Tidal Marsh Adaptation Project Information Summary Excerpts

The *Tidal Marsh Resilience Information Summary* is an outcome of the initial research phase of the Tidal Marsh Adaptation Project. The summary of tidal marsh resilience information was compiled to identify potential data layers, common marsh resilience topics, and discussion needs to inform stakeholder engagement and the Collaborative Tidal Marsh Adaptation Workshop planned for Fall 2023 (moved to January 2024).

Excerpt from *Tidal Marsh Resilience Information Summary*: Marsh Migration Data Synthesis Project

Source

Marsh Migration Data Synthesis Project. *Synthesis of Shoreline, Sea Level Rise, and Marsh Migration Data for Wetland Restoration Targeting Final Report.* Molly Mitchell, Karinna Nunez, Christine Tombleson, Julie Herman. Center for Coastal Resources Management, Virginia Institute of Marine Science, William & Mary. link

Project purpose: Develop a methodology for using results from existing marsh migration models combined with social, land use, and environmental data to inform marsh management, conservation, and restoration under sea level rise.

The project reviews and compiles existing datasets and information related to marsh migration in context of sea level rise due to climate change, topography, shoreline condition, existing wetlands and corridors, and other relevant data. Then, the project team proposes a methodology that synthesizes information to support marsh restoration and conservation decisions under various sea level rise scenarios.

There are extensive datasets related to marsh migration considerations, including:

- Sea level rise forecasts
- Subsidence rates
- Topographic and topo-bathy surfaces and bank height
- Shoreline erosion rates and soil types
- Type and extent of shoreline alterations (e.g., bulkheads, revetments)
- Locations of living shorelines
- Distribution of natural resources (e.g., marshes, beaches, dunes)

In addition to reviewing over 110 datasets, the team reviewed five marsh migration models that have been run in the Bay. Review of marsh migration models identified three model types:

1. **Landscape-scale models** are predominantly driven by land elevation and often use fixed rates (i.e., erosion). These include topography-driven models (SLOPE, Evolution of Tidal Marsh) and elevation/process driven models (SLAMM, NOAA MM, Nicholas Institute). Data needed to run landscape models is broadly available.
2. **Site-specific models** simulate responses for a specific site with a particular set of conditions and settings (MEM/CWEM), they contribute to our understanding of marsh persistence and change, however, they do not model migration. Data for these models is more limited in geographic and temporal scope.

3. **Combination and cross-scale** models combine spatial dynamics of salt marshes and predict the impacts of possible future sea-level conditions (Hydro-MEM, TMM). They require extensive data sets of hydrological, sedimentological, and biological data and often substitute fixed rates for missing data. Data for these models is more limited in geographic and temporal scope.

Marsh models vary in resolution, parameters, and data sources for parameterization. Because analysis shows no strong patterns between model parameters and results and none have been extensively validated, the project team does not consider one model more accurate than another.

See the following page for more information from the report about the specific models.

A description of the models used for the MMCE: (pages 8-9)

1. SLAMM 5.0 – Sea Level Affecting Marshes Model

This model was developed by Warren Pinnacle Consulting, Inc. It simulates dominant processes involved in wetland conversion under different SLR scenarios (inundation, erosion, accretion, soil saturation, and barrier island over wash). SLAMM uses a decision tree incorporating geometric and qualitative relationships to represent transfer among coastal classes. SLAMM is available as a raster coverage (30m pixel resolution) for select scenarios of sea level rise for the Chesapeake Bay.

2. InVEST - Integrated Valuation of Ecosystem Services and Tradeoffs

A modified InVEST model was run for the Coastal Protection and Blue Carbon for Eastern States project by the Nicolas Institute. InVEST is a suite of models used to map and value the goods and services from nature. InVEST models are based on production functions that define how changes in an ecosystem's structure and function are likely to affect the flows and values of ecosystem services across a land- or a seascape. In this model, water elevations rise uniformly across all areas. InVEST is available as a raster coverage (30m pixel resolution) for multiple elevations of sea level rise, up to 4 ft, for the Chesapeake Bay and the Mid-Atlantic coastal areas.

3. NOAA – Sea Level Rise Viewer: Marsh Migration

It maps sea level rise marsh migration using a process developed by the NOAA Office for Coastal Management. Model outputs show potential impacts to marsh environments from sea level rise for the Sea Level Rise Viewer. In this model water elevations rise relatively uniformly across all areas, but the model attempts to account for some local and regional tidal variability. These data represent the potential distribution of each wetland type based on their elevation and how frequently they may be inundated under potential future SLR scenarios, from 0 to 10ft of SLR. The Sea Level Rise Viewer: Marsh Migration is available as a raster coverage (30m pixel resolution) for multiple elevations of sea level rise for the Chesapeake Bay and the United States.

4. ETM – Evolution of Tidal Marsh

The Evolution of Tidal Marsh Model was developed by the Center for Coastal Resources Management (CCRM), VIMS (Mitchell et al. 2020). This is a static model. Data layers represent the land that is encompassed by the average tidal range (2 ft) as sea level rises in the Virginia coastal region. In this model, water elevations rise uniformly across all areas. Data layers represent each 2-foot range of elevation incremented by 0.5 ft (e.g., 0-2 ft, 0.5-2.5 ft, 1-3 ft, etc.) with the current land cover that exists in that range. ETM is available as a raster coverage (1m pixel resolution) for multiple elevations of sea level rise for the Virginia portion of the Chesapeake Bay.

5. TMM – Tidal Marsh Model

The Tidal Marsh Model (TMM) was developed by the CCRM, VIMS (Nunez et al. 2020), within the SCHISM framework (Semi-implicit Cross-scale Hydroscience Integrated System Model). This model performs hydrodynamic simulations. The TMM simulates marsh migration under the joint influence from tides, wind waves, sediment transport, precipitation, and sea level rise. The model accounts for shoreline bank erosion, upland erosion inputs at the upland-marsh edge, marsh vertical accretion through mineral sediment deposition, and marsh landward migration under changing sea levels with constraints from physical barriers (e.g., development, shoreline structures). ETM is available as a vector/raster coverage (variable resolution) for select scenarios of sea level rise for 2 creeks (Carter and Taskinas) in the York River tributary of the Chesapeake Bay.

Model data availability:

- NOAA – Sea Level Rise Viewer: Marsh Migration model results are available around the continental United States; however, the other marsh models have more limited geographic scope.
- SLAMM 5.0 – Sea Level Affecting Marshes Model has been used in various locations along the coastline but has not been systematically run for the entire United States.
- InVEST - Integrated Valuation of Ecosystem Services and Tradeoffs model has been run for the Mid-Atlantic states.
- TMM – Tidal Marsh Model has been run for the coastline of Virginia.
- ETM – Evolution of Tidal Marsh has the most limited geographic scope, only having been run for two watersheds.
- **In the Chesapeake Bay, there should always be three available models (NOAA, SLAMM, and InVEST).**

The team proposes a methodology that leverages the five models to identify Marsh Migration Corridor Envelopes (MMCE), which encompasses the potential area of current upland expected to become marsh under a select sea level rise scenario to target conservation/preservation areas. The MMCE calculation is to mitigate the biases in any given model by including the results from multiple models. This method is faster and less expensive than running large scale marsh migration models. The report indicates a more detailed analysis of the parcel characteristics and potentially some small-scale modeling should be done for the target area identified using the MMCE methodology. See page 7 of the report for a detailed description of the targeting methodology.

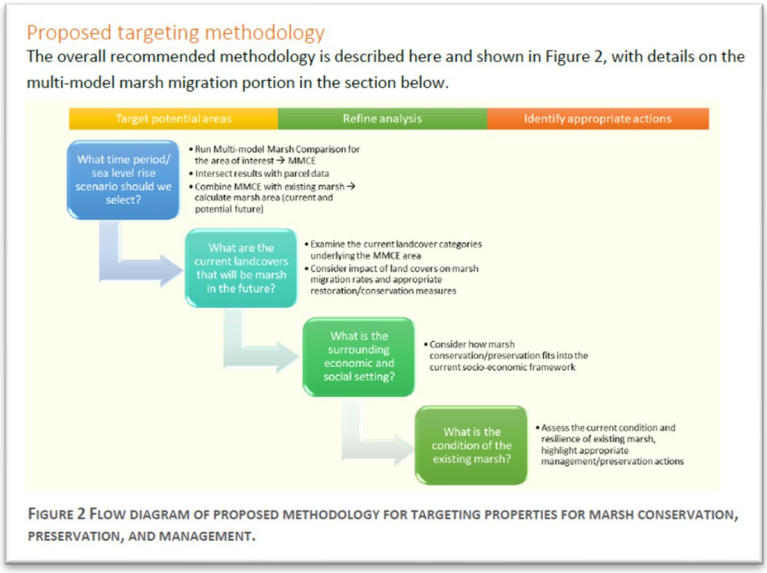
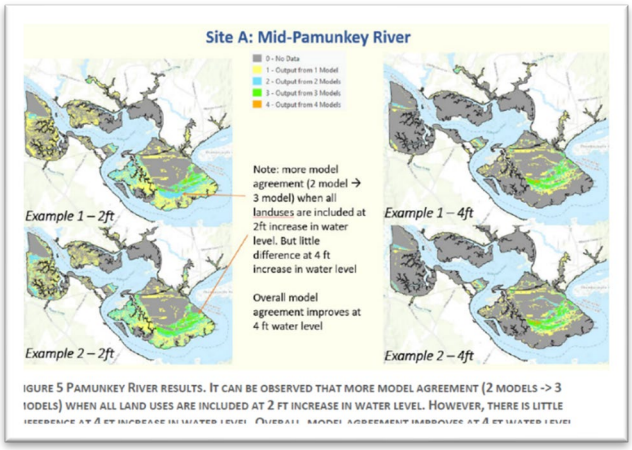


FIGURE 2 FLOW DIAGRAM OF PROPOSED METHODOLOGY FOR TARGETING PROPERTIES FOR MARSH CONSERVATION, PRESERVATION, AND MANAGEMENT.

Model, data, and study comparison notes for consideration:

- The study used two water levels were selected to allow for consistent comparison across models: 2 ft (0.6 m) and 4 ft (1.2) increase in MSL above the current tidal datum.
- The model comparison clipped outputs clipped to three study areas in the Middle Peninsula, removing current marsh extent using the Tidal Marsh Inventory as the reference layer.
- ETM and InVEST allow projected marsh migration to occur in any type of land uses. In contrast, the code for the rest of the models only allows marsh migration in "natural" land use categories (i.e., excluding development).
- The InVEST model removed marshes that are not spatially connected to existing coastal marshes; if they are not connected to any marsh, those areas are not projected by the InVEST model. Therefore, major differences may be prompted by the models' classifications of land use.
- To cover different management scenarios, two different approaches were taken to conduct the model comparison in the study:
    - **Example 1**: ETM and InVEST projected marsh migration area includes only the "**natural**" land use categories (i.e., excludes development).
    - **Example 2**: ETM and InVEST projected marsh migration area includes **all** the land use categories.

Visual figures of comparison at study sites:



IGURE 5 PAMUNKEY RIVER RESULTS. IT CAN BE OBSERVED THAT MORE MODEL AGREEMENT (2 MODELS -> 3 ODELS) WHEN ALL LAND USES ARE INCLUDED AT 2 FT INCREASE IN WATER LEVEL. HOWEVER, THERE IS LITTLE

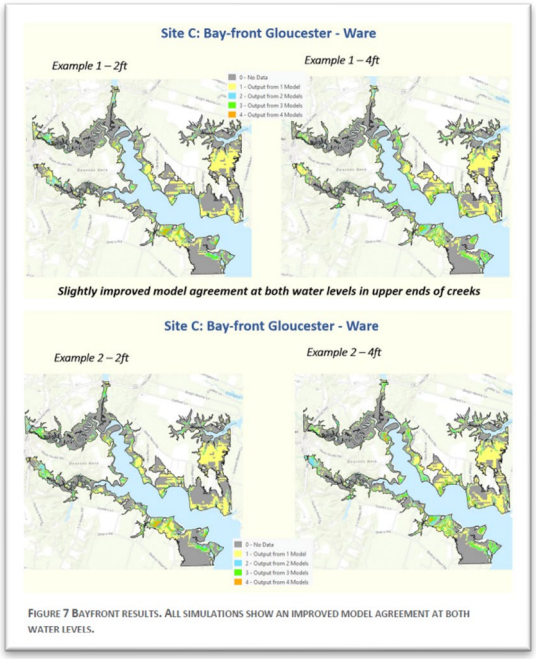
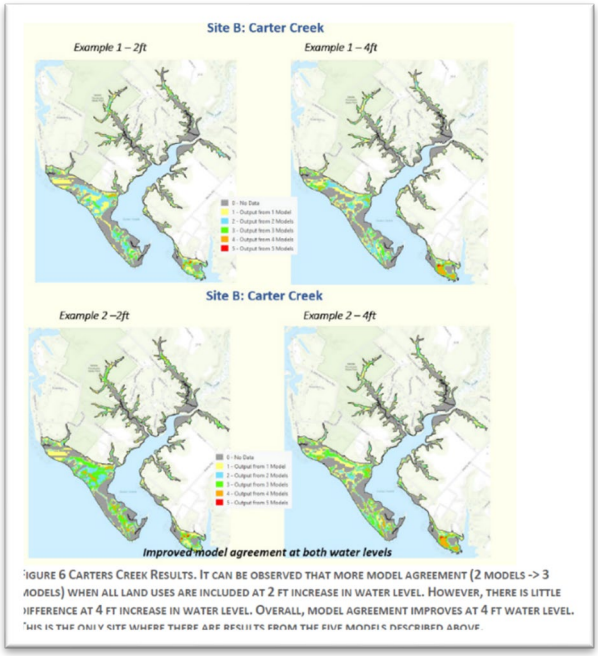


FIGURE 7 BAYFRONT RESULTS. ALL SIMULATIONS SHOW AN IMPROVED MODEL AGREEMENT AT BOTH WATER LEVELS.



IGURE 6 CARTERS CREEK RESULTS. IT CAN BE OBSERVED THAT MORE MODEL AGREEMENT (2 MODELS -> 3 ODELS) WHEN ALL LAND USES ARE INCLUDED AT 2 FT INCREASE IN WATER LEVEL. HOWEVER, THERE IS LITTLE IFFERENCE AT 4 FT INCREASE IN WATER LEVEL. OVERALL, MODEL AGREEMENT IMPROVES AT 4 FT WATER LEVEL. HIS IS THE ONLY SITE WHERE THERE ARE RESULTS FROM THE FIVE MODELS DESCRIBED ABOVE

- Transferability: The methodology should transfer to any location with existing marsh migration models.
- Limitations and caveats:
    - Differences in model input structure and nuances in how models define current marsh contribute to differences between output.
    - InVEST and TMM only allow migration in areas with current marsh.
    - Resolution of underlying data has a critical impact on areas designated as being within the MMCE; also, water level alignment, differing sources, and individual model parameters lead to cumulative differences.

MODEL	Resolution (land cover)	Resolution (elevation)	Elevation source	Vertical datum	Marsh Source
SLAMM	30m x 30m	10m x 10m	CUDEM[1]	Mean Tide Level	NWI (1988 - 1992)
InVEST	30m x 30m	3m x 3m	CUDEM[1]	MHHW	VIMS TMI (Berman et al. 2016)
TMM	30m x 30m (C-CAP)	1m x 1m	CBTBDEM[2]	NAVD88	VIMS TMI (2016)
NOAA	30m x 30m (C-CAP)	*	CUDEM[1]	tidal datums	C-CAP
ETM	1m x 1m (VGIN)	1m x 1m (lidar)	CBTBDEM[2]	NAVD88	NWI and TMI

TABLE 3 COMPARISON OF MODEL INPUTS FOR DATA PARAMETERS AND SOURCES. * THESE DATA WERE DERIVED FROM THE MOST RECENT ELEVATION DATA AVAILABLE AT THE DATE OF PROCESSING THAT MET PROJECT SPECIFICATIONS, THE MOST RECENT VDATUM TIDAL MODEL DATA AVAILABLE AT THE DATA OF PROCESSING, AND 2011 CCAP LAND COVER DATA.

In conclusion, the methodology for assessing marsh migration potential can identify large areas for conservation and watershed-wide marsh restoration plans.

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Excerpt from *Tidal Marsh Resilience Information Summary*: Healthy Marsh Migration Review

Source

Healthy Marsh Migration Review. *Harnessing sea level rise to create marshes: A literature review defining potential metrics and ideal landscape characteristics for healthy marsh migration*, June 2022. Matthew L. Kirwan, Virginia Institute of Marine Science. link

Summary

The document examines the potential of upland marsh migration to help offset the loss of ecosystem services provided by coastal wetlands that are diminishing due to sea level rise. Kirwan identifies and closely examines the landscape characteristics suggested by literature sources (moderate upland slopes, larger tidal ranges, and proximity to tidal channels and embayment) that support healthy marsh migration. The author reviews examples of unhealthy marsh migration (forest mortality accompanied by degrading marshes) and healthy marsh migration (forest mortality accompanied by increasing vegetation).

Kirwan frames the imminent need to study the viability of marsh expansion and resilience by identifying the limitations of conventional wetland restoration strategies and metrics, which focus on survival of wetlands and marshes in place, not migrating marshes. Because marsh vulnerability is directly linked to sediment supply and tidal range, the conventional wetland restoration strategies focus on management practices like sediment placement and stabilization. This conventional marsh management approach offers limited potential in many areas of the Chesapeake Bay, where many marshes are in sediment limited systems, and migration might the be only alternative opportunity to offset the loss of existing wetlands and marshes in areas where conventional restoration approaches are not possible.

Marsh migration as a management approach (or alternative to restoration) raises questions about anthropogenic barriers and landowner resistance, sustainability considering sea level rise, and the ecological integrity of newly formed marshes. Kirwan proposes that land management practices can overcome these challenges, and that new metrics are needed to define healthy marsh migration and to evaluate landscape characteristics and management actions that lead to successful migration.

Kirwan's literature review focuses on four questions that help the writer hypothesize the ideal conditions for successful long term marsh migration in the Chesapeake Bay:

- *What is a healthy mosaic of connected coastal habitat (vegetation and hydrology)?*

- *What processes promote ideal conditions for persistent, healthy marshes in SLR dynamics?*
- *What are ideal upland conditions for marsh migration at site scale?*
- *What example of mosaic of healthy coastal habitat exists in Maryland today?*

Key findings relevant for Collaborative Marsh Targeting

Critical factors to consider for marsh migration in the context of connected coastal ecosystems:

- Connected ecosystems are critical for marsh migration. Healthy marsh migration relies on tidal connectivity for water, sediment, nutrients, and drainage.
- Natural (steep slopes) and manmade barriers (development) can reduce connectivity, causing marshes to diminish in size and function. Likewise, expanded marshes that migrate inland beyond the reach of tidal channels can diminish in size and function due to a lack of connectivity.
- Poor drainage, which causes ponding and reductions in plant biomass, is the biggest challenge for ecological function and longevity for marshes migrating to upland edges.
- Ditching marshes or finding other ways to create channels for tidal connectivity and improve drainage might be reconsidered.

Metrics of successful healthy marsh migration:

- Marsh restoration success metrics focus on current marsh health; successful migration must consider resilience (to ensure ecosystem function is maintained as sea level rise continues).
- Traditional wetland restoration metrics focus on structure and function of soils, biota, and hydrology, which also can be used to measure the health of migrating marshes. Studies show old and newly formed marshes offer similar ecosystem benefits.
- Soil and plant-based metrics do not include habitat value of new marshes, which are typically dominated by Phragmites australis. A habitat quality metric might be necessary for management of marsh migration to support certain species. *
- Hydrology metrics to evaluate waterlogged soils and ponding are needed for evaluating migrating marsh health and resilience. Examples include hydrogen sulfide concentration, soil redox potential, UVVR, and remote sensing products that calculate the prevalence and frequency of standing water.

Metrics of marsh resilience to sea level rise:

- The traditional measure of sustainability for marshes (soil vertical accretion rate compared with rate of SLR) likely overestimates marsh vulnerability because the metric does not account for increased plant productivity and sediment deposition associated with inundation.
- National Estuarine Research Reserve System (NERRS) developed an extensive list of metrics to assess marsh stability and vulnerability, but they have limited value in context of migrating marshes because they do not account for lateral erosion or inland migration.

- Spatially integrated metrics are necessary to measure marsh resilience in context of marsh migration. Two suggested metrics relevant to understand marsh vulnerability in context of inland migration include:
    - Unvegetated to Vegetated Marsh Ratio (UVVR) which calculates the portion of a give marsh that is occupied by vegetation versus open water. (Ganju et al.) Kirwan posits this metric can be used to calculate the lifespan of existing marshes.
    - Vertical resilience index (calculates the threshold rate of SLR beyond which marshes will accrete more slowly than SLR as a function of tidal range); and lateral resilience index (calculates vulnerability of marshes as the ratio between current wetland area and area of land suitable for wetland migration for a given amount of SLR). Lateral resilience index indicates that large marshes with small migration areas would be most vulnerable. (Holmquist et al.). **Kirwan posits this index can be useful to identify where management intervention should be prioritized.**

Landscape characteristics associated with healthy marsh migration:

- In addition to evaluating marsh migration rate and extent, healthy marsh migration metrics should evaluate ecological function and persistence.
- Research suggests poor drainage and invasive species* are key threats to health marsh migration.
- Landscape characteristics for marsh migration:
    - Hydrological connectivity is the key landscape characteristic associated with healthy marsh migration. Connectivity relies on large tidal ranges and proximity to tidal channels and marine environments (faster sediment deposition, higher vertical resilience, more extensive channel networks).
    - High soil salinity (limits grown of *P. australis*) *
    - Upland land use (anthropogenic barriers, considerations for agricultural or residential uplands transitioning to marsh such as vegetative succession, ecosystem benefits, land use value)
    - Slope (Gentle slopes lead to rapid migration and larger mashes; rapidly forming marshes typically outpace the elongation of channel networks, increasing vulnerability to ponding and SLR.)
- Consider tradeoffs between characteristics that promote large marshes versus healthy marshes (largely determined by hydrologic connectivity over time).

Examples of healthy and unhealthy marsh migration in Maryland:

- Through a detailed study of six sites in Maryland, Kirwan tests the landscape characterization hypothesis for migrating marshes developed during the literature review: healthiest migration would occur near tidal channels, rivers or embayment, and areas with steeper uplands may have healthier migration because the poorly drained transition zone would be narrower.

- Chesapeake Bay characteristics important to consider for the study include small tidal range, low sediment availability, fresh to brackish salinities and gentle upland slopes – all of which suggest ponding and invasive vegetation are likely the most significant marsh migration issues.
    - UVVR and NDWI were unsuitable metrics to evaluate ponding and waterlogged soils in marsh-forest transition. UVVR datasets were limited to marsh outside the transition zone and a single year.
    - Used Normalized Difference Vegetation Index (NDVI), a proxy for aboveground biomass based on Landsat imagery, captured the effects of waterlogged soils.
    - Used Tidal Marsh Vegetation Classification (3m) dataset to evaluate phragmites distribution.

Conclusion

- Kirwan verifies the characteristics associated with migration patterns, and calls for new metrics (see p. 15, Table 1) and land management practices to define healthy, successful long-term marsh migration.
- Marsh health generally followed topographic gradients where steeply sloping, more exposed sites showed more positive NVDI trends, and the unhealthiest marsh migration occurred in areas with gently sloping and less exposed sites with wide transition zones. Takeaway: Marsh extent and quality may be at odds.
- Kirwan raises questions about the tradeoffs between large, short-lived marshes and smaller healthy marshes, as well as how to evaluate overall ecosystem value in new marshes largely comprised of *Phragmites australis*, which provide ecosystem benefits but offer limited habitat for native species.
- Successful marsh migration landscape characteristics for the Chesapeake Bay area: 1, larger tidal ranges with faster sediment deposition rates, moderate slope, and proximity to extensive channel networks; 2, high soil salinity (limits growth of P. australis; important if habitat is a priority). Gentle slopes may have short-term successful marsh migration (but eventual ponding), and steeper slopes have smaller, more sustainable migrated marsh. Tradeoffs between large marshes versus healthy marshes must be considered.
- Additional observations:
    - Identified that poorly drained transitional marsh may recover as channels erode and drain the evolving landscape.
    - Effects of ditching had mixed results across sites.

*Applies if habitat value is relevant to goal.

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Excerpt from *Tidal Marsh Resilience Information Summary*:
USGS Coastal Wetland Synthesis Products and Tools for Chesapeake Bay

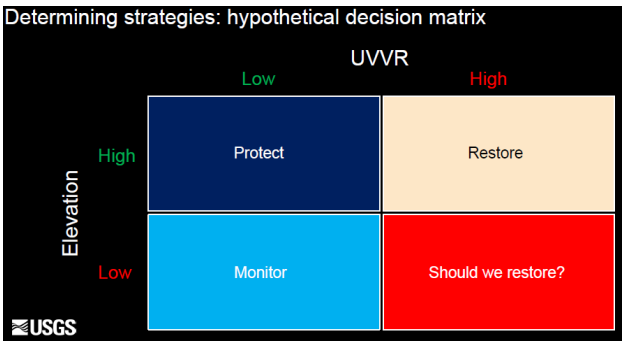
Source

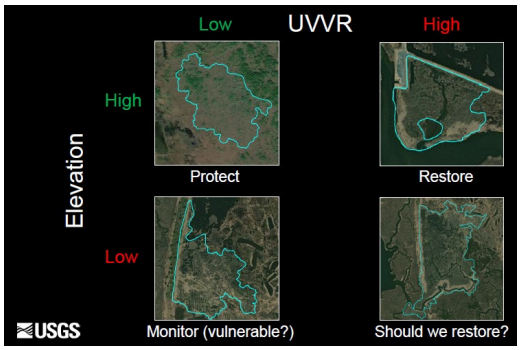
Coastal Wetland Synthesis Products and Tools for Chesapeake Bay. Neil Ganju, Kate Ackerman, and Zafer Defne, Woods Hole Coastal and Marine Science Center U.S. Geological Survey. link

Summary

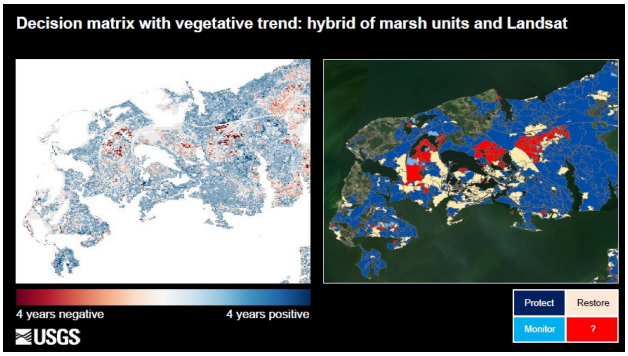
The presentation (comprised of slides with images, charts, and bullets; no notes available), illustrates the processes and factors associated with salt marsh vulnerability and provides updates about new data that will be available from USGS to support marsh adaptation and management decision making. The Collaborative Tidal Marsh Adaptation Project team is building on the hypothetical decision matrix presented in the research to create scenarios to consider for evaluating tidal marsh adaptation opportunities.

- Migration potential a function of slope, inundation frequency, salinity, land use, canopy cover
- Close correlation between sediment budget and UVVR (loss of vegetation releases sediment); estimates stability value to be approx. 0.10 – 0.15 KG / M^2/Y
- The following marsh-unit metrics by subregion are available in new USGS layers for geospatial analysis in Chesapeake Bay; the layers are complete and in review:
    - UVVR: open water conversion
    - Elevation: vertical resilience
    - Tidal range
    - Lifespan (this metric combines UVVR, elevation and SLR)
- Study of correlation between UVVR and Elevation at Deal Island, Blackwater and Plum Tree Island leads to hypothetical decision matrix:





- Introduces marsh lifespan concept between elevation, UVVR and SLR:
    - Mass in marsh plain above MSL is your account balance.
    - Sediment deficit goes up with increasing UVVR and increasing SLR; deficit applies to whole complex including subtidal.
    - To offset the deficit, account balance must be drawn down until the whole complex is at MSL and/or unvegetated, i.e., "cannibalization."
    - See slides for examples of calculations of lifespan.
- Chesapeake Bay lifespan data is now available.
- Presents decision matrix with vegetative trend: hybrid of marsh units and Landsat:



- Summarizes available scientific information to guide efforts in the Bay:
    - Geospatial mapping of salt marshes
        - Provides baseline status of vegetated habitats.
        - Delivers objective, spatially complete metrics.
        - Drives decision-making tools.
    - Marsh lifespans in Chesapeake Bay
        - Highly variable based on location and geomorphology
        - Several regions vulnerable in the coming decades

        - Predictions can be updated with new aerial imagery and elevation data.
    - Guiding restoration investments
        - Simple decision matrix useful for rapid assessment
        - Restoration calculator a simple, robust approximation
        - Provides approximate answers to crucial questions.