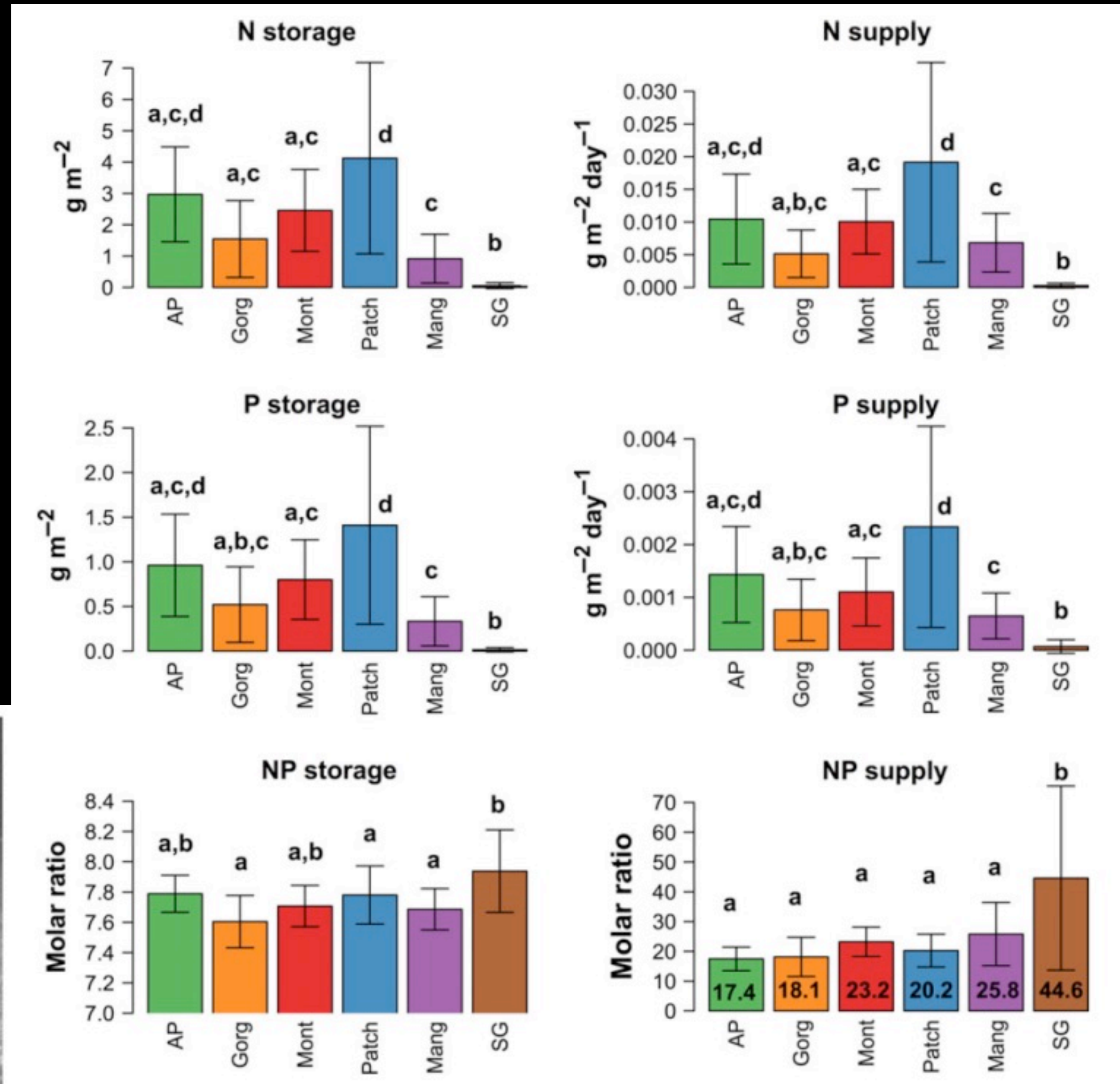
Capps and Flecker 2013

SW Georgia Anurans

Panama

Rugenski et al. *In review*





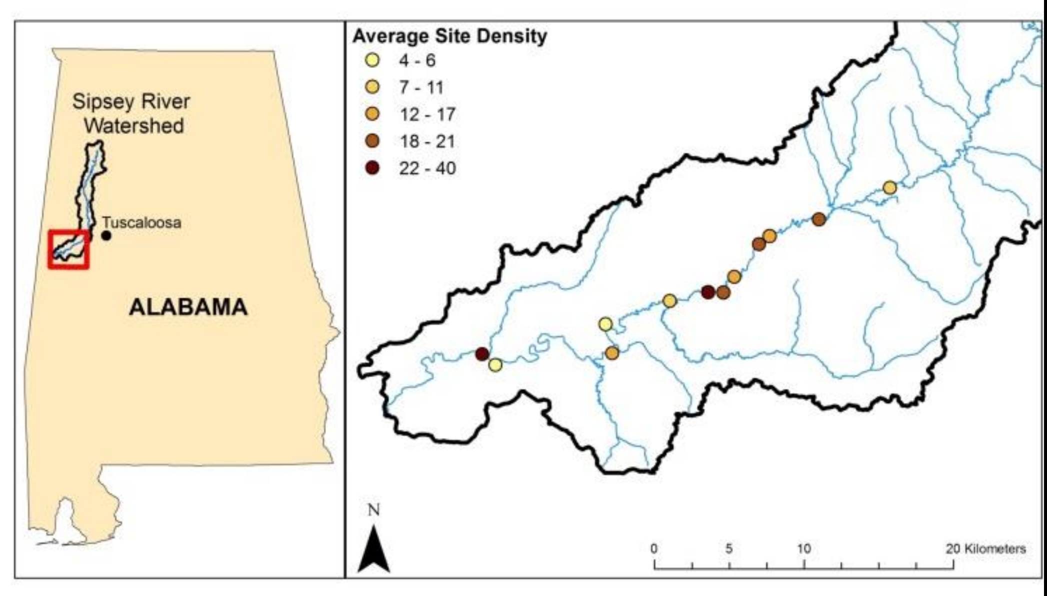
Allgeier et al. 2014 (*Global Change Biology*)

Mussel Sampling:

Quantitatively sampled 12 sites with georeferencing.

Excretion and egestion rates measured for 12 species

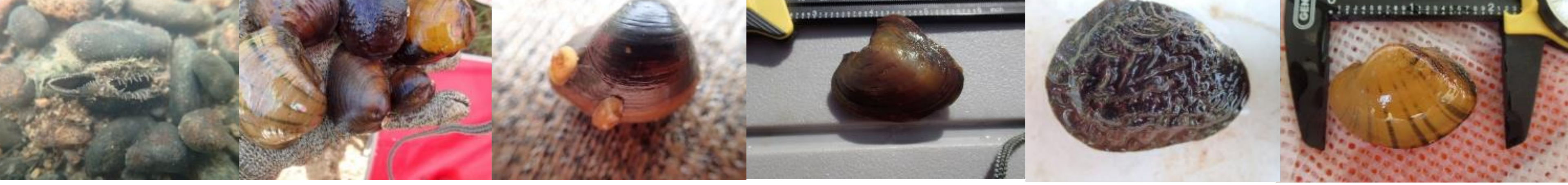
30 species encountered

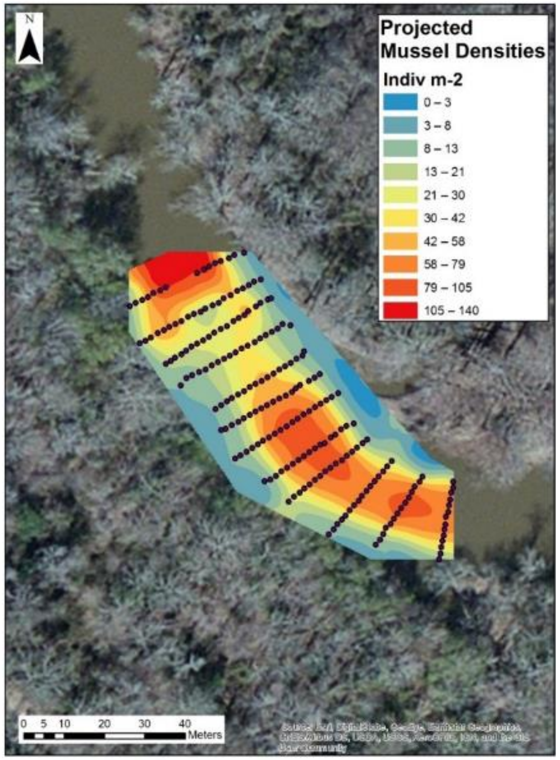


Excretion Rates

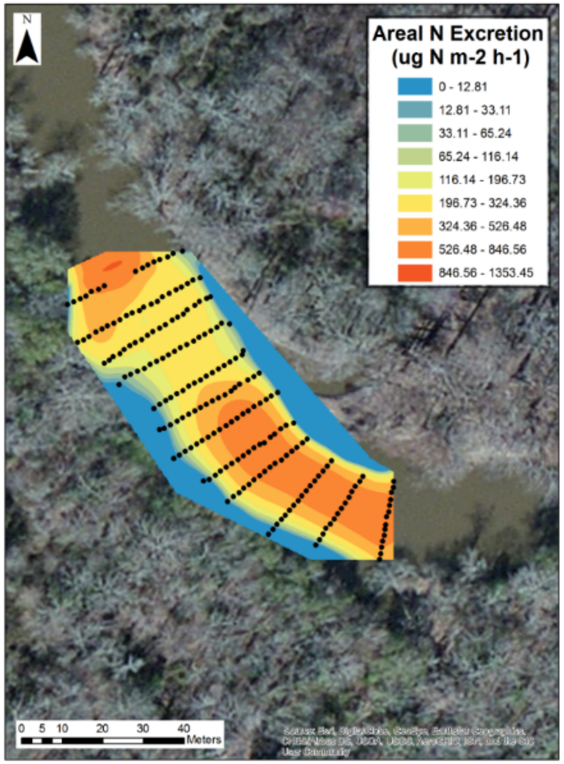
N Excretion Rates

P Excretion Rates

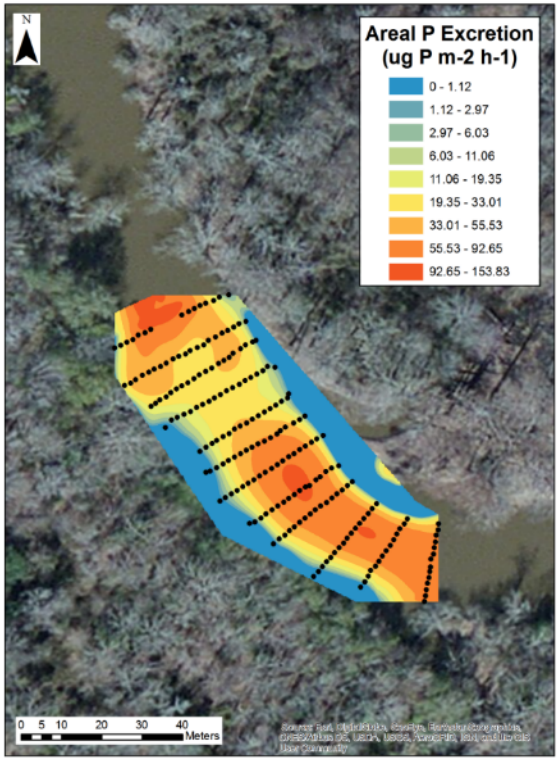




Densities



Areal N Excretion

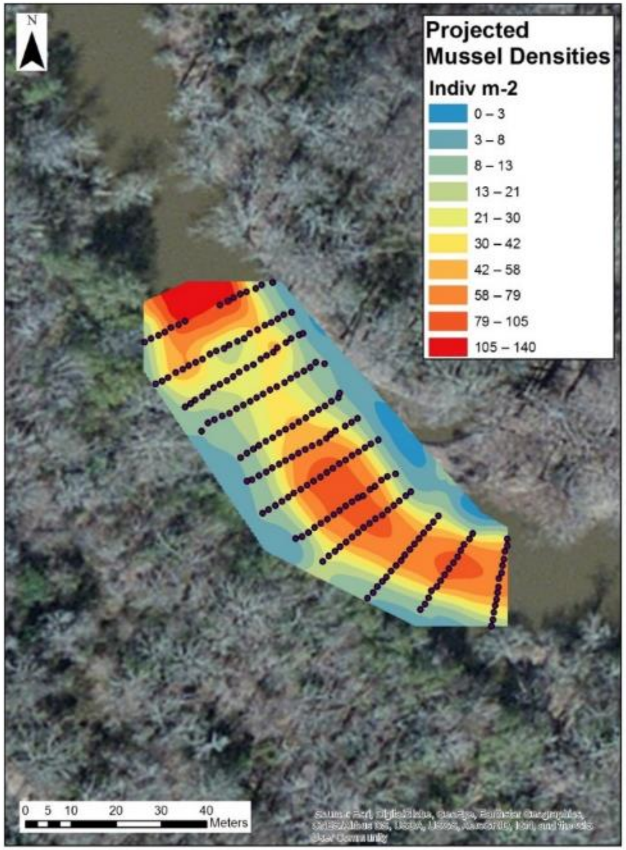


Areal P Excretion

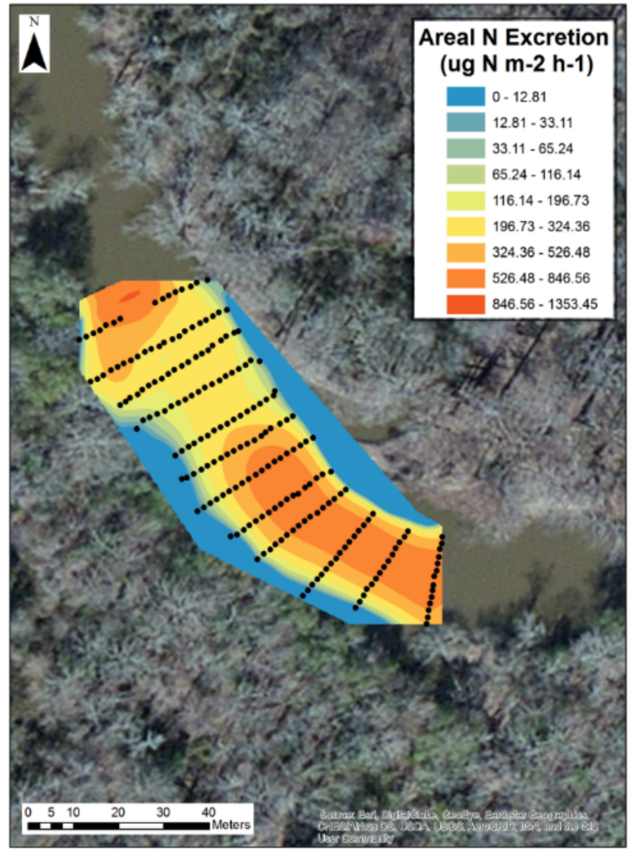
Average = 35 indiv m^{-2}

Average = 369 μg NH_4-N m^{-2} h^{-1}

Average = 44.9 μg P m^{-2} h^{-1}



Densities



Areal N Excretion

Average = 35 indiv m^{-2}

Average = 369 μg NH_4-N m^{-2} h^{-1}

Some species doing more than what their biomass would suggest

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

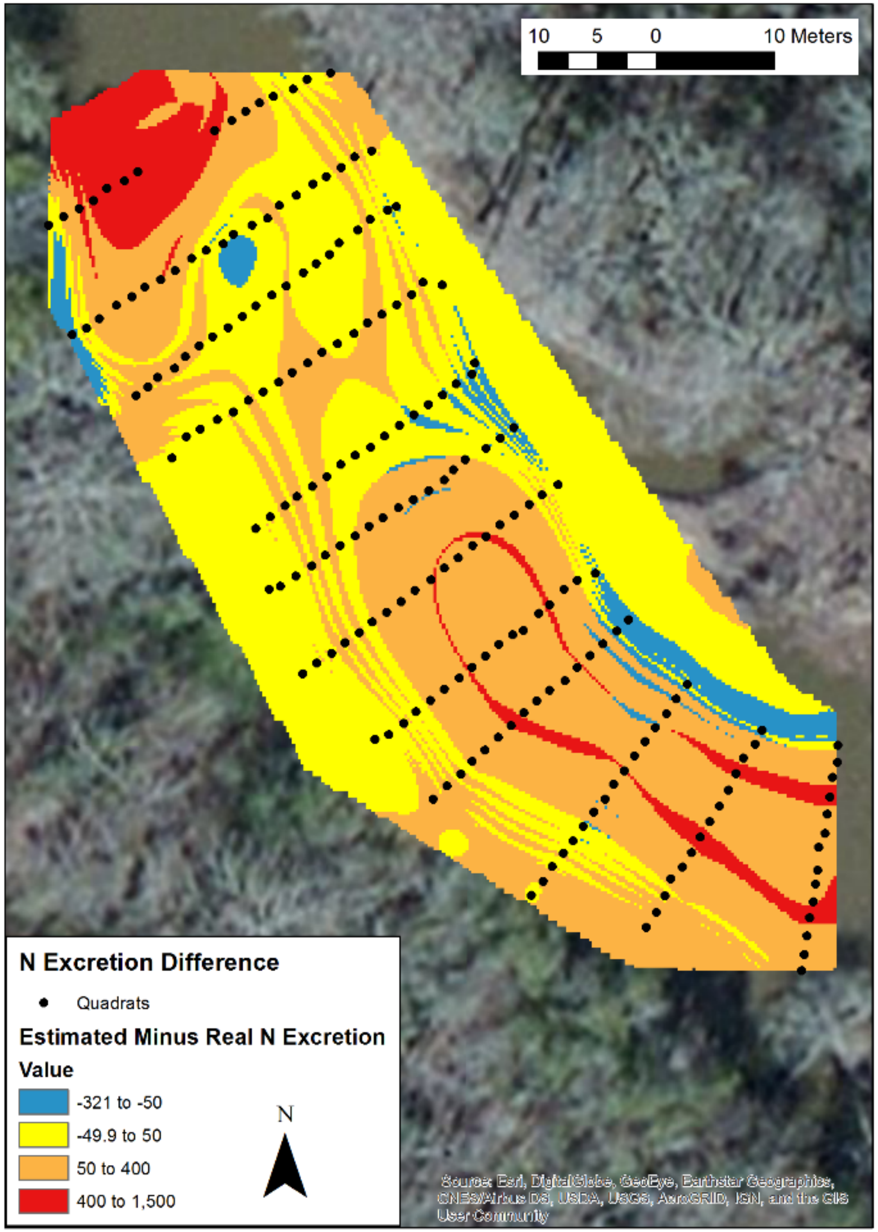
Biomass-corrected average N:P of Excretion = 18.2; Background water column N:P ~8.9

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

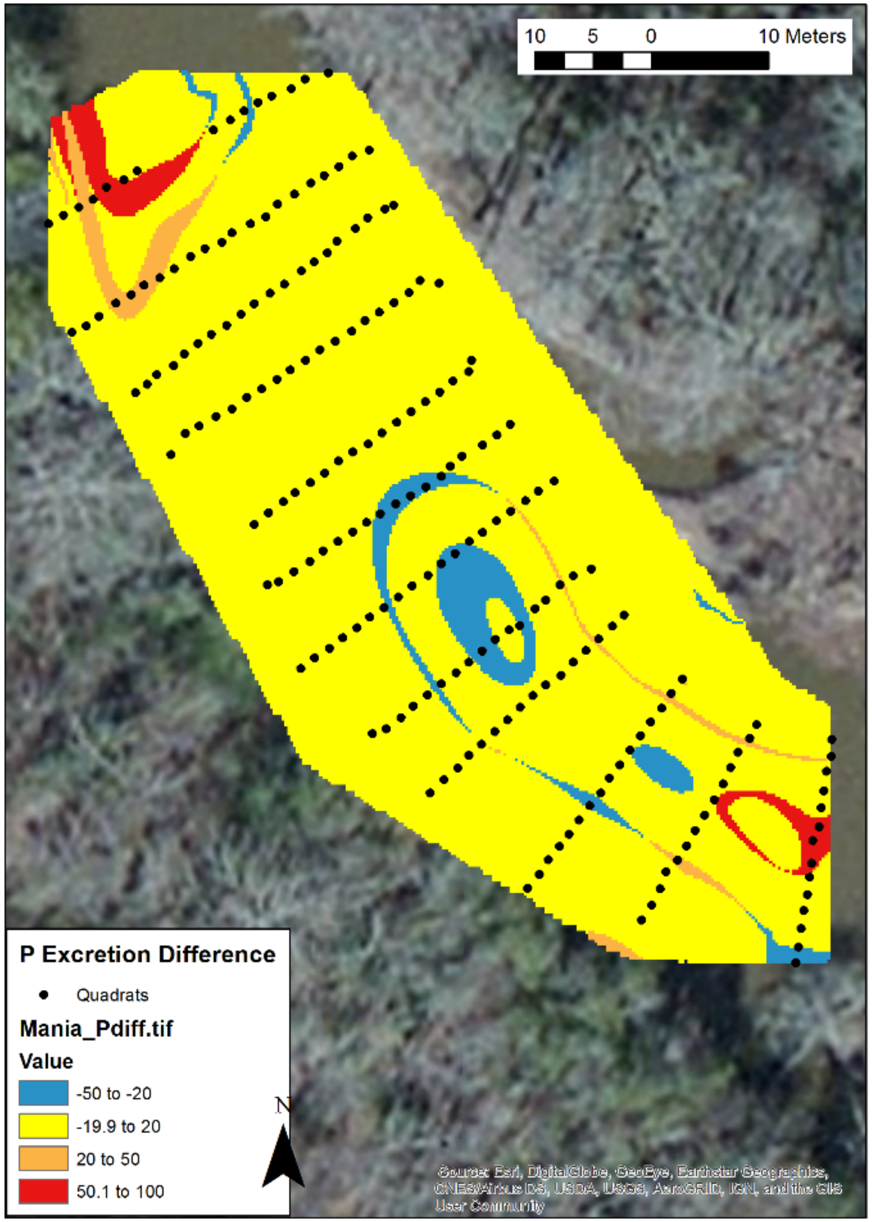


Do species matter?

Applying a Average Excretion value versus the Species-Weighted

P Excretion

Accuracy	Percentage Coverage
Underestimate	4.6
Good	90.7
Small Overestimate	2.4
High Overestimate	2.3

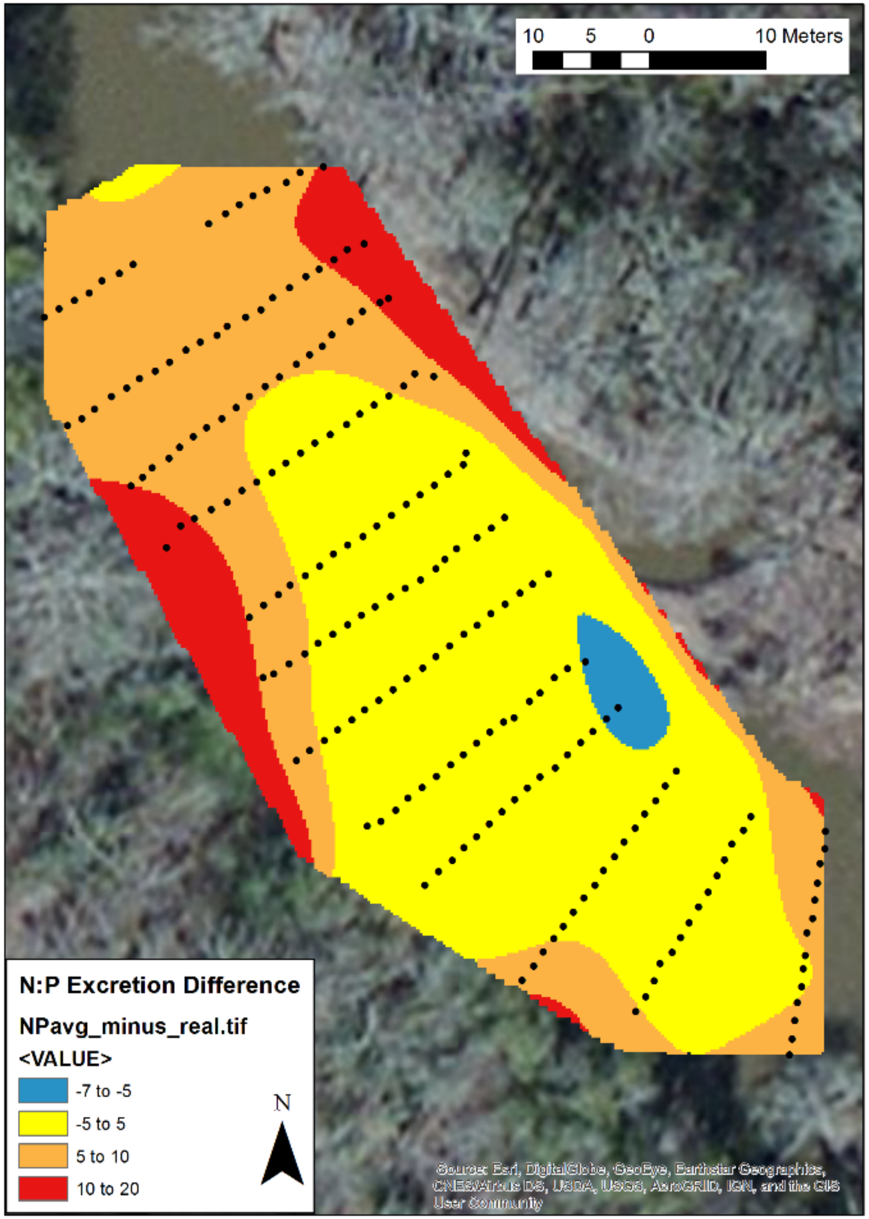


Do species matter?

Applying a Average Excretion value versus the Species-Weighted

N:P Excretion

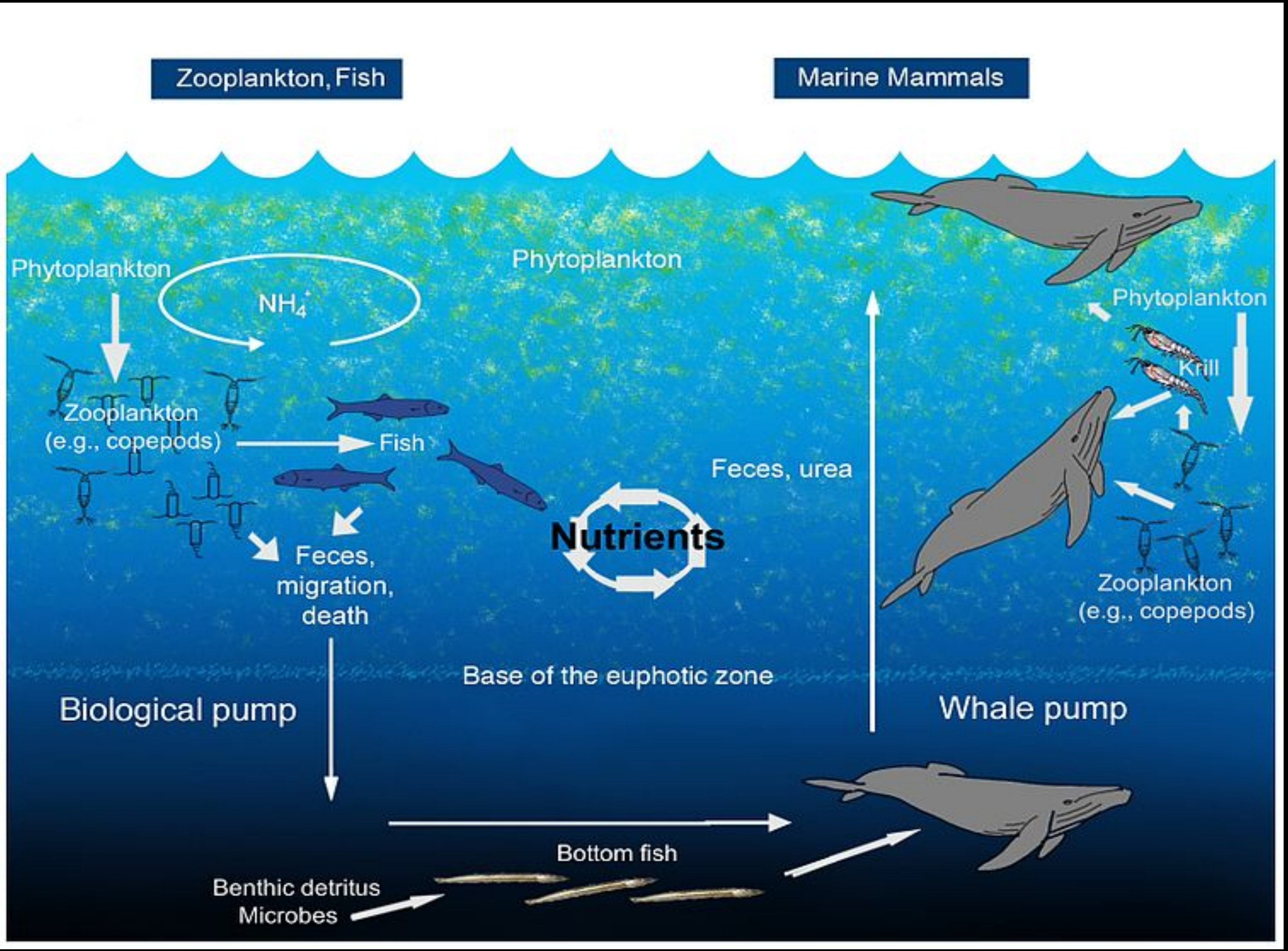
Accuracy	Percent Coverage
Underestimate	2.0
Good	64.7
Small Overestimate	23.4
High Overestimate	10.0



Effects on Ecosystem Processes

Nutrient limitation, Biogeochemical cycling, Production,
Decomposition, Energy flow within food webs, Sink-subsidy dynamics

Organism effects are often temporally and spatially variable



Roman and McCarthy 2010 (PLoS One)

Ecology, 89(8), 2008, pp. 2335–2346
© 2008 by the Ecological Society of America

FISH DISTRIBUTIONS AND NUTRIENT CYCLING IN STREAMS: CAN FISH CREATE BIOGEOCHEMICAL HOTSPOTS?

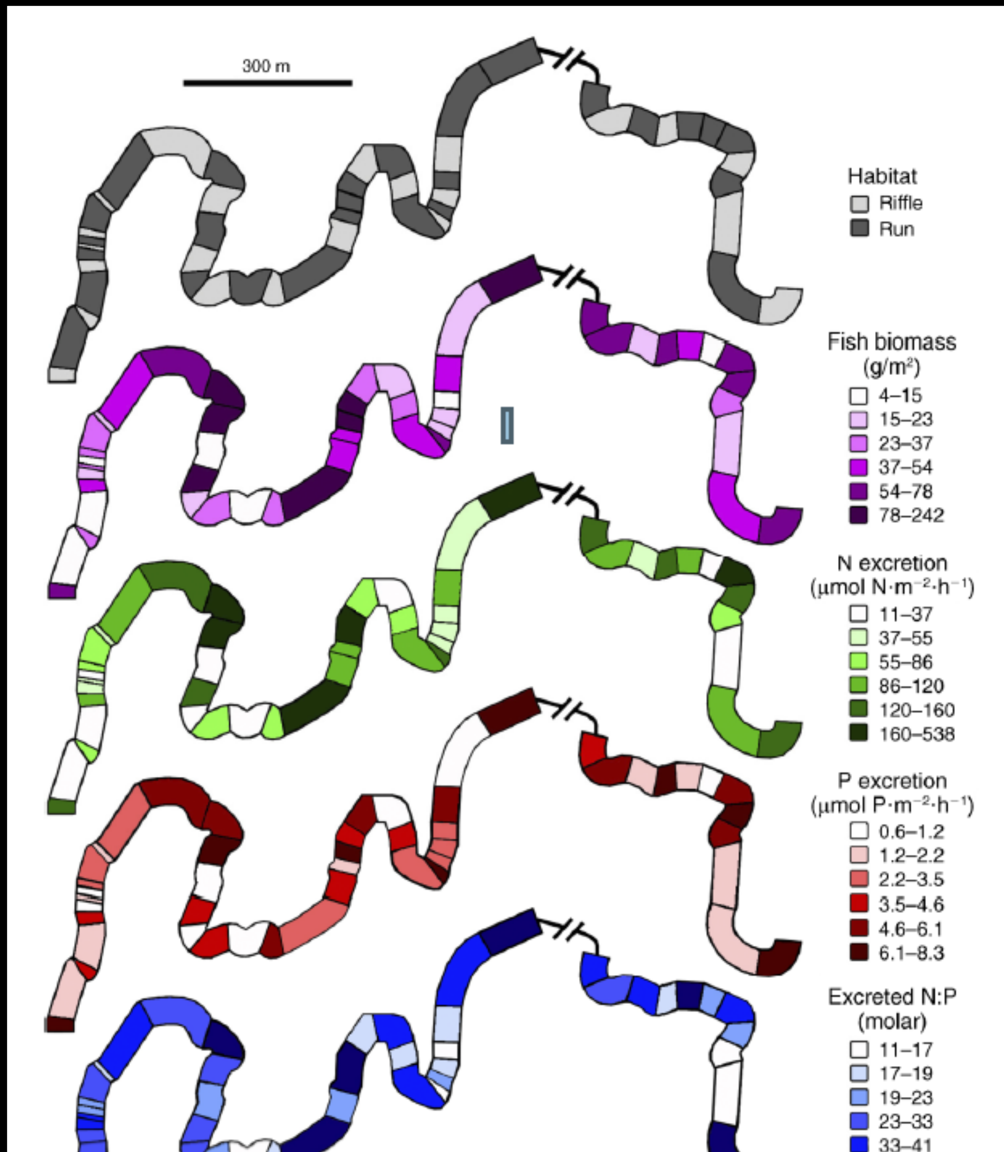
Peter B. McIntyre,[1,2,7] Alexander S. Flecker,[1] Michael J. Vanni,[3] James M. Hood,[4] Brad W. Taylor,[5] and Steven A. Thomas[6]

[1] *Department of Ecology and Evolutionary Biology, Cornell University, Itha*
[2] *School of Natural Resources and Environment, University of Michigan, Ann*
[3] *Department of Zoology, Miami University, Oxford, Ohio 4*
[4] *Department of Ecology, Evolution, and Behavior, University of Minnesota, St.*
[5] *Department of Biological Sciences, Dartmouth College, Hanover, New*
[6] *School of Natural Resources, University of Nebraska, Lincoln, Ne*

Abstract. Rates of biogeochemical processes often vary widely characterizing this variation is critical for understanding ecosystem spatial hotspots of nutrient transformations are generally attributed processes. Here we examine the potential for heterogeneous distrib hotspots of nutrient recycling. We measured nitrogen (N) and phosp of 47 species of fish in an N-limited Neotropical stream, and we c

Biogeochemical hotspots

patches that show disproportionately high reaction rates relative to the surrounding matrix (McClain et al. 2003)



OPEN ACCESS Freely available online

PLOS ONE

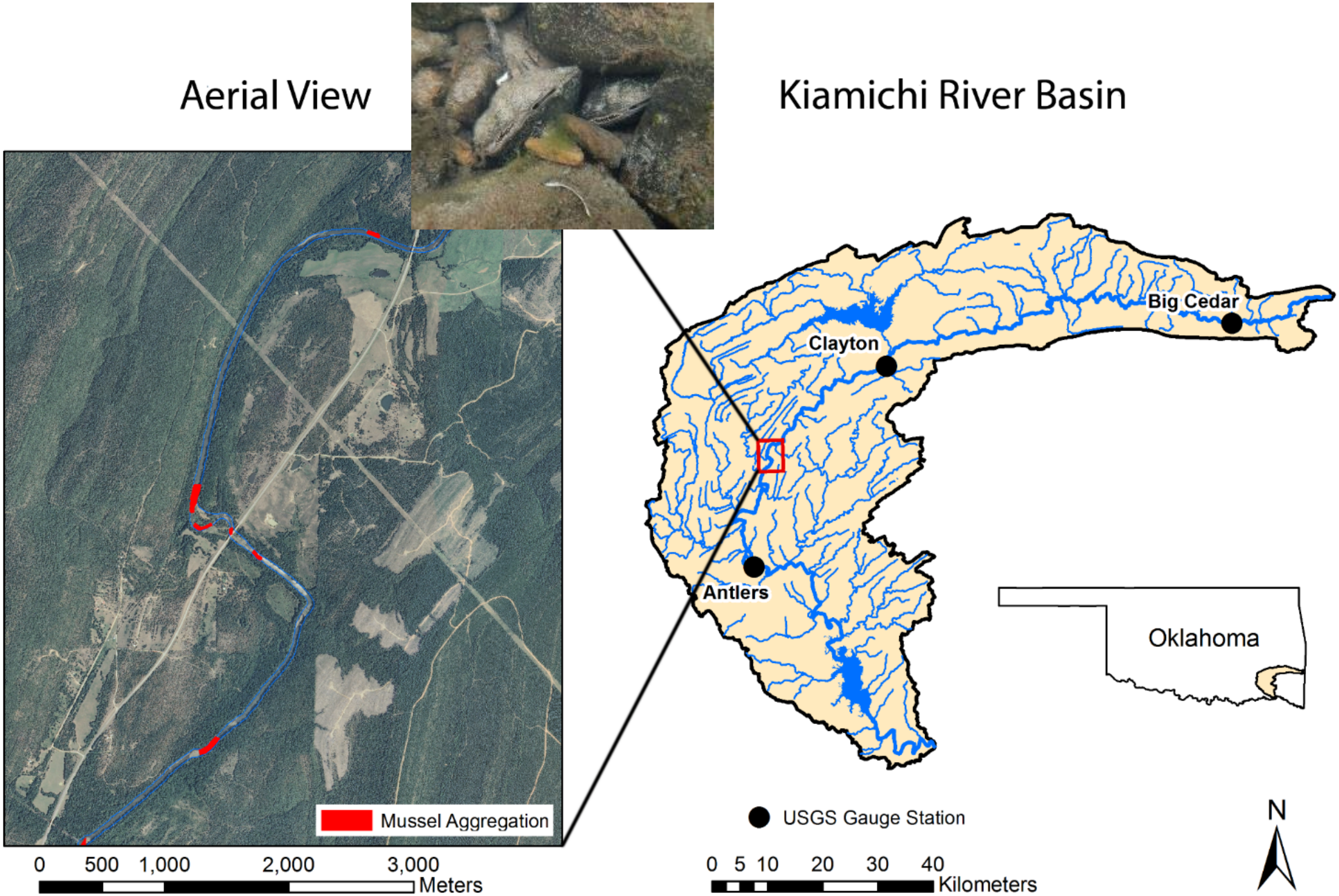
Invasive Fishes Generate Biogeochemical Hotspots in a Nutrient-Limited System

Krista A. Capps[1,2*], **Alexander S. Flecker**[1]

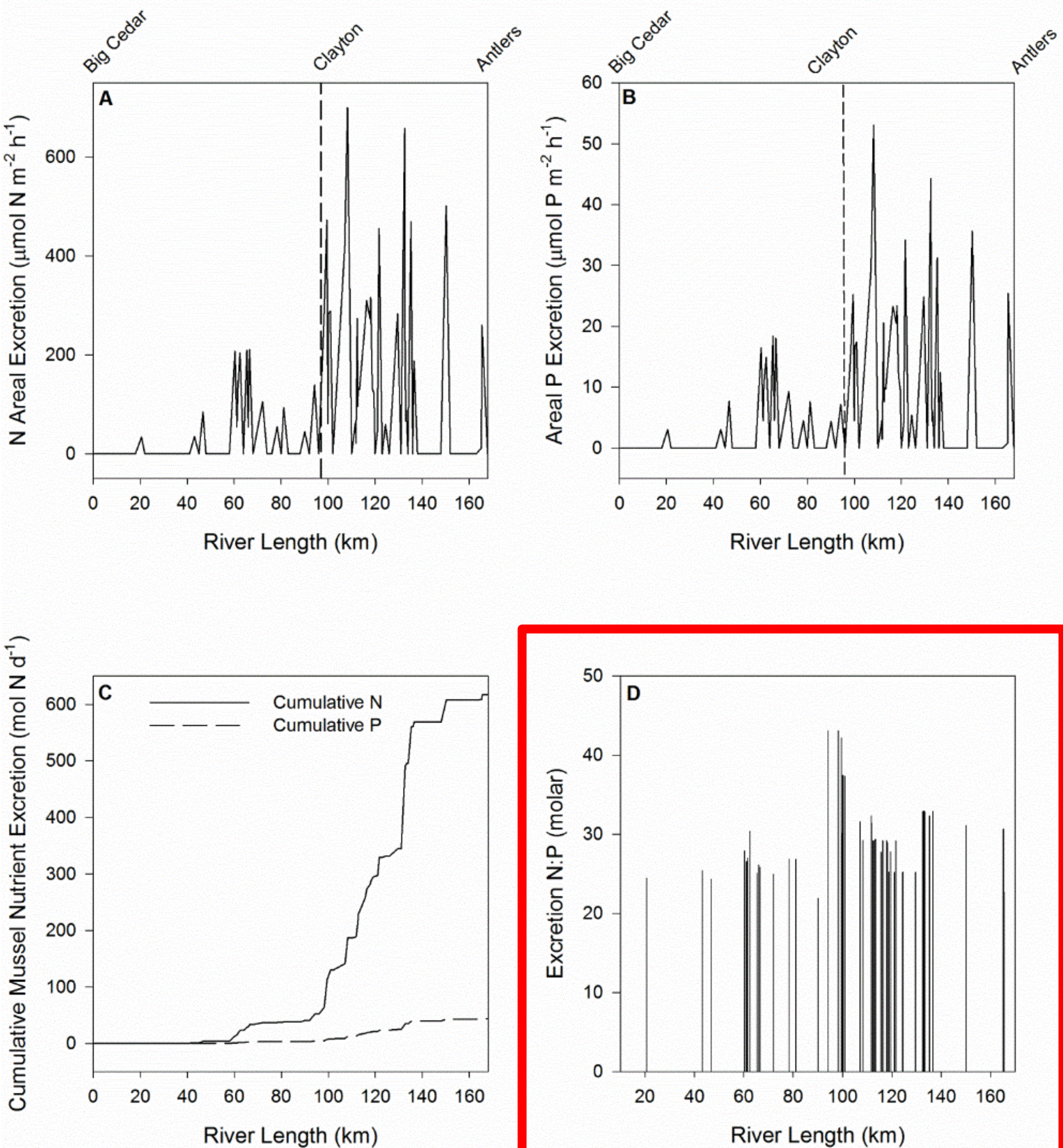
1 Department of Ecology and Evolutionary Biology, Cornell University, Ithaca, New York, United States of America, 2 Sustainability Solutions Initiative, University of Maine, Orono, Maine, United States of America

Abstract

Fishes can play important functional roles in the nutrient dynamics of freshwater systems. Aggregating fishes have the potential to generate areas of increased biogeochemical activity, or hotspots, in streams and rivers. Many of the studies documenting the functional role of fishes in nutrient dynamics have focused on native fish species; however, introduced fishes may restructure nutrient storage and cycling freshwater systems as they can attain high population densities in novel environments. The purpose of this study was to examine the impact of a non-native catfish (Loricariidae: *Pterygoplichthys*) on nitrogen and phosphorus remineralization and estimate whether large aggregations of these fish generate measurable biogeochemical hotspots within nutrient-limited ecosystems. Loricariids formed large aggregations during daylight hours and dispersed throughout the stream during evening hours to graze benthic habitats. Excretion rates of phosphorus were twice as great during nighttime hours when fishes were actively feeding; however, there was no diel pattern in nitrogen excretion rates. Our results indicate that spatially heterogeneous aggregations of loricariids can significantly elevate dissolved nutrient concentrations via excretion relative to ambient nitrogen and phosphorus concentrations during daylight hours, creating biogeochemical hotspots and potentially altering nutrient dynamics in invaded systems.



Atkinson and Vaughn 2015, *Freshwater Biology* Special Issue



Mussel Nutrient Recycling

Hotspots of nutrient regeneration – densest beds

>600 mol N d^{-1} =

>8.5 kg N d^{-1} =

>3 metric tons N y^{-1}

Atkinson and Vaughn 2015, *Freshwater Biology* Special Issue

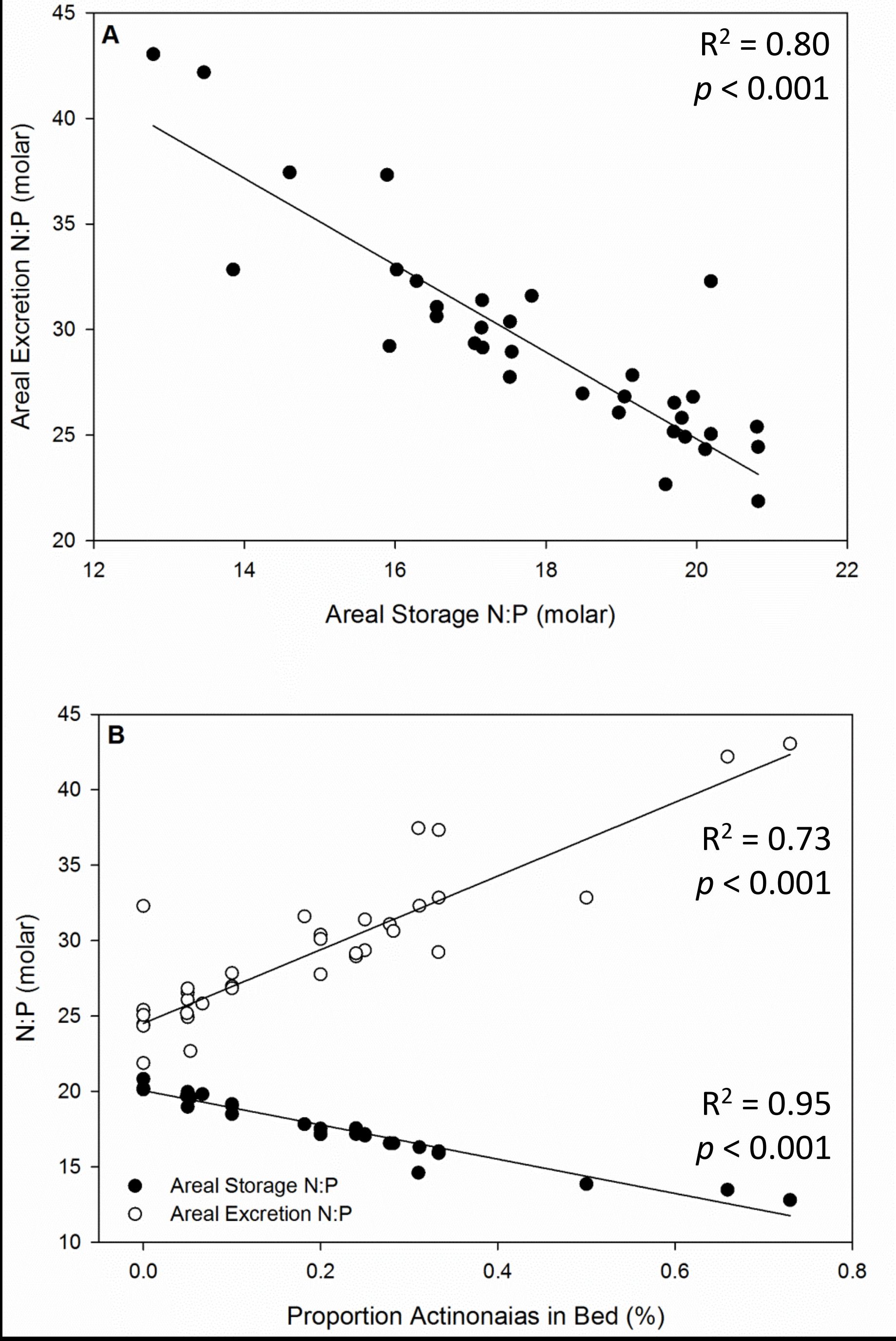
Stoichiometry and Species Traits

Meets the expectations of ecological stoichiometry

Higher excretion N:P = beds dominated by *Actinonaias ligamentina*

A. ligamentina classified as a thermally sensitive species*

*Spooner & Vaughn 2008 (*Oecologia*)



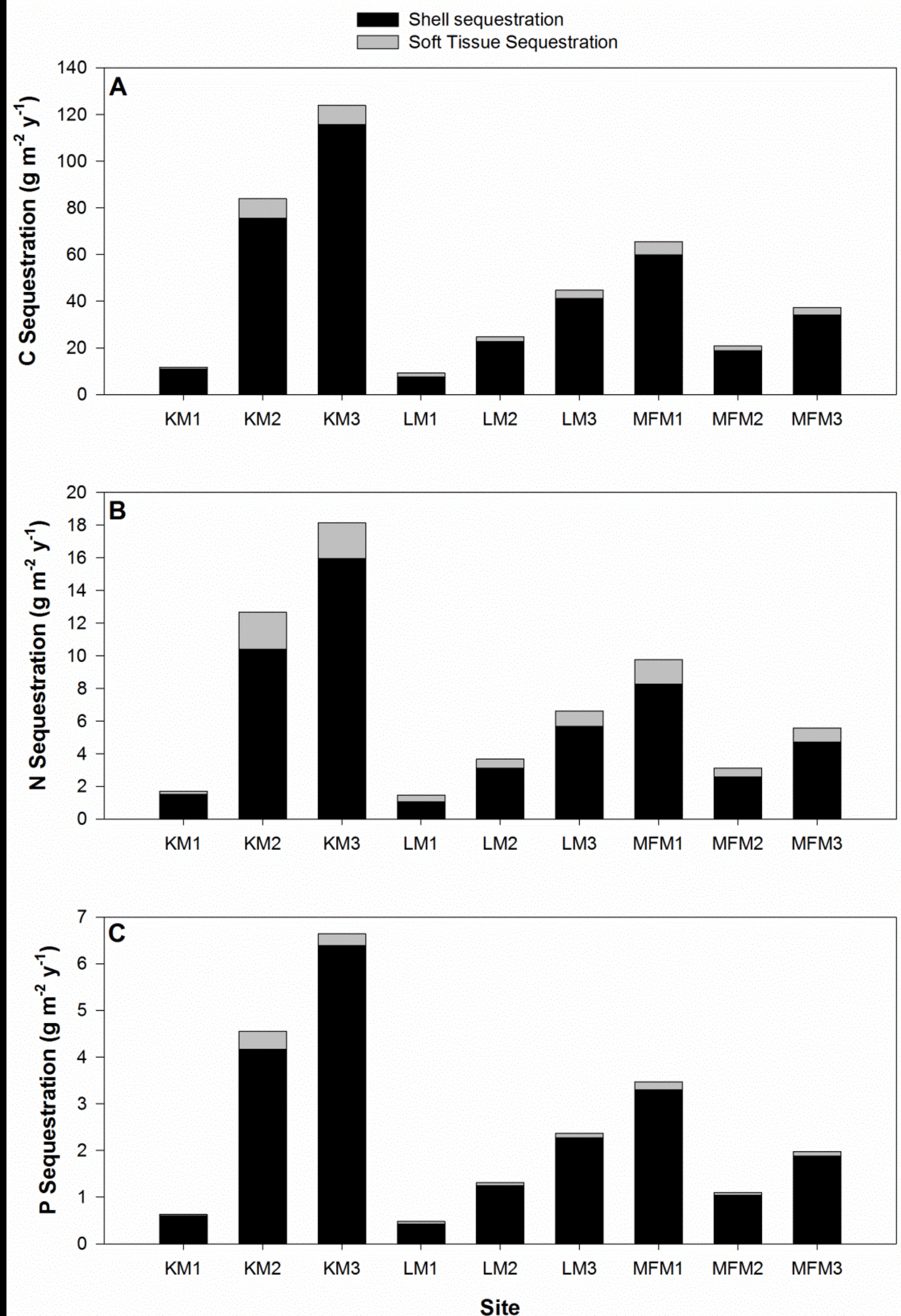
Storage & Sequestration

Mussels live 5 to >50 years (Shell = long term store, “nutrient sink”*)

Across the Kiamichi (47 reaches) ~ Storing:

- 14 tons C
- 5 tons N
- 0.5 tons P

*Vanni et al. 2013 (*Ecology*)
Atkinson et al. 2015 (*FWB*)
Atkinson et al. *Accepted, Ecosystems*



Consumer Aggregations Drive Nutrient Dynamics and Ecosystem Metabolism in Nutrient-Limited Systems

Carla L. Atkinson,[1]* Brandon J. Sansom,[2] Caryn C. Vaughn,[3] and Kenneth J. Forshay[4]

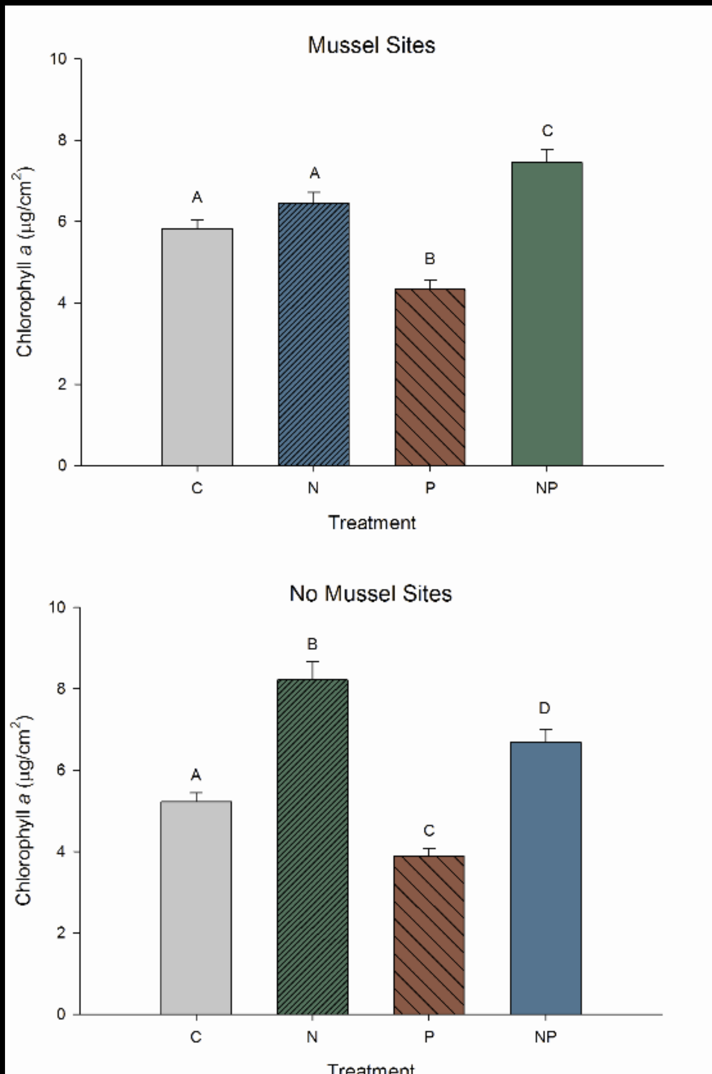
PROOF

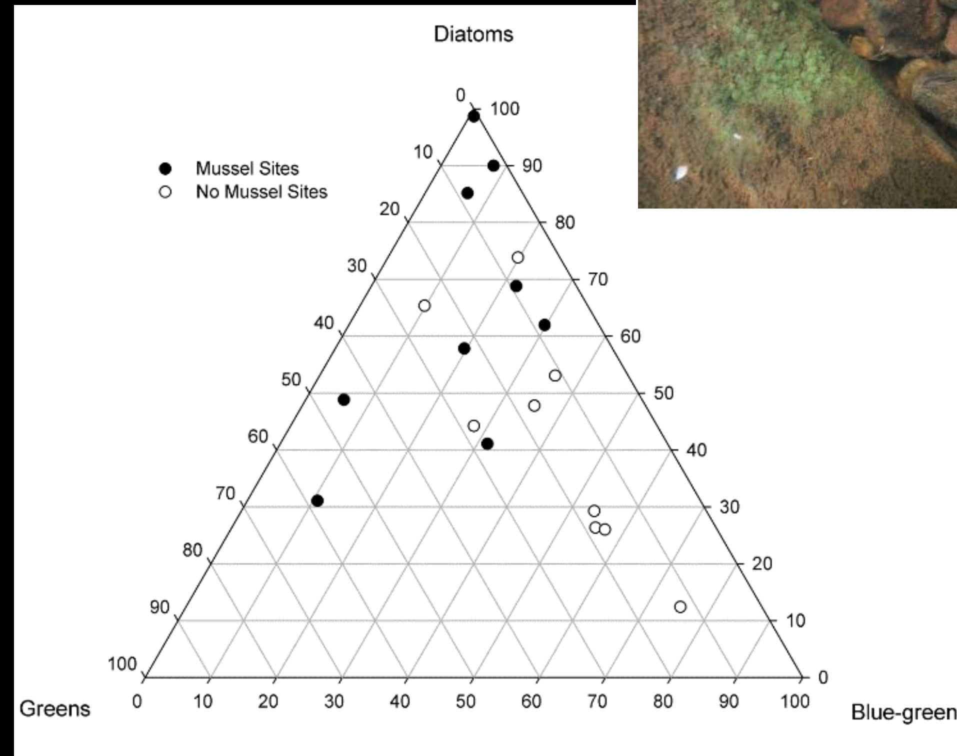
In press

Mussels are acting as sequestration and cycling hotspots

Higher gross primary productivity in reaches with mussels

Alleviation of Nitrogen Limitation by Mussels





Difference in benthic algae community composition

Atkinson et al. 2013 (*Ecology*)

Nutrient recycling by mussels: comparing to uptake rates and tracing N in the food web

Ecosystems (2014) 17: 485–496
DOI: 10.1007/s10021-013-9736-2

ECOSYSTEMS

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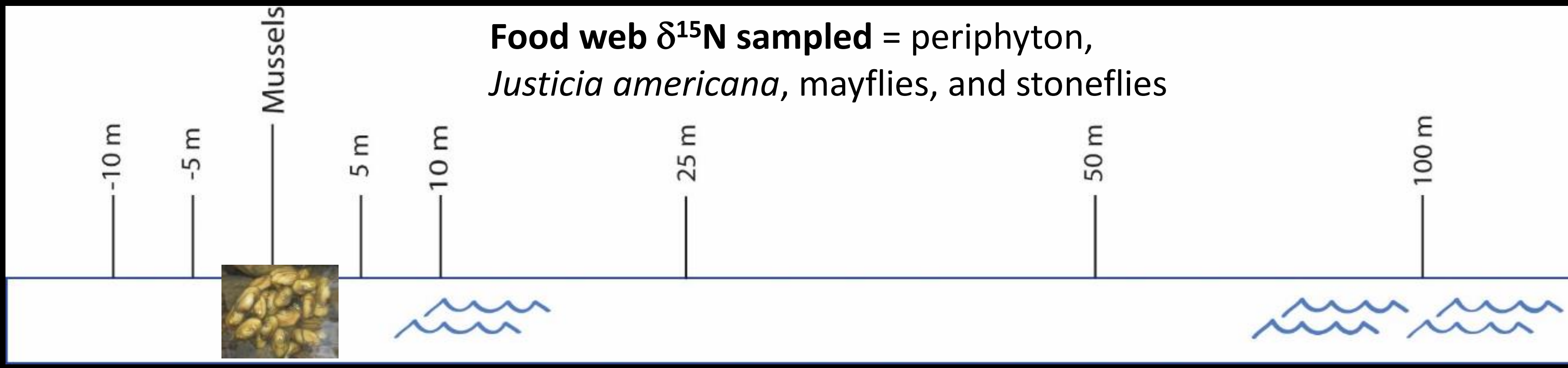
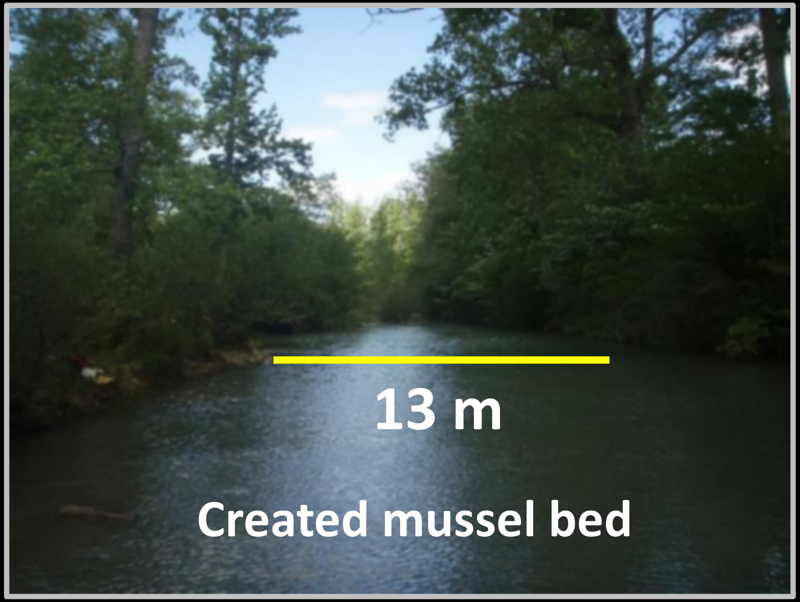
Tracing Consumer-Derived Nitrogen in Riverine Food Webs

Carla L. Atkinson,* Jeffrey F. Kelly, and Caryn C. Vaughn

Tracing $\delta^{15}N$ into the Food Web

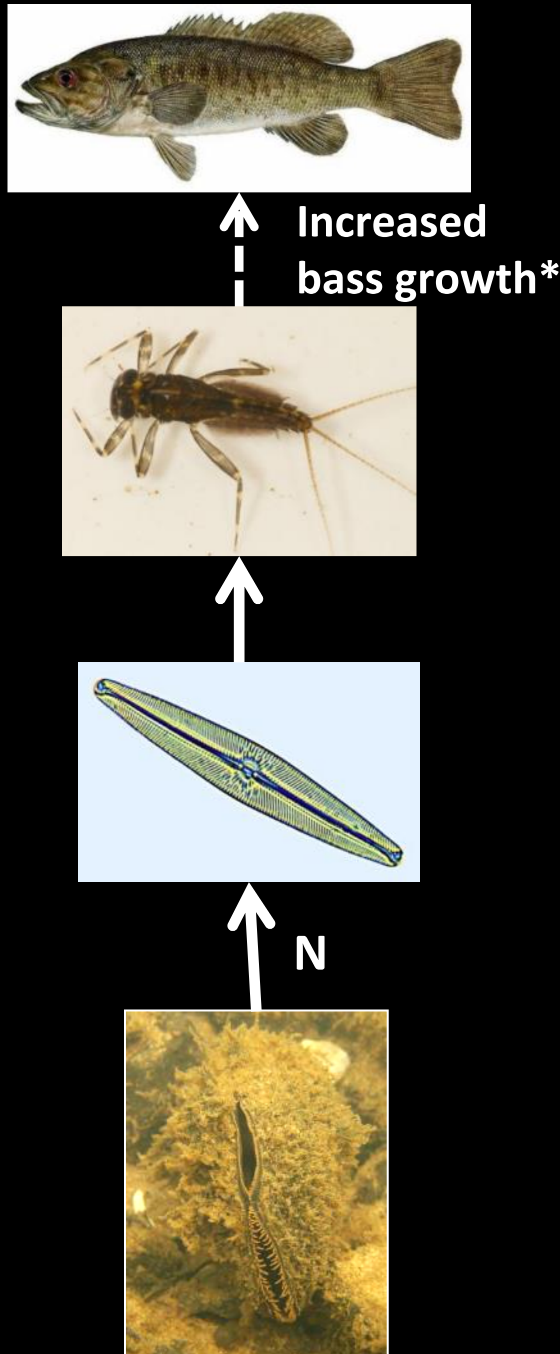




Little River, Oklahoma

Nutrient Uptake Measurements

Excretion Rate Measurements



Mussel Derived N moved into the food web

Mussels meet up to 40% of N demand; could be up to 98% in natural mussel beds

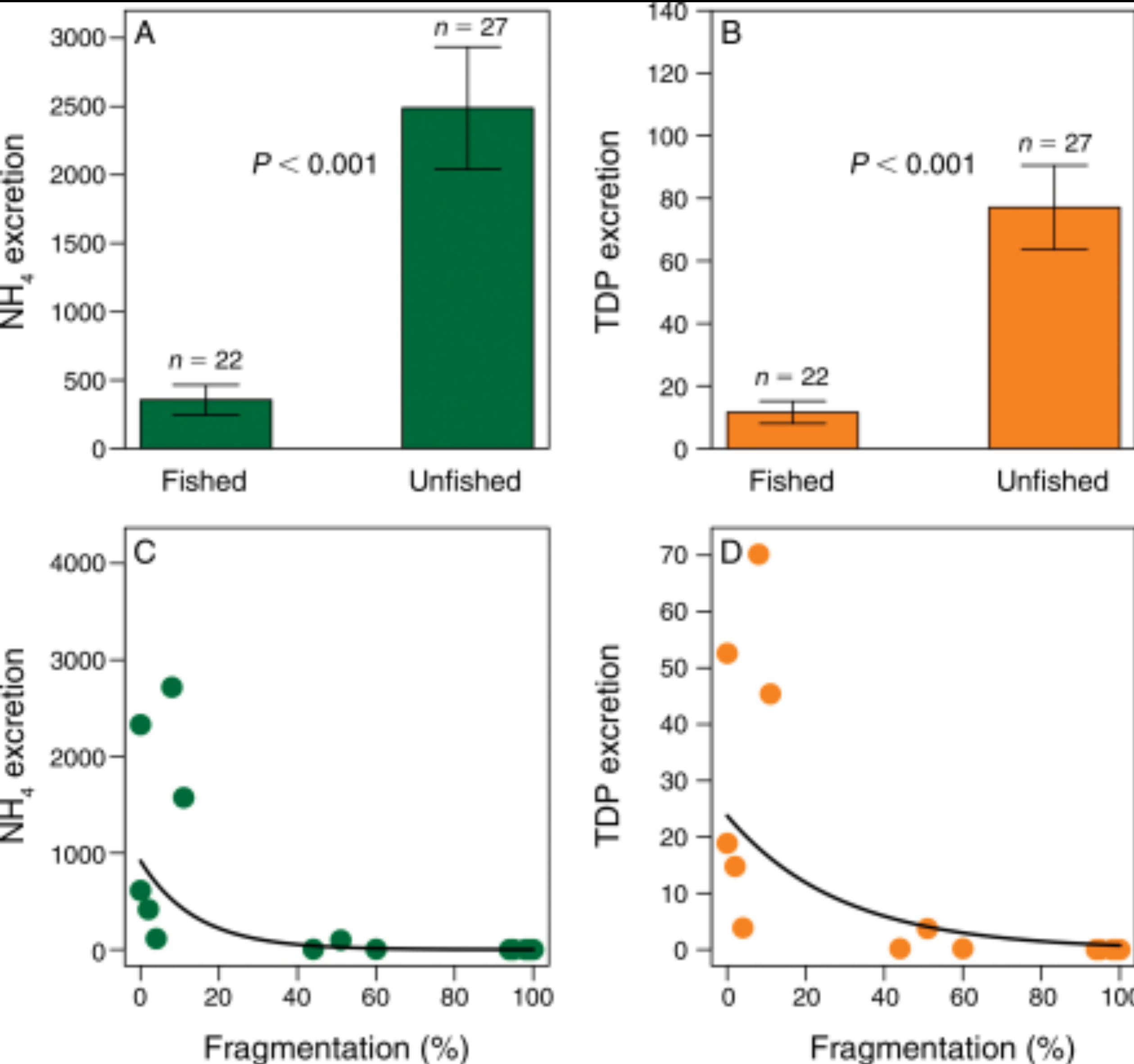
Up to 70% of N in the tissue of organisms near mussels beds from N remineralized by mussels

Atkinson et al. 2014 (*Ecosystems)*
*Sansom et al. *In prep*

Under increased human impact - implications

Climate change, Fishing pressure, Nutrient loading, etc.

Over-fishing & Habitat Fragmentation



Areal excretion
$\mu g \cdot m^{-2} \cdot h^{-1}$ for
NH_4-N and TDP-P

Layman et al. 2011
(*Ecological Applications*)

ECOLOGY LETTERS
Ecology Letters, (2013) **16**: 1115–1125 doi: 10.1111/ele.12146

LETTER

Nutrient loading associated with agriculture land use dampens the importance of consumer-mediated niche construction

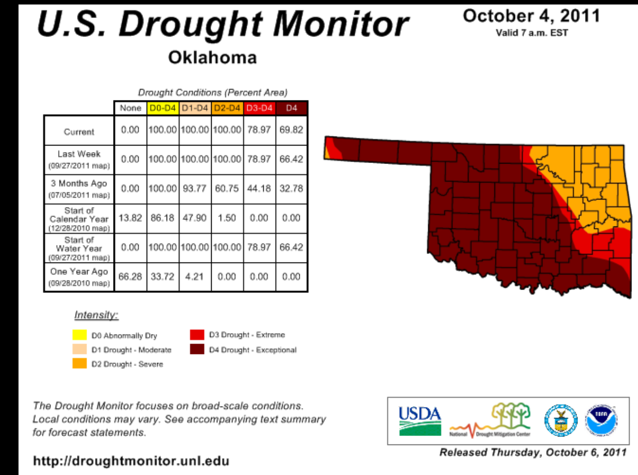
Daniel E. Spooner,[1,2]* Paul C. Frost,[1] Helmut Hillebrand,[3] Michael T. Arts,[4] Olivia Puckrin[1] and Marguerite A. Xenopoulos[1]

Abstract

The linkages between biological communities and ecosystem function remain poorly understood along gradients of human-induced stressors. We examined how resource provisioning (nutrient recycling), mediated by native freshwater mussels, influences the structure and function of benthic communities by combining observational data and a field experiment. We compared the following: (1) elemental and community composition (algal pigments and macroinvertebates) on live mussel shells and on nearby rocks across a gradient of catchment agriculture and (2) experimental colonisation of benthic communities on live vs. sham shells controlling for initial community composition and colonisation duration. We show that in near pristine systems, nutrient heterogeneity mediated by mussels relates to greater biodiversity of communities, which supports the notion that resource heterogeneity can foster biological diversity. However, with increased nutrients from the catchment, the relevance of mussel-provisioned nutrients was nearly eliminated. While species can persist in disturbed systems, their functional relevance may be diminished or lost.

Consumers lead to greater nutrient heterogeneity, but enhanced nutrient loading dampens this.

What are the ecological consequences for the continued loss species?

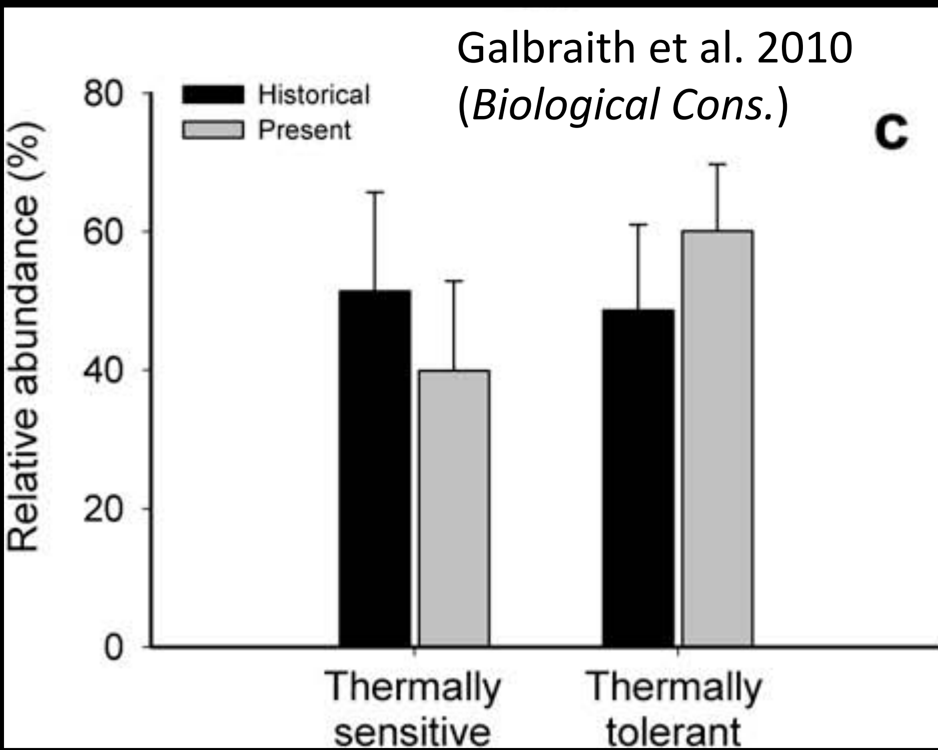


Atkinson et al. 2014, *Biological Conservation*

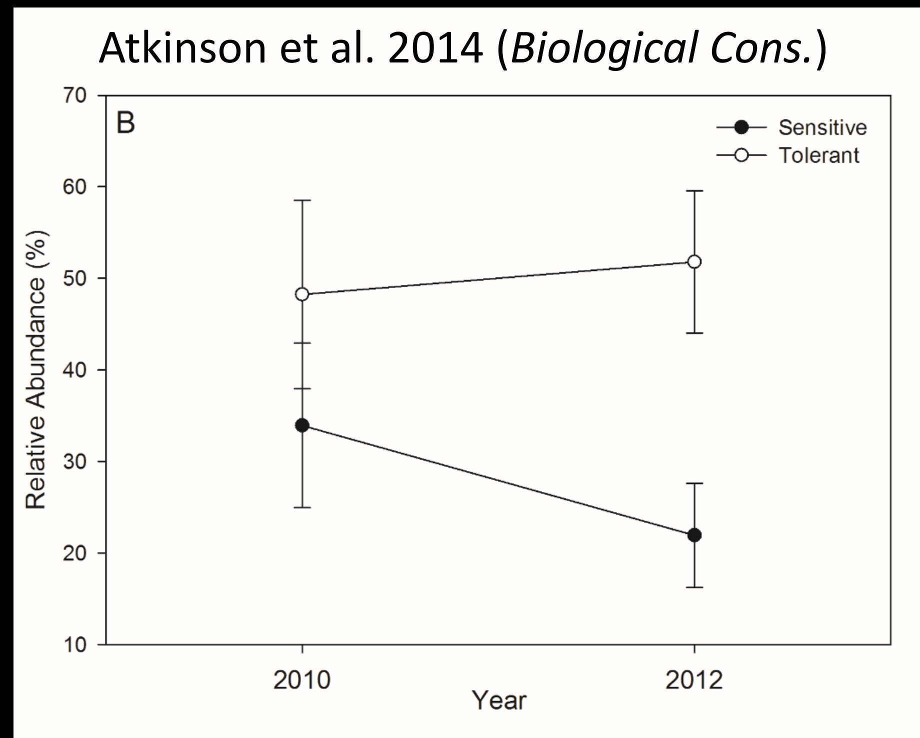
Reduction of Thermally Sensitive Species







Between 1992 and 2003



Between 2010 and 2012 (severe drought 2011)

Loss in ecosystem function

Remineralization

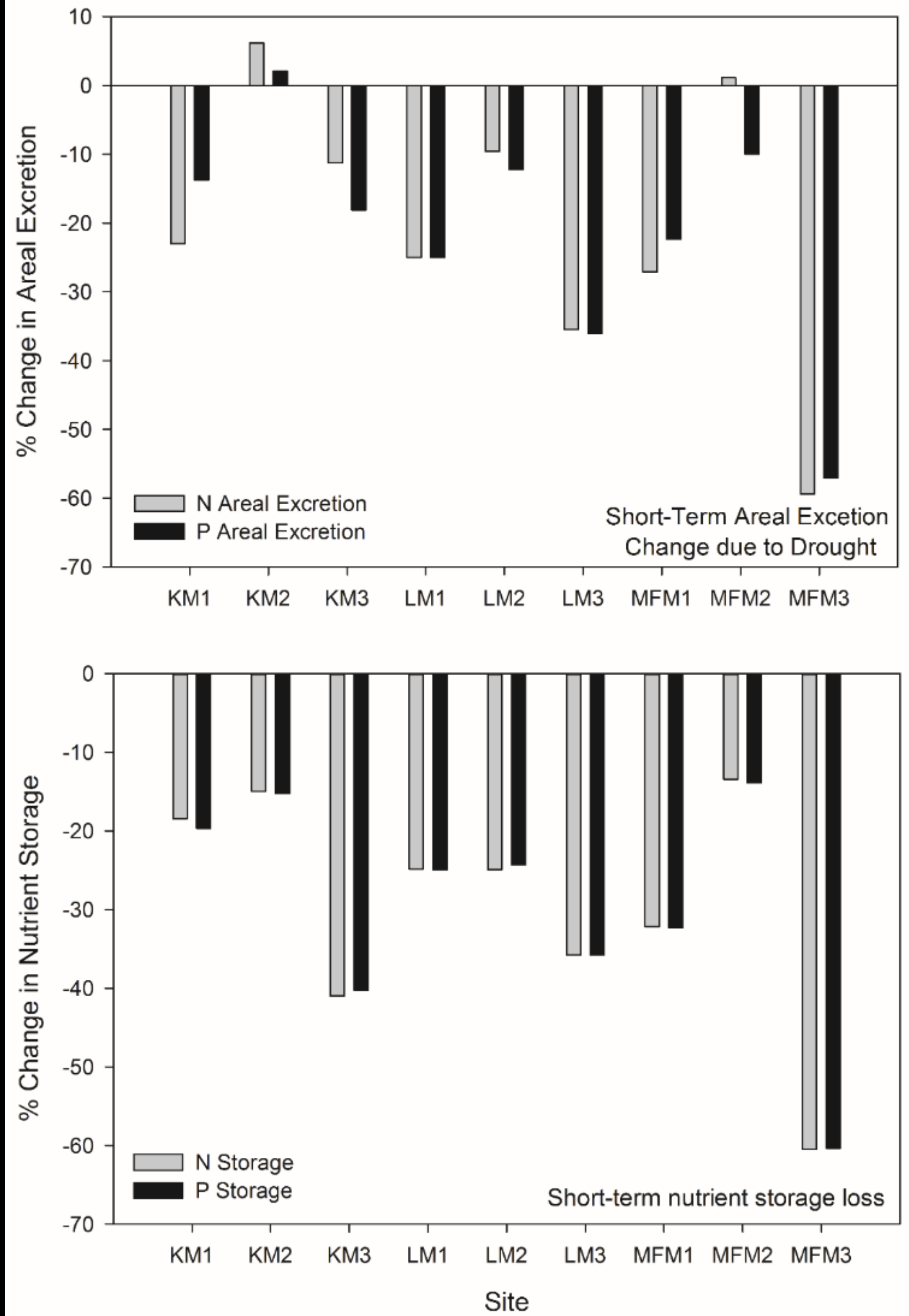
– 30% N loss = 40 μmol N m^{-2} h^{-1}

– 20% P loss = 5 μmol P m^{-2} h^{-1}

Storage Average

– 29% Loss = >15 g N m^{-2}

– 30% P Loss = 5 g P m^{-2}



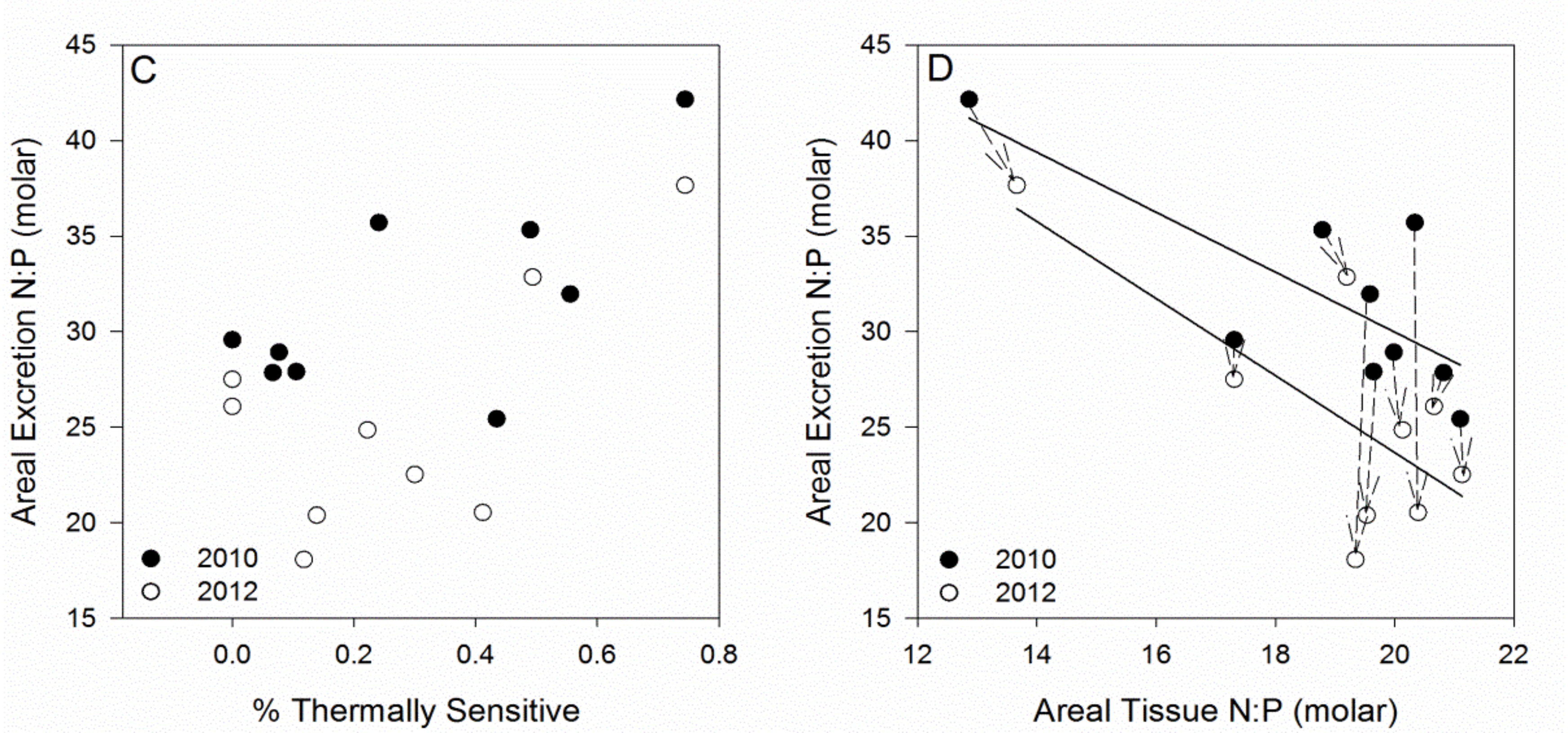
Atkinson et al. 2014 (*Biological Conservation)*

Alteration of N:P

Excretion N:P increased with increasing numbers of thermally sensitive species, but not significantly ($p = 0.10$)

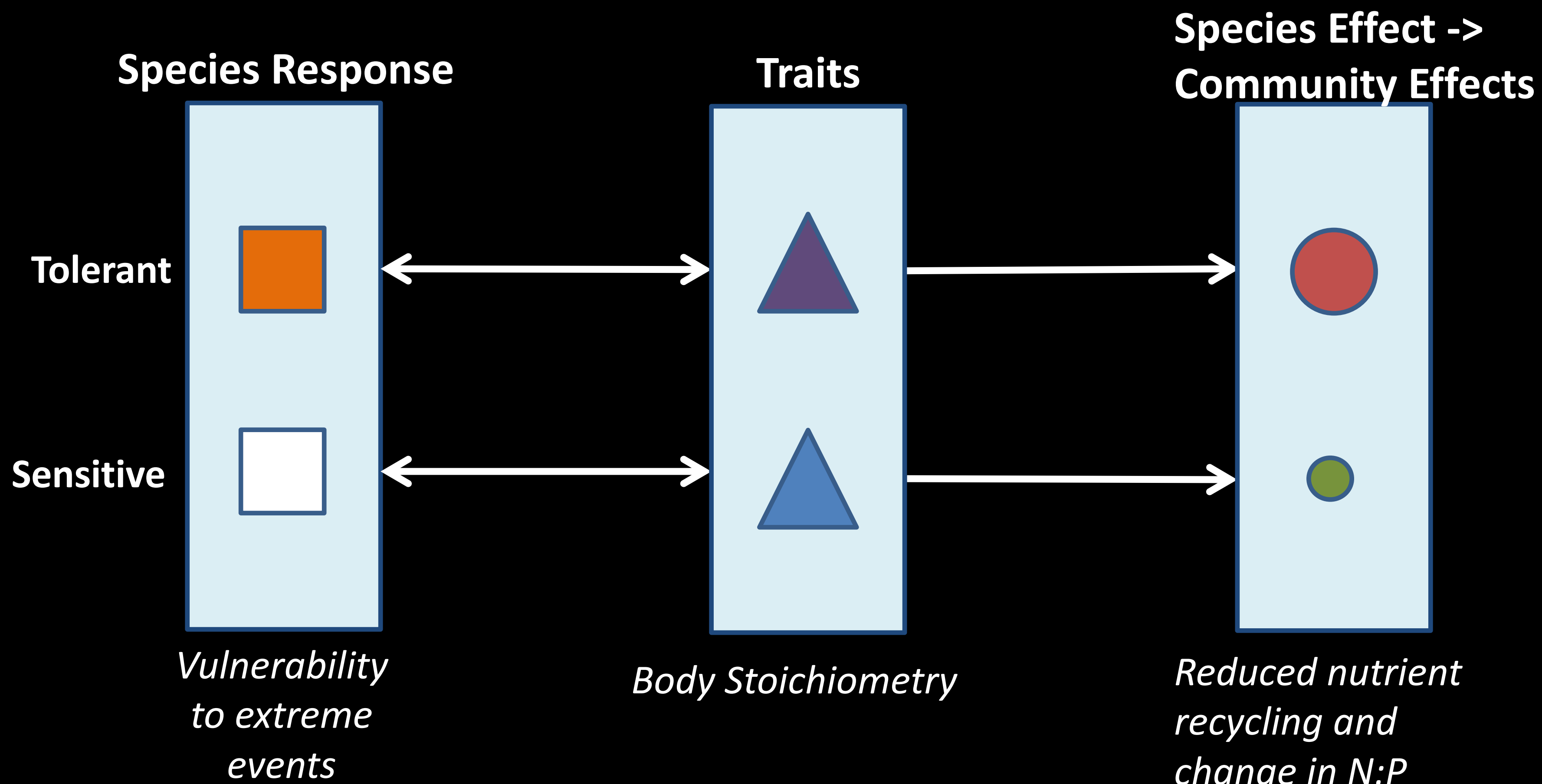
N:P declined significantly due to drought conditions ($W = -45.0$, $p = 0.004$)

Excretion N:P was predicted by tissue N:P

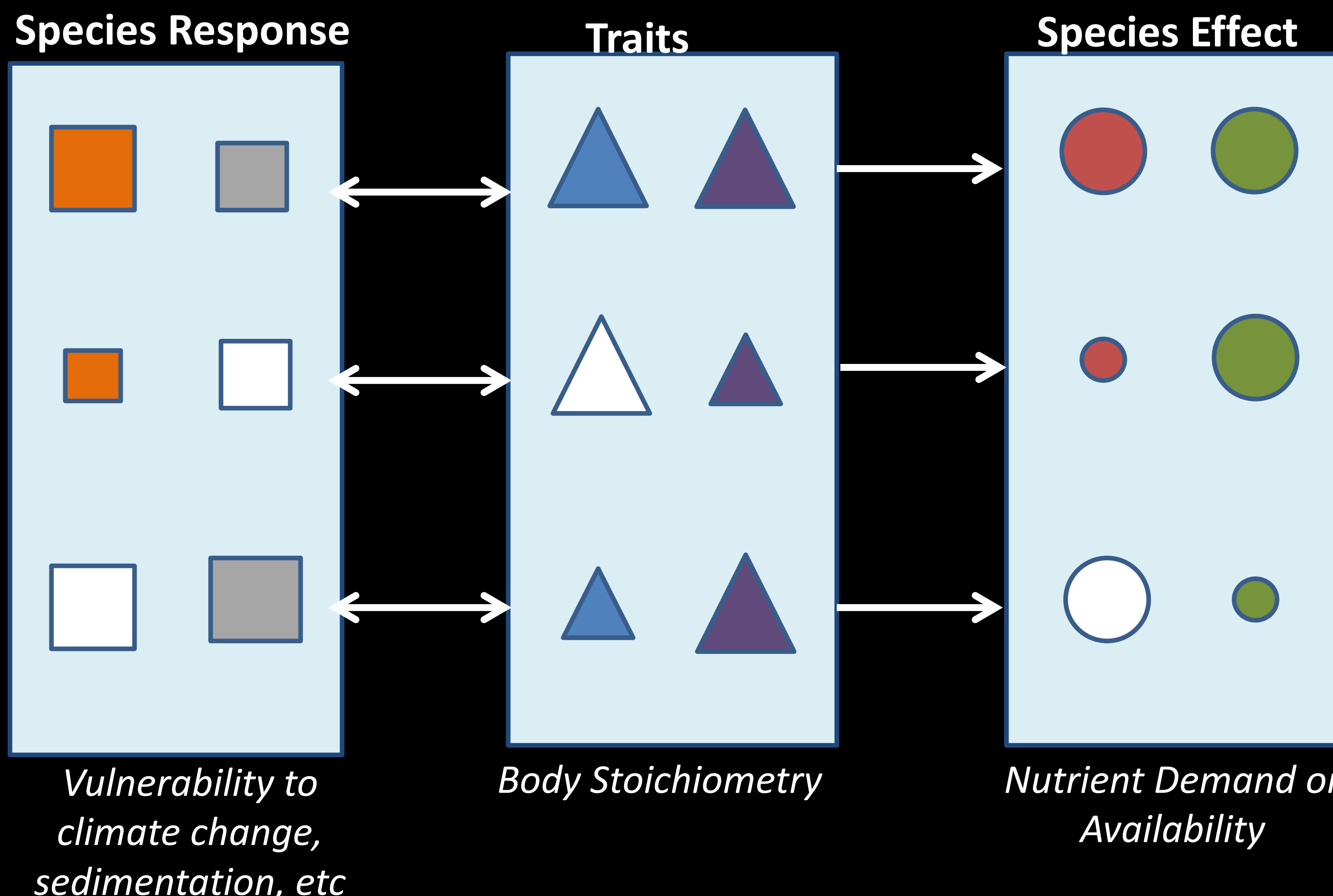


Atkinson et al. 2014 (*Biological Conservation)*

Stoichiometric traits may vary as a function of tolerance



Can we link stoichiometric traits and physiological traits (i.e. thermal traits) to understand ecosystem vulnerability and predict species losses and consequential declines in ecosystem function?



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

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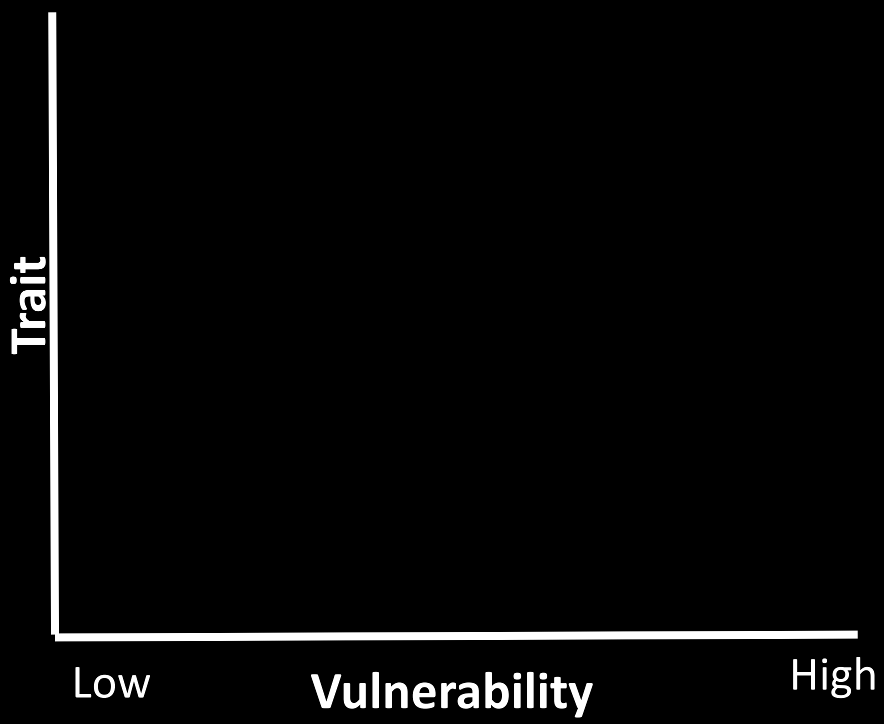

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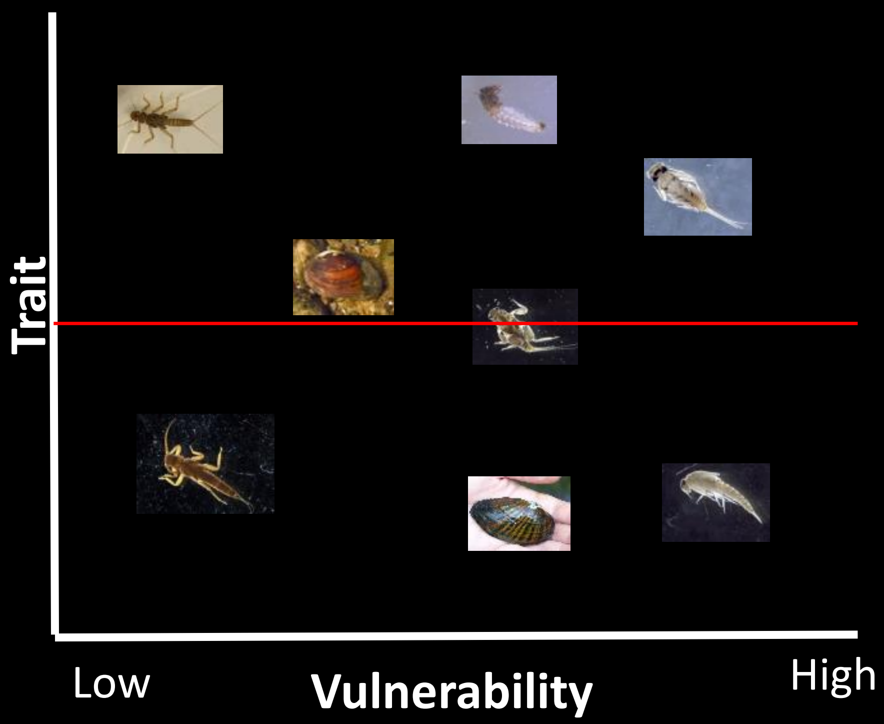

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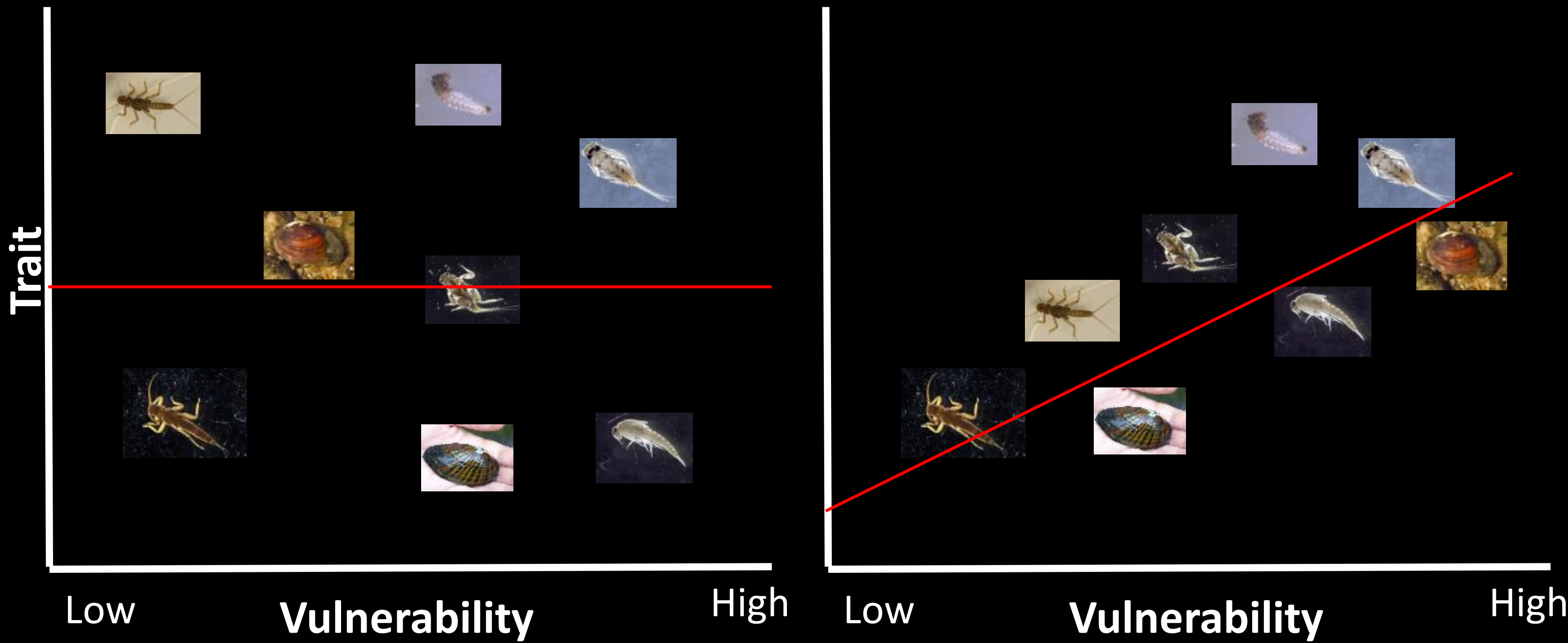
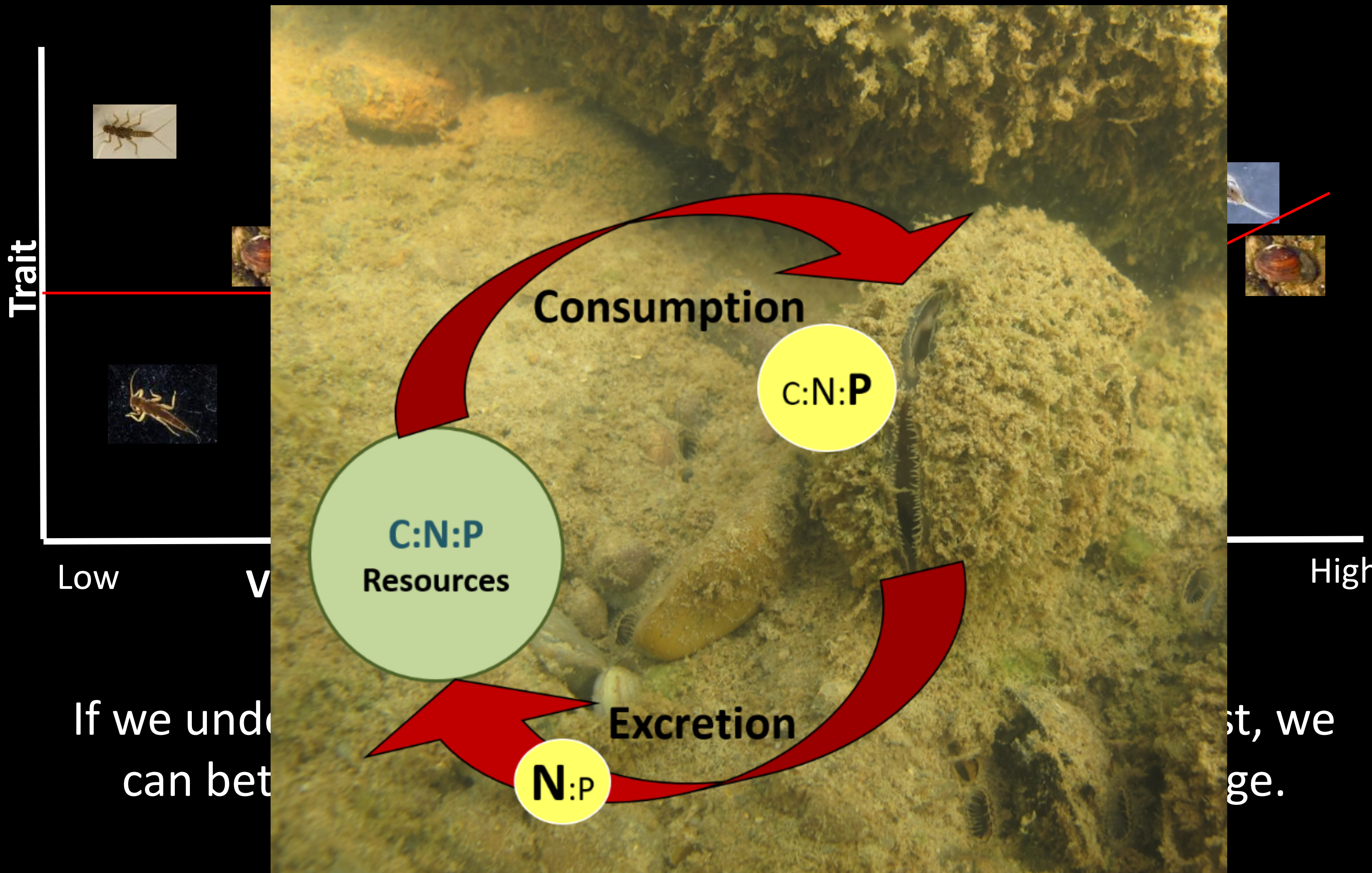
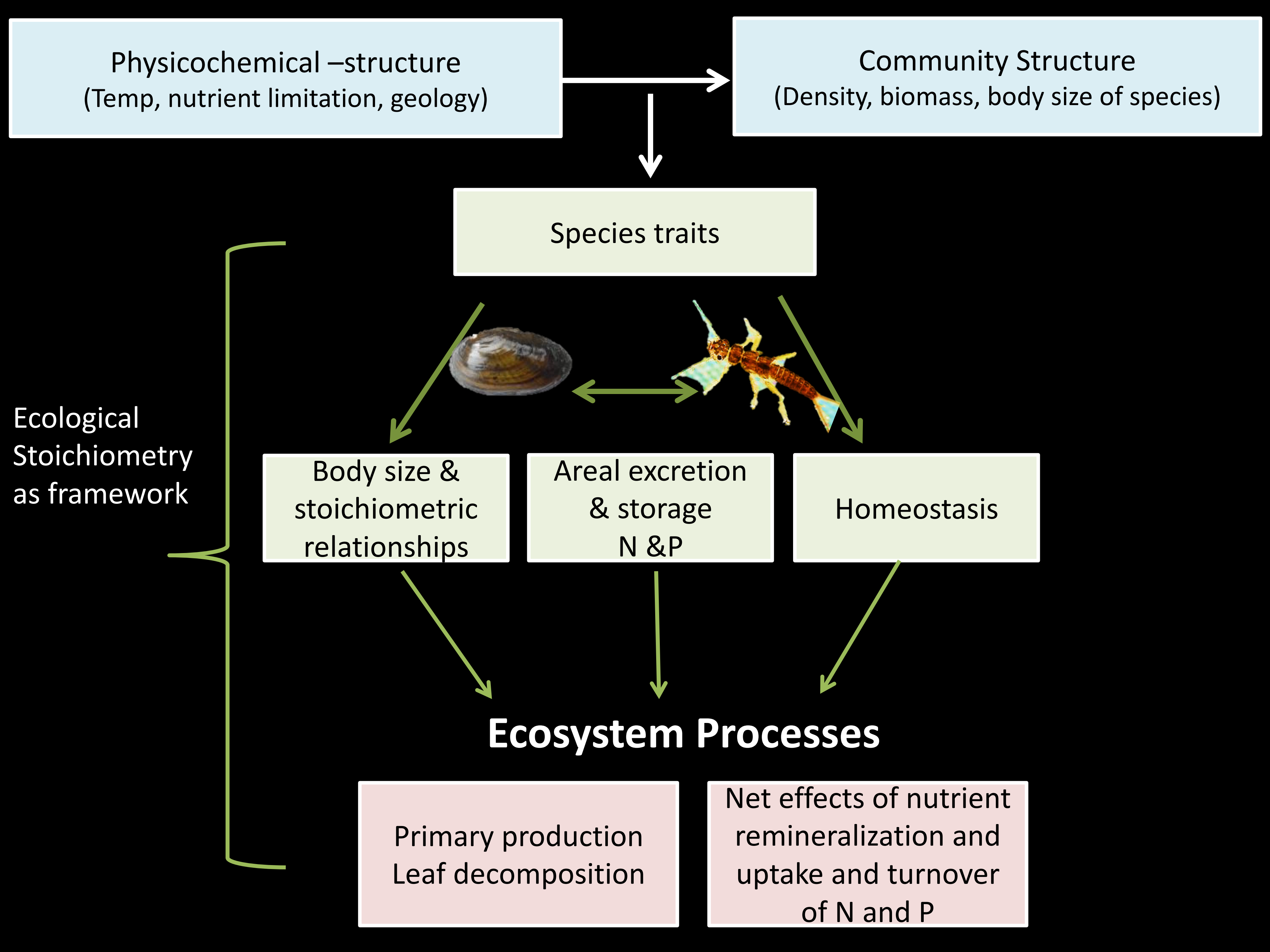


If we understand the traits and functions that may be lost, we can better predict the ramifications of ecological change.

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



If we unde… st, we
can bet… ge.



Physicochemical –structure
(Temp, nutrient limitation, geology)
Community Structure
(Density, biomass, body size of species)
Species traits
Ecological Stoichiometry as framework
Body size & stoichiometric relationships
Areal excretion & storage N &P
Homeostasis
Ecosystem Processes
Primary production
Leaf decomposition
Net effects of nutrient remineralization and uptake and turnover of N and P

ANY QUESTIONS?

<u>More info</u>

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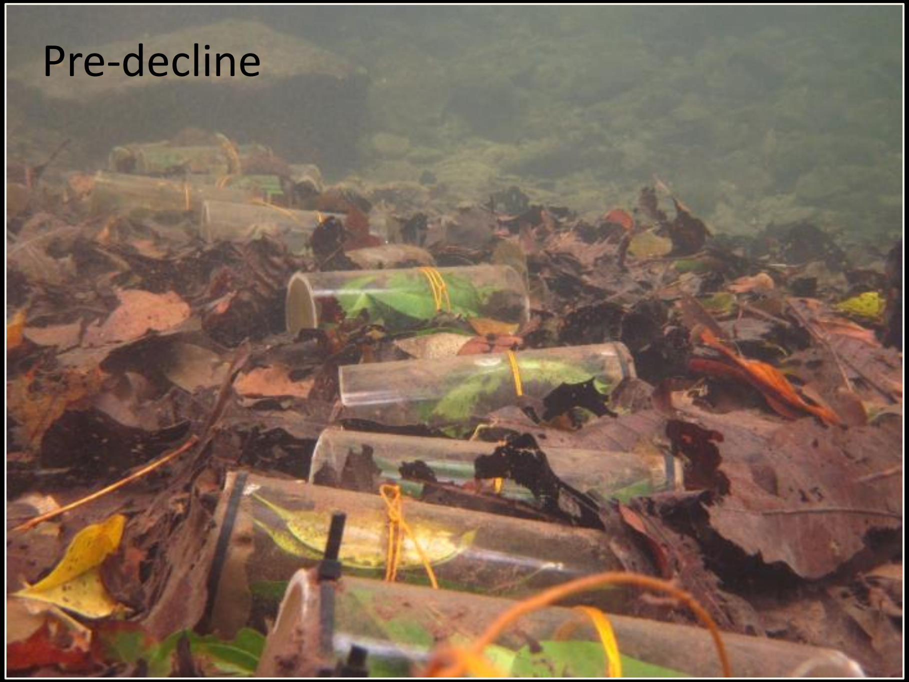
"Mussels are not dismissible, even by those who have little interest in the natural world. Their presence is a signature of healthy aquatic ecosystems, to which they contribute as living water filters."

- E.O. Wilson

Tadpole chamber experiment

What are the effects of tadpoles & invertebrate shredders on leaf decomposition processes?



4 Treatments: 32 day incubation

Control

Tadpoles (Grazer on algae)

Tadpoles + Shredders

Shredders

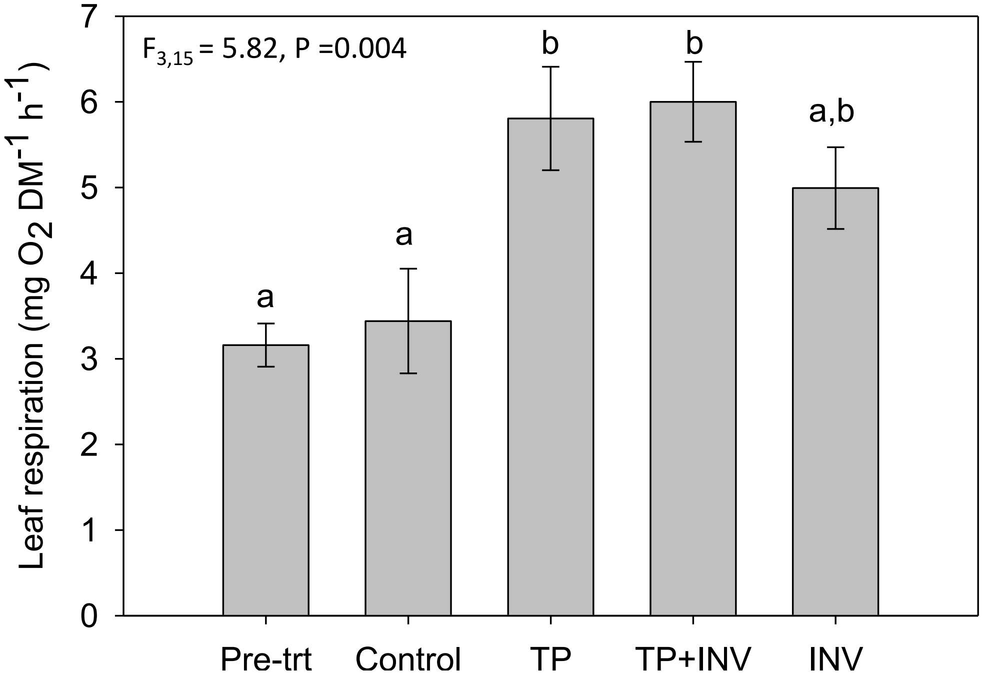
* Natural stream densities used for each chamber

Smilisca

Anchytarsus

Phylloicus

Rugenski et al. 2012

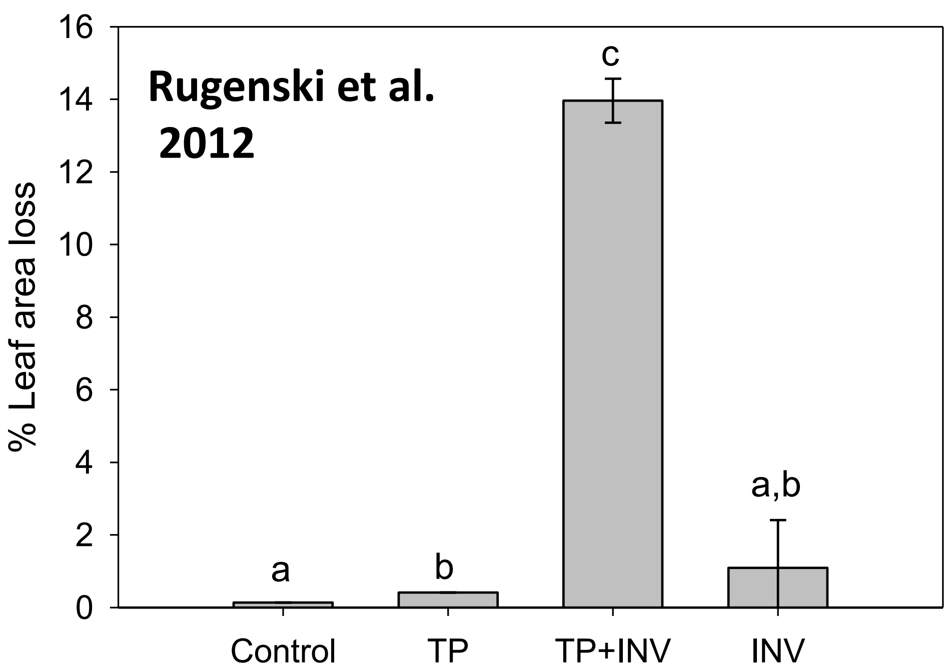


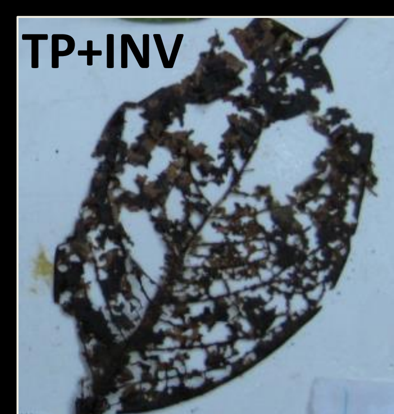
Chamber experiment

↑ Respiration in Tadpole & Tadpole+INV

↑ Leaf area loss in Tadpole+INV

Facilitation between tadpoles & shredding macroinvertebrates





Stoichiometric Traits, Age, and Phylogeny

Some phylogenetic signal

Decline in N:P with age