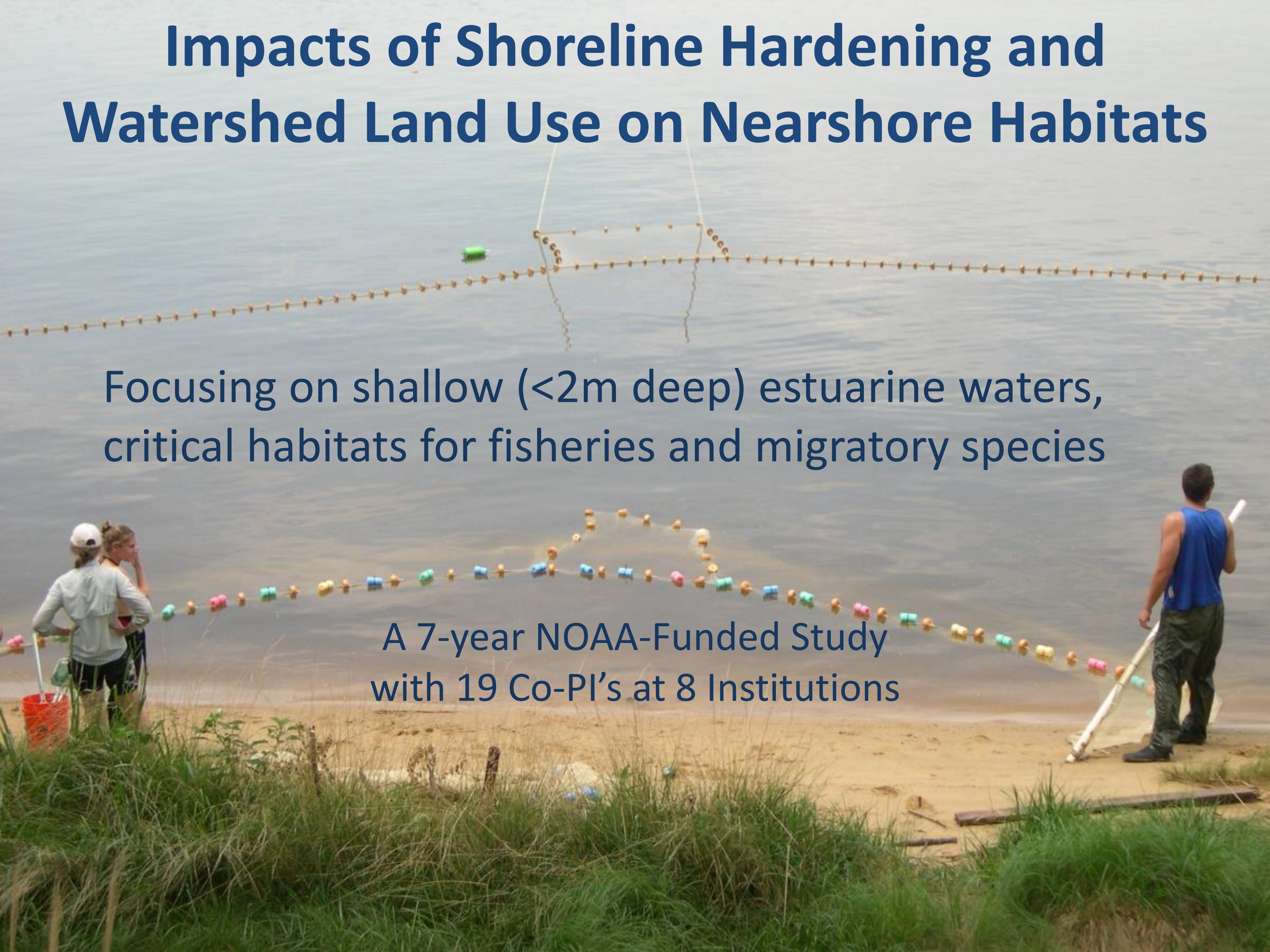
Impacts of Shoreline Hardening and Watershed Land Use on Nearshore Habitats

Focusing on shallow (<2m deep) estuarine waters, critical habitats for fisheries and migratory species

A 7-year NOAA-Funded Study
with 19 Co-PI's at 8 Institutions



19 Principal Investigators, 8 Institutions, led by the Smithsonian Environmental Research Center (SERC)

From SERC:

- Thomas Jordan (lead)
- Denise Breitburg
- Charles Gallegos
- Eric Johnson
- Xuyong Li
- Melissa McCormick
- Patrick Neale
- Gerhardt Riedel
- Donald Weller
- Dennis Whigham

From other institutions:

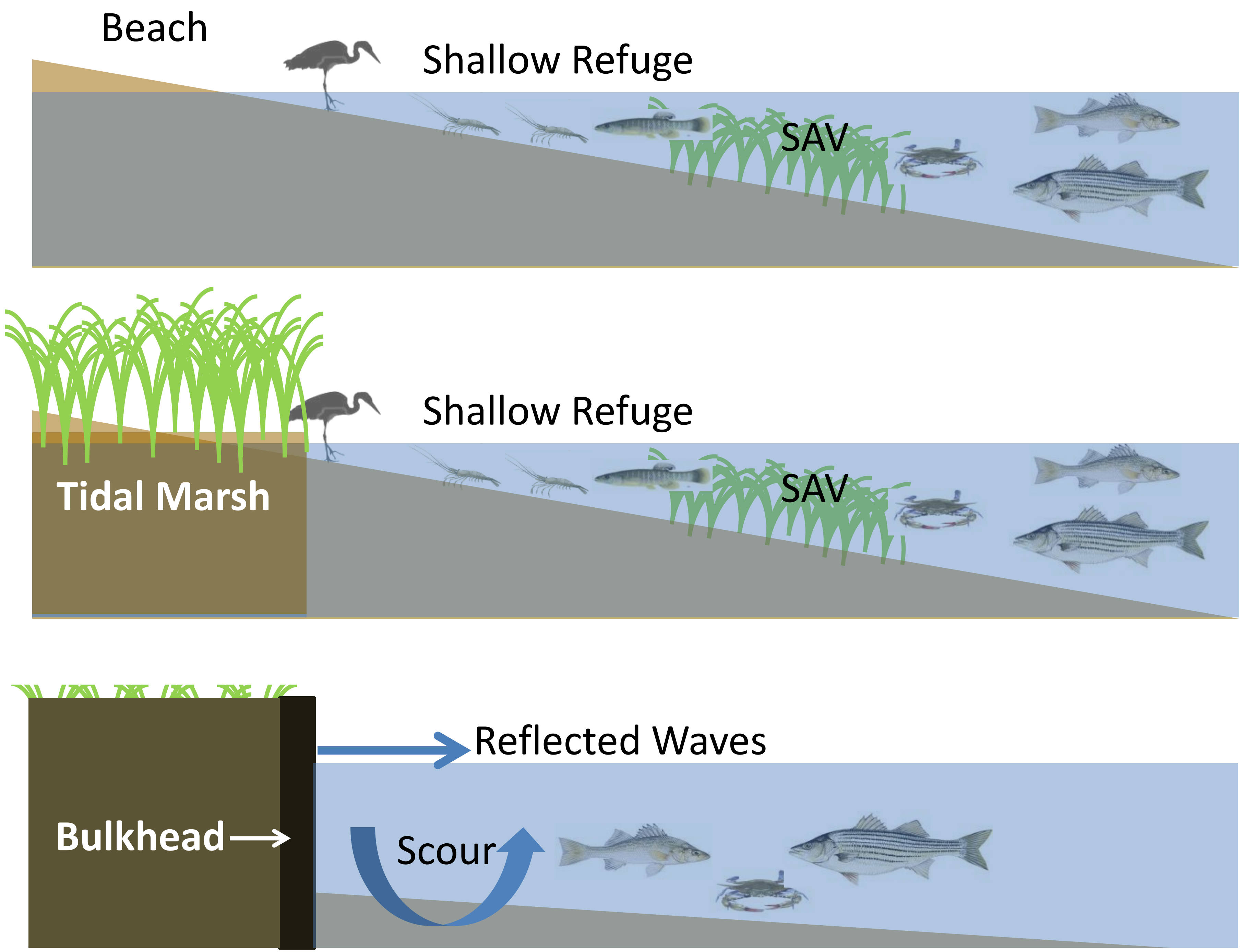
- Karin Kettenring, Utah State
- Michael Erwin, USGS
- Diann Prosser, USGS
- Lee Karrh, MD DNR
- Evamaria Koch, UMCES
- Larry Sanford, UMCES
- Rochelle Seitz, VIMS
- Timothy Targett, UDE
- Denice Wardrop, PSU

Notable SERC Postdocs:

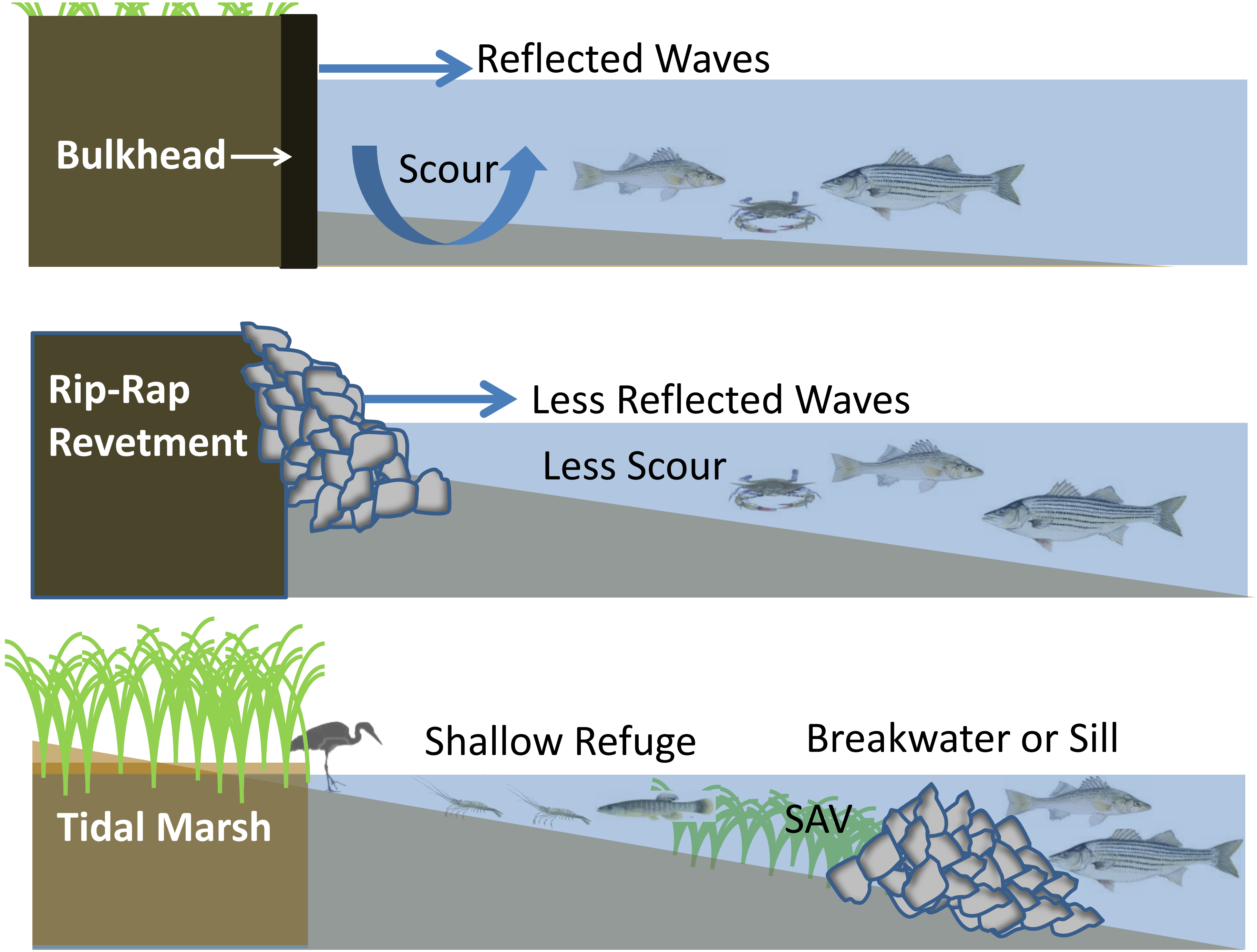
- Matt Kornis
- Chris Patrick
- Michael Hannam

Land use effects compounded with stressors at the intertidal zone

- Watershed inputs of nutrients, sediments, and toxic substances
- Shoreline alterations: Bulkhead, riprap revetments, and “living shorelines”
- Spread of invasive reed *Phragmites*



Beach
Shallow Refuge
SAV
Shallow Refuge
Tidal Marsh
SAV
Reflected Waves
Bulkhead
Scour



Reflected Waves
Bulkhead
Scour
Rip-Rap
Revetment
Less Reflected Waves
Less Scour
Shallow Refuge
Breakwater or Sill
SAV
Tidal Marsh

Compare shoreline types…


Natural Marsh


Phragmites Marsh


Rip-Rap


Bulkhead


Beach

…in bays and sub-estuaries with watersheds that have differing land use


Forested


Residential Development


Agricultural

Our study sites include Chesapeake Bay sub-estuaries and Coastal Bays.

142 systems identified

- 128 in Chesapeake Bay
- 14 in Coastal & Inland Bays

Our study sites include Chesapeake Bay sub-estuaries and Coastal Bays.

142 systems identified
- 128 in Chesapeake Bay
- 14 in Coastal & Inland Bays

50 systems sampled

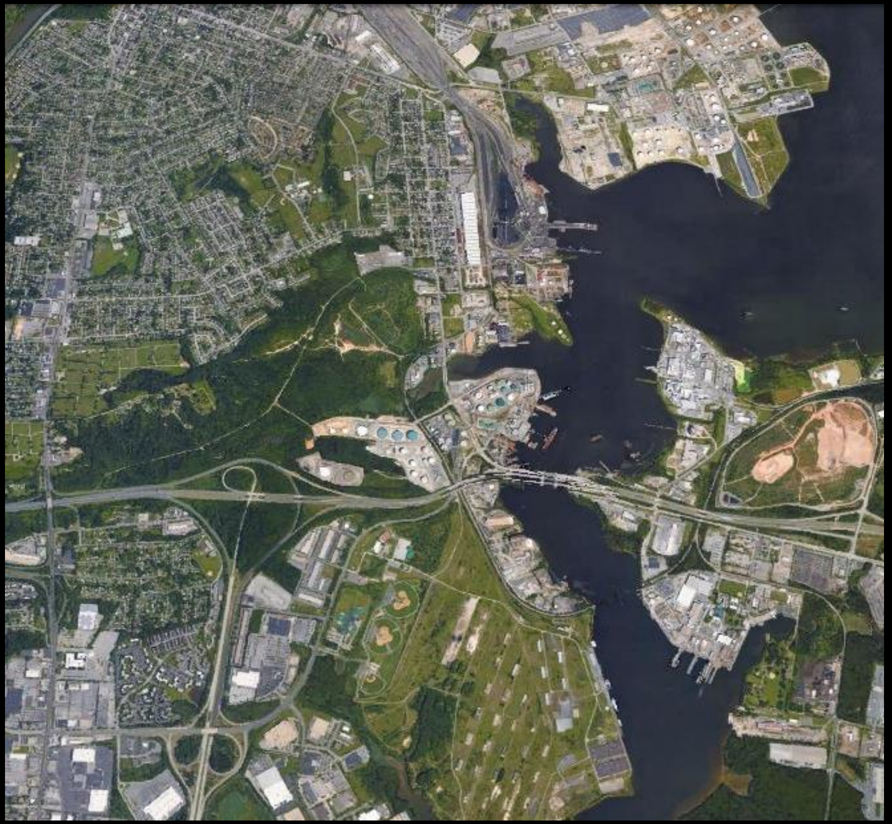
100 modeled

Estuarine responses

- Water quality
- Submerged aquatic vegetation (SAV)
- Macrofauna (benthic, fish, jellyfish, water birds)
- *Phragmites* invasion

Water Quality: Local land use matters

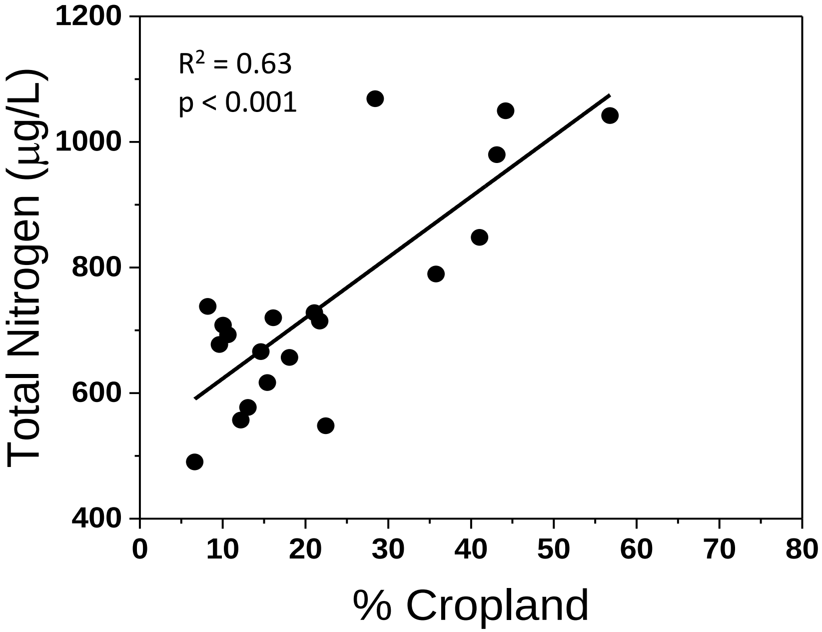
Agricultural Land



Developed Land

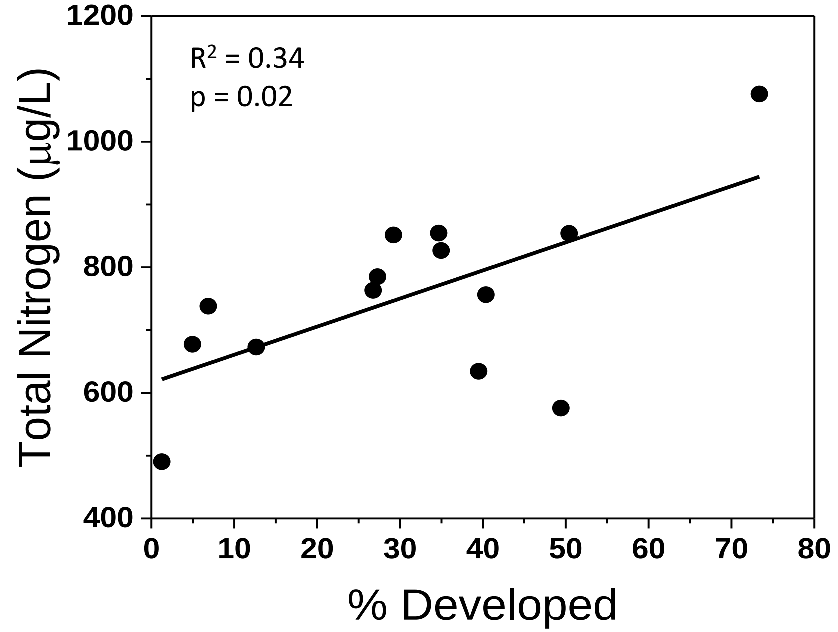
Total Nitrogen vs. Land Use Percentages

Cropland



(Exclude if >10% Developed)

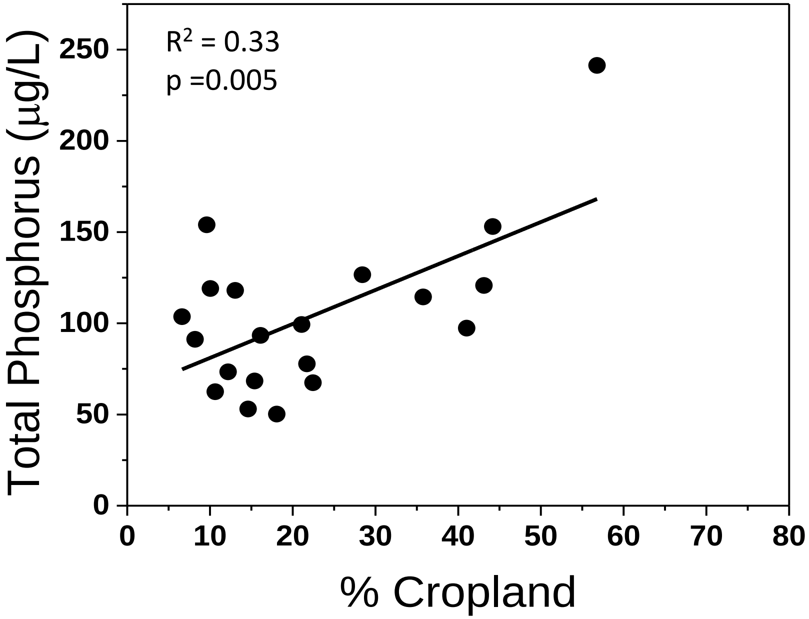
Developed Land



(Exclude if >10% Cropland)

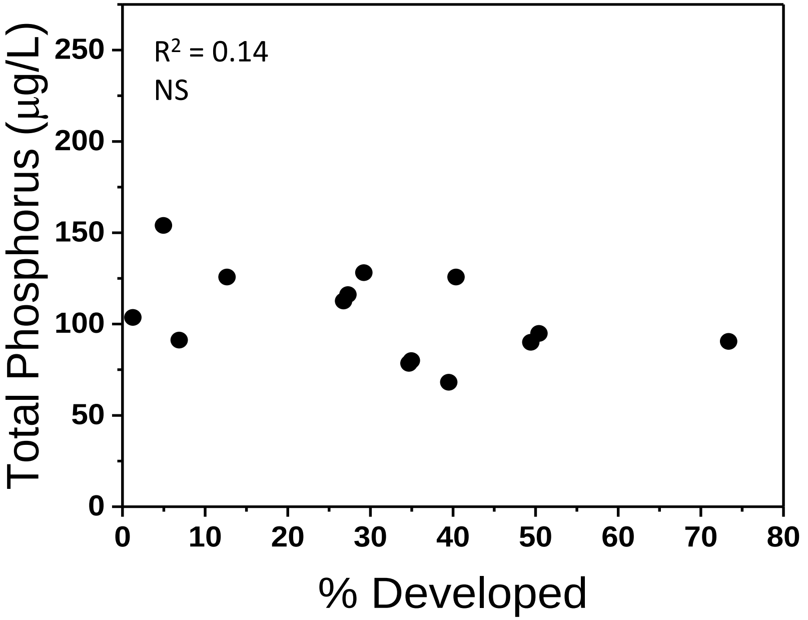
Total Phosphorus vs. Land Use Percentages

Cropland



(Exclude if >10% Developed)

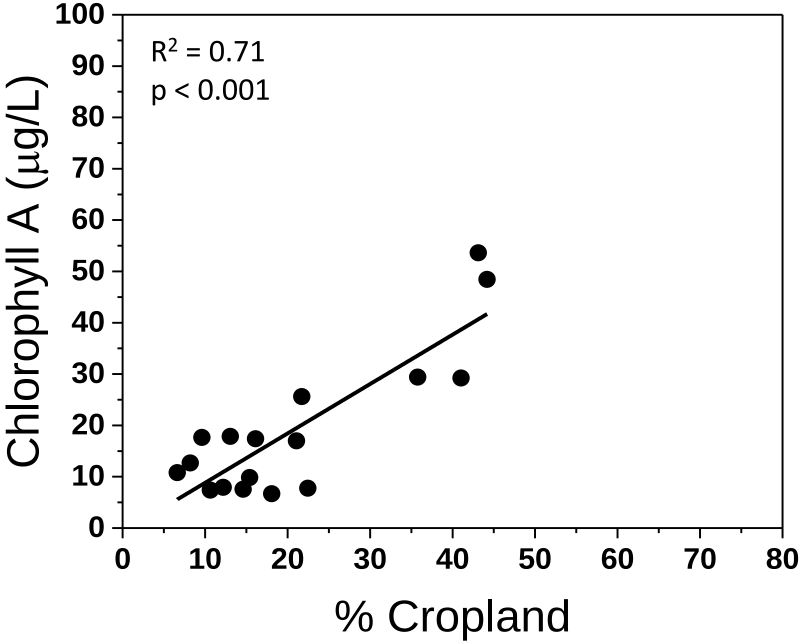
Developed Land



(Exclude if >10% Cropland)

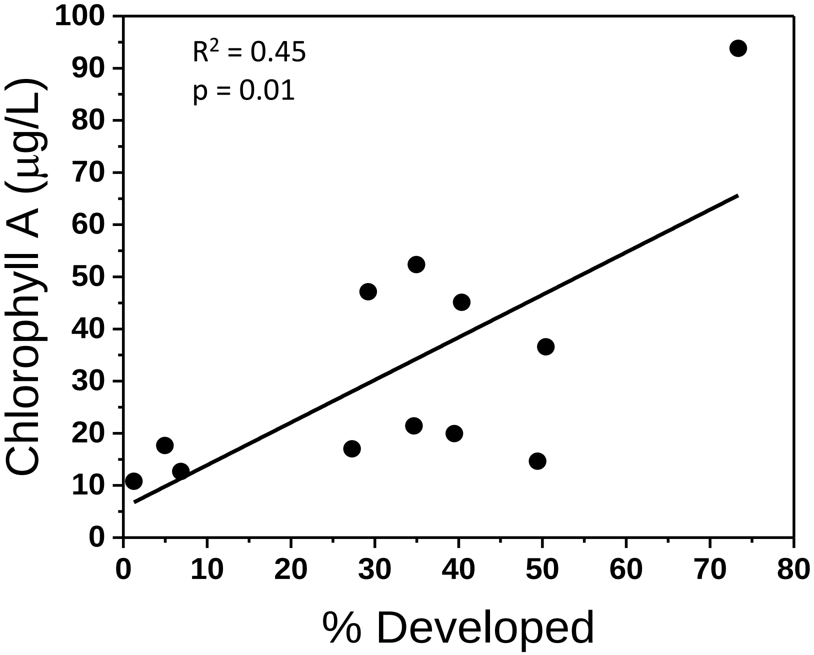
Chlorophyll *a* vs. Land Use Percentages

Cropland



(Exclude if >10% Developed)

Developed Land



(Exclude if >10% Cropland)

Interacting Effects of Land Use and Shoreline Armoring on Submerged Aquatic Vegetation (SAV)

Don Weller, Chris Patrick, Chuck Gallegos, Meghan Williams, Micah Ryder, Xuyong Li, Mike Hannam

Lee Karrh, Brooke Landry, Becky Golden, Mark Lewandowski

Eva Koch, Dale Booth, Becky Swerida, Larry Sanford

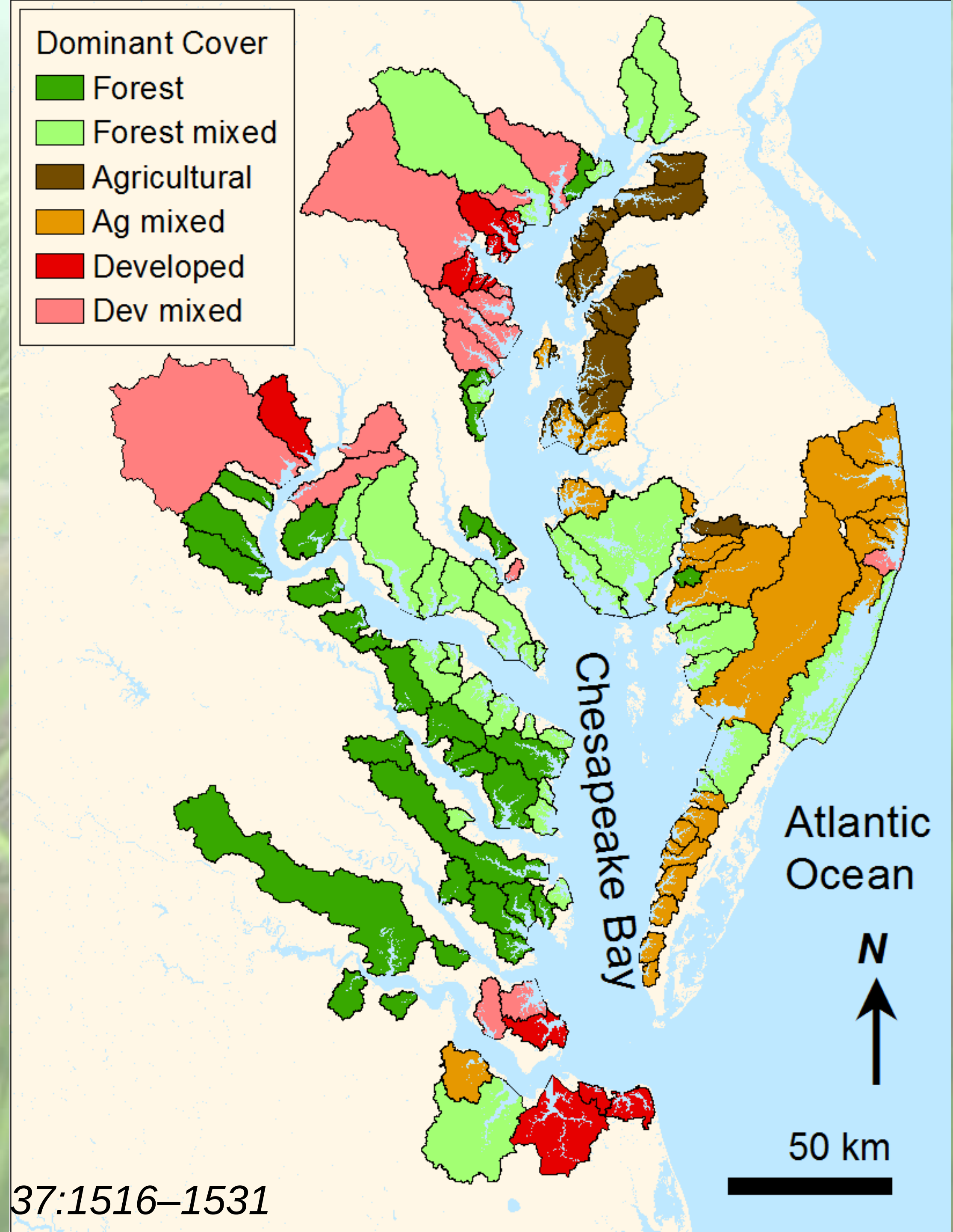
Outline

- ~~SAV is a keystone component of estuaries~~
- Statistical analysis of digital maps (SAV, land cover, salinity, shoreline armoring)
  - Comparing among subestuaries
  - Contrasting shoreline segments (natural, bulkhead, riprap)
- Field study of SAV beds next to natural and riprapped shorelines
- Headlines

Subestuary-scale models

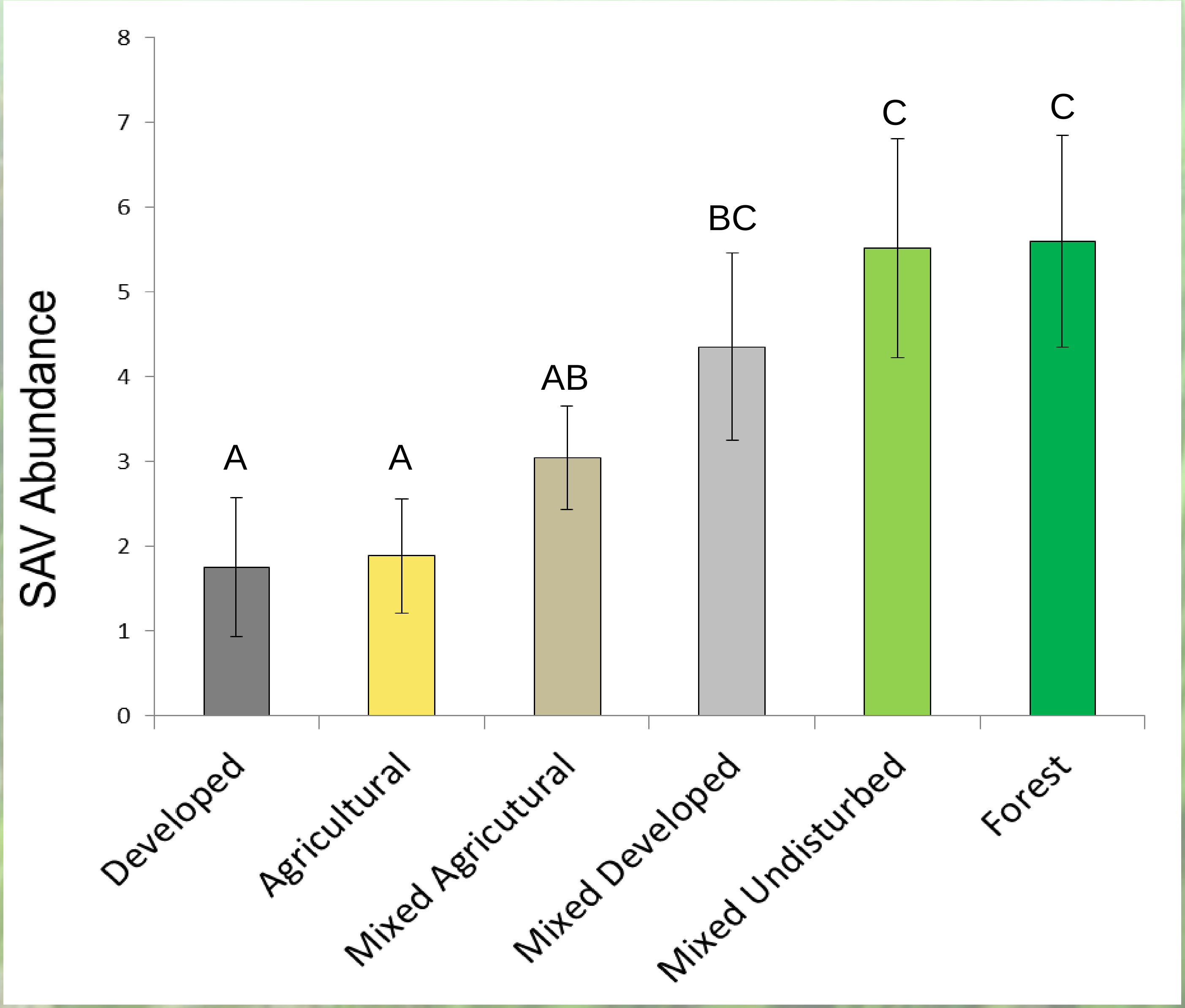
100 study subestuaries

- 1984-2009 SAV maps
- 2001 NLCD land cover
- Salinity zones
- Shoreline condition maps



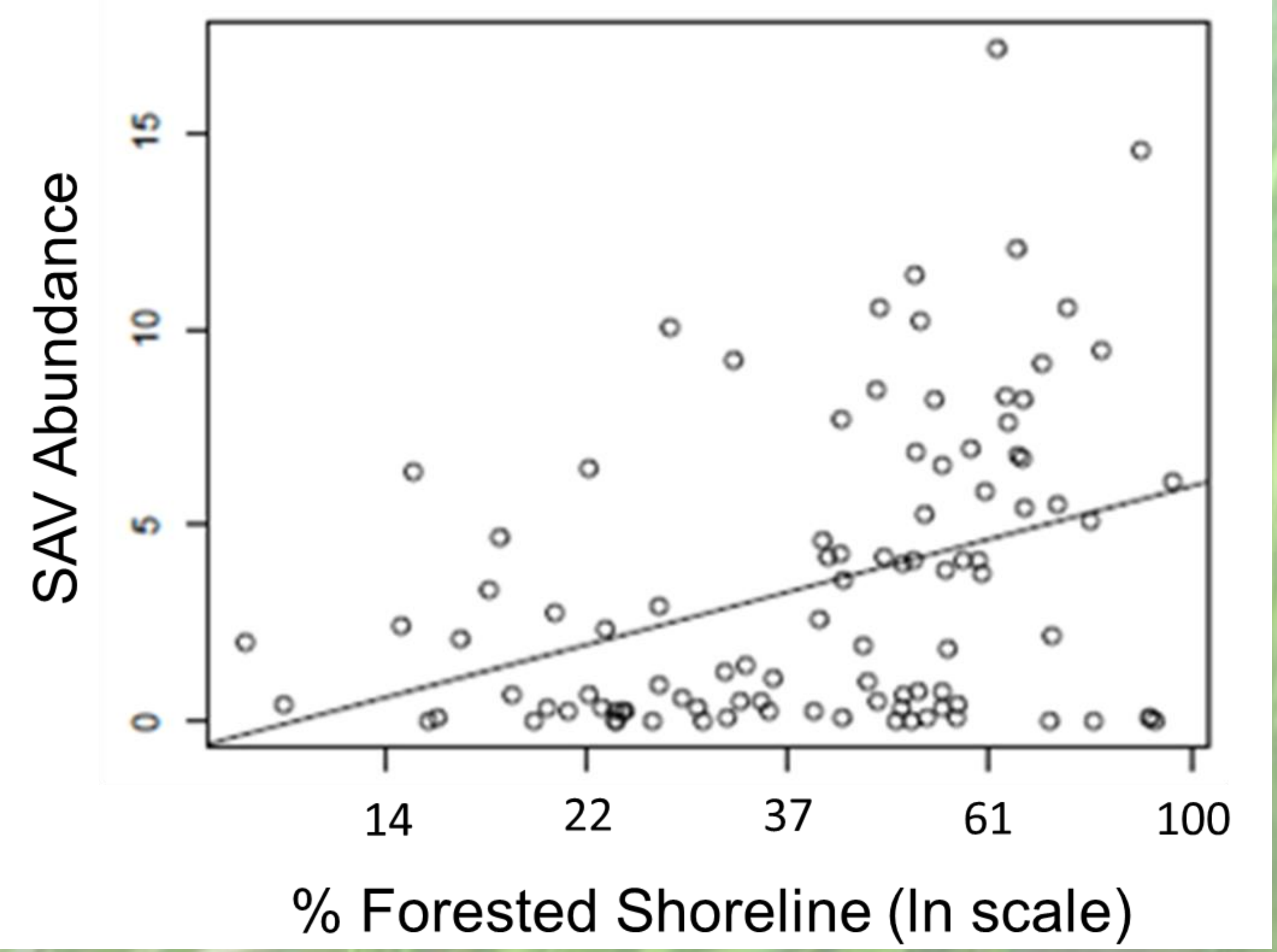
Patrick et al. 2014. Estuaries Coasts 37:1516–1531

Watershed land use affects SAV abundance



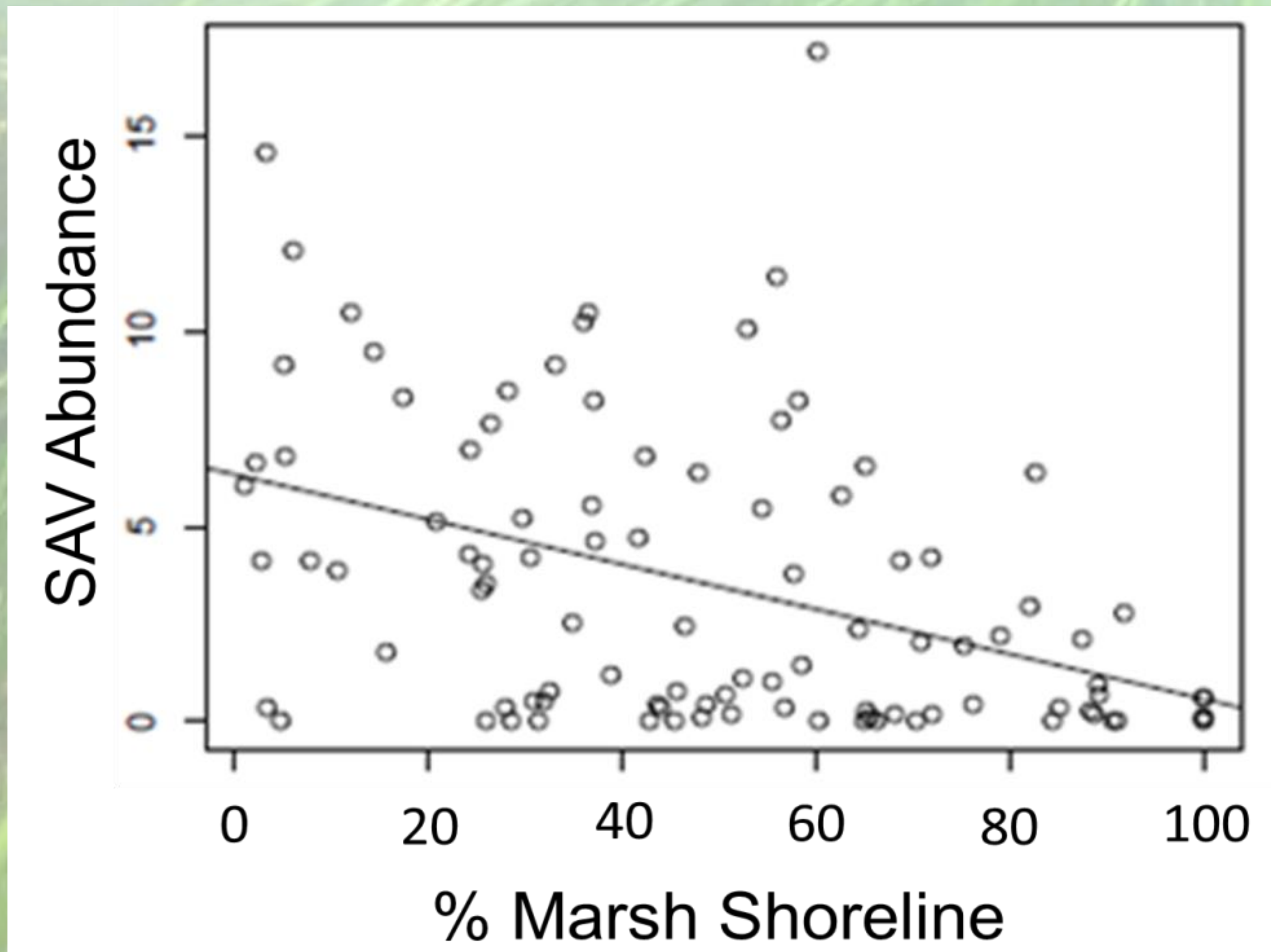
Patrick et al. 2014. Estuaries Coasts 37:1516–1531

Forested shoreline is positively related to subestuary SAV abundance



Patrick et al. 2014. Estuaries Coasts 37:1516–1531

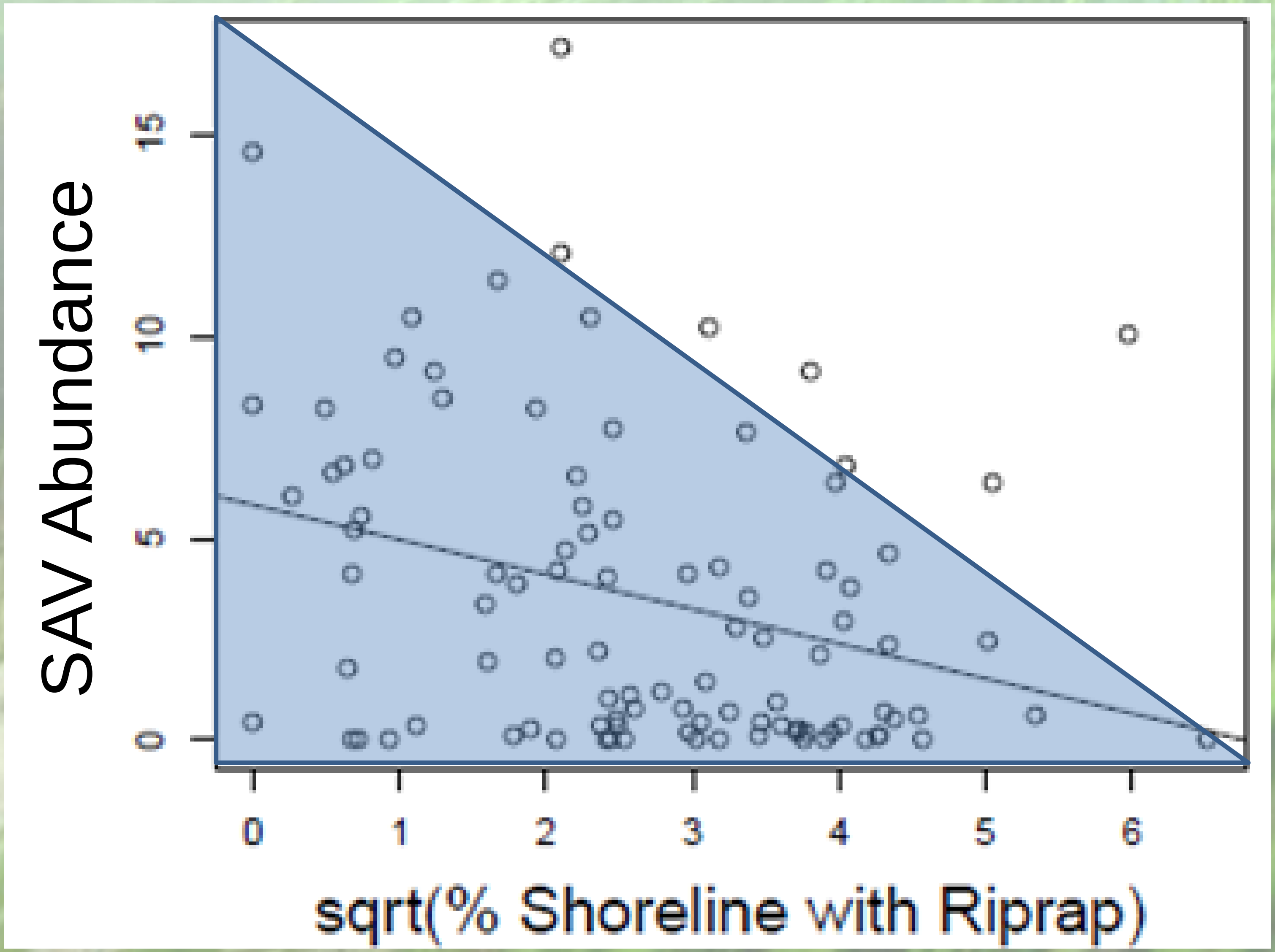
Surprisingly, shoreline marsh is negatively related to SAV abundance…



…possibly because marshes release peat or mud

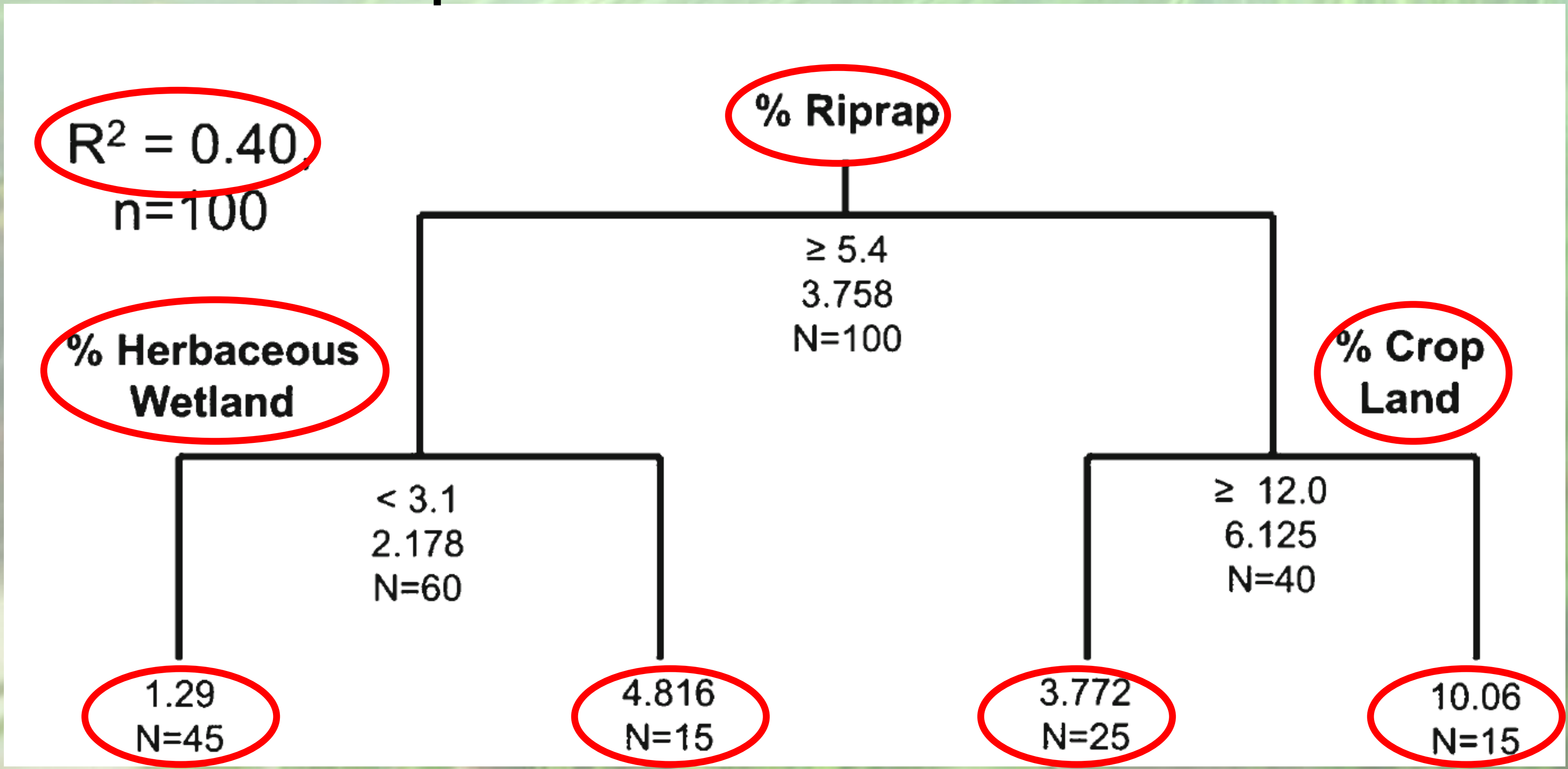
Patrick et al. 2014. Estuaries Coasts 37:1516–1531

Subestuary-wide armoring is negatively related to SAV abundance



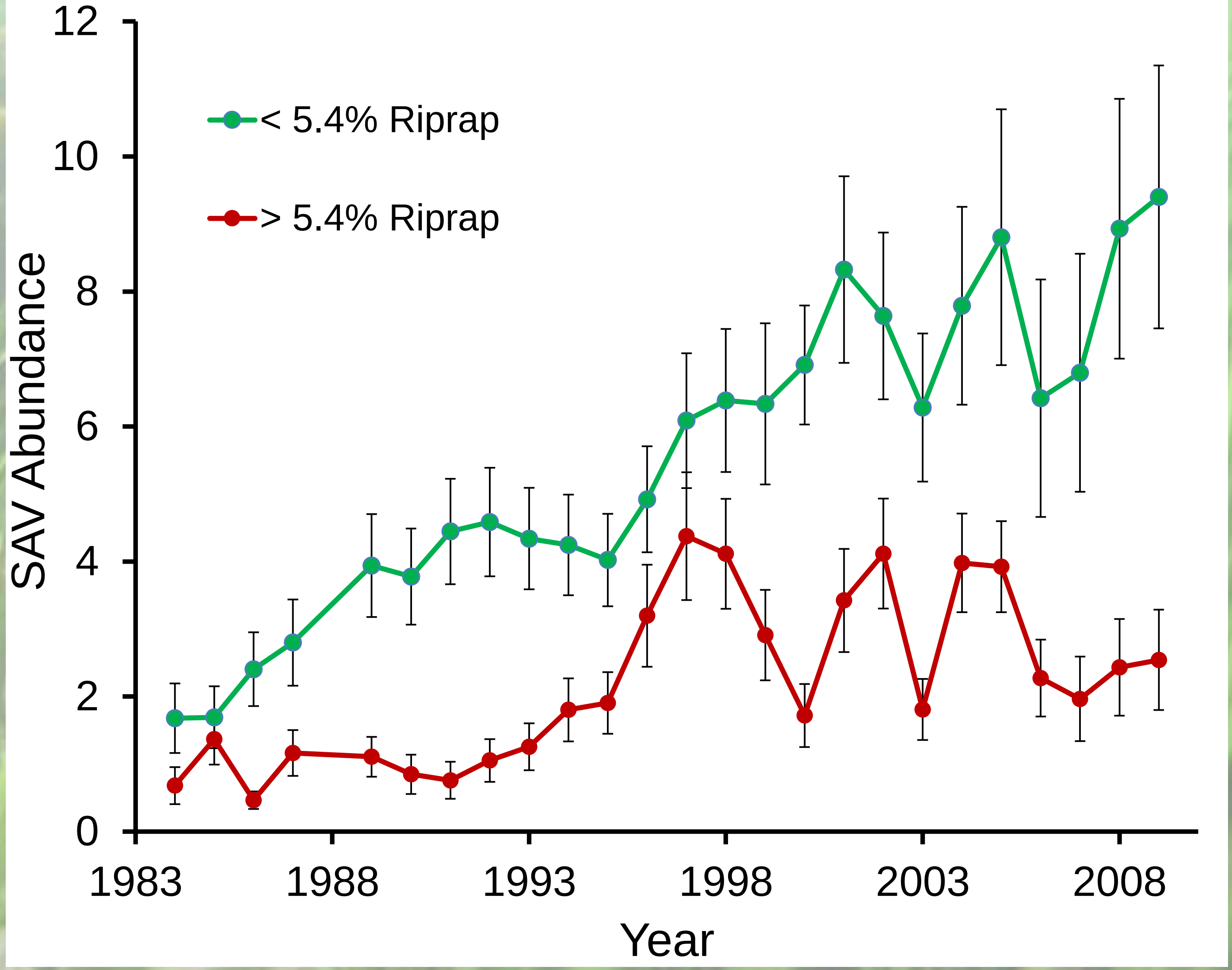
Patrick et al. 2014. Estuaries Coasts 37:1516–1531

Shoreline armoring & watershed land use predict abundance



Patrick et al. 2014. Estuaries Coasts 37:1516–1531

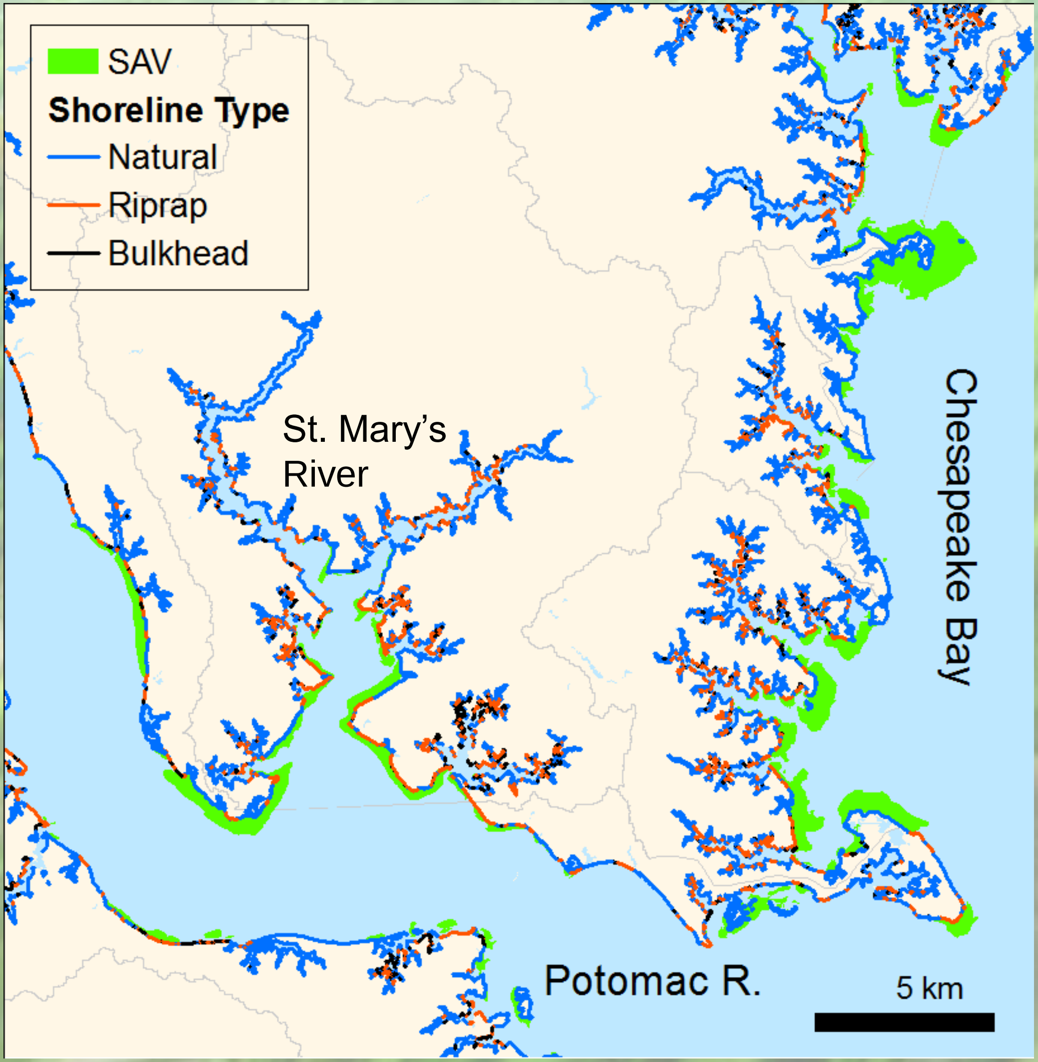
Abundance is greater and recovery stronger in subestuaries with little armoring (<5%)



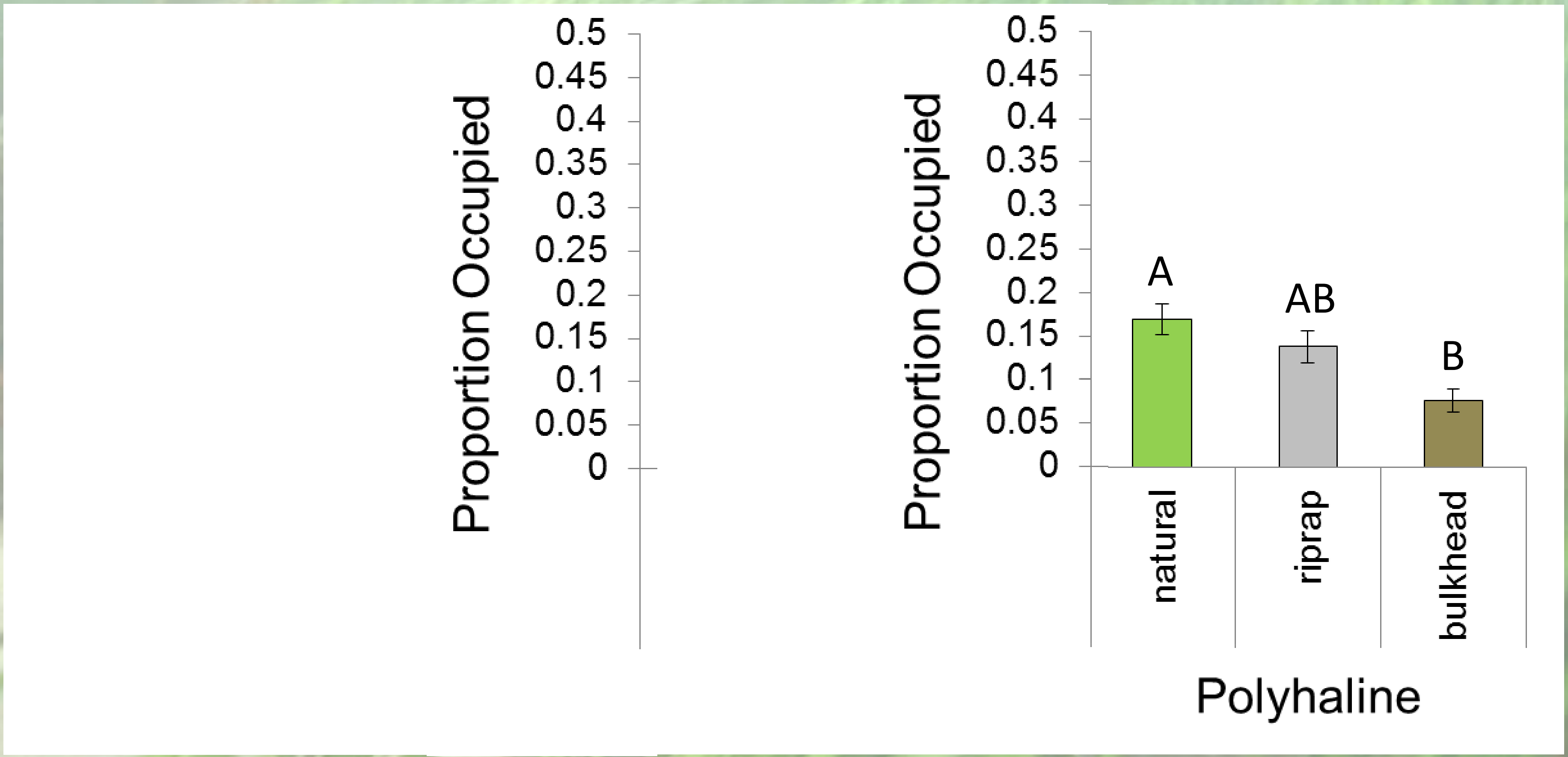
Patrick et al. 2014. Estuaries Coasts 37:1516–1531

Shoreline-scale models

A shift to a much finer scale!

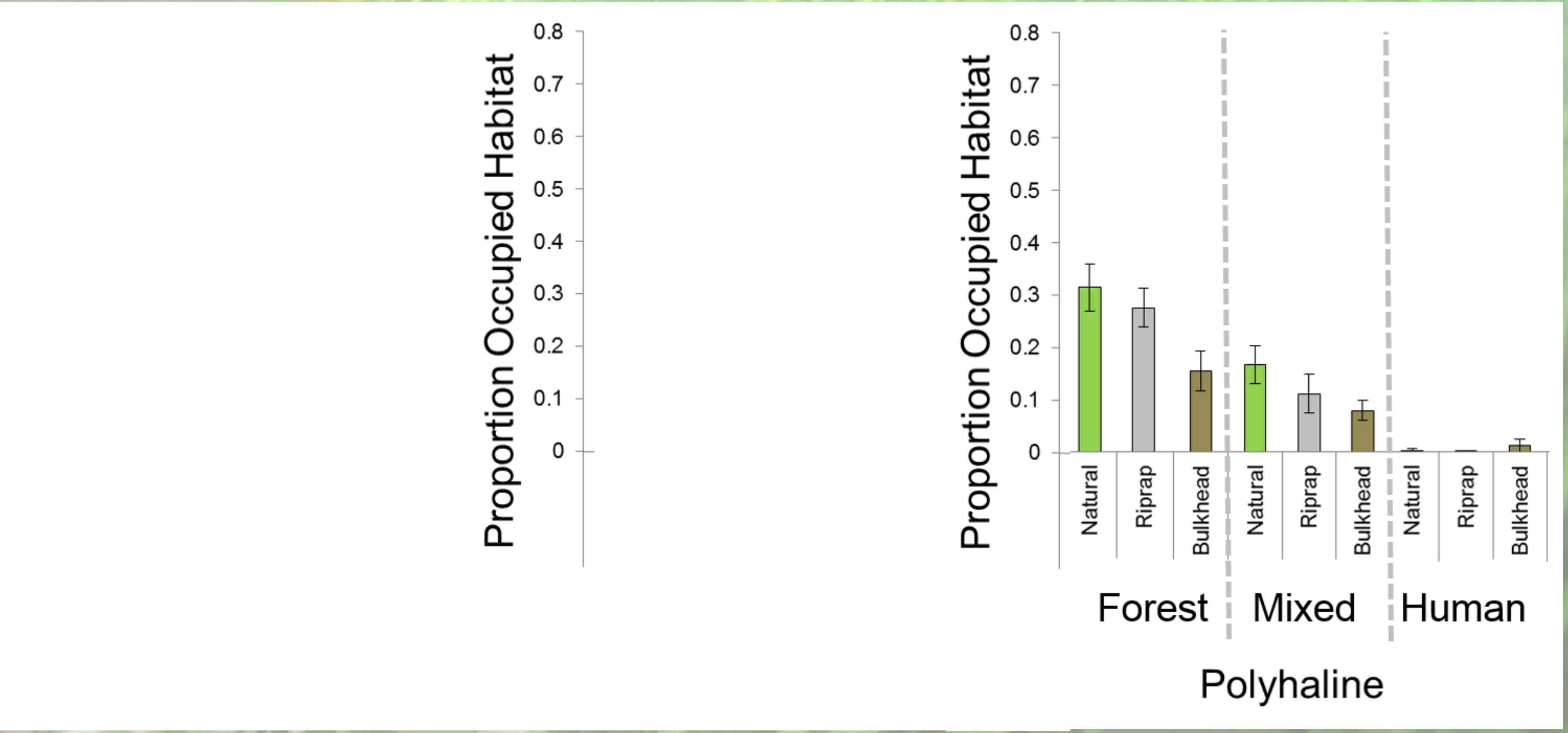


Armoring effects vary with community



Patrick et al. 2016. Estuaries & Coasts 39:158–170

Land use constrains shoreline effects



Patrick et al. 2016. Estuaries & Coasts 39:158–170

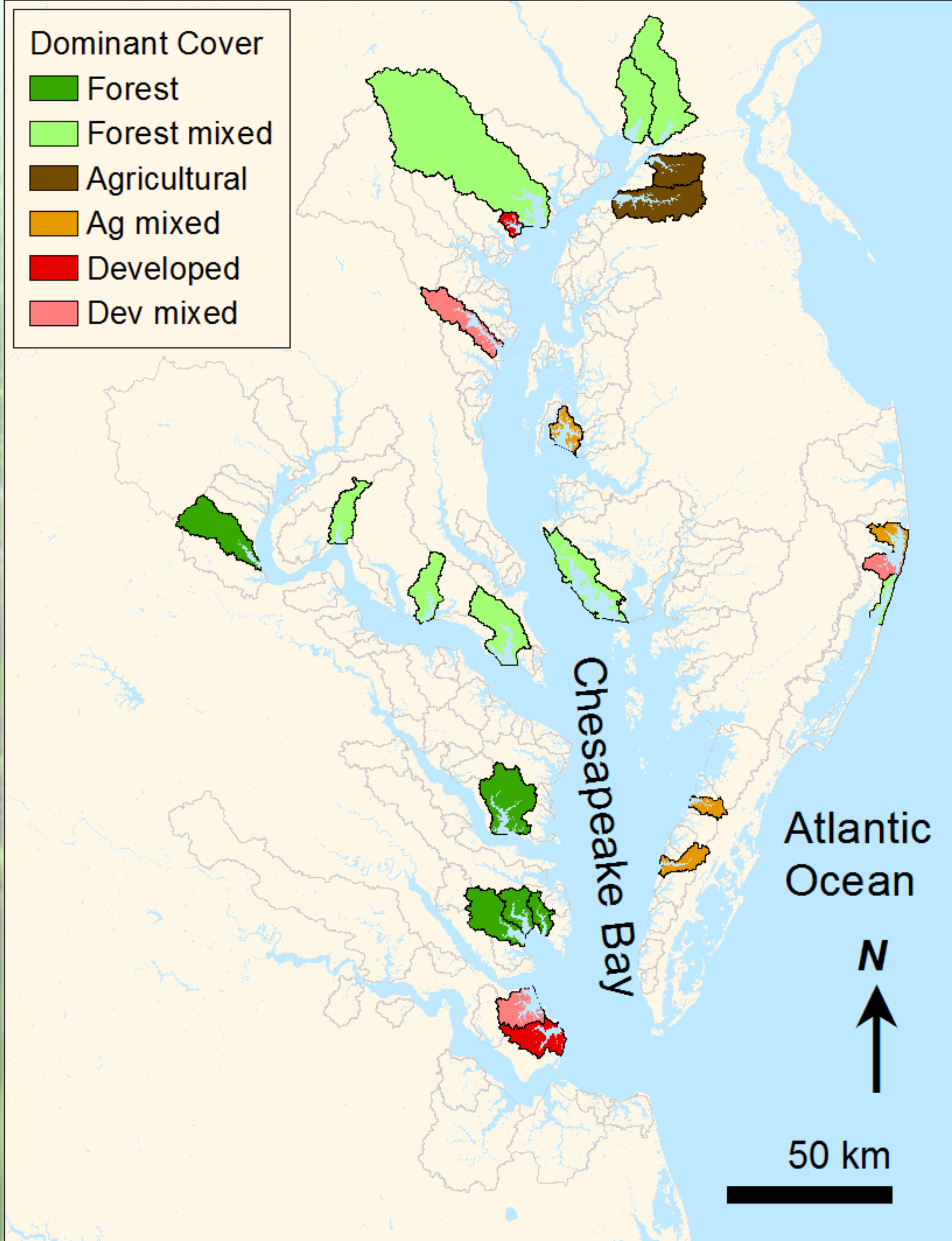
Other and ongoing work

- Temporal patterns in SAV abundance
  - Synchrony among subestuaries
  - Factors driving interannual variation
  - Trends in SAV abundance by subestuary
- SAV communities instead of salinity zones
- Bayesian modeling and SEM

Field study

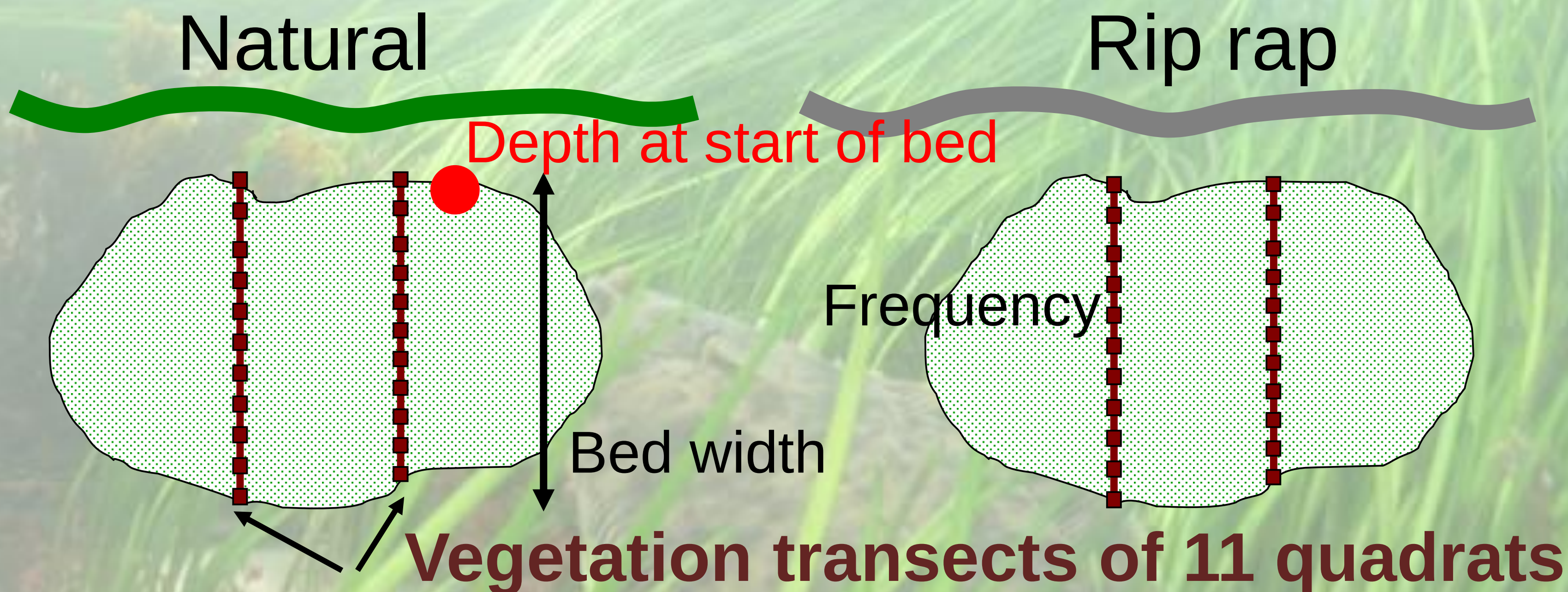
24 study subestuaries

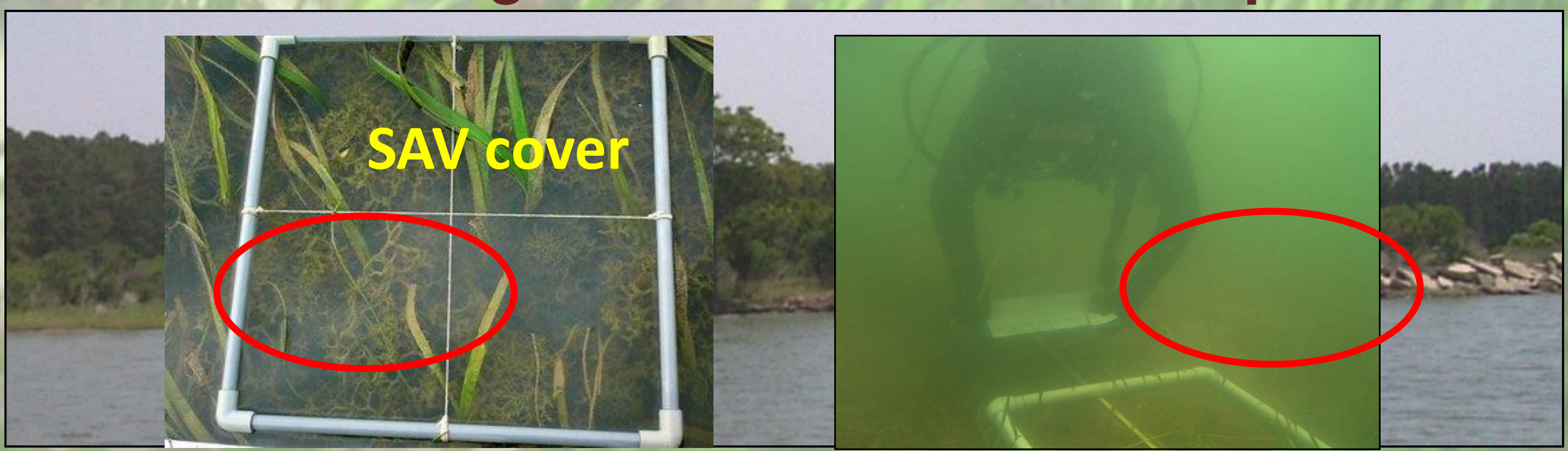
- 17 surveyed once
- 7 surveyed annually
- Different salinity and dominant land use



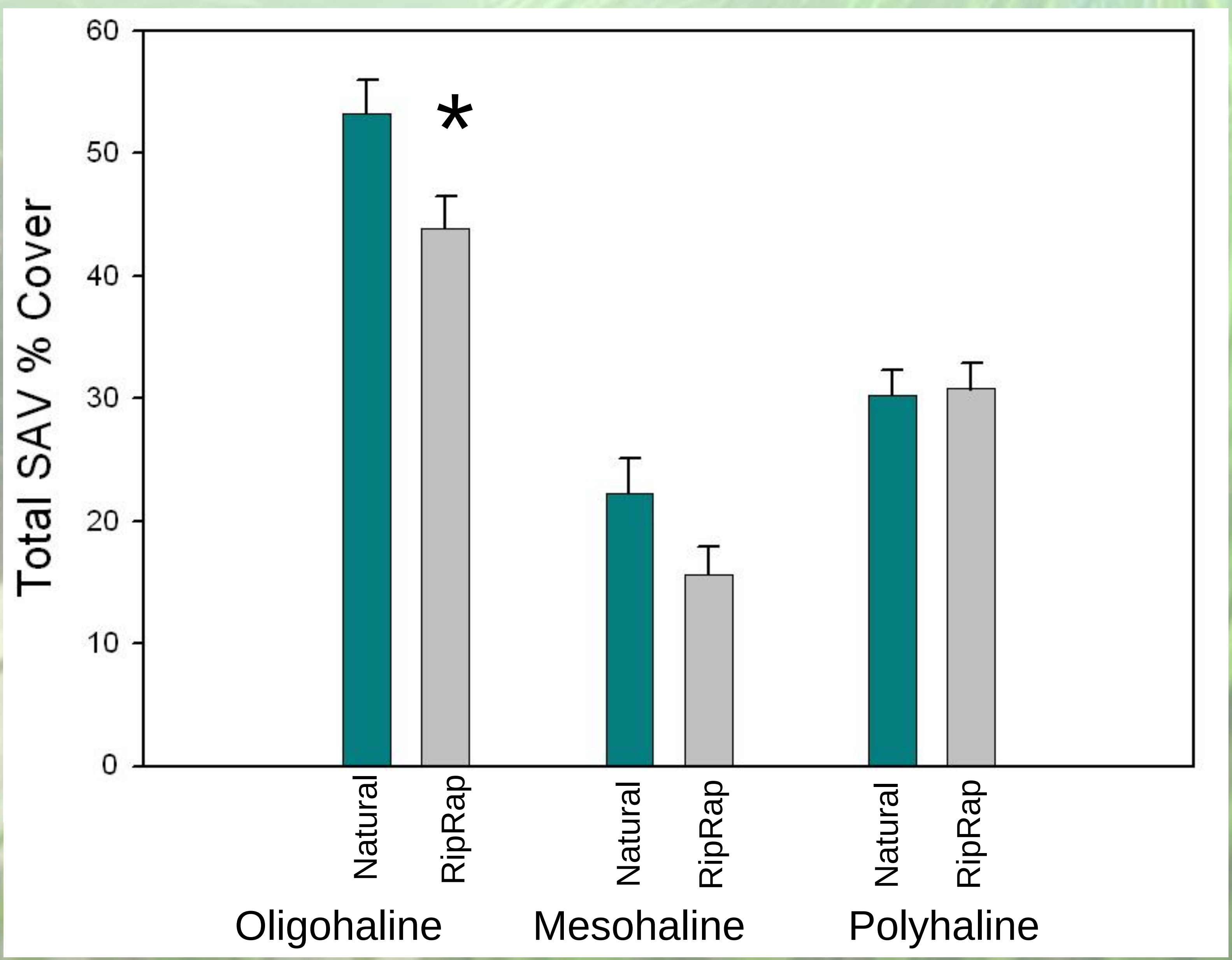
Vegetation survey design

Shoreline condition

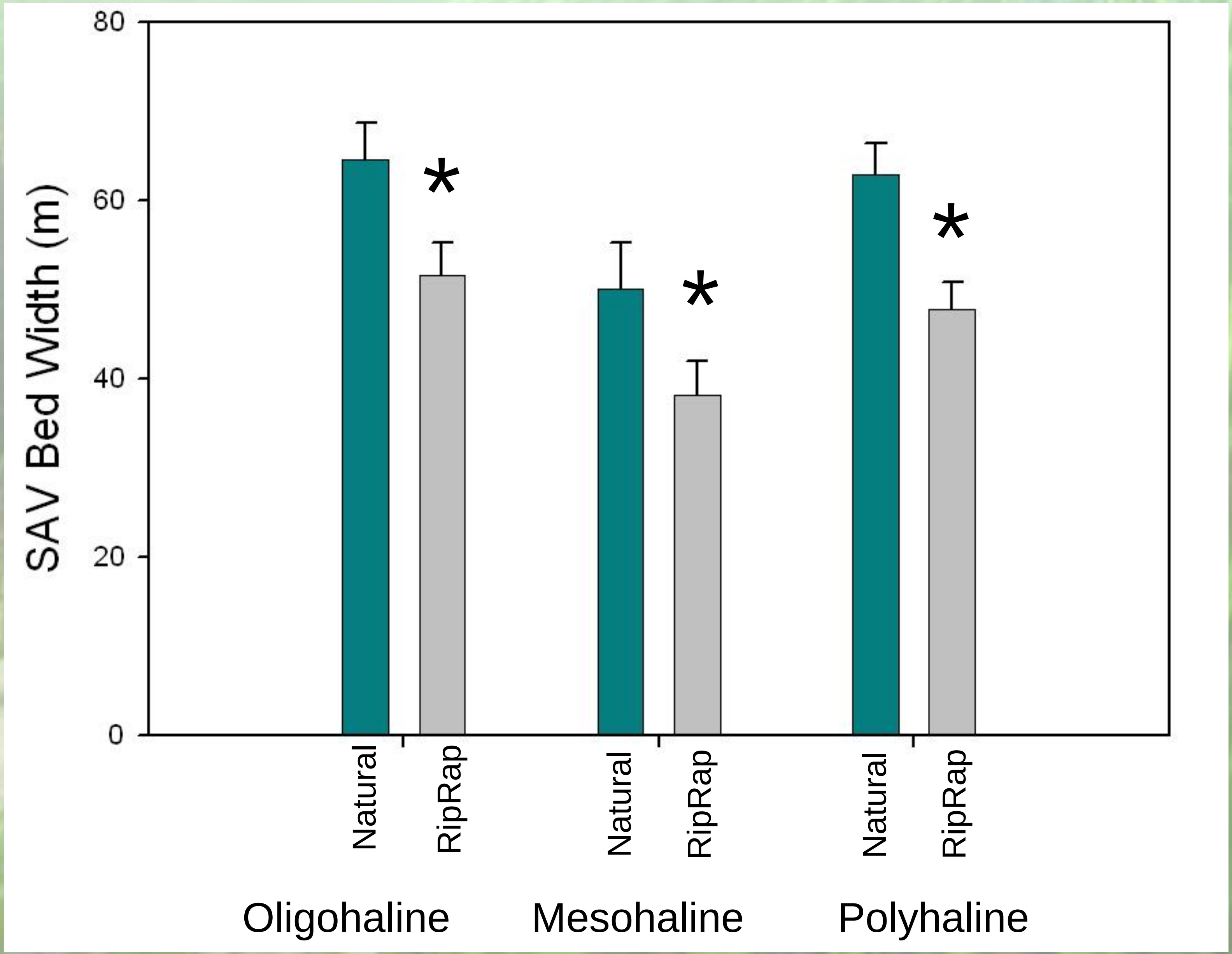




Riprap significantly reduces SAV cover

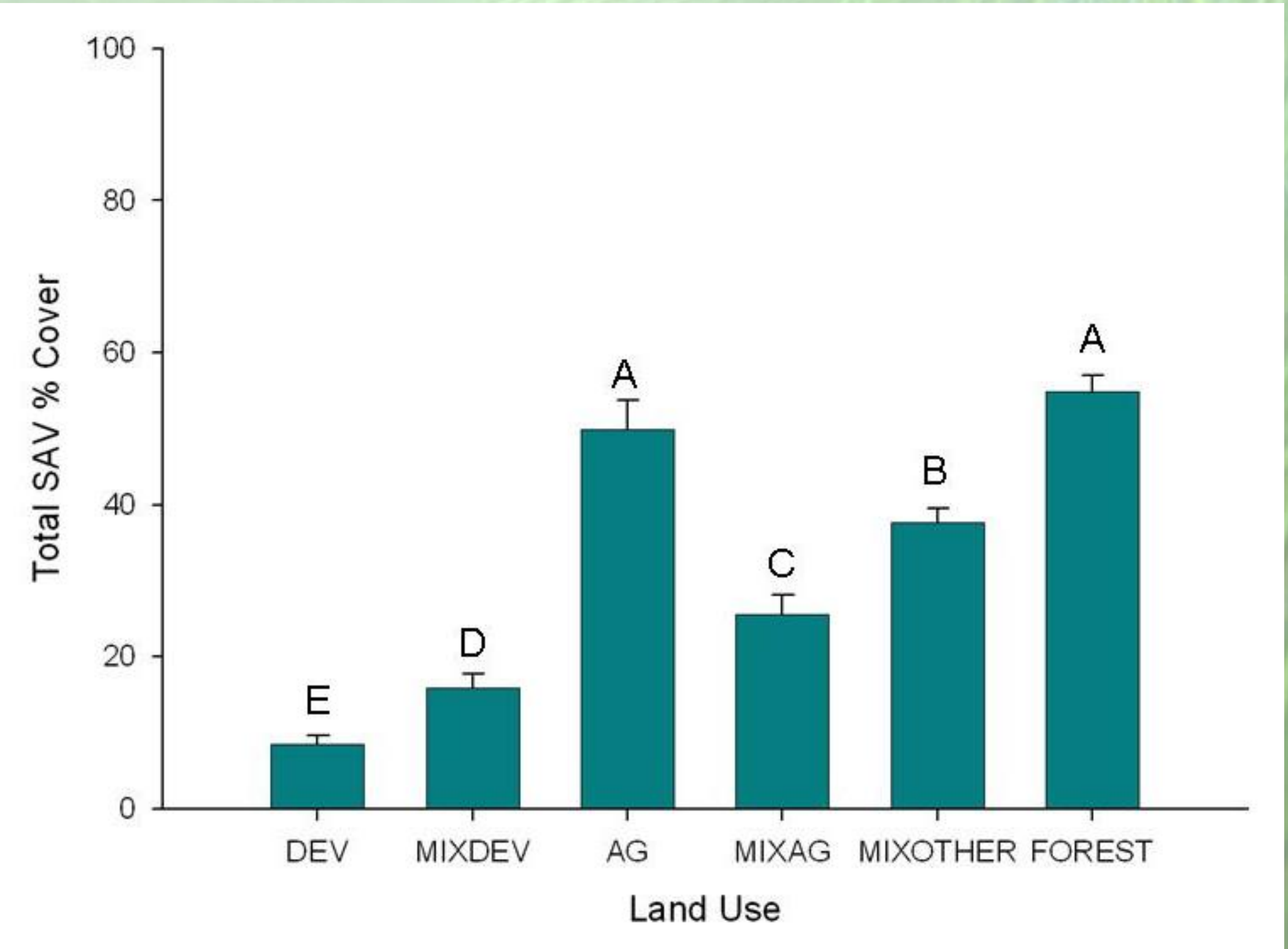


Riprap significantly reduces bed width

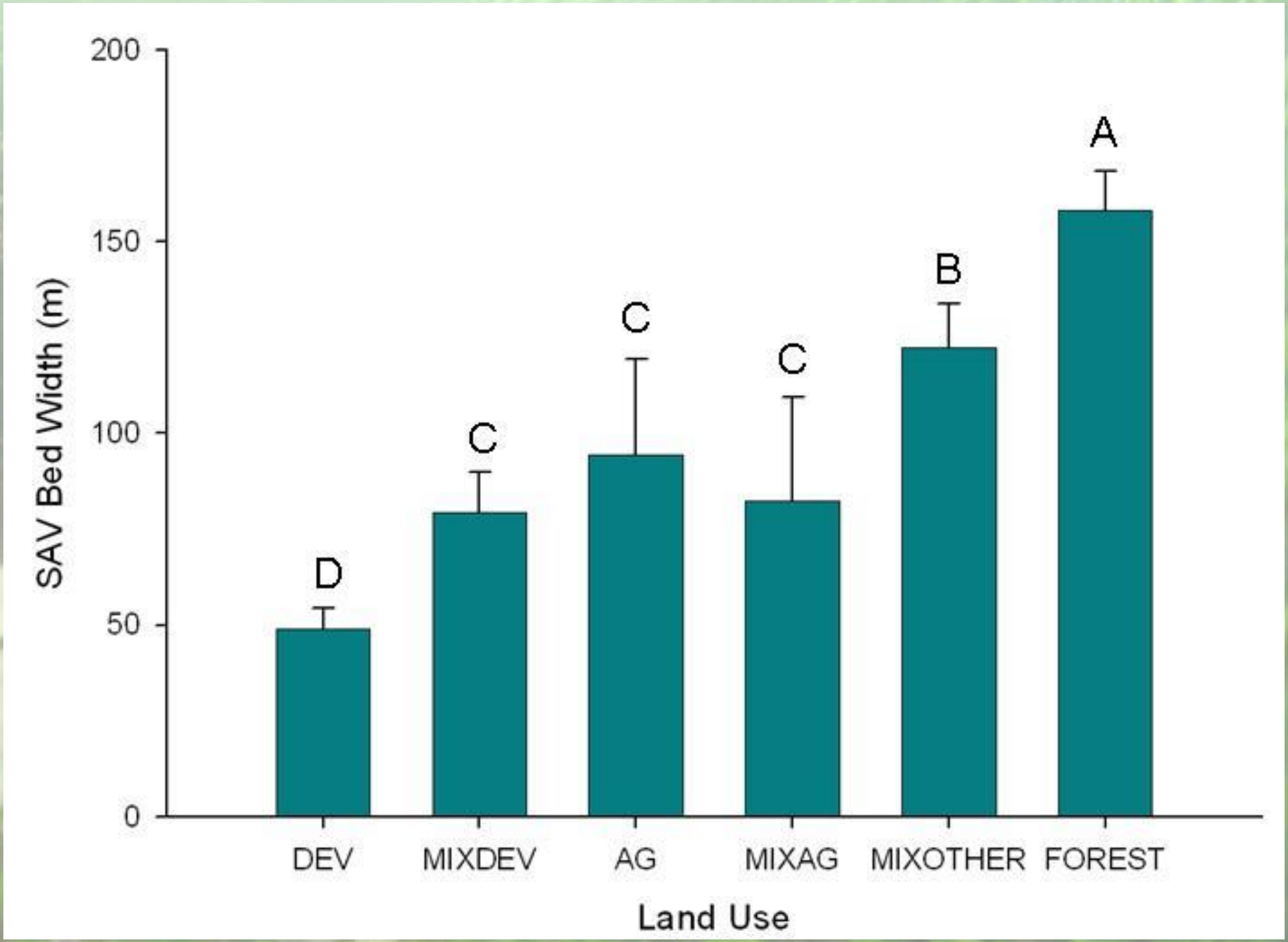


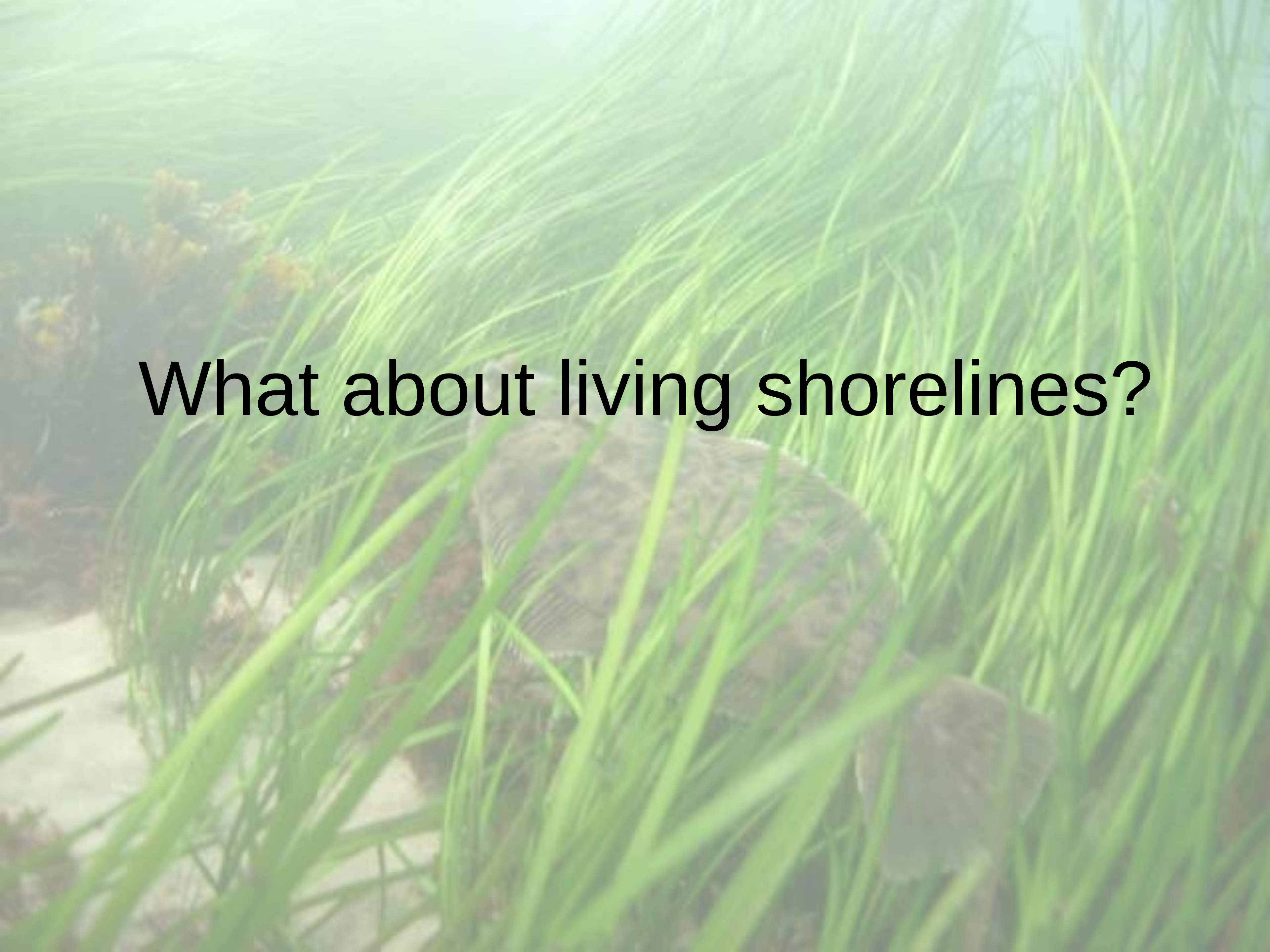
Riprap also reduces Frequency and increases Depth at Start of Bed

Human land use reduces SAV cover



… and bed width





What about living shorelines?

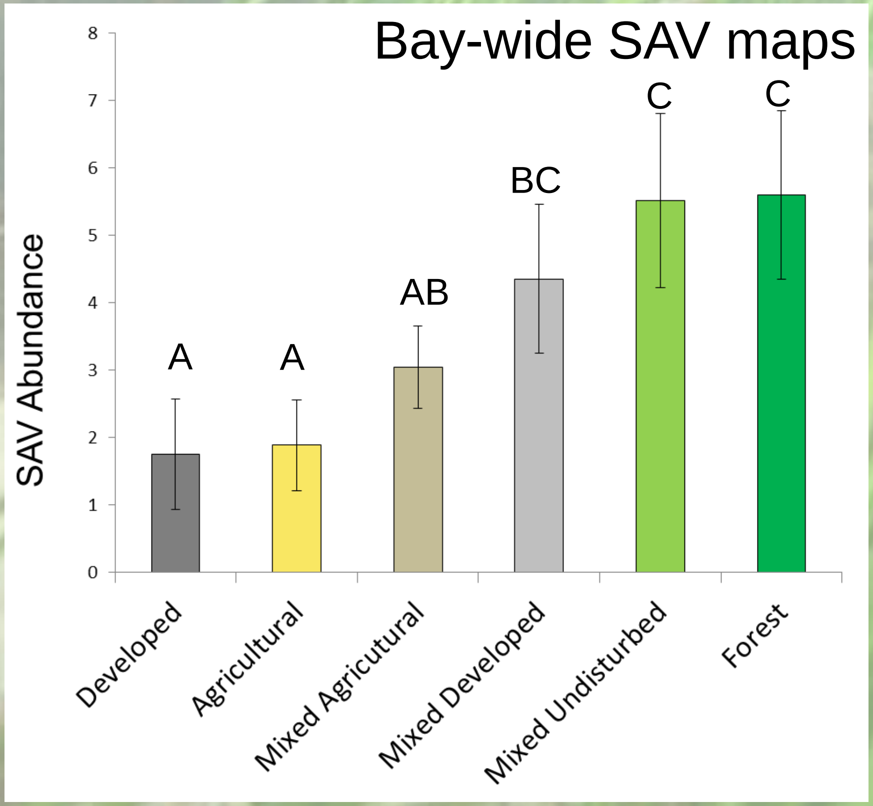
Living shoreline field transect

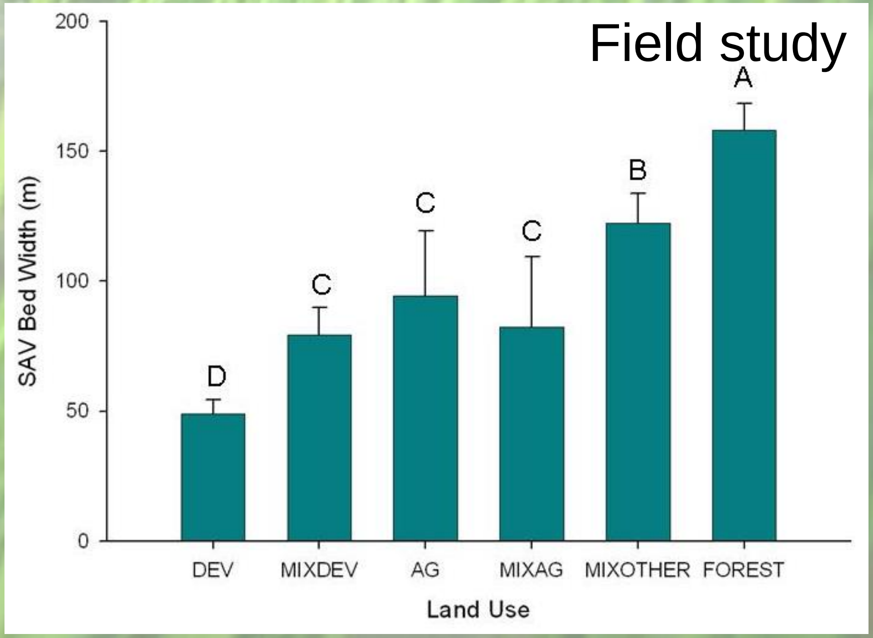
Barbara Haddock Taylor, Baltimore Sun

Summary headlines

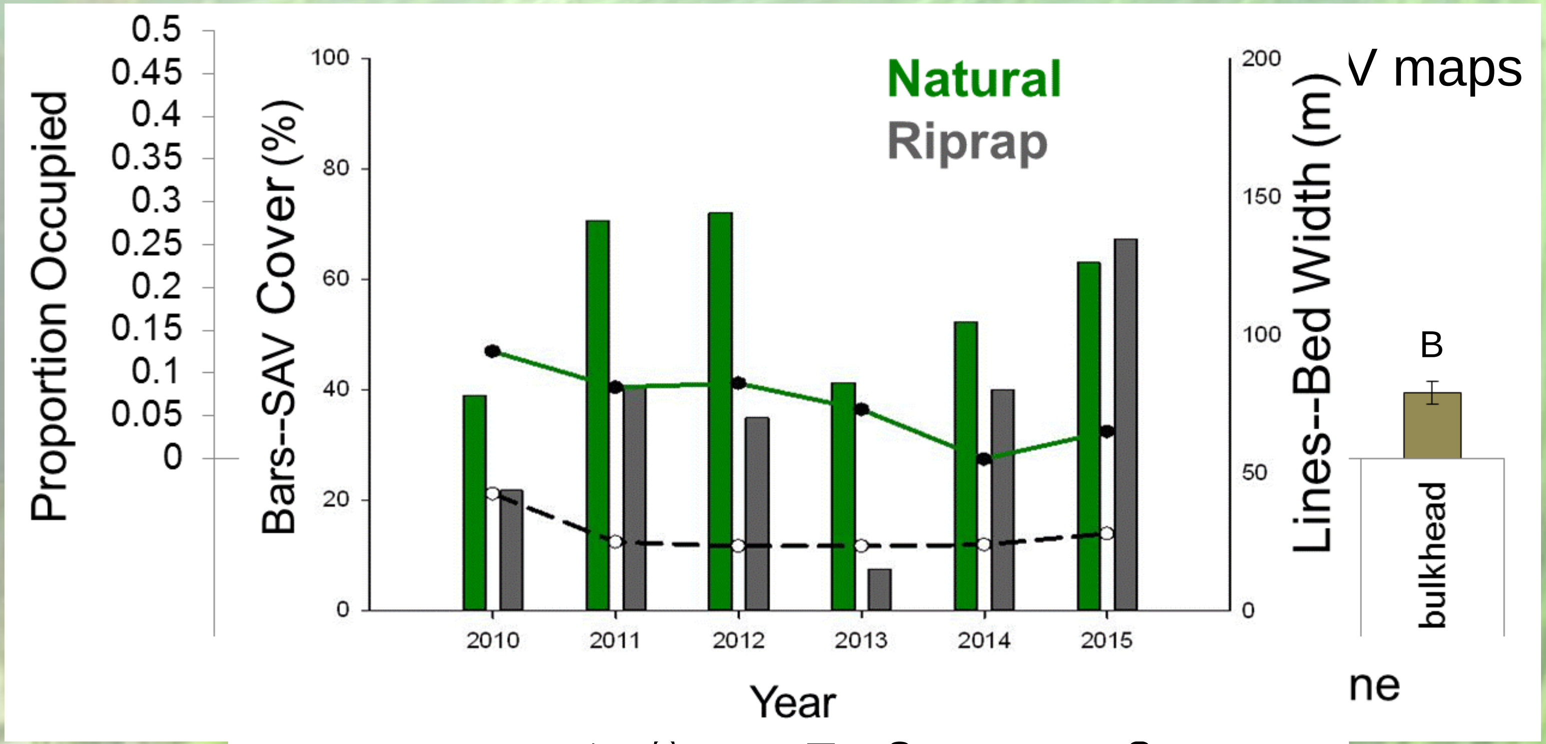
Local watershed land use affects subestuary SAV abundance

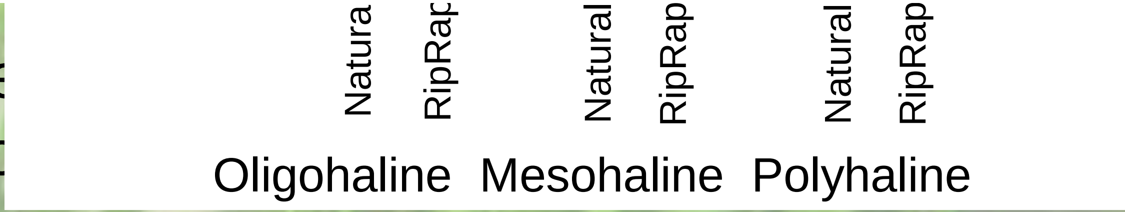
- Lower abundance in watersheds dominated by agriculture or developed land





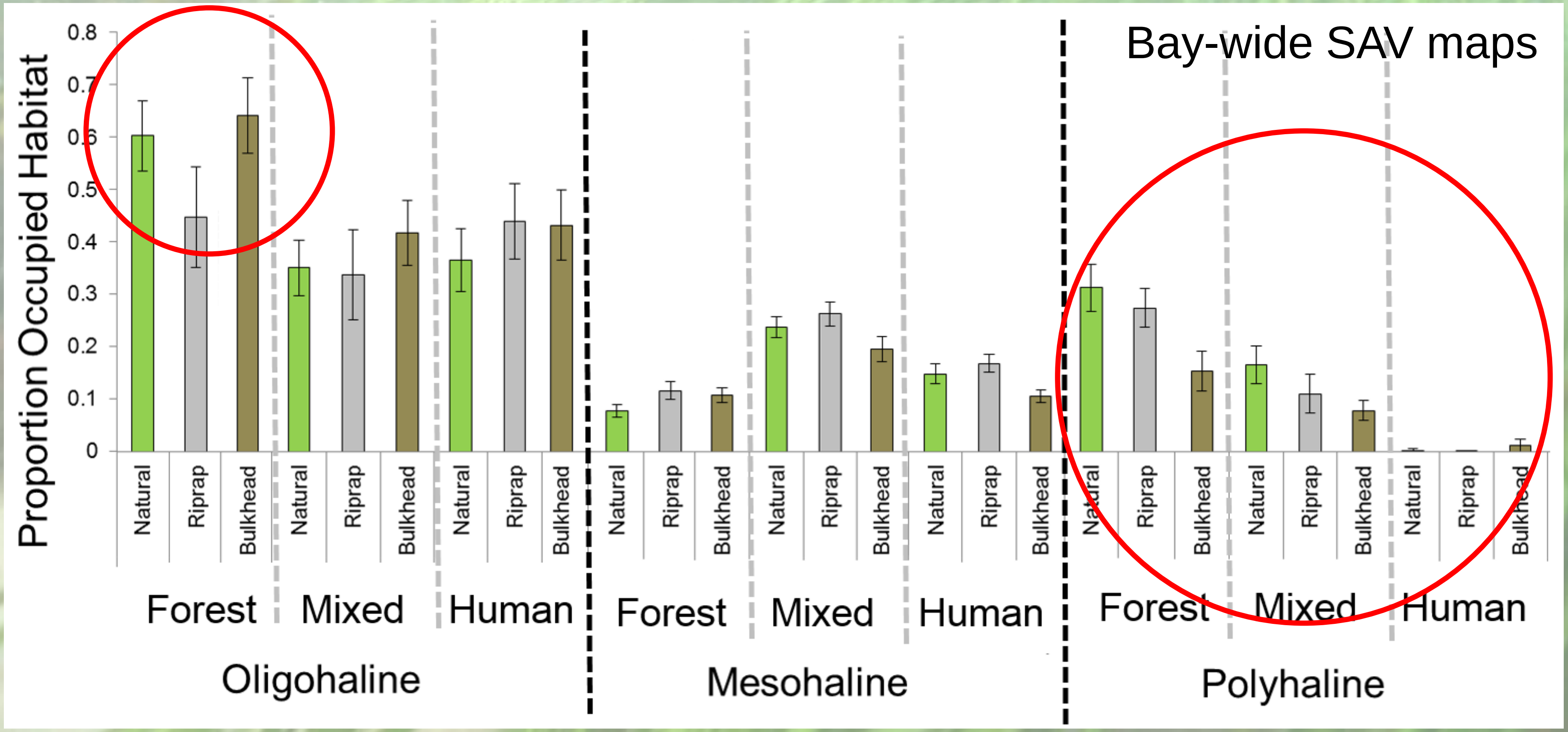
Shoreline hardening can reduce SAV abundance





- The d are stro
- Bulkhead has stronger effects than riprap
- Living shorelines *may* also reduce SAV

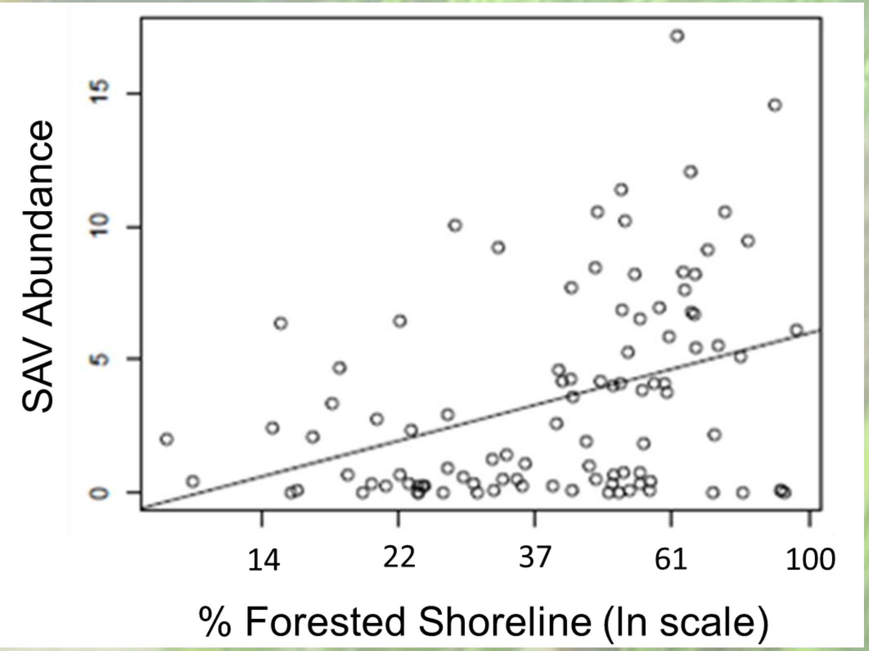
Shoreline hardening has more impact on SAV in subestuaries with healthy watersheds

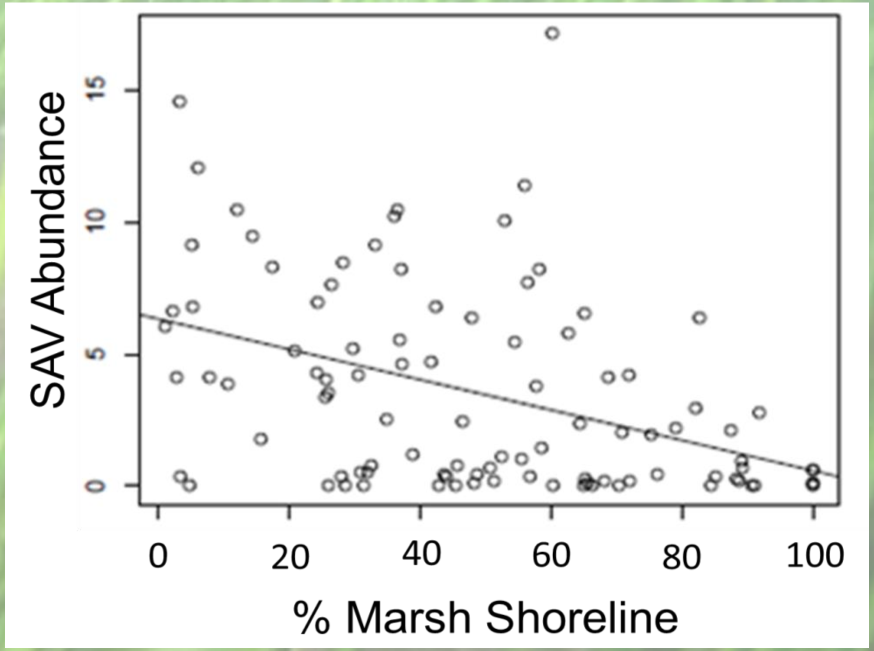


- Shoreline effects are weaker where development or agriculture already limit SAV

Natural shorelines are not all equal

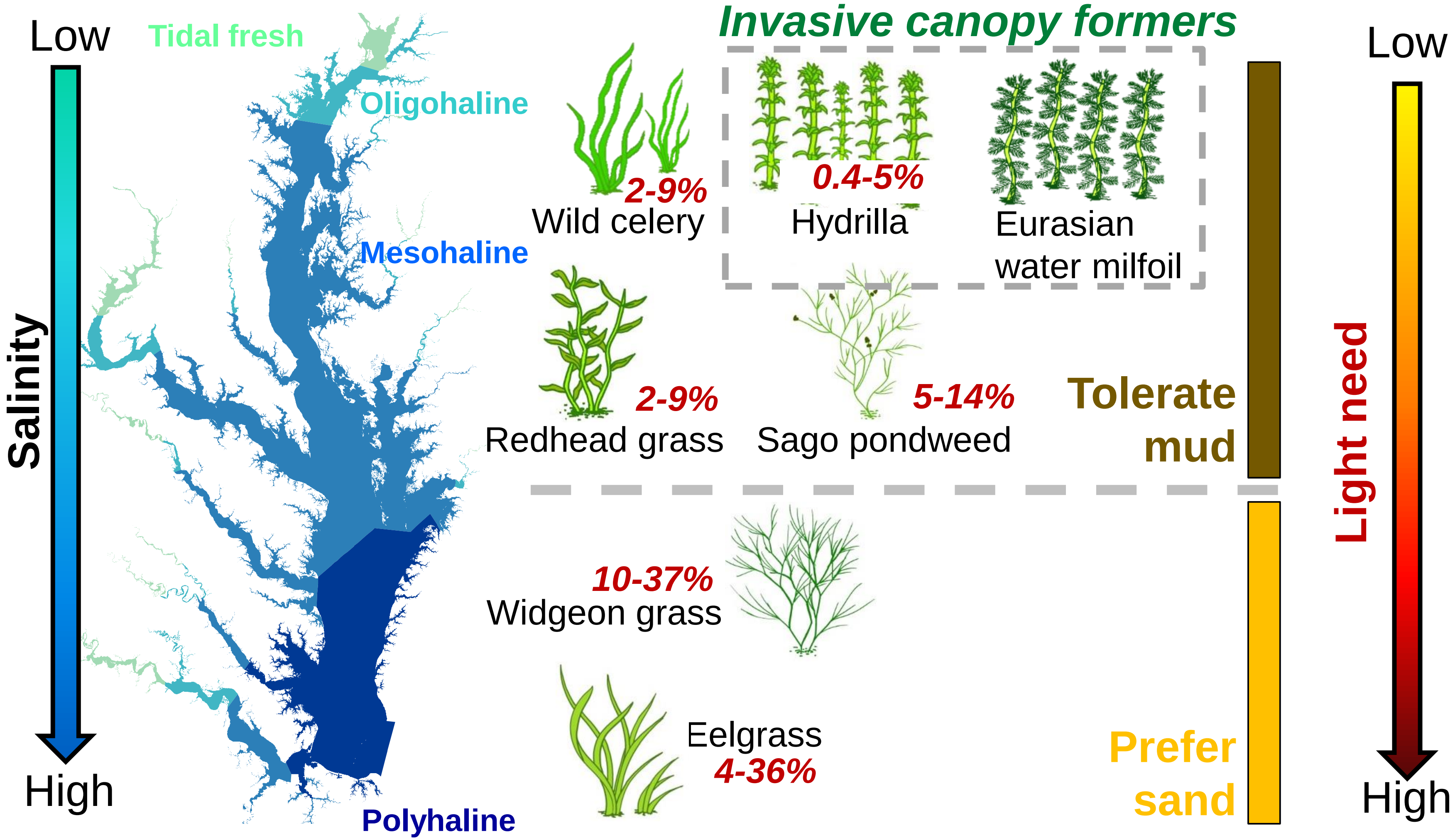
- Forested shorelines are positively related to adjacent SAV abundance





- Shoreline marsh has a negative effect, possibly by promoting peat or mud

Stressor impacts differ among SAV species and salinity zones



- Communities may need different management strategies!
- Salinity is a poor proxy for community type

Acknowledgements

Data Sources: Chesapeake Bay Program, VIMS, MDNR

Supported by award number NA09NOS4780214 from the National Oceanic and Atmospheric Administration Center for Sponsored Coastal Ocean Research (CSCOR).

Following slides not used …

Using the VIMS ground survey data to determine which species occur in which subestuaries

- Collaboration with JJ Orth and David Wilcox
- Organizing ground survey data and helping us interpret analyses on those data
- ~30 years of data, 26 species, organized by subestuary

- What communities are found in each subestuary?
- How does community identity moderate the affect of stressors on SAV?

Salinity zone as a proxy for community type is useful, but not terribly satisfying

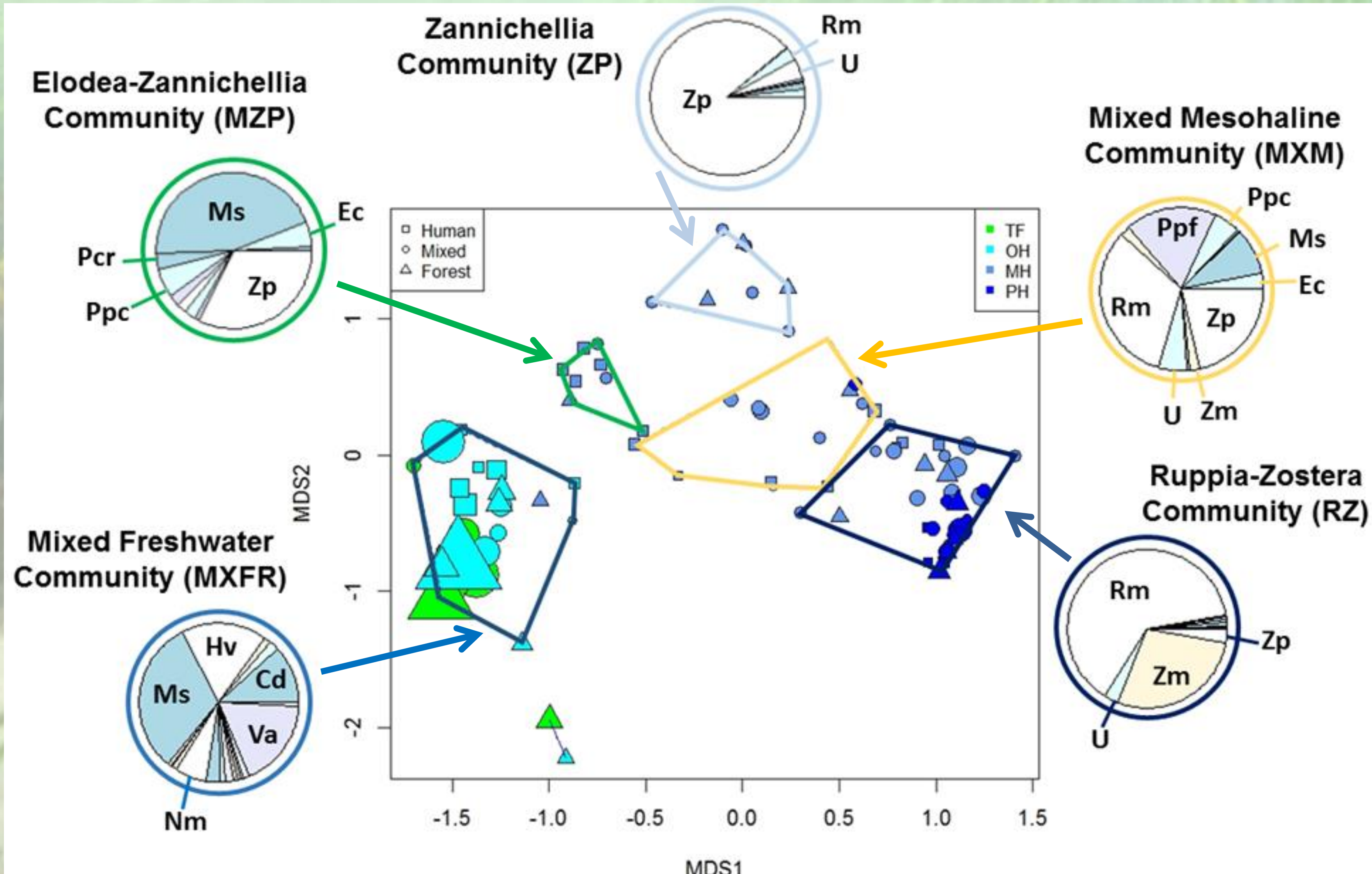
• ZOSTERA Community	*Zostera marina**
	Ruppia maritima
• RUPPIA Community	*Ruppia maritima**
	Potamogeton perfoliatus
	Potamogeton pectinatus
	Zannichellia palustris
• POTAMOGETON Community	*Potamogeton pectinatus**
	*Potamogeton perfoliatus**
	Potamogeton crispus
	Elodea canadensis
• FRESHWATER MIXED Community	*Myriophyllum spicatum**
	*Hydrilla verticillata**
	*Vallisneria americana**
	Ceratophyllum demersum
	Heteranthera dubia
	Elodea canadensis
	Najas guadalupensis
	Najas gracillima
	Najas minor
	Najas sp.
	Potamogeton crispus
	Potamogeton pusillus

Moore et al 2000. Estuaries & Coasts

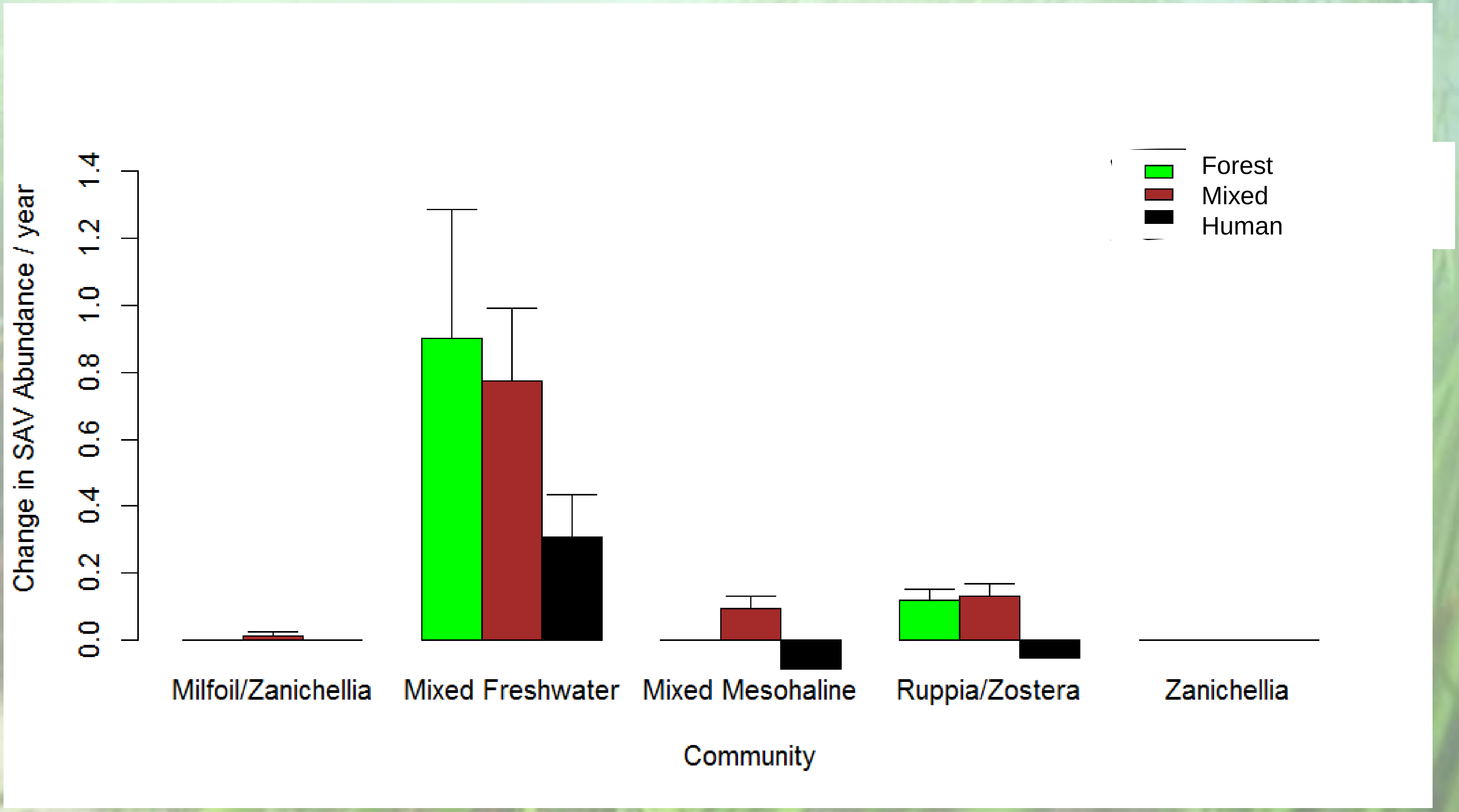
Moore et al. found that between 1986 and 1995 there were four distinct community types.

Salinity tolerances of many of the taxa are broad and overlapping

NMDS ordination of ground survey data

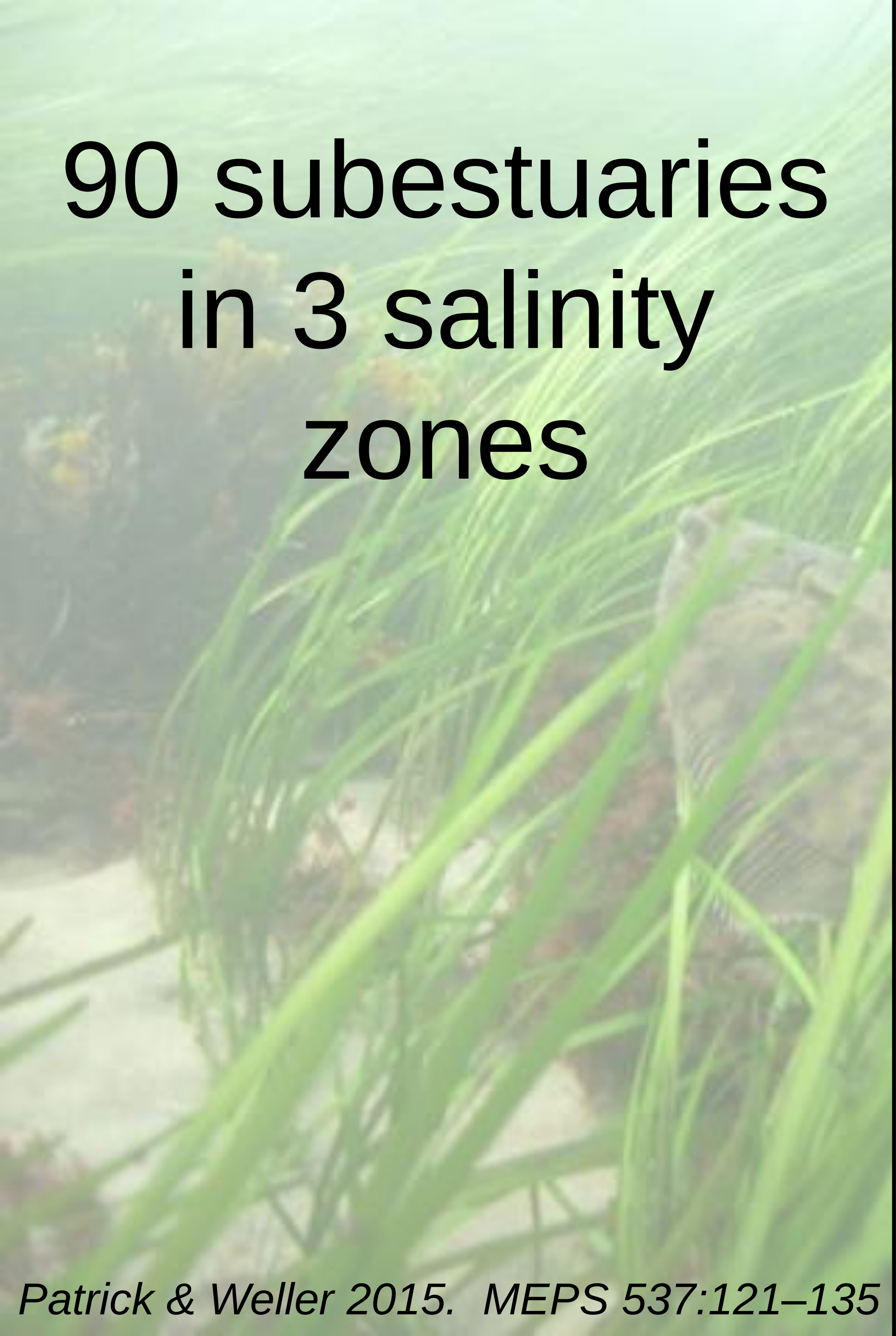


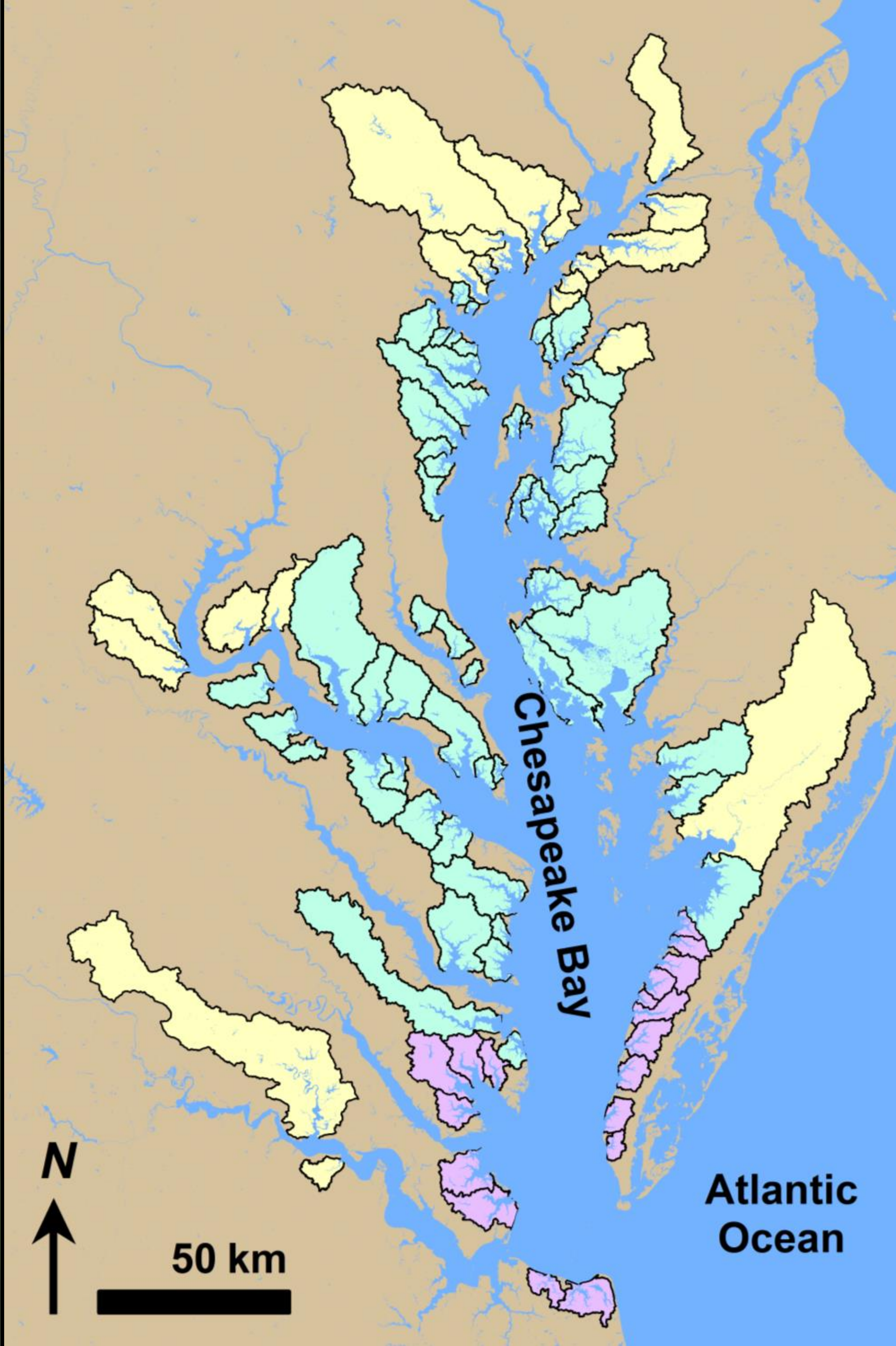
5 community types, 4 occur in the mesohaline



Trends in SAV change through time strongly vary between community types and also between land use types

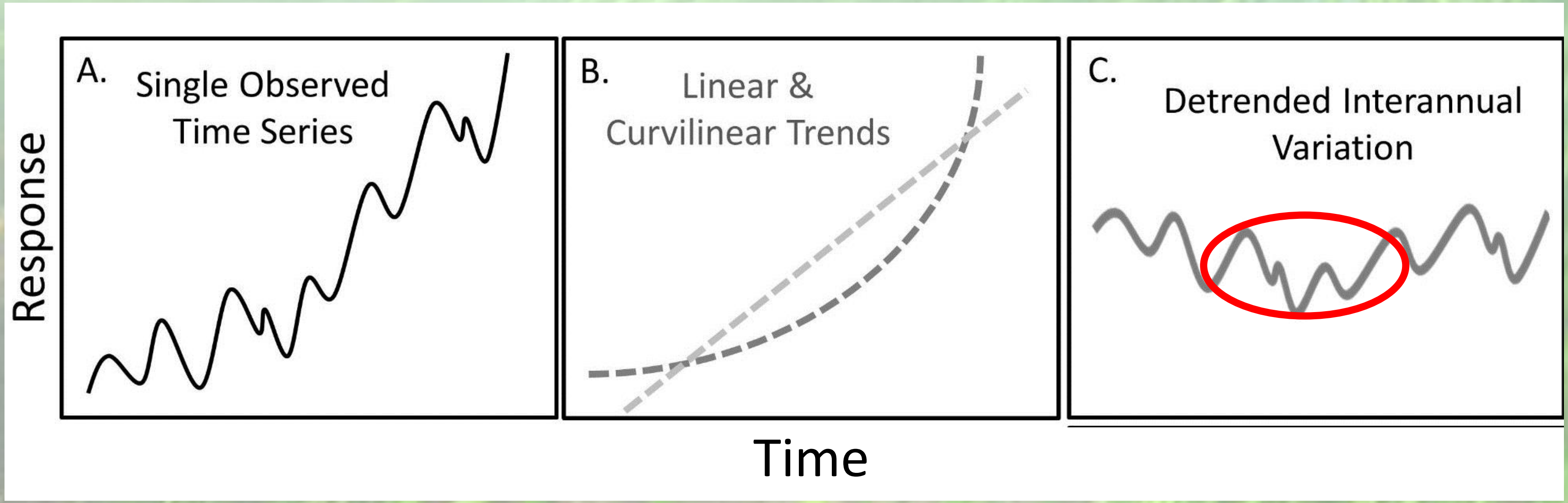
90 subestuaries in 3 salinity zones





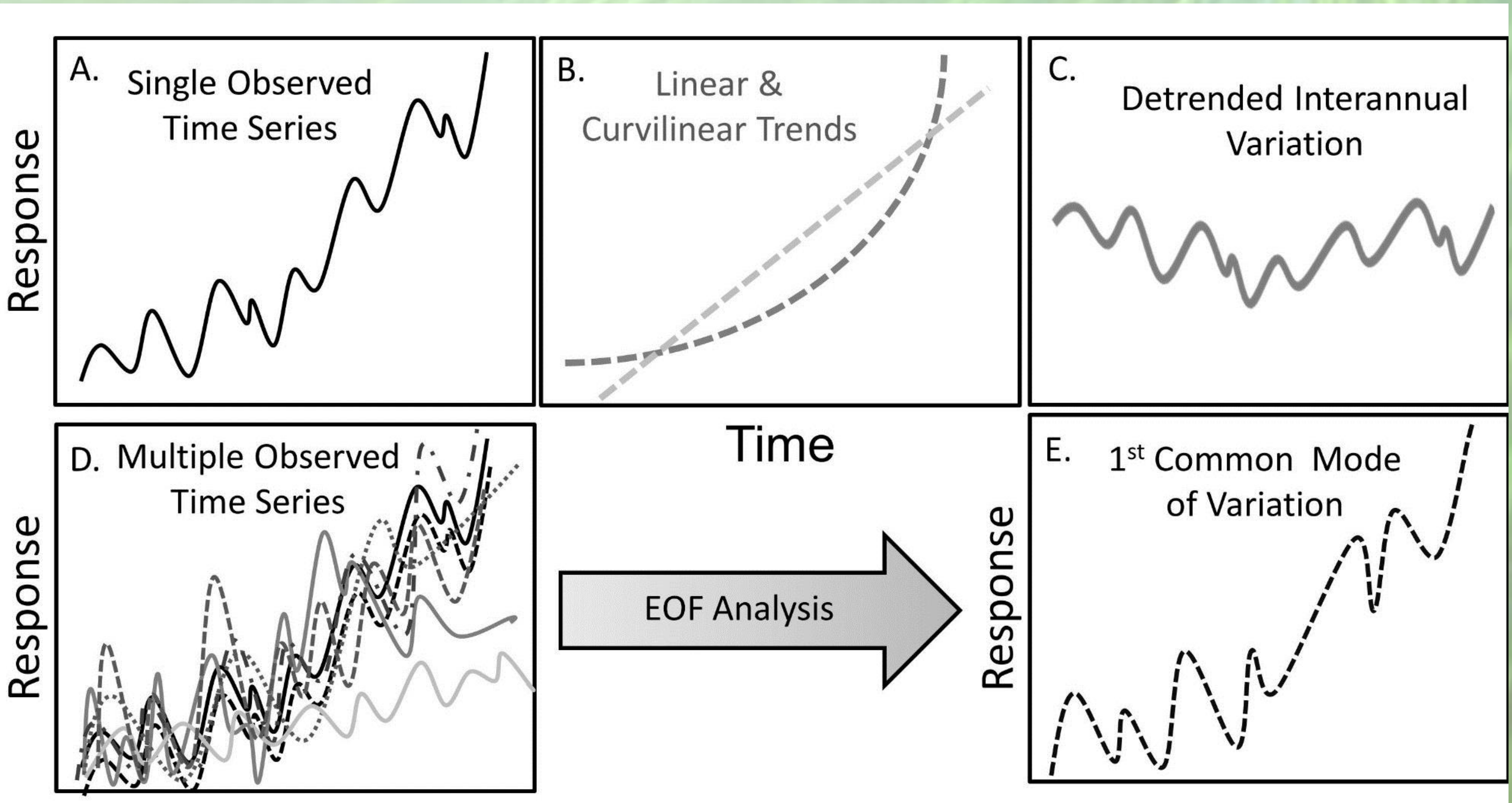
Patrick & Weller 2015. MEPS 537:121–135

Temporal components



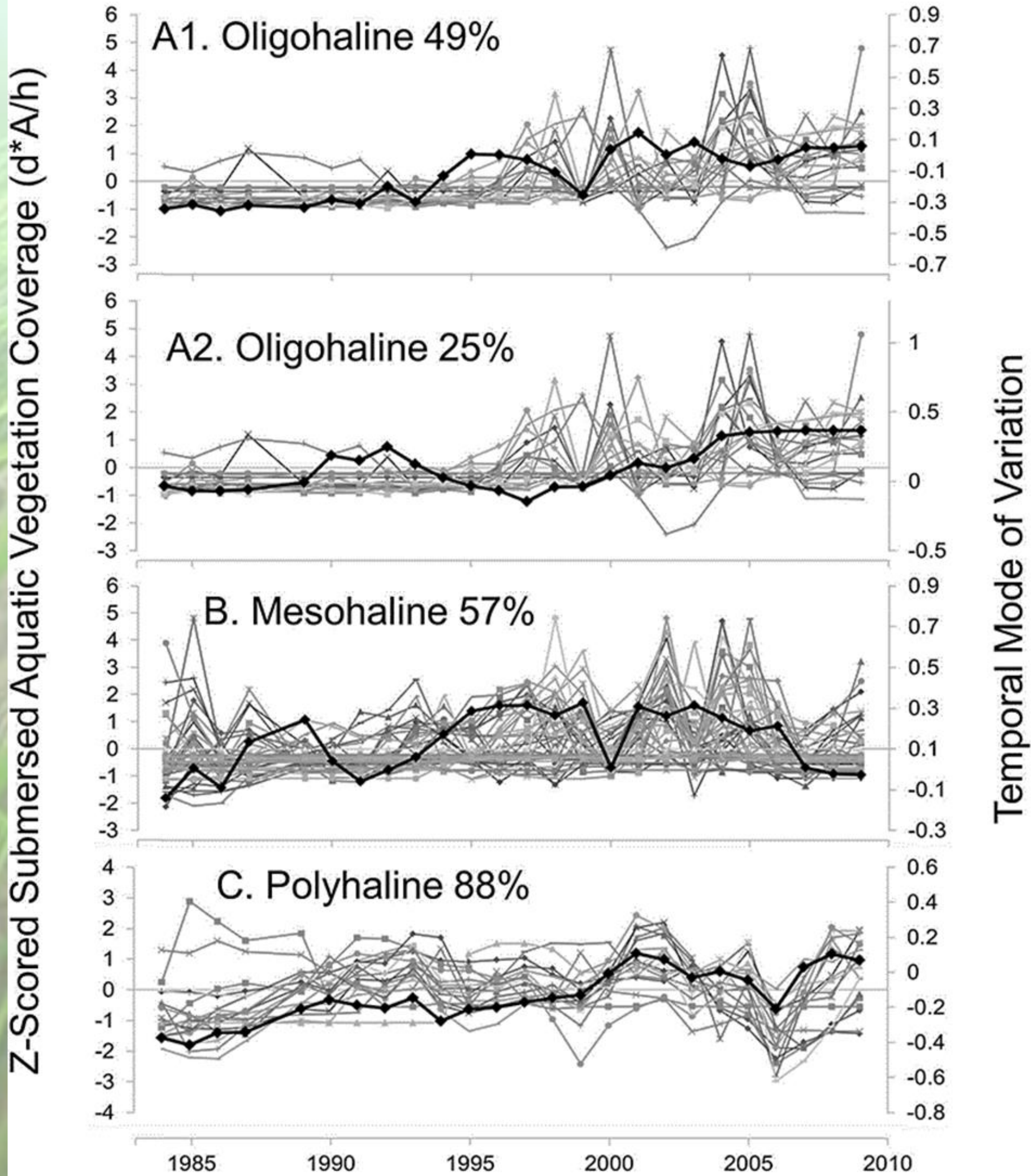
Patrick & Weller 2015. MEPS 537:121–135

EOF analysis



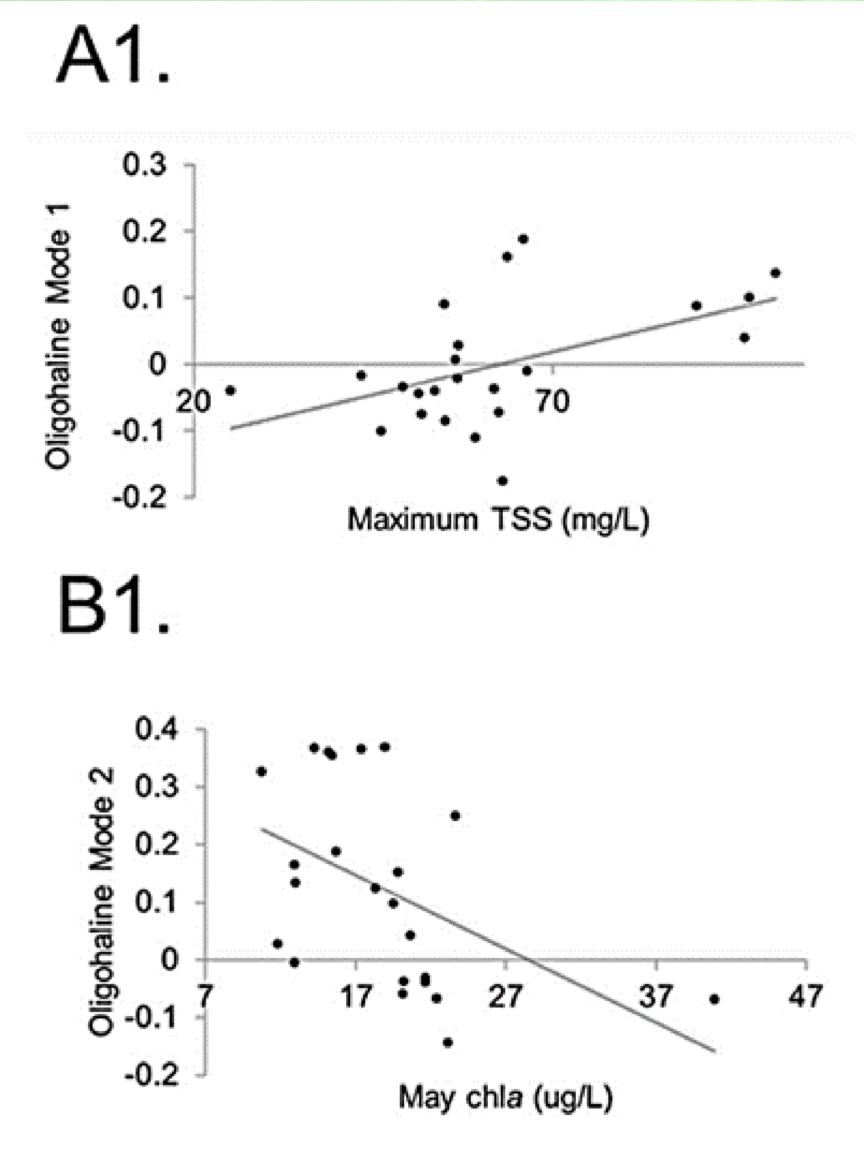
Patrick & Weller 2015. MEPS 537:121–135

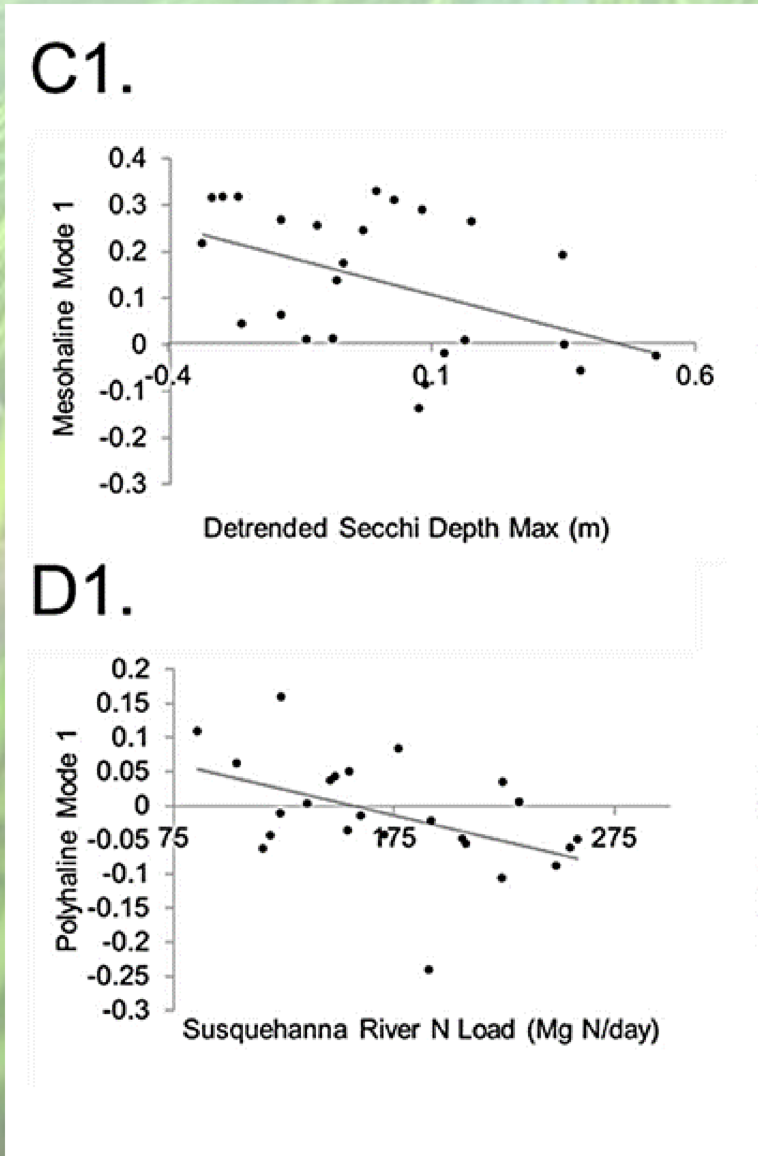
Synchronicity differs among salinity zones & increases with salinity



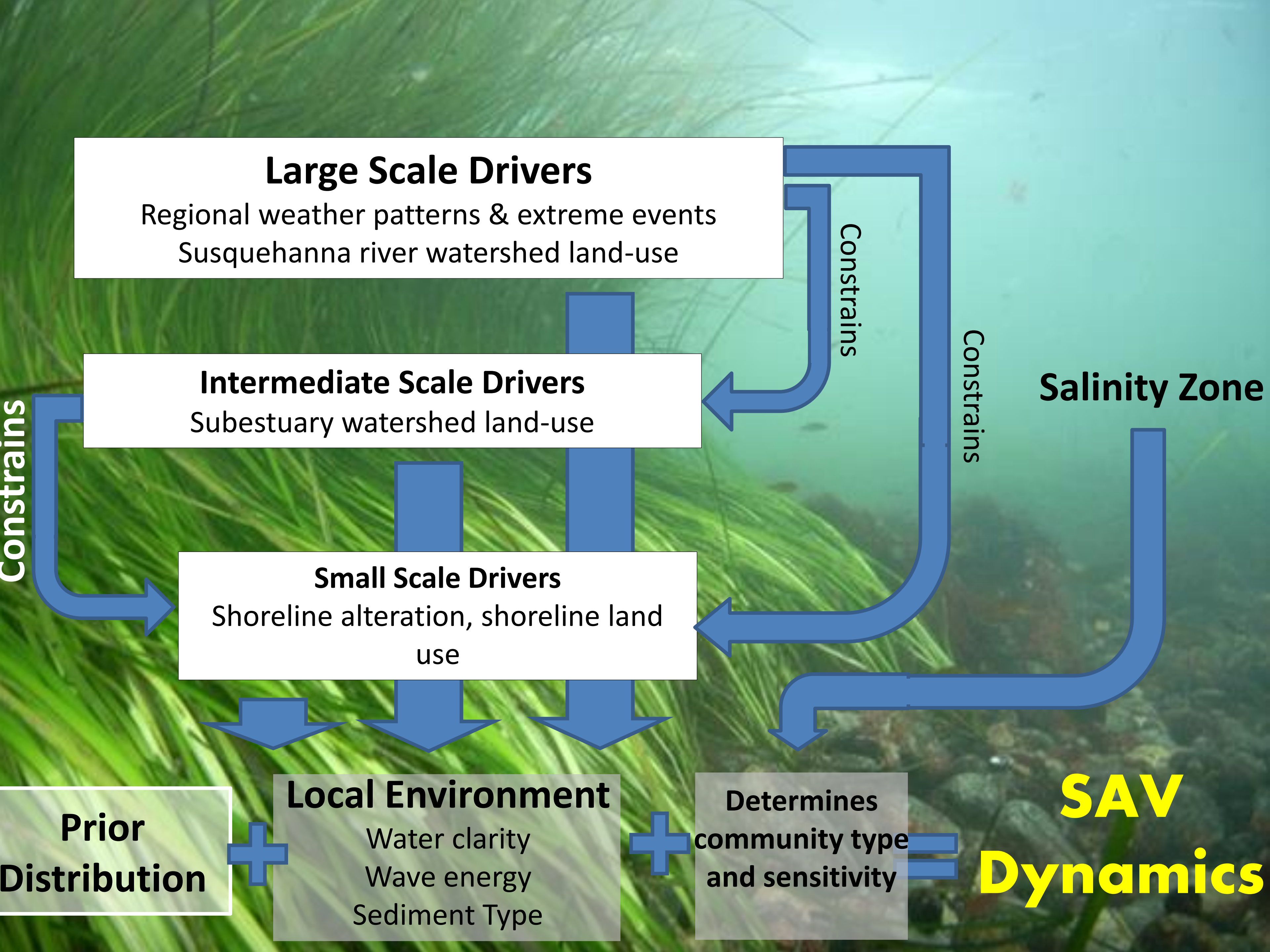
Patrick & Weller 2015. MEPS 537:121–135

Significant cross correlations with dominant modes

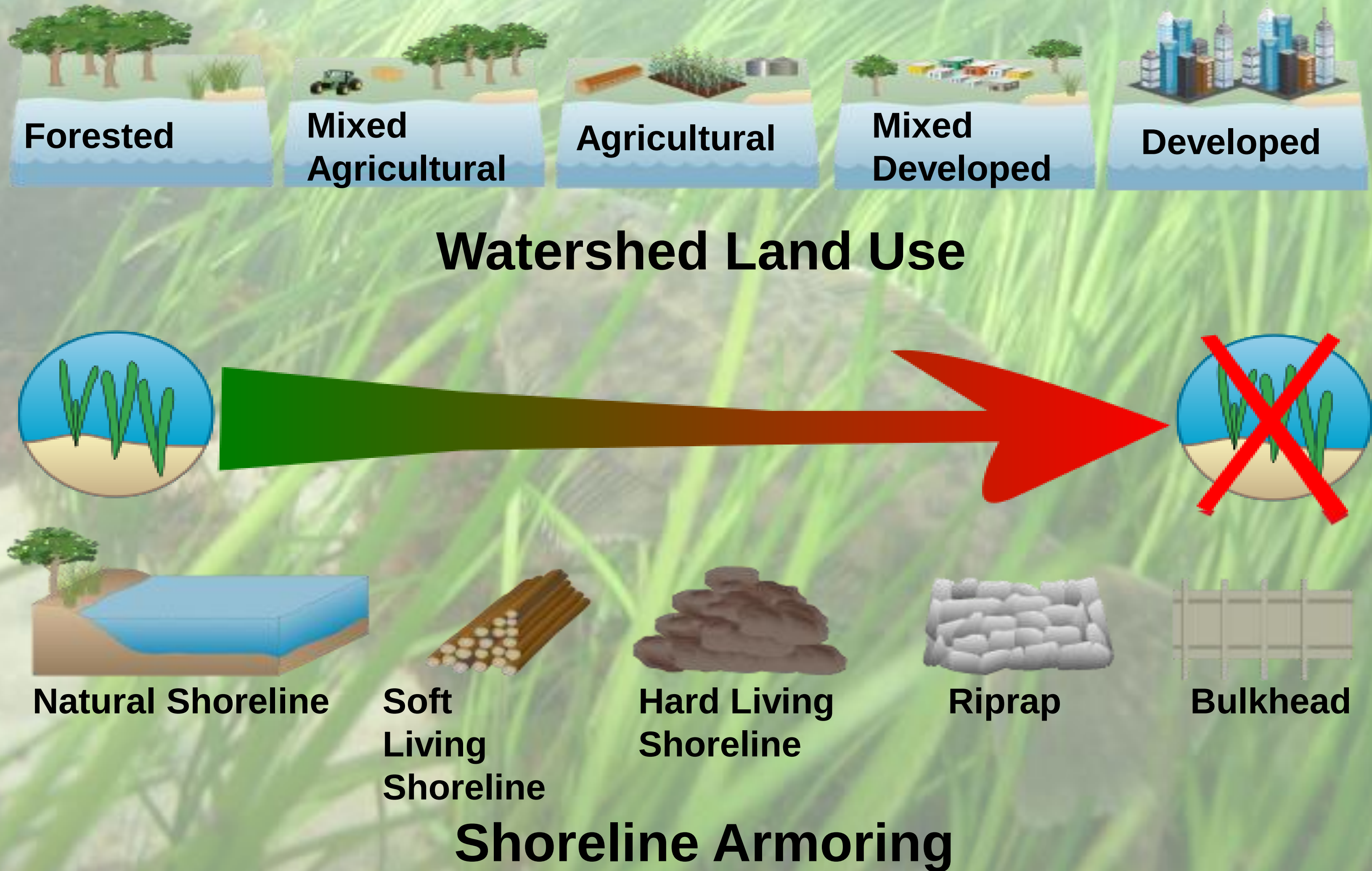




Patrick & Weller 2015. MEPS 537:121–135

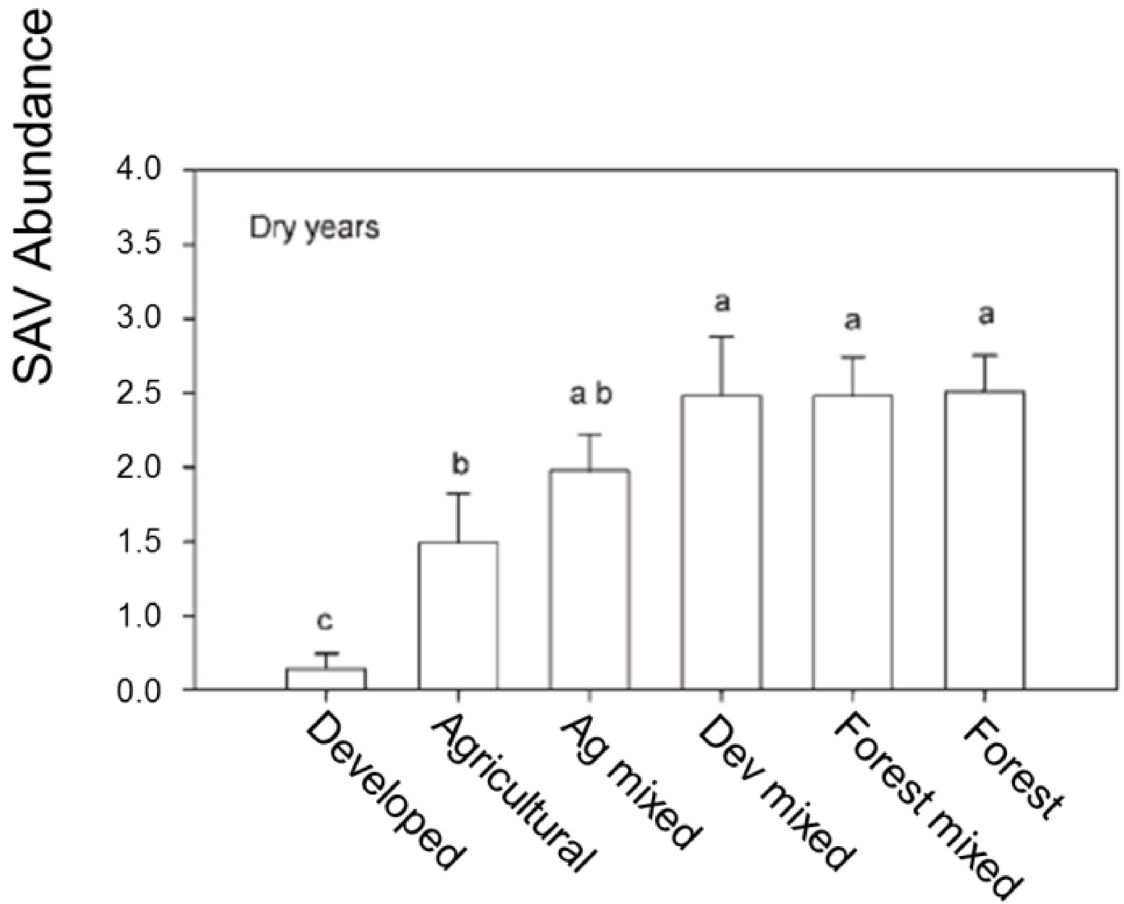

Large Scale Drivers
Regional weather patterns & extreme events
Susquehanna river watershed land-use
Constrains
Constrains
Intermediate Scale Drivers
Subestuary watershed land-use
Constrains
Salinity Zone
Small Scale Drivers
Shoreline alteration, shoreline land use
Prior Distribution
Local Environment
Water clarity
Wave energy
Sediment Type
Determines community type and sensitivity
SAV Dynamics

Breaking bad

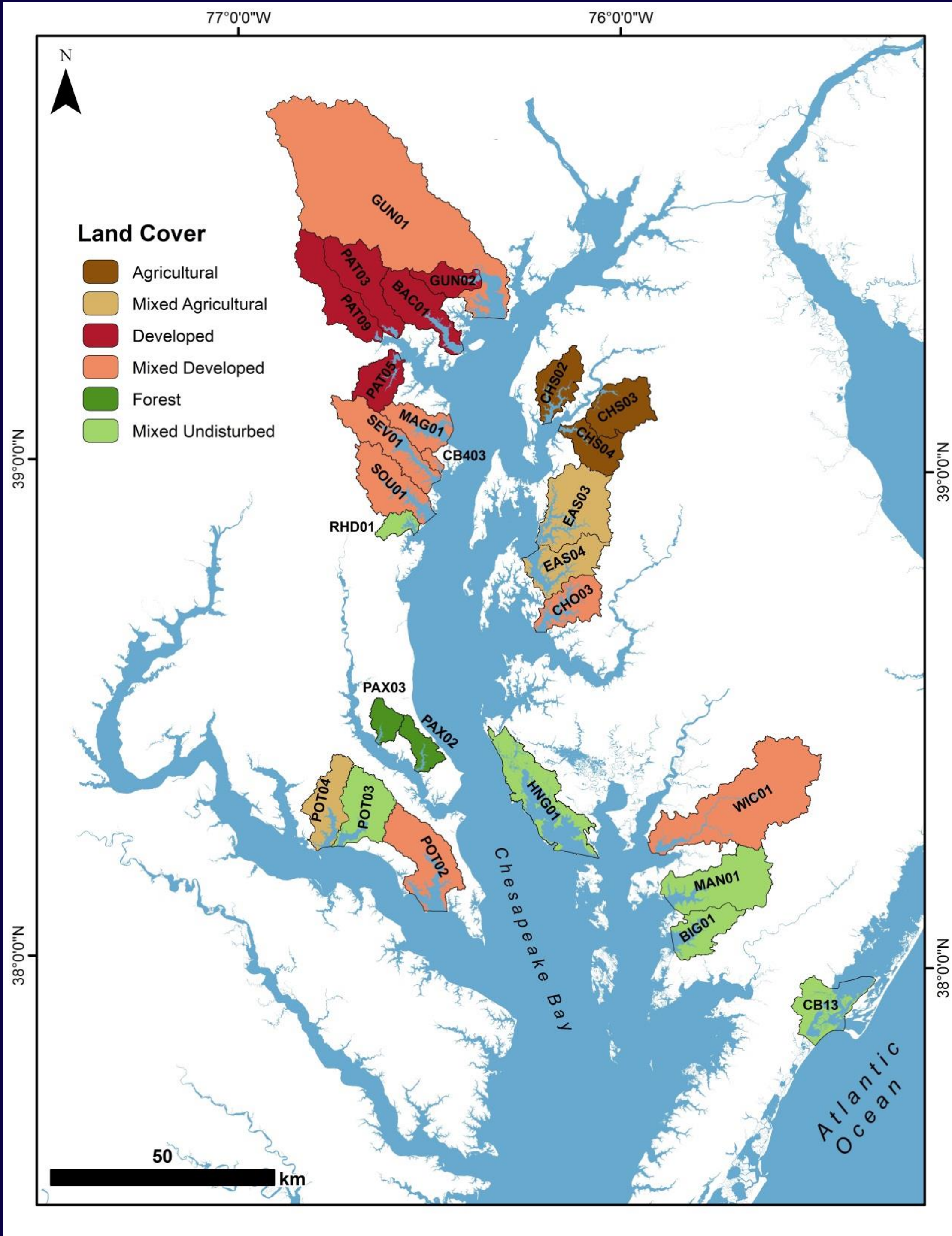


Land use affects SAV abundance

…more in wet years than in dry years



Li et al. 2014. Estuaries Coasts 37:1516–1531



Study Sites

- 27 subestuaries sampled over programs & years
- 342 measurements of 3 particulate IOPs

19 metrics from spatial analysis

Energy

- Tidal range
- Mouth width
- Surface area
- Volume
- % <2 m deep
- Fractal dimension
- Max. wave ht.
- Watershed area
- Watershed:estuary ratio

Composition

Watershed land cover

- % Forest
- % Cropland
- % Developed
- % Grassland
- % Wetland

Shoreline characteristics

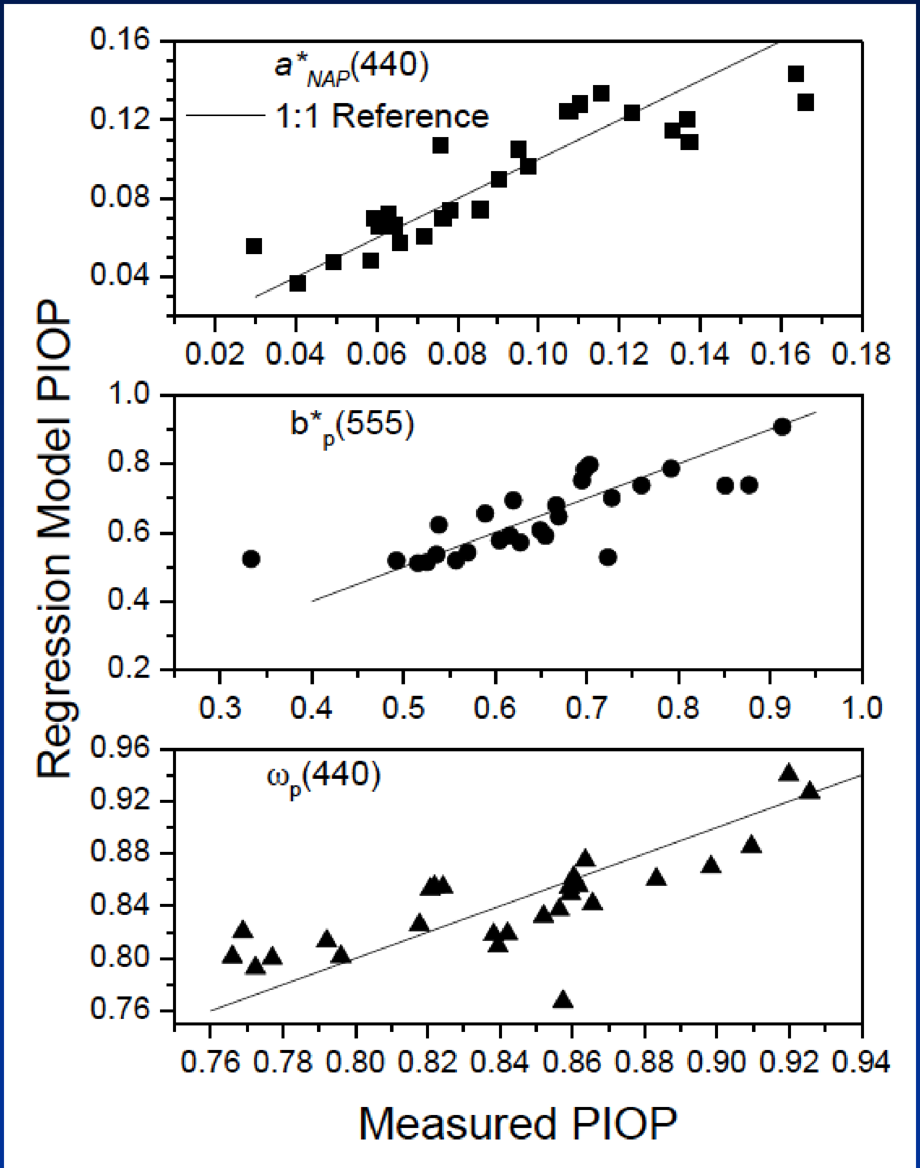
- % Un-hardened shoreline
- % Developed shoreline
- % Vegetated bank
- % Shoreline with beach
- % Shoreline with marsh

Significant univariate correlations

23 significant (*P*≤0.05), 4 expected by chance alone

	$a^*_{NAP}(440)$			$b^*_p(555)$			$w_p(440)$		
Correlate	Rank	Sign	R^2	Rank	Sign	R^2	Rank	Sign	R^2
Tide range (m)	1	-	0.37	2	-	0.22	2	+	0.33
% Bank developed	2	+	0.32	3	+	0.20	4	-	0.22
% Cropland	3	-	0.27	1	-	0.30			ns
% Wetland	4	-	0.23			ns	1	+	0.42
% Unhardened shoreline	5	-	0.22	4	-	0.20			ns
% Forested watershed	6	+	0.20	5	+	0.19			ns
Mean depth (m)	7	+	0.18			ns			ns
% Shoreline with marsh	8	-	0.15			ns			ns
% Shoreline with beach	9	+	0.15			ns	3	-	0.25
Fractal dimension	10	-	0.15	6	-	0.17			ns
Mouth width (km)			ns			ns	5	+	0.19
Subestuary area (km^2)			ns			ns	6	+	0.17
% Developed watershed			ns			ns	7	-	0.17

Multiple linear regression models



Adjusted R^2 0.60 to 0.73

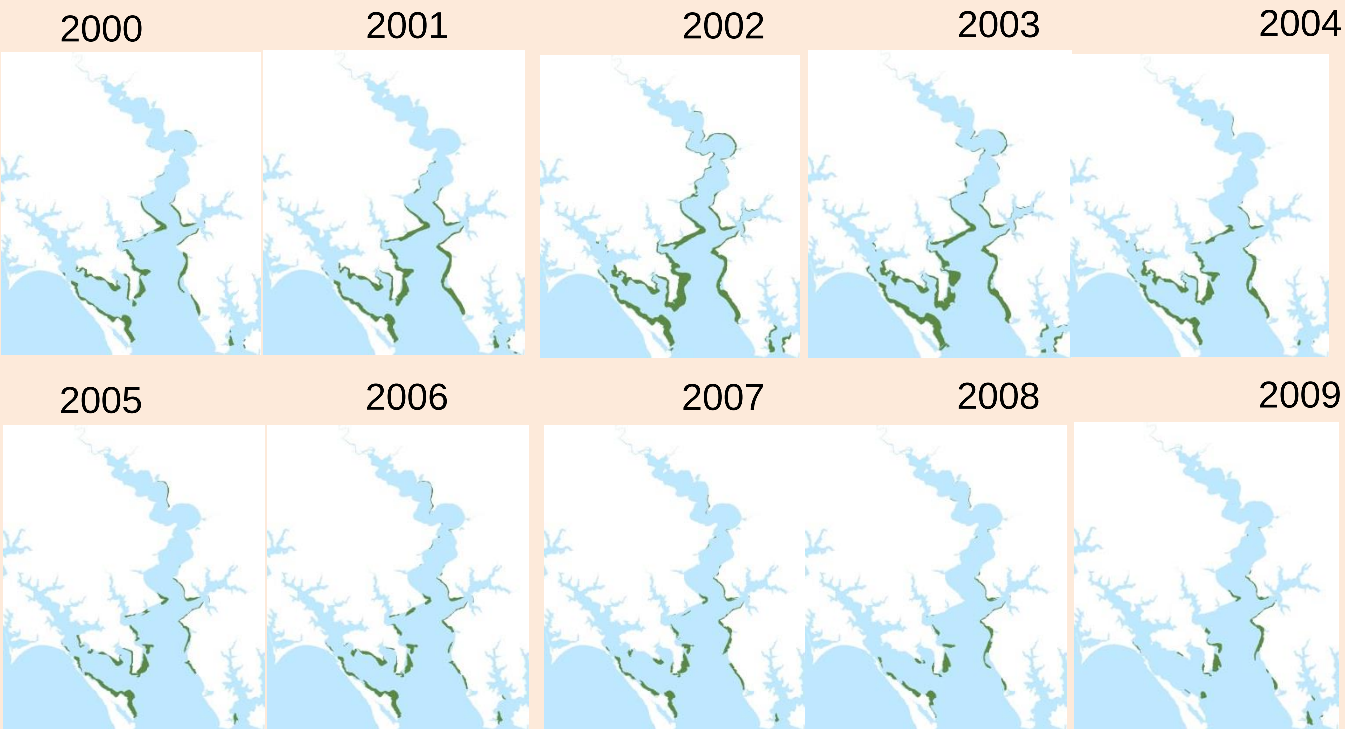
X-validated R^2 0.45 to 0.66

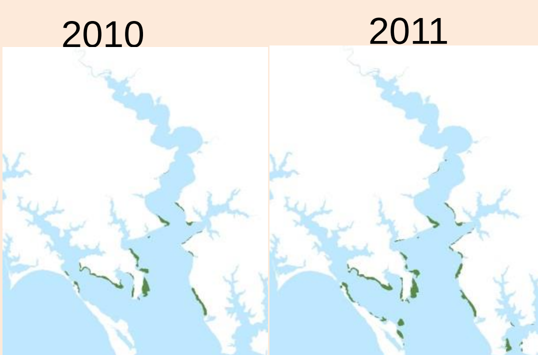
Suggests robust performance with unmeasured systems

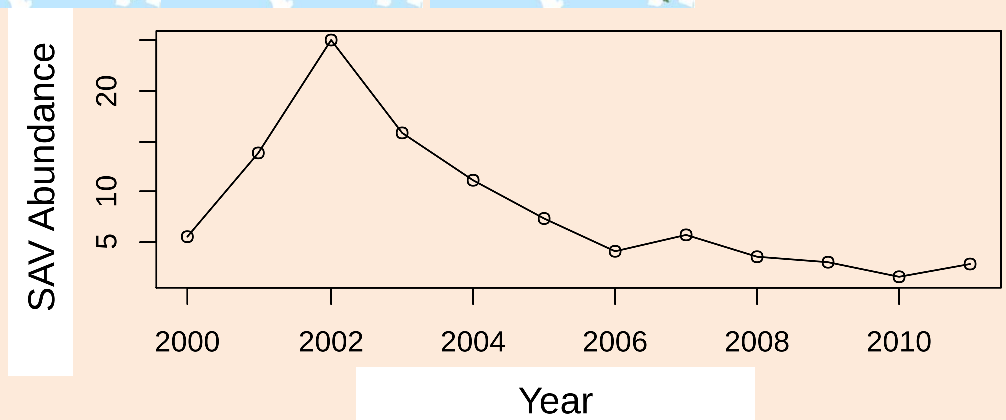
Conclusions

- Watershed & estuary characteristics affect particle composition & size to yield differences in IOPs
- Models may be used for *supervised* prediction of IOPs for unmeasured systems
- Need studies to discern underlying mechanisms

Time series of SAV maps



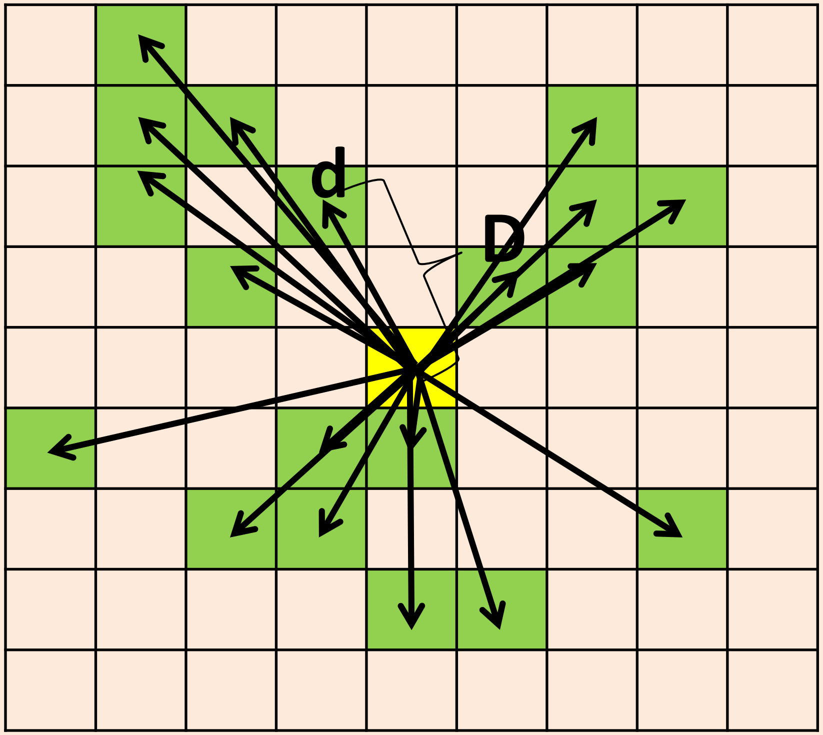




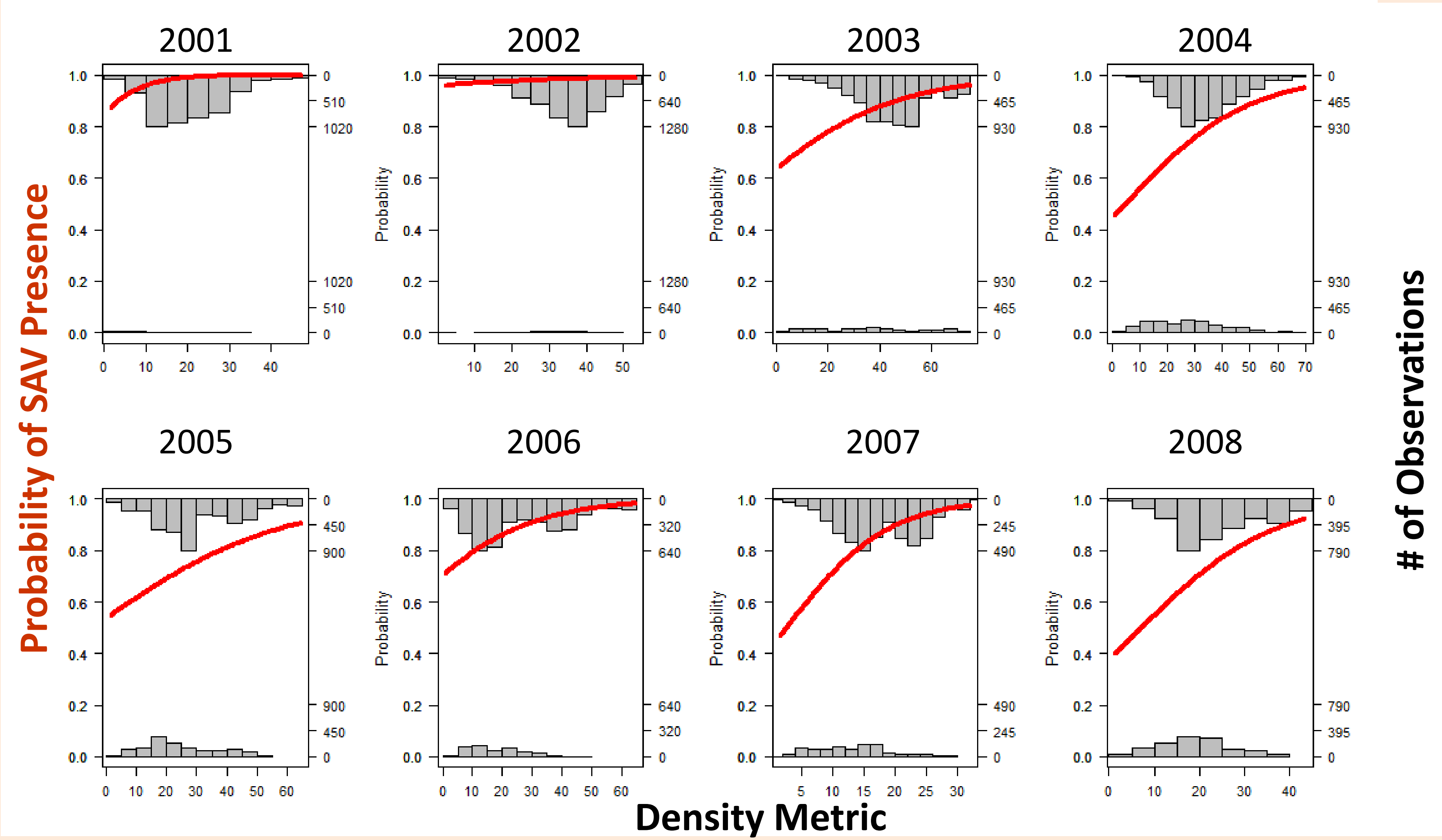
Effects of neighboring SAV

- **Locations with more nearby SAV have a higher probability of supporting SAV the following year.**
  - **Provide seeds**
  - **Improves water quality**

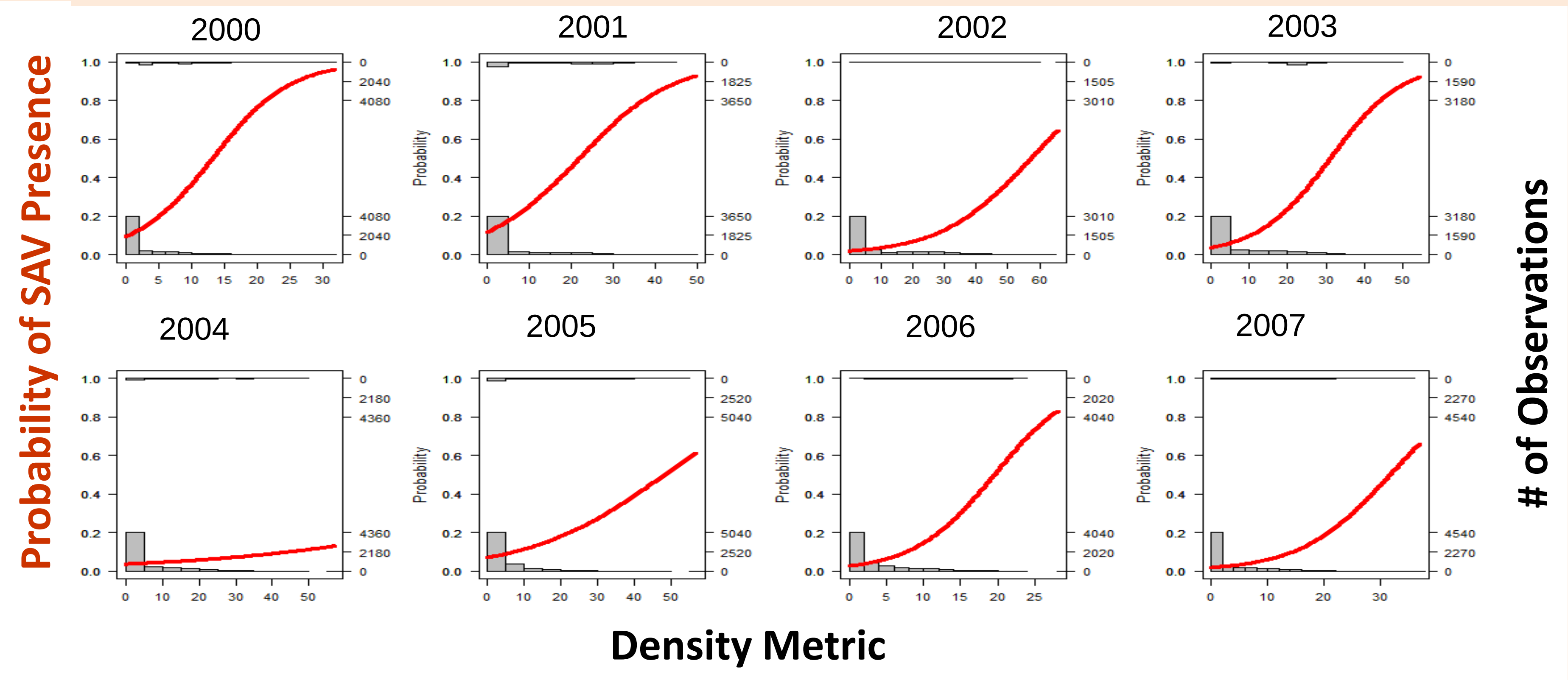
$$Density\ Score = \sum \frac{1}{D} * \mathrm{d}$$



Probability of an occupied location retaining SAV



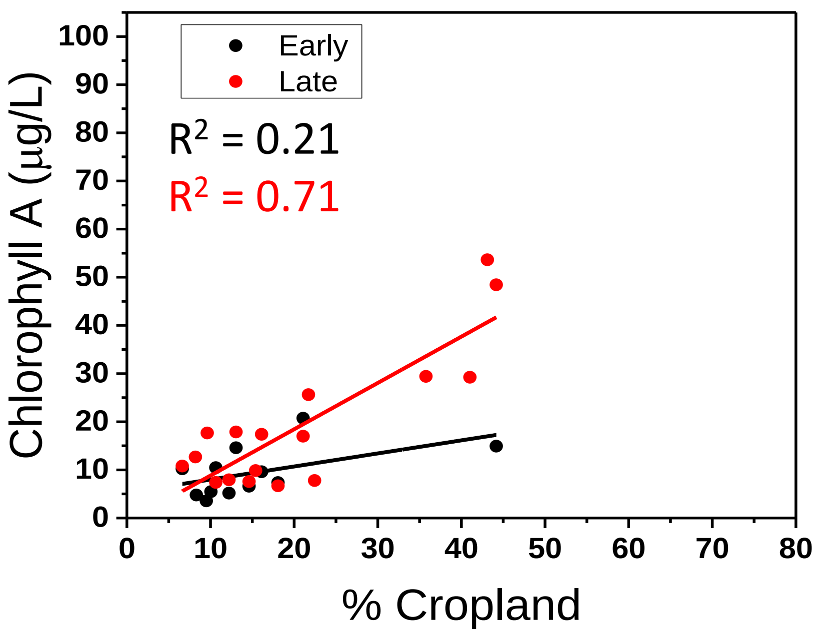
Probability of an empty location being colonized



Effect of Time of the Year

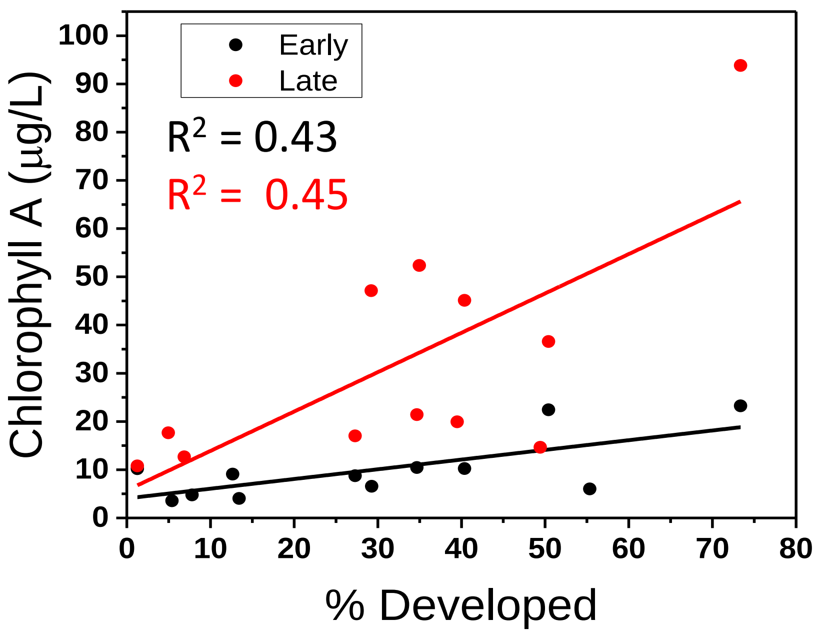
Chlorophyll *a* vs. Land Use Percentages

Cropland



(Exclude if >10% Developed)

Developed Land



(Exclude if >10% Cropland)

Early = April – June

Late = July – October

Compare SAV abundance adjacent to different shoreline types …

Natural

Riprap

Bulkhead

…in subestuaries with different watershed land use

Forested

Developed

Agricultural

…in different salinity zones