Porfolio effects and species diversity in Chesapeake Bay SAV

Christopher J. Patrick, Kevin E. McCluney, Albert Ruhi, Andrew Gregory, John Sabo, and James H. Thorp

SAV Working Group
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VIMS | William & Mary
Virginia Institute of Marine Science
BGSU
University of California Berkeley
ASU Arizona State University
KU

Why do we find some species here, but not there?

What controls the distribution of species and communities (or SAV) in space and time?

> The world is changing

Land use change


Habitat Connectivity

Fragmentation

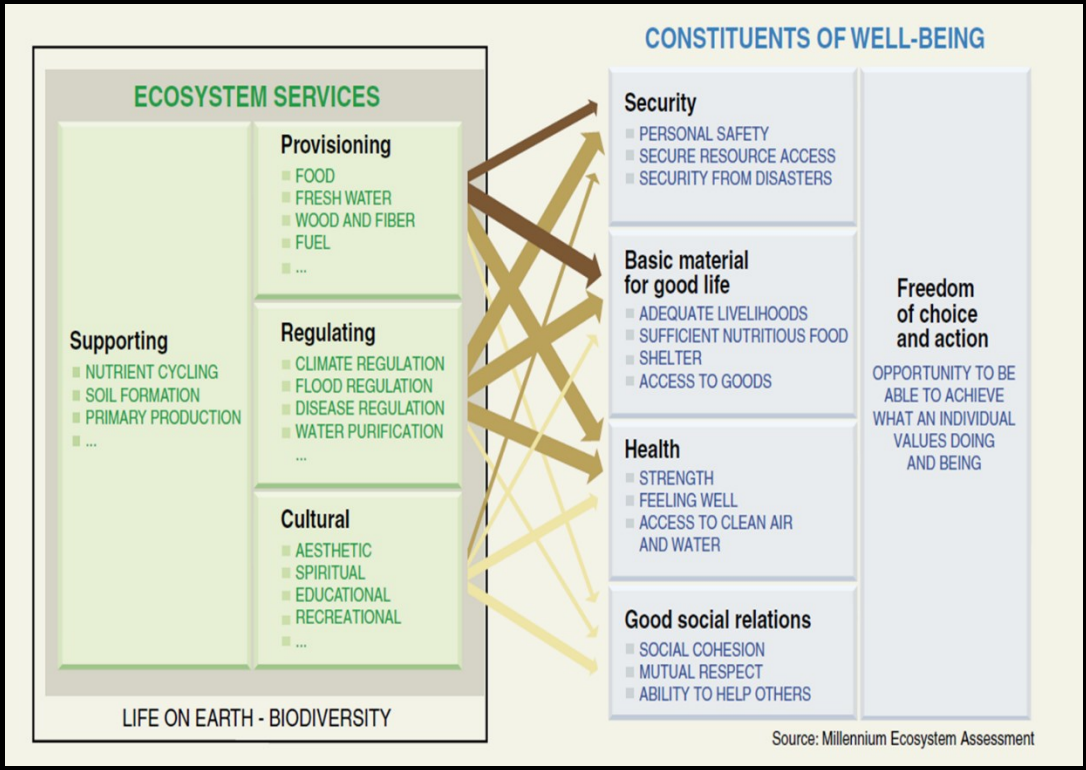

Climate change


New connections


Invasive Species

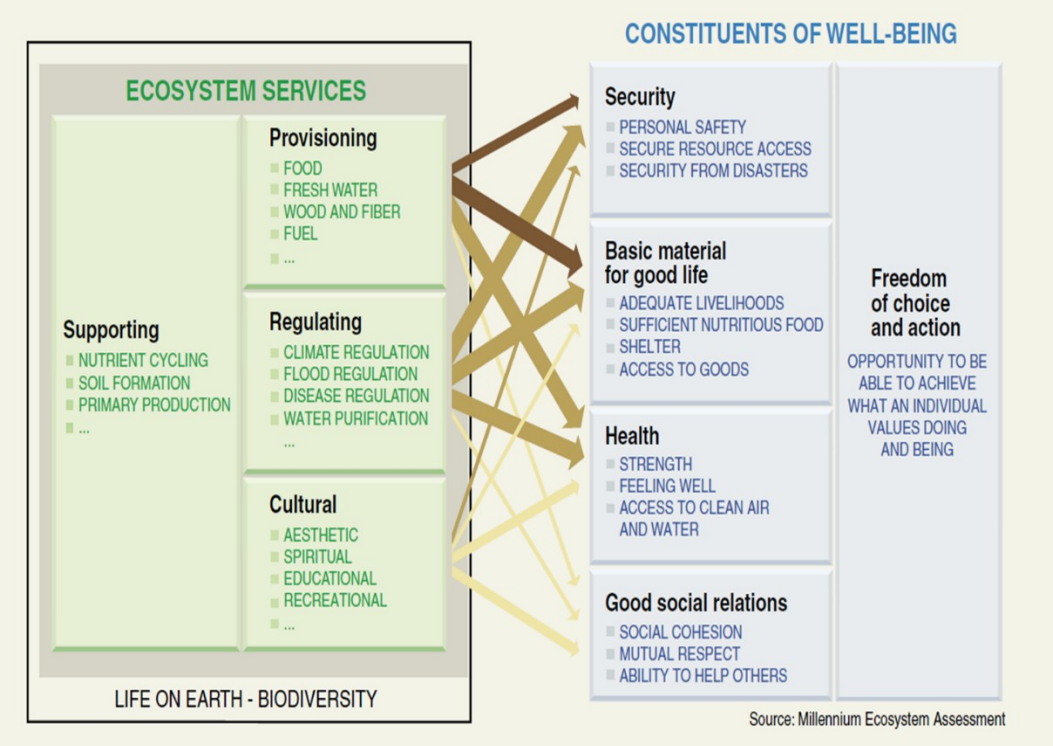


> Ecosystem Functions and Services



- Submersed aquatic vegetation (**SAV**):
  - Provides habitat
  - Stores carbon
  - Protects shorelines
  - Improves water quality

> Ecosystem Functions and Services



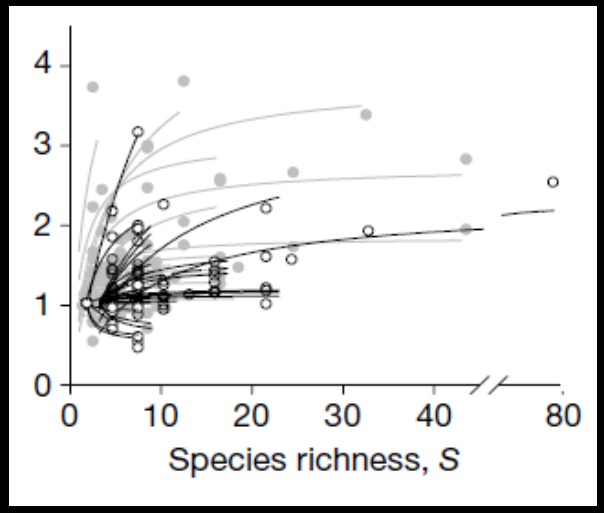
What is the relationship between biodiversity and ecosystem functioning?

What drives stability in ecosystem functioning?

> Biodiversity and Ecosystem Functioning

What is the relationship between biodiversity and ecosystem functioning?

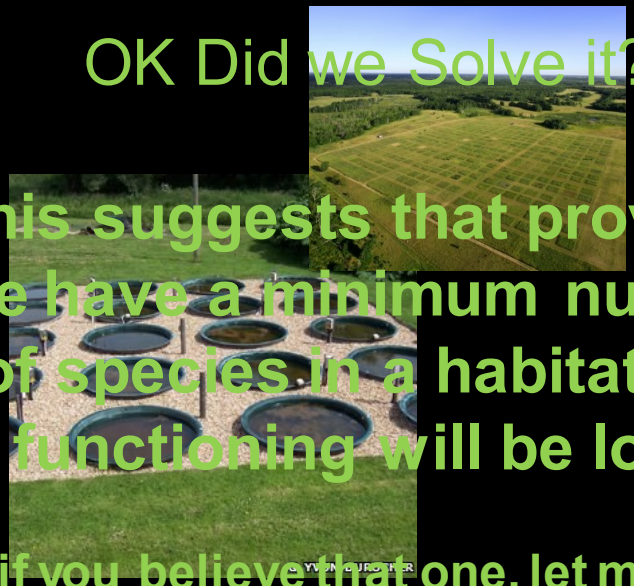
Positive relationship between α-richness and ecosystem functioning



Cardinale et al. 2006. *Nature* 443: 989-992

To make this a tractable question ecologists have looked at the number of species in a mesocosm

OK Did we Solve it?



This suggests that provided we have a minimum number of species in a habitat, no functioning will be lost.

(if you believe that one, let me tell you another one)

> Biodiversity and Ecosystem Functioning

What is the relationship between biodiversity and ecosystem functioning?

Assemblage Time Series Reveal Biodiversity Change but Not Systematic Loss

Maria Dornelas,[1]* Nicholas J. Gotelli,[2] Brian McGill,[3] Hideyasu Shimadzu,[1,4] Faye Moyes,[1] Caya Sievers,[1] Anne E. Magurran[1]

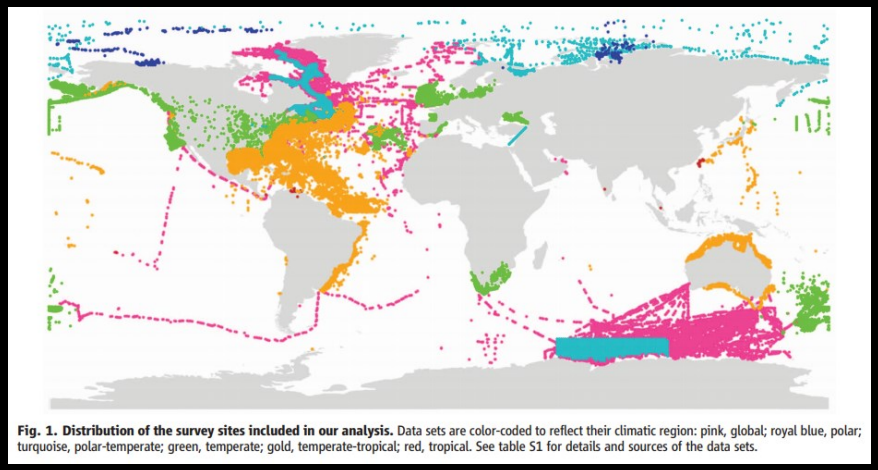
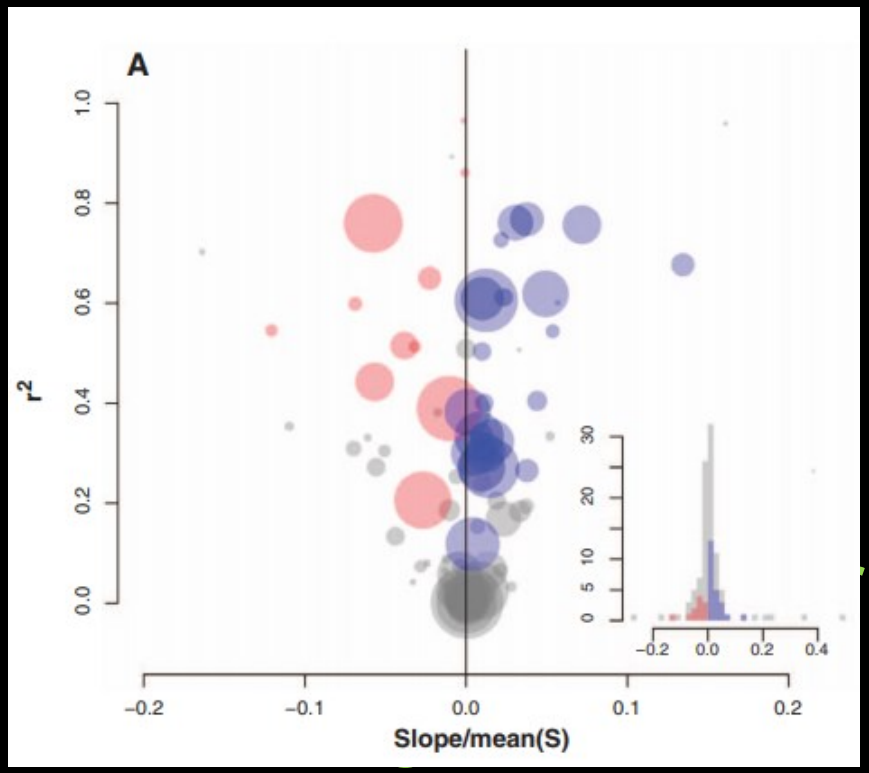


Fig. 1. Distribution of the survey sites included in our analysis. Data sets are color-coded to reflect their climatic region: pink, global; royal blue, polar; turquoise, polar-temperate; green, temperate; gold, temperate-tropical; red, tropical. See table S1 for details and sources of the data sets.



Dornelas et al. 2014. *Science Reports*

Local richness doesn't seem to be changing, despite global extinctions.

So does that mean that global extinctions are not impacting ecosystem functioning?

> Biodiversity and Ecosystem Functioning

What is the relationship between biodiversity and ecosystem functioning?

Assemblage Time Series Reveal Biodiversity Change but Not Systematic Loss

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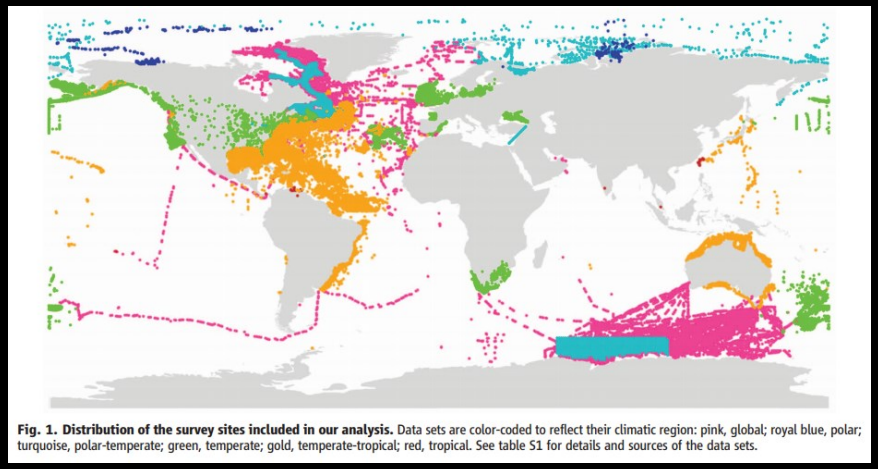

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Dornelas et al. 2014. *Science Reports*

NO!

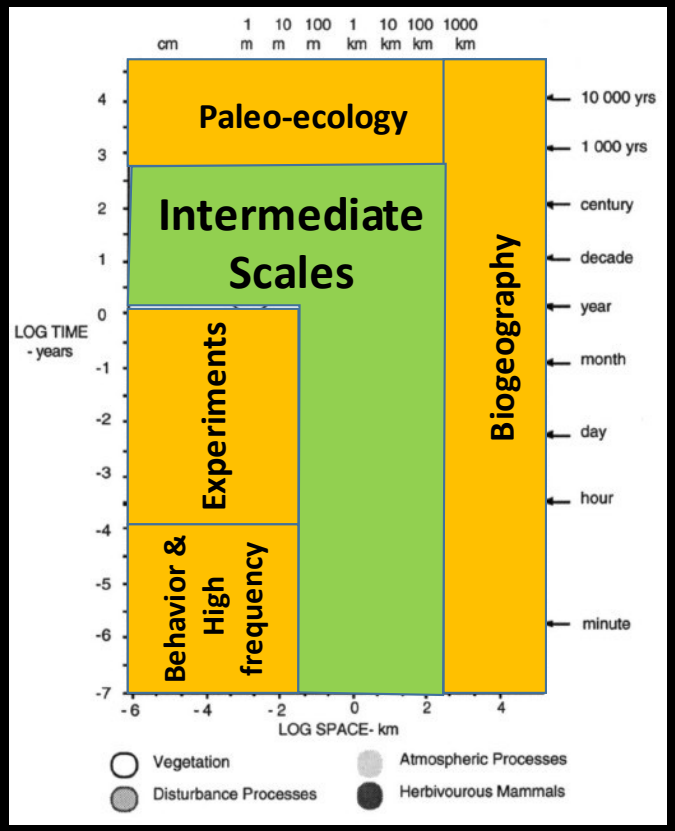
But this shows that it is very difficult to scale the results of small experiments to the **biodiversity change** we're observing in the real world at **landscape scales**

Local richness doesn't seem to be changing, despite global extinctions.

So does that mean that global extinctions are not impacting ecosystem functioning?

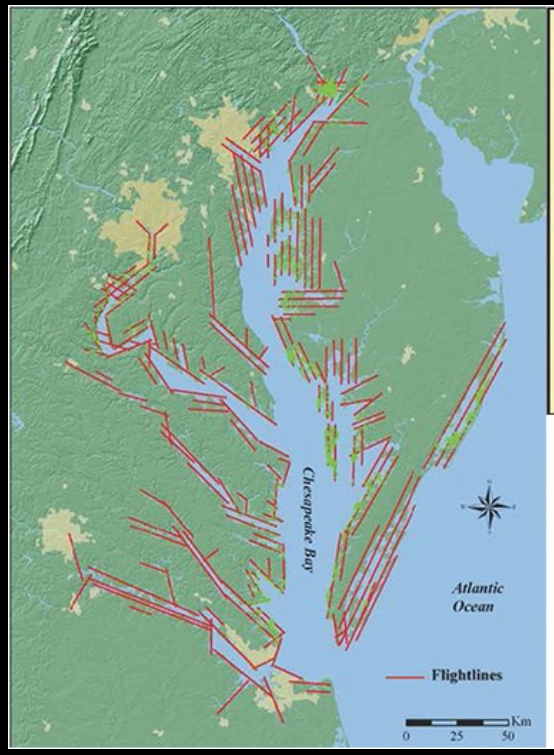
> A question of scale

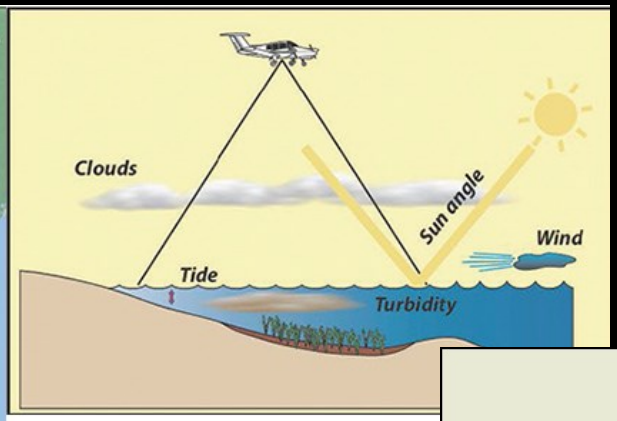
"Perhaps in focusing on local diversity, we have been asking the wrong questions or, perhaps, the right questions on the wrong scale."
- Robert Ricklefs



Petersen et al. Ecosystems 1998 1(1): 6–18

> SAV in Chesapeake Bay – a Model System

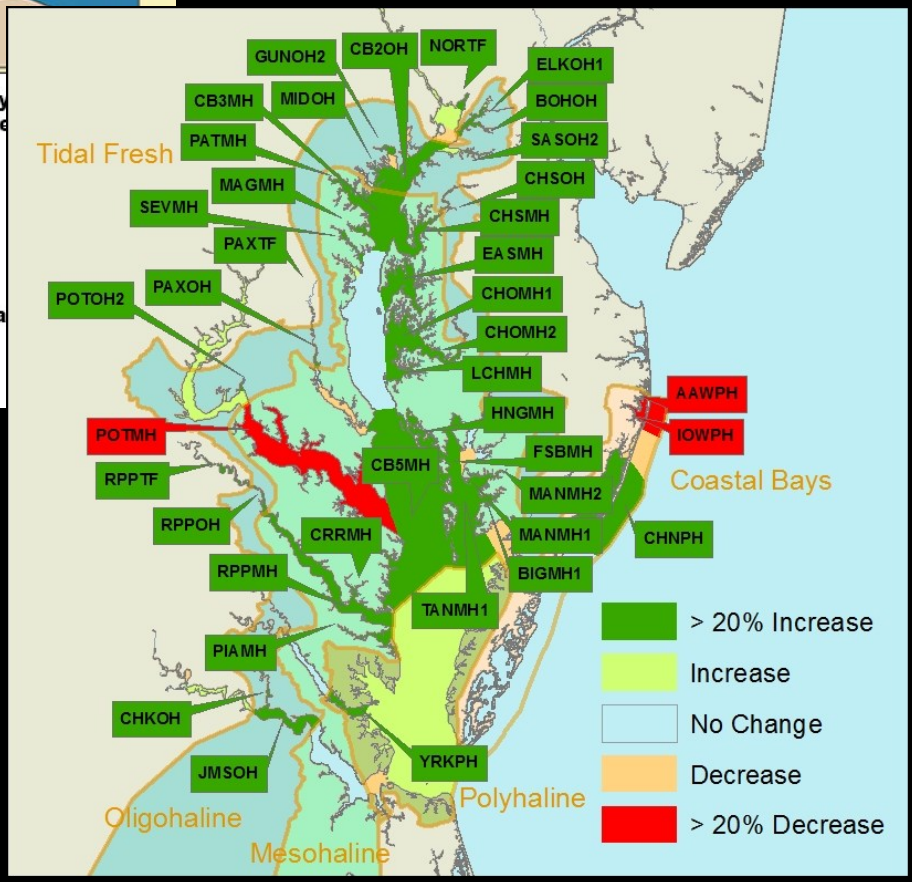




Aerial photographs and digital imagery along the red flight lines flown over the left. Flights require:
≈ low wind
≈ minimal cloud cover
≈ low tide
≈ low turbidity
≈ low sun angle

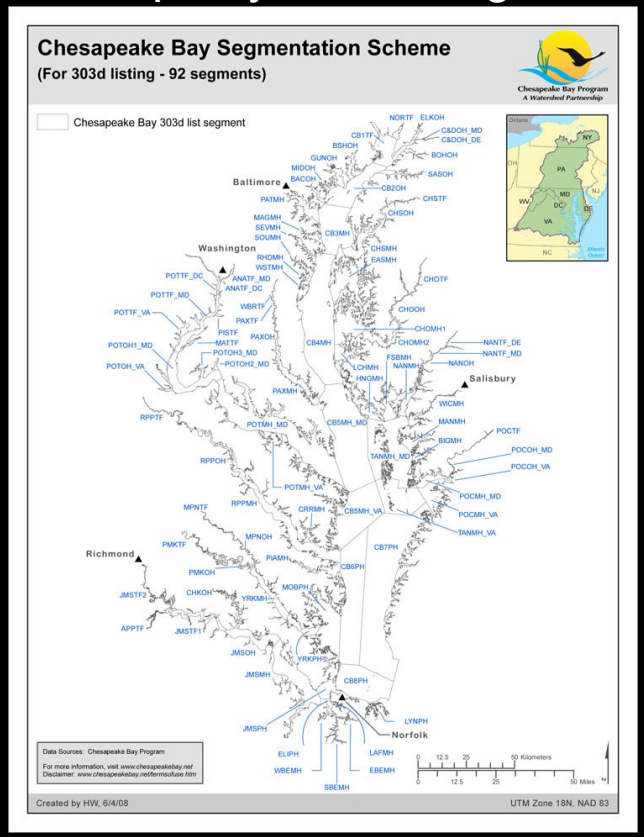
Funded by the EPA, VA DEQ, MD DNR a Coastal Program.

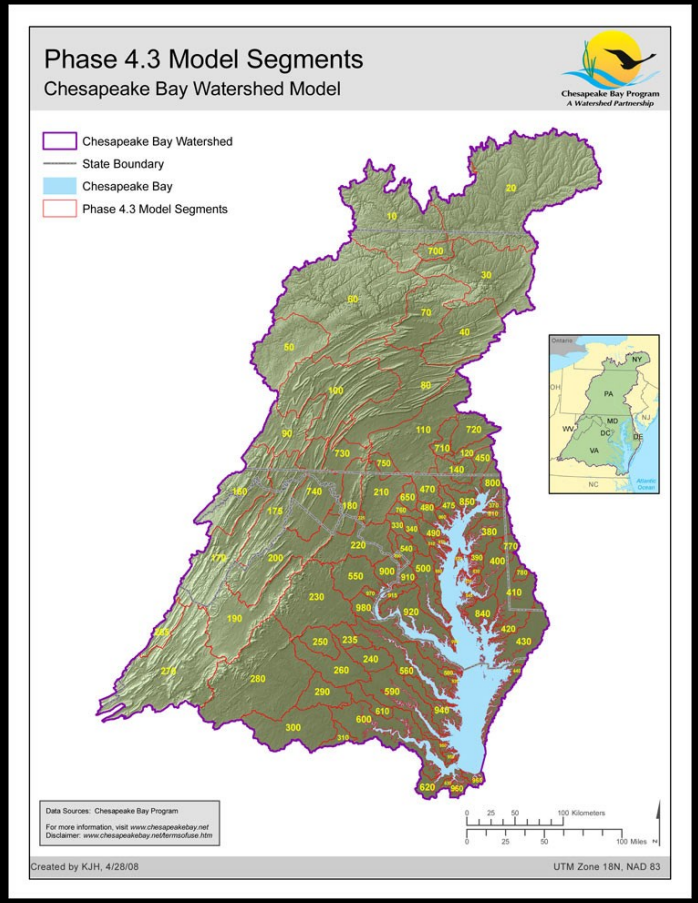
VIMS SAV Mapping Program



> Long-term surveys (1984-present)

Water quality monitoring





Chesapeake Bay Watershed Model

> 23 species of SAV in the Bay

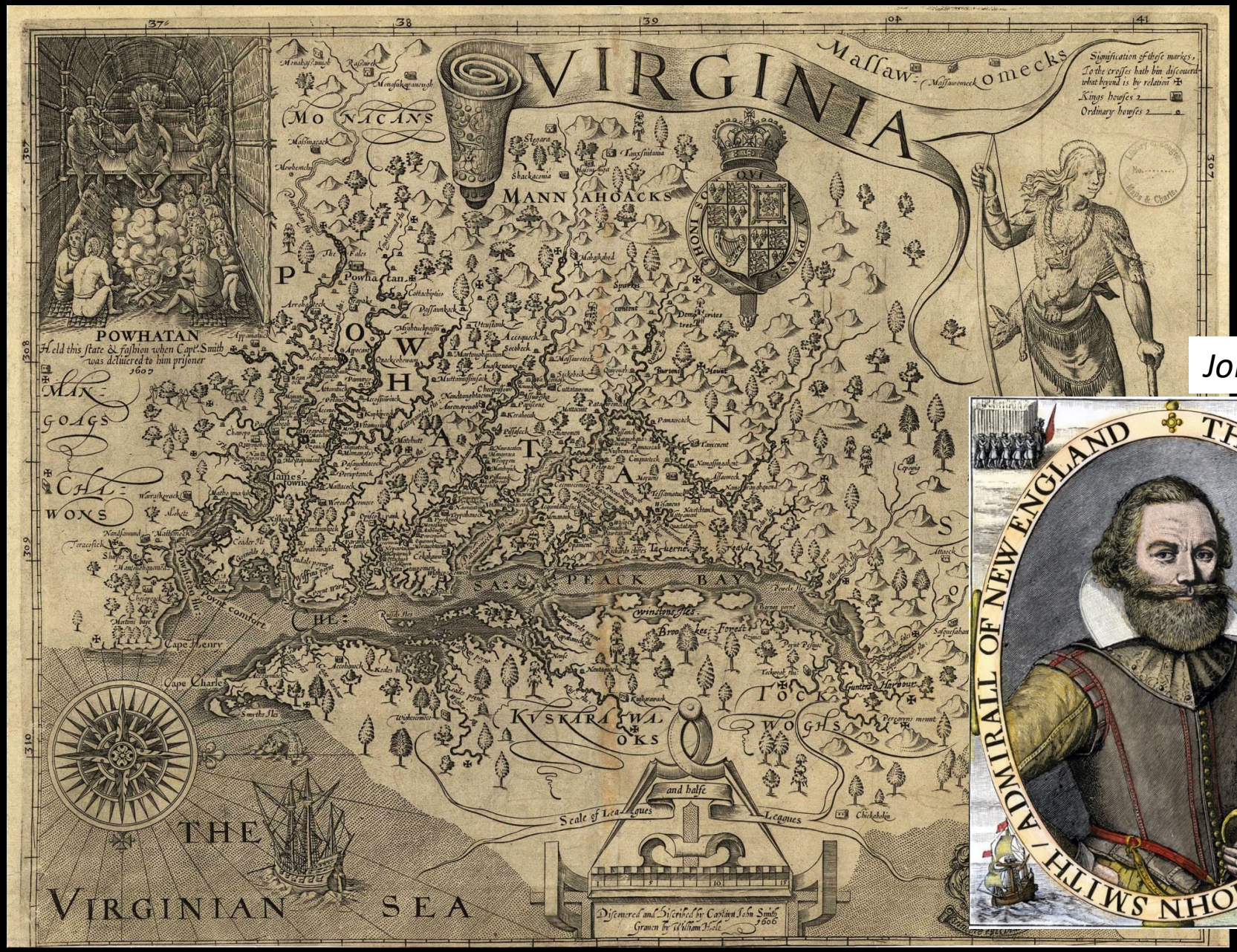
Freshwater grasses

Seagrasses

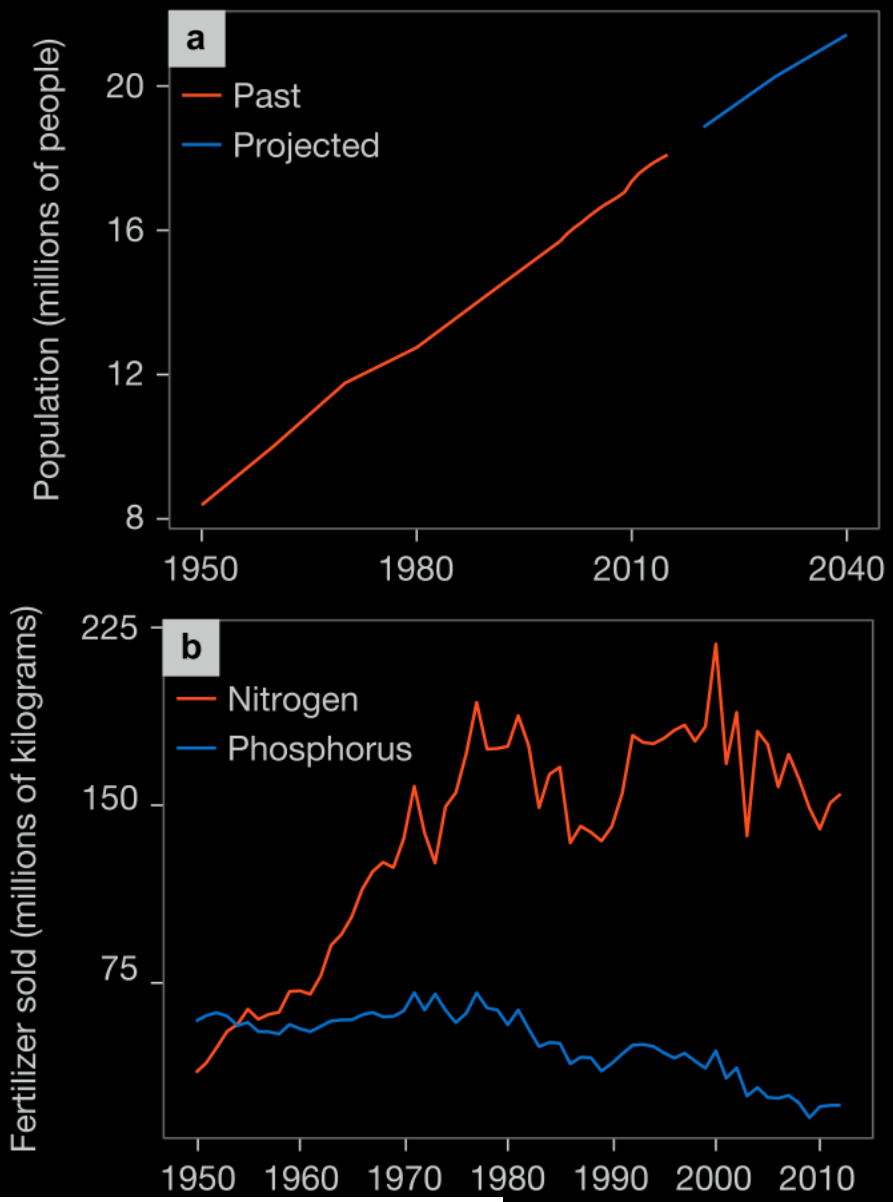
> Long-term surveys (1984-present)

30 years of sporadic ground survey data of species identity by river system collected by researchers, state agencies, and trained volunteers

> Chesapeake Bay: 400 years of change



> Human impacts are on the rise



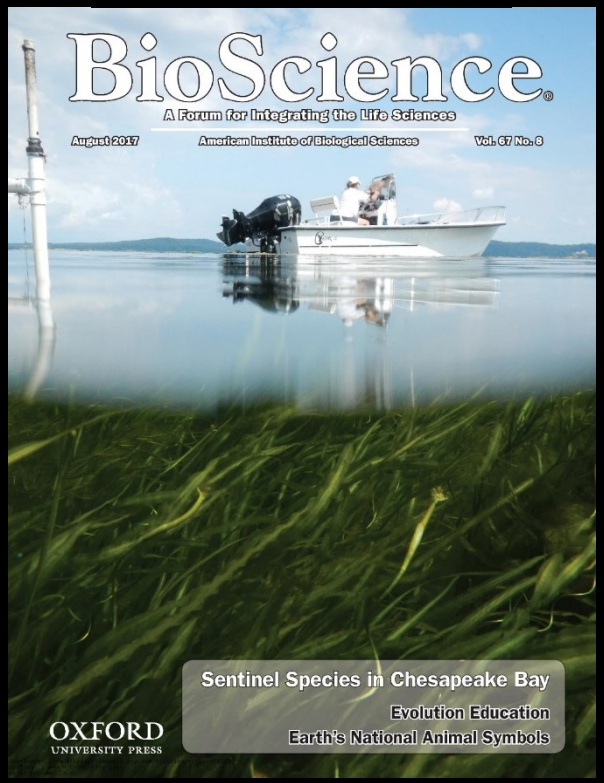
Eutrophication

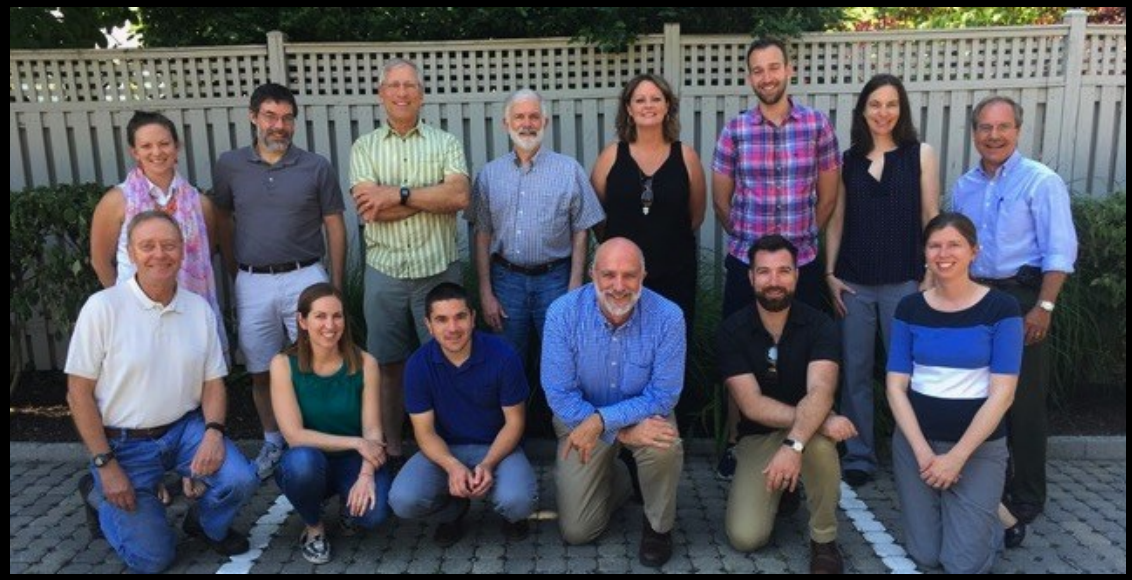
Shoreline modification

Orth et al. 2017 *BioScience*

> Those impacts trickle down…

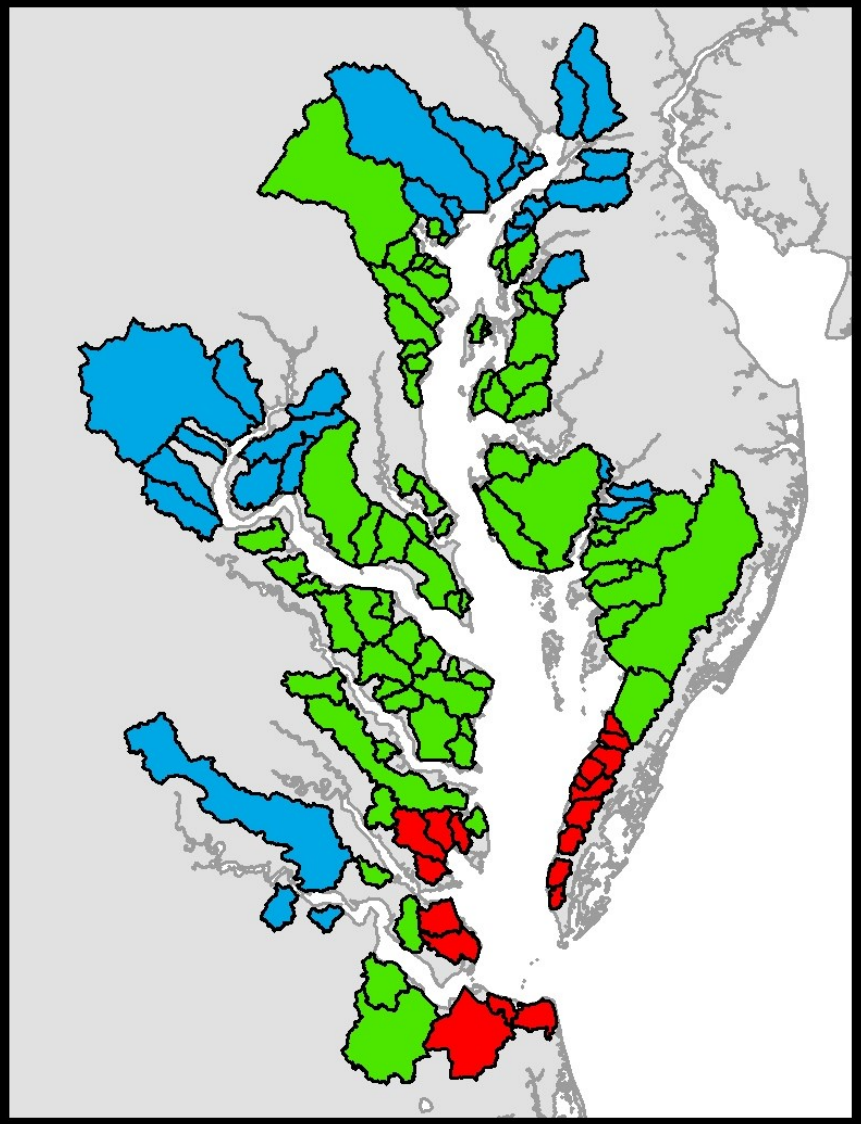
> SAV Synthesis



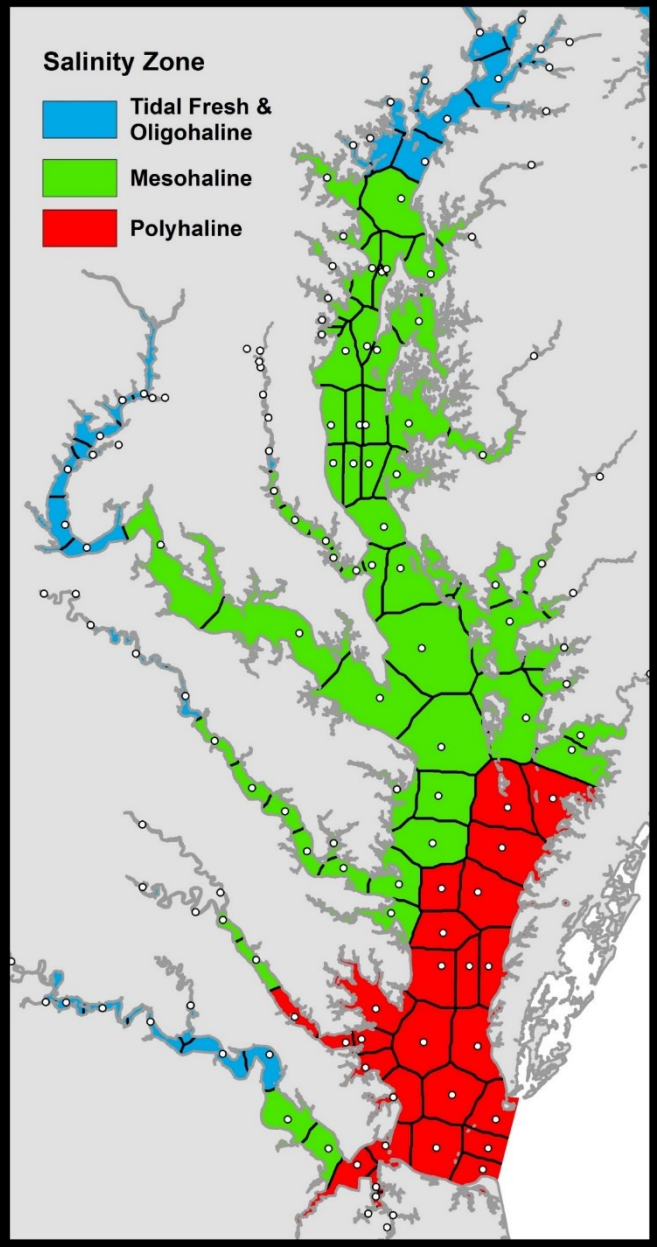


> Two separate analyses

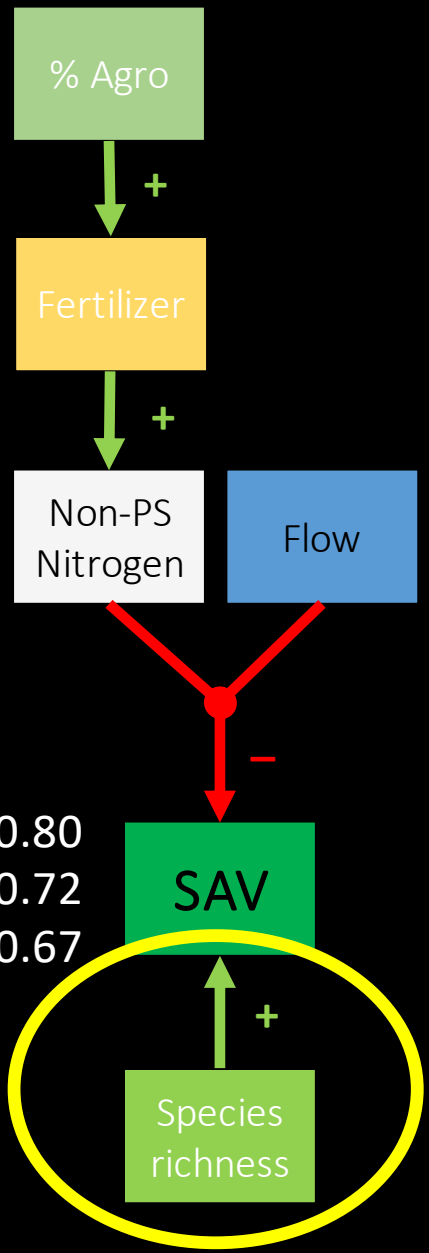
Subestuary analysis



Bay-wide analysis

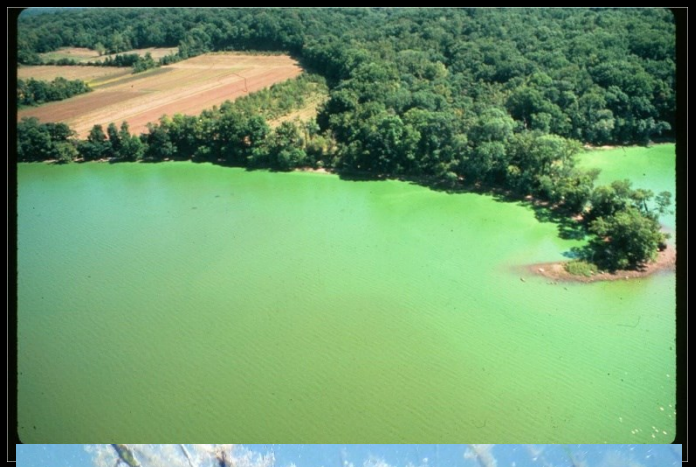


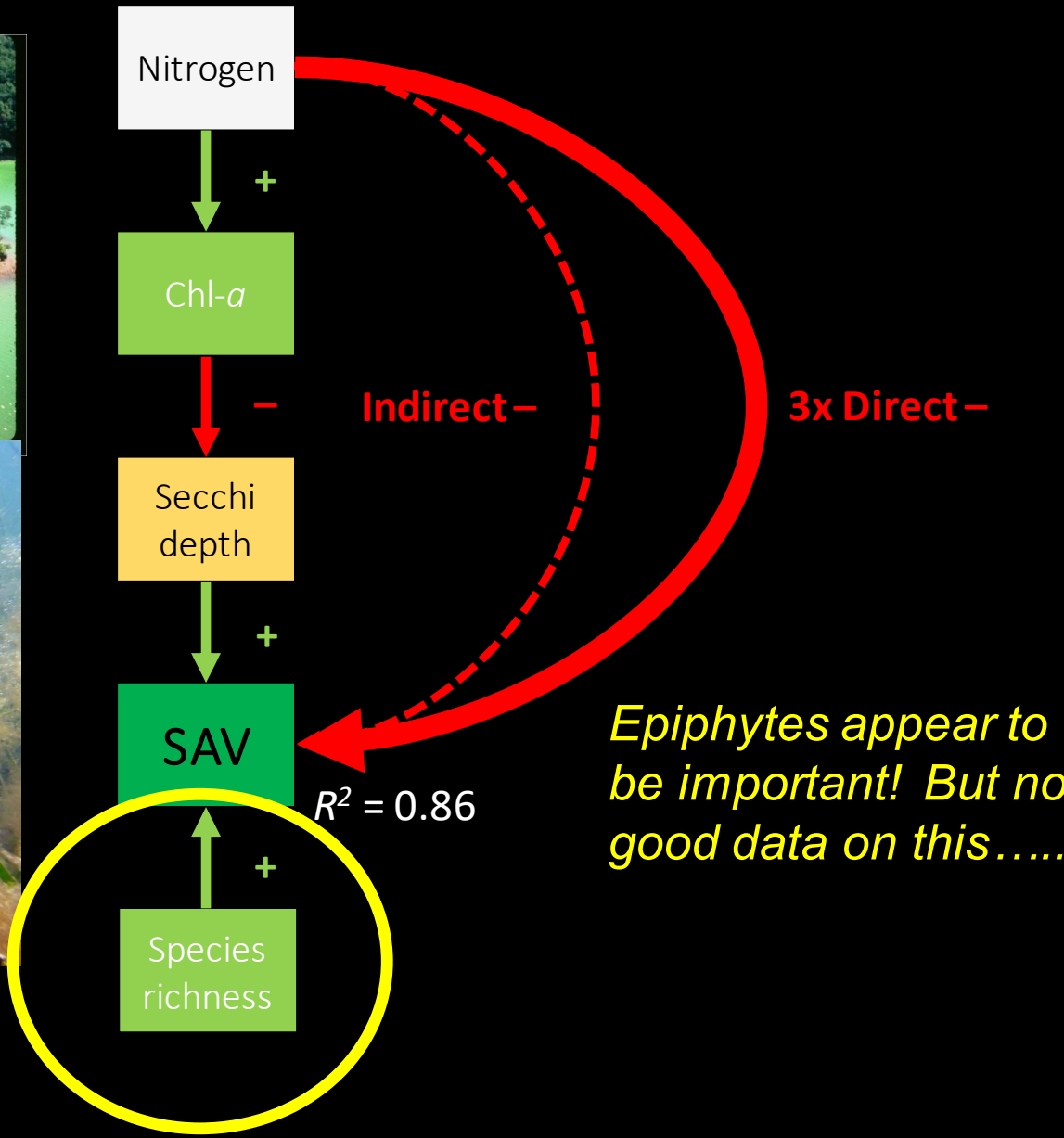
> What's happening in the watershed?



Freshwater R^2 = 0.80
Mesohaline R^2 = 0.72
Polyhaline R^2 = 0.67

> What's happening in the water column?





Epiphytes appear to be important! But no good data on this…..

> What do we still need to understand?

Biodiversity appears to be an important component of the recovery and a predictor of abundance.

Mechanistically how does biodiversity contribute to SAV stability?

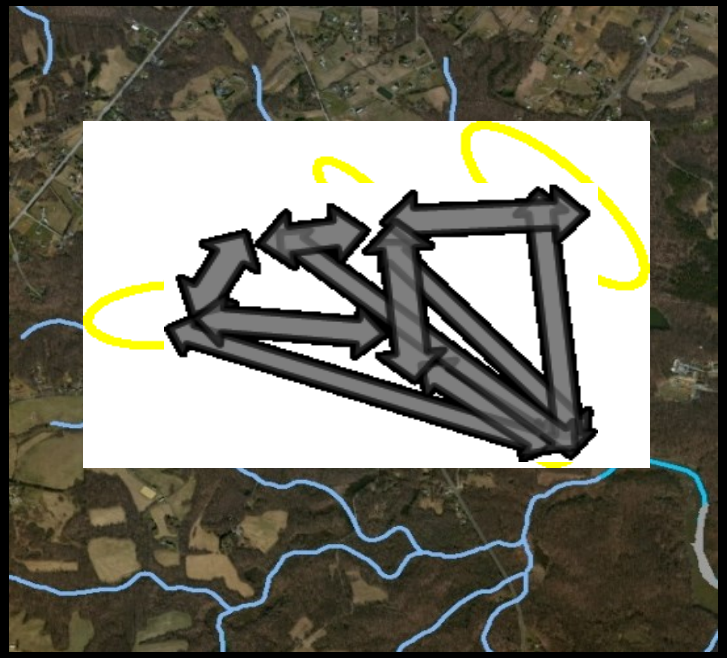
> But first… a few definitions

α-richness – Richness at the scale of the individual habitat

Scale of most experiments

β–diversity – measure of difference between communities in different habitats

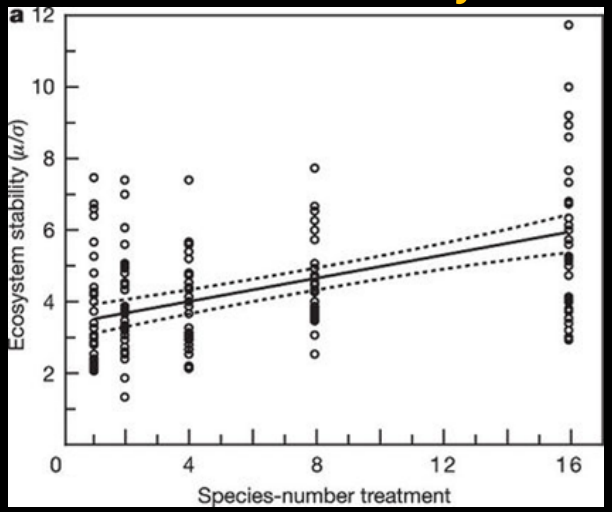
γ– richness: scale of regions or even the whole planet



> Drivers of Ecosystem Functioning

Portfolio Effects - Much like with mutual funds, a diverse portfolio of species confers temporal stability

Local Diversity

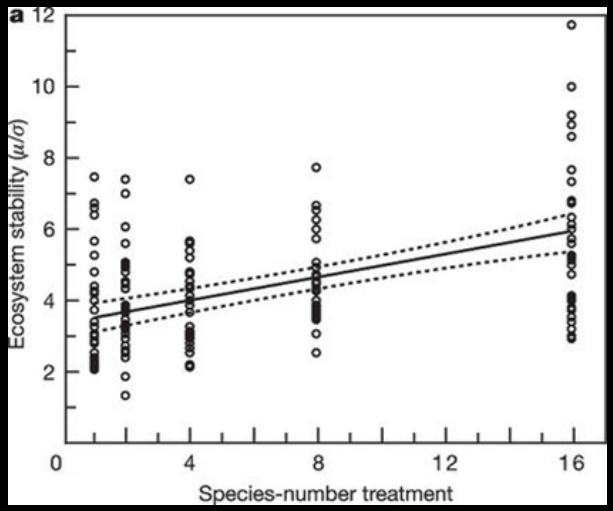


Tilman et al. 2006 Nature

> Drivers of Ecosystem Functioning

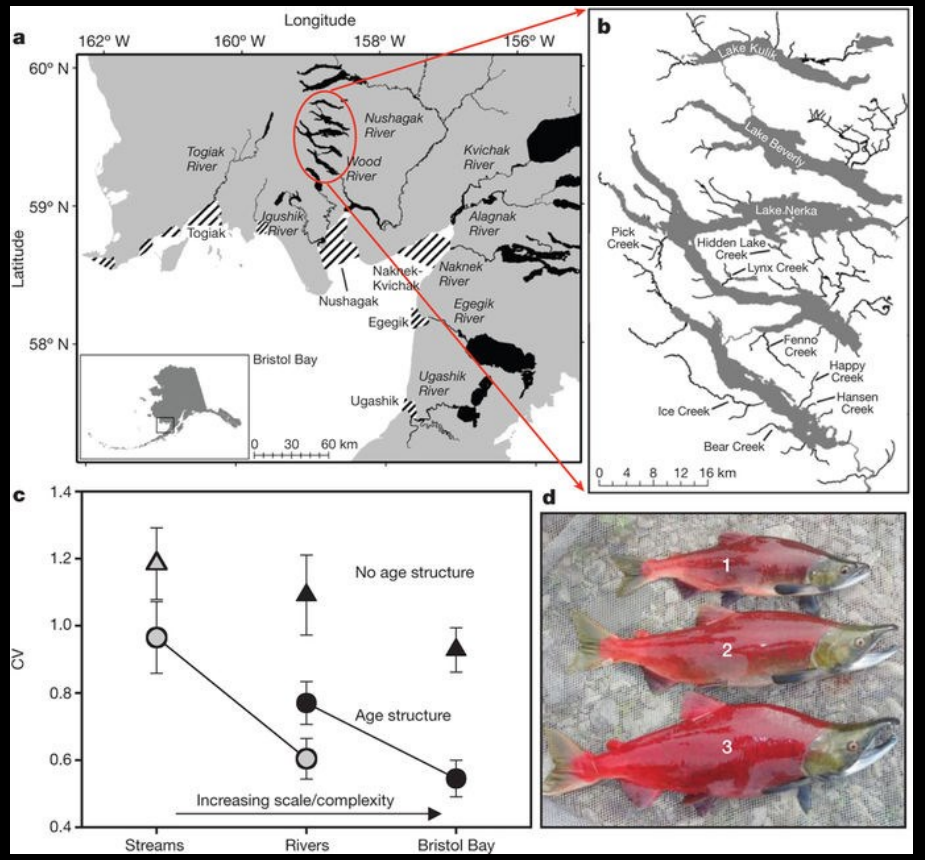
Portfolio Effects

Local Diversity



Tilman et al. 2006 Nature

Population Diversity on Landscapes



Schindler et al. 2010 Nature

> Drivers of Ecosystem Functioning

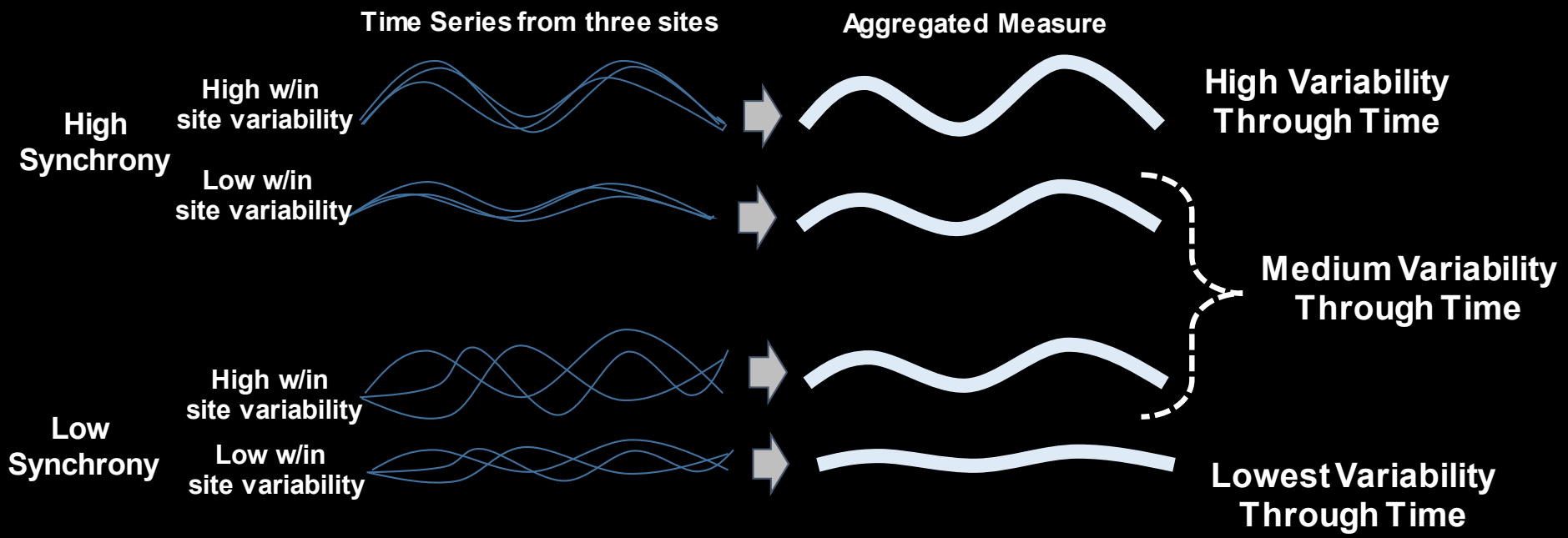
How about portfolio effects for entire communities across landscapes (β,γ)?

Multi-scale biodiversity drives temporal variability in macrosystems

Christopher J Patrick[1*], Kevin E McCluney[2], Albert Ruhi[3], Andrew Gregory[4], John Sabo[5], and James H Thorp[6]

> Stability in Macrosystems

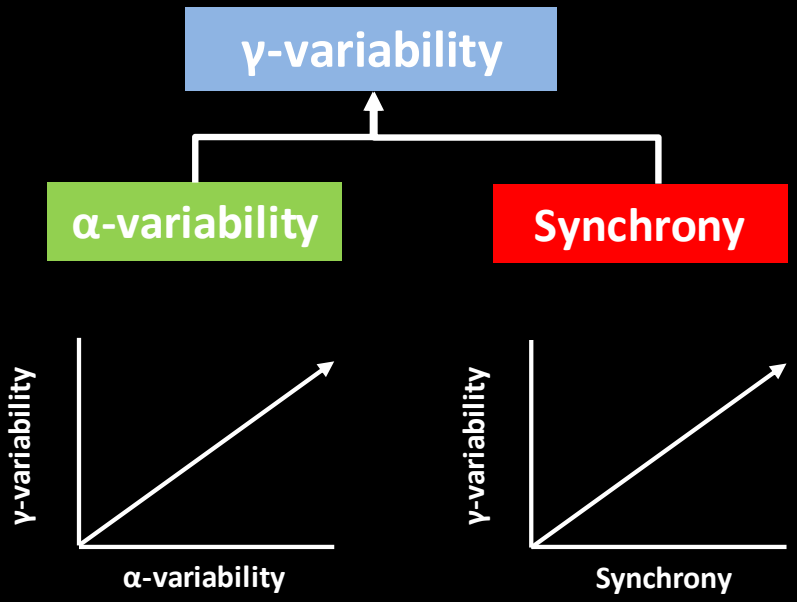
Two Major Drivers – Synchrony & Within Site Variability



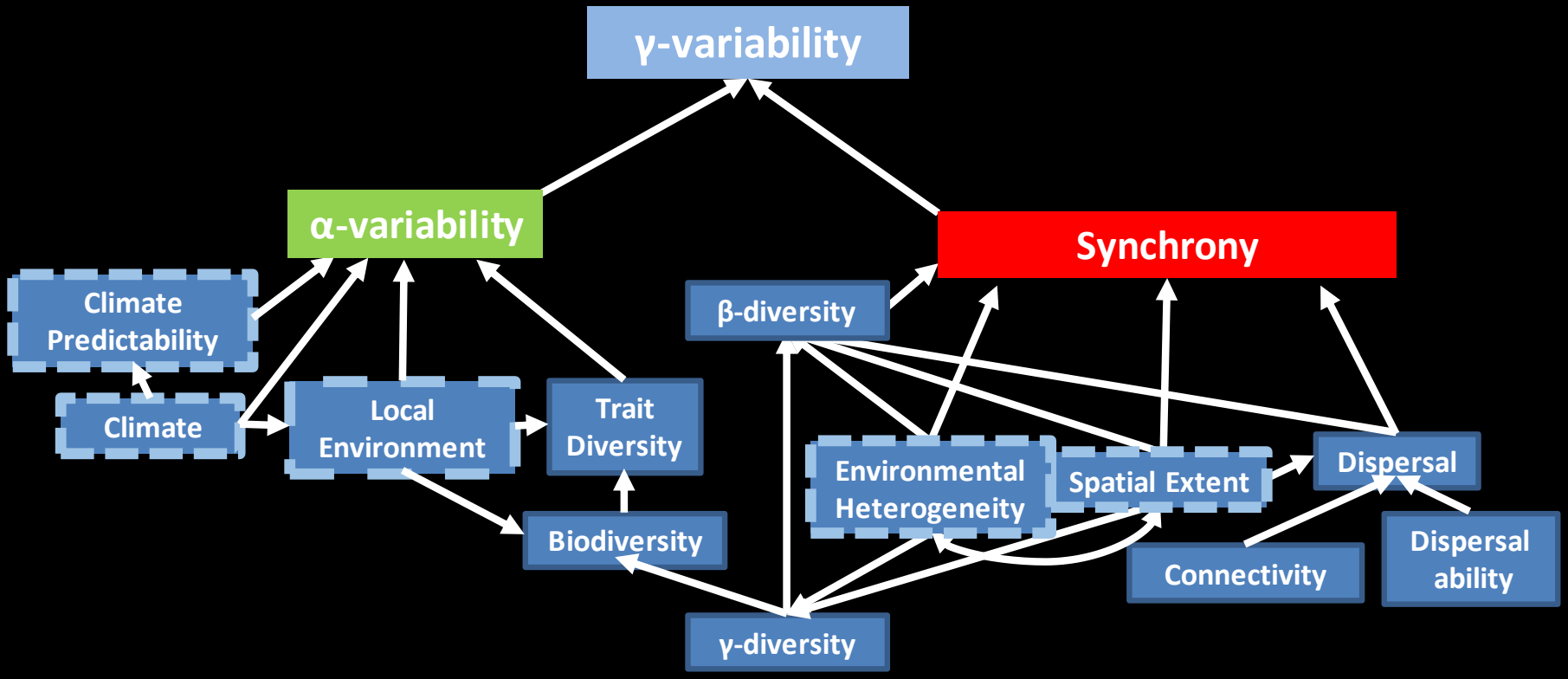
> Stability in Macrosystems

β-diversity and γ-richness should increase asynchrony among different communities – reducing variability at the regional (γ) scale

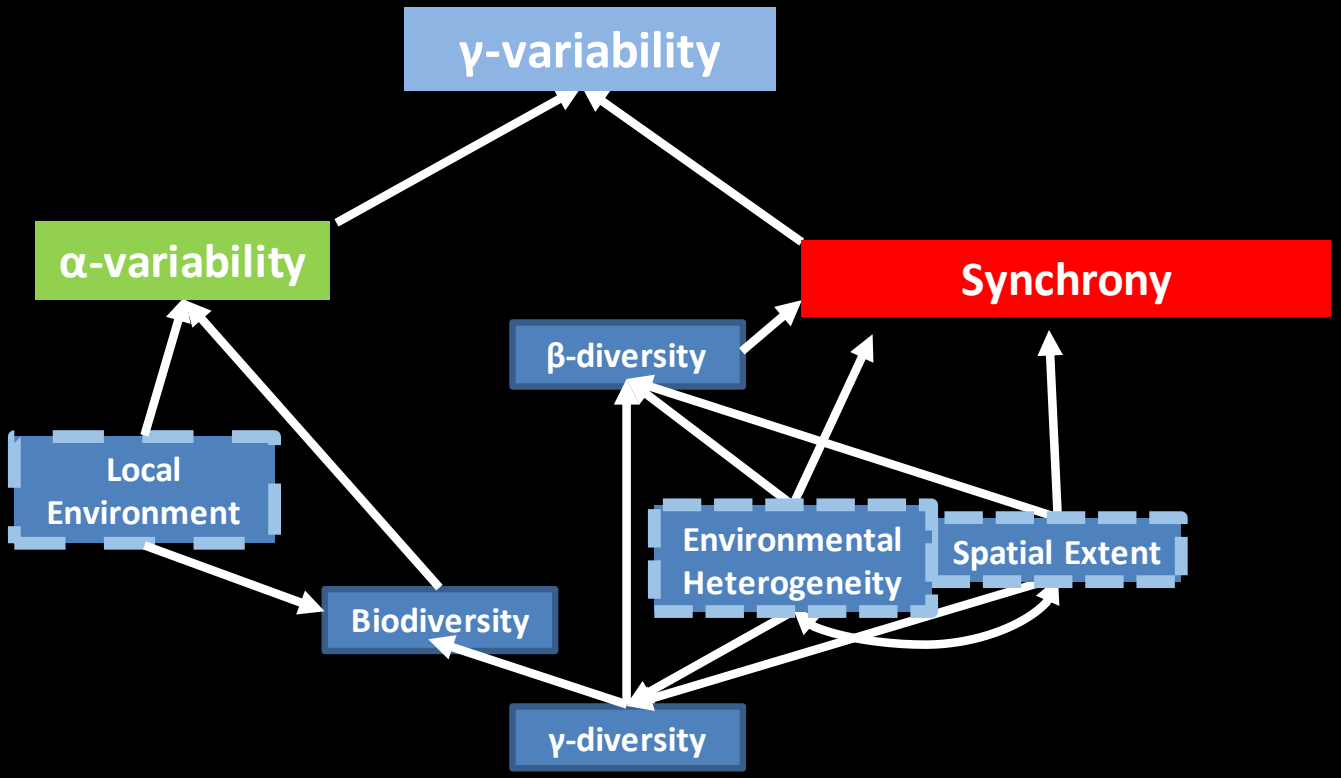
> Basic conceptual model



> Full conceptual model



> Intermediate conceptual model



> Data Sources

Four decadal datasets

Central Arizona-Phoenix Long-Term Ecological Research
CAP LTER

Ground beetles

Stream fish

VIMS | William & Mary
Virginia Institute of Marine Science

Seagrass

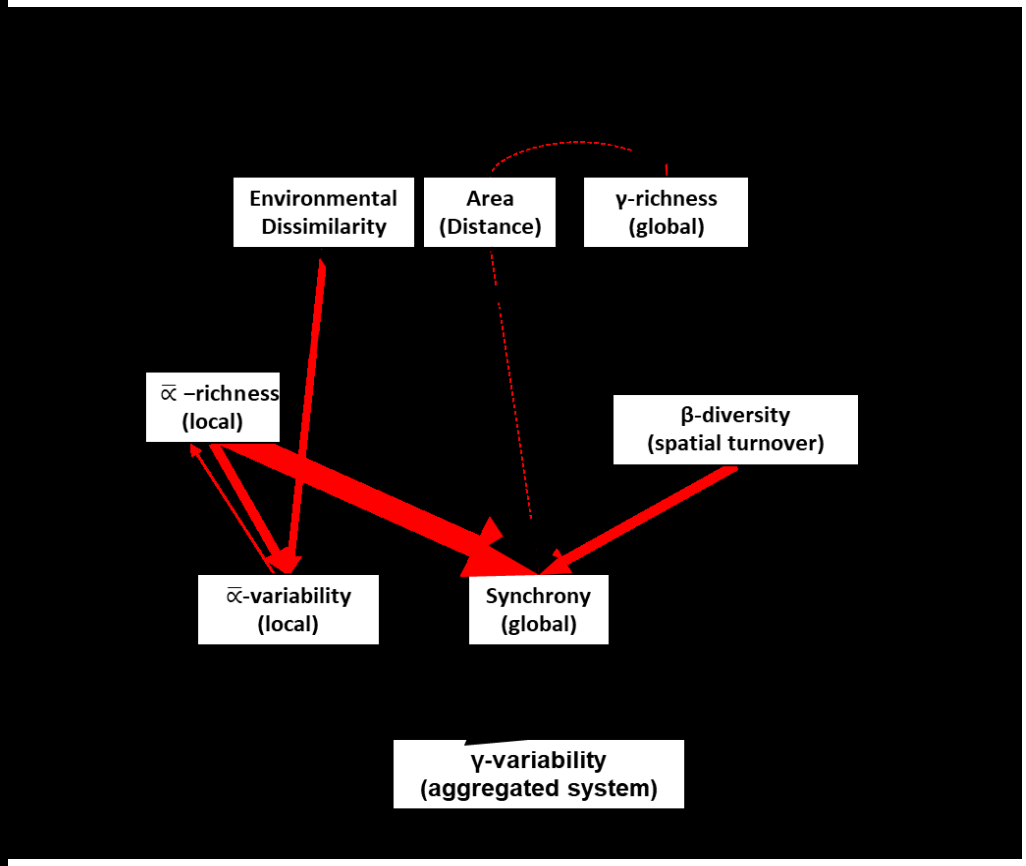
VIMS | William & Mary
Virginia Institute of Marine Science
Chesapeake Bay Program
Science. Restoration. Partnership.

Freshwater macrophytes

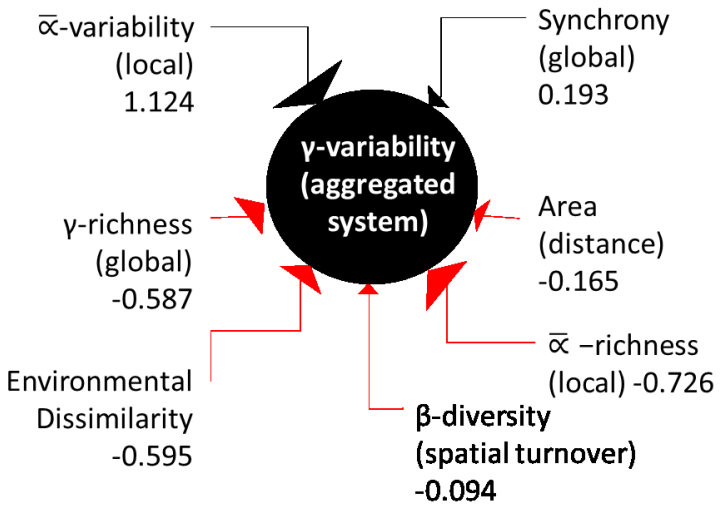
- **Spatially explicit replicate samples**
- **Decadal Time Scales**
- **Biomass or Abundance Data**
- **Community Data**
- **Environmental Covariate Data**

Patrick et al. (2021) Frontiers in Ecology and Evolution

> Complete Model Result



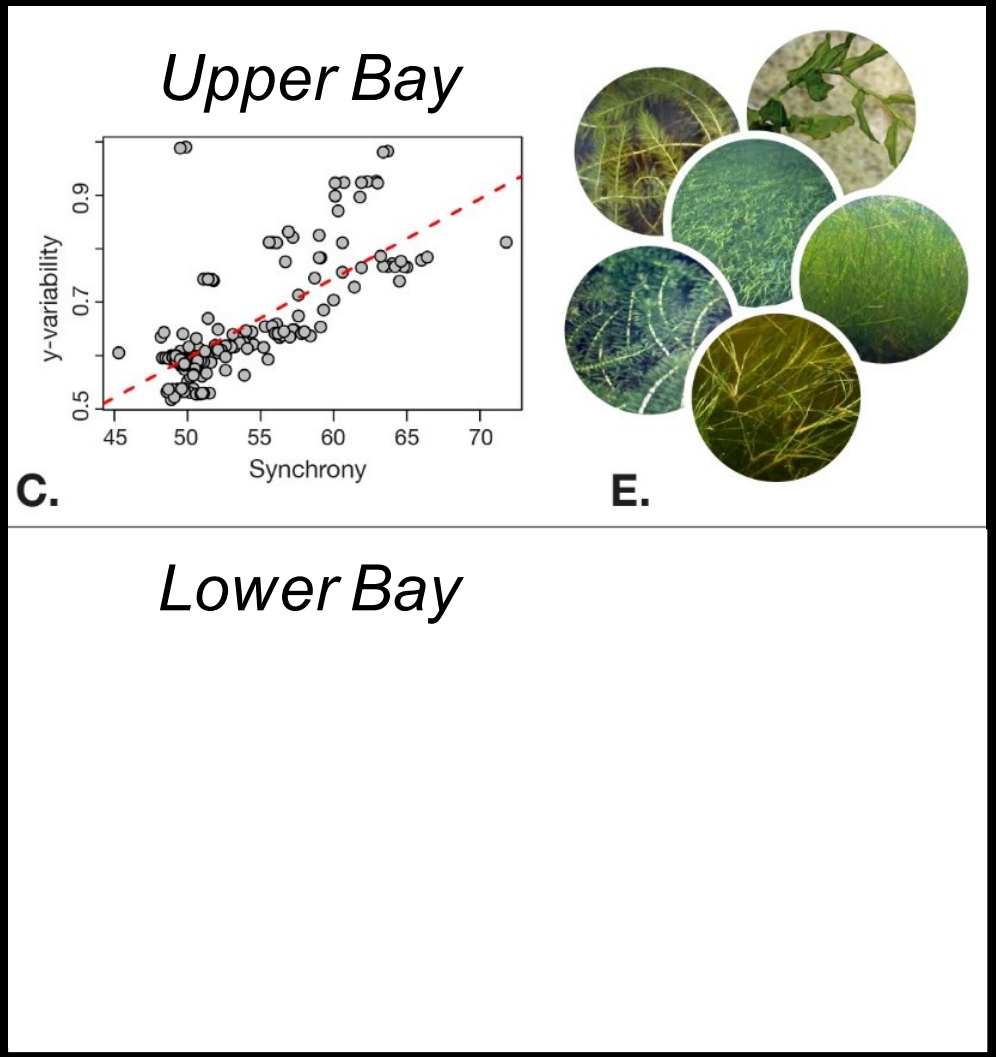
Total Effects



Patrick et al. (2021) Frontiers in Ecology and Evolution

> System Specific Model Results

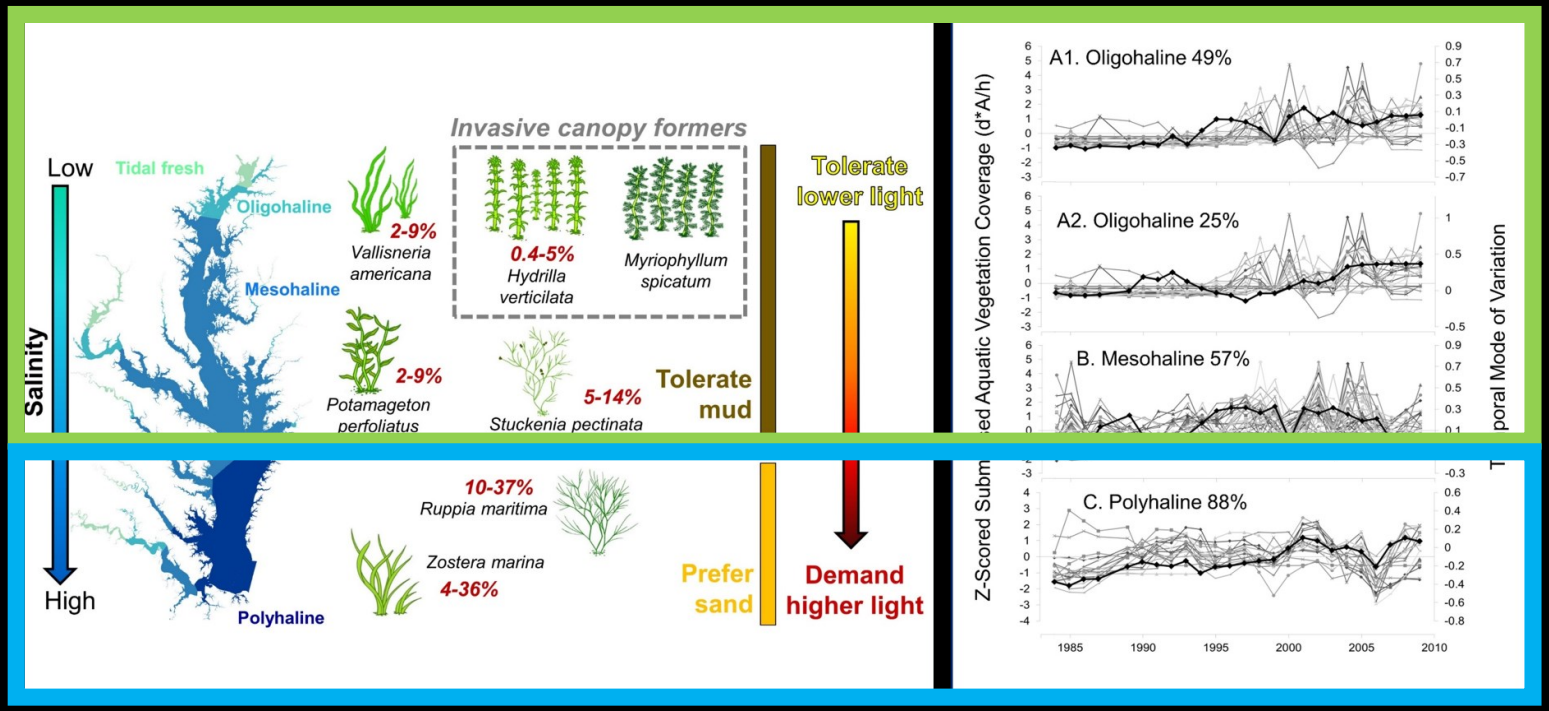
Higher Synchrony → Less Stability Matches Predictions



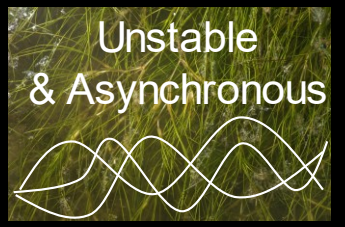
Patrick et al. (in press) Frontiers in Ecology and Evolution

> Reconciliation

Results, while surprising, perfectly supports the hypothesis…..



Patrick & Weller. 2015 Marine Ecology Progress Series



In the high diversity upper bay, the portfolio effect is operating

In the low diversity lower bay, higher synchrony is indicative of *Zostera marina*, which is much more locally stable than *Ruppia maritima,* and so synchrony is positively related to stability

The Exception That Proves the Rule

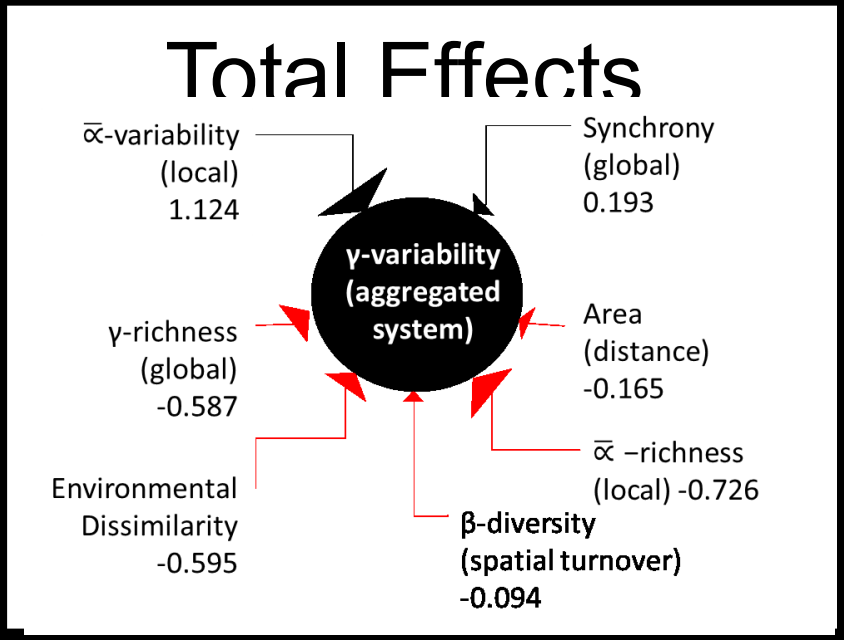
> Implication - Global

Regional Biodiversity Confers Regional Stability

A quantitative argument for the importance of global biodiversity to ecosystem functioning!

Global diversity losses will drive large scale temporal instability in ecosystem functioning and delivery of services

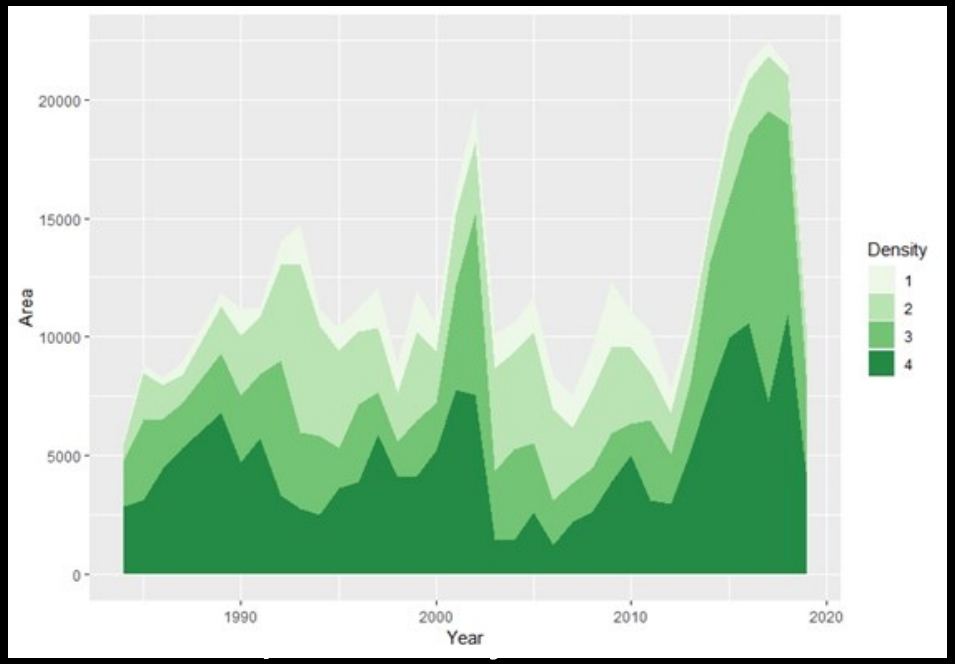
Major Implications: topics ranging from impact on harvest based industries to dynamics of disease vectors



Lots more to tackle on this topic, including testing in more macrosystems and incorporating functional traits….

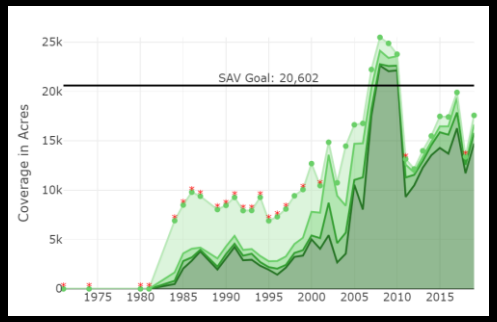
Patrick et al. 2020. Frontiers in Ecology and the Environment

> Implication for Chesapeake Bay



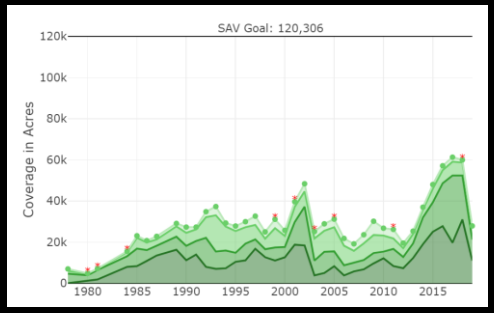
TF

But things weren't so bad in the upper bay



OH

MH



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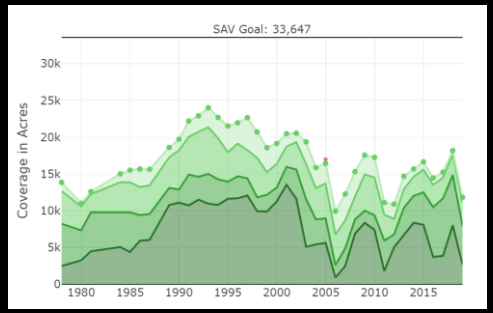
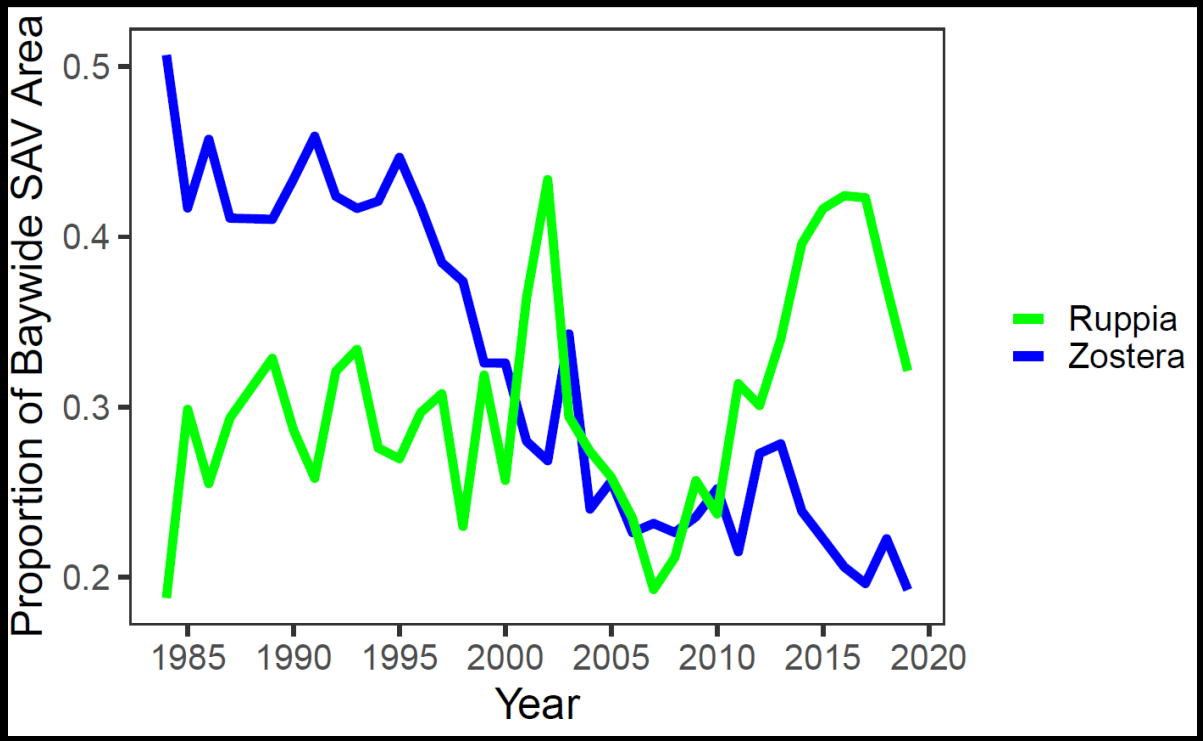


This is precisely what we predicted would happen!

Our biggest losses were in the Mesohaline

It was primarily Ruppia maritima

> Implication for Chesapeake Bay



As our dependence on a single species, *Ruppia maritima*, goes up, the potential for instability and catastrophic crashes goes up as well!

> Future Directions

Our next tasks are to:

1) Theory: Apply this framework to the other ecosystems and evaluate how common these patterns are.

2) Chesapeake Bay: Learn more about what controls dynamics in Ruppia, lessons for management and planning

3) Chesapeake Bay: Learn more about mechanistic ways that diversity in the middle and upper bay confer stability

> Acknowledgments

Data Sources: Chesapeake Bay Program, VIMS, MDNR, MBSS, CAP LTER

Funding: NSF 1928375, 1442595, 1926565, National Academy of Science Engineering and Medicine Gulf Early Career Fellowship

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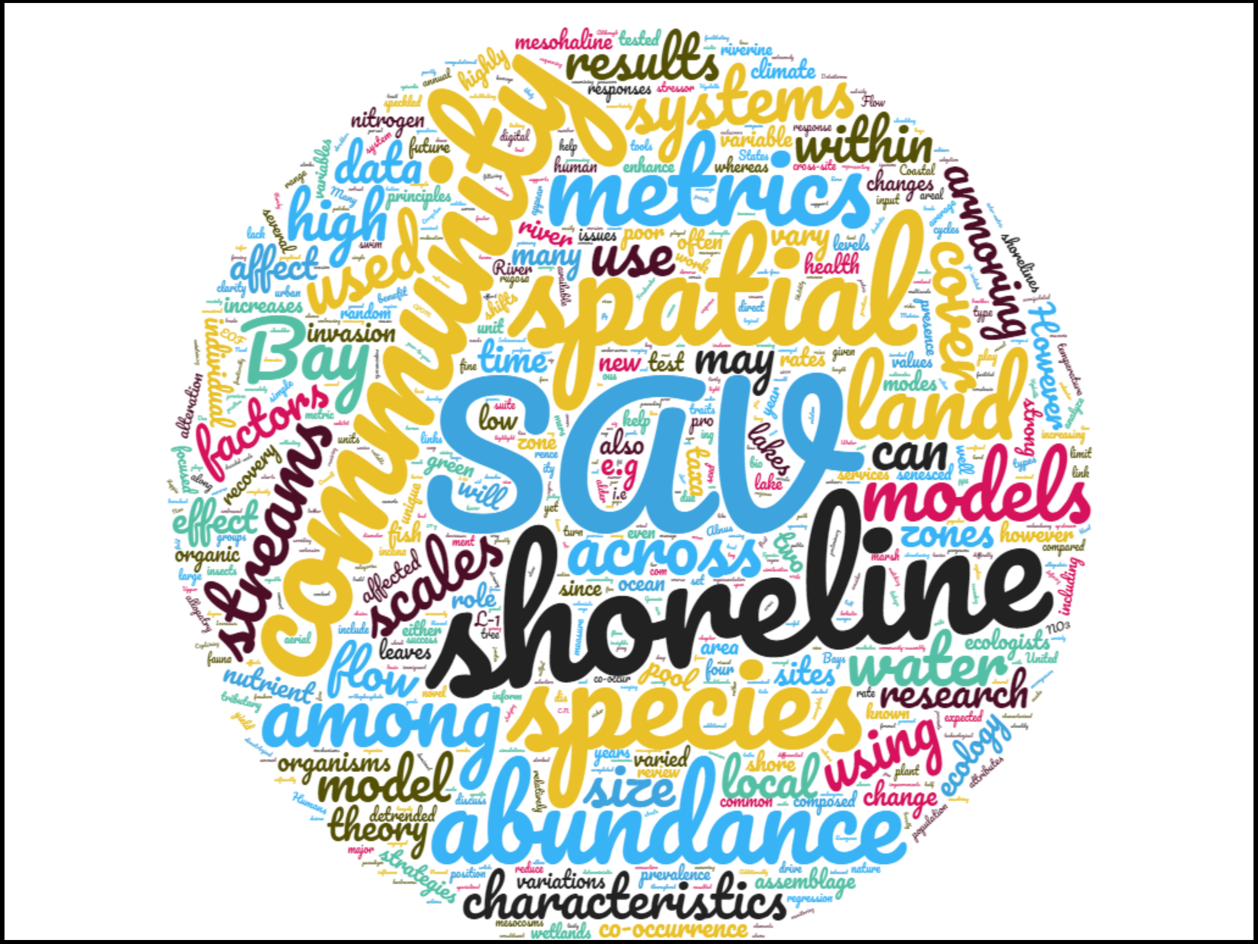
https://www.vims.edu/research/units/programs/sav/index.php

> Questions?



SAV
shoreline
spatial
community
species
abundance
metrics
systems
models
among
characteristics
streams
land
cover
within
results
scales
across
water
using
model
local
size
theory
research
factors
Bay
high
data
used
use
can
may
time
flow
zones
sites
armoring
However
affect
effect
ecology
organisms
invasion
nitrogen