GUIDANCE FOR THIN-LAYER SEDIMENT PLACEMENT AS A STRATEGY TO ENHANCE TIDAL MARSH RESILIENCE TO SEA-LEVEL RISE

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January 2020

Prepared by:
Researchers from eight National Estuarine Research Reserves (NERRs) collaborated on a two-year NERRS Science Collaborative-funded field experiment investigating thin-layer placement of sediment in tidal marshes, beginning in Fall 2017. An expert Advisory Committee for the two-year project was convened that helped prepare these guidance documents.

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nerrssciencecollaborative.org/project/Raposa17
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The Little River, Wells NERR. Courtesy of the Chesapeake Bay VA NERR.

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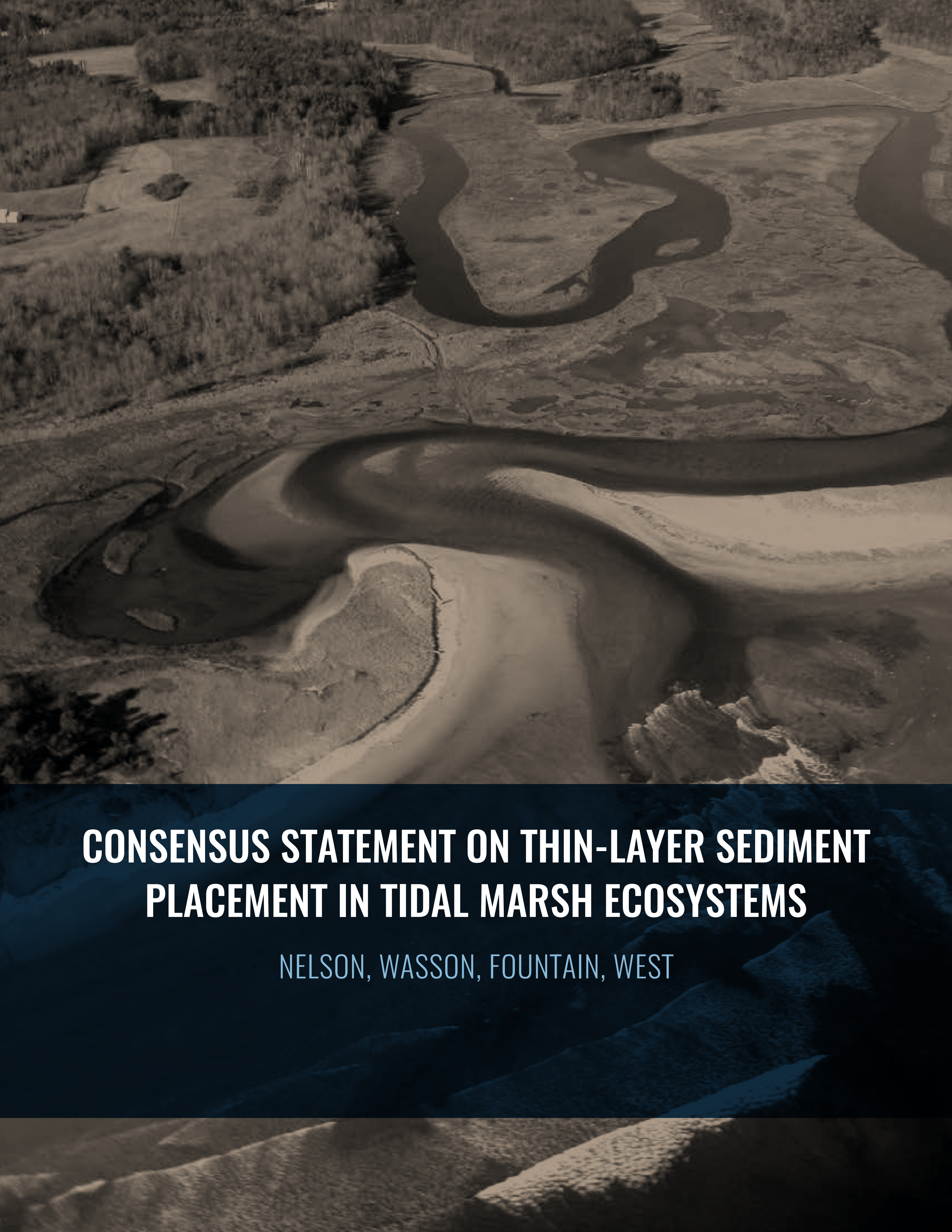


CONSENSUS STATEMENT ON THIN-LAYER SEDIMENT PLACEMENT IN TIDAL MARSH ECOSYSTEMS

NELSON, WASSON, FOUNTAIN, WEST

CHAPTER 1: CONSENSUS STATEMENT ON THIN-LAYER SEDIMENT PLACEMENT IN TIDAL MARSH ECOSYSTEMS

BACKGROUND

The **purpose** of this consensus statement is to increase understanding of the potential benefits of, and tradeoffs involved in, thin-layer placement (TLP) of sediment as a tool to restore or enhance tidal marsh resilience in the face of sea-level rise (SLR). The **intended audience** is persons considering the use of TLP as a marsh restoration alternative, including landowners, coastal managers, NGO staff members, resource management agency personnel, and members of organizations that fund and permit such projects. This statement was created through a collaborative process with 25 coastal managers and scientists[1].

Notes are listed in Appendix A. A glossary of terms may be found in Appendix B. Case studies are in Appendix C. A literature review of published TLP studies is in Chapter 2.

1. **Increasing tidal marsh resilience in the face of sea-level rise will require implementation of climate adaptation strategies.**

Many tidal marshes are threatened by multiple stressors, such as river diversion and loss of their historic sediment supply, subsidence caused by land use changes, ditching and draining for mosquito control or pasturelands, and adverse effects of invasive plant and animal species[2]. Significant loss of tidal marsh has already occurred throughout the coastal United States[3]. Added to this is the emerging stressor of accelerated sea-level rise (SLR)[4]. Without active management, such as enhancing migration pathways or increasing sediment supply, many tidal marshes are predicted to be lost in coming decades. Federal, state, and local agencies need a clear strategy and implementation plan for conserving and restoring marshes and their ecosystem functions.

2. **One emerging climate adaptation strategy for tidal marshes is thin-layer sediment placement.**

Marsh sustainability and integrity are determined, in large part, by vertical elevation relative to sea-level, since the plants and animals that comprise tidal marshes have tolerance limits to flooding frequency and duration. **Sediment** (or **soils**) may be added to raise the elevation of the tidal marsh platform to maintain the plant community relative to sea-level. The term "**thin-layer placement**" (TLP) has been used to describe sediment additions (Figure 1) from approximately 1 cm in depth to 50 cm or more[5]. Typical depths in existing project-scale applications are primarily in the 10-20 cm range.

3. **Thin-layer sediment placement emulates natural depositional processes in tidal marshes.**

Modern tidal marsh ecosystems evolved over thousands of years to withstand the storm-driven deposition of large volumes of sediment on the marsh plain[6]. For example, many dominant perennial wetland plant species are rhizomatous, can withstand burial, and can spread laterally and vertically through new sediment deposits. Other wetland species, such as many annuals, specialize in colonizing bare deposits of fresh mud and sand. Human development and the construction of flood management infrastructure – such as levees, tide gates, breakwaters, and flood control channels – have in many locations altered the natural movement of water and sediment from watersheds to tidal wetlands, and from high-energy shorelines to low-energy backbarrier embayments[7]. TLP has the potential to functionally re-create these natural episodic processes, thereby improving and maintaining topographic, substrate, and ecological diversity in tidal wetlands.

4. **Uncontaminated dredged sediments provide potential opportunities for sediment addition to degrading marshes.**

   Raising the elevation of a marsh platform often requires the costly transport and placement of a large volume of sediment. Using dredged sediments available locally provides an opportunity for the "**beneficial use**" of sediments and makes marsh restoration potentially more affordable by offsetting costs associated with dredged material disposal. The U.S. Environmental Protection Agency encourages the use of dredged sediment and provides a general approach and steps for considering dredging and beneficial use[8]. We should rely on, or develop, regional criteria for use, similar to what has been done in San Francisco Bay[9], and continue to look for ways to incentivize use and cover the additional placement.

5. **Because thin-layer placement is an unfamiliar tool for many coastal managers, further experimental restoration projects are needed across diverse conditions to test effectiveness.**

   Since the TLP approach is one of the few viable alternatives to protect marshes in their current locations, and since past projects and experimental plots have shown promise, we recommend that funders and permitters facilitate the implementation of project-scale (beyond plot-scale), carefully selected, well-designed and monitored restoration projects using TLP. Tracking the effectiveness of such projects at realistic spatial scales for long time periods is the only way to make wise future decisions about further use of dredged or other sediments for marsh enhancement. These experimental, project-scale efforts should be implemented within an adaptive management context to minimize potential harm and maximize benefit and lessons learned for subsequent projects. The majority of past projects occurred in the Mississippi Delta and proved effective (see Chapter 2), but further experimental tests and monitoring are needed for other regions, and in diverse plant community types and contrasting salinity and hydrodynamic regimes.

6. **Thin-layer placement is one of many climate change adaptation tools that may be used singly or in combination.**

   In addition to TLP, there is a suite of other potentially applicable measures to enhance tidal marsh resilience to stressors[10]. If extensive low-lying land is available for landward marsh migration, conservation of this upland habitat for future marsh migration may be preferable to raising the elevation of a marsh to protect it in its current location. Another option is enhancing resilience through restoration of riverine sediment supply through hydrologic restoration. The best single strategy or combination of strategies should be chosen on a site-by-site basis; therefore, TLP will be included in some, but certainly not all, cases.

7. **Any project involving thin-layer placement must take necessary precautions to minimize adverse impacts, but concerns about risk should be weighed against potential short- and long-term benefits.**

   In the short term, addition of sediment (dredged or from other sources) may have negative effects on plant communities and animal use of the site[11]. However, temporary negative impacts, such as the burying of existing marsh vegetation, should be weighed against the potential benefits of increasing the longevity of the tidal marsh in the face of marsh subsidence and SLR. Temporary negative impacts should also be weighed against the risks of inaction. Likewise, concerns about how closely to match sediment composition between the restoration site and added sediments should be tempered by consideration of the potential benefits of enhanced resilience in the long term, along with the practical and economic constraints of the project[12]. In addition to consideration of soil depth, there is a risk of sulfidic materials oxidizing – when added to the marsh platform – and creating **acid sulfate soils**[13].

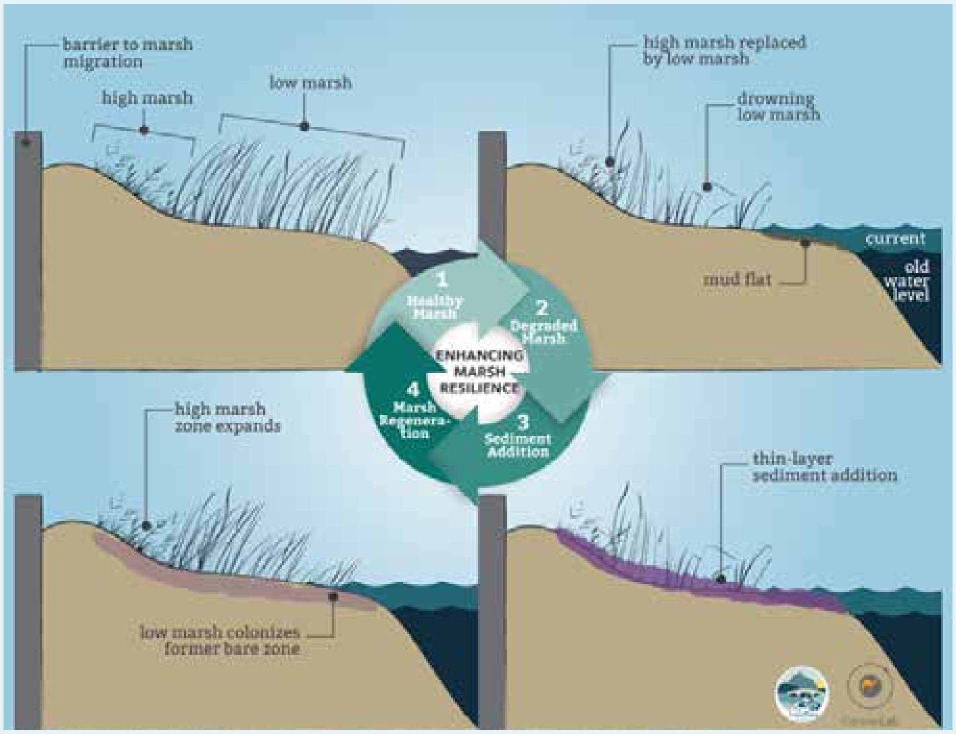
8. **There may be a trade-off between optimizing long-term sustainability of a marsh and decreasing vegetative cover in the short term.**

   The thicker the layer of sediment that is added, the greater "elevation capital" the marsh platform gains, enhancing its ability to withstand future SLR, but increasing the likelihood that current vegetation will be lost and new colonization by seed or plantings will be needed. Managers need to consider the goals for their site and the context of surrounding sites when deciding on the appropriate thickness of sediment to apply[14].

9. **Thin-layer placement projects should be assessed in a framework of thoughtful temporal planning.**

   There are resource and cost trade-offs between a one-time sediment application and a series of applications over time. It may

Figure 1. *How thin-layer placement of sediment works to support tidal marsh resilience. Healthy marsh (top left) exposed to additional inundation due to higher relative water levels (resulting from global sea-level rise or land subsidence) undergoes a landward shift within the intertidal zone, where high marsh plants are replaced by low marsh plants, and low marsh degrades and drowns, converting to mudflats (top right). With the addition of sediments to restore the marsh's vertical elevation relative to sea-level (bottom right panel), marsh sustainability and integrity are enhanced: the high marsh zone expands, and the low marsh recolonizes mudflats (bottom left). In this example, there is a hard barrier to upland migration of marsh, so marsh will be lost unless its relative elevation can be maintained.*



be unwise to overshoot a vertical elevation target, as this strategy may lead to reduced survival of existing vegetation, additional compaction of sediments underneath the new sediment with subsequent loss of elevation, creation of acid sulfate soil conditions if not kept saturated, or invasive species encroachment in the high marsh[15]. There are ecological benefits to repeated applications of sediment, such as practicing adaptive management; ensuring that existing tidal marsh plants can survive the 'overburden' of added sediment; and avoiding additional costs and challenges with invasive species, particularly in high marsh. However, multiple applications may not be cost-effective when factoring in the high mobilization costs. We recommend an explicit analysis of trade-offs between one-time and repeated applications of sediment[16].

10. Thin-layer placement project sites should be chosen in a framework of thoughtful spatial planning and restoration targets.

Since TLP projects may temporarily decrease plant cover and animal habitat, they should be planned in the context of a mosaic of marsh plant cover types so that adjacent areas provide a recruitment source for seeds and habitat for animals. We recommend using plant cover and elevational maps to set habitat goals and to identify the best approaches for achieving them. Documented successes include applying TLP in a mosaic approach where fractions of a marsh complex are augmented with sediment at any given time and temporary habitat is provided for threatened and endangered species (e.g., floating rafts for nesting birds[17]). The scale of the mosaic may vary by region, with appropriate sediment addition areas ranging from tens to hundreds of hectares.

11. Strong networks and relationships among managers, permitting staff, funders, scientists, and community members support effective thin-layer placement projects.

We encourage interdisciplinary regional groups to work together to plan, design, monitor, and learn from TLP projects. We present three case studies (Appendix C) as excellent examples of coalition-building, evaluation and implementation, and community engagement, with foundations of ecological, biological, geological and social sciences.

APPENDIX A

ENDNOTES

[1] Researchers from eight National Estuarine Research Reserves (NERRs) collaborated on a two-year NERRS Science Collaborative-funded field experiment investigating thin-layer placement of sediment in tidal marshes, beginning in Fall 2017. An expert Advisory Committee for the two-year project was convened that helped prepare this Consensus Statement in conjunction with the Research Team and LandSea Science. The first draft was written by Kerstin Wasson, Joanna Nelson, and Monique Fountain, and the Statement was refined through a collaborative process with the entire group in Winter 2018. Preparation of the Statement and facilitation of the collaborative process was led by Joanna Nelson, PhD, of LandSea Science and Jennifer West of Narragansett Bay NERR in Rhode Island. The statement has been endorsed by all of the following:

	NAME (ALPHABETICAL)	AFFILIATION/ORGANIZATION
1	Nicole Carlozo	Maryland Department of Natural Resources
2	Caitlin Chaffee	Rhode Island Coastal Resources Management Council
3	Charlie Endris	Elkhorn Slough National Estuarine Research Reserve, CA
4	Matt Ferner, PhD	San Francisco Bay National Estuarine Research Reserve, CA
5	Monique Fountain	Elkhorn Slough National Estuarine Research Reserve, CA
6	Scott Lerberg	Chesapeake Bay Virginia National Estuarine Research Reserve
7	Erin McLaughlin	Maryland Department of Natural Resources
8	Gregg Moore, PhD	University of New Hampshire (working with Great Bay NERR)
9	Jo Ann Muramoto, PhD	Association to Preserve Cape Cod and the Massachusetts Bays National Estuary Program
10	Elizabeth Murray	Engineer Research and Development Center, Environmental Laboratory, US Army Corps of Engineers, San Francisco District
11	Joanna Nelson, PhD	LandSea Science, CA
12	Richard Nye	Seal Beach National Wildlife Refuge, US Fish and Wildlife Service, CA
13	Brandon Puckett, PhD	North Carolina National Estuarine Research Reserve, NC
14	Kenny Raposa, PhD	Narragansett Bay National Estuarine Research Reserve, RI
15	Jackie Specht	National Oceanic and Atmospheric Administration (NOAA) fellow, with MD DNR
16	Rachel Stevens	Great Bay National Estuarine Research Reserve, NH
17	Rebecca Swerida	Chesapeake Bay Maryland National Estuarine Research Reserve
18	Rob Tunstead	USDA-NRCS, NJ
19	Christina Toms	San Francisco Bay Regional Water Quality Control Board, CA
20	James Turek	NOAA Restoration Center, RI
21	Megan Tyrrell, PhD	Waquoit Bay National Estuarine Research Reserve, MA
22	Kerstin Wasson, PhD	Elkhorn Slough National Estuarine Research Reserve, CA
23	Elizabeth Watson, PhD	Drexel University, PA
24	Cathy Wigand, PhD	US EPA Atlantic Ecology Division
25	Andrea Woolfolk	Elkhorn Slough National Estuarine Research Reserve, CA

When references are listed as endnotes, they are provided in reverse chronological order.

[2] **Mitsch, W.J. 2015.** Wetlands. Fifth Edition. Hoboken, New Jersey. Wiley.

Day, J.W., Christian, R.R., Boesch, D.M., et al. 2008. Consequences of climate change on the ecogeomorphology of coastal wetlands. Estuaries and Coasts 31: 477–491.

Zedler, J.B. and Kercher, S. 2005. Wetland resources: status, trends, ecosystem services, and restorability. Annual Review of Environment and Resources 30: 39–74.

[3] As an example of loss of tidal marsh area across the coastal United States, there has been a loss of 53% of historic marshes in Rhode Island (Bromberg and Bertness 2005) and a loss of 75-90% of historic marshes in California (Emmett et al. 2000).

Bromberg, K.D., and M.D. Bertness. 2005. Reconstructing New England tidal marsh losses using historical maps. Estuaries 28:823-832.

Emmett, R., R. Llanso, J. Newton, R. Thom, M. Hornberger, C. Morgan, C. Levings, A. Copping, and P. Fishman. 2000. Geographic signatures of North American West Coast estuaries. Estuaries 23:765-792.

[4] **Kirwan, M.L. and Megonigal, J.P. 2013.** Tidal wetland stability in the face of human impacts and sea level rise. Nature 504: 53–60.

Morris, J.T., Sundareshwar, P.V., Nietch, C.T., Kjerfve, B., and Cahoon, D. R. 2002. Response of coastal wetlands to rising sea level. Ecology 83: 2869–2877.

[5] **Ray, G.L. 2007.** Thin layer disposal of dredged material on marshes: A review of the technical and scientific literature. ACOE (U.S. Army Corps of Engineers), Vicksburg, MS.

[6] **Friedrichs, C.T., and Perry, J.E. 2001.** Tidal marsh morphodynamics: a synthesis. Journal of Coastal Research 27: 7-37.

[7] **Dusterhoff, S., Pearce, S., McKee, L., Doehring, C., Beagle, J., McKnight, K., Grossinger, R., Askevold, R. A. 2017.** Changing Channels: Regional Information for Developing Multi-benefit Flood Control Channels at the Bay Interface. Flood Control 2.0. SFEI Contribution No. 801. San Francisco Estuary Institute: Richmond, CA.

Goals Project. 2015. The Baylands and Climate Change: What We Can Do. Baylands Ecosystem Habitat Goals Science Update 2015 prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. California State Coastal Conservancy, Oakland, CA.

Boesch, D.F., Josselyn, M.N., Mehta, A.J., Morris, J.T., Nuttle, W.K., Simenstad, C.A., and Swift, D.J.P. 1994. Scientific assessment of coastal wetland loss, restoration and management in Louisiana. Journal of Coastal Research 20: 1–89.

[8] **US EPA. 2007.** The Role of the Federal Standard in the Beneficial Use of Dredged Material from U.S. Army Corps of Engineers New and Maintenance Navigation Projects. US Environmental Protection Agency, Washington, DC.

[9] **San Francisco Bay Regional Water Quality Control Board. 2000.** Beneficial Reuse of Dredged Materials: Sediment Screening and Testing Guidelines (Draft Staff Report). Retrieved from https://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/dredging/beneficialreuse.pdf

[10] **Wigand, C., Ardito, T., Chaffee, C., et al. 2017.** A climate change adaptation strategy for management of coastal marsh systems. Estuaries and Coasts 40:682-693.

[11] **Ford, M.A., D.R. Cahoon, and J.C. Lynch. 1999.** Restoring marsh elevation in a rapidly subsiding tidal marsh by thin-layer deposition of dredged material. Ecological Engineering 12:189-205.

Cahoon, D., and J.H. Cowan. 1987. Spray disposal of dredged material in coastal Louisiana: Habitat impacts and regulatory policy implications. Louisiana Sea Grant College Program, Louisiana State University, Baton Rouge, LA.

Reimold, R.J., M.A. Hardisky, and P.C. Adams. 1978. The effects of smothering a '*Spartina alterniflora*' tidal marsh with dredged material. ACOE (U.S. Army Corps of Engineers), Vicksburg, MS.

[12] Broad consistency between existing marsh soil composition and added soil, in terms of soil type and grain size, may provide benefits. Many of the impacts of sediment- or soil- addition are considered via state and federal permitting processes.

[13] One important risk of sediment or soil addition to tidal marshes – whether the source material is subaqueous, dredged material, quarry material, or soil sourced elsewhere – is the difficulty of predicting the extent of geochemical and biogeochemical activity, particularly in sulfidic sediments. Sulfide-bearing materials have the potential to form acid sulfate soils (Rickard 2012, Salisbury et al. 2017). When sulfide-bearing materials oxidize – as when dredged sediments or soils are applied to marshes and therefore exposed to air in the intertidal zone – they may create acid sulfate soils, in which sulfuric acid is produced. These acid sulfate soils may be toxic to plants, including marsh plants (Rickard 2012). At high acidity (low pH), heavy metal solubility increases, and metals bound in soils become available in the environment for plant uptake and distribution in food webs. At high enough concentrations, heavy metals may also be toxic to plants (Brady and Weil 2004 as cited in Salisbury et al. 2017). Most coastal subaqueous soils contain sulfide minerals, such as pyrite (Fanning et al. 2017). In one study seeking to bridge research and management applications, subaqueous soils from the US Northeast coast were applied to mesocosms to simulate upland placement of estuarine dredged materials (Salisbury et al. 2017). The soils were dug from two specific environments: low-energy environments (mapped as Sulfiwassents with a composition of <55% total sand and >8% total clay) and high-energy environments (these coarser materials were mapped as Psammowassents and had >80% total sand and ≤ 2% total clay). The researchers found clear differences in the impacts of the two soils. Although all initial soil pH values of dredged materials were near neutral (or slightly alkaline), with the addition of the finer-textured, higher sulfide-bearing Sulfiwassents, leachate showed a large drop in pH (to pH ≤ 4.0), indicating acid sulfate conditions. The researchers concluded that these Sulfiwassents should not be dredged and applied to uplands, given the risk of releasing highly acid leachate and metal ions. In contrast, the soils with a high proportion of sand did not develop into acid sulfate soils, but developed alkaline conditions (pH ~ 9), understood to be due to the build-up of salts. This type of research addresses important, open questions about which subaqueous soils to dredge and apply to uplands, and the length of time before the hazards of acid sulfate weathering, heavy metal release, and the leaching of salts are abated (Salisbury et al. 2017). More such studies are needed for use and management interpretations relevant to the use of TLP as a tool.

Brady, N.C., and R.R. Weil. 2004. Elements of the Nature and Properties of Soil. USA0-13-048038-X. Pearson Education Ltd., Upper Saddle River, NJ.

Fanning, D.S., M.C. Rabenhorst, and R.W. Fitzpatrick. 2017. Historical developments in the understanding of acid sulfate soils. Geoderma 308:191-206.

Rickard, D. 2012. Sulfidic Sediments and Sedimentary Rocks. Elsevier, Amsterdam, The Netherlands. 801 pages.

Salisbury, A., M.H. Stolt, and D.A. Surabian. 2017. Simulated upland placement of estuarine dredged materials. Geoderma 308:226-234.

[14]Although most studies investigate the effects of approximately 5-15 cm of soil addition, Reimold et al. (1978) examined a wide range of soil depths and found that *Spartina alterniflora* (smooth cordgrass) stems could emerge through 23 cm of "overburden" soil, whether the material was sand, sand/clay, or clay. However, at depths of 60 cm of material or more, plants could not recover. This study sets the clearest bounds on the depths of material from which smooth cordgrass, in this case, may recover (see Chapter 2 for a summary literature review). We suggest that managers also consider the ecological impacts of, and regulatory barriers to, converting marsh to upland (solely in the high-marsh zone); the limitations of precision associated with the equipment used to implement projects, such as bulldozers and spraying equipment; and the growing season of marsh plants and concomitant capacity to recover from an overburden of soil.

[15]**Reimold, R.J., M.A. Hardisky, and P.C. Adams. 1978.** The effects of smothering a '*Spartina alterniflora*' tidal marsh with dredged material. ACOE (U.S. Army Corps of Engineers), Vicksburg, MS.

The upper edge of the marsh is set by competition, where terrestrial plants and non-native wetland plants may outcompete native tidal marsh plants. Adding elevation to the high marsh may precipitate conversion of marsh to upland – presenting potential problems in terms of policy and law around wetland fill or wetland loss – or takeover by invasive species, such as *Phragmites australis* (common reed). The intention of marsh restoration is to bolster marsh resilience to sea-level rise; we point out the risk of inadvertent conversion, at the high marsh end of the intertidal zone, to upland habitats.

[16]An explicit analysis of trade-offs between one-time and repeated applications of sediment or soil should take into account multiple factors. For example, organizations/sites with access to beneficial use of dredged soil may have more opportunities for repeated applications. At the same time, dredging may occur on a set timescale, and that dredged soil may be available too frequently or not frequently enough. We recommend following an ecologically-focused management plan and an adaptive management framework – with reference sites when possible – and "before and after" monitoring to see if the TLP actions are meeting targets and goals, which will inform whether further applications of material are needed. Analyses of social, ecological, economic, hydrologic, and geomorphologic conditions may determine whether repeated applications of material best address the challenges of sea-level rise, or bigger, infrequent projects.

[17]See the case study of Seal Beach National Wildlife Refuge's use of TLP in Seal Beach, California, within the following report (freely available online): **Judge, J., Newkirk, S., Leo, K., Heady, W., Hayden, M., Veloz, S., Cheng, T., Battalio, B., Ursell, T., and Small, M. 2017.** Case Studies of Natural Shoreline Infrastructure in Coastal California: A Component of *Identification of Natural Infrastructure Options for Adapting to Sea Level Rise* (California's Fourth Climate Change Assessment). The Nature Conservancy, Arlington, VA. 38 pp.

APPENDIX B

GLOSSARY OF TERMS

Acid sulfate soils: "all soils in which sulfuric acid may be produced, is being produced, or has been produced in amounts that have lasting effects on main soil characteristics" (Pons 1973 as *cited* in Fanning et al. 2017)

Beneficial use (often used interchangeably with "**beneficial re-use**"): Maryland has defined the use of dredged material on aquatic or semi-aquatic habitats as "beneficial use," and the use of dredged material on land as "innovative re-use." Beneficial use is: Any of the following uses of dredged material from the Chesapeake Bay and its tributaries placed into waters or onto bottomland of the Chesapeake Bay or its tidal tributaries, including Baltimore Harbor: (i) the restoration of underwater grasses; (ii) the restoration of islands; (iii) the stabilization of eroding shorelines; (iv) the creation or restoration of wetlands; and (v) the creation, restoration, or enhancement of fish or shellfish habitats. Environment Article, §5-1101(a) (3) (Maryland Department of the Environment 2017). This Statement uses the term "beneficial re-use," which is used widely in science, restoration, and policy literature to describe the use of dredged sediment or soil.

Sediment: the particulate matter that settles to the bottom of a liquid (Dodds 2002). In this Statement, we refer to dredged sediments, dredge materials, or other types of subaqueous sediment. Although subaqueous materials are now considered soils (Fanning et al. 2017; Soil Survey Staff 2014), most of the scientific literature refers to "thin-layer placement of sediment," so we retain the use of the term "sediment" in this Statement.

Soil: "Soil…is a natural body comprised of solids (minerals and organic matter), liquid, and gases that occurs on the land surface, occupies space, and is characterized by one or both of the following: horizons, or layers, that are distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy and matter or the ability to support rooted plants in a natural environment." (Soil Survey Staff 1999 as cited in Soil Survey Staff 2014). In the mid-twentieth century, it was suggested that permanently submerged sediments be recognized as soils, but recognition did not come until later in the 1980s and 1990s, when the definition of "soil" was decoupled from supporting the growth of plants and it was understood that subaqueous soils form as a result of the generalized processes of additions, losses, transfers, and transformations (research of George Demas highlighted in Fanning 2017).

Thin-layer placement of sediment (TLP) or thin-layer deposition of sediment. These phrases are used interchangeably, and in this statement, we have chosen the phrase "thin-layer placement." 1) The use of applied sediment to increase marsh surface elevations (Rhode Island Coastal Resources Management Council); 2) "deposit[ing] thin-layers of sediment, usually by spraying a sediment slurry under high pressure over the marsh surface. The technique is essentially a modification of existing hydraulic dredging methods in which sediments are hydraulically dredged, liquefied, and then pumped through a high-pressure spray nozzle" (Ray 2007).

LITERATURE CITED IN THIS GLOSSARY

Dodds, W. K. 2002. Freshwater Ecology: Concepts and Environmental Applications. Academic Press: an imprint of Elsevier, San Diego.

Fanning, D. S., M. C. Rabenhorst, and R. W. Fitzpatrick. 2017. Historical developments in the understanding of acid sulfate soils. Geoderma 308:191-206.

Ray, G. L. 2007. Thin layer disposal of dredged material on marshes: A review of the technical and scientific literature. ACOE (U.S. Army Corps of Engineers), Vicksburg, MS.

Soil Survey Staff. 2014. Keys to Soil Taxonomy, US Department of Agriculture Natural Resources Conservation Service, 12th edition. Washington DC.

APPENDIX C

CASE STUDIES

1. **Seal Beach National Wildlife Refuge,** in the following report: Judge, J., S. Newkirk, K. Leo, W. Heady, M. Hayden, S. Veloz, T. Cheng, B. Battalio, T. Ursell, and M. Small. 2017. Case Studies of Natural Shoreline Infrastructure in Coastal California: A Component of Identification of Natural Infrastructure Options for Adapting to Sea Level Rise (California's Fourth Climate Change Assessment). The Nature Conservancy, Arlington, VA.

   https://scc.ca.gov/files/2017/11/tnc_Natural-Shoreline-Case-Study_hi.pdf

2. **Ninigret Pond Salt Marsh Restoration and Enhancement Project.**

Project Team Diversity

The Ninigret Marsh Enhancement Project (implemented in 2017) benefitted from a diverse project team that drew upon a wide range of local, state and regional expertise during all phases of the project, from feasibility and conceptual design through implementation, adaptive management and post-restoration monitoring.

Feasibility and Conceptual Design

A core team of resource managers and restoration practitioners from Save The Bay, US Fish and Wildlife Service's Coastal Program, Audubon Society of Rhode Island and the RI Coastal Resources Management Council had early conversations about thin-layer placement (TLP)—the use of applied sediment to increase marsh surface elevations—as a restoration / management technique. A statewide assessment of Rhode Island's marshes completed in 2012 by Save The Bay showed widespread degraded conditions due to increased inundation (presumed to be a result of accelerating sea-level rise). These results were shared with the core team, and several site visits were conducted to assess the potential for TLP implementation. At the time, the US Fish and Wildlife Service (USFWS) Refuge Program was considering implementing the technique on National Wildlife Refuge lands within Rhode Island, and the USFWS Coastal Program consulted with the state team on additional sites, most of them within state-owned conservation lands.

The core team consulted with Dr. Charles Roman from the National Park Service to discuss his experience using TLP techniques for a restoration and research project in Big Egg marsh in Jamaica Bay, New York within the Gateway National Recreation Area. The Rhode Island team traveled to Wertheim National Wildlife Refuge on Long Island to take part in an all-day information session about TLP projects, with focus on the Jamaica Bay projects implemented by the US Fish and Wildlife Service and US Army Corps of Engineers. Also present were representatives from the Delaware Center for Inland Bays, The Nature Conservancy, National Estuarine Research Reserves and New York and Connecticut state mosquito abatement programs.

The core team identified the Rhode Island south shore coastal lagoons, commonly referred to as the Salt Ponds, as potential TLP project sites. The area of primary focus was Ninigret Pond, which had a manmade stabilized inlet and had been the site of a previous dredging and beach nourishment project. The Town of Charlestown joined the project team and provided technical assistance for project conceptual design via their GIS coordinator. The town was able to provide high resolution elevation and bathymetry data that were key to the initial project design. When the National Fish and Wildlife Foundation announced its Hurricane Sandy Coastal Resiliency funding program in 2013, a funding proposal was developed by CRMC, which built upon a previous proposal written by the Town of Charlestown with public support letters provided by the Salt Ponds Coalition, a local watershed organization. The proposal was one of 54 proposals approved for funding through the program.

Monitoring and Project Implementation

In addition to the core project team, a monitoring team was formed to develop the monitoring and quality assurance plans for the project. The monitoring team is led by Save The Bay and includes staff members from the Narragansett Bay National Estuarine Research Reserve and EPA's Office of Research and Development. Monitoring parameters were assigned to different monitoring team members, with CRMC serving as the central repository for monitoring schedules, data and project information. Most recently, the CRMC has partnered with the University of Rhode Island Environmental Data Center to add additional monitoring parameters to the existing plan and organize collected data within an online GIS platform.

During project implementation, CRMC served as the main project manager and point of contact for the construction contractor, and was in close consultation with the Charlestown harbormaster, public safety department and the RI Department of Environmental Management for the duration of the dredging operation. Save The Bay led the post-restoration planting effort at the site, engaging volunteers from various corporate and nonprofit groups, as well as a local marina owner who provided a boat for transporting plant material to the project site. CRMC has continued to work with the project and monitoring teams to develop a post-restoration adaptive management plan, and has consulted with outside experts from other regions such as USFWS staff from the Prime Hook National Wildlife Refuge. The teams have continued to work together to identify additional potential project sites, and successfully securing funding for another TLP project through the NOAA Coastal Resilience Program.

3. Elkhorn Slough National Estuarine Research Reserve Case Study—Hester Marsh

Project Team Diversity

The Hester Marsh Restoration Project drew on an existing, 10-plus-year ecosystem-based management (EBM) evaluation and implementation process, the Tidal Wetland Program (TWP). The TWP is coordinated by the Elkhorn Slough National Estuarine Research Reserve (ESNERR), which is administered by NOAA, managed by the California Department of Fish and Wildlife (CDFW), and working in partnership with the non-profit Elkhorn Slough Foundation. The diverse project team drew upon interdisciplinary collaboration; a wide range of local, state and regional expertise; stakeholder and community meetings; and the support of a Science Panel during all phases of the project. Phases included evaluation of restoration alterations; examination of tradeoffs among hydrologic, geomorphologic, conservation biology, water quality, and socioeconomic analyses; and the conceptual design of restoration projects through current implementation. The restoration at this one marsh site, which employs sediment addition for marsh resilience, is part of a multi-site effort and 10 approved TWP recommendations. The background for this case study of Hester's Marsh is drawn from the 2015 published paper by K. Wasson and others, "Lessons learned from an ecosystem-based management approach to restoration of a California estuary." [1]

Background

Elkhorn Slough, in Moss Landing, California, provides regionally important representation of estuarine habitat types, including some of the most extensive tidal marshes in the state, after San Francisco Bay. The estuary has been highly impacted over the past century by human activities, especially hydrological alterations. The primary hydrologic alteration was the 1946 construction of the Moss Landing Harbor, with a straight, deep, channelized estuary mouth, and the current maintenance of the harbor. Today about half of the original estuarine wetlands are behind water control structures, and there has been extensive loss of tidal marsh and degradation of water quality in these areas. In contrast, the portion of the estuary that has not been diked has been subject to a dramatic increase in tidal energy since the creation of the harbor. One of the challenges to decision-making about the estuary was the diversity of jurisdictions, regulatory authorities, landowners and community interests involved. In 2004, the TWP launched in order to meet the critical need for scientific, coordinated, and collaborative management of the estuary. Over one hundred coastal stakeholders have engaged in this EBM initiative. A Strategic Planning Team has decision-making authority, supported by the Science Panel, which is tasked with providing expertise to support the process. The local community has been engaged through numerous public meetings, electronic updates, and comment periods. Stakeholder ranking of TWP objectives included these top three: 1) Reduce eutrophication; 2) Marsh research; 3) Sediment addition.

Feasibility and Conceptual Design

In November 2012 the TWP Strategic Planning Team voted for TWP to proceed with ten recommendations. One recommendation was to directly restore tidal marshes through sediment addition to subsided areas (adjusting local marsh plain elevation rather than water levels in the whole estuary). After years of planning and permitting, in January 2018 ESNERR began earth-moving to restore 61 acres of lost coastal tidal marsh in the Slough in the Hester Marsh Restoration Project. The work adds soil from the nearby Pajaro River flood control project to increase the elevation of drowned marshes. Site selection for Hester Marsh involved a combination of factors: ownership of the land (by CDFW), topography of the site, amount of sediment needed to restore vertical elevation, and access. The restoration will improve marsh resilience to sea-level rise, provide healthy habitat for sea otters, and capture greenhouse gases.

Approximately 20% of the restoration site involves thin-layer placement (TLP) of sediment. The added sediment ranges from a depth of approximately 2.5 cm to 90 cm, and is being distributed with a bulldozer. Permits were obtained from 15 different agencies. The entire TWP process made the implementation possible – the coalition of diverse groups and the relationships built with funders, permitters, restoration practitioners, and community members. Funding for the project came from the California Department of Fish and Wildlife's Wetlands Restoration for Greenhouse Gas Reduction Program, a statewide program that puts Cap-and-Trade dollars to work reducing greenhouse gas emissions; the California Coastal Conservancy; the California Department of Water Resources Integrated Water Resource Management Program; the Wildlife Conservation Board; and the United States Fish and Wildlife Service National Coastal Wetlands Conservation Program.

Project Implementation and monitoring

During project implementation, TWP leadership is serving as the main project manager and point of contact for the construction contractor, all permitting agencies, and funders. As part of the TWP project, ESNERR research scientists, in partnership with local universities, are conducting pre- and post- implementation monitoring and research. They will monitor natural revegetation of Hester Marsh after sediment addition, carbon storage in marsh sediments (referred to as "blue carbon"), and sea otter use of the site.

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[1] **Wasson, K., B. Suarez, A. Akhavan, E. McCarthy, J. Kildow, K. S. Johnson, M. C. Fountain, A. Woolfolk, M. Silberstein, L. Pendleton, and D. Feliz. 2015.** Lessons learned from an ecosystem-based management approach to restoration of a California estuary. Marine Policy 58:60-70.