SHORE-BET: DETAILED CALCULATION DESCRIPTIONS

Community Benefits From Marsh Restoration

Average value of each benefit gained from marsh restoration was determined from a literature review of marsh ecosystem services. This average value is multiplied by the total restored marsh area. Additional adjustments to refine the value for local conditions are noted. For example, the value of reduced storm impacts was adjusted based on the width of the marsh, which effects wave attenuation ability, and the shoreline's storm exposure.

Community Benefit from Marsh Restoration	Average value ($/ha/yr)	Adjustments
Reduced Storm Impacts	$11,244.74	Marsh width, Shoreline's storm exposure
Improved Fish Habitat	$1,679.82	Low marsh width, length, and area
Nutrients Removed/Stored	$4,065.33	-
Carbon Removed/Stored	$1,908.50	-
Improved Recreational Fishing	$1,085.73	Distance to water public access

Detailed Description of Community Benefit Estimation

Reduced Storm Risk

The mean economic value for reduced storm risk to areas behind the marshes was determined from a literature review of marsh ecosystem services ($11,244.74/ha/year, n=6, in 2020 US dollars). Reduced storm risk annual value is estimated by multiplying the mean value by adjustments for the *i*) restored marsh area, *ii*) capacity for wave attenuation by the restored marsh, and *iii*) shoreline's storm exposure.

Adjustment for marsh wave attenuation capacity is based on the width of the restored marsh (low and high marsh, measured perpendicular to the shore). Values were extracted from previous studies evaluating attenuation in similar salt marsh ecosystems to estimate the relationship between wave height reduction and marsh width. These studies suggest that generally, marshes are able to attenuate up to ~ 40% of wave energy within the first meter (3 ft), with a linear increase to 100% by 25 m (82 ft). The proportion of wave height reduction for marshes (Whr) with widths between 0 and 24 m is estimated with the following equation:

$$Whr = \frac{(40.76830 + 2.29049 * Marsh\,Width\ (m))}{100}$$

Marshes ≥ 25 m wide are assumed to be able to fully attenuate waves, and thus receive the full estimated mean value ($11,244.74/ha/year). Marshes < 25 m wide are downscaled in value to reflect

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their less protective capacity by multiplying the mean value by the proportion of wave height reduction based on the marsh width and area.

Adjustment for shoreline storm exposure is based on storm risk exposure, categorized as low, medium, or high, for the restoration project location. Storm risk was classified on the basis of combined scoring of wave heights that occurred during two historic storms for the region – Hurricane Isabel in 2003 (https://scholarworks.wm.edu/data/485/) and a 2009 Nor'Easter (https://scholarworks.wm.edu/data/486/). The height of the storm surge generated by Hurricane Isabel was modelled throughout Virginia using SCHISM (Semi-implicit Cross-scale Hydroscience Integrated System Model, http://ccrm.vims.edu/schismweb/).

Weight heights were scored as follows: 0 = 0 m; 1 = 0-0.5 m, 2 = 0.5-1 m, 3 = > 1 m. Storm scores were then combined and categorized into the following weight factors: 0-1 = 0.5, 2-3 = 1.0, ≥4 = 1.5. Low exposure locations are assumed to require less storm protection and values are weighted downward with a factor of 0.5. Medium to High exposure locations are assigned weight factors of 1.0 and 1.5, respectively as an indication of increasing importance of risk reduction as exposure increases.

Studies used to estimate wave attenuation in relation to distance into a marsh:

- Augustin, L.N., Irish, L.I. and Lynett, P. 2009. Laboratory and numerical studies of wave damping by emergent and near-emergent wetland vegetation. Coastal Engineering 56(3), pp. 332-340. https://doi.org/10.1016/j.coastaleng.2008.09.004
- Castagno, K.A., Ganju, N.K., Beck, M.W., Bowden, A.A. and Scyphers, S.B., 2022. How Much Marsh Restoration Is Enough to Deliver Wave Attenuation Coastal Protection Benefits?. Frontiers in Marine Science, 8. https://www.frontiersin.org/articles/10.3389/fmars.2021.756670/full
- Foster-Martinez, M.R., Lacy, J.R., Ferner, M.C. and Variano, E.A. 2018 Wave attenuation across a tidal marsh in San Francisco Bay. Coastal Engineering 136, pp. 26-40.
- Knutson, P. L., W. N. Seeling, and M. R. Inskeep. 1982. Wave dampening in Spartina alterniflora marshes. Wetlands 2:87–104.
- Shepard, C. C., C. M. Crain, and M. W. Beck. 2011. The protective role of coastal marshes: A systematic review and meta-analysis. PloS ONE 6:e27374. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0027374

Improved Fish Habitat

The mean economic value of marshes for fish habitat was determined from a literature review of marsh ecosystem services ($1679.82/ha/year, n=8, in 2020 US dollars). The mean value derived from the literature was adjusted with previously collected data on the relative abundance of nekton (fish and crustaceans) at natural marshes and living shorelines with restored marsh within the Middle Peninsula (see Guthrie et al. 2022 for details).

With those data, a relationship between marsh configuration and relative nekton abundance was quantified by examining abundance quantiles in relation to low marsh width, length, and area. Fish habitat annual value is estimated by multiplying the mean value ($1679.82/ha/year) by adjustments for a low marsh configuration weight factor.

In general, the highest nekton abundance was associated with low marshes that were ≥ 750 m^2 and these marshes are adjusted with a weight factor of 1.5 to indicate exceptional habitat provision. Low marshes with a width ≤ 1 m or a length ≤ 10 m had the lowest abundance and these marshes are

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adjusted with a weight factor of 0.5 to indicate fair habitat provision. All other marshes are considered good habitat provision and valued at the mean economic value (i.e., weight factor of 1).

Guthrie, A.G., Bilkovic, D.M., Mitchell, M., Chambers, R., Thompson, J.S. and Isdell, R.E., 2022. Ecological equivalency of living shorelines and natural marshes for fish and crustacean communities. Ecological Engineering, 176, p.106511. https://doi.org/10.1016/j.ecoleng.2021.106511

Nutrient Removal/Storage

The mean economic value of marshes for nutrient removal/storage was determined from a literature review of marsh ecosystem services ($4065.33/ha/year, n=12, in 2020 US dollars). Nutrient removal/storage annual value is estimated by multiplying the mean economic value by adjustments for the area of restored marsh ($4065.33 * total marsh area).

Carbon Removal/Storage

The mean economic value of marshes for carbon removal/storage was determined from a literature review of marsh ecosystem services ($1908.50/ha/year, n=9, in 2020 US dollars). Carbon removal/storage annual value is estimated by multiplying the mean economic value by adjustments for the area of restored marsh ($1908.50 * total marsh area).

Improved Recreation

The mean economic value of marshes for recreational fishing was determined from a stated preference survey of recreational fishers in the Middle Peninsula that quantified habitat use, willingness to pay, and distance to water public access. Improved recreation annual value is estimated by multiplying the mean value ($1085.73/ha/year) by adjustments for the restored marsh area and a water public access weight factor.

Distance to water public access (locations with boat ramps for motorized boat access) is used to represent the number of potential community users and thus recreational value. Those restoration sites with a nearby water public access that is i) less than 2.3 km away are weighted by 1.5 (high access), ii) between 2.3 and 5.6 km away are weighted by 1 (medium access), and iii) more than 5.6 km away are weighted by 0.5 (low access).

Other Information Presented

Social Vulnerability

Social vulnerability is the ability of an individual or group to anticipate, cope with, and resist and recover from natural or man-made hazards. This index uses socio-economic data to classify census tracts in Virginia based on their social vulnerability. Classes: Very High Social vulnerability, High Social Vulnerability, Moderate Social Vulnerability, Low Social Vulnerability, and Very Low Social Vulnerability.

Data and methods can be viewed and downloaded here:
http://cmap2.vims.edu/socialvulnerability/sociovul_SS.html

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Pollution load reduction potential

The Chesapeake Bay Program has approved a best management practice (BMP) for pollution removal rates by shoreline management practices. Pollutant removal rates are applied as credit for reductions in pollution (nitrogen, phosphorus, and suspended sediments) entering Bay and tributary waters. Living shorelines qualify for pollutant load reductions under four general protocols.

Protocol 1. Credit for prevented sediment. Project specific determined by shoreline erosion rate, bank height, bulk density and sand reduction factor. Not included in the total value displayed.
Protocol 2. Denitrification in vegetated areas: 85 lbs TN/acre/yr
Protocol 3. Sedimentation in vegetated areas: 5.289 lbs TP/acre/yr and 6,959 lbs TSS/acre/yr
Protocol 4. Marsh Redfield ratio for vegetated areas: 6.83 lbs TN/acre/yr and 0.3 lbs TP/acre/yr

Values are in linear feet for protocol 1 and lbs/acre for protocols 2-4. Only vegetated practices qualify for protocols 2,3 and 4.

To determine the load reduction values, the *Shore-Bet* tool multiplies the area of marsh vegetation inputted by the rate for each protocol. Total values are the sum of each protocol value. Protocol one is not included in this calculation as it is determined by site specific data that requires erosion rate.

For example, a living shoreline project includes 21,780 square feet of marsh vegetation planting. This equals 0.5 acres.

Protocol 2.	Area of marsh planting 0.5 acres * 85 lbs TN/acre/yr	= 42.5 lbs/yr
Protocol 3.	Area of marsh planting 0.5 acres * 5.289 lbs TP/acre/yr	= 2.64 lbs/yr
	Area of marsh planting 0.5 acres * 6,959 lbs TSS/acre/yr	= 3479.5 lbs/yr
Protocol 4.	Area of marsh planting 0.5 acres * 6.83 lbs TN/acre/yr	= 3.415 lbs/yr
	Area of marsh planting 0.5 acres * 0.3 lbs TP/acre/yr	= 0.15 lbs/yr
Total TN:	P2 + P4 = 42.5 lbs/yr + 3.415 lbs/yr	= **45.915 lbs/yr**
Total TP:	P3 + P4 = 2.64 lbs/yr + 0.15 lbs/yr	= **2.79 lbs/yr**
Total TSS:	P3	= **3479.5 lbs/yr**

Virginia land parcels

These parcel boundaries represent legal descriptions of property ownership, as recorded in various public documents in the local jurisdiction. The boundaries are intended for cartographic use and spatial analysis only, and not for use as legal descriptions or property surveys. Tax parcel boundaries have not been edge-matched across municipal boundaries.
https://gismaps.vdem.virginia.gov/arcgis/rest/services/VA_Base_Layers/VA_Parcels/FeatureServer

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Water Public Access Locations

These water public access points include locations with a boat ramp for motorized boat access. Data sources include Virginia Department of Wildlife Resources (DWR) public boating access points with additions based on local knowledge by CCRM-VIMS. https://dwr.virginia.gov/boating/access/

Living Shoreline Locations

Existing living shorelines in the Middle Peninsula (Gloucester, Middlesex and Matthews) may be displayed on the interactive map. This data layer includes living shorelines that protect or restore tidal marsh vegetation (i.e., marsh with rock sill, or coir logs, or oyster reefs) and were confirmed as built. Approved permits for living shoreline projects that either protected or restored marsh vegetation were extracted from the CCRM Tidal Shoreline Permit Database (n= 531 permits from 1974 to mid-2020, CCRM 2023). Of those, 398 living shorelines were verified as built. In-field verification was completed between June 2022 and May 2023 at sites that could not be accurately delineated via desktop (n=84). Display information for each living shoreline point includes the Virginia Marine Resources Commission (VMRC) permit number and the first two digits in the code represent the last 2 digits of the year the permit was requested (e.g., 12-xxx indicates the permit was requested in 2012). A subset of living shoreline projects that involved restoring (planting) marsh vegetation was used to estimate the 30-yr community benefit value of living shoreline projects that created marsh in the Middle Peninsula (185 permit locations, total restored marsh area = 10.7 hectares).

Center for Coastal Resources Management (CCRM), 2023. Tidal Shoreline Permit Database. Virginia Institute of Marine Science, William & Mary, Gloucester Point, Virginia. Available at: https://www.vims.edu/ccrm/advisory/ccrmp/permits/.

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For More Information

Project: https://www.vims.edu/ccrm/research/climate_change/adaptation/eco-services/index.php

SHORE-BET Tool: https://cmap22.vims.edu/ShoreBet/

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