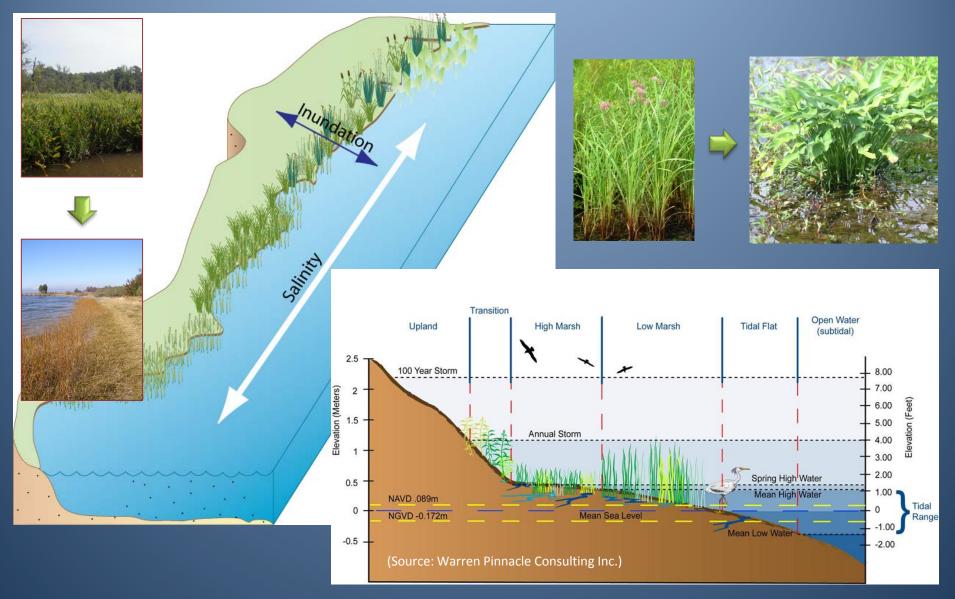
# Loss of Coastal Marshes to Sea Level Rise







## The tidal marsh community continuum







## Sea Level Rise in the CB

Table 1. East Coast rise  $(\beta_1^*)$ , acceleration  $(\beta_2^*)$ , and projected year 2050 height percentiles given 1969–2014 monthly RMSL.

Height above 19

0.5

1970

Ne = 0.952

1980

1990

2000

2010

Year

2020

2030

Station   ID Number   2.5%   50%   97.5%   2.5%   2.5%   3.29   0.112   0.112   0.357   41   56   71   3.5%   3.	va Scotia
2. Eastport, Maine 8410140 0.73 1.73 2.72 0.183 0.271 0.357 41 56 71 3. Portland, Maine 8418150 0.15 1.23 2.41 0.153 0.256 0.359 33 51 69 4. Boston, Massachusetts 8443970 2.08 3.07 4.08 0.164 0.257 0.357 46 62 80 5. Nantucket, Massachusetts 8449130 2.97 3.64 4.37 0.071 0.157 0.242 33 48 62 6. Newport, Rhode Island 8452660 2.29 3.04 4.37 0.071 0.157 0.242 33 48 62 7. New London, Connecticut 8461490 2.59 3.52 4.45 0.098 0.209 0.316 37 55 75 8. The Battery, New York 8518750 2.63 3.49 4.37 0.047 0.158 0.266 29 47 66 9. Sandy Hook, New Jersey 8531680 3.25 4.26 5.23 0.104 0.212 0.319 43 61 79 10. Adamtic City, New Jersey 8534720 3.71 4.56 5.48 -0.003 0.105 0.251 19 43 68 11. Baltimore, Maryland 8574680 2.57 3.38 4.18 0.049 0.151 0.247 29 45 61 12. Annapolis, Maryland 8575512 2.66 3.53 4.41 0.080 0.181 0.280 34 51 67 13. Washington, DC 8594900 2.15 3.24 4.27 0.011 0.163 0.308 23 46 70 14. Solomons Island, Maryland 8577330 3.71 4.76 5.70 0.113 0.221 0.330 48 64 81 15. Yorktown, Virginia 8637624/689 <sup>a</sup> 3.75 4.82 5.86 0.059 0.197 0.318 40 61 81 15. Yorktown, Virginia 863200 2.96 3.68 4.46 -0.037 0.077 0.181 16 34 52 18. Wilmington, North Carolina 8658120 0.84 1.70 2.58 -0.054 0.079 0.214 -1 23 45	faine       8410140       0.73       1.73       2.72       0.183       0.271       0.357       41       56       71         faine       8418150       0.15       1.23       2.41       0.153       0.256       0.359       33       51       69         ssachusetts       8443970       2.08       3.07       4.08       0.164       0.257       0.357       46       62       80         Massachusetts       8449130       2.97       3.64       4.37       0.071       0.157       0.242       33       48       62         thode Island       8452660       2.29       3.04       3.82       0.074       0.165       0.257       30       46       62         n, Connecticut       8461490       2.59       3.52       4.45       0.098       0.209       0.316       37       55       75         y, New York       8518750       2.63       3.49       4.37       0.047       0.158       0.266       29       47       66         k, New Jersey       8531680       3.25       4.26       5.23       0.104       0.212       0.319       43       61       79         ty, New Jersey       8534680 <t< th=""></t<>
3. Portland, Maine 8418150 0.15 1.23 2.41 0.153 0.256 0.359 33 51 69 4. Boston, Massachusetts 8443970 2.08 3.07 4.08 0.164 0.257 0.357 46 62 80 5. Nantucket, Massachusetts 8449130 2.97 3.64 4.37 0.071 0.157 0.242 33 48 62 6. Newport, Rhode Island 8452660 2.29 3.04 3.82 0.074 0.165 0.257 30 46 62 7. New London, Connecticut 8461490 2.59 3.52 4.45 0.098 0.209 0.316 37 55 75 8. The Battery, New York 8518750 2.63 3.49 4.37 0.047 0.158 0.266 29 47 66 9. Sandy Hook, New Jersey 8531680 3.25 4.26 5.23 0.104 0.212 0.319 43 61 79 0.4 Adante City, New Jersey 8534720 3.71 4.50 3.48 -0.055 0.105 0.201 15 43 68 11 67 9 11 11 11 11 11 11 11 11 11 11 11 11 1	Maine 8418150 0.15 1.23 2.41 0.153 0.256 0.359 33 51 69 sesachusetts 8443970 2.08 3.07 4.08 0.164 0.257 0.357 46 62 80 Massachusetts 8449130 2.97 3.64 4.37 0.071 0.157 0.242 33 48 62 thode Island 8452660 2.29 3.04 3.82 0.074 0.165 0.257 30 46 62 m., Connecticut 8461490 2.59 3.52 4.45 0.098 0.209 0.316 37 55 75 y, New York 8518750 2.63 3.49 4.37 0.047 0.158 0.266 29 47 66 k, New Jersey 8531680 3.25 4.26 5.23 0.104 0.212 0.319 43 61 79 ty, New Jersey 8531680 3.25 4.26 5.23 0.104 0.212 0.319 43 61 79 ty, New Jersey 8531680 2.57 3.38 4.18 0.049 0.151 0.247 29 45 61 Maryland 8574680 2.57 3.38 4.18 0.049 0.151 0.247 29 45 61 Maryland 8575512 2.66 3.53 4.41 0.080 0.181 0.280 34 51 67 a, DC 8594900 2.15 3.24 4.27 0.011 0.163 0.308 23 46 70 tyriginia 8637624689 3.75 4.82 5.86 0.059 0.197 0.318 40 61 81 trginia 8637624689 3.75 4.82 5.86 0.059 0.197 0.318 40 61 81 trginia 8638610 4.15 5.11 6.04 0.034 0.160 0.289 37 57 78 tyriginia 8638200 2.96 3.68 4.46 -0.037 0.077 0.181 16 34 52 tyriginia 863200 2.96 3.68 4.46 -0.037 0.077 0.181 16 34 52 tyriginia 863200 2.96 3.68 4.46 -0.037 0.079 0.214 -1 23 45 tyriginia 863200 2.96 3.68 4.46 -0.037 0.077 0.181 16 34 52 tyriginia 863530 2.09 2.79 3.49 -0.048 0.079 0.214 -1 23 45 tyriginia 863530 2.09 2.79 3.49 -0.048 0.079 0.214 -1 23 45 tyriginia 863500 2.09 2.79 3.49 -0.048 0.079 0.214 -1 23 45 tyriginia 863500 2.09 2.79 3.49 -0.048 0.079 0.214 -1 23 45 tyriginia 863500 2.09 2.79 3.49 -0.048 0.079 0.214 -1 23 45 tyriginia 863510 4.15 5.11 6.04 0.034 0.079 0.214 -1 23 45 tyriginia 863510 4.15 5.11 6.04 0.034 0.079 0.214 -1 23 45 tyriginia 863500 2.09 2.79 3.49 -0.048 0.079 0.214 -1 23 45 tyriginia 863510 4.15 5.11 6.04 0.034 0.079 0.214 -1 23 45 tyriginia 863510 2.09 2.79 3.49 -0.048 0.079 0.214 -1 23 45 tyriginia 863510 4.15 5.11 6.04 0.034 0.079 0.214 -1 23 45 tyriginia 863510 4.15 5.11 6.04 0.034 0.079 0.214 -1 23 45 tyriginia 863510 4.15 5.11 6.04 0.004 0.0070 0.184 72 tyriginia 863510 4.15 5.11 6.04 0.0070 0.184 72 tyriginia 863510 4.15 5.11 6.04 0.0070 0.184 72 tyriginia 863510
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re   Norrolk (Sewells Point), VA 1969-2011	
M 1/2*h2 = 0.002 mmh/cor² **	$1(2^{\circ})^{\circ} = 11103 \text{ mm//opr}^{\circ}$
K: 2 b1 = 4 996 mm/year **	b1 = 4.996 mm/year **

Boon 2012

2040

0.84

2050

...stations 5 (Galveston) and 6 (Rockport), which have the highest median rise rates of any station in this study at 5.46 mm/y and 6.11 mm/y, respectively (Table 2), followed by station 16 (Norfolk) at 5.11 mm/y ...





# Increasing inundation

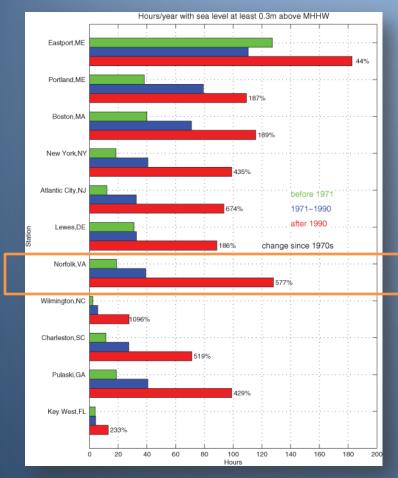


Photo by Marvin Nauman/FEMA



Ezer and Atkinson 2014

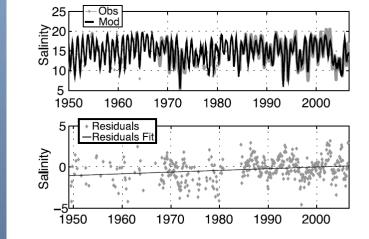
- Birds that nest in tall grasses lose habitat (king rails, least bitterns, etc.)
- Projections indicate that a 3-foot loss sea level rise could reduce populations by 48% (Wilson and Watts 2010)





### Increasing salinity

- Salinity has increased ~ 0.5 ppt since 1949 (Hilton et al 2008), water levels have increased by ~ .22m (8.6 in)
- Chesapeake Bay estimates for salinity in 2100: 4-12 ppt increase over current levels



**Figure 5.** Salinity and residual time series for cell (4, 1). Model  $r^2 = 0.78$ .

Table 3. Number of days that salinity is predicted to exceed 0.1 parts per thousand at the head of the York estuary from June 1 to December 31 (total 214 days) of the year indicated for the no-rise scenario and the three sealevel rise scenarios.

[cm, centimeter]

Model scenario	Dry year 2002	Wet year 2003	Typical year 2005
No rise	214	183	214
30-cm rise	214	201	214
50-cm rise	214	211	214
100-cm rise	214	214	214

"...a large increase in mean salinity is predicted for each sea-level rise scenario. This will greatly alter the existing water-quality gradients between the brackish water and freshwater. (Rice et al. 2011)







#### Chesapeake Bay 18% of tidal shoreline hardened

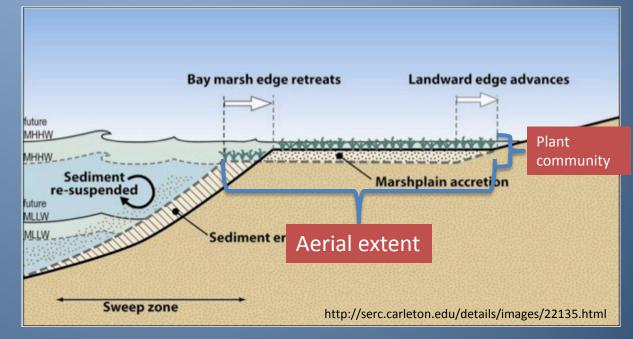
**VA**: 11% **MD**: 28%

32% riparian land developed

~5 km² of artificial substrate introduced (*intertidal impacted*)

#### To keep pace with sea level

- Marshes migrate
- Marshes accrete (grow upwards)

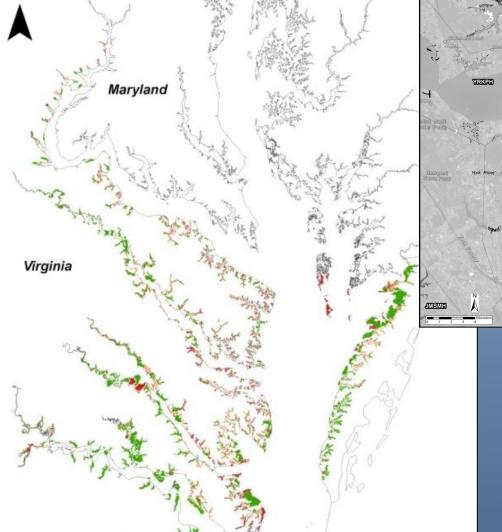




#### Tidal Marshes – SLR & barriers to migration



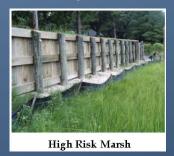




Tidal marshes in the meso-polyhaline reaches at highest risk due to land development & SLR



Nearly 40% of Virginia marshes are vulnerable to SLR due to adjacent development





Bilkovic et al. 2009 Vulnerability of shallow tidal water habitats in Virginia to climate change. http://ccrm.vims.edu/research/climate\_change/index.html

Tidal marsh vulnerability





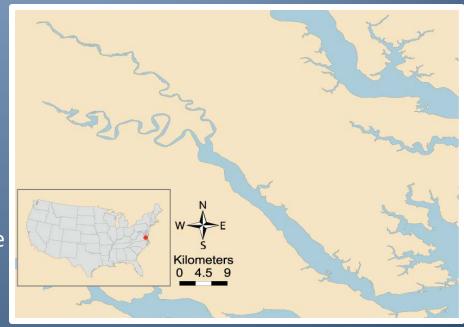
# How are marshes responding to sea level rise?

 Compare the extent and composition of communities from the previous surveys with the

existing marshes

Begin to establish trends of either marsh loss or gain

- No net loss of wetlands is a management goal
- Changes in community composition (indicative of estuarine processes)
  - Each community supports unique food webs and chemical processes





# Original Tidal Marsh Inventory

- Covers all marshes in Virginia
- Every marsh location and extent was mapped
  - Marshes were digitized off topographic maps in the 1970s at 1:24,000
  - Marshes were verified during plant community survey
- Field sampling for vegetation data -- species %cover was collected for every marsh
  - Conducted between 1973 1991 for Virginia
  - The York River was done in several segments, between 1974 -1987









# New Tidal Marsh Inventory

- Will cover all marshes in Virginia (maybe ½ done)
- Every marsh location and extent mapped
  - Marshes were digitized off 2009 aerial photography at 1:1,000
  - Marshes were verified during plant community survey
- Field sampling for vegetation data -- species %cover was collected for every marsh
  - Conducted in 2010 for the York River
  - 4-5 localities being done every year











# Tidal wetland area changes between the 2 surveys

Used coverages of mapped wetlands for two time periods

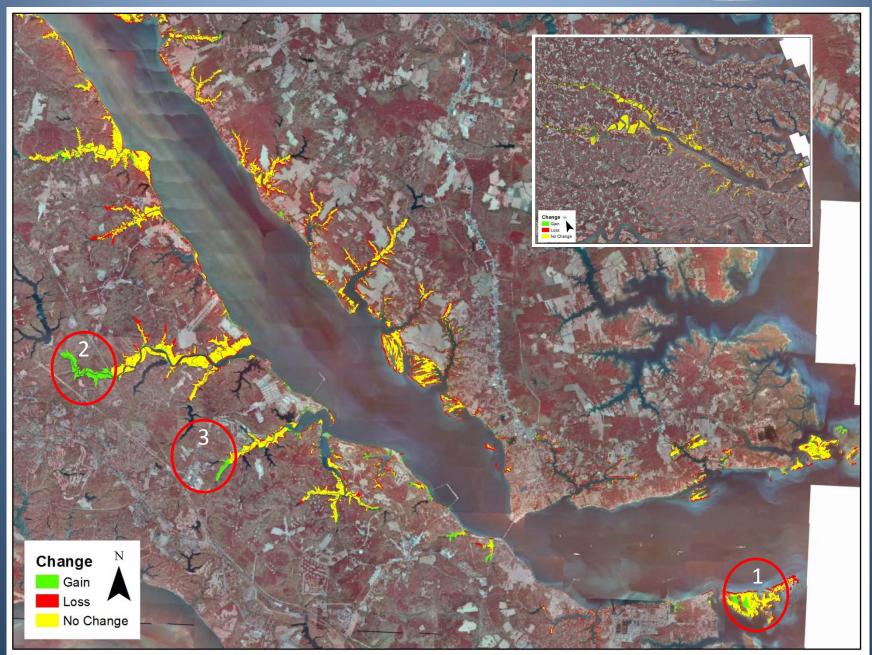
- Both coverages were clipped to the same study boundaries to insure a direct comparison
- Used superposition techniques in ArcMap to analysis of change in coverage

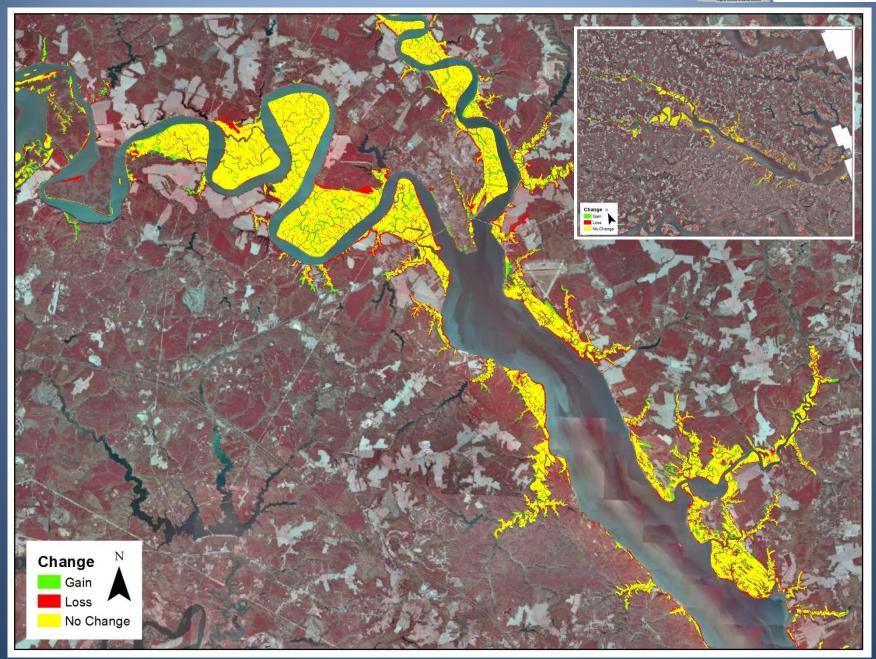
Marsh Class	1973 TMI	2009 TMI	Change
Embayed	5,462.279	4,872.708	-589.571
Extensive	13,934.873	13,077.216	-857.657
Fringe	999.927	714.400	-285.527
Marsh Island	798.140	736.492	-61.648
Total	21,195.219	19,400.816	-1,794.403

Marsh Class	Unchanged (ac)	Loss (ac)	Gain (ac)
Embayed	3,570.313	1,892.015	1,312.850
Extensive	11,872.249	2,062.629	1,222.298
Fringe	310.659	689.270	384.962
Marsh Island	566.777	231.363	160.708

Fringe marshes = 69% of the original marshes lost Embayed marshes (34%); extensive marshes (15%), and marsh islands (29%).







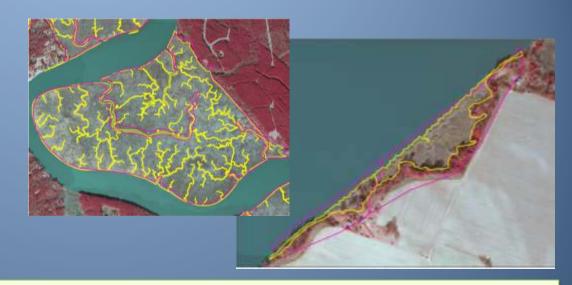




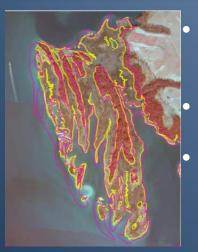


### What is our confidence in these results?

- We know there are some overestimations of marsh loss
  - Mostly due to differences in scale and increased precision in digitizing
- We are working on techniques to minimize known errors



#### We have verified apparent erosion against other work.



- Marsh lost ~ 44 acres between 1979 and 2009
- Predominantly due to shoreline erosion
- Milligan *et al*. (2010) found up to 1.5 meters of erosion/year here

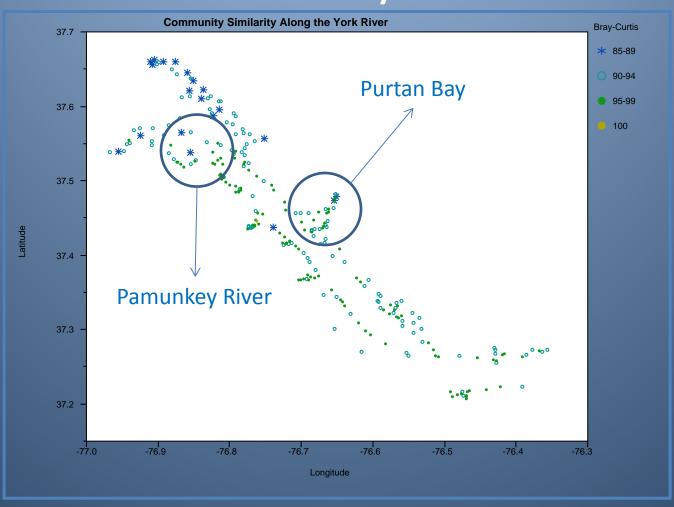


- Marsh lost ~ 134
   acres between 1979
   and 2009
- Predominantly due to shoreline erosion
- Milligan et al. (2010) found continuous recession here
- Some inland migration





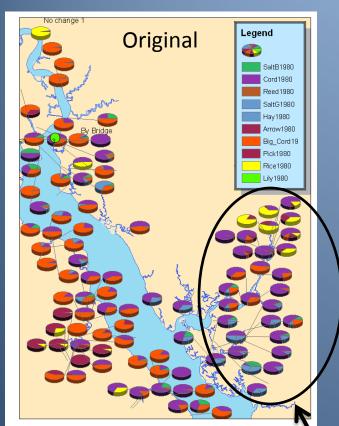
# Community shifts between the 2 surveys

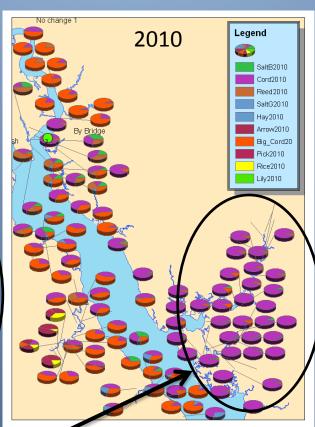






#### Purtan Bay







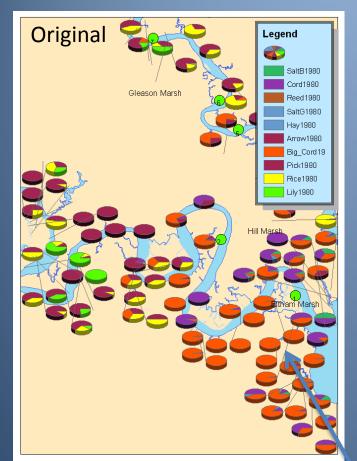
Purtan Creek Marsh Island

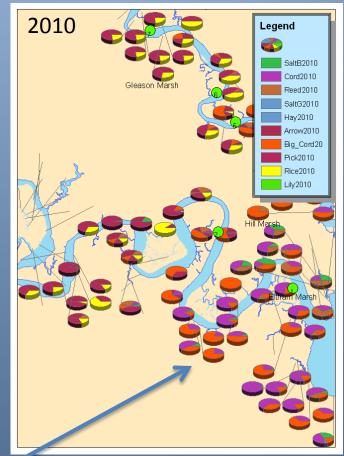
- Shift from fairly diverse marshes to almost monotypic Spartina alterniflora.
- Lost fresh water community at top of creek

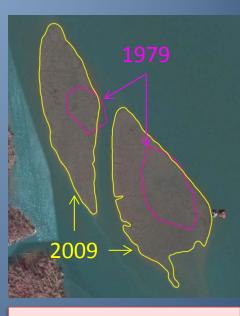




#### Pamunkey River

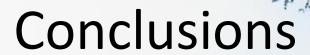






Accretion of Pamunkey marsh islands

- Increased S. alterniflora presence
- Shift in dominant species
  - >= shift in salinity, innundation, or both?



 Marsh extent and plant composition have changed over the past 30 years, concurrent with sea level rise

- •Highest risk:
  - Fringe marshes (throughout)
  - High salinity/high energy marsh islands
  - Freshwater-headwater wetlands
  - Marshes in front of shoreline structures
- •Lowest risk:
  - Extensive riverine marshes



- What changes in function may have occurred with changes in communities?
- •Have land use and shoreline alterations been a driver of changing communities?
- •How do community change patterns shift across the Chesapeake Bay?
- •How can this inform models of future marsh distribution?