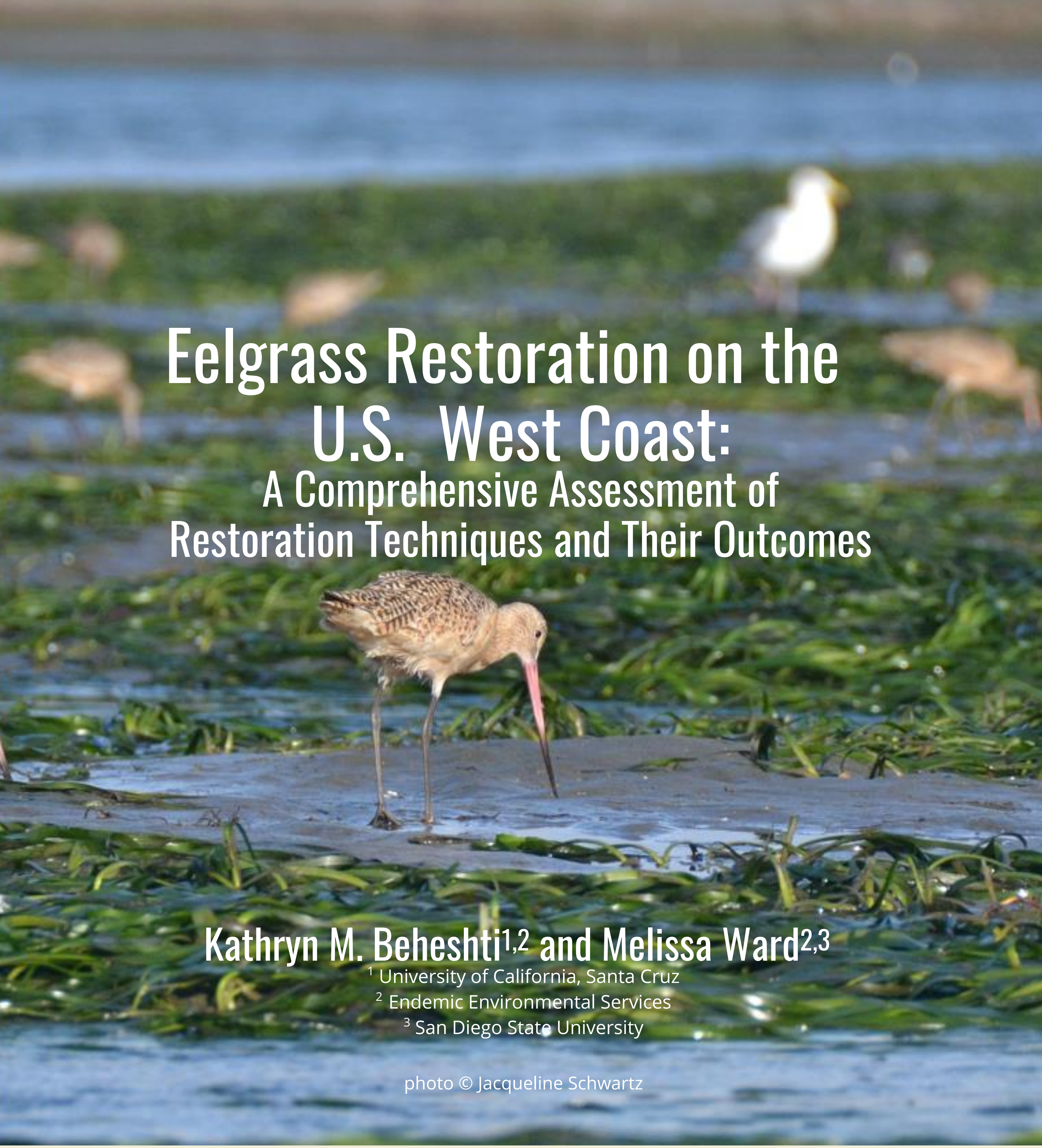

Eelgrass Restoration on the U.S. West Coast:

A Comprehensive Assessment of Restoration Techniques and Their Outcomes

Kathryn M. Beheshti[1,2] and Melissa Ward[2,3]

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PMEP

Friends of South Slough

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Indigenous Land Acknowledgement

The eelgrass restoration projects included in this report span a wide geographic area, covering the traditional lands of numerous Indigenous tribes. We honor and recognize these tribes and their legacies across the U.S. West Coast.

This report was commissioned by The Pew Charitable Trusts, which does not necessarily endorse the findings or conclusions, and developed by the Pacific Marine and Estuarine Fish Habitat Partnership (PMEP) to synthesize best practices for eelgrass restoration and protection on the U.S. West Coast (California, Oregon, and Washington), and identify those environmental, policy, and regulatory conditions that provide the best chances for success.

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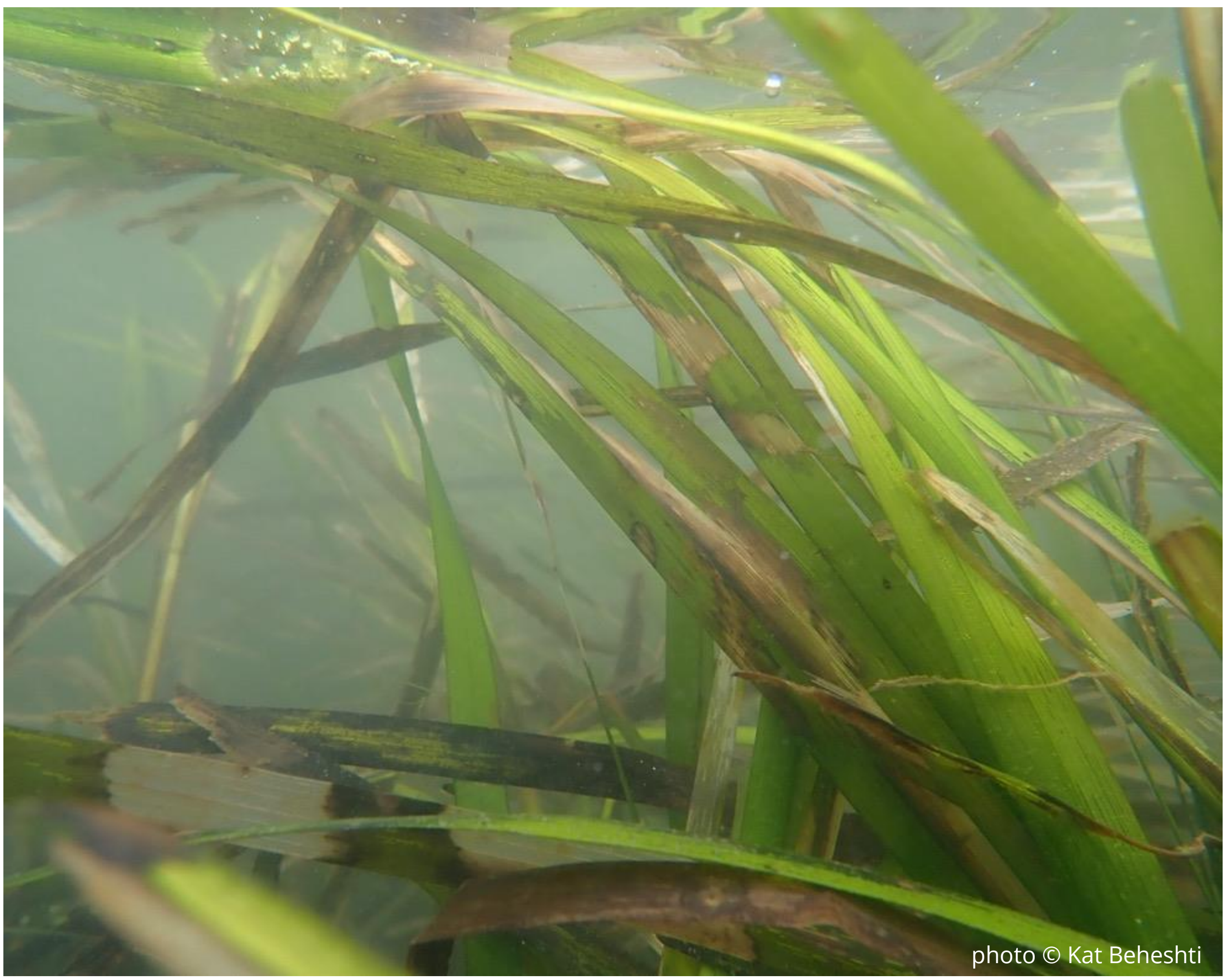
Executive Summary

As a foundation species, eelgrass (*Zostera marina*) provides critical functions that structure the ecosystem in which they occur. The importance of this species has been long recognized among practitioners, managers, and academics. In recent years, public enthusiasm for restoring and conserving eelgrass and the species it supports has only grown. While enthusiasm for eelgrass restoration is growing, there is currently no comprehensive 'how-to guide', specific to the U.S. West Coast, to help restoration practitioners ensure success of their restoration. Much has been learned through trial and error with previous authors attempting to synthesize these learnings (Thom 1990, Merkel 1998, Thom et al. 2008). This report aims to further identify best practices for eelgrass restoration and mitigation along the U.S. West Coast by reviewing and synthesizing data from past projects, culminating in guidance for restoration practitioners.

Eelgrass restoration is undertaken for research purposes, to achieve management goals, or for mitigation purposes to compensate for negative impacts to the habitat. The size, approach, and evaluation of the restoration can vary widely depending on why the restoration was undertaken. To identify best practices for eelgrass restoration along the U.S. West Coast, we synthesized data from 51 eelgrass restoration (non-mitigation and mitigation) projects from California, Oregon, and Washington. We conducted 22 interviews with leaders in the field, ranging from practitioners and managers to academics and consultants. Through these interviews we gathered qualitative data on past restoration efforts, gained a better understanding of best practices used, and filled gaps in data that were missing from formal reports and publications. We also conducted an extensive literature review of 51 total restoration projects.

Overall, we found that **restoration method**, while important, **is not typically the primary driver of restoration success or failure**. Instead, **environmental conditions have a**

substantial impact on whether or not a project will meet desired outcomes. Classifying a restoration as successful or interpreting relative restoration success across projects is difficult because practitioners' success criteria vary widely. When defined, practitioners typically measured success in terms of an increase in shoot density or transplant area. Very few practitioners measured success by evaluating a gain in ecosystem services - a direction for future work. In generating this report we provided a series of recommendations intended to improve alignment and coordination of eelgrass restoration along the U.S. West Coast. Broadly, we recommend that best restoration practices be applied by all practitioners through a 5-step process: assessing site suitability, selecting methods, conducting a pilot restoration, conducting a full-scale restoration, and evaluating restoration success using a reference meadow. The report presented here elucidates the details and motivations for these best practices, while demonstrating their importance in improving knowledge and success of eelgrass restoration across the U.S. West Coast.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1. Background and Project Overview

Seagrass is declining worldwide and human impacts play a significant role in this decline. Along the U.S. West Coast, eelgrass (*Zostera marina*), the dominant seagrass species in the region, is continually affected by human activities such as dredging, dyking, eutrophication, and pollution (Waycott et al. 2009). These acute stressors are compounded by the current and future impacts of sea-level rise, rising water temperatures, and changes in precipitation patterns. Restoration of eelgrass to counteract its decline is a strategy of growing importance along the West Coast.

In the United States, eelgrass is considered a special aquatic site under the Clean Water Act (40 C.F.R. § 230 Section 404(b)(1) guidelines), which provides special consideration when evaluating permit applications for dredged or fill material pursuant to Section 404 of the Clean Water Act. In addition, eelgrass is designated as essential fish habitat (EFH), and a habitat area of particular concern (HAPC) for various federally managed species under the Magnuson-Stevens Conservation and Management Act (MSA) (NMFS, 2007), and is important to the conservation of some species protected under the Endangered Species Act, such as Chinook salmon (*Oncorhynchus tshawytscha*), chum salmon (*O. keta*) and green sea turtles (*Chelonia mydas*). NOAA's National Marine Fisheries Service (NMFS) also established a policy goal of no net loss of eelgrass function in California waters, and developed guidelines to help achieve this goal (NMFS, 2014). NMFS's habitat protection efforts indirectly serve to conserve the suite of ecosystem services associated with eelgrass beyond the provisioning of critical fish habitat.

Eelgrass supports a suite of ecosystem services and functions, thus the preservation and restoration of eelgrass is a top priority for the region. Eelgrass plays an important role in biogeochemical cycling, stabilizing sediments, and supporting estuarine food webs. Eelgrass meadows provide food and shelter for many fishes and invertebrates. As a nursery habitat, meadows provide refuge for juveniles protected within its dense canopy. Commercially important species such as Dungeness crab, California Halibut, English Sole, Pacific herring, and Gaper, Jacknife, Littleneck, and Manila clams (Sherman and DeBruyckere 2018). By creating structure and microhabitats, eelgrass increases biodiversity. By slowing water flow and attenuating waves, eelgrass can act as a storm buffer and can protect developed coastlines from storm surges. Relatedly, as water slows, particulates can settle out of the water column--one pathway through which eelgrass facilitates carbon storage in underlying sediment. The other pathway is through the removal of aqueous carbon dioxide (CO_2) from seawater. Currently, legislation and guiding documents from California, Oregon, and Washington call for eelgrass restoration and conservation as a means to enhance ecosystem resilience through these carbon services (Nielsen et al. 2018; Barth et al. 2018; Washington Marine Resources Council 2017; California Ocean Protection Council Strategic Plan 2020). However, few restoration projects along the West Coast have included assessments of carbon services in their evaluations of success.

In a review of 17 restoration projects extending from San Francisco to British Columbia between 1974-1990, Thom (1990) made a series of recommendations based on the knowledge gained from past efforts. Recommendations included conducting comprehensive site suitability assessments and experimental transplanting, especially when eelgrass was not present at a potential restoration site, and quantifying whether restored and reference sites were performing similar functions. These recommendations were made during a period of time when the majority of reviewed projects were failing and practitioners rarely assessed functional equivalency. Years later, Thom et al. (2008) reviewed an additional 30+ eelgrass restoration projects in Western Washington and British Columbia and synthesized results and lessons learned. Through this effort, the authors identified an immediate need for a 'clearinghouse' of eelgrass restoration and monitoring results and standardization of monitoring techniques. In 1998, Merkel released a review of 56 restoration projects (excluding research transplants) from British Columbia to San Diego between 1976-1998. Comparing project outcomes was a challenge due to inconsistent definitions of success, but he was able to determine that restoration success was relatively higher when environmental conditions were improved prior to transplanting versus transplanting at unmanipulated sites (Merkel 1998). Building on previous synthesis reports outlined above, this report aims to identify best practices for eelgrass restoration and mitigation along the U.S. West Coast by reviewing and synthesizing data from past projects (1986-2020) and interviewing local experts and practitioners leading restoration efforts across the region.

In completing this report, we anticipated one of the primary challenges in assessing restoration outcomes to be defining restoration "success". How restoration success is defined varies, yet common metrics of success often include comparisons to reference sites, specifically comparing ecosystem attributes related to ecosystem functioning, diversity, or vegetative structure (Ruiz-Jaen and Aide 2005). Others measure restoration success as the persistence of transplanted or seeded plots through time or by whether restored plots are reproducing and/or expanding. Rarely do practitioners have the personnel or funding to monitor restored plots beyond 3-5 years. Yet long-term monitoring is necessary to track the stability and resilience of restored habitats relative to reference sites and the status and condition of the reference sites themselves.

In this report we review and synthesize the data from 51 projects from California, Oregon, and Washington. Using the qualitative data from 22 interviews with practitioners, we identify leading causes of restoration failure and develop a cautionary approach to restoration that aims to prevent further eelgrass loss. The report ends with several recommendations that we believe will increase effectiveness of eelgrass restoration along the U.S. West Coast.


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2. Methods

We conducted a review of the effectiveness of a variety of eelgrass restoration techniques to examine possible correlates of restoration outcomes across the U.S. West Coast (California, Oregon, and Washington). This work moves beyond the review of eelgrass status and services to identify best practices for eelgrass restoration within the region. We generated a database that includes qualitative and quantitative information gathered during 1-hour interviews with 22 eelgrass restoration practitioners and a rigorous literature review. The synthesis was developed from the database, which is summarized in Appendix A.

2.1 Interviews

From October 2020 to January 2021, we interviewed 22 eelgrass restoration practitioners, managers, and scientists from California, Oregon, and Washington. The primary goal of the interviews was to gather as much qualitative information as possible on eelgrass restoration methods and project success. The interviewees, many of whom have been working in the field for decades, have a wealth of knowledge and experience that is often unpublished or overlooked in existing reports of eelgrass restoration. Interviews followed a standard protocol and list of questions, but also allowed time for an open-ended discussion based upon the interviewees relevant expertise in eelgrass restoration. The questions were designed to 1) improve our technical understanding of which methods may be best applied for future restorations, and 2) understand reasons aside from transplantation methods that might contribute to eelgrass restoration success or failure. Interview notes may be made available upon request. Our database, described below, was structured to include this type of qualitative information, in an effort to document interviewees' expertise and knowledge.

In addition to the information gained during the interviews themselves, we requested reports, publications, or available project data prior to each interview. Data on restoration projects gleaned from materials provided were entered into the literature review database (described below) prior to each interview. Obtaining and reviewing reports and data prior to conducting the interviews, allowed us to clarify project details and findings from the provided material during the subsequent interviews.

2.2 Literature review and database

We extracted eelgrass restoration data from a variety of sources including technical reports or other grey literature, raw data, and peer-reviewed articles. For raw data to be included, data needed to be sent directly from the project manager or data collector, to ensure we could ask additional questions about the project and ensure data quality prior to inclusion in our database.

Within the database, we defined the following terms and extracted data accordingly:

Project: Each report, publication, or dataset we received typically included restoration efforts that were initiated on a single transplant date or during a single transplant season. In these cases, this was defined as a single project. However, some reports of eelgrass restoration spanned a given managing agency's restoration efforts across numerous years (e.g. Projects 19-22 in Appendix A). In these cases, projects were considered distinct in each transplant year (or for passive projects, each year where the site was 'created', for example by debris removal).

Plot: A unique plot within a project was defined by the practitioner or report - creating large variation in plot sizes within the database. For example, a mitigation project may restore a relatively large area (e.g. 100 m^2) and consider this a single plot, monitoring the total area and the average shoot density within it during each monitoring period. On the other hand, other projects may have relatively small plots (e.g. 1 m^2), transplanting many more of these plots and monitoring each separately within a larger area.

Mitigation project: Mitigation projects are defined as any project conducted for compliance purposes due to previous loss of eelgrass, which all targeted pre-defined mitigation criteria for areal coverage or shoot density of eelgrass.

Non-mitigation project: All other projects not falling under the "mitigation project" category were defined as non-mitigation projects. These were restoration projects conducted for a variety of reasons (e.g., for experimental purposes or to meet management targets).

Passive restoration project: Passive restoration projects were defined as projects where no seeding or transplanting occurred. Instead, passive projects altered site conditions in such a way that natural recruitment or expansion of eelgrass could occur. This could have been through debris removal or by altering substrate by adding or removing sediment to create a depth zone suitable for eelgrass.

Active restoration project: Active restoration projects were defined by either the direct transplant of shoots via any of the methods displayed in Figure 4, including seeding techniques. Both mitigation and non-mitigation projects frequently used active restoration techniques.

To be considered for analysis, selected projects (mitigation or non-mitigation) needed to report the transplanted shoot density and monitored shoot density at least one month after planting *or* the transplanted area and monitored area at least one month after planting. If neither of these metrics were evaluated, we were unable to assess success and thus excluded them from the database. We applied different criteria for inclusion of non-mitigation versus mitigation projects because of the high number of mitigation projects and low number of non-mitigation projects. Specifically, all non-mitigation projects with available data (n=21) were included because they typically measured more variables than mitigation projects, and we received fewer reports from non-mitigation projects, allowing us to include all we received. For instance, non-mitigation reports were more likely to conduct a comparative analysis of restoration methods or monitor for ecosystem services gained via restoration. Of the mitigation projects included (n=30), many project reports were extracted from EcoAtlas, while some were sent directly by practitioners (CWMW, 2021). Given the high number and ready availability of mitigation reports, particularly from Southern California, we selected a subset of these projects for analysis. Of the included mitigation projects, 17 came from California, given its long history of eelgrass mitigation and associated policies (e.g. the California Eelgrass Mitigation policy, or CEMP). Mitigation projects were selected for inclusion based on whether or not the watershed where restoration occurred was represented in the database yet, with priority given to projects with longer monitoring periods and to those that had been conducted in recent years.

All included projects and their meta-data are included in Appendix A. Despite numerous projects being excluded in our quantitative assessment for the aforementioned reasons, we noted all other eelgrass projects that were considered for the report in Appendix B.

Variables extracted from each project included meta-data such as the project date, project type (mitigation versus non-mitigation) as well as methodological information such the method type (e.g., seeding, garden stake anchors). In addition to these broader data, data regarding the transplantation and each consecutive monitoring period for each plot were input into the database. These included spatial and structural attributes of the planted area as well as any reference meadows, when available. The primary spatial and structural variables collected included plot area and plot density, however when available, additional attributes such as canopy height or percent cover were also collected. Information on any co-collected environmental variables (e.g. temperature, dissolved oxygen, depth) or ecosystem services (e.g. habitat provisioning, species richness, carbon burial) were also collected. Projects were also assigned an “estuary ID” to be consistent with PMEP’s other estuary data and included in the West Coast USA Eelgrass (*Zostera* sp.) Habitat Data Layer. A full list of the extracted variables can be viewed in Appendix C.

2.3 Data processing and analysis

From each project, all data from each plot (regardless of the defined plot size) was extracted in an effort to include the finest spatial resolution possible, rather than losing information by averaging across plots. For passive restoration projects (n=4), the plot size was defined as the area monitored for eelgrass return (e.g. the area over which debris was removed). In these projects, the “starting shoot density” (analogous to the transplanted shoot density in active restorations) would be input as the average shoot density in this area

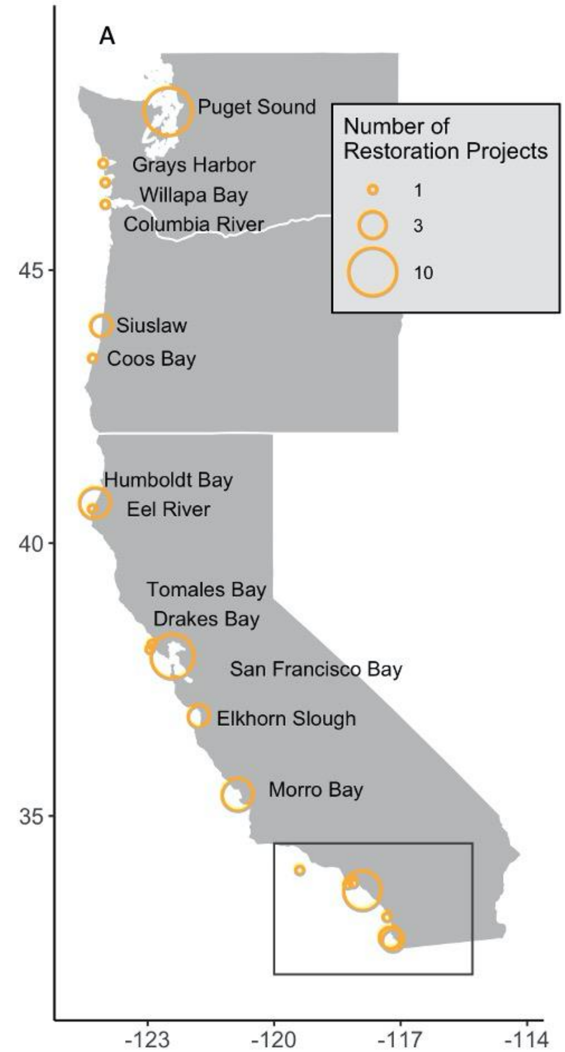

Figure 1. Map of projects included in our analyses. The circle size is indicative of the total number of projects included. Panel A depicts all included projects, while Panel B includes a more detailed view of projects conducted within the Southern California bight (depicted within the square in Panel A).

immediately post-restoration (e.g. upon removal of debris). If no eelgrass was present this would be input as '0'. The monitored shoot densities were input as the average shoot densities measured within the plot in each future monitoring period. Similarly, for the area of passive restoration projects, the starting area was defined as the area restored that contained eelgrass. If no eelgrass was present, this would be '0', in an effort to capture areal growth in the same way as active restoration projects. The subsequent monitored area was likewise input as the total area with eelgrass present in each future monitoring period. The above metrics are summarized in Table 1.

To standardize data for comparison, incongruencies in reported data were resolved through communications with the project contact or report author. Where incongruencies could not be resolved, data were flagged and excluded from analysis. Few peer-reviewed articles were found. This data quality issue presented many challenges, and its implications are reviewed in the discussion section below.

2.4 Defining Success

There are many ways a restoration project can be deemed 'successful', and how it is defined can vary widely across projects. In mitigation projects, there are typically rigid definitions of success based around meeting predefined shoot density and areal coverage criteria. Other projects compare ecosystem attributes related to ecosystem functioning, diversity, and vegetative structure to reference sites (Ruiz-Jaen and Aide 2005). To evaluate restoration success across all projects, we used three definitions of success:

1. Practitioner-defined success
2. Shoot density in the last monitoring period ≥ transplanted shoot density
3. Plot area in the last monitoring period ≥ transplanted plot area

Defining our own metrics (definitions 2 and 3) allowed us to assess success across projects that may have had varying practitioner-defined success metrics (see Table 2). Unfortunately, too few studies conducted analyses of ecosystem services for us to assess restoration success based on ecosystem services provided in restored relative to reference habitats. Ecosystem services were therefore excluded from formal definitions of success. Details of the nature of these ecosystem services are discussed in section 3.4.

3. Results

3.1 Summary of restoration projects

We identified 113 total restoration projects, 51 of which were included for analysis in this study (Fig. 1). These 51 projects restored a total of 505 individual restoration plots across California, Oregon, and Washington (Fig. 2). 30 projects were conducted for mitigation purposes, while 21 projects were non-mitigation restoration projects. Project data come from technical reports or other grey literature (n= 34), raw data or data extracted from powerpoint presentations (n=11), and peer-reviewed articles (n= 6). Four projects were passive restoration projects, while 47 were conducted through active transplanting of shoots or seeding (Fig. 2).

Average transplanted shoot density (shoots per m^2) was 37.5 ± 7.08 (mean ± standard error, SE), and the average area each project transplanted was 11,159 m^2 or 2.75 acres (mean), but with very high variability (7,632 m^2; SE; Table 1). This variation in project area is in part due to the purpose of the projects. One project may focus on experimental restorations which transplant relatively small total areas but conduct extensive monitoring and evaluation (e.g., Projects 10, 11, 13-15 in Appendix A; Case Study

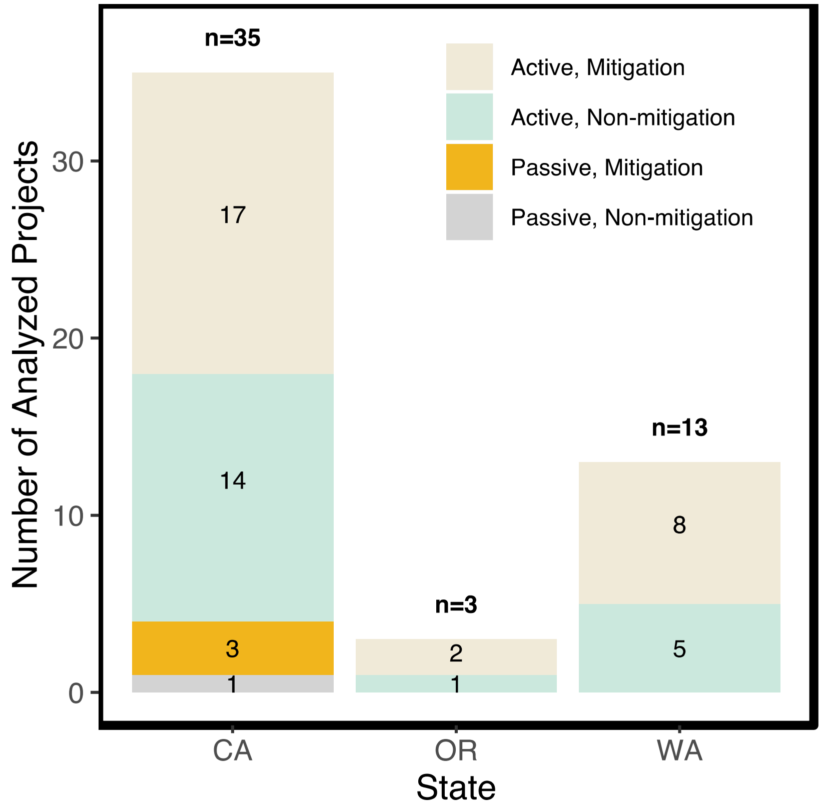

Figure 2. Number of analyzed projects (n=51) by region and type (active vs. passive, mitigation vs. non-mitigation). One project (Project 41 in Appendix A) took place in both Oregon and Washington and is represented in the above figure as having occurred in both states even though it was a single project.

Average project monitoring time (months)	**Average transplant shoot density** (shoots/m2)	**Average project transplant area** (total project size) (m2)	**Average change in shoot density** (%)	**Average change in plot area** (%)	**Total projects (n) quantitatively measuring *any* ecosystem service**	**Total projects (n) quantitatively measuring carbon ecosystem services**
41	37.5 ± 7.08	11,159 ± 7,632.1	817 ± 383	7,775 ± 5,417	8	4

Table 1. Summary of analyzed projects. Average (±) SE for structural attributes across all 51 projects included in the database and total number of projects measuring any and/or carbon-specific ecosystem services. For data expressed at % change, positive values indicate project increase in shoot density or area by the last monitoring timepoint, while negative values indicate a decrease. Passive restoration projects are excluded from % change analyses when starting shoot densities and areas are zero.

2). On the other hand, projects seeking to reach a management acreage target or a mitigation requirement may restore larger areas, but are often relatively data-poor (e.g., Projects 23, 34 in Appendix A; Case Studies 1, 4). Of the projects included that quantified transplant area (n=49), a total of 140.6 acres (568,988 m^2) of eelgrass habitat was transplanted (Table 1).

Given that the database (Appendix A) does not include many of the restoration projects we know have been performed in the region (Appendix B), this value only represents a fraction of the total area transplanted in recent decades. Moreover, many of the projects we selected for their data-rich nature were small in area. If additional projects from Appendix B and other restorations in the region are included in future analyses, it may be possible to determine an accurate estimate of total eelgrass area restored in the region.

3.2 Restoration Methods

Practitioners employed a wide variety of restoration methods across the included projects. The most commonly used methods were variations on bare root transplant techniques, followed by seeding, plugs, TERFS (Transplanting Eelgrass Remotely with Frames), or unanchored shoot techniques (Fig. 3). Other methods included transplant with a burlap based anchor (Project 1 in Appendix A) and pliable paper anchors (Project 17 in Appendix A; Case Study 1).

Bare root transplanting involves using anchors such as garden staples, popsicle sticks, bamboo or rebar stakes (Fig. 3). In many of these methods, practitioners collect bundles of shoots, which are then fastened to the anchors on shore before being taken to the restoration site. These anchors are then pushed into the sediment along with the attached eelgrass roots and associated rhizomes. Materials used to tie eelgrass to the anchors are typically biodegradable or paper-covered metal-wire twist ties. Eelgrass was not always tied to anchors (e.g. Projects 10, 11 in Appendix A).

Seeding was conducted typically by buoy deployed seeding (BuDS), whereby collected seed was placed into mesh bags and tied to buoys to allow for natural spread. Hand broadcasting was also utilized, but less common than BuDS. In both seeding cases,

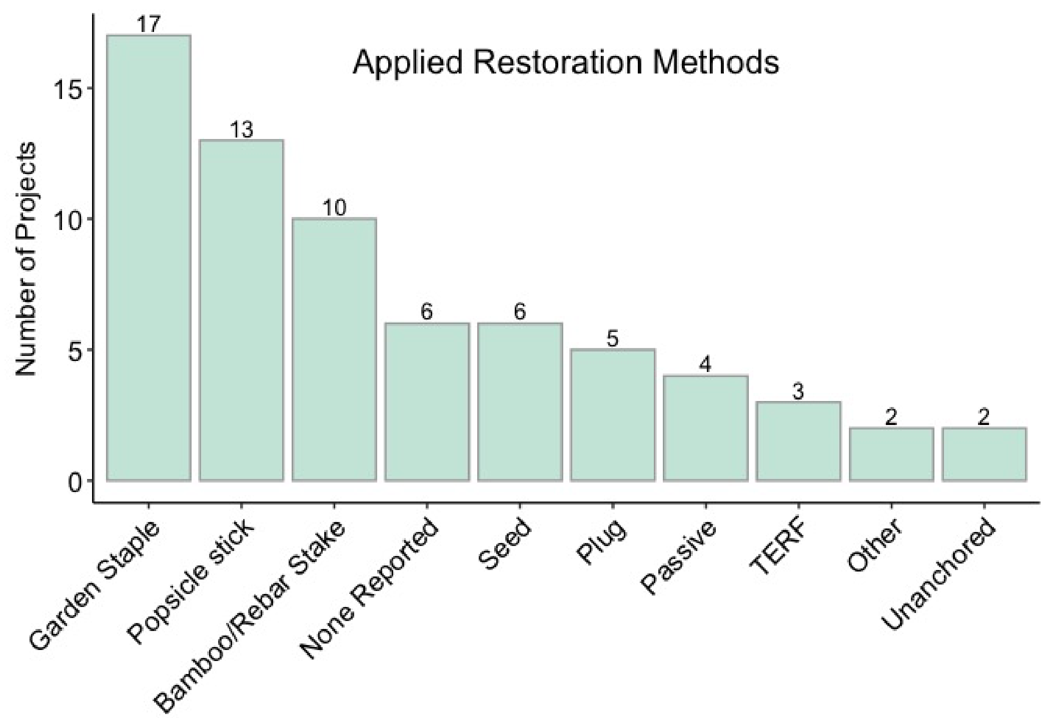

Figure 3: **Summary of the methods applied in each project within the database.** If a project employed more than one method, both were counted and displayed in the figure above.

these methods were often used as a secondary method to supplement restoration plots where shoots had been directly transplanted to increase the chance of plot success and increase genetic diversity (e.g. Projects 19, 32-34 in Appendix A).

Plugs are defined by transplants in which the natural, donor meadow sediment around the eelgrass root and rhizosphere is retained through to transplantation.

TERFS feature numerous shoots secured to frames made of a variety of materials (e.g. vexar or metal), which are then placed onto the surface sediment.

Unanchored techniques include either the hand burial of shoots directly into sediment, or the lack of subsurface anchor whereby shoots are tied to rebar which is left to sit on the sediment surface to let shoots naturally anchor themselves to the sediment.

The defined method categories above encompass the vast majority of techniques within the West Coast region (Fig. 4). During our interviews practitioners mentioned other transplant techniques such as tying shoots to metal washers or bolts, though none of the reviewed reports included either of these techniques. Six mitigation projects (n = 6) did not report which method was used (Fig. 3). Based upon what was reported in other mitigation projects, it is likely that many of these 'none reported' data points are also variations of anchored, bare root transplants.

Practitioners identified numerous advantages and disadvantages for each applied method, which informed their methods selection prior to beginning a restoration project (Fig. 5). Factors identified for consideration when selecting a restoration method included budget, personnel, site type (environmental/sediment conditions), and project duration (Fig. 5).

Within the bare root transplant methods, 'garden staples', 'popsicle sticks' and 'bamboo or rebar stakes' methods were most favored by project practitioners and were used repeatedly in projects showing success. These methods were often favored for their relatively low cost and ease of preparation and transplantation. Of bare root transplant methods, the 'bamboo stakes' method can be effective for shallow transplant sites where currents are weaker. However, more equipment is needed for the 'bamboo stake' method compared to the 'garden staple' method and handling of the transplants can be cumbersome. Because shoots are tied at the meristem to bamboo stakes that are 75 cm long, a minimum of two people are required to transplant due to their size. The bamboo stakes stick out of the substrate which offers the added benefit of ease of locating transplanted sites during monitoring, regardless if shoots are present or not. The 'popsicle stick method' is better at deeper transplant sites, partly because it is less cumbersome and can be managed in a way that allows one person to work independently without assistance. It is also well suited in soft sediment, where insertion of these anchors into the sediment can be relatively easy and fast.

The 'garden staple' technique is both easy and fast to install, but during our interviews, one practitioner expressed concern about the bridge of the garden staple eventually eroding and becoming a safety hazard. Another practitioner mentioned that transplants anchored by garden staples are easily pushed up by burrowing animals, removing contact between the transplanted shoot and sediment surface and making shoots more likely to either drift away or die. Despite these concerns, other practitioners that have used the garden staple method have shown tremendous success for small scale restorations and did not cite issues of staples eroding or being dislodged from the sediment (Projects 10,11 in Appendix A). While TERFs have been employed by many restoration practitioners (Addy 1947a, 1947b, Short et al. 2002), they ranked lowest of the discussed transplantation methods.

Although bare root anchoring methods are most popular and have led to success in many projects, less common methods may still be appropriate in certain cases. For example, the Siuslaw Bridge project (Projects 4, 5 in Appendix A) saw success using plugs, in an effort to minimize alterations to the plants' microenvironment and decrease transplantation stress. However, this mitigation project was small-scale, and the donor material was taken from a meadow very close to the restoration site, making transfer of the heavy eelgrass sediment accompanying the shoots feasible. Moreover, the donor meadow was expected to be lost due to construction, making harvesting impacts to the donor meadow a non-issue (the entire donor meadow could be removed and re-transplanted). For larger scale restorations that rely on a persistent donor meadow, the number of shoots that need to be transplanted may be too large to support the 'plug' method given its potential sediment disruption to donor meadows.

There are practical limitations to using plugs that limit their utility, such as the unwieldy weight and volume of the donor material that would be needed to support large projects. In more urbanized areas such as San Francisco Bay, the potential to facilitate spread of invasive species through sediment movement increases. In those areas, bare root transplants are typically rinsed prior to transplantation (to remove invasive epifauna). On the other hand, in watersheds where spread of invasive species is limited or the distance between donor meadows and restoration sites is small, plugs may also facilitate eelgrass persistence by encouraging the development of healthy ecological communities in the restored meadow.

Although seeding has been very successful in Virginia's coastal lagoons and throughout the mid-western Atlantic (Orth et al. 2020), to date, few restoration projects across the U.S. West Coast employed seeding. Those that have have experienced variable success. It should be noted that this variable success does not necessarily indicate complete inefficacy of seeding in restoration, rather methods may need to be refined. For instance, environmental conditions (some of which are still unknown or constantly changing with shifting baselines) may need to be ideal to yield positive restoration outcomes. Although the mechanism behind seeding failure is unclear, it is possible that the low success is due to challenges with seed viability, timing, water quality, or hydrodynamics (Boyer pers comms, see Projects 19 and 41 in Appendix A). Often, seed buoys are deployed in summer, leading to growth of new shoots mid-winter (Projects 19, 32-34 in Appendix A). At the time of first growth, new eelgrass shoots are small and unable to penetrate the upper water column like adult shoots. This makes them highly affected by a low light environment. If seed propagation corresponds with times of high turbidity associated with winter storms and swells, this may decrease or prevent success of seeded restoration plots.

Additionally, tracking seeded restoration plot success is challenging because seeds can travel great distances before settling and germinating. While we do not recommend using seeding as the primary method for restoration, it still may serve as a useful tool, and could become more useful if new research can identify seeding approaches that improve its viability. One large benefit to seeding methods is the subsequent increase in genetic diversity it provides in restored plots, which can be harder to attain through expansion and vegetative growth of transplants (Williams and Orth 1998, Williams 2001, Hays et al. 2021). Given some studies have shown that success of restoration can vary based on the location of the donor meadow (e.g., showing signs of phenotypic plasticity or local adaptation), addition of genetic diversity may clearly play a role in facilitating restoration success. So seeding might be a valuable additional method to be used in conjunction with other methods, even if it is not highly viable as a stand-alone strategy (Projects 38-40 in Appendix A).

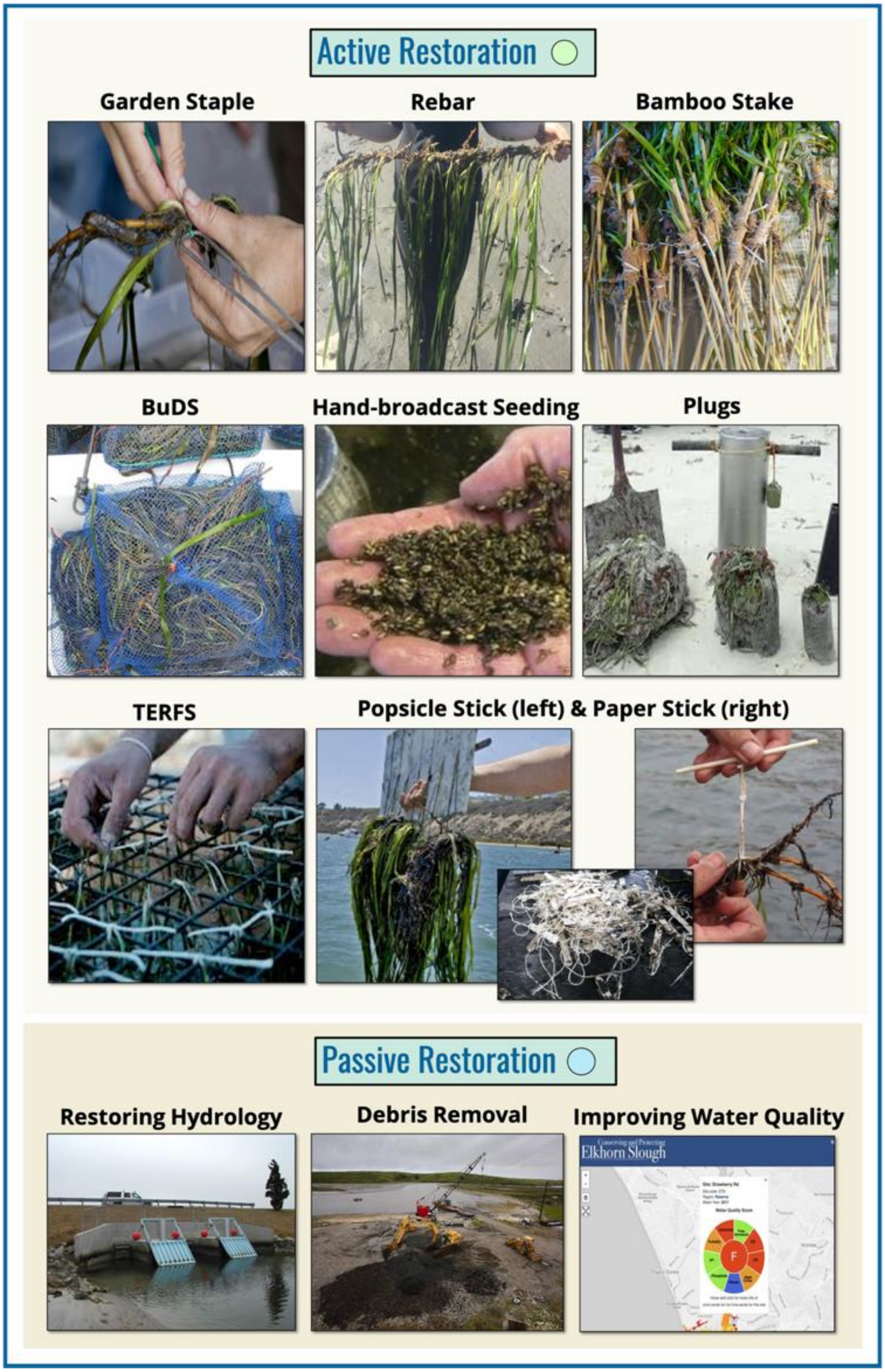

Figure 4. Common restoration techniques. Active (top) and passive (bottom) restorations commonly used along the U.S. West Coast.

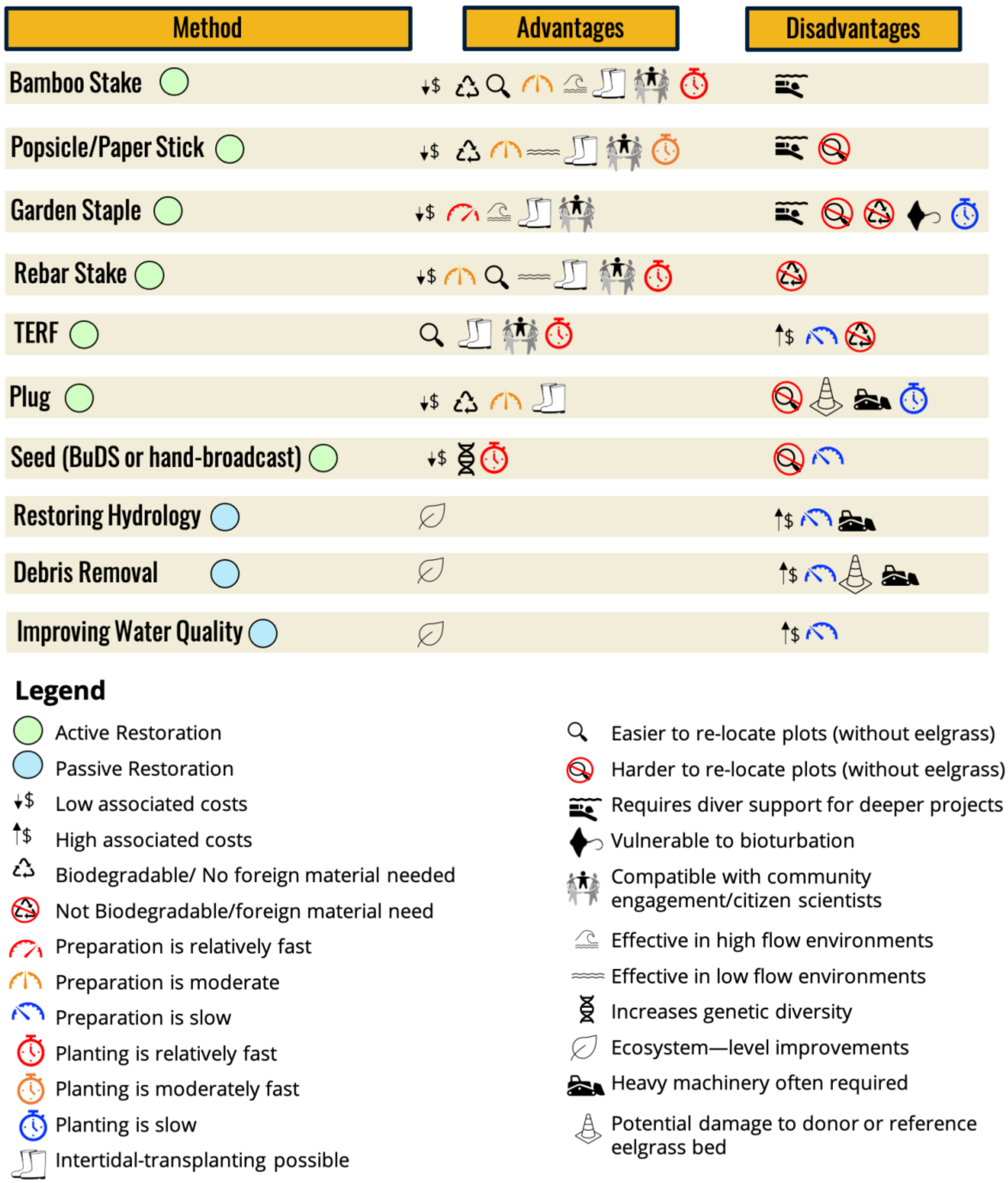

Figure 5: The advantages and disadvantages of the restoration methods identified primarily by interviewees.

3.3 Regional success

3.3.1 Success under varied definitions

We evaluated the success of 505 defined plots within our database of 51 projects using the three definitions of success:

1) Practitioner-defined success,
2) Shoot density in the last monitoring period ≥ transplanted shoot density
3) Plot area in the last monitoring period ≥ transplanted plot area.

Practitioner defined success
Typically, these criteria were based on achieving predefined shoot densities or areas by the end of the project. These criteria also varied based on the length of the project or goals of the practitioners. Of the plots where practitioners had defined success, 87 (49.7%) plots met at least one defined criteria and 88 (50.3%) failed to meet the defined criteria for success. The majority (330) of the plots could not be evaluated because no criteria were defined by the practitioners (see Appendix A for projects where practitioners defined success).

Increase in shoot density and plot area
When success is defined as an increase in shoot density by the end of the project, 224 (65%) plots of projects that measured shoot density met this goal and 119 (37%) failed to meet this goal (Table 2). When the actual transplanted shoot densities are examined, we see that the mean change in shoot densities across all projects was an increase by 82.5 shoots/m^2, while the median was 29 shoots/m^2 (Figure 6). Fewer studies quantified areal coverage over the course of their projects, with no data on 353 of the included plots. Of the plots that did measure areal growth, 81 (53%) of these plots had areas equal or greater than what their initial transplant areas (Table 2).

density (29) is shown by the brown, short-dashed line and the mean Δ density (82.5) is shown by the blue, long-dashed line.

It should also be noted that we hoped to assess the number of projects where a pre-defined ecosystem service in a restored plot was greater than or equal to an unvegetated control plot. However, so few plots evaluated success based on such criteria (see Table 1), these data were excluded from analyses in Table 2. Similarly, of the 535 plots we could evaluate for success, only 39 of these plots were part of projects where a reference meadow was co-monitored for shoot densities over the duration of the restoration project, making evaluation of success in the context of reference meadow success very difficult.

However, we can take a 'case studies' approach to understand the variety of project outcomes where both reference meadows and restoration plots are both monitored (Fig. 7). In some cases, projects restore multiple plots, each of which had an accompanying reference plot (Fig. 7B and 7C). In other cases, a single reference meadow was monitored to accompany one or more restoration plots (Fig. 7A and 7D). While there is considerable variability, reference plot and restoration plot shoot densities often change in similar ways over the course of the monitoring periods. However, this is not always the case as can be seen in the Salt River Channel Creation project (Fig. 7B), a passive restoration project, where reference areas within the project nearly all disappeared, despite success within the restored plots.

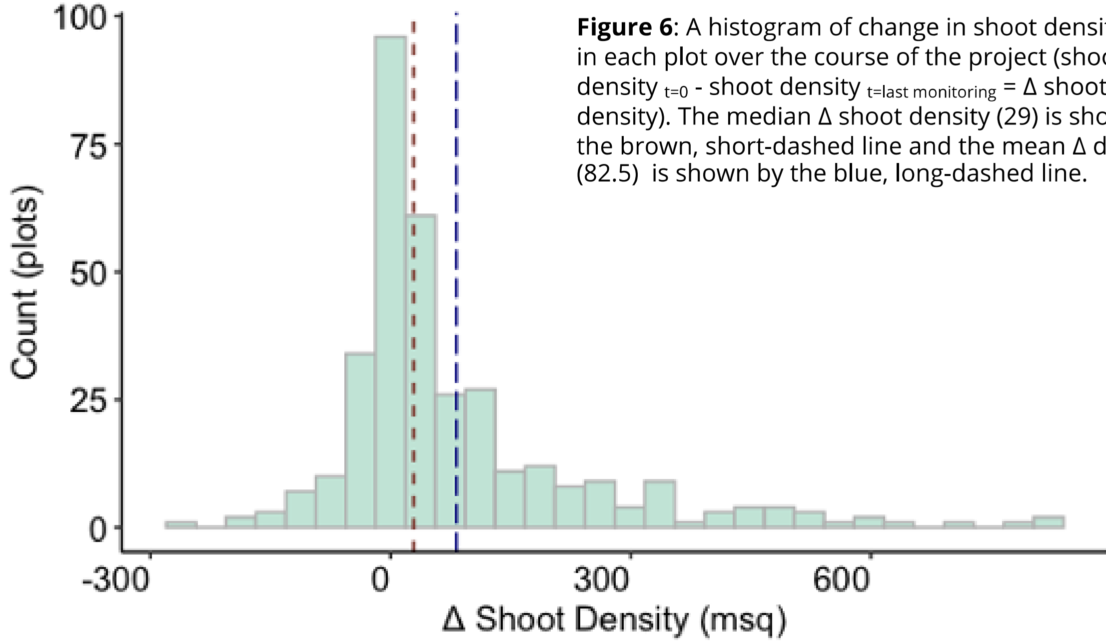

Figure 6: A histogram of change in shoot density (m^2) in each plot over the course of the project (shoot density $_{t=0}$ - shoot density $_{t=last\ monitoring}$ = Δ shoot density). The median Δ shoot density (29) is shown by the brown, short-dashed line and the mean Δ density (82.5) is shown by the blue, long-dashed line.

Defined success criteria	Practitioner-defined success criteria	Shoot density in the last monitoring period ≥ transplanted shoot density	Plot area in the last monitoring period ≥ transplanted plot area
Number of plots meeting (at least one) criteria	87	224	81
Number of plots failing to meet criteria	88	119	71
Number of plots where this criteria was not evaluated	330	162	353

Table 2. Success criteria tally. Describes the total number of plots that met various definitions of success, either defined by the practitioner, or created herein to further identify success.

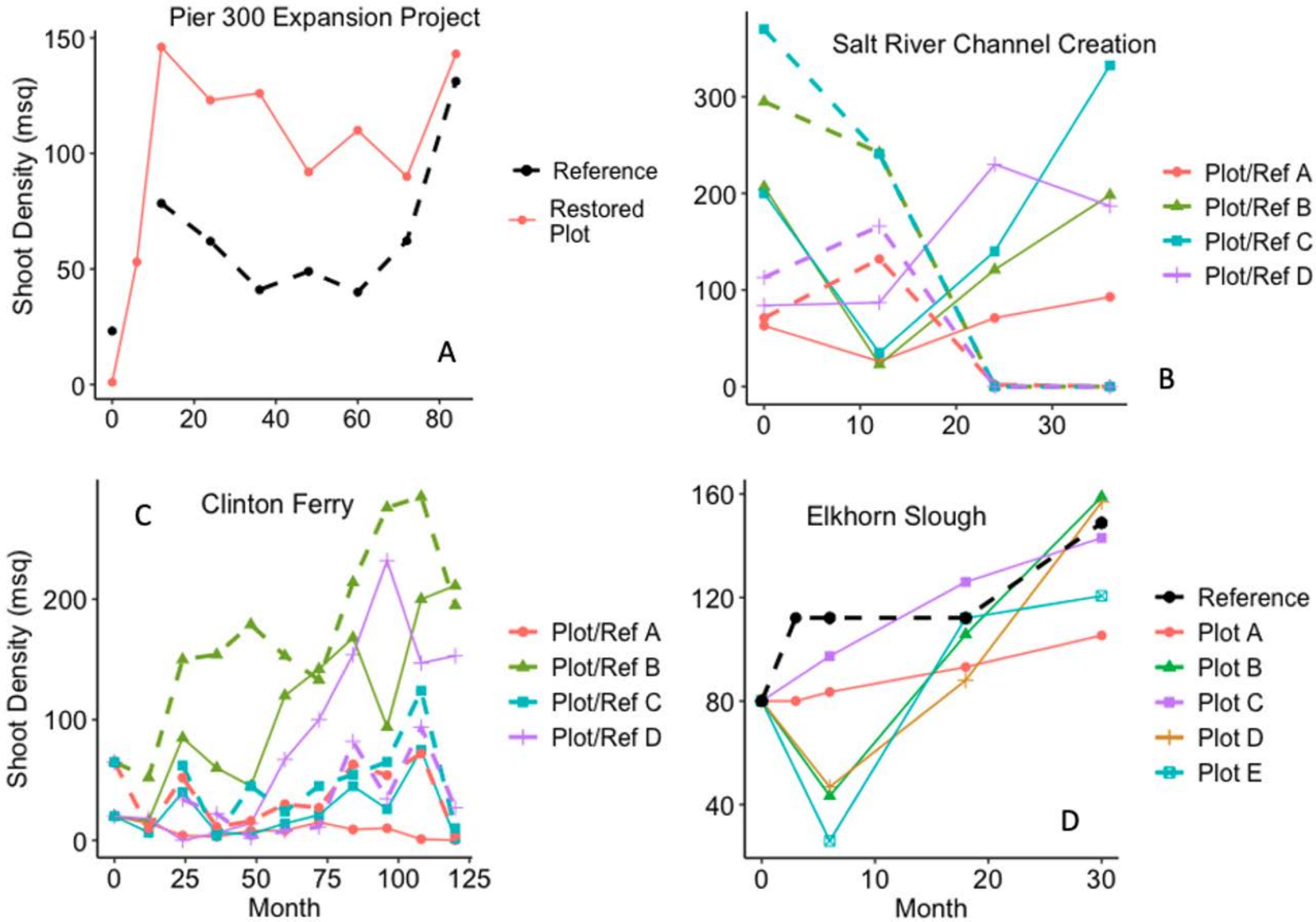

Figure 7. **Time series of shoot density in restored and reference plots.** A selection of projects that co-monitored reference plots (dashed lines) alongside their restoration plots (solid lines). Figures show measured shoot densities (shoots/m^2) over the full course of the project monitoring period. Unconnected data points (panel A) indicate periods of monitoring lapses - where the restored plot was monitored but the reference was not. From the projects listed in Appendix A, plots A-D reference project numbers 17, 7, 42-44, and 10-11, respectively.

3.3.2 Environmental drivers and reasons for eelgrass loss

Reasons for restored eelgrass loss or project failure were cited in reports or in practitioner interviews and were based on observations during transplantation or monitoring. We found that the majority of cited factors were physical (n=35), while the rest were either biological (n=17) or logistical (n=11). Macroalgae was the highest cited factor of eelgrass loss (n=8), followed by sedimentation (n=7) and light-limitation (n=6). An additional 13 projects met their project goals and 14 projects did not

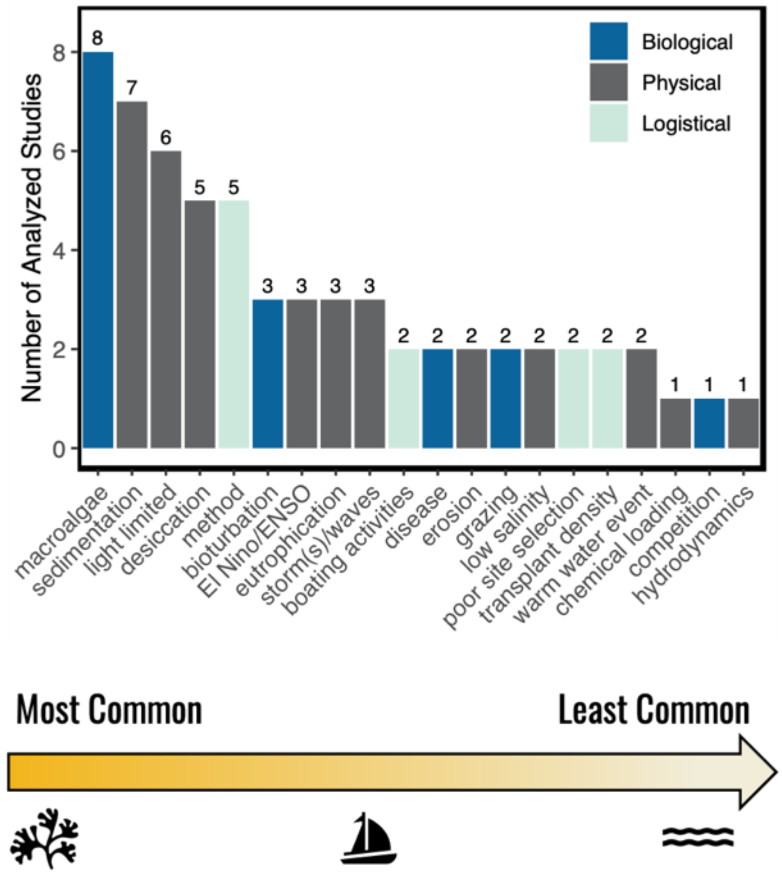

Figure 8. Cited reasons for restoration failure or loss or transplants. Projects that cited losses or failure at the project or plot level are represented in the graph to the left. The associated table lists each of the categories from most to least commonly cited reasons for failure or loss of transplanted or restored habitat. An additional 13 projects met their project goals and 14 projects did not include any known or suspected causes of project failure or loss, both of which are not represented in the above figure. Table 4 breaks up the drivers of loss and/or failure by state. For a full list of projects included in this figure and Table 4, see Appendices A and D.

include any known or suspected causes of project failure or loss. Though, as we discuss below (see Section 4.3), many of these factors are interrelated. It should be noted that these factors were not *quantitatively* attributed to eelgrass loss. This section highlights observations by practitioners that spend numerous hours in their restoration sites and in the system under study and should not be discounted as these data allude to probable mechanisms of eelgrass decline and can serve to inform future quantitative, mechanistic work.

3.4 Ecosystem Services

The majority of projects performed minimal analysis of ecosystem services, focusing instead on basic metrics such as shoot density, areal coverage, and percent cover. However, some project reports do include qualitative dataabout species use in restored habitat, typically in the form of species lists or discussion of species observed. Although this presentation does not allow for a quantitative assessment of habitat use in restored areas, many projects did note that restored eelgrass provided habitat for marine fish and invertebrates, including halibut, spiny lobster, Dungeness crab, Pacific herring, salmon, and sole. 14 projects quantitatively measured species-level data such as richness, diversity, or abundance, although not all projects used a reference meadow or unvegetated site for comparison. Responses across these projects were varied, and it is difficult to draw overarching conclusions given the variation in methods and metrics evaluated. However, generally, species richness and abundance was higher in restored eelgrass relative to unvegetated habitats (e.g., Projects 10,11 in Appendix A; Case Study 4).

Box 1.

Trophic cascade facilitates eelgrass recovery

Elkhorn Slough is a nutrient loaded or eutrophic estuary, heavily impacted by surrounding agriculture. Typically, eutrophication leads to macroalgal blooms, including epiphytic algae that blocks sunlight and negatively impacts eelgrass bed health and potential for expansion.

Research led by Brent Hughes and colleagues found that sea otters mitigate these negative nutrient effects through consumption of large predatory crabs. These crabs feed on critical mesograzers (*Pentidotea resecata* and *Phyllaplysia taylori*) that graze on epiphytic algae growing on eelgrass blades. Sea otters were shown to have an indirect positive effect on eelgrass bed health and growth by lowering the intense predation pressure on these mesograzers.

Hughes, B.B., R. Eby, E. Van Dyke, M.T. Tinker, C.I. Marks, K.S. Johnson, and K. Wasson. (2013). Recovery of a top predator mediates negative eutrophic effects on seagrass. *PNAS* 110:15313–15318.

No included projects monitored the role of positive species interactions in facilitating restoration success (Box 1). In general, the effect of species on eelgrass restoration was not addressed in the projects analyzed. Both of these questions are important in informing management and future eelgrass restoration.

Two types of carbon services were considered when evaluating success in terms of ecosystem services. However, these services were measured in even fewer projects than those measuring habitat provisioning. The first carbon service was evidence of carbon burial facilitated by eelgrass restoration, or “blue carbon”. This was measured by practitioners by taking sediment cores inside and outside restored plots for comparison. Only one of the included studies reported data on sediment carbon stocks or sequestration (Projects 10,11 in Appendix A), making comparative analyses on this front impossible. One other study (Project 22) measured sedimentation in restored sites, but reports very little information on their findings and fails to connect these data to carbon accumulation. Understanding the impacts of restoration on estuarine carbon stocks is a clear data gap, and should be further explored in projects seeking to evaluate the ecosystem services gained through their restoration.

The second carbon service evaluated was “OA amelioration” whereby evidence showed increased pH over time in restored eelgrass relative to neighboring unvegetated areas, due to photosynthetic carbon usage. This was typically measured by practitioners by placing sensors inside the restored plots to measure and compare pH through time. Only three projects evaluated pH amelioration, and data were sparse within these projects (Projects 1, 10, and 11 in Appendix A). From literature on the subject, we know that there is an extraordinary amount of variability in pH due to a large number of environmental factors. In many projects where pH was measured in restored plots, results were mixed, with some evidence supporting pH amelioration in restored eelgrass and other evidence contradicting it. However, within all of these projects, pH was typically only monitored over the course of hours to days, very poor temporal resolution to definitively assess whether OA amelioration was occurring due to restoration. While there is strong evidence to support the idea that eelgrass can significantly increase pH and ameliorate ocean acidification (e.g., Ricart et al. 2021), restoration projects seeking to assess this service would need to monitor meadows and corresponding control plots over a much longer period of time, preferably across multiple seasons and tidal cycles.


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photo © Melissa Ward

4. Discussion

4.1 Restoration Approach

The U.S. West Coast has a long history of eelgrass restoration, with mixed success. Restoration results have been extensively reported in previous syntheses (Merkel 1998, Thom 1990, Thom et al. 2008, Schanz et al. 2010). A broad framework to adaptively conduct coastal eelgrass restoration has been well summarized - particularly for meadows in the Pacific Northwest (e.g. San Francisco Bay Subtidal Habitat Goals 2010, Thom et al. 2005, Thom et al. 2008;). For example, we now know that restoration should consider the site's environmental features/conditions and historical disturbance levels, as well as management constraints such as funding or personnel availability. Thom et al. 2008 succinctly summarizes many of these recommendations. Building off existing literature on the subject and based upon the interviews conducted with experts, we recommend the following steps be taken when implementing eelgrass restoration:

Step 1) Assess Site Suitability

Given the mixed success of eelgrass restoration (Table 2), in part due to a large number of possible environmental variables (Fig. 7), practitioners should take care to thoroughly evaluate each site where restoration might occur prior to restoration action. When possible, this should include use of a site suitability model, which quantitatively assesses locations likely to be suitable for eelgrass based on known environmental inputs in the model

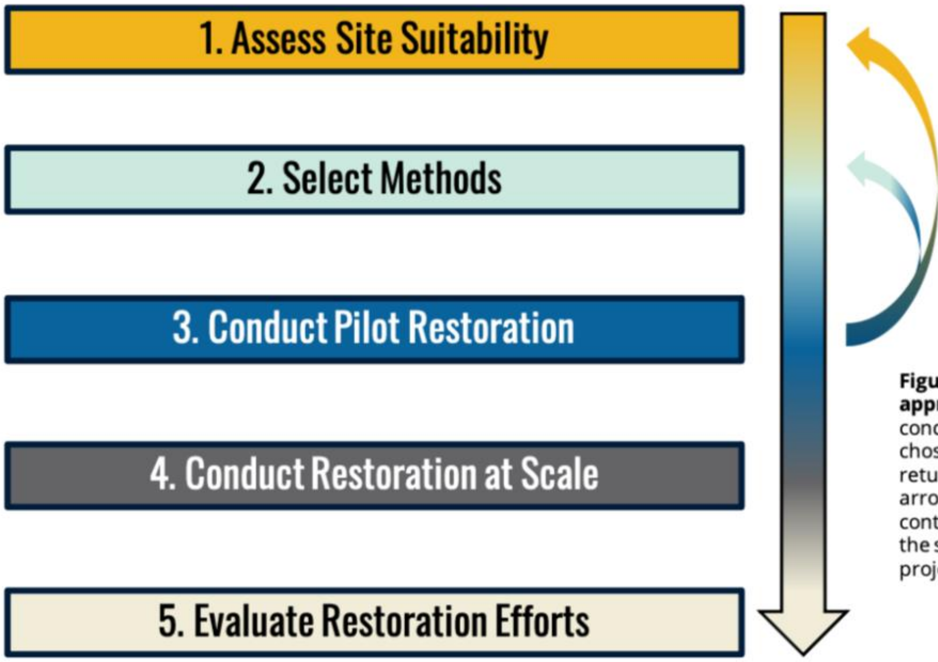


Figure 9. The five steps in the recommended approach to eelgrass restoration. Once a pilot is conducted, practitioners may have to reassess the chosen method (signified by the curved arrow returning to Step 2) or site (signified by the curved arrow returning to Step 1). A project should only continue moving forward if there is evidence that the site and method are appropriate for meeting project objectives.

(Projects 1, 2, 33, 38-40, Appendix A). However, development and implementation of site suitability models may not always be available or possible, in which case careful consideration of the site can serve practitioners well. For example, knowledge of each site's environmental variables (Box 2) can be immensely helpful to practitioners, and suitable ranges for specific parameters may already be available based on the region of interest (e.g. Puget Sound, Judd et al. 2009 and Thom et al. 2018; Pacific Northwest, Thom et al. 2012; California, NMFS 2014).

In particular, light availability and depth should be considered carefully. Observations of the depths and light conditions of neighboring sites where natural eelgrass persists can be immensely helpful to inform and guide restoration (Thom et al. 2014, Shannon et al. 2018). Additional project-specific considerations should also be made, such as identifying sites with the possibility of plot expansion to meet project coverage goals and to allow for the largest possible footprint of the restoration project over time. Similarly, the status of the natural meadows may also be a consideration in site selection. If natural meadows are known to be in steep decline within a restoration region, it may serve practitioners to postpone or consider alternative locations until the reason for the decline is known (See Project 16 in Morro Bay). It is also important to note that even if a site suitability model is used, practitioners should still ground-truth the sites identified by the model using the criteria discussed above - models may not be able to effectively prioritize the identified sites due to possible site attributes not captured within the model (e.g. presence of debris in sediment).

Understanding local environmental drivers of eelgrass habitat suitability is the key first step to improving restoration outcomes. For example, to meet Washington's statewide targets of increasing eelgrass area by 20% by 2020, practitioners first needed to locate suitable potential areas for restoration (Thom et al. 2018). Their comprehensive approach used simulation modeling to address how well eelgrass would grow based on changes in environmental conditions (depth, temperature, salinity, water clarity) through time. Practitioners then integrated data on stressors, current and historical eelgrass extent and stakeholder feedback into an Eelgrass Restoration Site Prioritization Geodatabase,

Box 2.

What to assess for site suitability?

1. Light
2. Chlorophyll a/Nutrients
3. Substrate type (e.g. grain size)
4. Temperature
5. Salinity
6. Water velocity (or flow)
7. Elevation

To assess whether a site is potentially suitable for eelgrass restoration, practitioners use an assortment of water quality instruments (sondes, probes, and pendants) that measure one or more of the listed parameters (turbidity, light, pH, DO, Chl a, water velocity), secchi disks (turbidity), RTKs/GPS (elevation), or sieves (sediment grain size).

Assessing site suitability should also include monitoring the site over multiple seasons to determine whether large scale environmental variability such as sedimentation, erosion, or macroalgal blooms are characteristic of the site. Regional guidance is well documented in previous literature to account for variation in local site conditions (see Section 4.1, Step 1).

followed by test plantings in a subset of areas corroborated by the simulation model and geodatabase to investigate specific site suitability. Test plantings were chosen in areas believed to be dispersal-limited, preventing natural colonization and in areas where environmental conditions were thought to have improved enough to support eelgrass (Thom et al. 2018). This exemplary approach aligns with our proposed approach and should be widely adopted, when data and necessary funding are available.

Step 2) Select methods

Selection of eelgrass restoration methodology should be informed by project-specific criteria (see section 3.2). While bare root, anchored transplants are most common, practitioners should consider the funding, personnel, timing, and environmental characteristics of their site and choose the method that best fits the needs of the project. Where possible, passive restoration projects should be considered to facilitate the natural expansion of eelgrass.

Step 3) Conduct Pilot Restoration

Pilot restoration projects can be very valuable in identifying sites with high chance of restoration success. In particular, when practitioners aim to restore larger areas, a well thought out pilot project (e.g., projects 13, 33, 38-40) can be used to identify if or where a follow-up, at-scale restoration project might be appropriate. After assessing site suitability and selecting methods, pilot projects should plant multiple small plots (e.g., 1 to 10 m^2) across these sites, ideally spanning numerous environmental gradients (such as depths, currents, or sediment types). In San Francisco, practitioners have seen success in using pilot restoration plots planted in “L” shapes, in an effort to span multiple depths and current directions (Projects 38-40 in Appendix A). This effort and others like it (Gaeckle 2019, Shannon et al. 2018) have been employed by successful restoration practitioners across the region. In the event that pilot restorations fail, transplanting additional pilot plots or testing alternative methods should be conducted prior to moving on to a full-scale restoration.

Step 4) Conduct Restoration at Scale

Once a suitable site and method has been selected, and pilot restoration has proved successful, practitioners can conduct restoration at-scale. Here, we refer to a restoration ‘at-scale’ the total planned footprint or size of the full-restoration, an expansion of the small scale pilot study (Step 3). In this case, the season and environmental conditions must still be carefully considered. While most restoration projects analyzed in this report transplanted shoots in spring (n=10) or summer (n=31), during the onset of eelgrass peak growth period (and ideal daylight low tides), others transplanted eelgrass across all seasons. Selection of methods may factor into timing decisions based on environmental and logistical constraints. For example, in some locations where SCUBA based transplants are not possible due to logistical constraints, ideal low tides can occur in winter. Transplanting in winter, while less common, offers opportunities to transplant during low tides with minimal risk of desiccation.

Coordination and a comprehensive understanding of the system's dynamics are also needed for seeding efforts. For example, flowering shoots must be harvested at the appropriate time for there to be a chance of propagation success. In San Francisco Bay, practitioners monitored the natural meadows very closely and have become exact in their ability to predict flowering events, harvest reproductive shoots, and prepare BuDS.

Relatedly, scaling up a project requires appropriate personnel support. If trained divers are needed, this adds complexity to the project. If holding tanks for shoots are unavailable, this impacts how many shoots can be harvested each day (limited by how many shoots the team can transplant).

Step 5) Evaluate Restoration Efforts

In general, more frequent (seasonal) monitoring over a longer duration (5 years) will always provide more detailed information on restoration outcomes. Understanding drivers of restoration success or failure are contingent on data from before, during, and after a project begins to succeed or fail. For mitigation projects in California, the CEMP acts as a robust policy to ensure minimum monitoring needs are met. Specifically, CEMP requires areal coverage and shoot density be monitored annually for 5 years, at a minimum. Ideally, all restoration projects (not just those for mitigation) would monitor to these CEMP standards, as is recommended in section 5.1 below.

Restoration monitoring should include at a minimum, shoot densities and areal coverage in both the restored meadow, and in a concomitantly monitored reference meadow. Given that trends and drivers affecting natural meadows are often reflected in restored plots, monitoring a reference meadow can provide key insight as to the relative success of the restoration and may also allude to possible restoration failures. When selecting a reference meadow, proximity to the restored meadow should be considered as one aspect of site selection, however there are other factors that can be as or more important than choosing a site as close as possible. For example, depth is known as a covariate with shoot densities (Thom et al. 2005), and thus if no site of comparable depth exists nearby, it may be preferable to choose a site farther away, but at comparable depth.

4.2 Defining Success

How eelgrass restoration success is defined should be considered carefully prior to starting any restoration. California-based mitigation projects have a very clearly defined set of success criteria, specifying areal coverage and density relative to reference meadows (Table 3), which provide the basis for standardized evaluation metrics and success criteria across projects. By requiring mitigation projects to measure *at least* these criteria this facilitates evaluation across projects. Such standardization serves a valuable role in improving understanding of regional success.

For non-mitigation projects, the metrics evaluated become far more diverse, making cross-comparisons very challenging (Thom et al. 2008). For example, some projects measure either areal coverage OR shoot densities, but not both (Projects 13-15, 31 in Appendix A). Some projects measure neither of these, but percent cover instead (e.g. Case Study 3). In other projects, quantitative metrics are not truly measured, but estimated. For instance, many projects only make statements such as "plots appear to have expanded" or "less than 5% of the eelgrass shoots remained after a year". These observations may be valuable, and may support the goals of the practitioner, but they make quantitative or even robust qualitative comparisons with other projects difficult or impossible (e.g. Project 51 in Appendix A).

Due to the fact that mitigation projects are *required* to meet success criteria (Table 3) for compliance purposes, projects that are not meeting success criteria are often adapted to do so. This can be done by additional transplanting mid-project in order to boost areal coverage or density levels of transplants and also by extending monitoring as was done in the Port of Los Angeles' Pier 300 Expansion Project (Case Study 1, Projects 16 & 25 in Appendix A). This can also be done by transplanting areas greater than the required mitigation ratio in order to meet coverage goals by the end of the five-year monitoring period. Although there are exceptions (e.g. Humboldt Bay), the typical required mitigation ratio in California is 1.2:1, meaning a project damaging 1 acre of eelgrass would require a minimum restoration area of 1.2 acres after 5 years. Yet when reported, the average ratio applied across all mitigation projects was 2.8:1 – considerably higher, in an effort to meet these targets by the end of the project. Other mitigation project practitioners may conduct a mid-project re-assessment of the damage to the existing eelgrass meadow that triggered the mitigation. If damage is lower than planned, the required successful transplant area can be decreased, making 'success' easier to attain (Project 25, Appendix A). While in most cases, these adaptations are suitable for mitigation purposes (and in fact are recommended to achieve mitigation goals; Thom et al. 2005), they can make evaluating the role of restoration methods, site suitability, or environmental drivers in success more challenging. This is due to the fact that these reports and projects are typically less focused on identifying drivers of loss or success, and more focused on checking the "in compliance" box. Furthermore, given the defined criteria for success can change mid-project, comparisons of success across mitigation projects should additionally consider these alterations rather than only looking at whether or not a project met practitioner-defined success criteria, which alone can be misleading (Fig. 10).

Reference meadows, if chosen appropriately, offer a benchmark upon which to measure and track restoration outcomes. In reviewing these 51 projects, we found that less than half of the projects used reference meadows and even fewer had data on shoot counts and/or area over time. Due to the lack of data on reference meadows, we were unable to conduct a comprehensive assessment of restoration progress relative to reference meadows over time, though we were able to do so for a select subset of projects (Fig. 7). Overall, across the four projects analyzed, we found that shoot densities in restored plots roughly tracked reference meadows over time. The high degree of spatial variability (indicated by different plot and reference letter identifiers, i.e. "A", "B", "C") speaks to the dynamism of eelgrass within systems across space and time.

Understanding the dynamics of reference meadows within a particular system is key to contextualizing restoration progress. In Morro Bay, 2010 restored eelgrass plots showed large declines at the same time the natural meadows were experiencing dramatic losses, indicating that conditions may not have been suitable for eelgrass growth and survival at the time of restoration (Project 16, Appendix A). In Newport Bay, a 2012 eelgrass restoration led by Orange County Coastkeeper showed marked success at the same time the natural meadows were increasing in areas (Project 19, Appendix A). Natural meadows are typically considered more resilient and stable than restored habitats and thus healthy natural meadows may serve as a litmus test for potential restoration success system-wide (Fig. 10).

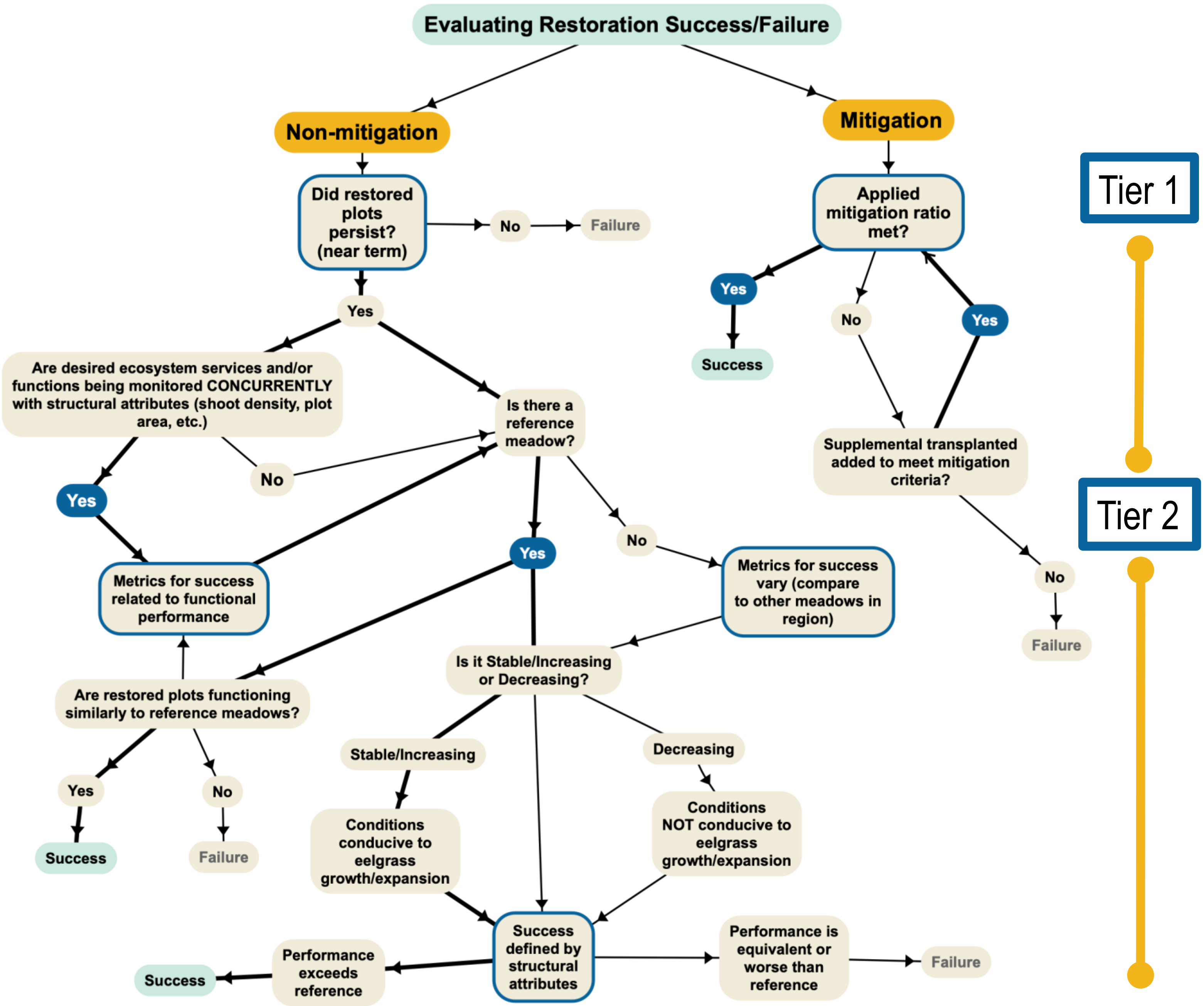


Figure 10. Evaluating Restoration Success/Failure Flow Diagram. Broken into two 'Tiers', the first tier represents broad restoration success and/or failure at a very high level (i.e. did plots persist or were mitigation criteria met?). The second tier represents the nuance of restoration success/failure based on the status and/or presence of natural reference meadows, whether or not ecosystem services and functions are being assessed, and the relative performance of restored plot structural attributes (i.e. shoot density, plot area) compared to reference meadows. The flow diagram for mitigation projects is purposely circular, since mitigation requires that practitioners meet the stated criteria. Typically efforts continue until criteria are met (but see Project 16). Wider arrows indicate pathways to success.

Ideally, success should include assessments of ecosystem services and/or functions. The motivation to protect and restore eelgrass is driven by our need to protect and restore the ecosystem services and functions supported by this critical foundation species and our definition of success should reflect this ultimate goal. However, it cannot be assumed that restored plots that structurally resemble reference meadows also function like reference meadows (Fig. 10). There is a growing body of literature assessing ecosystem services and/or functions in natural eelgrass meadows (Rumrill and Sowers 2008, Plummer et al. 2013, Sherman and DeBruyckere 2018, Ricart et al. 2021). This literature provides a great baseline for comparison to restored plots but is not a substitute for *in-situ* measurements of functions within restored plots (Lewis and Henkel 2016, Beheshti et al. *in review*).

Restoration success can also be measured as the relative functional performance of restored plots relative to reference or control meadows. Often restoration is motivated by a need or management goal to restore key ecosystem functions. Therefore, how quickly restored plots mirror the functional performance of reference meadows is of great interest to practitioners and should be assessed concurrently with structural attributes (shoot density, plot area, canopy height). Sufficient time should be incorporated into a restoration plan that incorporates time lags allowing restored habitat function to evolve and mature over time. Of reviewed projects, only eight collected data on ecosystem services and of those eight projects only four assessed carbon ecosystem services (Table 1). Thus, we were unable to assess success based on functional performance or services provided. Although we did review one exemplary study that assessed ecosystem services and functions in restored, reference, and unvegetated habitats (Projects 10, 11 in Appendix A). This work has shown that the rate of functional recovery is non-linear and varies by function. Functions such as biodiversity were rapidly restored while biogeochemical functions (i.e. carbon storage and water quality) were slower to recover, though they remained on a trajectory towards reference meadow levels approximately 3 years post-restoration (Projects 10, 11 in Appendix A).

The longevity of restoration success should also be considered, as appropriate. For non-mitigation projects, evaluations rarely exceed 1-2 years. It is questionable whether or not two years of persistence ultimately qualifies as 'success', especially if functional attributes are not measured over this time. Given the variability of seagrass density and distribution observed naturally, we should expect that restoration plots may wax, wane, or disappear altogether over time. In the case of a fully lost restoration meadow, whether or not this is deemed failure may depend on your definition of what is "long enough" to be called success. For example, if a restored meadow persists for 7 years and then is lost during an episodic rain event, does this then qualify as failure? Does this qualification change if natural meadows also declined at this time? Or perhaps regardless, it is deemed successful because for 7 years, this meadow provided key ecosystem services and habitat structure. It may also have contributed to propagation of meadows elsewhere in the watershed, and despite its loss, still facilitated overall watershed health

Time after transplant	Minimum areal coverage criteria (%)	Minimum shoot density (%)
1 year	70	30
2 years	85	70
3, 4, and 5 years	100	85

Table 3. Required CEMP guidelines. At each of the listed time points (Years 1, 2, and 3-5) there are particular regulatory requirements that need to be met for areal coverage and shoot density.

during its lifetime. We challenge practitioners to expand their definition of restoration success to consider the longevity of the restoration, its level of functioning, and to view the gains and losses of restored habitat within the context of the dynamics that define a particular system (Fig. 10).

4.3 Importance of Environmental Drivers

Stressors to eelgrass are synonymous with drivers of restoration failure and include both natural (e.g., grazing, disease, storms) and anthropogenic (e.g., dredging, contamination, chemical fouling, propeller scars) stressors. Previous efforts have outlined primary threats to eelgrass and linked specific stressors to signs or symptoms of stress observed in eelgrass meadows (Bernstein et al. 2011, Dowty et al. 2007, Merkel & Associates 2017).

Environmental conditions dictate site suitability, which in turn predicts the likelihood of restoration success. In Merkel & Associates (1998) review of eelgrass transplant successes from 1976-1998, they found that restorations that occurred on un-manipulated sites were substantially less successful (~38%) compared to restorations that first improved environmental conditions identified as possibly limiting transplant success (~90%), prior to planting. Our results confirm that appropriate environmental conditions, rather than specific transplant methods, are the leading determinants of restoration success or failure (see section 4.1). Of the 51 projects we analyzed, only 12% cited restoration method as a potential reason for lower than expected restoration performance (Fig. 8).

To improve restoration outcomes, environmental conditions should be assessed and if stressors are identified, amelioration should follow. Below we outline possible strategies for mitigating the effects of poor environmental conditions known to negatively impact eelgrass, as identified by the projects analyzed (Table 4, Appendix D).

4.3.1 Nutrients

Eutrophication is a leading cause of seagrass habitat loss (Waycott et al. 2009). Due to the cumulative effects of upwelling and human-derived nutrient loading, many bays and estuaries along the U.S. West Coast are considered eutrophic. Triggered by excess nutrients entering our bays and estuaries, macroalgal blooms (mainly of the families Ulvaceae and Gracilariaceae) pose a threat to eelgrass growth and persistence. The negative impacts of macroalgae on eelgrass have been shown across the U.S. West Coast (Tomales Bay; Huntington and Boyer 2008, Coos Bay; Cummis et al. 2004, Hessing-Lewis at al. 2011; Grays Harbor, Clinton Harbor, and Eagle Harbor; Thom et al. 2012). Direct effects of macroalgae include smothering of eelgrass shoots and outcompeting eelgrass for space. Indirect effects of macroalgae include increased concentrations of toxic sulfides with decomposition of macroalgal mats (Holmer and Nielson 2007).

As a leading cause of restoration failure or loss (Fig. 8), controlling the ultimate causes of macroalgal growth (i.e. nutrient-inputs) should be a priority. While the impacts of eutrophication and associated blooms on eelgrass vary spatially (i.e. along a salinity gradient) and temporally (i.e. seasonally, inter-annually) (Hessing-Lewis et al. 2011), macroalgal production can largely be driven by human-derived nutrient loading (Orth et al. 2006, Waycott et al. 2009, Wasson et al. 2017) and thus has the potential to be mitigated. Eelgrass management plans should include targeted actions (e.g., establish Total Maximum Daily Loads or TMDLs, reduce fertilizer application) to reduce human-derived nutrient inputs, coupled with water quality monitoring programs similar to those led by the National

Estuarine Research Reserves' System-wide Monitoring Program (SWMP) or the California State Water Resources Control Board Surface Water Ambient Monitoring Program (SWAMP).

4.3.2 Light

Eelgrass is restricted to shallow water environments due to its high light requirements; >10% of surface irradiance (Zimmerman et al. 1997). Many factors limit light availability via shading (overwater structures) and/or degraded water clarity (dredging, erosion, phytoplankton blooms, re-suspension via bioturbation, tidal scour, boating activities) (San Francisco Bay Subtidal Habitat Goals Project 2010). Impacts can be both temporary (i.e. ephemeral macroalgal blooms, boat wake, dredging, storm run-off, anchored barges) or permanent in nature (i.e. ferry terminals, mariculture infrastructure).

Given its narrow depth range of (+1.4 m to - 12 m relative to MLLW), mitigating impacts that degrade light availability is a priority for coastal managers (Hannam et al. 2015). Potential regulatory actions for avoiding or mitigating impacts to light availability should be adopted when feasible (Case Study 3). The Clinton Ferry Terminal Project is an excellent example of a coordinated and iterative effort between scientists, regulators, engineers, and developers to avoid impacts, when possible, by exploring innovative solutions and carefully planning built improvements (Pentec Environmental 2009). Aligned actions to avoid impacts related to light availability are also nicely outlined in the San Francisco Bay Subtidal Habitat Goals Project Report and include establishing no wake-zones for vessels, re-routing ferries, avoiding new dredging projects or anchoring barges in close proximity to eelgrass beds.

4.3.3 Climatic events

Many of the aforementioned environmental drivers of eelgrass growth and/or loss are interrelated and should not be considered in isolation, but rather as a suite of factors interacting additively or synergistically to impact eelgrass dynamics. For example, during large freshwater events, common during El Nino years, turbidity increases, light availability decreases, and salinity drops to levels dangerous to eelgrass. During large storm events, transplants can also be ripped out of the ground. The adaptive approach employed by practitioners in San Francisco Bay allowed them to halt restoration in an anomalous rain year where salinities dropped and impacting restored and natural eelgrass meadows dramatically.

Warm water events (e.g. the 2014-2016 marine heatwave known as the 'Blob') can also be detrimental to eelgrass, especially sparsely or newly transplanted, stressed eelgrass transplants. Intertidal transplants are particularly vulnerable to warm water events, drought, and high air temperatures, with increased risk of desiccation. During our interviews, many practitioners mentioned losses that occurred at the upper elevation limits of eelgrass during anomalous periods of warm weather, when the normal cloud cover and fog were absent at low tide in summer months (in Northern California, Oregon, and Washington). Unfortunately, there are few options to eelgrass restoration practitioners for mitigating this global change. Trade-offs between transplanting intertidally where light availability is maximized but desiccation risk is highest presents practitioners with a difficult decision.

4.3.4 Biological and Mechanical disturbances

Mitigating biological stressors (invasives, disease, macroalgal blooms, bioturbation) can be difficult as these are transient stressors. Invasive species (e.g. *Caluerpa taxifolia*) often outcompete and displace eelgrass, triggering a cascade of impacts to native flora and fauna. Eradicating marine invasives can be an enormous challenge for managers, as they are typically fast-growing and highly reproductive. Disease (*Zoobotryon verticallum*, *Labyrinthula zosterae*) presents another management challenge that can threaten restored natural eelgrass and contribute to significant habitat loss. Preventing macroalgae from growing or foraging bat rays from forming feeding pits is challenging, especially if you consider a large-scale restoration (Appendix D). Similar management challenges exist for preventing mechanical disturbances associated with dredging or boating activity (anchoring, propeller scarring, grounding). While the mechanism of disturbance is different, the consequences are similar. In Richardson's Bay, CA there is a project that is currently underway that seeks to tackle this issue through implementation of their Eelgrass Protection and Management Plan. Managers plan to establish an Eelgrass Protection Zone that limits boat activity and practitioners are monitoring how foraging bat rays impact natural and restored eelgrass habitats, while concurrently conducting an eelgrass transplant study in the mooring and anchor scars left by abandoned or recently removed vessels. The results from this and other projects will help inform best practices around these overlapping stressors.


photo © Kat Beheshti

5. Conclusions and Recommendations

The primary goal of this report was to use past restoration projects to determine best practices. We expected project outcomes to vary based on the appropriateness of the technique used. Instead, we found that restoration method, while important, is not typically the primary driver of restoration success or failure, rather, environmental conditions have a substantial impact on whether or not a project will meet its specified success criteria. In addition, our ability to classify a restoration as successful or not depended on whether or not practitioners' stated criteria for success. Understanding relative restoration success was difficult because practitioners' success criteria vary widely across projects.

Based upon guidance from interviewed practitioners and from our analyses of eelgrass restoration projects, we make seven recommendations that we believe will increase effectiveness of eelgrass restoration along the U.S. West Coast.

5.1 Create, refine, and follow standardized eelgrass restoration transplant and monitoring protocols

Standardization across planting and monitoring techniques can guide new projects, and allow greater continuity between projects. This can make understanding local or regional success easier, when similar metrics are used for evaluation. The strength of such standardization is readily evident when reviewing multiple CEMP-compliance projects in California. For example, *every* California eelgrass mitigation projects included in our analysis evaluated area and shoot density over 5 years, making comparisons of success between these projects relatively easy. Comparing non-mitigation restoration projects to these CEMP-compliance projects can be extremely difficult due to vastly different monitoring methods, metrics, or durations. Given the CEMP is only applied to California eelgrass mitigation projects, we recommend comparable policies or monitoring methods be adopted as minimum guidelines in Oregon and Washington, and that eelgrass restoration for non-mitigation projects in these regions also apply CEMP monitoring protocols to evaluate success at a minimum.

5.2 Support efforts to coalesce and publish data on previously completed eelgrass restoration efforts

After considerable literature review, we found that information on a large number of eelgrass restoration projects is not publicly available, let alone published in peer-reviewed journals or reports (see Appendix A). In the case of management projects, these data are often kept internally, and never written into formal reports. In the case of mitigation projects, reports are produced, but these may be proprietary in some cases, or may not be readily available to the public. Despite the fact that mitigation makes up a significant portion of eelgrass restoration in the region, lack of accessibility makes gaining any information from these projects extremely difficult. When possible, reports produced on eelgrass restoration should be made publicly accessible. Given mitigation projects in California are guided by the CEMP, we recommend that the involved government agencies include a reporting accessibility standard to improve public access to information. Access to such information could greatly increase the likelihood of future project success and reduce duplication of efforts.

An effort to coalesce existing eelgrass restoration data to advance knowledge has been called for numerous times (e.g., Thom et al. 2008; Stamey 2004). For example, Thom et al. 2008 addresses this, noting the particular need "for a comprehensive data set or clearinghouse of restoration and monitoring results that is readily available and easy to use. A central location of restoration results would help facilitate learning and reduce duplication of efforts". The need for such a database and centralized location remains pressing. Practitioners could rely on such a database in many ways - learning what restoration has been done in their region, when it was conducted, the methods applied, likely reasons for failure and numerous other key insights to inform future restoration success. Access to such information can bolster support for future projects while also increasing the likelihood of their success. We are hopeful that this recommendation will be met by the Coordinated Global Research Assessment of Seagrass System (C-GRASS) or similar efforts. There are an abundance of eelgrass monitoring networks with associated protocols that track natural meadows (e.g. ZEN, SeagrassNET, SeagrassWatch, MarineGEO)-- we recommend expanding these existing networks and associated databases to include restoration efforts and serve as repositories for eelgrass restoration data.

5.3 Support broad, baseline eelgrass monitoring

Given eelgrass' ecological and economic importance, the policies protecting it, and the large number of projects seeking to restore it over the decades, it is clear that conservation of eelgrass remains a priority along the U.S. West Coast. Nonetheless, it is difficult to say whether or not eelgrass coverage has increased or decreased in the last decades due to lack of overarching eelgrass monitoring (Bernstein et al. 2011). Clearly eelgrass monitoring does occur, yet the lack of a regional monitoring plan leaves only a patchwork of information based on when and where monitoring for mitigation, research, or bay-specific monitoring plans have been implemented (Merkel & Associates 2017). We therefore recommend consideration of a comprehensive eelgrass monitoring plan for the region that includes basic metrics such as areal coverage and shoot density, as has been previously suggested (Bernstein et al. 2011, Waycott et al. 2009). Ideally, ecosystem functions such as species richness or carbon storage would be included in such a monitoring program. A standardized monitoring plan for all major waterways containing eelgrass (not just for meadows where mitigation occurs) would be beneficial in many ways. First, it would improve our knowledge of what might control eelgrass distribution by providing consistent, long-term data on eelgrass variability through time - an integral aspect of successful restoration. Second, it may also inform future eelgrass restoration by aiding in the identification of locations that were previously suitable for eelgrass, but where eelgrass has been lost.

5.4 Support scientific studies investigating eelgrass restoration methods and drivers of loss

Previous efforts to review and compare eelgrass mitigation and non-mitigation project outcomes and techniques have been inconclusive (Stamey 2004, Thom et al. 2008). We recommend supporting robust scientific studies comparing eelgrass transplant methodologies that are well replicated at various spatial scales from site to regional levels. This will allow methods to be fine-tuned for a particular site (or locations within site) while also increasing the application of a promising technique to sites within a region. It is also noteworthy that seeding on the U.S. West Coast remains relatively experimental (e.g., Pickerel et al. 2005, Thom et al. 2008, this study) and its success variable, compared to the Chesapeake Bay where large-scale seeding is the primary method used and has been incredibly successful (Orth et al. 2020). To test the efficacy of seeding on the west coast we first recommend further study on seed viability. Practitioners are interested in large-scale seeding, but this would require substantial regional investment to develop infrastructure and facilities comparable to those in the Chesapeake.

While we recommend more robust methods comparisons, our findings show that site-specific conditions and understanding local drivers of eelgrass dynamics is more important than transplant method in ensuring eelgrass restoration success over time. As such, we additionally recommend support for scientific work that investigates drivers of eelgrass dynamics and loss to strengthen our ability to meet restoration and conservation goals through the region.

5.5 Use community-led science, volunteer programs, and local university dive programs to foster stewardship

Engaging the public in restoration efforts is an effective way to elevate public awareness of the ecological importance of and services provided by eelgrass habitats. Integrating public outreach and on-the-ground restoration can also help scale-up restoration efforts--with more "boots on the ground", practitioners with limited staff support can more easily execute large-scale projects. For example, the strong community scientist network and Volunteer Monitoring Program at the Morro Bay National Estuary Program has played an integral role in tracking restoration efforts in the estuary while bolstering local stewardship. Similarly, in Elkhorn Slough, the majority of eelgrass restoration is done on SCUBA, and researchers at the University of California, Santa Cruz have relied heavily on diver support from American Academy of Underwater Sciences Certified undergraduate students. Community scientist programs (i.e., ReefCheck, LiMPETS, BioBlitz, PADI) continue to support and lead data collection efforts for nearshore restoration and monitoring (Eby et al. 2017, Freiwald et al. 2018). Many of these programs offer certifications (e.g., PADI Coral Reef Conservation Certification, PADI AWARE Shark Conservation Certification), acting as existing models that could be emulated for eelgrass restoration and monitoring. Such a program would act to educate and engage participants on the importance of eelgrass conservation, Moreover, funds generated from an Eelgrass Restoration and Monitoring Certification Program could be put directly into a Fund, managed by the certifying company or agency for the explicit use in eelgrass restoration and/or conservation. Recommendations of a program akin to those described above were mentioned in multiple interviews with practitioners and would undoubtedly increase public attention around eelgrass conservation.

5.6 Support Communication and Networking Amongst Eelgrass Managers, Restoration Practitioners, and Scientists

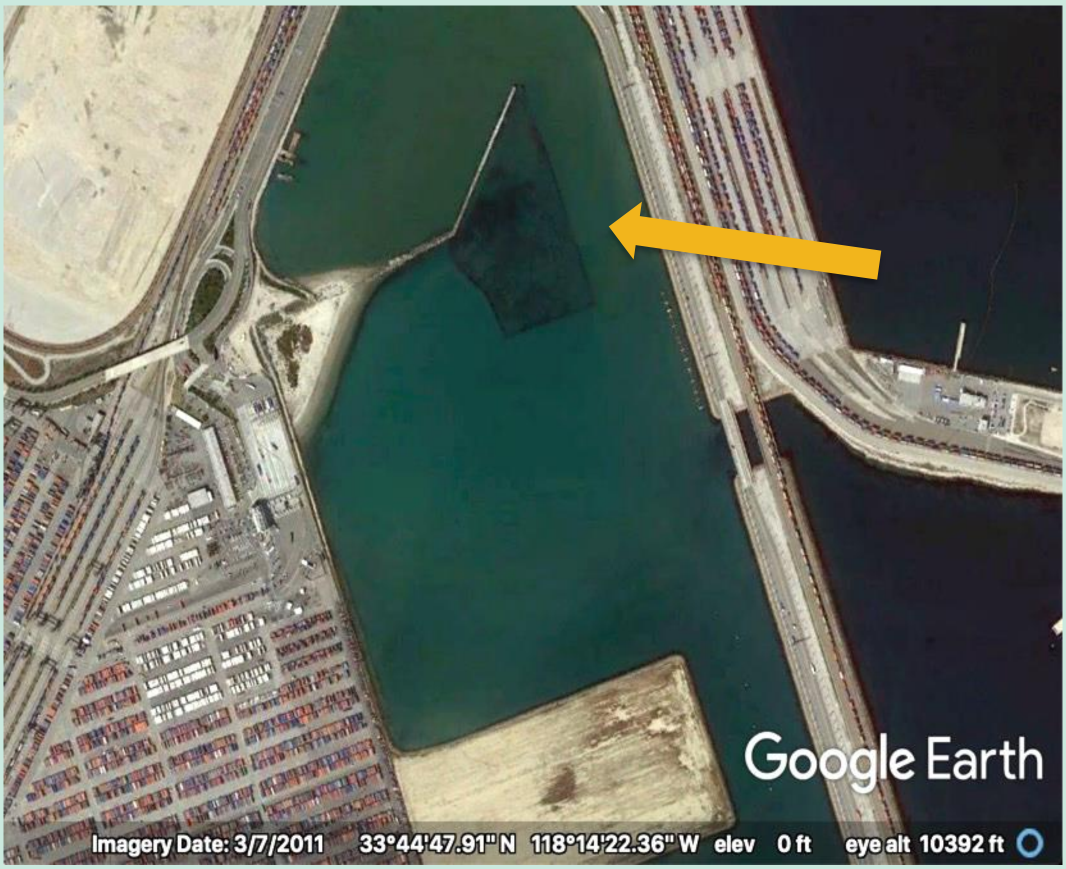
It is of the utmost importance to create and support opportunities for eelgrass practitioners throughout the region to communicate and share lessons learned. This communication can come in the form of workshops, webinars, reporting and dissemination efforts, working groups, and many others. The aforementioned lack of publicly available information on eelgrass restoration projects and their success underscores this need for communication. Such efforts can ensure that we, as a region, are using the best available information for future restoration projects and for understanding eelgrass dynamics along the U.S. West Coast.

7. CASE STUDIES (SEE NEXT PAGE)

Case Study 1: Pier 300 Expansion Project

Port of Los Angeles, California

*For symbol legend see Fig. 5



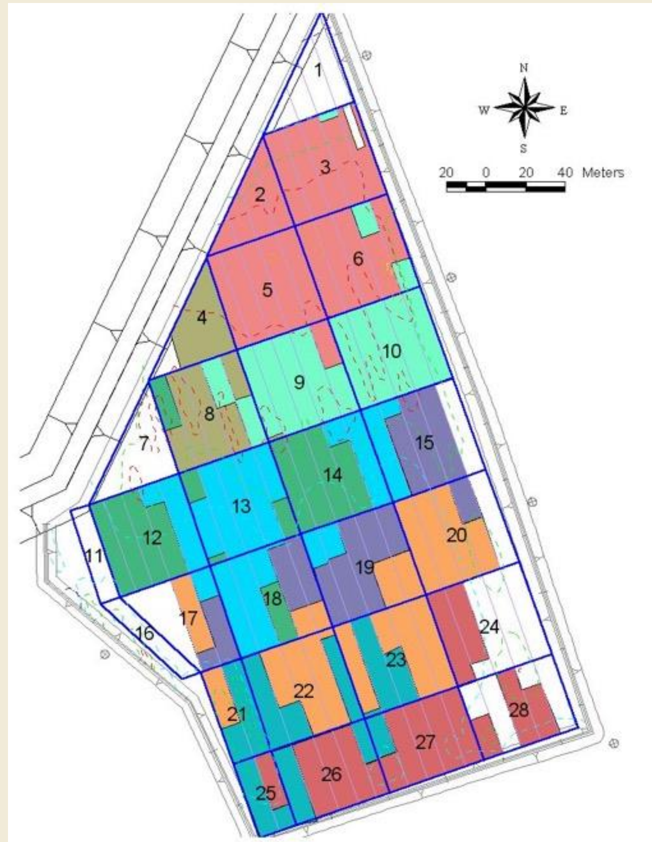
Aerial image showing the eelgrass transplant site and constructed berm (orange arrow). Source: Google Earth

Background: The Pier 300 Expansion Project impacted an estimated 11.65 acres of eelgrass habitat. In Summer 2003, Merkel and Associates led an eelgrass mitigation project spanning 13.98 acres to meet the required mitigation ratio of 1.2:1. In large projects or where sufficient suitable habitat is unavailable for mitigation, habitat can be “created” as was the case here. Specifically, a 14.5-acre site was created by placing a rock dike within the bay, and hydraulically filling the area inside with new sediment. The fill was brought up to targeted elevations based on the natural elevation range of existing eelgrass within the basin. The site was then

capped with fine sand to stabilize the bottom and provide appropriate planting media. This resulted in a new bottom elevation of -5 to -2 ft MLLW – deemed sufficient for eelgrass transplants. Sediment stakes were installed to measure accretion and/or erosion and to assess site stability prior to transplanting. Shoots were directly transplanted as 62,322 bareroot planting units into the constructed sites using biodegradable, soft anchors ('Merkel Paper Stick Method') [1].

Success was measured as **"meeting the success criteria of the Southern California Eelgrass Mitigation Policy or SCEMP"**. As a mitigation project conducted prior to the adoption of the CEMP, this project was held to the criteria outlined in the SCEMP [1]. These are:

1. A minimum of 70% areal coverage and 30% density after 1 year
2. A minimum of 85% areal coverage and 70% density after 2 years
3. A minimum of 100% areal coverage and 85% density after 3, 4, and 5 years.



(Right) In process restoration area tracking map showing areas planted over the course of the restoration and the status relative to sediment stability, planting completion, and quality assurance inspection completion. Map Image: Keith Merkel

Outcomes: Initially, the project did not meet the SCEMP success criteria. Specifically, while areal coverage and shoot density criteria were met for the first 2 years, the area of eelgrass was not sufficient (100%) at the 3-year monitoring time. To compensate for this, additional transplants were added to the project during year three, extending the 5-year monitoring plan to 7 years. By year 7, the project just barely met the success criteria [2].

Although not definitively addressed, practitioners suspect two possible reasons for lack of success—poor sediment quality and competition with macroalgae. Prior to initial planting, the fine sediment used to fill the lower quadrant of the site was a concern but expected to consolidate and subside. Practitioners used sediment stakes to monitor dynamics and ultimately found that additional corrective actions were needed. In the report, practitioners cite an unidentified red alga, likely order Gigartinales, competing with eelgrass. Initially, practitioners restored the exact area needed to meet their mitigation ratio (13.98 acres to compensate for impacts to 11.65 acres) but to meet SCEMP criteria supplemental transplants were needed. To compensate for projects not meeting success criteria like those outlined in the CEMP, many mitigation projects will restore ratios greater than the required 1.2:1 ratio, increasing the chance of this ratio being met after the 5-year mark.

- [x] Assessed site suitability
- [x] Selected methods
- [ ] Conducted pilot restoration
- [ ] Used pilot to inform restoration at scale
- [x] Evaluated restoration efforts over time

Contact for Project: Keith Merkel; KMerkel@merkelinc.com

Merkel and Associates preparing shoots for transplanting using the 'Merkel Paper Stick Method'.

References:

1. Merkel & Associates, Inc. 2007. 48-month Post-transplant Survey at the Eelgrass Mitigation Site in Support of the Pier 300 Expansion Project at the Port of Los Angeles. Prepared for: Port of Los Angeles.

2. Merkel & Associates, Inc. 2010. 84-month Post-transplant Survey at the Eelgrass Mitigation Site in Support of the Pier 300 Expansion Project at the Port of Los Angeles. Prepared for: Port of Los Angeles.

Case Study 2: San Francisco Bay – Oakland Bay Bridge Eelgrass Restoration

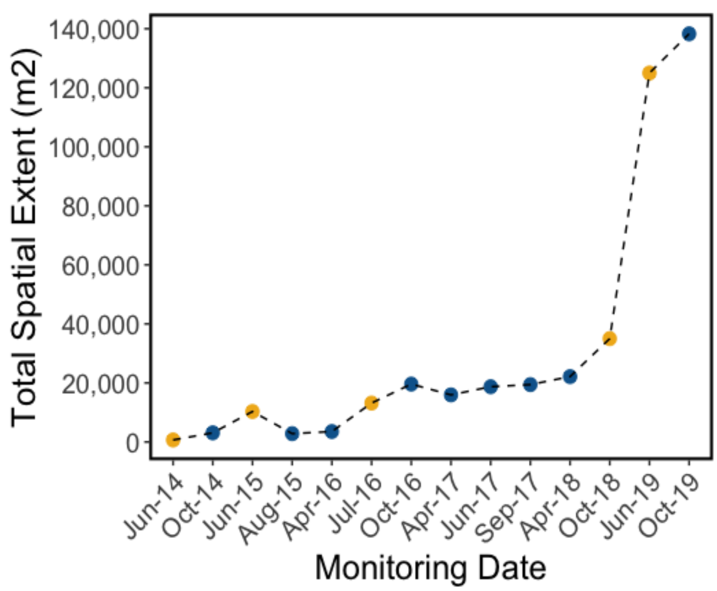
San Francisco, California

*For symbol legend see Fig. 5

A) Collecting eelgrass for transplanting. Photo: Melissa Patten B) Planting eelgrass with paper stick method, Marin Rod and Gun Club. Photo: Stephanie Kiriakopolos

Background: A restoration fund was developed to mitigate impacts (~ 3.6 acres) to eelgrass related to the San Francisco-Oakland Bay Bridge East Span Seismic Safety Project (SFOBB Project). A restoration goal of 10.8 acres was initially established and later updated to reflect the actualized impact which was less than the 3.6 acre estimate [1]. This restoration was tracked in conjunction with the Cosco Busan Damage Assessment and Restoration Plan, or DARP eelgrass restoration that was mitigation for the release of 53,000 gallons of fuel oil into the Bay.

Practitioners took an adaptive approach to planning and implementing the SFOBB restoration. First, potential restoration sites were identified using the Baywide Ecological Limits Viability and Sustainability Model, or ELVS [2] and a subset (n=3) of the sites were chosen for their historical restoration successes, and land-owner willingness to allow for restoration in the area [3]. Second, test plots were used at each of the proposed sites using multiple techniques (Kiriakopolos Bamboo-Stake Method, hereafter 'bamboo-stake method' and Merkel's Paper Stick Method, hereafter 'paper-stick method') using donor material from a single meadow to test the efficacy of both site and technique. At a subset of test plots buoy-deployed seeding or BuDs were also used. If, after 1 year test plots persisted and/or expanded, restoration was scaled up to ½ acre plots and if test plots showed patterns of attrition additional test plots were installed—an adaptive measure to ensure that increased investment was not going into sites that were failing for known or unknown reasons. The primary transplant method was the paper-stick, with bands of transplants of donor plants sourced from the three natural beds or mixed (Point San Pablo/Point Pinole, Point Molate, and Richardson Bay). On the end rows of each ½ acre the bamboo-stake method was used sourcing transplant material from the Point Molate bed. Each row was separated by a gap for the deployment of BuDs to improve genetic diversity or allow for lateral expansion of transplants in the absence of BuDs [1]. Low expected success or bioturbation from burrowing bay ghost



Total spatial extent (m^2) across all restoration sites from 2014-2018 [Modified Fig. 24. from Merkel & Associates and SFSU Estuary and Ocean Center 2020] Orange points indicate approximate season and year when transplants were added.

shrimp and foraging bat rays precluded two sites as possible candidates for BuDs. Over the course of three transplanting years (June 2014, May 2015, June 2016, July 2018 and 2019), practitioners planted 18 half acre plots and 36 test plots.

Success was measured as **meeting mitigation criteria through increasing the overall cover, extent, and distribution of eelgrass at each site**.

Outcomes: Prior to the SFOBB restoration, parts of the Bay experienced significant eelgrass losses (~917 acres), exacerbated by a warm water event [1]. By 2016, the SFOBB restoration had expanded to 2.8 acres but in 2017 a large freshwater event decimated restored and natural eelgrass in the Bay. The SFOBB restoration saw a 91-99% reduction in eelgrass distribution, with most dramatic losses observed in shallow versus deep waters. One site remained unaffected by the freshwater event and was the only site that continued to expand throughout 2017. Despite the 2017 freshwater event, the SFOBB restoration plots have been increasing in cover and extent (see above Figure). As of October 2019, the spatial distribution of the SFOBB restoration reached 138,277 m^2 or 34.17 acres [1].

- [x] Assessed site suitability
- [x] Selected methods
- [x] Conducted pilot restoration
- [x] Used pilot to inform restoration at scale
- [x] Evaluated restoration efforts over time

Contact(s) for Project: Dr. Katharyn Boyer; katboyer@sfsu.edu and Keith Merkel; KMerkel@merkelinc.com

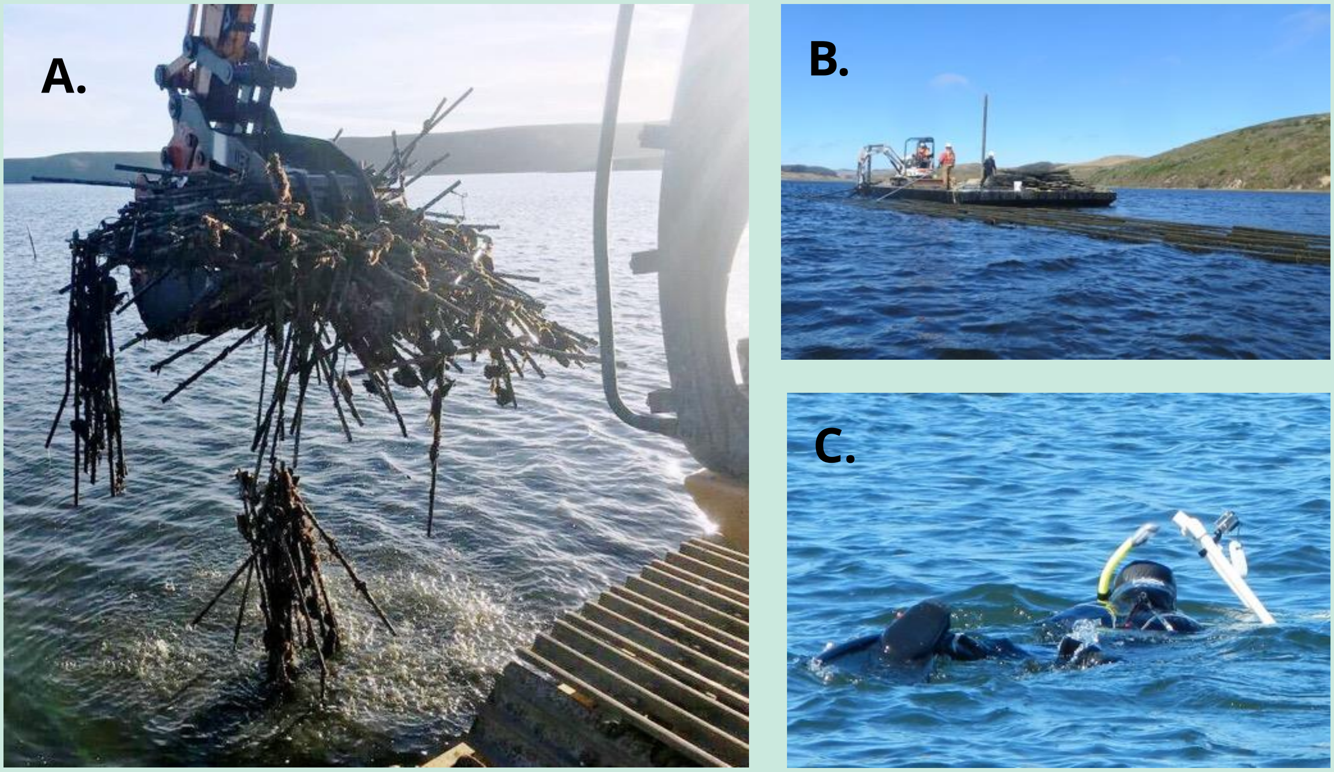
References:

1. Merkel & Associates, Inc. and San Francisco State University Estuary and Ocean Center. 2020. Eelgrass (Zostera marina) Restoration and Baywide Inventory Services. Annual Report 2019 for NOAA National Marine Fisheries Service and Western Acquisition Division.
2. Merkel & Associates, Inc. 2005. Baywide Eelgrass (Zostera marina L.) Inventory in San Francisco Bay: Eelgrass Bed Characteristics and Predictive Eelgrass Model. Prepared for CalTrans and NOAA as part of the San Francisco – Oakland Bay Bridge East Span Seismic Safety Project. September 2005.
3. Boyer, K. E. and S. Wyllie-Echeverria. 2010. Eelgrass Conservation and Restoration in San Francisco Bay: Opportunities and Constraints. Appendix 8-1, San Francisco Bay Subtidal Habitat Goals Project Report.

Rigging transplant units at the Estuary & Ocean Science Center, Tiburon. Photo Kathy Boyer

Case Study 3: Drakes Estero
Marin County, California

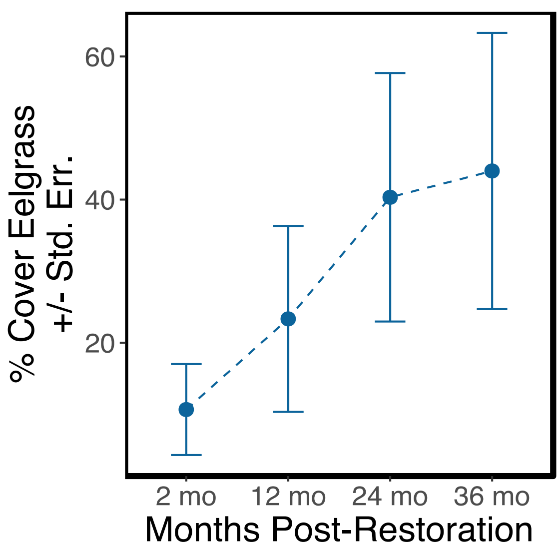
*For symbol legend see Fig. 5



Excavator removed mariculture debris from the estuary (A-B) and the Research team conducted snorkel-based surveys of the restoration plots before and after the restoration, pictured here holding the photo-quadrat rig. Photos: NPS

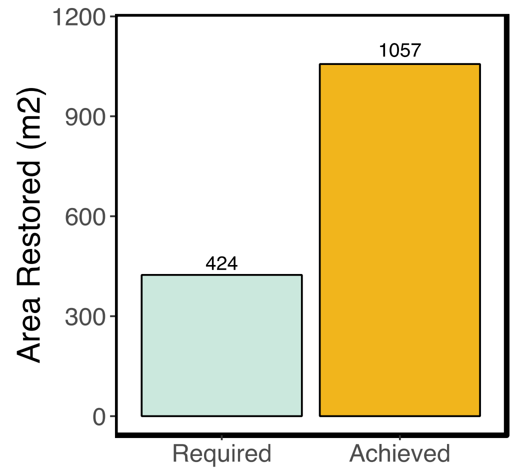
Background: The National Park Service (NPS) is the entity responsible for leasing land within Drakes Estero for aquaculture, which has been ongoing since the 1930s. Recently, NPS decided not to renew the last remaining 1,000 acre lease that was set to e xpire in 2012. This action by the NPS actualized Drakes Estero's 1976 designation as a wilderness area under the Wilderness Act and kickstarted a passive restoration effort in 2016 to return the Estero to a more natural state by removing over 3.8 millions pounds of derelict mariculture gear (i.e., oyster racks, pressure treated wood, plastic). This passive restoration occurred in three steps—1) an excavator on a floating barge was used to remove the wooden oyster rack infrastructure, 2) a custom designed excavator bucket was used to remove debris from the benthos in areas without eelgrass, and 3) in areas with eelgrass, debris was hand-picked by SCUBA divers [1]. Success was measured as **"meeting the 1.2:1 mitigation ratio."**

Outcomes: Overall, the passive restoration was hugely successful in minimizing impacts and facilitating natural eelgrass recovery (see Figures to the left). Impacts were limited to the footprint of the project area and the impact to eelgrass was far below what was permitted (2390 m^2 or 25,730 ft^2) at only 353 m^2 (3,803 ft^2) [1]. The required mitigation ratio was 1.2:1 or an area of 424 m^2 (4,564 ft^2) and by 2019, eelgrass cover increased 249% or 1057 m^2 (11,376 ft^2) [2]. Prior to restoration, eelgrass growth was inhibited by the effects of mariculture debris, mainly through chronic shading and disturbance. Thus, by removing the debris, eelgrass was able to naturally recover into the area.



Cover has been steadily increasing over the past 3 years.

- [ ] Assessed site suitability
- [x] Selected methods
- [ ] Conducted pilot restoration
- [ ] Used pilot to inform restoration at scale
- [x] Evaluated restoration efforts over time



To meet the required mitigation ratio of 1.2:1, 424 m2 of eelgrass habitat needed to be restored ('Required'). By 2019, 1057 m2 of eelgrass habitat was restored ('Achieved')—thus, this restoration was considered a great success.

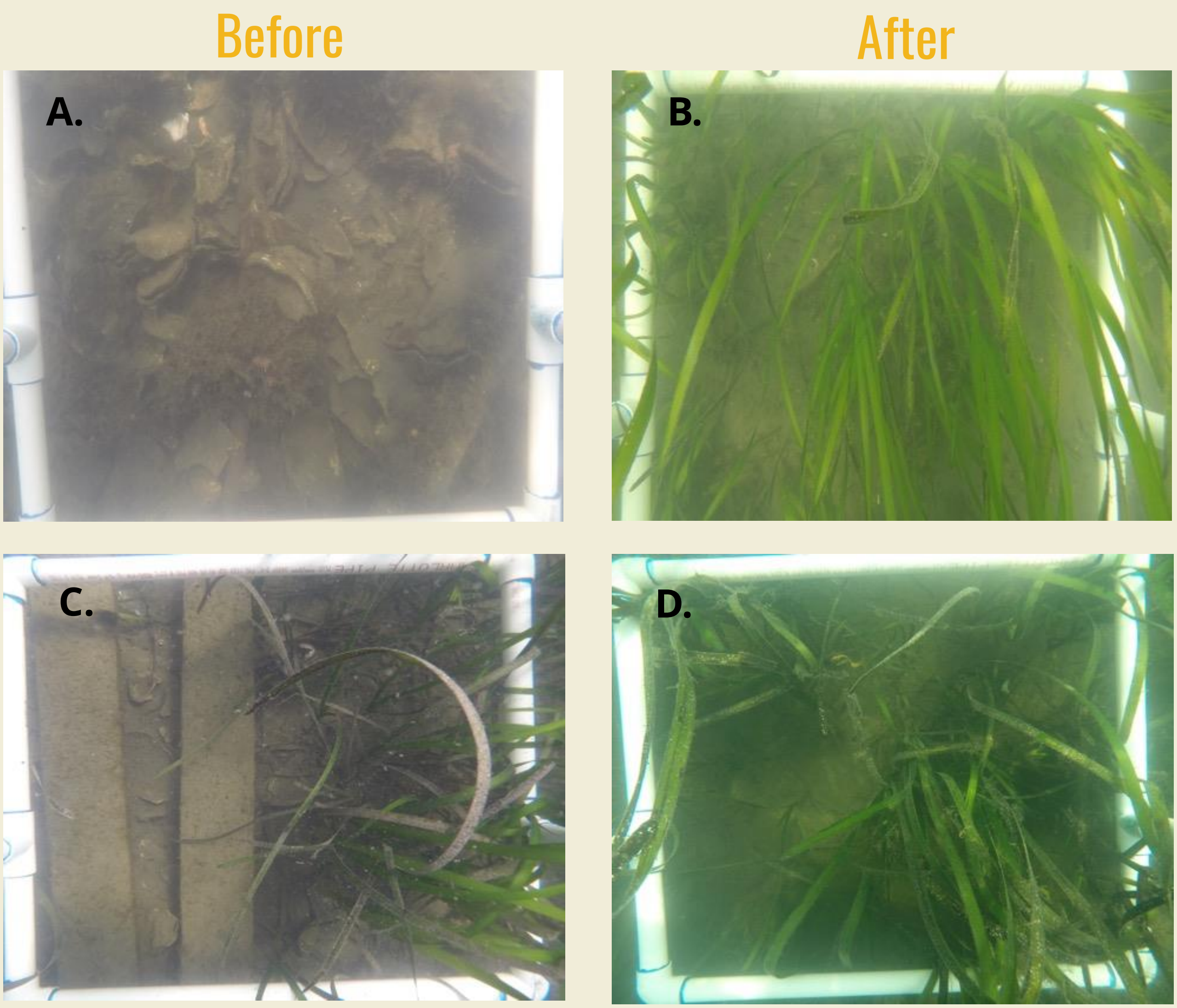
Contact for Project: Dr. Ben Becker; ben_becker@nps.gov

References:

1. Becker et al. 2017. Drakes Estero Restoration Project Eelgrass Monitoring report: Pre, Post, and 1 Year Monitoring: August 2016-October 2017.

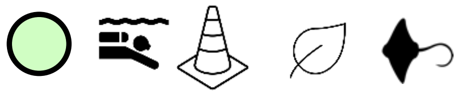
2. Becker et al. 2020. Drakes Estero Restoration Project Eelgrass Monitoring Report: Year 3. Report to satisfy permitting requirement for California Coastal Commission, National Marine Fisheries Service, US Army Corp of Engineers,

and the San Francisco Regional Water Quality Control Board.



Before (A,C) and After (B,D) photo quadrats from a single plot surveyed in 2016 (A) and 2019 (B). Photos: NPS

Case Study 4: Mount Baker Terminal
Port of Everett, Washington



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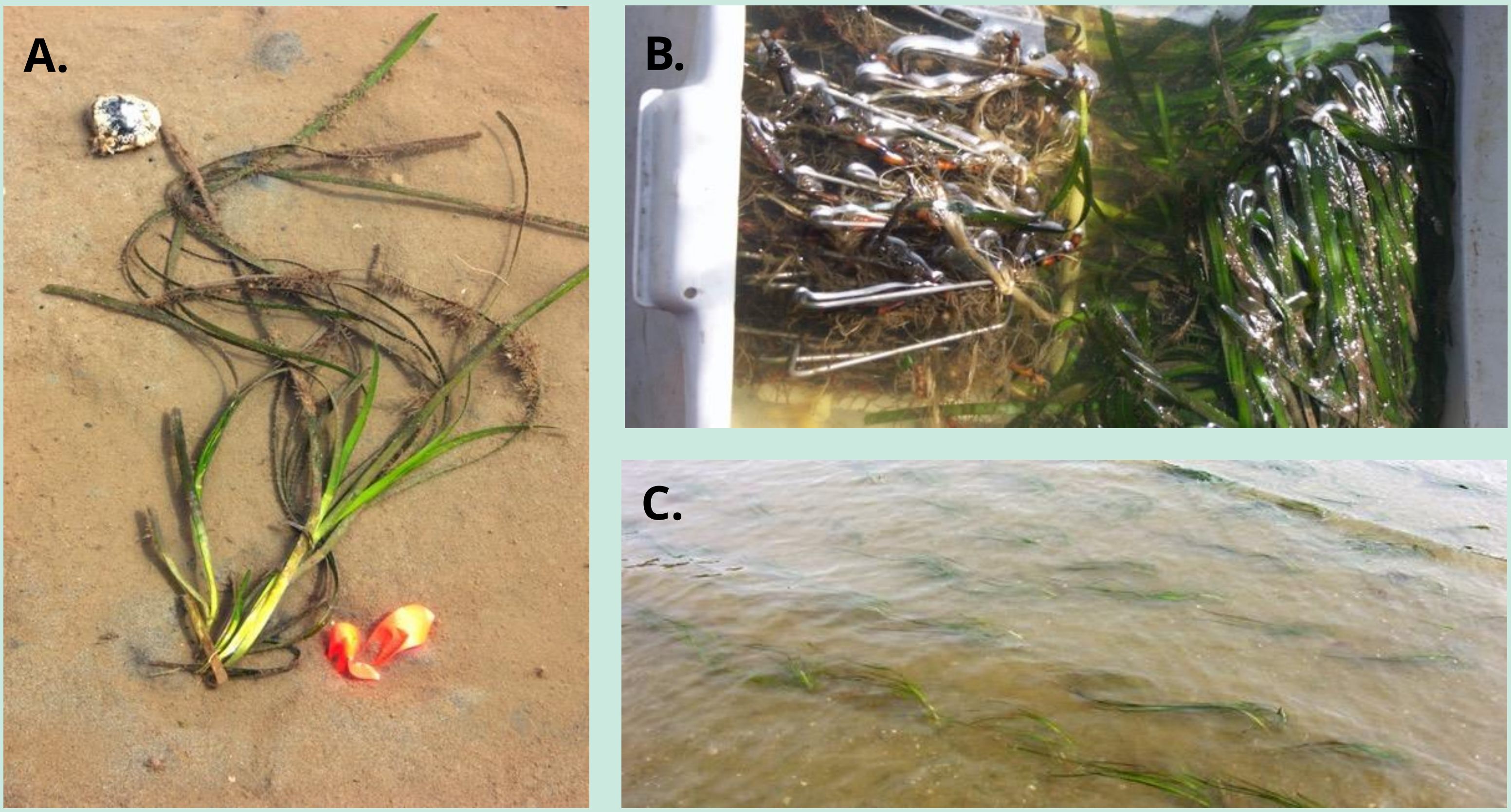
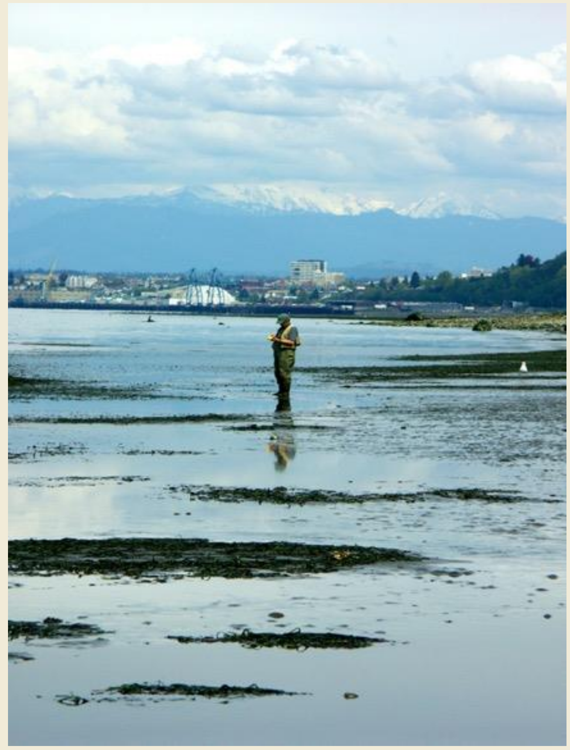


Transplanted shoots A) prepared in bundled with 6” garden staple, B) transplanted in the intertidal, C) organized in rows. Photos: Jason Stutes

Background: The Port of Everett needed to build a new rail/barge transfer facility (hereafter the ‘Mount Baker Terminal’) contracted Pentec Environmental to carry out a biological evaluation. Pentec found that the construction of Mount Baker Terminal would require a series of actions to offset the minor, yet unavoidable losses to nearshore and riparian habitat function [1]. A Conservation Measures and Monitoring Plan (CMMP) was developed by the Port to track impacts and associated mitigation measures. To offset the impacts to eelgrass, the CMMP determined that approximately 100 m^2 (1100 ft^2) of eelgrass habitat would need to be added to compensate for permanent (Mount Baker Terminal) and temporary (moored barges) shading impacts to the eelgrass bed. The CMMP established a 20-year monitoring program to assess efficacy of mitigation, including pre (2003 and 2004) and post-construction (2006 - onward) surveys. Pre-construction eelgrass surveys were incorporated in planning the location of Mount Baker Terminal, as allowed.

In April 2004, a pilot transplanting study was conducted in various locations to determine which sites had the highest likelihood of success. In 2005, viable sites were expanded to meet the area required by the CMMP (~100 m^2) and supplemental transplants were added as needed in 2006 and 2007. Shoots and associated rhizomes were bundled, tied with twine, and anchored using 6" staples. The number of shoots bundled depended on the year and depth (intertidal vs. subtidal) of transplanting--all plantings from 2004-2006 used 3 shoot bundles and in 2007, subtidal transplants used both 3 and 10 shoot bundles and intertidal transplants 3 and 5 shoot bundles. A subset of the transplanted sites also included sod transplantings--this method removes ~0.09m^2 (1 ft^2) of seagrass and underlying sediment from the donor bed, which in this project was also the reference site, and transplants it into an excavated plot to ensure the transplanted sod is level with the surrounding habitat. Adjusting the number of shoots per bundle had no detectable effect on restoration outcomes nor was there a reported difference in the efficacy of anchored bare root transplants versus sod transplants.

Success was measured as **"no temporal loss of eelgrass productivity...area of eelgrass beds created, and the calculated number of eelgrass shoots in the transplant areas must equal or exceed any declines in the project vicinity, adjusted for changes in the reference bed."** [1] and if criterion was not met, transplants would have to meet a 1.5:1 mitigation ratio.

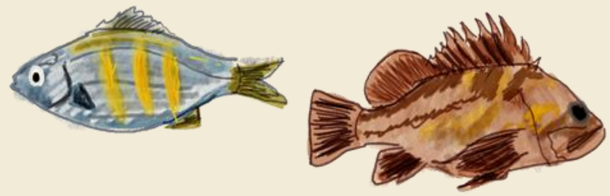


Pentec team collecting GPS points. Photo: Jason Stutes

Outcomes: Pre-construction surveys showed natural eelgrass meadows declining in area—from 2005 to 2008, 563m^2 was lost. Meanwhile, shoot densities (per m^2) increased—from approximately 30 shoots per m^2 (2005) to 48 shoots per m^2 (2008). Transplant success (2005-2008) varied across space and time. Supplemental plantings were often needed throughout this three-year period to counter losses and a handful of the sites established in 2005 were later abandoned. Changes to beach morphology, shifting sands, erosion, and tidal scour may have contributed to observed losses in the intertidal, while macroalgae (Gracilaria sp., Saccharina latissima, Ulva sp.) may have increased drag and uprooted or dislodged transplanted shoots in the subtidal. Additionally, there was no detectable effect of burrowing crabs on transplant success in the subtidal, but frequent observations of crab activity were noted [1,2].

Despite these losses, the cumulative performance of initial and supplemental eelgrass transplants **met the success criteria of both area and shoot density** (as of 2009). Factoring in 2007 supplemental plantings, by early 2009 intertidal transplants covered approximately 38 m^2 (412 ft^2) and shoot survival averaged 118%, or 841 shoots and subtidal transplants covered approximately 136 m^2 (1,464 ft^2) and shoot survival averaged 247%, or 3946 shoots [2].

[1]Reports indicated that 20 years of monitoring would be conducted, we were only able to access reports from 2008 and 2009—2 and 3 years post-construction. We suspect more current reports could be made available upon request.



Repeated beach seining showed that commercially (salmon, trout, perch, sole, etc.) and ecologically important species of fishes were utilizing the transplanted habitat and adjacent restored beach.

Contact(s) for Project: Drs. Jon Houghton and Jason Stutes; jstutes@geoengineers.com

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1. Pentec Environmental. 2007. Mount Baker Terminal 2007 (Year 2) Monitoring Report Everett, Washington. Prepared for Port of Everett, February 20, 2008; 12021-138.

2. Pentec Environmental. 2009. Mount Baker Terminal 2008 (Year 3) Monitoring Report Everett, Washington. Prepared for Port of Everett, April 10, 2009; 12021-140.

- [x] Assessed site suitability
- [x] Selected methods
- [x] Conducted pilot restoration
- [x] Used pilot to inform restoration at scale
- [x] Evaluated restoration efforts over time

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8. APPENDICES (SEE NEXT PAGE)

Appendix A – Included Projects

All projects below were included into analyses described in the report. Project numbers denoted by an asterisk (projects 52-57) mark restorations where quantitative information was unavailable (i.e., shoot densities or areas), but whose qualitative data on likely drivers of eelgrass loss were included in analyses. Information on whether projects "met defined success criteria" refers to practitioner defined success, whereby "varies" implies that some plots may have met criteria while others failed. [1]The parenthetical values in 'Method Category & Type' cells indicate the applied mitigation ratio (i.e., if an active mitigation project planted a 1.2:1 ratio, the cell would read 'Active, Mitigation (1.2)'.

Project #	Estuary ID or Best Available Lat/Long	Project	Site	State	Year Planted	Season Planted	Total monitor-ing time (months)	Number of plots	[1]Method Category & Type	Specific Method	Reference Meadow (Y/N)?	Did project meet defined success?	Ecosystem services measured	Citation (see works cited)
1	Multiple Locations	Puget_2016	Puget Sound	WA	2016	Spring, Summer	24	6	Active, Non-mitigation	Other (burlap)	N	NA	pH amelioration	23, 65
2	Multiple Locations	Puget_2017	Puget Sound	WA	2017	Spring, Summer	12	15	Active, Non-mitigation	TERF, Bamboo/Rebar Stake	N	NA	None	23, 65
3	2023_Willapa Bay	RuesinkWillapa_2018	Willapa Bay	WA	2016	Spring, Summer	3	22	Active, Non-mitigation	Unanchored	N	NA	None	63
4	2060_Siuslaw River	Siuslaw_2007	Siuslaw	OR	2007	Summer	108	3	Active, Mitigation (1.5)	Plugs and EPUs (bare roots tied to rebar, anchored by bamboo)	Y	Yes	None	Raw data
5	2060_Siuslaw River	Siuslaw_2008	Siuslaw	OR	2008	Summer	96	3	Active, Mitigation (1.5)	Plugs and EPUs (bare roots tied to rebar, anchored by bamboo)	Y	Yes	None	Raw data
6	2065_Coos Bay	SouthSlough_ValinoIsl	Coos Bay	OR	2020	Summer	4	24	Active, Non-mitigation	Garden staple	Y	NA	None	Raw data
7	2106_Humboldt Bay	SaltRiver_ChannelCreation	Salt River (Humboldt)	CA	2014	NA	36	4	Passive, Mitigation	Passive (geomorph changes)	Y	NA	None	34, 35
8	3038_Tomales Bay	Tomales_MooringRemoval	Tomales Bay	CA	2016	NA	12	29	Passive, Non-mitigation	Passive (debris removal)	Y	NA	ND	51

Project #	Estuary ID or Best Available Lat/Long	Project	Site	State	Year Planted	Season Planted	Total monitor-ing time (months)	Number of plots	[1]Method Category & Type	Specific Method	Reference Meadow (Y/N)?	Did project meet defined success?	Ecosystem services measured	Citation (see works cited)
9	3040_Drakes Estero	Drakes_DebrisRemoval	Drakes Bay	CA	2016	Spring	36	3	Passive, Mitigation (1.2)	Passive (debris removal)	Y	Yes	None	5, 6
10	3078_Elkhorn Slough	ElkSlu_1_2015_Restoration_Project	Elkhorn Slough	CA	2015	Spring	30	51	Active, Non-mitigation	Garden staple	Y	Yes	Biodiversity, Nursery Function, pH amelioration, Carbon Storage	Raw data
11	3078_Elkhorn Slough	ElkSlu_2_2016_Restoration_Project	Elkhorn Slough	CA	2016	Winter	40	66	Active, Non-mitigation	Garden staple	Y	Yes	Biodiversity, Nursery Function, pH amelioration, Carbon Storage	Raw data
12	3048_San Francisco Bay	SF_Living_Shorelines	San Francisco	CA	2012	Summer	24	3	Active, Non-mitigation	Bamboo/rebar stake, seeding	Unclear	Varied	Species abundance & behavior	31, 32
13	3098_Morro Bay	MBNEP_2018	Morro Bay	CA	2018	Winter, Spring	12	32	Active, Non-mitigation	Garden staple	N	NA	ND	Raw data
14	3098_Morro Bay	MBNEP_2019	Morro Bay	CA	2019	Winter, Spring	6	46	Active, Non-mitigation	Garden staple, Bamboo/ rebar Stake	N	NA	ND	Raw data
15	3098_Morro Bay	MBNEP_2020	Morro Bay	CA	2020	Winter, Spring	6	87	Active, Non-mitigation	Garden staple, bamboo/rebar Stake, unanchored	N	NA	ND	Raw data
16	3098_Morro Bay	MorroBay_MaintenanceDredging	Morro Bay	CA	2010	Summer	60	1	Active, Mitigation (2.4)	ND (transplant)	Y	Y	None	49

Project #	Estuary ID or Best Available Lat/Long	Project	Site	State	Year Planted	Season Planted	Total monitor-ing time (months)	Number of plots	[1]Method Category & Type	Specific Method	Reference Meadow (Y/N)?	Did project meet defined success?	Ecosystem services measured	Citation (see works cited)
17	4025_Los Angeles Harbor	PortOfLA_Pier300_EelgrassMitigationProject	Los Angeles Harbor	CA	2003	Summer	88	1	Active, Mitigation (1.2)	Other (biodegradable, soft anchors)	Y	Varied	None	47
18	4029_Alamitos Bay	CerritosBahia	Alamitos Bay	CA	2012	Summer	48	1	Active, Mitigation (1.55)	Popsicle stick	Y	Y	None	49
19	4036_Newport Bay	OCCK_LivingShorelines_2012	Newport Bay	CA	2012	Summer	30	3	Active, Non-mitigation	Popsicle stick, BuDs, TERFs	Y	Varied	None (but show habitat provisioning)	55
20	4036_Newport Bay	OCCK_LivingShorelines_2013	Newport Bay	CA	2013	Summer	24	2	Active, Non-mitigation	Popsicle stick	Y	Varied	None (but show habitat provisioning)	55
21	4036_Newport Bay	OCCK_LivingShorelines_2014	Newport Bay	CA	2014	Summer	12	3	Active, Non-mitigation	Popsicle stick	Y	Varied	None (but show habitat provisioning)	55
22	4036_Newport Bay	OCCK_LivingShorelines_2016	Newport Bay	CA	2016	Summer	36	4	Active, Non-mitigation	Popsicle stick	N	Varied	Species richness, Sedimentation	56
23	4057_Mission Bay	Seaworld_mitigation	Mission Bay	CA	1991	Summer	60	1	Active, Mitigation (3.125)	ND (transplant)	N	Y	None	43
24	4059_San Diego Bay	GloriettaBay	San Diego Bay	CA	2007	Spring	60	1	Active, Mitigation (4.5)	ND (transplant)	Y	Y	None	48

Project #	Estuary ID or Best Available Lat/Long	Project	Site	State	Year Planted	Season Planted	Total monitor-ing time (months)	Number of plots	[1]Method Category & Type	Specific Method	Reference Meadow (Y/N)?	Did project meet defined success?	Ecosystem services measured	Citation (see works cited)
25	4059_San Diego Bay	SD_ConvairLagoon	San Diego Bay	CA	1998	Summer	60	1	Active, Mitigation (1.22 & 1.17)	Popsicle stick	Y	Varied	None (but showed habitat provisioning)	36
26	4057_Mission Bay	MissionBayDredge_2010	Mission Bay	CA	2011	Fall	60	2	Active, Mitigation (6.8)	ND ("biodegradable, soft anchors")	Y	N	None	39
27	4052_Agua Hedionda	AguaHedionda_1999	Agua Hedionda Lagoon	CA	2001	Summer	60	2	Active, Mitigation (1.21)	ND (transplant)	N	Y	None	45
28	4036_Newport Bay	MBC_NBBEelgrassMitigation	Newport Bay	CA	2011	Summer	60	2	Active, Mitigation (8.27)	ND (transplant)	Y	Y	None (but show habitat provisioning)	40
29	4036_Newport Bay	BalboaMarina	Newport Bay	CA	2009	Summer	36	1	Active, Mitigation (6.1)	ND (transplant)	Y	Y	None	41
30	4013_Channel Islands Harbor	AnaCapaIsland	Channel Islands	CA	2002	Summer	120	3	Active, Non-mitigation	Garden staple (modified)	Y	Varied	None	3
31	3048_San Francisco Bay	SFOakBayBridgeESpanSeismicSafetyProj	San Francisco	CA	2002	Summer	12	6	Active, Mitigation	Popsicle stick, plugs	Y	NA	None	46
32	3048_San Francisco Bay	SFB_HabitatRestorationForSalmonids	San Francisco	CA	2008	Summer	8	2	Active, Non-mitigation	Bamboo/Rebar stake, BuDS	Y	NA	Fish visitation and epifaunal abundance and diversity	11

Project #	Estuary ID or Best Available Lat/Long	Project	Site	State	Year Planted	Season Planted	Total monitor-ing time (months)	Number of plots	[1]Method Category & Type	Specific Method	Reference Meadow (Y/N)?	Did project meet defined success?	Ecosystem services measured	Citation (see works cited)
33	3048_San Francisco Bay	SFB_CICEET	San Francisco	CA	2006	Summer	23	3	Active, Non-mitigation	BuDS, TERFs (modified)	Y	Varied	None (but show habitat provisioning)	10
34	3048_San Francisco Bay	SF_CMA_Mititgation_Project	San Francisco	CA	2010	Summer	44	28	Active, Mitigation (3)	Bamboo/rebar stake, BuDS	Y	Varied	None	12
35	2106_Humboldt Bay	Wright Scuchart Harbor Co Indudstrial Yard Dredging	Humboldt Bay	CA	1986	Summer	13	ND	Active, Mitigation (2.1)	Garden staple	ND	N	None	50
36	2106_Humboldt Bay	PGE_HBP_Pipeline_Removal_Project	Humboldt Bay	CA	2010	Spring	60	ND	Active, Mitigation	Plugs	ND	Varied	None	50
37	2106_Humboldt Bay	HSU_Aquatic_Center_Eureka_Waterfront	Humboldt Bay	CA	2010	Spring	60	ND	Passive, Mitigation	Passive (debris removal)	ND	Varied	None	50
38	3048_San Francisco Bay	SFOBB_and_DARP_Restoration_2014	San Francisco	CA	2014	Summer	42	4	Active, Mitigation (1.5)	Popsicle stick	N	N	Herring egg count and dry weight	83
39	3048_San Francisco Bay	SFOBB_and_DARP_Restoration_2015	San Francisco	CA	2015	Spring	31	12	Active, Mitigation (1.5)	Bamboo/rebar stake, popsicle stick	N	Varied	Herring egg count and dry weight	83
40	3048_San Francisco Bay	SFOBB_and_DARP_Restoration_2016	San Francisco	CA	2016	Summer	18	12	Active, Mitigation (1.5)	Bamboo/rebar stake, popsicle stick	N	Varied	Herring egg count and dry weight	83

Project #	Estuary ID or Best Available Lat/Long	Project	Site	State	Year Planted	Season Planted	Total monitor-ing time (months)	Number of plots	[1]Method Category & Type	Specific Method	Reference Meadow (Y/N)?	Did project meet defined success?	Ecosystem services measured	Citation (see works cited)
41	2025_Columbia River - Reach A	Judd_LowerColumbia_2009	Columbia River	WA (and OR)	2009	Summer	12	5	Active, Non-mitigation	Garden staple	Y (but do not report any monitoring data)	Varied	Habitat provisioning (Dungeness crab)	30
42	Not PMEP Estuary	Clinton_Ferry_WA_1996	Puget Sound	WA	1996	ND	120	6	Active, Non-mitigation (3.2)	Garden staple	Y	Varied	Salmonid prey abundance	79
43	Not PMEP Estuary	Clinton_Ferry_WA_2001	Puget Sound	WA	2001	ND	84	3	Active, Non-mitigation (3.2)	Garden staple	Y	Varied	Salmonid prey abundance	79
44	Not PMEP Estuary	Clinton_Ferry_WA_2003	Puget Sound	WA	2003	ND	12	2	Active, Non-mitigation (3.2)	Garden staple	N	N	Salmonid prey abundance	79
45	Not PMEP Estuary	Puget_Sound_SSM_Test_Plots_2013	Puget Sound	WA	2013	ND	12	9	Active, Non-mitigation	Garden staple	Y	Varied	None	76
46	2022_Grays Harbor	Grays_Harbor_WA_Dungies_Mitig_1990	Grays Harbor	WA	1990	ND	62	6	Active, Mitigation	Garden staple (modified)	Y	Y	None	71
47	1059_Eagle Harbor	Eagle_Harbor_WA_1998	Puget Sound	WA	1998	ND	24	1	Active, Mitigation	Garden staple, popsicle stick	Y	N	None	72
48	Not PMEP Estuary	Mount Baker Terminal 2005	Puget Sound	WA	2005	Winter, Spring	40	8	Active, Mitigation (1.5)	Garden staple	Y	Varied	Fish seine for species diversity and abundance	60

Project #	Estuary ID or Best Available Lat/Long	Project	Site	State	Year Planted	Season Planted	Total monitor-ing time (months)	Number of plots	[1]Method Category & Type	Specific Method	Reference Meadow (Y/N)?	Did project meet defined success?	Ecosystem services measured	Citation (see works cited)
49	Not PMEP Estuary	Mount Baker Terminal 2007	Puget Sound	WA	2007	Spring	23	5	Active, Mitigation (1.5)	Garden staple + plugs	Y	Varied	Fish seine for species diversity and abundance	60
50	Not PMEP Estuary	Holmes Harbor	Puget Sound	WA	2004	Summer	12	1	Active, Mitigation	BuDs	N	N	None	74
51	1059_Eagle Harbor	Milwaukee Dock	Eagle Harbor	WA	2014, 2016	ND	ND	ND	Active, Non-mitigation	ND	Y	N	None	85
*52	2106_Humboldt Bay	Uknown_Proponent_Projects_Indian_Island_1982	Humboldt Bay	CA	1982	ND	ND	ND	Active, Mitigation	Bare root transplant	ND	N	ND	47
*53	2106_Humboldt Bay	Uknown_Proponent_Projects_Indian_Island_1986	Humboldt Bay	CA	1986	ND	ND	ND	Active, Mitigation	Bare root transplant	ND	N	ND	47
*54	2106_Humboldt Bay	City_of_Eureka_SmallBoatBasin_2000	Humboldt Bay	CA	2000	ND	ND	ND	Active AND Passive, Mitigation (4)	Constructed site + plug	ND	Y	ND	47
*55	2106_Humboldt Bay	Caltrans_SR255Bridge_2004	Humboldt Bay	CA	2004	Summer	24	ND	Active AND Passive, Mitigation (1.2)	Substrate remediation + bare root transplant	ND	N	ND	47
*56	2106_Humboldt Bay	HB_HRCD_InnerChannelMaintenance_2005	Humboldt Bay	CA	2005	ND	84	ND	Active, Mitigation	Garden staple	ND	Varied	ND	47
*57	2106_Humboldt Bay	HB_Rowing_Association_Dock_2012	Humboldt Bay	CA	2012	Summer	60	ND	Active AND Passive, Mitigation (2)	Substrate remediation + bare root transplant	ND	Y	ND	47

Appendix B – Excluded Projects

All projects below detail eelgrass restoration projects known to occur within California, Oregon and Washington in recent decades that could not be included in the report. Many projects are cited as excluded due to 'Southern California Mitigation'. This is because there were so many southern California mitigation projects available, we could not pull all available data and prioritized less represented regions (Washington and Oregon) for inclusion in the report.

Project	Site	State	Reason(s) for exclusion	Where is project referenced or how was it found?
Puget_2015	Puget Sound	WA	They did not have funding to monitor at any time beyond the transplanting date	Found report online
Yaquina_MOCP	Yaquina Bay	OR	Cannot find the reports to the actual restoration. This is just a report of a follow up study evaluating whether or not the restored meadow is providing similar services to the nearby reference meadows.	Peer-reviewed publication exists, but it does not report details on the methods or restoration itself.
Brightwater Treatment Plant	Puget Sound	WA	Cannot find data or reports	Salmon Recovery Portal
South Oregon Regional Airport Runway Safety Expansion	Coos Bay	OR	This data is proprietary, and we cannot get access to it	Personal communications
San Juan Mooring Buoy Eelgrass Restoration Pilot Project	Puget Sound	WA	Cannot find data or reports	Salmon Recovery Portal
Eelgrass Restoration Assessment - Westcott Bay, FSJ	Puget Sound	WA	Cannot find data or reports	Salmon Recovery Portal
Milwaukee Dock Eelgrass Restoration - Bainbridge Island - 2008	Puget Sound	WA	Cannot find a report that includes data	Salmon Recovery Portal
Crescent City Harbour Outer Boat Basin Project	Crescent Harbor	CA	Out of project scope	Personal communications

Project	Site	State	Reason(s) for exclusion	Where is project referenced or how was it found?
Port Gamble Bay Eelgrass Restoration	Puget Sound	WA	Cannot find data or reports	Found report online
Former Scott Paper Mill, Drayton Harbor	Puget Sound	WA	Cannot find data or reports	Found report online
Keil Cove, SF Bay	San Francisco	CA	Cannot find data or reports	from Judd et al. 2009 Appendix D
Paradise Cove, SF Bay	San Francisco	CA	Cannot find data or reports	from Judd et al. 2009 Appendix D
Blaine Marina, WA	Salish Sea	WA	Cannot find data or reports	from Judd et al. 2009 Appendix D
Padilla Bay, WA	Padilla Bay	WA	Cannot find data or reports	from Judd et al. 2009 Appendix D
Dakota Creek, WA	Salish Sea	WA	Cannot find data or reports	from Judd et al. 2009 Appendix D
Smith Cove, WA	Puget Sound	WA	Cannot find data or reports	from Judd et al. 2009 Appendix D
Magnolia, WA	Puget Sound	WA	Cannot find data or reports	from Judd et al. 2009 Appendix D
Siuslaw River, OR	Siuslaw	OR	Cannot find data or reports	from Judd et al. 2009 Appendix D
Bodega Harbor, CA	Bodega Harbor	CA	Cannot find data or reports	from Judd et al. 2009 Appendix D
Richmond Harbor, San Francisco Bay, CA	San Francisco	CA	Cannot find data or reports	from Judd et al. 2009 Appendix D
Uknown_Proponent_Projects_Indian_Island_Proj1	Humboldt Bay	CA	Cannot find data or reports	History of Eelgrass Mitigation Transplants in Humboldt Bay - Eelgrass Management Plan 2017 (Table 5, p 76)
City_of_Eureka_SmallBoatBasin	Humboldt Bay	CA	Cannot find data or reports	History of Eelgrass Mitigation Transplants in Humboldt Bay - Eelgrass Management Plan 2017 (Table 5, p 76, 77)
Caltrans_SR255Bridge	Humboldt Bay	CA	Cannot find data or reports	History of Eelgrass Mitigation Transplants in Humboldt Bay - Eelgrass Management Plan 2017 (Table 5, p 76, 77)
HB_HRCD_InnerChannelMaintenance	Humboldt Bay	CA	Cannot find data or reports	History of Eelgrass Mitigation Transplants in Humboldt Bay - Eelgrass Management Plan 2017 (Table 5, p 76, 78-79)

Project	Site	State	Reason(s) for exclusion	Where is project referenced or how was it found?
HB_Rowing_Association_Dock_2012	Humboldt Bay	CA	Cannot find data or reports	History of Eelgrass Mitigation Transplants in Humboldt Bay - Eelgrass Management Plan 2017 (Table 5, p 79)
Crown Cove Dock Eelgrass Mitigation Project	San Diego Harbor	CA	Southern California Mitigation	EcoAtlas
Sweetwater-Silvergate Eelgrass Mitigation Project	San Diego Harbor	CA	Southern California Mitigation	EcoAtlas
Ventura Cove Eelgrass Mitigation Project	Mission Bay	CA	Southern California Mitigation	EcoAtlas
Sunroad Marina Eelgrass Mitigation Project	San Diego Harbor	CA	Southern California Mitigation	EcoAtlas
San Diego Harbor Excursion Eelgrass Mitigation Project	San Diego Harbor	CA	Southern California Mitigation	EcoAtlas
San Diego Harbor Police & Transient Dock Eelgrass Mitigation	San Diego Harbor	CA	Southern California Mitigation	EcoAtlas
San Dieguito Saltmarsh Eelgrass Mitigation Project	San Dieguito Lagoon	CA	Southern California Mitigation	EcoAtlas
San Diego Bay Shipyard Sediment Eelgrass Mitigation Project	San Diego Harbor	CA	Southern California Mitigation	EcoAtlas
San Diego Bay-Shelter Island Eelgrass Mitigation Project	San Diego Harbor	CA	Southern California Mitigation	EcoAtlas
San Diego Bay-Delta Beach Eelgrass Mitigation Project	San Diego Harbor	CA	Southern California Mitigation	EcoAtlas
Le Meridien Eelgrass Mitigation Project	San Diego Harbor	CA	Southern California Mitigation	EcoAtlas
North Harbor Drive Bridge Eelgrass Mitigation Project	San Diego Harbor	CA	Southern California Mitigation	EcoAtlas
Marine Group Boatworks Eelgrass Mitigation Project	San Diego Harbor	CA	Southern California Mitigation	EcoAtlas
National City Wharf Expansion Eelgrass Mitigation Project	San Diego Harbor	CA	Southern California Mitigation	EcoAtlas
U.S. Coast Guard Pier Renovation Eelgrass Mitigation	San Diego Harbor	CA	Southern California Mitigation	EcoAtlas

Project	Site	State	Reason(s) for exclusion	Where is project referenced or how was it found?
Navy NEMS 1 Eelgrass Mitigation Project	San Diego Harbor	CA	Southern California Mitigation	EcoAtlas
Navy NEMS 2 Eelgrass Mitigation Project	San Diego Harbor	CA	Southern California Mitigation	EcoAtlas
Navy (NEMS 6) at NAB Coronado Eelgrass Mitigation Project	San Diego Harbor	CA	Southern California Mitigation	EcoAtlas
Embarcadero Marina Eelgrass Mitigation Project	San Diego Harbor	CA	Southern California Mitigation	EcoAtlas
Campbell Shipyard Remediation Eelgrass Mitigation Project	San Diego Harbor	CA	Southern California Mitigation	EcoAtlas
East Ski Island Eelgrass Mitigation Project	Mission Bay	CA	Southern California Mitigation	EcoAtlas
Coronado Bay Bridge Eelgrass Mitigation Project	San Diego Harbor	CA	Southern California Mitigation	EcoAtlas
Channel Shoals Eelgrass Mitigation Project	Mission Bay	CA	Southern California Mitigation	EcoAtlas
BAE Systems Pier 1 Eelgrass Mitigation Project	San Diego Harbor	CA	Southern California Mitigation	EcoAtlas
Bristol Cove Dredging Eelgrass Mitigation Project	Agua Hedionda	CA	Southern California Mitigation	EcoAtlas
2209 Bayside Drive Eelgrass Mitigation Project	Newport Bay	CA	Southern California Mitigation	EcoAtlas
Orange Coast College Eelgrass Mitigation Project	Newport Bay	CA	Southern California Mitigation	EcoAtlas
Sunset Harbor Dredging Phase II Eelgrass Mitigation Project	Seal Beach Harbor	CA	Southern California Mitigation	EcoAtlas
Linda Isle/Harbor Island Eelgrass Mitigation Project	Newport Bay	CA	Southern California Mitigation	EcoAtlas
Talbert Marsh Experimental Eelgrass and Cordgrass Survey	Santa Ana River Channel	CA	Southern California Mitigation	EcoAtlas

Project	Site	State	Reason(s) for exclusion	Where is project referenced or how was it found?
Lower Newport Bay Eelgrass Mitigation Project	Newport Bay	CA	Southern California Mitigation	EcoAtlas
Newport Beach Harbor Patrol Eelgrass Mitigation Project	Newport Bay	CA	Southern California Mitigation	EcoAtlas
2210 Channel Road Eelgrass Survey	Newport Bay	CA	Southern California Mitigation. Not clear if or when mitigation was performed.	EcoAtlas
Coast Guard Mooring Corona del Mar Eelgrass Mitigation	Newport Bay	CA	Southern California Mitigation	EcoAtlas
Anaheim Bay Naval Weapons Station Eelgrass Mitigation	Seal Beach Harbor	CA	Southern California Mitigation	EcoAtlas
Cerritos Bahia Marina Eelgrass Mitigation Project	Alamitos Bay	CA	Southern California Mitigation	EcoAtlas
Marine Stadium Eelgrass Survey	Alamitos Bay	CA	Southern California Mitigation	EcoAtlas

Appendix C – Extracted Variables

Data on all plots from all projects included in Appendix A (aside from projects denoted by an asterisk) were extracted for the following variables.

1. Project title
2. Agencies involved & points of contact
3. Bay
4. Specific project location
5. Noted bay characteristics, including dredging impacts
6. Project latitude and longitude
7. State
8. Total project funding
9. Was a site suitability model used?
10. Mitigation vs non-mitigation?
11. Active vs. passive restoration?
12. Restoration method
13. Was SCUBA used?
14. Were supplemental transplants used mid-project?
15. Status of natural meadows during project duration
16. Was a reference meadow monitored?
    a. Reference meadow size during all monitoring periods
    b. Reference meadow shoot densities during all monitoring periods
17. Year of restoration
18. Season of restoration
19. Month of restoration
20. Frequency of restoration monitoring
21. Actual mitigation ratio applied
22. Area of restoration plots upon transplant and during all monitoring periods
23. Shoot densities of restoration plots upon transplant and during all monitoring periods
24. Canopy height upon transplant and during all monitoring periods
25. Epiphytic loads
26. Practitioner defined success criteria
    a. Did plots meet areal cover criteria?
    b. Did plots meet shoot density criteria?
27. Did they measure any of the following environmental data?
    a. Depth
    b. Wasting disease
    c. Sea surface temperature
    d. Salinity
    e. Light/turbidity
    f. Algal cover
    g. Grain size
    h. Distance from mouth of watershed
    i. Dissolve oxygen
    j. pH
    k. other environmental data
28. Did they evaluate the following ecosystem services, and if so, what were the results?
    a. Provisioning of habitat for marine megafauna
    b. Species richness
    c. Habitat usage, particularly by species of economic significance
    d. Blue carbon stocks or sequestration
    e. pH or hypoxia amelioration
    f. Improved water clarity
    g. Any other evaluated ecosystem services
29. Data references and location

Appendix D—Reasons for Loss

Using qualitative data collected from reports and interviews we have generated a list of the main factors associated with eelgrass restoration loss or failure. The "Cited Reason for Loss" are listed chronological based on the number of projects that listed each 'reason'. We have sorted each factor into three categories—'Biological', 'Physical', and 'Logistical'. Projects are listed by Project Number; see Appendix A for list of Projects by 'Project #'. We have also included projects (bottom) where there was no cited factors linked to restoration loss/failure OR the project met its goals/criteria.

Cited Reason for Loss	# of Projects	Category	Projects
macroalgae	8	Biological	1, 14, 15, 32, 35, 36, 40, 41
sedimentation	6	Physical	1, 5, 22, 32, 36, 41, 47
light limited	7	Physical	1, 5, 15, 35, 22, 43
desiccation	5	Physical	1, 5, 6, 32, 39
method	5	Logistical	2, 17, 29, 36, 37
eutrophication	3	Physical	1, 5, 37
bioturbation	3	Biological	21, 34, 40
El Nino/ENSO	3	Physical	21, 30, 37
storm(s)/waves	3	Physical	37, 40, 43
disease	2	Biological	1, 14
erosion	2	Physical	32, 41
grazing	2	Biological	26, 34
low salinity	2	Physical	34, 36
transplant density	2	Logistical	36, 43
poor site selection	2	Logistical	31, 43
boating activities	2	Logistical	37, 40
warm water event	2	Physical	6, 34
hydrodynamics	1	Physical	36
chemical loading	1	Physical	5
competition	1	Biological	14

Other			
project goals met	13	na	3, 5, 7-10, 12, 18-20, 24, 25, 49
unknown/no reported cause(s)	14	na	4, 11, 13, 15, 23, 27, 28, 33, 38, 42, 44-46, 48