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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Suggested citation: Raposa, K., K. Wasson, J. Nelson, M. Fountain, J. West, C. Endris, and A. Woolfolk. 2020. "Guidance for thin-layer sediment placement as a strategy to enhance tidal marsh resilience to sea-level rise." Published in collaboration with the National Estuarine Research Reserve System Science Collaborative.

Cover page photo credit:
The Little River, Wells NERR. Courtesy of the Chesapeake Bay VA NERR.

Project Support:
This work was sponsored by the National Estuarine Research Reserve System Science Collaborative, which supports collaborative research that addresses coastal management problems important to the reserves. The Science Collaborative is funded by the National Oceanic and Atmospheric Administration and managed by the University of Michigan Water Center (NAI4NOS4190145).

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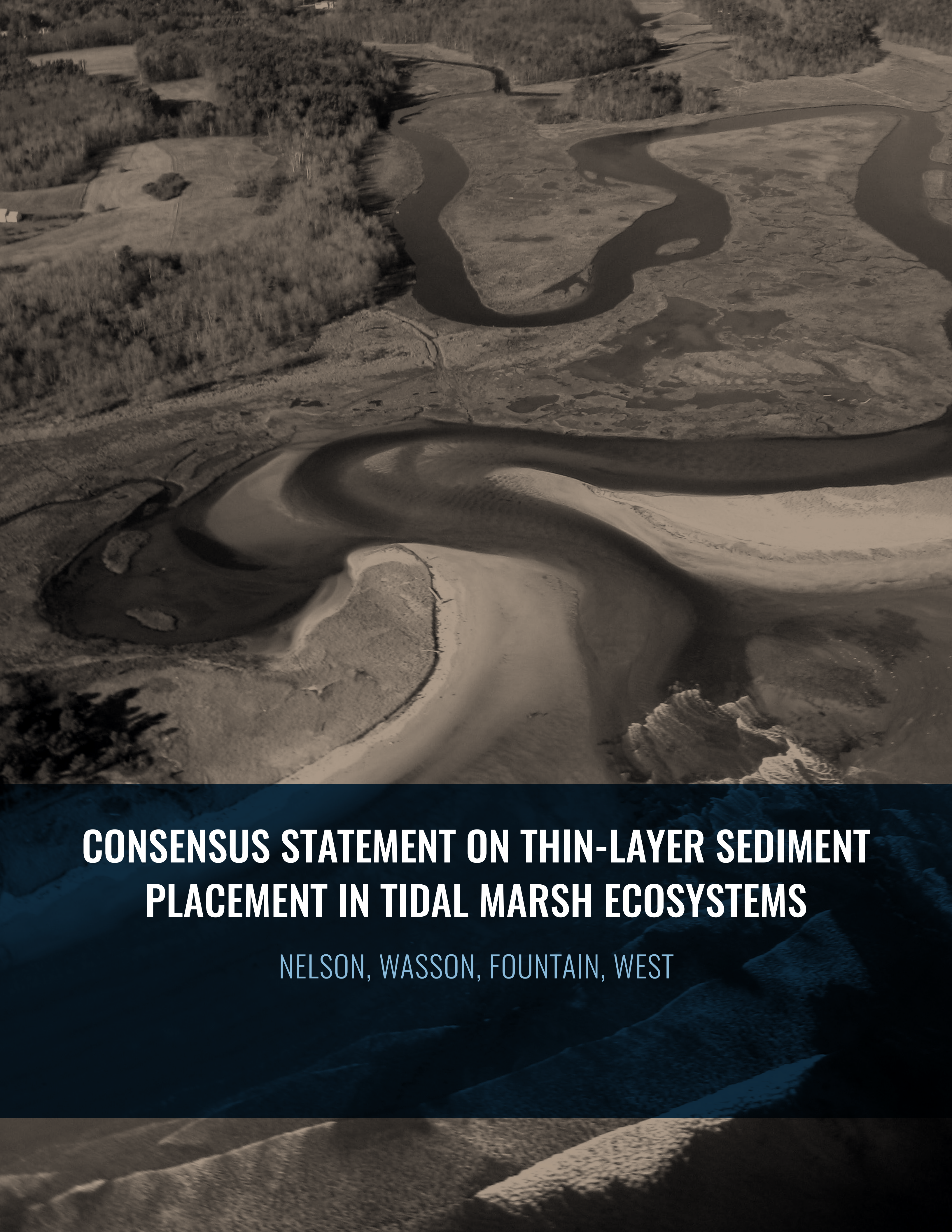


CONSENSUS STATEMENT ON THIN-LAYER SEDIMENT PLACEMENT IN TIDAL MARSH ECOSYSTEMS

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].

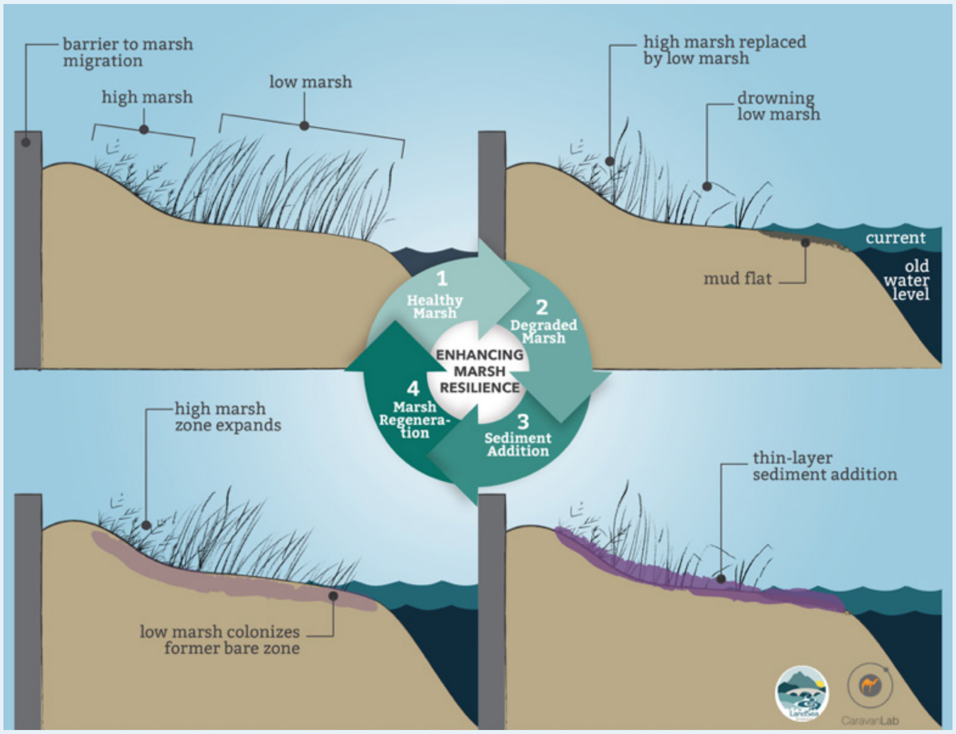
8. **There may be a trade-off between optimizing long-term sustainability of a marsh and decreasing vegetative cover in the short term.**

   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 <u>temporal</u> 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.

THIN-LAYER PLACEMENT OF SEDIMENT FOR TIDAL MARSH RESILIENCE IN THE CONTINENTAL UNITED STATES: A LITERATURE REVIEW

NELSON

CHAPTER 2: THIN-LAYER PLACEMENT OF SEDIMENT FOR TIDAL MARSH RESILIENCE IN THE CONTINENTAL UNITED STATES: A LITERATURE REVIEW

INTRODUCTION

The earliest studies of how tidal marsh responds to sediment addition had little to nothing to do with restoration; instead, TLP had its origins in disposing of dredged sediments from drilling sites, navigation channels, and pipeline canals – documented most thoroughly in Louisiana. To our knowledge, the practice of thin-layer placement is now fully focused on marsh restoration and resilience. Sediments may be sourced from a variety of places, including the proposed “win-win” relationship where dredged sediments are beneficially used to build marsh surface elevations in order to keep pace with accelerating sea-level rise. No matter the source of the sediment, primary attention is given to ecological function and services of tidal marsh. There has been interest in the impact of sediment addition on marsh for 50 years; as one example, the U.S. Army Corps of Engineers initiated a Dredged Materials Research Program in 1973. In early, seminal research, Reimold et al. (1978) explored the effects of sediment addition depths of 8-91 cm on *Spartina alterniflora* (smooth cordgrass).

Across the studies reviewed, results tend to show that a) tidal marsh plants can recover through 5-15 cm of sediment addition (although this depends greatly on marsh geomorphology and integrity, rather than being a rule of thumb); b) plants recover through resprouting in about two years, and through re-seeding in a longer time frame; and c) added sediment may improve marsh re-vegetation (plant cover), and increase marsh biomass, plant stem density, and nutrient uptake into plant tissue, as long as the pitfall of sulfuric acid toxicity is avoided. There are many open questions as to how to avoid conditions which lead to transformation of sulfidic soils to acid sulfate soils, but one factor is that saturated, anaerobic soils (a reducing environment) with a composition of fine-grain sediments that are exposed to air (an oxidizing environment) are more likely to lead to sulfuric acid development. The quality of the sediment certainly comes into play as to whether added nutrients are beneficial or detrimental to marsh resilience; whether there are contaminants or toxicants present; and grain size or sediment type, from coarse sand to fine silt or mud.

A review by the Army Corps of Engineers’ Research and Development Center, “Maintaining tidal marshes in the face of sea-level rise,” (VanZomeren et al. 2019) states, “Thin-layer placement of dredge material was used as the major restoration technique in ten references (Cahoon and Cowan 1987, Delaune et al. 1990, Wilber 1993, Ford et al. 1999, Cornu and Sadro 2002, Mendelssohn and Kuhn 2003, Croft et al. 2006, Ray 2007, Schrift et al. 2008, Wigand et al. 2017).” This review covers those ten references (substituting the published article by Cahoon and Cowan (1988) for the 1987 report and not listing the Ray 2007 review). In addition, the table includes the following references: Reimold et al. (1978), Frame et al. (2005), Slocum et al. (2005), and La Peyre et al. (2009). Thin-layer placement of sediment has been investigated or applied in Georgia, Louisiana, North Carolina, New York, Oregon, and Rhode Island.

There are various concerns with TLP, especially for those unfamiliar with it as a nature-based adaptation tool. As mentioned, TLP’s origin and history is one of dumping dredged sediments for convenience, not restoration: canals were cut through Louisiana marshes for oil and gas extraction, and dredged sediment dumped on the sides. That is the beginning of the literature — although not in the spirit or direction of TLP, which is a restoration tool. The vast majority of papers come from Barataria Bay, Louisiana, and the LA Delta, so geographic variation is limited in terms of scientific results. Second, TLP currently has the same permit process as filling wetlands: legal and policy frameworks do not distinguish between filling wetlands for development and adding sediments to marsh for the purpose of marsh sustainability. Again, in the policy framework, we have not differentiated harm to marsh from restoration of marsh — making it, perhaps, difficult for TLP to have a positive association. Lastly, few designers and engineers are familiar with nature-based techniques for coastal protection (Restore America’s Estuaries 2015), so they may not readily look to living shorelines or TLP. It will take more education and awareness about nature-based options, which this guidance document can provide for TLP.

Note: Results of completed studies are presented geographically, starting in the Northeast and proceeding clockwise.

PROJECTS SORTED BY LOCATION: CLOCKWISE AROUND THE U.S. BY STATE, STARTING IN THE NORTHEAST

PROJECT TEAM OR CO-AUTHORS	DATE	LOCATION	PROJECT DESCRIPTION	PLANT COMMUNITY(IES)	SEDIMENT DEPTH (CM) AND TYPE	RESULTS/DID IT RESTORE MARSH VEGETATION AND FUNCTION?
C Wigand, T Ardito, C Chaffee, W Ferguson, S Paton, K Raposa, C Vandemoer, E Watson	2017	Narrow River, RI	A climate change adaptation framework is presented, where one aspect of adaptation is TLP on the Narrow River, RI. Dredged sediment will be added to high marsh to improve habitat for the tidal marsh sparrow.	*Spartina patens* (salt meadow hay) and *Juncus gerardii* (black rush).	Reporting on a stakeholder process; sediment depths still to be decided at time of publication.	Planned project, where results will be monitored using a Before/After/Control/Impact design.
G.W. Frame, M.K. Mellander, D.A. Adamo	2006	Jamaica Bay, NY	Big Egg Marsh, Jamaica Bay, NY restoration through thin-layer placement of sandy sediments, using high-pressure spray.	*Spartina alterniflora*.	20 cm higher than any of the remnant *Spartina alterniflora* tussocks, which meant up to 1.0 m in low-lying areas.	*Spartina alterniflora* survived spray application of sand in the first season if sediment thickness was 20 cm or less. Found that sand was transforming into a silty and organic tidal marsh soil, there was a dense cover of smooth cordgrass, and an appropriate animal community was becoming established on the treatment site.
AL Croft, LA Leonard, TD Alphin, LB Cahoon, MH Posey	2006	Masonboro Island, NC	Examined sediment additions of 0-10 cm; two deteriorated plots and two non-deteriorated plots received sediment additions; control areas did not.	*Spartina alterniflora* marsh, "deteriorating and non-deteriorating," in monospecific stands. Non-deteriorating marsh was defined by >200 stems per m^2 of *S. alterniflora*, and deteriorating marsh had <150 stems per m^2.	Zero (control) to 10 cm: applied as categories of thick, medium, and thin. 50% fine sand; 50% silt and clay.	Stem densities of *S. alterniflora* increased in all sediment addition plots, with the greatest increases in deteriorated plots. Stem heights were not influenced by treatment.

PROJECT TEAM OR CO-AUTHORS	DATE	LOCATION	PROJECT DESCRIPTION	PLANT COMMUNITY(IES)	SEDIMENT DEPTH (CM) AND TYPE	RESULTS/DID IT RESTORE MARSH VEGETATION AND FUNCTION?
RJ Reimold, MA Hardisky, PC Adams (US Army Corps of Engineers)	1978	Glynn County, GA	The goal was to examine the spreading of dredged material so that it is both cost effective and environmentally sound.	*Spartina alterniflora* marsh.	8, 15, 23, 30, 61, and 91 cm. Type: 1) coarse sand; 2) mixed sand and clay; 3) clay as experimental treatments.	*S. alterniflora* stems can grow through "overburden" sediment up to 23 cm deep regardless of the sediment type. Plots covered with 60 cm or more of dredged material did not recover.
RD DeLaune, S Pezeshki, JH Pardue, J Whitcomb, H Patrick, Jr.	1990	Barataria Basin, LA	Manual addition of sediment to tidal marsh plots enclosed in plywood boxes: two different sediment heights, with initial sediment addition in July 1986 and second sediment addition in June 1987. Plants sub-sampled in November 1987.	*Spartina alterniflora* marsh, degrading.	Two phases of application: first, thicknesses of 2-3 cm and 4-5 cm; after second application, thicknesses were 4-6 cm and 8-10 cm. Type: 40% fine sand, 28% coarse-fine silt, and 32% clays and organics.	Sediment addition resulted in increases in aboveground biomass (AGB) and density of *S. alterniflora* shoots in both treatments (both levels of sediment application). Increase in AGB was only significant for the deeper sediment treatment; number of plant shoots was significantly greater for both levels of sediment input. Nitrogen uptake in plants in deepest sediment level was twice that of the controls.
MK La Peyre, B Gossman, BP Piazza	2009	Six sites in Barataria Basin, LA	Project examined short-term (< 1 yr) and long-term (1-8 years) response to sediment enhancement in terms of functional response of vegetated brackish marsh and interior open water ponds. Used a chronosequence of sediment addition sites (a space-for-time substitution).	*Spartina patens* (salt meadow hay) and *Schoenoplectus americanus*, dominant species in brackish marsh; previously vegetated open water ponds.	Rather than targeting specific sediment addition levels, targeted elevations ranged from 36 to 54 cm NAVD88.	Vegetation response depended on pre-enhancement conditions, whether it was vegetated marsh or open pond (with an intention of restoring open ponds to marsh). In marsh habitat that was vegetated before enhancement, aboveground vegetation biomass decreased over time and belowground biomass neither increased nor decreased over time. In open water habitat, both above-ground and below-ground vegetation increased over time until they approached the biomass of reference marshes over a 7-year period.

PROJECT TEAM OR CO-AUTHORS	DATE	LOCATION	PROJECT DESCRIPTION	PLANT COMMUNITY(IES)	SEDIMENT DEPTH (CM) AND TYPE	RESULTS/DID IT RESTORE MARSH VEGETATION AND FUNCTION?
IA Mendelssohn, NL Kuhn	2003 (work related to Slocum et al. 2005 paper)	near Venice, LA, within the Modern (Birdfoot) Delta of the MS River	Assessed the plant structural and soil physico-chemical responses to different intensities of sediment subsidy in a salt marsh experiencing a high rate of relative sea level rise.	*Spartina alterniflora* tidal marsh, degrading. *S. patens* and *Distichlis spicata* were present, but had low percent cover.	Range of 0 cm to >30 cm.	*S. alterniflora* showed a significant increase in percent cover with sediment subsidy; plant height was 30–60% greater with increasing sediment subsidy (significant); alive+dead biomass increased significantly with sediment addition, but pattern was less clear in alive biomass alone. No change in species composition occurred at the sites with increasing sediment addition. Soil bulk density increased with sediment thickness; interstitial soil salinity was significantly higher with more added sediment.
MG Slocum, IA Mendelssohn, NL Kuhn	2005	near Venice, LA, within the Modern (Birdfoot) Delta of the MS River	Tested how different amounts of sediment ameliorated the effects of sea-level rise and subsidence over 7 years; sediment slurry addition.	*Spartina alterniflora* tidal marsh, degrading.	0-22 cm after compaction (at end of 7-yr. experiment): originally 0-40 cm.	At end of 7-year experiment, areas receiving moderate amounts of sediment (5-12 cm) had better plant vigor (55% plant cover) and soil condition, more than double bulk density and 0 mM hydrogen sulfide (HS) compared to areas not receiving sediment (20% plant cover, lower bulk density, and >1.0 mM HS). Sediments were also high in nutrients, which led to 3-year increase in plant growth.
MA Ford, DR Cahoon, JC Lynch	1999	near Venice, LA, within the Modern (Birdfoot) Delta of the MS River	Investigated high-pressure spray of dredged material onto two habitats: degraded marsh on spoil banks of a canal, and recently-opened shallow water (previously tidal marsh).	*Spartina alterniflora*.	2.3 cm.	Most emergent plants were flattened by the spray application of sediment and then recovered. One year after spray, *Spartina alterniflora* (percent cover) increased significantly.

PROJECT TEAM OR CO-AUTHORS	DATE	LOCATION	PROJECT DESCRIPTION	PLANT COMMUNITY(IES)	SEDIMENT DEPTH (CM) AND TYPE	RESULTS/DID IT RESTORE MARSH VEGETATION AND FUNCTION?
AM Schrift, IA Mendelssohn, MD Materne	2008	near Leeville, LA	After 40,000 ha of *Spartina alterniflora* marsh died due to drought, researchers assessed the effectiveness of sediment-slurry application for vegetation recovery to compensate for post-dieback soil consolidation. Researchers added sediment and created high, medium, and low elevation treatments.	*Spartina alterniflora* marsh, with some *Salicornia virginica* (species list in Table 1).	Rather than depth of sediment added, measured surface elevation relative to ambient, healthy marsh (e.g., low elevation/13–18 cm above ambient healthy marsh). Type: semi-fluid, mineral soil.	The addition of sediment slurries increased the rate of recovery (plant cover) following disturbance in a rapidly subsiding tidal marsh. Elevations, averaging 14 and 20 cm above ambient marsh (44 and 50 cm above NAVD 88, respectively), in the low elevation and vegetated treatment levels had rapid plant recruitment and species richness similar to that of the healthy reference marsh sites.
DR Cahoon, JH Cowan	1987, 1988	Lake Coquille and Terrebonne Parish wetlands (Dog Lake), LA	First description of response of LA coastal wetland to TLP by high-pressure spraying.	Lake Coquille: *Spartina alterniflora* marsh.	10-15 cm at Dog Lake; 18-38 cm at Lake Coquille. Type not described: slurry from canal dredging.	14 months after placement, vegetation still smothered at both sites; however, recolonization by tidal marsh plant species was underway.
Wilber	1993	LA and NC	Technical report for Army Corps of Engineers, including review of four studies.		General conclusion that marsh vegetation can survive or recolonize through placement of 5-15 cm of overlying sediment.	Healthy stands of marsh vegetation atop 5 to 15 cm layers of dredged materials. Presents conceptual model for marsh recovery after TLP with two pathways, a) new shoots emerging through sediment, or b) after hypoxia and sulfides kill rhizomes, recolonization through seeds reaching new surface.

PROJECT TEAM OR CO-AUTHORS	DATE	LOCATION	PROJECT DESCRIPTION	PLANT COMMUNITY(IES)	SEDIMENT DEPTH (CM) AND TYPE	RESULTS/DID IT RESTORE MARSH VEGETATION AND FUNCTION?
C Cornu, S Sadro	2002	South Slough National Estuarine Research Reserve, OR	Kunz Marsh 5-ha restoration project: originally mature high marsh, then diked and drained in 1900s for agricultural use; restoration created four separate cells and dike material was used as fill to create three intertidal elevations (high, mid, and 2 reps of low marsh).	Competitive dominant, permanent plant species included: *Agrostis alba, Carex lyngbyei, Grindellia integrifolia, Potentilla pacifica, Deschampsia caespitosa, Triglochin maritimum,* and *Salicornia virginica* (pickleweed).	Rather than sediment thickness added to marsh surface, dike material used to create elevations of high, mid, and low marsh.	After project construction there was no vegetation cover in any of the four cells. After three years of monitoring: average of 53% plant cover across all cells, compared with 100% cover at mature (high marsh) reference sites. Marsh elevation and associated tidal inundation did not influence vertical accretion, in contrast to numerous other studies.

CITED LITERATURE FROM REVIEW IN TABLE FORM

Cahoon, D.R., 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.

Cahoon, D.R., and J.H. Cowan, Jr.. 1988. Environmental impacts and regulatory policy implications spray disposal of dredged material in Louisiana wetlands. Coastal Management 16:341-362.

Cornu, C. E., and S. Sadro. 2002. Physical and functional responses to experimental marsh surface elevation manipulation in Coos Bay's South Slough. Restoration Ecology 10:474-486.

Croft, A. L., L. A. Leonard, T. D. Alphin, L. B. Cahoon, and M. H. Posey. 2006. The effects of thin layer sand renourishment on tidal marsh processes: Masonboro Island, North Carolina. Estuaries and Coasts 29:737-750.

Delaune, R. D., S. R. Pezeshki, J. H. Pardue, J. H. Whitcomb, and W. H. Patrick. 1990. Some influences of sediment addition to a deteriorating salt marsh in the Mississippi River Deltaic Plain: a pilot study. Journal of Coastal Research 6:181-188.

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

Frame, G. W., M. K. Mellander, and D. Adamo. 2005. Big Egg Marsh Experimental Restoration in Jamaica Bay, New York. Pages 123-130 in People, Places, and Parks: Proceedings of the 2005 George Wright Society Conference on Parks, Protected Areas, and Cultural Sites. George Wright Society, Philadelphia, PA.

La Peyre, M. K., B. Gossman, and B. P. Piazza. 2009. Short- and Long-Term Response of Deteriorating Brackish Marshes and Open-Water Ponds to Sediment Enhancement by Thin-Layer Dredge Disposal. Estuaries and Coasts 32:390-402.

Mendelssohn, I. A., and N. L. Kuhn. 2003. Sediment subsidy: effects on soil-plant responses in a rapidly submerging coastal salt marsh. Ecological Engineering 21:115-128.

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.

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

Restore America's Estuaries (RAE). 2015. Living Shorelines: From Barriers to Opportunities. Arlington, VA. https://estuaries.org/wp-content/uploads/2019/02/Living-Shorelines-From-Barriers-to-Opportunities.pdf.

Schrift, A. M., I. A. Mendelssohn, and M. D. Materne. 2008. Salt marsh restoration with sediment-slurry amendments following a drought-induced large-scale disturbance. Wetlands 28:1071-1085.

Slocum, M. G., I. A. Mendelssohn, and N. L. Kuhn. 2005. Effects of sediment slurry enrichment on salt marsh rehabilitation: Plant and soil responses over seven years. Estuaries 28:519-528.

VanZomeren, C. M., D. Acevedo-Mackey, E. Murray, and T. J. Estes. 2019. Maintaining Salt Marshes in the Face of Sea Level Rise - State of the Practice. U.S. Army Engineer Research and Development Center (ERDC) Environmental Laboratory Vicksburg, MS.

Wigand, C., T. Ardito, C. Chaffee, W. Ferguson, S. Paton, K. Raposa, C. Vandemoer, and E. Watson. 2017. A Climate Change Adaptation Strategy for Management of Coastal Marsh Systems. Estuaries and Coasts 40:682-693.

Wilber, P. 1993. Managing dredged material via thin-layer disposal in coastal marshes. US Army Corps of Engineers, Engineer Research and Development Center, Vicksburg, MS.

GUIDE TO NAVIGATING THE PERMITTING PROCESS FOR THIN-LAYER SEDIMENT PLACEMENT PROJECTS IN TIDAL MARSHES

FOUNTAIN

CHAPTER 3: GUIDE TO NAVIGATING THE PERMITTING PROCESS FOR THIN-LAYER SEDIMENT PLACEMENT PROJECTS IN TIDAL MARSHES

Permitting large-scale thin-layer sediment placement (TLP) projects that involve wetland fill can be complex and challenging. It is not uncommon to have to obtain multiple permits, particularly if the project is in an area with county, regional, state and federal jurisdictions. Each agency has one or more laws that serve as the nexus for their jurisdiction, with different agencies often enforcing different sections of a law as is the case with the Clean Water Act (33 U.S.C. §1251 et seq. (1972)). In general, the laws that are most often triggered by TLP are in place to protect water, habitat, species, and cultural resources. While each project location will be unique and have distinct circumstances, federal laws will cover all projects in the United States.

STEP-BY-STEP GUIDE FOR PERMITTING TLP PROJECTS

Step 1 – Determine which permits are needed

The first step in planning a large-scale TLP project is to determine which permits are needed. This is to ensure that as the next steps are worked through, the specific requirements of each applicable permit are being met. For example, marine mammal surveys would not be needed in step 3 if no marine mammals are present in the area. See the accompanying Permitting Table for a list of Federal and State permits likely needed for a large-scale TLP project. While California was used as a State example, other states are likely similar but could have other types of special districts or regulatory bodies with permitting oversight. Contact regional offices to check for updated permit requirements.

Step 2 – Clarify project goals

It is important at this step to have well-articulated project goals to provide clarity to funders on what is being attempted. It is standard practice to use SMART goals (Specific, Measurable, Attainable, Relevant and Timely). This is a good time to engage the entire project team, including stakeholders, in reviewing and agreeing to project goals.

Step 3 – Develop a clear picture of existing conditions

The first step in determining the potential project impacts is to characterize the existing conditions with initial monitoring and assessments. This will include characterizing the extent of the project, current land use, and physical conditions and processes (such as topography and hydrology, sediment type, and impacts of sea-level rise). It will also include characterization of the existing habitat and species with special attention on both state and federally listed species. During this step it is important to review the guidelines from various permitting agencies and work with staff to ensure the proposed project is characterized relevant to permit needs.

Step 4 – Design project and determine construction sequencing

This step of the process will allow the project team to inform the design through setting ecological as well as physical parameters (e.g., a range of allowable elevations or a range of tidal creek densities). An important component is setting thresholds for ecological outcomes that may be translated into engineering designs. These parameters may be relatively simple such as setting minimum and maximum elevations, or may be more complex and include hydrologic modeling of water flow over the marsh and through tidal creeks. This is a good time to bring in experts in TLP and other aspects of tidal marsh restoration.

Step 5 – Outline potential impacts

Construction sequencing is important to think through and characterize in order to determine potential impacts when applying for permits. For example, different types of containment needed during larger-scale TLP projects will use different equipment (e.g., from hay bale containment of slurry to sheet pile containment of tidal channels), which may have varying temporal and spatial impacts. In general, this is also an opportunity to characterize equipment that will be needed and how the use of that equipment could impact the water, land, species or cultural resources of the site.

Step 6 – Explore different mitigation measures

Use best management practices to determine which mitigation measures are most appropriate to reduce the impact of your project to less than significant. For example, project timing may be changed to avoid nesting birds or pupping marine mammals (if applicable), biological surveys may be done to ensure no special status species are present, or water quality protection measures such as installing straw bales may be applied to protect against increased turbidity.

Step 7 – Establish a compliance monitoring plan

This is sometimes called a Mitigation, Monitoring and Reporting Plan (MMRP) and summarizes the permitting requirements in one document for use as a guide throughout the project.

While these guidelines are by no means exhaustive, the ultimate goal is to ensure that when TLP projects are considered, the permit hurdles are identified early on. As project leads get deeper into the planning process and contact regional agency offices through the links provided (see Permitting Table), a clearer picture will emerge on area-specific permits needed and any streamlined processes already in place to facilitate restoration projects.

OVERVIEW OF FEDERAL & STATE NATURAL RESOURCE LAWS AND REGULATIONS THAT MAY BE APPLICABLE TO THIN-LAYER SEDIMENT PLACEMENT PROJECTS (USING CALIFORNIA AS THE STATE EXAMPLE)*

	LAW	FEDERAL OR STATE	RESPONSIBLE AGENCY	IMPLEMENTING AGENCY	PERMIT, AUTHORIZATION, STUDY OR AGREEMENT	REGULATED ACTIVITY AND RESOURCE	ADDITIONAL INFORMATION
WATER	Section 401, Clean Water Act (CWA) (33 USC 1341)	Federal	State water board (EPA Oversight)	State or regional water board	Water Quality Certification	Discharges requiring a federal license or permit to comply with state or federal water quality standards	https://www.epa.gov/cwa-401/clean-water-act-section-401-state-certification-water-quality
	Section 404, Clean Water Act (CWA) (33 USC 1344)	Federal	USACE (EPA oversight)	USACE	General Permit (Nationwide, Regional); Standard Permit (Individual); Letter of Permission	Discharge of dredge or fill material into waters of the U.S., including wetlands	http://www.usace.army.mil/Missions/CivilWorks/RegulatoryProgramandPermits.aspx
	Section 10, Rivers and Harbors Act (RHA) (33 USC 403)	Federal	USACE	USACE	Section 10 Permit	Work in, under, or over a navigable waterway	http://www.usace.army.mil/Missions/CivilWorks/RegulatoryProgramandPermits.aspx
WATER/ LAND	Coastal Zone Management Act (CZMA) (16 USC 1451)	Federal	NOAA	CCC / BCDC	Federal Consistency Determination	Project modifies land or water use in the coastal zone of a state with an approved CMP	https://coast.noaa.gov/czm/act/
SPECIES	Section 7 & 10, Endangered Species Act (16 USC 1531-1544)	Federal	USFWS / NMFS	USFWS / NMFS	Incidental Take / Biological Opinion (BO) (Section 7); Incidental Take Permit (Section 10)	Activities affecting species listed as threatened or endangered under the ESA	https://www.fws.gov/endangered/
	Marine Mammal Protection Act (MMPA) (16 USC 1361 et. seq.)	Federal	USFWS / NMFS	USFWS / NMFS	Letter of Authorization (LOA); Incidental Harassment Authorization (IHA)	Activities affecting marine mammals and their products	http://www.fws.gov/international/permits/by-species/marine-mammals.html
	Section 305(b)(4)(A) of Magnuson-Stevens Fishery Conservation and Management Act (MSA)	Federal	NMFS	NMFS	Essential Fish Habitat (EFH) Consultation	Activities affecting eelgrass and other essential fish habitat	https://www.fisheries.noaa.gov/national/habitat-conservation/consultations-essential-fish-habitat

OVERVIEW OF FEDERAL & STATE NATURAL RESOURCE LAWS AND REGULATIONS THAT MAY BE APPLICABLE TO THIN-LAYER SEDIMENT PLACEMENT PROJECTS (USING CALIFORNIA AS THE STATE EXAMPLE)*							
	LAW	FEDERAL OR STATE	RESPONSIBLE AGENCY	IMPLEMENTING AGENCY	PERMIT, AUTHORIZATION, STUDY OR AGREEMENT	REGULATED ACTIVITY AND RESOURCE	ADDITIONAL INFORMATION
CULTURAL RESOURCES	National Environmental Policy Act (NEPA) (42 USC 4312)	Federal	CEQ and EPA oversight	Federal Lead Agency	Environmental Assessment (EA); Finding of No Significant Impact (FONSI); Environmental Impact Statement (EIS)	Major federal actions significantly affecting the quality of the human environment	https://www.whitehouse.gov/ceq/
	National Historic Preservation Act (NHPA) (16 USC 470)	Federal	ACHP / SHPO	Federal Lead Agency	Memorandum of Agreement / Programmatic Agreement	Activities affecting cultural resources	http://ohp.parks.ca.gov/ http://www.achp.gov/
WATER	Porter-Cologne Water Quality Control Act (Division 7, California Water Code)	State	SWRCB	RWQCB	Waste Discharge Requirement (WDR)	Activities that may affect surface or groundwater quality	http://www.waterboards.ca.gov/water_issues/programs/land_disposal/waste_discharge_requirements.shtml
WATER/ LAND	California Coastal Act (CCA) (PRC §30000 et. seq.)	State	CCC / BCDC	CCC / BCDC / Local Govt	Coastal Development Permit (CDP)	Activities that modify land or water use in the coastal zone	http://www.coastal.ca.gov/cdp/cdp-forms.html http://www.bcdc.ca.gov/forms/forms.html
SPECIES	California Endangered Species Act (CESA) (FGC § 2081 & 2090)	State	CDFW	CDFW	Incidental Take Permit (Section 2081) or Consistency Determination (Section 2080.1)	Activities affecting state-listed species	http://www.dfg.ca.gov/habcon/cesa/
	Section 1600-1616, California Fish and Game Code (FGC § 1602 et. seq.)	State	CDFW	CDFW	Lake or Streambed Alteration Agreement	Activities that divert or obstruct the natural flow or substantially change the bed, bank or channel of a river, stream or lake, or use material from a streambed	http://www.dfg.ca.gov/habcon/1600/
ALL		State	OPR and SCH (oversight)	State Lead Agency	Initial Study (IS); Negative Declaration (ND); Mitigated Negative Declaration (MND); Environmental Impact Report (EIR)	Discretionary actions proposed to be carried out or approved by California public agencies	http://resources.ca.gov/ceqa/ 2019 CEQA Handbook: http://resources.ca.gov/ceqa/docs/2019_CEQA_Statutes_and_Guidelines.pdf

ACRONYMS	
ACHP – Advisory Council on Historic Preservation	**OCRM** – Office of Ocean & Coastal Resource Management
BCDC – San Francisco Bay Conservation and Development Commission	**OPR** – Office of Planning and Research
CCC – California Coastal Commission	**RWQCB** – Regional Water Quality Control Board
CDFW – California Department of Fish and Wildlife	**SCH** – State Clearinghouse
CEQ – Council on Environmental Quality	**SHPO** – State Historic Preservation Officer
EPA – Environmental Protection Agency	**SWRCB** – State Water Resources Control Board
NMFS – National Marine Fisheries Service	**USACE** – U.S. Army Corps of Engineers
NOAA – National Oceanic & Atmospheric Administration	**USFWS** – U.S. Fish and Wildlife Service

* Modified from a table developed for an Elkhorn Slough NERR Coastal Training Program Workshop in 2013 titled "Navigating the Rules for Environmental Compliance with Wetlands Restoration in Coastal California" with April Zohn, Lux Environmental.

RECOMMENDED MONITORING FOR THIN-LAYER SEDIMENT PLACEMENT PROJECTS IN TIDAL MARSHES

RAPOSA, WASSON, ENDRIS

CHAPTER 4: RECOMMENDED MONITORING FOR THIN-LAYER SEDIMENT PLACEMENT PROJECTS IN TIDAL MARSHES

INTRODUCTION

Most marsh thin-layer sediment placement (TLP) projects share overarching objectives such as increasing elevation, supporting desired foundational vegetation communities, and sustaining key ecological functions and processes. Comprehensive monitoring is essential for any TLP project in tidal marshes in order to evaluate to what extent, and how rapidly, the project met its objectives. Additionally, monitoring data may shed light on the mechanisms behind restoration success or failure, and thereby inform adaptive management of the project or similar projects to be implemented in the future. Although every project will include some specific objectives or questions that are only relevant locally, it is possible to provide general monitoring recommendations that are broadly applicable across systems.

This document represents the first set of universal guidelines for monitoring indicators of TLP project success. It is intended to be useful for TLP projects in diverse types of tidal marshes and geomorphic settings anywhere in the world. Another purpose of this document is to increase standardization in monitoring approaches across future projects, which will facilitate syntheses and meta-analyses to determine the conditions under which TLP represents an effective approach for enhancing the resilience of tidal marshes in the face of sea-level rise. It was developed by teams at the Narragansett Bay and Elkhorn Slough National Estuarine Research Reserves (NERRs), with input from a key group of TLP advisors and practitioners from diverse programs across the US.

These guidelines do not include detailed monitoring instructions; instead we set out to identify broad categories of objectives that all TLP projects should address with monitoring and provide some general suggestions and resources for how specifically to go about monitoring. For each monitoring category, we provide a general rationale and objective for inclusion in monitoring programs as well as examples of how these may in turn be applied specifically to a TLP project. The objectives we present for each category are intended to serve as guidance; we recognize that objectives for some real-world projects may need to accommodate some degree of flexibility to reflect site-specific issues. Examples include when enhanced compaction and subsidence from large amounts of added sediment leads to tempering of initial elevation objectives, or when unsuitable sediment chemistry hinders early plant survival and necessitates altered vegetation objectives. Identifying specific quantifiable objectives is key for any project; monitoring may then help determine whether set objectives were met. It is also important to implement a sound monitoring approach and plan that is developed in conjunction with TLP designs to improve coordination between monitoring and construction and ensure monitoring data are not compromised. Finally, we provide for each category one or more examples of different approaches to monitoring that include references to detailed existing protocols, when available.

TEMPORAL AND SPATIAL CONSIDERATIONS FOR SETTING MEASURABLE OBJECTIVES AND MONITORING

Any TLP project must have explicit and quantitative objectives. These objectives will be instrumental in shaping the general design of the project and in preparation of detailed construction plans. A TLP project may serve to restore conditions more typical of the past, as an enhancement of desired services or conditions, or both.

For restoration projects, objectives typically involve reversing aspects of human-driven degradation to return a site or system toward the range of conditions documented for historic or prehistoric times. Many marshes have lost elevation due to human alterations to natural wetland hydrology, and TLP may be used as a tool to restore lost elevation, associated vegetation, and functions. Thus, past conditions at the focal restoration site (such as marsh extent calculated from historic photos or maps) may serve to set quantitative objectives, and time series data at the site may be used to determine if they are met post-restoration (Figure 1).

For enhancement projects, objectives typically involve improvement of a particular process or function. For instance, TLP may be used to create more acreage of a particular type of marsh habitat critical to endangered bird, fish or mammal species. TLP may also be used to enhance resilience to climate change and accelerating rates of sea-level rise by increasing marsh surface elevations or creating gentle slopes that allow for migration.

Whether a project is conducted for restoration or enhancement, the use of reference sites may inform the setting of numeric objectives and be incorporated into monitoring (Figure 2). Sites in the region that have not been degraded may also serve as references for restoration. Regional sites may also be used as references for enhancement projects if they currently achieve the desired

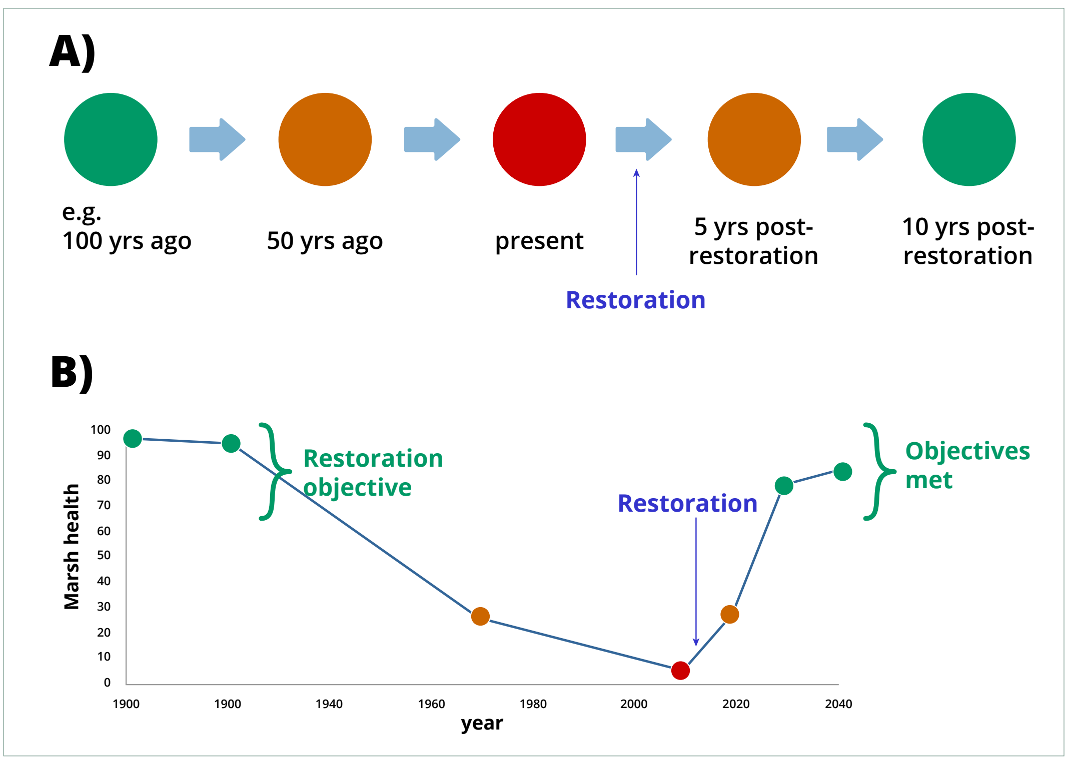

Figure 1. Temporal changes at focal site. Past conditions at the focal restoration site are used to set objectives, and comparison of conditions before/after restoration is used to monitor restoration success. A) Conceptual model of sequence of changes at focal site, where conditions were healthy (green) in the past, were degraded (red), but then restored to health through restoration. B) Example of time series of data from this site, quantifying past conditions (which are the restoration objectives), degraded conditions, and restored conditions. The X axis represents time; the Y axis may be any indicator of marsh health, such as percent vegetated cover, elevation, density of a target nesting bird species (e.g., Clapper Rail, *Rallus longirostris*), etc.

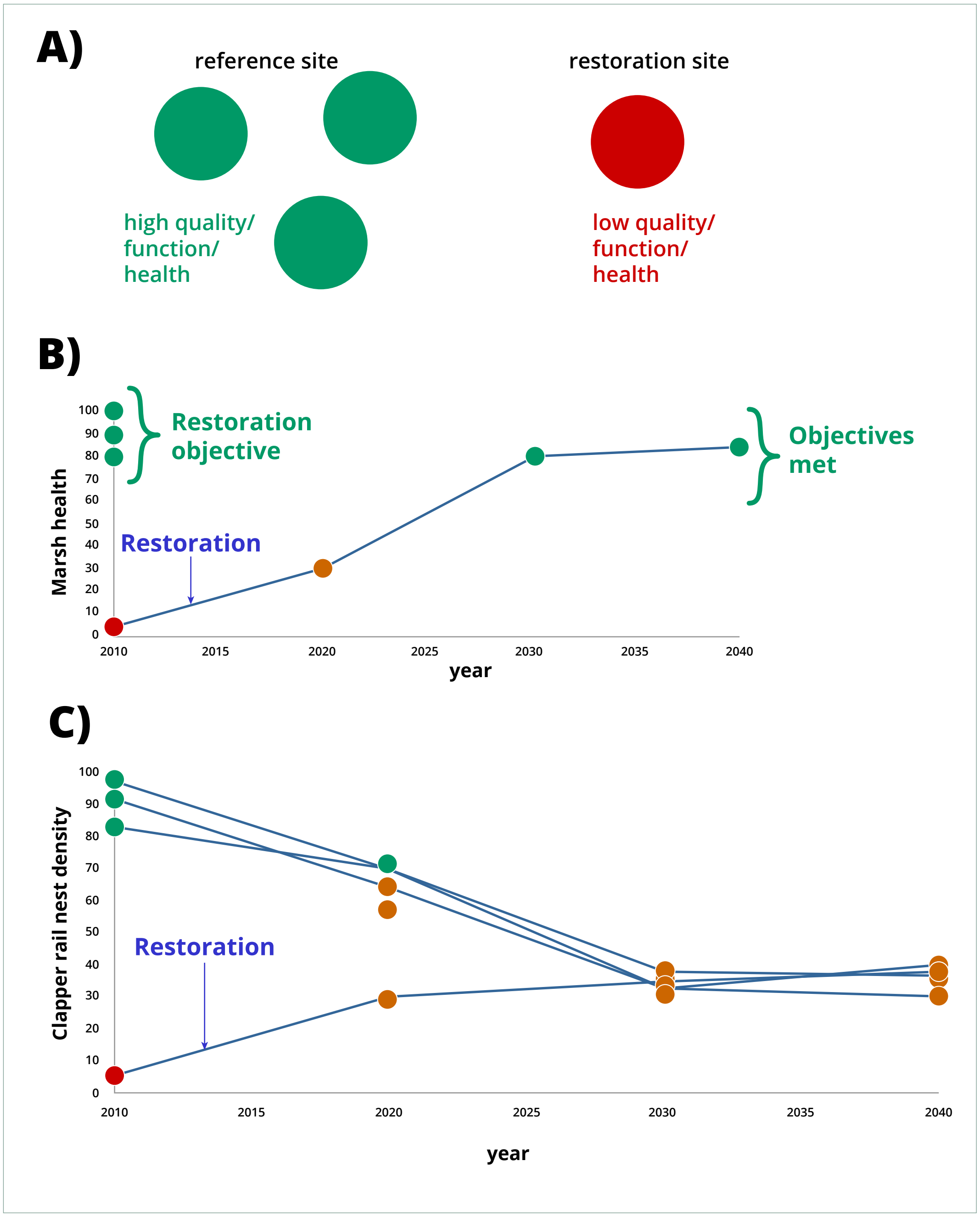

Figure 2. Spatial comparisons of focal site to healthier reference sites. Conditions at reference sites are used to set objectives, and comparison of conditions before/after restoration is used to monitor restoration success at the focal site relative to these reference sites. If current conditions at reference sites are presumed to resemble past conditions, then the actions at the focal site represent restoration in a strict sense of the word. Reference sites may also be chosen to represent desired ecosystem services or functions, regardless of past conditions (e.g., high carbon sequestration rates, support for endangered species), in which case the actions at the focal site represent enhancement. A) Conceptual model where conditions are healthy (green) at reference sites and used to set quantitative objectives for restoration site, which is degraded (red). B) Example of restoration monitoring, quantifying conditions at reference sites initially, and restoration site over time, to determine whether objectives have been met. For an attribute of marsh health such as elevation, rate of change is slow at reference sites, and just the initial measurement is sufficient (reference sites do not need to be monitored over time). C) For a dynamic attribute of marsh health, such as Clapper Rail breeding density, it is important to also monitor the reference sites over time. In this example, there has been a decline in reference sites, making it unlikely that the restoration site can meet the original objectives, but it may do as well as the reference sites.

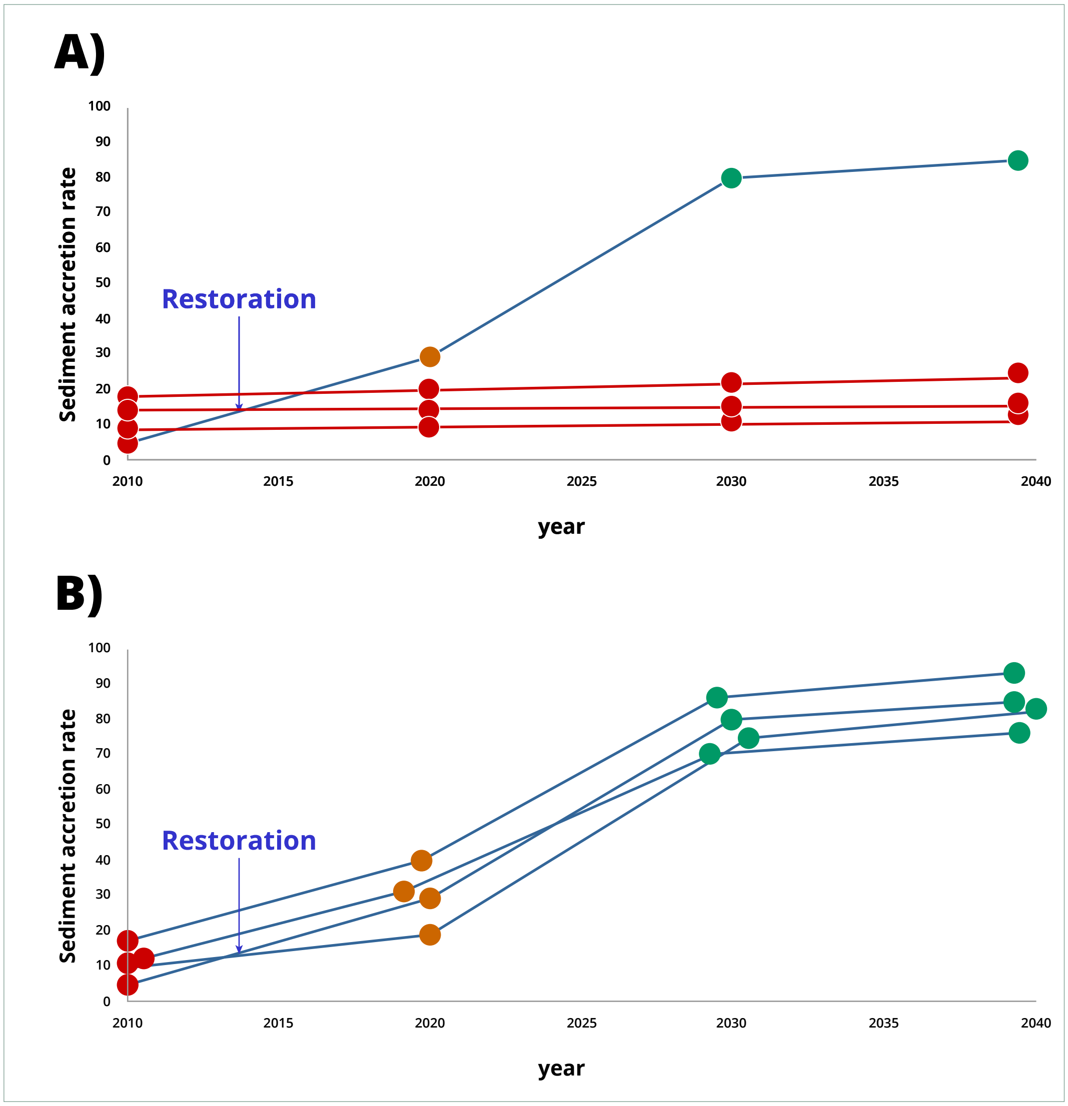

Figure 3. Spatial comparisons of focal site to degraded control sites. For dynamic parameters that show considerable temporal variation, changes at the focal restoration site may also be compared to changes at unrestored control sites. This is important for distinguishing changes due to restoration actions from changes due to broader regional factors or other drivers. This type of monitoring is called Before-After-Control-Impact (BACI) monitoring. A) For example, sediment accretion rate may start low at both the focal restoration site and other degraded sites in the region. However, if restoration restores healthier processes to the site, accretion rates will increase only at the focal site and not control sites. The cause of the improvement in this marsh health parameter is likely to be the restoration activity. B) In this example, an increased sediment accretion rate occurred at all sites, perhaps due to dam removal on a nearby river which enhanced sediment supply to the entire region. Here, improvements at the restoration site cannot be attributed to the restoration activity. (Note that in these examples, there is a single point for the restoration site, but in reality, multiple measurements should be taken there).

functions. For instance, desired elevations, vegetation cover, composition or height, or animal densities may be determined at these reference sites and be used to set quantitative objectives for the project area.

Temporal and spatial comparisons may be important not just for setting objectives, but also for monitoring (Figures 1-3). The development of a statistical approach for monitoring of indicators may incorporate comparisons over time, comparisons over space, neither or both (Figure 4).

- **Project area after construction only:** some objectives may only involve conditions at the project area after construction. For example, an objective might be to have 50 acres within defined boundaries at the project site occur above the elevation corresponding to Mean Higher

TEMPORAL SAMPLING					
	past baseline	current	1 yr post restoration	5 yr post restoration	10 yr post restoration
SPATIAL SAMPLING	**1920**	**2015**	**2020**	**2025**	**2030**
Restoration site					
station 1					
station 2					
station 3					
etc.					
Reference site					
site 1					
site 2					
site 3					
etc					
Control site					
site 1					
site 2					
site 3					
etc					

Figure 4. Summary of spatial and temporal sampling options. When designing a monitoring plan, it may be helpful to prepare a table with the full scale of temporal and spatial possibilities for data collection. Then, for each parameter, the team may determine what sort of spatial and temporal sampling is needed by placing an "X" in the appropriate boxes. For some objectives, such as "create at least 50 hectares of marsh platform higher than Mean Higher High Water," you only need a single X for assessing this once, across the entire restoration site, after restoration. For other objectives, such as Clapper Rail breeding density, your table would have an "X" in many boxes, as this parameter is dynamic in space and time, so you would need monitoring data from multiple years before and after restoration and at multiple sites within and outside the restoration area.

High Water when construction is complete. Monitoring must be conducted to determine if the construction contractor meets this goal, but no time series and no spatial comparisons are necessary (though temporal and spatial data likely were used to set this objective in the first place).

- **Project area before/after construction:** many objectives are likely to involve a comparison of the project area before vs. after restoration. For example, a project may have a quantitative objective of increasing area of tidal marsh by 20 acres by three years post-construction. This may be monitored only at the restoration site; there is no need for monitoring of major vegetation increases at other sites without TLP since there is no mechanism that would make this likely.
- **Project vs. control sites:** some objectives relate to improvements at the project area vs. similarly degraded areas without projects. For example, a project may have a quantitative objective of increasing denitrification rates relative to similar areas. Since these are variable spatially, monitoring may be conducted at replicate sites within the project area and at multiple control sites post-restoration to ensure that rates are higher in the project area than comparable sites. The more spatial variability there is in the indicator, the larger the number of replicate sites needed to have confidence in the results. If there is also high temporal variability in the indicator due to processes unrelated to the management action, a before-after-control-impact (BACI) design may prove useful, effectively combining the above two approaches. Changes in the project area are compared to changes in control sites to ensure that the rate of change in the former is greater than in the latter (Figure 3).

- **Project vs. reference sites:** some objectives involve the project area achieving levels comparable to those in systems that were not degraded or are supporting desired species or functions. For example, a project might have as an objective to support as many nesting pairs of a given target bird species (e.g., Clapper Rail, *Rallus longirostris*) per mile of shoreline as healthy reference sites did in a recent monitoring year. In this case, monitoring could occur post-restoration at the project area vs. reference sites to determine if the objective was met. Alternatively, the temporal trajectory may be monitored using a before-after design as above (in this case hopefully showing a dramatic increase in the number of Clapper Rails at the project area and no major changes at the reference sites), or with a tool such as the Restoration Performance Index (RPI) (Moore et al. 2009; Raposa et al. 2018).

Project managers and scientists must work together from the outset to develop objectives based on an understanding of the project area and/or other regional sites. Decisions should be made in advance about which indicators need to be monitored repeatedly vs. once, which need to be monitored before and after restoration or just after restoration, and which need to be monitored at control or reference sites or only at the project area. There are no universal answers to these questions since they depend on the restoration objectives.

The above discussion of objectives focuses on the desired outcomes that motivated the project to begin with, typically related to increasing marsh health and sustainability. In addition to these sorts of objectives, TLP projects will also have objectives related to environmental compliance. These are both about avoiding inadvertent harm during the course of construction and about long-term goals.

TLP OBJECTIVES AND MONITORING

All of the categories listed in this section are valuable for inclusion in TLP monitoring programs to evaluate project trajectories if key objectives are met. However, we recognize that many projects will not have the resources to include each category and therefore ***recommend that all TLP projects include a critical minimal amount of monitoring focused on elevation and vegetation,*** with other categories added on as resources allow. Specifically, the recommended minimum monitoring would be comprised of monitoring elevation and percent cover of all plant species present at representative spots throughout the restoration site, with a density of at least one measurement spot per hectare, and measurements taken at least once prior to sediment addition, once immediately after sediment addition, once one year later, and once five years later.

ELEVATION

General objective: achieve desired elevation target (e.g., optimal elevations for plant growth) during initial construction and maintain it for a certain amount of time (i.e., no major loss in elevation due to erosion/compaction during the identified time period).

Examples of specific objectives: lower 30% of marsh platform (or 'marsh plain' as it is sometimes referred to) ranges from 20-40 cm above MHW; upper 70% of marsh platform ranges from 40-60 cm above MHW; elevation remains within 10% of the level achieved at the end of construction for the first two years; at least 50 hectares of project area have elevation at or above +1.5 m NAVD88 for at least 5 years.

Monitoring approaches:

- **Field surveys along permanent transects or across a grid network** that spans the entire elevational range of the marsh platform using leveling surveys from permanent benchmarks, or real-time kinematic (RTK) GPS or Terrestrial Laser Scanner. This method is appropriate for collecting high-resolution data with either centimeter (RTK-GPS) or sub-centimeter (levelling equipment) accuracy but it can be spatially limited, especially when a small number of points is collected. Examples of protocols for monitoring elevations across marshes include Neil et al. (2017) for RTK-GPS and Cain and Hensel (2018) for digital leveling.
- **Remote sensing and GIS** for landscape-scale elevation changes using commercial LiDAR or unmanned aerial

vehicle (UAV) imagery with ground control points (GCPs). In recent years, the creation of digital elevation models (DEMs) produced from Structure-from-Motion (SfM) principles (i.e., creating a 3-D structure from a series of overlapping and offset images) has emerged as a low cost and highly accurate alternative to aerial LiDAR surveys (Westoby et al. 2012). While both are capable of producing DEMs that may be used to assess change, UAV flights may be performed on a much more frequent basis and can produce DEMs with sub-decimeter resolution for identifying small-scale change in a marsh. Establishing permanent or semi-permanent GCPs, using either RTK or terrestrial laser scanning, may also vastly improve the accuracy of the DEMs. Examples of using LiDAR and UAVs to remotely assess tidal marsh elevations include Kalacska et al. (2017) and Buffington et al. (2016).

RESILIENCE TO SEA-LEVEL RISE (SLR)

General objective: TLP initially builds the marsh platform to heights amenable for withstanding an extended period (e.g., decades) of projected SLR; marsh elevation gain after TLP tracks at least the current rate of local SLR.

Examples of specific objectives: elevation is high enough for new marsh to withstand at least 30 years of projected SLR; current annual rate of marsh elevation gain does not fall below the rate of recent local SLR.

Monitoring approaches:

- **Surface Elevation Tables (SETs) and marker horizons** to track fine-scale changes in elevation over time in discrete locations in a marsh. Accurately measuring marsh surface elevation change is best accomplished with paired deep and shallow surface elevation tables (SETs), and partitioning change due to different processes is possible by also using replicated marker horizons established in conjunction with SETs (Cahoon et al. 2011). Guidelines for using the paired SET and marker horizon technique in tidal marshes are provided by a collaboration between the National Park Service (NPS), US Geological Survey (USGS), and National Geodetic Survey (NGS) (Lynch et al. 2015).
- **Landscape-scale surveys.** One drawback of SETs is that they are spatially very limited; each SET covers approximately 1 m^2 of marsh. Repeated surveys using sub-centimeter digital leveling may provide the same accuracy as SETs for monitoring marsh elevation change, but at a much greater spatial coverage. Details are provided in Cain and Hensel (2018). Yet another approach is the use of unmanned aerial vehicles (UAV) to collect elevations across entire marsh landscapes.
- **Quantify elevation capital by pairing marsh elevations with a local tidal datum.** Any marsh monitoring program should include tracking elevations of the marsh over time, but alone this does not indicate where the marsh sits relative to local water levels. By also calculating a site-specific tidal datum (see 'Hydrology and Inundation' section below), elevations of the marsh and tidal water may be related to one another and used to calculate elevation capital (how high the marsh is relative to tidal water). Guidance for calculating tidal datums and linking with marsh elevations to explore elevation capital are provided by NOAA (2003), Cahoon and Guntenspergen (2010), and Rasmussen et al. (2017).

VEGETATION

General objective: achieve desired marsh cover and community composition relatively rapidly (through survival and regrowth of existing plants, colonization by seeds, or by targeted plantings), and maintain this for at least a few decades.

Examples of specific objectives: at least 50% of new TLP areas are covered with native plants within three years; invasive species cover is less than 5% of total vegetation coverage of new TLP areas after three years; species composition is statistically similar to high-functioning reference sites after 10 years; canopy height of the marsh dominant is appropriate to support Clapper Rail breeding; 80% survival rate by rare marsh plants planted into high marsh at the end of the first year.

Monitoring approaches:

- **Field surveys using transects and quadrats.** This is a classic way to monitor plants in tidal marshes and it may provide quantitative data on vegetation species composition, cover, canopy height, and stem density. Typically, monitoring is conducted along established transects that stretch from water to upland and encapsulate the entire vertical extent of the marsh platform; vegetation is then surveyed from within replicated quadrats spaced along the transects using various techniques (e.g., point-intercept, visual/ocular). Detailed guidelines for this type of vegetation monitoring are provided by Roman et al. (2001), which has since been refined and adopted by the National Estuarine Research Reserve System (Moore 2017).

- **Remote sensing (e.g., aerial photos, UAVs)** to assess entire marsh landscapes. This is similar to remote sensing for elevation as described above, but instead uses cameras mounted to an aircraft or UAV to take a series of high-resolution georeferenced photographs for mapping vegetation and habitats across an entire marsh, or representative areas for very large marshes. Resultant maps are typically comprised of general vegetation and habitat types (e.g., low marsh vs. high marsh) and may include quantitative data on individual plant species cover and health. For example, multispectral imagery (e.g., 4-band NAIP imagery and some UAV imagery using near-infrared sensors) enables us to map and quantify vegetation based on a unique spectral signature. Other example methods for monitoring marsh vegetation and habitats with remote sensing techniques include Ballanti and Byrd (2018) and Ganju et al. (2017).
- **Focused assessments** to quantify the success of newly-planted areas. A common approach to accelerate TLP marsh plant colonization and regrowth is to use targeted planting of key species at appropriate elevations. In some cases, however, planted areas are placed distant to field survey plots to help distinguish the natural recolonization process from success of plantings; this therefore requires the use of separate assessments focused specifically on newly planted areas. In the first months after planting, survival of individual flagged plants may be quantified. Later, transects through the planted areas may provide data on changes in cover of different plant species or different experimental treatments (e.g., soil amendments).
- **Repeat photography to track changes in vegetation over time.** At the landscape scale, photo stations where landscape scale photographs may be taken (e.g., PVC posts where a camera is mounted at the same location each time) allow for oblique landscape views of vegetation changes to complement aerial images. At a closer scale, photographs taken of the monitoring quadrats or of planted individuals may be useful for visualizing changes in growth or cover over time.
- **Soil characteristics and chemistry.** In many cases, it may also be useful to collect ancillary data on soil characteristics (e.g., bulk density, percent organic, grain-size composition) and porewater chemistry (e.g., sulfide concentrations, pH, salinity) in conjunction with vegetation monitoring. It is not uncommon for plant colonization and/or survival to differ among various types of sediment or to suffer in early stages of TLP projects, especially when sulfidic sediments become exposed to air and lead to acidic conditions harmful to some plants. Soil data may therefore help explain why certain vegetation objectives may not have been met, or to help adjust these objectives accordingly.

HYDROLOGY AND INUNDATION

General objective: establish appropriate tidal flooding regimes and adequate drainage to promote healthy and sustained plant growth.

Examples of specific objectives: percent of time marsh surface is inundated is similar to a nearby reference marsh; water levels drop below expected plant root zone depth during at least 90% of low tides for at least 20 years into the future; density and structure of tidal creeks similar to reference sites supporting desired nekton communities and not eroding substantially over time.

Monitoring approaches:

- **Collect data from water level loggers** deployed either in shallow subtidal areas adjacent to the marsh or in shallow wells inserted directly into the marsh platform to quantify short-term tidal datums, surface inundation, and drainage. Reference water levels or the exact elevation of these loggers should be measured with precise surveying so that orthometric heights may be linked to tidal datums. These two hydrologic indicators – frequency and duration of inundation and drainage — are key to establishing and maintaining healthy marsh plants. The National Park Service (NPS) has two guides for using water level loggers adjacent to a marsh (Curdts 2017; Rasmussen et al. 2017) and the US Fish and Wildlife Service (USFWS) provides guidelines for how to install and use them in shallow wells in the marsh (Neckles et al. 2013). If using purchased water level loggers is not an option, data from a nearby NOAA tide station may also be used (https://tidesandcurrents.noaa.gov/) under the assumption that tidal datums at the tide station are very similar to the marsh.
- **Remote sensing** to track the evolution of new tidal creeks and other hydrologic features in new TLP sites. This may be especially useful if a project objective is to establish a certain areal coverage of key aquatic habitats favorable for nekton and birds (e.g., shallow creeks and pools). Mapping these features may be accomplished in conjunction with vegetation and habitat mapping using remote sensing techniques as described above.

ECOLOGICAL FUNCTIONS

General objective: establish ecological functionality at levels similar to or better than reference marshes, or at appropriate levels to achieve desired ecosystem services or support needs of particular species.

Examples of specific objectives: nekton density and richness is ≥75% of nearby reference marshes after five years; marsh bird community composition is statistically indistinct from reference marshes after three years; numbers of an endangered marsh mouse double in the first five years; carbon sequestration rates exceed 200 g/m^2/year.

Example monitoring approaches:

- **Assess desired animal communities** of regional importance (e.g., sea otters for CA, horseshoe crabs for the western Atlantic) or species of concern that may cause negative impacts (e.g., crabs, geese). Fish, birds, and wildlife are often conspicuous and charismatic components of marshes. They not only represent integrative indicators of marsh health, but are also easily relatable to the general public and key user groups. Example monitoring protocols and guidelines include James-Pirri et al. (2012) for nekton, the Saltmarsh Habitat & Avian Research Program (SHARP; https://www.tidalmarshbirds.org/) and Conway (2011) for marsh birds, and Tinker et al. (2018) for otters. Conversely, some of these animals, even native species, may elicit negative impacts to marshes, and potentially to TLP projects, often through herbivory. For monitoring some of these species, the documents listed above may suffice, but more targeted monitoring for specific species or in certain habitats may require alternate methods (e.g., extensive burrow counts or pitfall trapping for crabs; Wasson et al. 2019).
- **Carbon sequestration.** "Blue carbon," the carbon sequestered in tidal marshes, has become an important ecosystem service. Carbon storage by vegetation may be quantified by collecting standing stock of aboveground vegetation (harvesting, drying, and weighing all tissue in a quadrat of known size), or for below-ground vegetation. Coastal soils tend to store more carbon than vegetation, so taking cores and quantifying carbon in known areas is an important part of quantifying carbon storage. To assess rates of carbon sequestration, changes in carbon content over time must be quantified, in repeat cores (e.g., before vs. after vegetation grows at a TLP site) or at the surface by analysis of carbon in newly accumulated sediment. Carbon sequestration may also be estimated using measures of carbon dioxide exchange using open-path sensors coupled with anemometers (the eddy covariance method; Baldocchi et al. 2001) although this method may overestimate carbon sequestration relative to soil and vegetation-based methods as it does not account for lateral fluxes of carbon via tidal advection. Emissions of other potent greenhouse gases (nitrous oxide and methane) may also be measured with open path or chamber-based methods to ensure that the benefits of carbon sequestration are not outweighed by methane or nitrous oxide emissions. Details on all of these methods may be found in Howard et al. (2014).
- **Denitrification or other biogeochemical functions.** Denitrification is the conversion of bioavailable nitrogen to inert nitrogen gas. Because tidal marshes provide the anoxic conditions and high organic matter inputs necessary to support denitrification, reductions in dissolved nitrogen concentrations and improved water quality are often expected to result from restoration. Denitrification potential or actual denitrification rates may be quantified with a range of methods, appropriate to the question under consideration (Groffman et al. 2006).

COMMUNITY ENGAGEMENT

General objective: engage local communities and other relevant stakeholders to increase their sense of ownership in coastal ecosystem restoration, and their understanding of coastal processes and ecosystem services.

Examples of specific objectives: at least 100 volunteer hours devoted to monitoring TLP marsh responses; three presentations given to regional government agencies and nonprofits; at least 60 local school children involved in marsh planting; at least five citizen scientists trained in collecting monitoring data at the site; at least two articles in local newspapers about the project.

Example monitoring approaches:

- **Community participation.** Monitor/quantify volunteer hours, school group visits, media stories, community meetings, information sessions, etc. as part of a TLP project.
- **Landscape development.** Repeat photography at photo stations or from aerial photographs is instrumental for conveying to the community the changes that the landscape has undergone over time.

COMPLIANCE

General objective: avoid unintended negative consequences resulting from TLP, as dictated by relevant regulations and authorities.

Examples of specific objectives: avoid turbidity spikes in adjacent channels, where suspended sediment concentrations exceed pre-construction annual average by more than one standard deviation for more than one week; avoid sedimentation of adjacent eelgrass beds; avoid disturbance to threatened or endangered species.

Example monitoring approaches:

- **Turbidity.** Grab samples for suspended sediment or water quality sondes measuring turbidity in an adjacent channel.
- **Sedimentation.** Install traps in eelgrass beds or other adjacent habitats sensitive to sedimentation and track the amount of sediment deposition during and immediately post-construction.
- **Federally-listed species.** Conduct surveys before and during construction, with experts or trained biologists.

REFERENCES

Baldocchi, D., Falge, E., Gu, L., Olson, R., Hollinger, D., Running, S., Anthoni, P. et al. 2001. FLUXNET: A new tool to study the temporal and spatial variability of ecosystem-scale carbon dioxide, water vapor, and energy flux densities. Bulletin of the American Meteorological Society 82:2415-2434.

Ballanti, L. and Byrd, K.B. 2018. Green vegetation fraction high-resolution maps for selected US tidal marshes, 2015. ORNL DAAC, Oak Ridge, Tennessee, USA.

Buffington, K.J., Dugger, B.D., Thorne, K.M., and Takekawa, J.Y. 2016. Statistical correction of lidar-derived digital elevation models with multispectral airborne imagery in tidal marshes. Remote Sensing of Environment, 186.

Cahoon, D.R. and Guntenspergen, G.R. 2010. Climate change, sea-level rise, and coastal wetlands. National Wetlands Newsletter 32:8–12.

Cahoon, D.R., Perez, B.C., Segura, B.D., and Lynch, J.C. 2011. Elevation trends and shrink–swell response of wetland soils to flooding and drying. Estuarine, Coastal and Shelf Science 91:463-474.

Cain, M.R. and Hensel, P.F. 2018. Wetland elevations as sub-centimeter precision: exploring the use of digital barcode leveling for elevation monitoring. Estuaries and Coasts 41:582-591.

Conway, C.J. 2011. Standardized North American marsh bird monitoring protocol. Waterbirds 34:319-346.

Curdts, L.T. 2017. Continuous water level data collection and management using Onset HOBO® data loggers: A Northeast Coastal and Barrier Network methods document. Natural Resource Report NPS/NCBN/NRR—2017/1370. National Park Service, Fort Collins, Colorado.

Ekberg, M.L.C., Raposa, K.B., Ferguson, W.S., Ruddock, K., and Watson, E.B. 2017. Development and application of a method to identify salt marsh vulnerability to sea level rise. Estuaries and Coasts 40:694-710.

Ganju, N.K., Defne, Z., Kirwan, M.L., Fagherazzi, S., D'Alpaos, A., and Carniello, L. 2017. Spatially integrative metrics reveal hidden vulnerability of microtidal salt marshes. Nature Communications 8.

Groffman, P.M., Altabet, M.A., Böhlke, J.K., Butterbach-Bahl, K., David, M.B., Firestone, M.K., Giblin, A.E., Kana, T.M., Nielsen, L.P., and Voytek, M.A. 2006. Methods for measuring denitrification: diverse approaches to a difficult problem. Ecological Applications 16(6):2091-122.

Howard, J., Hoyt, S., Isensee, K., Telszewski, M., and Pidgeon, E. 2014. Coastal blue carbon: methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrasses. The Blue Carbon Initiative.

James-Pirri, M.J., Roman, C.T., and Nicosia, E.L. 2012. Monitoring nekton in salt marshes: A protocol for the National Park Service's long-term monitoring program, Northeast Coastal and Barrier Network. Natural Resource Report NPS/NCBN/NRR—2012/579. National Park Service, Fort Collins, Colorado.

Kalacska, M., Chmura, G., Lucanus, O., Bérubé, D., and Arroyo-Mora, J. 2017. Structure from motion will revolutionize analyses of tidal wetland landscapes. Remote Sensing of Environment 199:14-24.

Lynch, J.C., Hensel, P., and Cahoon, D.R. 2015. The surface elevation table and marker horizon technique: A protocol for monitoring wetland elevation dynamics. Natural Resource Report NPS/NCBN/NRR—2015/1078. National Park Service, Fort Collins, Colorado.

Moore, G.E., Burdick, D.M., Peter, C.R., Leonard-Duarte, A., and Dionne, M. 2009. Regional assessment of tidal marsh restoration in New England using the Restoration Performance Index. Final report submitted to NOAA Restoration Center. 237 pp.

Moore, K. 2017. NERRS SWMP vegetation monitoring protocol. Long-term monitoring of estuarine vegetation communities. National Estuarine Research Reserve System Technical Report.

Neckles, H.A., Guntenspergen, G.R., Shriver, W.G., Danz, N.P., Wiest, W.A., Nagel, J.L., and Olker, J.H. 2013. Identification of Metrics to Monitor Salt Marsh Integrity on National Wildlife Refuges in Relation to Conservation and Management Objectives. Final Report to U.S. Fish and Wildlife Service, Northeast Region. USGS Patuxent Wildlife Research Center, Laurel, MD.

Neil, A., Rasmussen, S., Bradley, M., and Stevens, S. 2017. On-the-ground collection of high-resolution elevation data in salt marsh environments: A Northeast Coastal and Barrier Network methods document. Natural Resource Report NPS/NCBN/NRR—2017/1371. National Park Service, Fort Collins, Colorado.

NOAA, National Ocean Service, and Center for Operational Oceanographic Products and Services. 2003. Computational Technique for Tidal Datums Handbook: NOAA Special Publication NOS CO-OPS 2. U.S. Department of Commerce. Silver Spring, Maryland.

Raposa, K.B., Lerberg, S., Cornu, C., Fear, J., Garfield, N., Peter, C., Weber, R.L.J., Moore, G., Burdick, D., and Dionne, M. 2018. Evaluating Tidal Wetland Restoration Performance Using National Estuarine Research Reserve System Reference Sites and the Restoration Performance Index (RPI). Estuaries and Coasts 41:36-51.

Rasmussen, S.A., Neil, A.J., Bradley, M., and Lynch, J. 2017. Local, short-term tidal datums and salt marsh elevations for three coastal national parks: Assateague Island National Seashore, Fire Island National Seashore, and Gateway National Recreation Area-Sandy Hook Unit. Natural Resource Report NPS/NCBN/NRR—2017/1462. National Park Service, Fort Collins, Colorado.

Roman, C.T., James-Pirri, M.J., and Heltshe, J.F. 2001. Monitoring salt marsh vegetation: a protocol for the long-term Coastal Ecosystem Monitoring Program at Cape Cod National Seashore.

Tinker, M.T, Espinosa, S.M., Staedler, M.M., Tomoleoni, J.A., Fujii, J., Eby, R., Scoles, R., Kenner, M.C., Hatfield, B., Fuentes, C., Lindsay, J.K., Nicholson, T., Murray, M., Young, M., Mayer, K., Dodd, E., Fork, S., and Wasson, K. 2018. The Population Status and Ecology of Sea Otters in Elkhorn Slough, California. Final Report for California Coastal Conservancy and U.S. Fish and Wildlife Service. 109 pp. plus appendices.

Wasson, K., Raposa, K., Almeida, M., Beheshti, K., Crooks, J.A., Deck, A., Dix, N., Garvey, C., Goldstein, J., Johnson, D.S., Lerberg, S., Marcum, P., Peter, C., Puckett, B., Schmitt, J., Smith, E., St. Laurent, K., Swanson, K., Tyrrell, M., and Guy, R. 2019. Pattern and scale: evaluating generalities in crab distributions and marsh dynamics from small plots to a national scale. Ecology, online first. https://doi.org/10.1002/ecy.2813

Westoby, M., Brasington, J., Glasser, N., Hambrey, M., and Reynolds, J. 2012. 'Structure-from-Motion' photogrammetry: A low-cost, effective tool for geoscience applications. Geomorphology 179:300-314.

EXAMPLE MONITORING PLANS FROM SELECT TLP CASE STUDIES

- Fountain, M., Jeppesen, R., Endris, C., Woolfolk, A., Watson, E., Aiello, I., Fork, S., Haskins, J., Beheshti, K., Wasson, K. Hester Marsh Restoration. Annual Report 2019. Elkhorn Slough National Estuarine Research Reserve. https://www.elkhornslough.org/wp-content/uploads/2019/09/Hester_Report190625_200p_online_updated.pdf
- Kutcher, T.E. and Chaffee, C.M. 2018. NOAA Coastal Resilience Project #NA17NMF4630288. Improving coastal habitat and community resiliency in Quonochontaug Pond, Charlestown, RI. Project monitoring plan. Prepared for the Rhode Island Coastal Resources Management Council. 34 pp.
- Seal Beach National Wildlife Refuge (CA) thin-layer sediment augmentation project reports; https://www.fws.gov/refuge/seal_beach/what_we_do/resource_management/Sediment_Pilot_Project.html