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*
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

Developed Land

R² = 0.63  
(Exclude if >10% Developed)

R² = 0.34  
p = 0.02  
(Exclude if >10% Cropland)
Total Phosphorus vs. Land Use Percentages

**Cropland**

- Total Phosphorus vs. % Cropland
- \( R^2 = 0.33 \)
- \( p = 0.005 \)
- (Exclude if >10% Developed)

**Developed Land**

- Total Phosphorus vs. % Developed
- \( R^2 = 0.14 \)
- NS
- (Exclude if >10% Cropland)
Chlorophyll $a$ vs. Land Use Percentages

**Cropland**

- Chlorophyll A (µg/L) vs. % Cropland
- $R^2 = 0.71$
- $p < 0.001$

(Exclude if >10% Developed)

**Developed Land**

- Chlorophyll A (µg/L) vs. % Developed
- $R^2 = 0.45$
- $p = 0.01$

(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

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

Shoreline armoring & watershed land use predict abundance

$R^2 = 0.40$, n=100

% Herbaceous Wetland

< 3.1
2.178
N=60

1.29
N=45

≥ 3.1
4.816
N=15

3.772
N=25

% Riprap

≥ 5.4
3.758
N=100

≥ 12.0
6.125
N=40

% Crop Land

10.06
N=15

Patrick et al. 2014. Estuaries Coasts 37:1516–1531
Abundance is greater and recovery stronger in subestuaries with little armoring (<5%)
Shoreline-scale models
A shift to a much finer scale!
Armoring effects vary with community

Land use constrains shoreline effects

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

Natural

Depth at start of bed

Rip rap

Frequency

Vegetation transects of 11 quadrats

SAV cover
Riprap significantly reduces SAV cover

![Graph showing the effect of Riprap on SAV cover across different salinity conditions.](Image)
Riprap significantly reduces bed width

![Graph showing SAV Bed Width (m) for different conditions: Natural, RipRap, Oligohaline, Mesohaline, Polyhaline. Significant differences marked with * symbols.](image)
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

Bars--SAV Cover (%)

Lines--Bed Width (m)

Year

Barbara Haddock Taylor, Baltimore Sun
Local watershed land use affects subestuary SAV abundance

- Lower abundance in watersheds dominated by agriculture or developed land

**Bay-wide SAV maps**

**Field study**
Shoreline hardening can reduce SAV abundance

- The effects differ among salinity zones, and are strongest in the polyhaline.
- 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.

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.

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Moore et al 2000. Estuaries & Coasts

<table>
<thead>
<tr>
<th>Community Type</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZOSTERA Community</td>
<td>Zostera marina*</td>
</tr>
<tr>
<td></td>
<td>Ruppia maritima</td>
</tr>
<tr>
<td>RUPPIA Community</td>
<td>Ruppia maritima*</td>
</tr>
<tr>
<td></td>
<td>Potamogeton perfoliatus</td>
</tr>
<tr>
<td></td>
<td>Potamogeton pectinatus</td>
</tr>
<tr>
<td></td>
<td>Zannichellia palustris</td>
</tr>
<tr>
<td>POTAMOGETON Community</td>
<td>Potamogeton pectinatus*</td>
</tr>
<tr>
<td></td>
<td>Potamogeton perfoliatus*</td>
</tr>
<tr>
<td></td>
<td>Potamogeton crispus</td>
</tr>
<tr>
<td></td>
<td>Elodea canadensis</td>
</tr>
<tr>
<td>FRESHWATER MIXED Community</td>
<td>Myriophyllum spicatum*</td>
</tr>
<tr>
<td></td>
<td>Hydrilla verticillata*</td>
</tr>
<tr>
<td></td>
<td>Vallisneria americana*</td>
</tr>
<tr>
<td></td>
<td>Ceratophyllum demersum</td>
</tr>
<tr>
<td></td>
<td>Heteranthera dubia</td>
</tr>
<tr>
<td></td>
<td>Elodea canadensis</td>
</tr>
<tr>
<td></td>
<td>Najas guadalupensis</td>
</tr>
<tr>
<td></td>
<td>Najas gracillima</td>
</tr>
<tr>
<td></td>
<td>Najas minor</td>
</tr>
<tr>
<td></td>
<td>Najas sp.</td>
</tr>
<tr>
<td></td>
<td>Potamogeton crispus</td>
</tr>
<tr>
<td></td>
<td>Potamogeton pusillus</td>
</tr>
</tbody>
</table>
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

A. Single Observed Time Series

B. Linear & Curvilinear Trends

C. Detrended Interannual Variation

Patrick & Weller 2015. MEPS 537:121–135
EOF analysis

A. Single Observed Time Series

B. Linear & Curvilinear Trends

C. Detrended Interannual Variation

D. Multiple Observed Time Series

E. 1st Common Mode of Variation

EOF Analysis

Patrick & Weller 2015. MEPS 537:121–135
Synchronicity differs among salinity zones & increases with salinity
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

Intermediate Scale Drivers
Subestuary watershed land-use

Small Scale Drivers
Shoreline alteration, shoreline land-use

Local Environment
Water clarity
Wave energy
Sediment Type

Determines
community type
and sensitivity

Prior Distribution

Salinity Zone

SAV Dynamics

Constrains

Constrains

Constrains

Constrains
Watershed Land Use

Forested

Mixed Agricultural

Agricultural

Mixed Developed

Developed

Breaking bad

Watershed Land Use

Natural Shoreline

Soft Living Shoreline

Hard Living Shoreline

Riprap

Bulkhead

Shoreline Armoring
Land use affects SAV abundance

...more in wet years than in dry years

Study Sites

- 27 subestuaries sampled over programs & years
- 342 measurements of 3 particulate IOPs
19 metrics from spatial analysis

<table>
<thead>
<tr>
<th>Energy</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Tidal range</td>
<td>Watershed land cover</td>
</tr>
<tr>
<td>• Mouth width</td>
<td>• % Forest</td>
</tr>
<tr>
<td>• Surface area</td>
<td>• % Cropland</td>
</tr>
<tr>
<td>• Volume</td>
<td>• % Developed</td>
</tr>
<tr>
<td>• % &lt;2 m deep</td>
<td>• % Grassland</td>
</tr>
<tr>
<td>• Fractal dimension</td>
<td>• % Wetland</td>
</tr>
<tr>
<td>• Max. wave ht.</td>
<td>Shoreline characteristics</td>
</tr>
<tr>
<td>• Watershed area</td>
<td>• % Un-hardened shoreline</td>
</tr>
<tr>
<td>• Watershed:estuary ratio</td>
<td>• % Developed shoreline</td>
</tr>
<tr>
<td></td>
<td>• % Vegetated bank</td>
</tr>
<tr>
<td></td>
<td>• % Shoreline with beach</td>
</tr>
<tr>
<td></td>
<td>• % Shoreline with marsh</td>
</tr>
</tbody>
</table>
Significant univariate correlations

23 significant ($P \leq 0.05$), 4 expected by chance alone

<table>
<thead>
<tr>
<th>Correlate</th>
<th>$a^*_{NAP(440)}$</th>
<th>$b^*_p(555)$</th>
<th>$w^*_p(440)$</th>
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<tbody>
<tr>
<td></td>
<td>Rank</td>
<td>Sign</td>
<td>$R^2$</td>
</tr>
<tr>
<td>Tide range (m)</td>
<td>1</td>
<td>-0.37</td>
<td></td>
</tr>
<tr>
<td>% Bank developed</td>
<td>2</td>
<td>+0.32</td>
<td></td>
</tr>
<tr>
<td>% Cropland</td>
<td>3</td>
<td>-0.27</td>
<td></td>
</tr>
<tr>
<td>% Wetland</td>
<td>4</td>
<td>-0.23</td>
<td></td>
</tr>
<tr>
<td>% Unhardened shoreline</td>
<td>5</td>
<td>-0.22</td>
<td></td>
</tr>
<tr>
<td>% Forested watershed</td>
<td>6</td>
<td>+0.20</td>
<td></td>
</tr>
<tr>
<td>Mean depth (m)</td>
<td>7</td>
<td>+0.18</td>
<td></td>
</tr>
<tr>
<td>% Shoreline with marsh</td>
<td>8</td>
<td>-0.15</td>
<td></td>
</tr>
<tr>
<td>% Shoreline with beach</td>
<td>9</td>
<td>+0.15</td>
<td></td>
</tr>
<tr>
<td>Fractal dimension</td>
<td>10</td>
<td>-0.15</td>
<td></td>
</tr>
<tr>
<td>Mouth width (km)</td>
<td>ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subestuary area (km$^2$)</td>
<td>ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Developed watershed</td>
<td>ns</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

2000 2001 2002 2003 2004
2005 2006 2007 2008 2009
2010 2011

SAV Abundance vs. Year

Year
Effects of neighboring SAV

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

\[
\text{Density Score} = \sum \frac{1}{D} \times d
\]
Probability of an occupied location retaining SAV

<table>
<thead>
<tr>
<th>Year</th>
<th>Probability of SAV Presence</th>
<th>Density Metric</th>
<th># of Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td><img src="image1" alt="Graph" /></td>
<td>0 - 1020</td>
<td>0 - 510</td>
</tr>
<tr>
<td>2002</td>
<td><img src="image2" alt="Graph" /></td>
<td>0 - 1280</td>
<td>0 - 640</td>
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<tr>
<td>2003</td>
<td><img src="image3" alt="Graph" /></td>
<td>0 - 930</td>
<td>0 - 455</td>
</tr>
<tr>
<td>2004</td>
<td><img src="image4" alt="Graph" /></td>
<td>0 - 930</td>
<td>0 - 465</td>
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<tr>
<td>2005</td>
<td><img src="image5" alt="Graph" /></td>
<td>0 - 320</td>
<td>0 - 455</td>
</tr>
<tr>
<td>2006</td>
<td><img src="image6" alt="Graph" /></td>
<td>0 - 320</td>
<td>0 - 455</td>
</tr>
<tr>
<td>2007</td>
<td><img src="image7" alt="Graph" /></td>
<td>0 - 245</td>
<td>0 - 395</td>
</tr>
<tr>
<td>2008</td>
<td><img src="image8" alt="Graph" /></td>
<td>0 - 245</td>
<td>0 - 395</td>
</tr>
</tbody>
</table>
Probability of an empty location being colonized
Effect of Time of the Year

Chlorophyll a vs. Land Use Percentages

Cropland

Developed Land

Early = April – June
Late = July – October

R^2 = 0.21
R^2 = 0.43
R^2 = 0.71
R^2 = 0.45
Compare SAV abundance adjacent to different shoreline types …

…in subestuaries with different watershed land use

…in different salinity zones