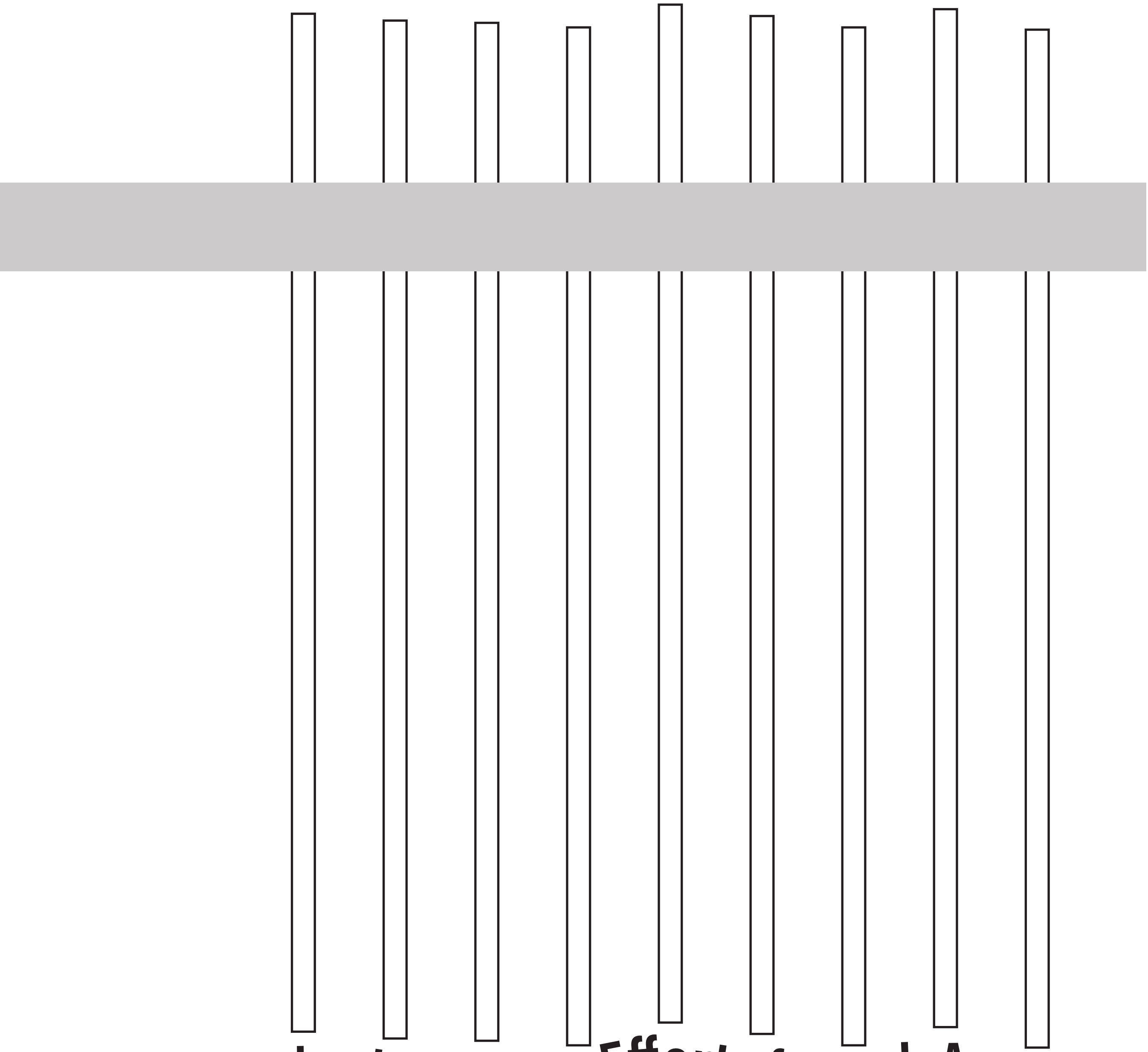
SENTINEL SITE COOPERATIVE



Conceptual Modeling Effort of Marsh Accretion Rates

University of Maryland
CENTER FOR ENVIRONMENTAL SCIENCE

Sea Grant
Maryland

Summary Report

Maryland Sea Grant
Publication number
UM-SG-TS-2022-01

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This brief report summarizes an effort by a subset of the Chesapeake Bay Sentinel Site Cooperative Surface Elevation Table Working Group to craft conceptual models highlighting variables in the region that are especially important for predicting and understanding local rod surface elevation tables-determined marsh accretion rates.

This publication was made possible by a grant to Maryland Sea Grant from the National Oceanic and Atmospheric Administration, Department of Commerce, through the National Sea Grant College Program, Grant number NA18OAR4170070, and funding from the state of Maryland through the University of Maryland Center for Environmental Science.

Preferred citation:
Harris, Lora & Taryn Sudol. 2022. Report on Conceptual Modeling Effort of Marsh Accretion Rates. Maryland Sea Grant Publication UM-SG-TS-2022-01.

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This brief report summarizes an effort by a subset of the Chesapeake Bay Sentinel Site Cooperative (CBSSC) Surface Elevation Table (SET) Working Group (WG) to craft conceptual models highlighting variables in the region that are especially important for predicting and understanding local rod SET (rSET)-determined marsh accretion rates. This effort was intended to serve as a starting point for identifying explanatory variables for a statistical analysis and to ascertain the availability of these data for the work.

BACKGROUND AND MOTIVATION

The spirit of the CBSSC's SET WG is that "the whole is greater than the sum of its parts." We see the value of a community of practice based around marsh monitoring and the impacts of sea level rise. Not only does knowledge exchange help each site work towards community-agreed-upon best practices, but by combining expertise and data, we can draw regional conclusions from our site-specific measurements. In that vein, the SET WG, which has been meeting regularly since 2016, has collaborated to produce a Data and Infrastructure Report, a SET Inventory of metadata (which has since been replicated in North Carolina and the Gulf of Mexico), and a "MARS-Lite" analysis (manuscript in development) based on the NERRS "Marsh Resilience to Sea Level Rise" analysis.

For several years, the SET WG has identified a longstanding need and capacity to harness the power of the SET data among WG members. In particular, an opportunity exists to leverage these data to provide recommendations regarding optimal monitoring for elevation change in tidal wetlands, as well as forecast elevation change at sites that lack the same resources as the data-rich sentinel sites. Several efforts have been made to reach this goal. In 2019, Principal Investigator (PI) Lora Harris (co-PIs Jim Holmquist, Patrick Megonigal, Taryn Sudol, Dong Liang) submitted to the National Oceanic and Atmospheric Administration (NOAA) Ecological Effects of Sea Level Rise grant competition to produce a spatially explicit Bayesian Hierarchical Model to intercompare SET data, however the proposal was not funded. In 2020, Harris and co-PIs adapted the project to meet the objectives of the National Estuarine Research Reserve System (NERRS) Science Collaborative Grant. This included a statistical "power analysis" to recommend monitoring protocols in addition to a structural equation model (SEM) that uses SET data and other parameters to forecast elevation change. The team proposed a co-production, participatory modeling approach to help inform model inputs and outputs. For example, the SET WG would contribute to the process model (e.g. tidal range, sediment concentration, plant species present) of the SEM analysis, and other end users would guide the team on relevant sea level rise scenarios and useful visualizations. While among the top 10 proposals, unfortunately this project also did not receive funding. The SET WG reconvened to discuss next steps, and Glenn Guntenspergen (United States Geologic Survey, USGS) said that his lab had the capacity to pursue the SEM analysis in the Chesapeake region, which could perhaps feed into a larger national effort to analyze SET data.

The USGS SEM effort uses a slightly different statistical approach for a similar objective of capturing insights and evaluating hypotheses regarding elevation change in wetlands using rich empirical datasets. Like Bayesian approaches, SEM modeling can benefit from conceptual modeling efforts to formally frame hypotheses and assumptions regarding ecological mechanisms, interactions among explanatory variables, and scales of interrelationships among variables. This conceptual modeling and SEM analysis continues the SET WG track record of synthesis, even in the absence of robust funding.

CONCEPTUAL MODELING APPROACH

Harris and Sudol offered a 90-minute workshop structure solicitation of feedback and ideas around Chesapeake Bay-specific conceptual models regarding elevation changes in wetlands. All members of the SET WG were invited to participate, and the workshop outlined clear goals that included:

- This workshop will offer space for facilitated brainstorming of potential factors contributing to surface elevation rates at rSETs across the Chesapeake Bay.
- We will identify explanatory factors and provide some thoughts on the ways these contribute to elevation rates.

- We will crowdsource which of these factors are available with existing data, which are unmeasured, and which are possible to obtain with relatively low investments of time.
- We will solicit feedback on favored models, go through a voting exercise, and assemble a suite of alternative models to evaluate using SEMs.

The brainstorming session began with identifying meeting behavior expectations and outlining the day's objectives and agenda. Erin Reilly began the session with an overview of the MARS-Lite results that spurred creative thinking around elevation and rSETs and the diversity of our various field sites. The group then split into breakout rooms, each moderated by a SET WG member who had been briefed on the exercise ahead of time. We used Google Jamboards to synchronously brainstorm explanatory factors for elevation change in Chesapeake Bay wetlands, and organize these factors into cause-and-effect diagrams. The Run of Show, Facilitator Guidelines, and Jamboards are all available as links in this document.

We followed best practices by keeping breakout rooms in groups of four to five individuals. We found that this process often results in emergent themes and ideas and as such represents an expert crowd-sourcing approach. Indeed, at the conclusion of the breakout room times, when we met again in plenary, share-outs from the groups revealed several aligned concepts and relationships among variables. We shared key elements of the conceptual models using Slido synchronous polling tools.

Following the in-person workshop, Lora Harris and Taryn Sudol analyzed the Jamboards by creating a database of explanatory variables, looking at overlap, and noting similarities and differences across the breakout rooms. They worked together to propose several visualizations for the conceptual model that emerged from this exercise.

RESULTS

PARTICIPANTS

The 12 participants in the conceptual modeling workshop, representing a range of institutions and expertise, are listed in Table 1 below.

Table 1. Conceptual Model Workshop Participants

PARTICIPANTS	AFFILIATION	EXPERTISE
Linda Blum*	University of Virginia, Virginia Coast Reserve Long-Term Ecological Research	Salt marsh ecology—organic matter accumulation and soil forming processes
Joel Carr	United States Geologic Survey (USGS)	
Kyle Derby	Chesapeake Bay National Estuarine Research Reserve (CBNERR) - Maryland	
Glenn Guntenspergen	USGS	
Lora Harris*	University of Maryland Center for Environmental Science (UMCES)	Marsh ecosystem science and numerical modeling
Ron Lopez	Virginia Commonwealth University, Rice River Center	Tidal freshwater forest/ marsh ecology
Katherine Phillips	Maryland Coastal Bays Program	
Erin Reilly	James River Association	
Lori Staver*	UMCES	Marsh ecology
Kari St. Laurent	Delaware NERR	
Taryn Sudol*	Maryland Sea Grant	Chesapeake Bay Sentinel Site Cooperative (CBSSC) Coordinator
David Walters	USGS	

*Facilitator

The membership and Jamboards for each of the three breakout rooms are listed below.

Table 2. Breakout room composition and Jamboard links

BREAKOUT ROOM	PARTICIPANTS	JAMBOARD LINK
1	Taryn, David, Kyle, Ron	https://jamboard.google.com/d/1AyjrAMadcEZwDMTUmvbFbBBJ8IXXmPwO-rZHglJBrLc/edit?usp=sharing
2	Linda, Erin, Lora, Glenn	https://jamboard.google.com/d/1QsHNa5EdKb1fQF4J-9posaV3DNvYsQen0R3yaoiPMN8/edit?usp=sharing
3	Lorie, Katherine, Joel	https://jamboard.google.com/d/16EyG1BZ5BpK7IJtfKCmxhf2n0uQM-eEFcaB4zouCTBU/edit?usp=sharing

EXPLANATORY VARIABLES

The breakout rooms identified 33 explanatory variables/terms that are listed and grouped in Table 3. Of these, five terms were present in all three breakout groups, and 10 additional terms were present in at least two of the breakout groups. With nearly half of all variables emergent in all three breakouts, there is clearly agreement on some of the fundamentals related to elevation.

Table 3. Listing and groupings of explanatory variables identified in breakout rooms

EXPLANTORY VARIABLES, TERMS, PROCESSES	NUMBER OF MENTIONS
Site conditions	
SLR rates	2
Subsidence	
Wind conditions	
Exposure to waves	
SET elevation	3
Nutrient status/availabilty	
Salinity/Redox state	3
Anthropogenic modification (ditching, OMWM, restoration, TLDR)	2
Tides	
Tidal inundation/flood frequency	2
Tidal range	
Tidal harmonics	
Upland influences	
Adjacent land use	
Upland impervious surface (affects flashiness of freshwater flow into marsh)	
Watershed topography	
Precipitation	
Geomorphology	
Hummocky-ness	
Edge type	
Spatial location (x,y,z)	
Distance from tidal source	2
Hydrology changes - ditching	
Hydrologic connectivity	
Sediment supply	2

EXPLANTORY VARIABLES, TERMS, PROCESSES	NUMBER OF MENTIONS
Vegetation	
Vegetation type	3
Vegetation density	2
Above ground production	3
Below ground production	2
Root biomass volume	2
Decomposition	3
Other Processes	
Compaction	
Disturbance (animal/hurricane/etc)	
Wildlife disturbance	
Predation on plants	2
Accretion	

EXPLANATORY VARIABLE DATA AVAILABILITY

Following the workshop, we sent out a survey asking SET WG members about the availability of data that align with the explanatory variables identified in the workshop. We expected there to be a relationship between site-type, data availability, and end users as depicted in Figure 1.

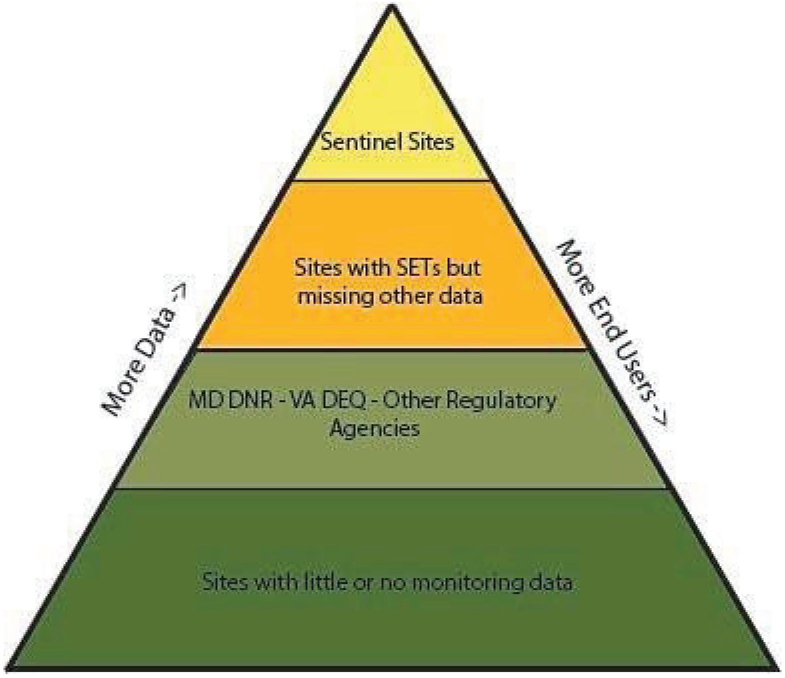

Figure 1. Types of sites characterized by monitored data collection and end users

We had eight survey participants who commented on data availability for 11 different marsh sites. Table 4 summarizes what data is available across the 11 sites, and Table 5 displays the responses by individual marsh site. Note that some survey respondents did not provide answers for all variables. Nearly all sites (10-11) have data available for accretion, vegetation type, and SET elevation. Most sites (8-9) have data available for decomposition, vegetation density, distance from tidal source, spatial location, tidal range, and sea level rise rates. The following variables scored highest as unavailable: Hydrology changes—ditching, anthropogenic modifications, wind conditions, and precipitation.

Table 4. Data availability for explanatory variables across 11 survey respondents/marsh sites.

	AVAILABLE SITE(S)	FIELD COLLECTIBLE SITE(S)	COMPUTABLE/ GIS SITE(S)	UNAVAILABLE SITE(S)
SLR rates	9	1	1	0
Subsidence	6	3	0	1
Wind conditions	6	0	0	3
Exposure to waves	3	0	4	2
Tidal inundation/ flood frequency	2	2	5	0
Tidal range	8	1	1	0
Tidal harmonics	1	1	6	1
Adjacent land use	4	0	6	0
Upland impervious surface	1	1	7	0
Watershed topography	5	1	3	0
Precipitation	6	0	0	3
Anthropogenic modifications (e.g., ditching, restoration, TLDR)	2	0	3	4
SET elevation	10	1	0	0
Salinity/redox state	4	6	0	0
Nutrient status/availability	5	5	0	0
“Hummocky-ness”	2	6	0	1
Edge type	2	5	1	1
Spatial location (x,y,z)	9	1	0	0
Distance from tidal source	8	0	3	0
Hydrology changes —ditching	2	1	0	6
Hydrologic connectivity	2	6	1	0
Sediment supply	6	1	2	0
Vegetation type	10	1	0	0
Vegetation density	8	1	0	1
Above-ground production	4	7	0	0
Below-ground production	4	7	0	0
Root biomass volume	2	6	1	0
Decomposition	8	2	0	0
Compaction	0	7	1	1
Disturbance (animal/hurricane/etc.)	2	6	0	1
Wildlife disturbance	2	5	0	2
Predation on plants	2	3	0	1
Accretion	11	0	0	0

Table 5. Data available for explanatory variables organized by marsh site.

	Goodwin Island	Catlett Island	Taskinas Creek	Sweet Hall	Virginia Coast Reserve - Upper Philips Creek Marsh	Poplar Island	Kirkpatrick Marsh (GCReW[1])	Monie Bay	St. Jones Reserve & Blackbird Creek Reserve	Assateague Island & Jamestown Island	Rice Rivers Center
SLR rates	🟢	🟢	🟢	🟠	🟢		🟢	🔵	🟢	🟢	🟢
Subsidence	🟢	🟢	🟢	🟢	🟢		🔴	🟠	🟠	🟢	🟠
Wind conditions	🔴	🔴	🟢	🟢	🟢		🟢	🔴	🟢		🟢
Exposure to waves	🟢	🟢	🔵	🔵	🟢		🔵	🔴	🔵		🔴
Tidal inundation/ flood frequency	🔵	🔵	🔵	🔵	🟢		🟢	🟠	🔵		🟠
Tidal range	🟢	🟢	🟢	🟢	🟢		🟢	🟠	🔵	🟢	🟢
Tidal harmonics	🔵	🔵	🔵	🔵	🟠		🟢	🔴	🔵		🔵
Adjacent land use	🔵	🔵	🔵	🔵	🟢	🟢	🟢	🟢	🔵		🔵
Upland impervious surface	🔵	🔵	🔵	🔵	🟠		🟢	🔵	🔵		🔵
Watershed topography	🟢	🟢	🟢	🟢	🟠		🟢	🔵	🔵		🔵
Precipitation	🔴	🔴	🟢	🟢	🟢		🟢	🔴	🟢		🟢
Anthropogenic modifications (e.g., ditching, restoration, TLDR)	🔴	🔴	🔴	🔴	🟢		🟢	🔵	🔵		🔵
SET elevation	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟠	🟢	🟢	🟢
Salinity/redox state	🟠	🟠	🟠	🟠	🟢	🟢	🟢	🟠	🟠		🟢
Nutrient status/availability	🟠	🟠	🟠	🟠	🟢	🟢	🟢	🟠	🟢		🟢
"Hummocky-ness"	🟠	🟠	🟠	🟢	🟠		🟢	🟠	🔴		🟠
Edge type	🟠	🟠	🟠	🟠	🟢		🟢	🟠	🔴		🔵
Spatial location (x,y,z)	🟢	🟢	🟢	🟢	🟢		🟢	🟢	🟢	🟢	🟠
Distance from tidal source	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🔵	🔵	🟢	🔵
Hydrology changes —ditching	🔴	🔴	🔴	🔴	🟢		🟢	🟠	🔴		🔴
Hydrologic connectivity	🟠	🟠	🟠	🟠	🟠		🟢	🟠	🔵		🟢
Sediment supply	🟢	🟢	🟢	🟢	🟢		🟢	🔵	🔵		🟠
Vegetation type	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟠
Vegetation density	🟢	🟢	🟢	🟢	🔴	🟢	🟢	🟢	🟢		🟠
Above-ground production	🟠	🟠	🟠	🟢 🟠	🟢	🟢	🟢	🟠	🟠		🟠
Below-ground production	🟠	🟠	🟠	🟢 🟠	🟢	🟢	🟢	🟠	🟠		🟠
Root biomass volume	🟢	🟠	🟠	🟠	🟢		🔵	🟠	🟠		🟠
Decomposition	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟠	🟢		🟠
Compaction	🟠	🟠	🟠	🟠	🔴		🔵	🟠	🟠		🟠
Disturbance (animal/hurricane/etc.)	🟠	🟠	🟠	🟠	🟢		🟢	🟠	🔴		🟠
Wildlife disturbance	🟠	🟠	🟠	🟢	🟢		🟠	🟠	🔴		🔴
Predation on plants				🟢	🟢		🟠	🟠	🔴		🟠
Accretion	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢

[1] *Global Change Research Wetland*

🟢 Available Site 🟠 Field Collectible Site 🔵 Computable/GIS Site 🔴 Unavailable Site

CONCEPTUAL MODEL

Harris and Sudol worked to consider how the explanatory terms and Jamboard organization of these terms might be represented visually. Several things stood out in this process. Importantly, mechanisms regarding the central processes governing elevation change were largely informed by general theories in marsh ecology describing biophysical feedbacks between vegetation and sediment capture. Kirwan and Megonigal (2019) have reviewed and articulated much of this work. In the conceptual modeling work done here, it was clear that the dynamic equilibrium between sea level rise, plasticity of above-ground plant vegetation and productivity in response to flooding, below-ground production, and sediment capture and supply were at the forefront of many participants' thinking.

Secondly, it was clear that there was a desire to constrain local conditions that might contribute to differential responses of wetlands to the process that affect elevation change. These included big-scale processes like sea level rise and subsidence rates alongside very specific consideration of local geomorphology and distance from tidal sources of water. There was also a focus on physical forcings like wind, waves, tidal conditions, and hydrological conditions in general (along with features that might impact the hydrology like local land use).

It also seemed clear that participants were concerned with issues related to disturbance. This might include wildlife issues and predation but also connect to site conditions and history, for example, whether a location is a restoration site, or the presence of legacy ditching.

Based on this work, Harris and Sudol present the following visualization of the conceptual model. The overlapping circles indicate the scaled and nested relationships among environmental variables, and all of these spotlight the biophysical feedbacks between vegetation, sediment, and ultimate accretionary processes. You can find a link to the presentation slide for this diagram here. We welcome you to play with these images by copying and pasting new slides for new versions and improvements.

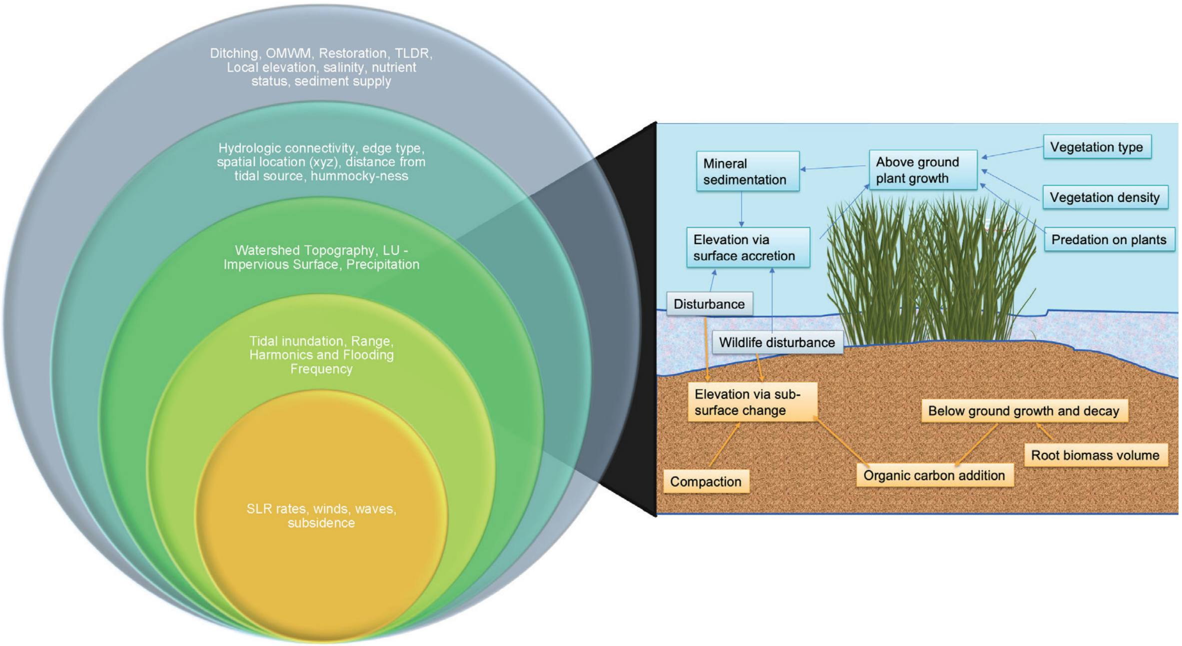

Figure 2. Conceptual model of explanatory variables responsible for marsh accretion rate.

RECOMMENDATIONS

The results of this SET WG participatory effort included a list of explanatory variables (Table 3), a visualization of these variables in a conceptual model (Figure 2), and a listing of data availability of the explanatory variables among SET WG marsh sites (Tables 4 and 5). While this was a preliminary activity, we see these results being applied in the following ways:

- Inform research questions regarding Chesapeake Bay wetland response to sea level rise
- Identify gaps in measurements and data availability
- Evaluate understanding via statistical or simulation modeling
- Evaluate understanding via empirical research involving experiments or data analyses

We encourage SET WG members to continue to exchange information, confer on data availability and potential insights, and develop research related to marsh resiliency in the face of chronic stressors and/or disturbances. We hope other members of the marsh research and conservation community benefit from our data products and analyses.