# July 31, 2024 Technical Working Group Summary

Welcome to our inaugural Crisfield/EPA ORD Technical Working Group (TWG) providing technical feedback on proposed nature-based solutions (NBS) for Crisfield’s coastal resilience! Thank you so much for joining and sharing your expertise!

 AGENDA for July 31:

• TWG process and expectations

• Storm surge attenuation modeling

• Metrics to assess NBS co-benefits

 Excited to explore these topics with you all! Please let us know if you have any questions (kashuba.roxolana@epa.gov).

Attendees:

|  |  |
| --- | --- |
| **Organization** | **Expertise** |
| City of Crisfield | Local knowledge, funding |
| EPA Region 3, Wetlands | Regulatory |
| EPA Region 3 | Climate planning |
| Somerset County, Public Works Department | Local engineering, dredging |
| Maryland Department of Planning | Planning |
| US Army Corps of Engineers, Engineering with Nature program | Hydrology, storm surge |
| Lower Shore Land Trust | Local marsh knowledge |
| Virginia Institute of Marine Science, Center for Coastal Resources Management | Estuaries and salt marshes |
| Eastern Shore Regional GIS Cooperative | Local mapping, spatial data |
| University of Maryland, Environmental Finance Center | Finance and green infrastructure |
| Federal Emergency Management Agency, Region 3, help with Building Resilient Infrastructure and Communities Direct Technical Assistance (BRIC DTA) program | Crisfield flood management plan |
| Sustainable Science, LLC | Salt marsh restoration |
| Tetra Tech (contracted by EPA) | Coastal engineering |
| EPA Office of Research and Development | Project Navigator |
| EPA Office of Research and Development | Ecosystem co-benefits |
| EPA Office of Research and Development | Community engagement |

Presentation content (see file: “Crisfield\_EPA\_TWG-07 31 2024-508.pdf”):

**[SLIDE 1] Supporting Coastal Community Resilience through Natural Infrastructure**

Thank you so much for agreeing to join the EPA/Crisfield Technical Working Group, co-developing research with Crisfield to explore nature-based options for coastal resilience. We are very grateful for you all taking the time to help Crisfield today. We’ve hand-selected you all in partnership with Crisfield to convene your expertise around the technical components of this project. We will plan to take notes of this meeting content and feedback and make those publicly available, along with materials shared for review. We will not be recording these meetings.

**[SLIDE 2] Technical Working Group Goals and Process**

To review process and expectations: we are looking to hold approximately 5 meetings of this Technical Working Group over the course of this next year, as our team is working on data analysis and modeling. The idea is to present new results at every meeting as we move forward in the research, and discuss what we think they mean, and make sure the work is being vetted by you all and moving in the right direction, and making any course corrections, as necessary.

Materials presented and feedback from meetings will be tracked on EPA project webpage (<https://www.epa.gov/water-research/coastal-community-resilience-research>), which is linked from Crisfield’s Flood Mitigation website (<https://crisfieldfloodmitigation.com/>).

**[SLIDE 3] Current Project Status**

To review project status: we are focused on two major research questions at this point—the first is exploring how much offshore nature-based solutions (recommended for Crisfield based on literature review) can help decrease waves and storm surge coming into Crisfield. And, specifically, making sure that our analysis coordinates with Crisfield’s FEMA plan they just won the grant for, which will essentially protect Crisfield up to a 5-foot flood level, which was calculated for a one-in-50-year storm. We are having a separate call with FEMA tomorrow to make we’re understanding and interpreting that correctly and to make sure we’re coordinating the two kinds of solutions in the way that makes the most sense for Crisfield.

The second major question is: what types of co-benefits provided by these nature-based solutions most contribute to Crisfield’s overall coastal resilience goals, and what metrics should we use to measure those?

Progress made thus far:

1. Narrowing down the top 3 offshore nature-based strategies for Crisfield, and
2. Narrowing down a set of top co-benefits that Crisfield prefers

Today – for the first half of the meeting-- we’d like discuss some initial estimates of current storm surge heights for storms of different magnitudes (in terms of wind speed and resulting water height), and share our thought process on which storm to model, and type of modeling we plan moving forward.

And for the second half—we’d like to talk through which top metrics it makes sense to model to represent the Crisfield community’s preferred co-benefits from nature-based strategies, and what kind of data do we need to assess that.

Let me stop here and see if there are any questions on the status and charge at this point…?

***FEMA:*** *What is your project timeline? When are we expecting to get a report out? Once research is done, if there are proposed solutions, what are the next steps to move forward?*

***EPA ORD:*** *Timeline has not changed since the once we showed at the April 19 institutional partner meeting: we expect to conduct modeling and analysis over the next year with results in Fall 2025. Then we will engage in a decision-making process for the next year after that, including community conversations about which solutions make the most sense, with final results expected by Fall 2026, and simultaneously working with regulatory groups for feedback on research and next steps.*

**[SLIDE 4] Proposed nature-based projects**

We’ve reviewed in previous meetings how we arrived at these three possible projects to evaluate (and we are working on publishing out all the details; will let you know when that is available), but, essentially, because larger storms typically come from the SW towards NE, and given information in the literature about which kinds of strategies could be most effective in a place with environmental conditions like Crisfield—we’ve narrowed down most potentially effective NBS options to (see map):

1. Marsh and sand dune restoration on Janes Island,
2. Marsh and sand dune restoration on Cedar Island, and
3. Living coastal breakwaters in the Lower Annemessex River between the two barrier islands.

The design of the projects will be iterated with the modeling, but we are planning on getting to 10% design and being able to specify project footprint, elevation, vegetation roughness, and restoration technique both for marsh sediment placement/edge protection, and for living breakwater construction.

The next step is to determine how much storm surge and wave height these kinds of projects can attenuate.

**[SLIDE 5] Wave height vs. marsh height – which storm to model?**

During a storm, the additional water (on top of the usual tide) can be thought of in two parts: (1) the storm surge – which is a rise in overall water level through larger scale weather processes – and then (2) on top of that is the additional height of waves driven by storm winds – which are smaller scale and more variable. During storms, these waves can be several feet tall. Salt marshes specifically have been documented to be able to attenuate these waves. And they can attenuate waves more, the denser and more rigid the vegetation is, and the taller the vegetation is relative to the overall depth of water.

These figures are not to scale (just conceptual) but in the top picture, the surge is higher than the marsh, so the waves do not get as much of a chance to be attenuated by the marsh. Literature shows that marshes can still decrease wave heights by up to 5-10% for water depths 3-5 times the effective canopy height. But for water heights this high, attenuation it is not going to be as much as in the middle case, where the wave is partially obstructed by the marsh, so it is able to be attenuated more. And then in the bottom case, is where you see the most attenuation because the vertical height of the whole wave is moving through the marsh.

So, we’d like to be able to take this into consideration when selecting which kind of storm, how extreme of a storm, and what height of storm surge and wave height, we think these nature-based strategies might be able to attenuate.

**[SLIDE 6] Baseline storm surge**

The first thing we did, to get an idea of the magnitudes of surge coming in, and how that compares to the height of the marsh, was to run scenarios of NOAA’s SLOSH model, specific to Crisfield storms.

SLOSH stands for “Sea, Lake, and Overland Surges from Hurricanes” model and it has pretty coarse resolution – for the Crisfield area we were able to extract water height information for grid cells at about 700 m (~0.4 miles). And we looked at how high storm surge has gotten in Crisfield over the last 34 years.

The output of this model is storm surge height on top of high tide. And it’s reporting it from the bottom of the grid cell, i.e., “ground level”, so the actual vertical amount of water from the ground to the top of the storm surge, including high tide. This model does not include waves.

So, what we’ve done is reported the distribution of storm surge heights across these 42 actual storms over time, and this tells you how likely it was that you would see surge this high. In the top left is the 1% exceedance probability. This means there is a 1% that you would see storm surge at least 7 feet high at the border of Crisfield over 34 years. So, this is a very rare extreme storm.

At the other end, --- bottom right, there is a 99% chance that storm surge would be at least 2 feet at the border of Crisfield in the last 34 years– so, very, very likely to happen.

What we want to do is figure out what is the worst-case storm that natural infrastructure can help out with. Where it’s possible to elevate marshes and sand dunes high enough to interfere with the waves at the top of the storm surge. And we also want to align with FEMA’s analysis, which is meant to protect against a 1-in-50-year storm with water levels up to 5 feet.

So, we’re thinking it might make sense to start with that storm (black bold box)– the storm likely to happen at least once in 50 years, where storm surge is predicted to reach 5 feet at the shore of Crisfield, and then determine how much that can be decreased with different infrastructure projects.

**[SLIDE 7] One-in-50-year storm**

Here is what the storm surge over high tide looks like relative to the same vertical location (essentially average zero elevation calculated in 1988 – NAVD88), not the bottom of each grid cell. This is showing us what the top of the water looks like for a one-in-50-year storm – and it’s showing the known reality that surge gets higher as it approaches land—because water is building up as the bottom gets higher toward shore.

These results are not able to show us the current effect of the marshes because we’d have to compare the amount of increase of surge with the current marshes to the amount of increase of surge with either no marshes or an implemented NBS strategy. That is, we need to look at change in increase of amount of surge, not just differences in water height offshore compared to near the border.

And we’re unable to use SLOSH to do that because:

* It has low spatial resolution relative to the kinds of nature-based features we are proposing putting in and the scale of effects (i.e., changes in water depth) that we’d like to detect,
* SLOSH cannot model anything other than current conditions, and
* SLOSH does not account for waves on top of storm surge, and that’s the part of the water column that the literature says salt marshes affect the most:

~40% wave attenuation in Crisfield area (Cassalho 2023[[1]](#footnote-1))

~50-70% wave attenuation reported elsewhere in literature (Moller 2014[[2]](#footnote-2), Zhang 2020[[3]](#footnote-3), Garzon 2019[[4]](#footnote-4), Stark 2015[[5]](#footnote-5), Marsooli 2017[[6]](#footnote-6), Miesse 2023[[7]](#footnote-7))

**[SLIDE 8] Delft 3D (surge) + EuroTOP (waves)**

So our next steps will involve using the Delft 3D model (<https://oss.deltares.nl/web/delft3d>) to estimate surge coupled with the EuroTOP model (<http://www.overtopping-manual.com/>) to estimate waves since this modeling approach is able to model:

* Finer spatial resolution (at the scale in which we are interested)
* The top wave part of the water column that NBS is known to attenuate, and
* The ability to change the current conditions to estimate impacts of additional vegetation, increased elevation, and the roughness and density of obstructions in the water.

We plan to model the three NBS options selected (and one model run with all three together to understand maximum benefits), using the 1-in-50-year storm from the two most common incoming storm directions (NE and NNE).

Model mesh will be developed and calibrated, and baseline storm surge attenuation compared to no marshes estimated by December 2024; NBS scenarios run by March 2025.

**[SLIDE 9] Questions for Technical Working Group**

We’d like to open it up for discussion. Some of the things we are interested in talking about and getting your perspective on include:

* Will modeling a 1-in-50-year storm provide the most useful information about NBS storm surge and wave attenuation capabilities? (or should we consider other storms and why?)
* Are there other data, studies, information, or resources specific to Crisfield that would be relevant to informing our Delft3D+EurOtop model approach?
* Do you have any other questions about the approach? Is there anything we have not thought of?
* Do you think this will inform decision-making in a way that gives the community the data they need? How will model results need to be framed to be sure they inform NBS decision-making?

We are also interested in collaborating if anyone would like to help conduct additional modeling.

***VIMS:*** *Can the model do iterative NBS changes, for example, if the breakwater at the mouth of the creek was implemented in addition to the one inside, or will they be modeled separately? Can you accumulate impacts?*

***EPA ORD:*** *It depends on time and budget. You need to create a separate model mesh for each NBS option to get a specific set of results. This is more complicated than a bathtub model (just comparing water height to elevation, versus simulating water movement over space and time) so we are trying to balance which solutions we think would have maximum effect with the number of model iterations we have the capacity to run. Cumulative effects of different solutions are important, but need to see if we have capacity to deconstruct each solution component by component.*

***VIMS:*** *Certain ones would probably have larger impact like slowing water at mouth of the creek is more likely to change the incoming wave height and flow rate. The coastal breakwaters. But it would be a costly solution, so it might be helpful for decision makers to know about doing the first one as a first line of defense. Might be interesting to look at them separately. Consider number 2 as a combination of things. You can model vegetation versus thin layer placement (elevation increase). Might be important for decision makers who might want to drill down into how and where they can be co-modeled or where we think there will by synergies as a smart way to set up a framework.*

***EPA ORD:*** *Yeah, there are many, many possible iterations. We were thinking to start with the best-case scenario as a first cut to determine maximum possible surge and wave attenuation and then decide from there. We definitely want to model all three solutions at once, which should not be much more of a lift once we set up the model mesh for each one, to run a combined scenario. We are not explicitly incorporating the cost of each solution, since there is currently lots of funding available for implementing natural infrastructure, so we didn’t want that to limit the analysis.*

***UMD EFC:*** *Coming at this from a "helping communities find funding to implement projects" perspective, we are of course very interested in how people can choose what to do and where without doing lots of (expensive and time-consuming) site-specific modeling.*

***VIMS:*** *A dune on the side of the islands could become a sediment source, as it redistributes sediment, and can increase elevation. Not sure if the model includes that, but probably not. Might think about how investing in dune restoration would buy you two benefits – protection against waves and sediment supplies.*

***EPA ORD:*** *There are models that do sediment transport but we early on eliminated erosion and sediment modeling due to budget to be able to first focus efforts on the community’s flooding attenuation priorities. Better to triage which kind of modeling gives you most info about what to do in the future around flood adaptation.*

***Sustainable Science:*** *I’m a newbie, open ears right now. But seeing the overall approach: I like it. You have to marry it together with the FEMA flood level to look at the situation at a landscape level. SLOSH is not as computer intensive as Delft. But it gives surge height, which is important to protect Crisfield. I recommend running SLOSH until you get ready for Delft because it takes more time and effort. I like the concept of wave attenuation through vegetation. You have to think through what kind of vegetation you want, though. Where is that vegetation base and height related to NAVD88? Grass is taller than salt marsh hay. Is phragmites better because it’s high and dense if you just want wave attenuation? This is interesting; you’re getting at landscape level questions. You’re right when we do projects we don’t get into the weeds as thick. I also like having community engagement – you need political buy-in to be able to implement any of these projects.*

***EPA ORD:*** *We are trying to balance level of effort and detail. We settled on 10% design, so you just need to know roughness coefficient (not yet specific vegetation type), and if you want native vegetation later that’s a discussion with the community and why we budgeted a whole year to talk about it.*

***EPA R3:*** *Looking at slide 8 and thinking about how the information would be consumed: the community’s choice would be the 3 NBS options and the output would tell you the wave height attenuation out of each option?*

***EPA ORD:*** *The model output is pretty extensive – water heights over time, speed, spatial distribution, so part of the question is how to synthesize all that info into what the community wants to know, e.g. average water height but maybe we want half mile increments across the shore.*

***EPA R3:*** *Is there a threshold that could be set at the outset to know if there isn’t going to be any impact on the 50-year storm? How is the community going to consume the outputs, and what they mean?*

***EPA ORD:*** *We are thinking about modeling lower storms first and building up to identify worst-case storm that NBS can provide benefits. We can then discuss: if it protects against lesser storms, is that still of interest?*

***EPA R3:*** *For example, if option A is most effective at the worst-case storm, but the others don’t pass, where is the (lower) storm intensity threshold for the less effective options?*

***EPA ORD:*** *We can’t run infinite storms, so we need to pick. I’m thinking the 5-foot FEMA protection at edge of Crisfield, whether storm surge is still above that given an NBS option is the threshold, and the question is: for which storm is that. But the engineering philosophy is to ask the community “what risk you want to protect against?” and design to meet that percentile storm. But that approach will run into biological limits (e.g., cannot build 20-foot-tall marsh to achieve 99% protection). So, the challenge is balancing those two approaches to storm selection.*

***VIMS:*** *To add, a lot of the conversations in the Chesapeake Bay climate adaptation framework is talking about spatial and temporal scales. When you’re thinking about future conditions, this data run is based on existing conditions for implementing something today. The persistence of that benefit is important to consider. Future mean sea level – is there any way to project against that? Modeling future climate changes might be outside the scope of this project, but it’s worth the conversation, and will some of the NBS be adaptable or are they one-offs? Can you build a process to enhance those features over time? In addition to putting out projections in big buckets like 1-in-50 year, consider what it would look like in 2050 and 2080 and maybe you can’t model it, but you could have expert input. For example, ask where the shore would be; could use marsh migration dataset from Chesapeake Bay. Ask questions to be able to frame efficacy of the solution, for example, it buys us immediate storm benefits and habitat benefit now and in the future. That helps with a lot of FEMA and NFWF programs, a lot of the funders (for example, the coastal climate thing NFWF just put out) to get habitat benefits important for Crisfield’s marine-based economy, providing blue crab habitat is important while people are still in Crisfield, and then over time you can implement what protective measures you want that might be less nature based.*

***EPA ORD:*** *Future scenarios we are modeling will be 2050 to align with FEMA and Crisfield preferences. Interesting idea to do expert elicitation post 2050. But it doubles all the model runs to add any additional time frame in the future.*

***Sustainable Science:*** *Modeling is trying to get to an answer of what we’re doing in the landscape. Models are only technical guestimates. Delft can do a lot of nifty things, but it takes a long time to do it. Sea grass grows between mid-high tide and mean high water. Climate predictions will affect the height of the tidal range, so not everything will be able to grow where it used to grow. To calculate the ecosystem service lift, it will be constrained within the tidal range. For surge protection it will be done by the dune, and then you can make it like Kitty Hawk in NC for kite surfing (other possible, new co-benefits in a changing climate).*

***EPA ORD:*** *Thanks that’s helpful, will have that conversation with the community. Any ideas in the chat welcome, want to leave Rich enough time for the second piece on co-benefits.*

**[SLIDES 10-17] Natural Infrastructure Co-benefits**

Our objective for this meeting was to recap the results of the ecosystem co-benefits workshops on April 19 and 20, 2024 and to introduce our working plan for analysis of NBS co-benefits in addition to storm surge and wave attenuation. We also hoped to get some input from the TWG on our selected co-benefits metrics to measure co-benefits from the NBS scenarios under consideration with the goal of identifying high priority metrics useful for comparing NBS options.

The ecosystem co-benefits workshops in April focused on how Crisfield residents and visitors use the natural environment. This involved asking workshop participants to think about:

* WHERE are the most important natural locations,
* WHO interacts with these locations, and
* HOW they use these natural locations.

This ‘Where, Who, How’ exercise gives us input on what ecosystem metrics best measure benefit by linking people to nature. We presented the initial list of 17 benefit categories for Crisfield along with a list of metrics we proposed to use, as well as some we might use to measure benefits of proposed NBS. The table on SLIDE 17 summarizes the metrics under consideration, and we hope to get more feedback from the TWG on high priority metrics on this list they think we should include.

**[SLIDE 18] Questions for Technical Working Group Discussion**

* Does the initial plan for analysis resonate with Crisfield’s information needs?
* What alternative measures may be as or more important to evaluate across NBS options?
* Are you aware of models, data, studies that we could leverage to evaluate important co-benefits of NBS?
* What might be the ~Top 5 most important co-benefit metrics to compare across NBS options?

***FEMA:*** *This is a really, really good list. Thank you for sharing the presentation; I learned a lot. We heard a lot around economic development and community, a lot of the place-based and quality of life aspects that are impacted by flooding. That’s something we heard a lot about, and I understand this solution is a little different, we’re addressing the problem in different ways. I’m wondering how this can be communicated when it comes to quality of life and promoting Crisfield as a city and some more of those aspects.*

***EPA ORD:*** *We’ve been wrestling with what are the most important habitats that feed back into quality of life.*

***EPA ORD:*** *We want to connect this to broad resilience goals, how we choose measures is how well we’re connecting to those things. Does what we’re measuring inform the quality-of-life aspect the community wants to see from the NBS?*

***UMD EFC:*** *To add to what FEMA said, we (NOAA-funded TNC, GMU, UMD EFC team) saw in Crisfield when EPA ORD did work on flooding impact on roadways, everyone is impacted by that all the time and affects access to jobs and medical care. Is there a way to recognize that in this process? It’s a big factor in all the places on the eastern shore.*

 ***EPA ORD:*** *[Researcher Name] is continuing that work, but now that there is a 5-foot border at the edge, it might not directly relate, but it could if we’re exceeding the 5-foot border.*

***Crisfield:*** *I think it will be directly related. The first phase is only 3.5 feet. When we get both phases in place, it’s 5 feet. This will directly impact the amount of flooding and that directly impacts economy and quality of life. The first line flood protection – quality of life and economics issues are directly related.*

***EPA ORD:*** *So, we need to discuss this with FEMA, so that we’re not duplicating efforts and identifying how each team’s modeling affects quality of life changes.*

**[SLIDE 19] Wrap-up**

Thank you so much for all your help! Does anyone have general feedback about this TWG meeting format and content?

***Crisfield:*** *To me this is a great format and extremely helpful but I’m not as technical as most people. I learned a lot.*

***VIMS:*** *It would be interesting to hear from Crisfield, do you want to be introduced to the deeper technical stuff or would you rather have it be rolled up a little more? You want to meet people where they are and give them info they can engage with.*

***EPA ORD:*** *This is the deep dive. We will have other public meetings that zoom out.*

***Crisfield:*** *This is not for me. I might not even be able to always attend. This is for technical folks to talk about technical stuff.*

***VIMS:*** *Then it’s important to walk it through more deeply, and you might have to add a meeting somewhere or have conversations offline. You’re covering such a broad geography and technical approach. Other experts to include – fisheries scientists. When you talk about which co-benefits, I would be mindful of our traditional flood protection approaches that are structural, and are good at flood attenuation, but are abiotic. The idea here is combining multiple approaches: NBS try to address the whole ecology and that’s an important consideration. So, the table you were just showing, the quality of life is connected to flood benefits but other parts of quality of life, what’s the next tier? And you look at NBS to provide some quality-of-life things. Tourism showed up as big word in word cloud and when it came into our tables it got broken down into smaller constituent pieces it becomes eco-tourism, e.g. fishing, hunting. “Recreation and tourism” is one whole budget.*

***EPA ORD:*** *That’s a great point. We wanted to break it down into specific metrics to explore what comprises “recreation and tourism” and be specific about how it’s related to the environment or ecosystem. But maybe by doing that you lose the bigger picture?*

***FEMA:*** *It is complicated but maybe there’s an economic development researcher that could take a look at this, someone in the planning field or an economist could get those benefits quantified.*

***EPA ORD:*** *We don’t have an economist on the ORD team so we don’t have the capacity to translate any of this into units of money. Maybe that’s a UMD question?*

***UMD EFC:***  *We would love to dig into that if anyone knows how we could pay ourselves to do that.*

***VIMS:*** *There are lots of meta-analyses on these co-benefits.*

***UMD EFC:*** *Is it worth it to figure out the dollars when we know we just need to reduce flooding?*

***FEMA:*** *I will think about it, BRIC DTA has some research partnerships with different universities and, looking at those questions, to pitch it to them and see if they could look at co-benefits of projects like this for communities like Crisfield. We haven’t unpacked that yet other than we know that flood reduction is critical.*

***EPA ORD:*** *Maybe there is a co-benefits piece to the wetlands restoration in the FEMA project?*

***FEMA:*** *I don’t know how that was figured into the BCA.*

***EPA ORD:*** *We might be able to help if you want some co-benefits analysis of the pieces on land.*

***FEMA:*** *If there are any needs, on data I’m committed to send whatever we need to you guys to make sure our projects align.*

***EPA ORD:*** *That’s awesome! We just want to not reinvent the wheel and make sure Crisfield doesn’t have to chase things down.*

*Looks like our time is up. Thank you so much, everyone! Feel free to contact any of us at any point.*

Questions?

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**[END MEETING]**

1. Cassalho, Felicio, Andre de S. de Lima, Celso M. Ferreira, Martin Henke, Gustavo de A. Coelho, Tyler W. Miesse, Jeremy Johnston, and Daniel J. Coleman. "Quantifying the effects of sea level rise driven marsh migration on wave attenuation." Environmental Monitoring and Assessment 195, no. 12 (2023): 1487. [↑](#footnote-ref-1)
2. Möller, Iris, Matthias Kudella, Franziska Rupprecht, Tom Spencer, Maike Paul, Bregje K. Van Wesenbeeck, Guido Wolters et al. "Wave attenuation over coastal salt marshes under storm surge conditions." Nature Geoscience 7, no. 10 (2014): 727-731. [↑](#footnote-ref-2)
3. Zhang, Xiaoxia, Pengzhi Lin, Zelin Gong, Bing Li, and Xinping Chen. "Wave attenuation by Spartina alterniflora under macro-tidal and storm surge conditions." Wetlands 40 (2020): 2151-2162. [↑](#footnote-ref-3)
4. Garzon, Juan L., M. Maza, C. M. Ferreira, J. L. Lara, and I. J. Losada. "Wave attenuation by Spartina saltmarshes in the Chesapeake Bay under storm surge conditions." Journal of Geophysical Research: Oceans 124, no. 7 (2019): 5220-5243. [↑](#footnote-ref-4)
5. Stark, J., T. Van Oyen, P. Meire, and S. Temmerman. "Observations of tidal and storm surge attenuation in a large tidal marsh." Limnology and Oceanography 60, no. 4 (2015): 1371-1381. [↑](#footnote-ref-5)
6. Marsooli, Reza, Philip M. Orton, and George Mellor. "Modeling wave attenuation by salt marshes in Jamaica Bay, New York, using a new rapid wave model." Journal of Geophysical Research: Oceans 122, no. 7 (2017): 5689-5707. [↑](#footnote-ref-6)
7. Miesse, Tyler, Andre de Souza de Lima, Arslaan Khalid, Felicio Cassalho, Daniel J. Coleman, Celso M. Ferreira, and Ariana E. Sutton-Grier. "Numerical modeling of wave attenuation: implications of representing vegetation found in coastal saltmarshes in the Chesapeake Bay." Environmental Monitoring and Assessment 195, no. 8 (2023): 982. [↑](#footnote-ref-7)