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Eelgrass (*Zostera marina L.*) Restoration in the Pacific Northwest: Recommendations to improve project success

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16. ABSTRACT

We summarize eelgrass (*Zostera marina* L.) restoration and mitigation project results and recommendations of transplant practitioners in the Pacific Northwest since 1990. Our purpose is to provide current information for programs considering eelgrass restoration by providing a synthesis of what practitioners and researchers have learned through experimentation and monitoring of discrete projects throughout western Washington and British Columbia. Reports, papers, personal communications, and a workshop were used to gather data on these projects. Our general null hypothesis is that eelgrass can be restored to match natural eelgrass meadows in terms of structure and function. We conclude that, under favorable site conditions, and if the reason for the initial loss of eelgrass is understood and corrected, that eelgrass can be restored. However, eelgrass restoration science is hampered by knowledge gaps, reducing restoration success. For example, mechanisms for recent eelgrass loss in the region are not obvious, which suggests that the scientific understanding of eelgrass biology and ecosystem conditions is inadequate to support environmental management actions in our region. To improve restoration project success in the Pacific Northwest requires further research knowledge gaps, closely evaluating the performance of restoration projects, and disseminating information for use by future generations. Workshop participants identified an immediate need to construct a clearinghouse of eelgrass restoration and monitoring results that provides summaries and data from eelgrass enhancement efforts. Furthermore, we found that it was difficult to summarize the relative performance of the more than 30 projects reviewed because of variations in goals, project size, planting methods employed, performance criteria, duration of monitoring, intensity of monitoring, and data interpretation. Hence, we recommend that standard monitoring protocols be developed and results from these methods be reported through the clearinghouse and periodic meetings.

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Abstract

We summarize eelgrass (*Zostera marina* L.) restoration and mitigation project results and recommendations of transplant practitioners in the Pacific Northwest since 1990. Our purpose is to provide current information for programs considering eelgrass restoration by providing a synthesis of what practitioners and researchers have learned through experimentation and monitoring of discrete projects throughout western Washington and British Columbia. Reports, papers, personal communications, and a workshop were used to gather data on these projects. Our general null hypothesis is that eelgrass can be restored to match natural eelgrass meadows in terms of structure and function. We conclude that, under favorable site conditions, and if the reason for the initial loss of eelgrass is understood and corrected, that eelgrass can be restored. However, eelgrass restoration science is hampered by knowledge gaps, reducing restoration success. For example, mechanisms for recent eelgrass loss in the region are not obvious, which suggests that the scientific understanding of eelgrass biology and ecosystem conditions is inadequate to support environmental management actions in our region. To improve restoration project success in the Pacific Northwest requires further research knowledge gaps, closely evaluating the performance of restoration projects, and disseminating information for use by future generations. Workshop participants identified an immediate need to construct a clearinghouse of eelgrass restoration and monitoring results that provides summaries and data from eelgrass enhancement efforts. Furthermore, we found that it was difficult to summarize the relative performance of the more than 30 projects reviewed because of variations in goals, project size, planting methods employed, performance criteria, duration of monitoring, intensity of monitoring, and data interpretation. Hence, we recommend that standard monitoring protocols be developed and results from these methods be reported through the clearinghouse and periodic meetings.

Introduction

Eelgrass (*Zostera marina* L.) is the most widespread of ~65 seagrass species (Green and Short 2003, Larkum et al. 2006). Seagrasses play an important ecological role in nearshore systems worldwide (Hemminga and Duarte 2000). However, seagrasses have and continue to suffer losses globally due to increased development and land use which often lead to degradation of nearshore water quality as well as accelerated climate change (Short and Wyllie-Echeverria 1996; Short and Neckles 1999). Because of this, seagrasses continue to remain a focus of conservation and restoration efforts (Kenworthy et al. 2006). Earlier reviews showed that success of eelgrass restoration was variable, with projects often failing to meet performance objectives (Thom 1990, Fonseca et al. 1998). Yet, pressure remains to develop and refine methods to enhance the probability of success, and thereby reverse the trend of losses attributed to anthropogenic factors. This pressure has been driven by requirements for development projects to compensate for potential project-related losses of eelgrass. Because compensatory mitigation remains a major driver in the Northwest, all but very few projects have been true restoration (i.e., repair damaged eelgrass meadows not associated with a development project) efforts. More often sites are reclaimed (i.e., use transplanting to modify an altered site with the intention of increasing biodiversity, and initiating a recovery trajectory), rehabilitated (i.e., modification of a site to support eelgrass) or created (i.e., modifying a site where eelgrass never occurred to make it suitable for eelgrass) (Fonseca et al. 1998).

Attempts at restoring eelgrass beds are not new. Sixty years ago, Addy (1947) provided guidance and techniques for eelgrass restoration that largely apply today. A review of numerous projects in the Pacific Northwest (i.e., Northern California, Oregon, Washington, British Columbia) up to 1989 showed that nearly 65% of the projects exhibited some level of success (Thom 1990). Except for a few small experimental plots planted to test hypotheses about environmental controls on phenotypic development, projects were conducted as mitigation to compensate for development of shoreline areas. In all cases the area planted shrunk in the years following planting. In a national review, Fonseca et al. (1998) showed that seagrass compensatory mitigation projects have resulted in a net loss of habitat. Most recently, Stamey (2004) showed using a subset of projects in the Northwest that eelgrass restoration still suffered from limited success and is an uncertain practice at best in the region.

Thus, even after 60+ years of experience with eelgrass and other seagrass species in the United States, the question remains whether eelgrass can be reliably restored. This question plagues regional programs that have as part of their agenda the goal to restore damaged or lost seagrass meadows (Stamey 2004). Furthermore, the impacts of coastal development on eelgrass often require that eelgrass meadows be created or restored as compensation. There is science-based restoration guidance available to accomplish this goal (Addy 1947, Thom 1990, Fonseca et al. 1998, Short et al. 2002a, Stamey 2004), but these recommendations are inconsistently followed in present-day projects (Fonseca et al 1998; Fonseca 2007). Partially because of the uncertainty in eelgrass restoration efforts, Kenworthy et al. (2006) recommended that conservation programs that minimize injuries to seagrasses be considered a priority while making every attempt to avoid expensive and uncertain repair projects.

The purpose of this paper is to provide recommendations to improve the success of eelgrass restoration projects in the Pacific Northwest based on the most current information. To do this we reviewed available results from eelgrass restoration projects in the Pacific Northwest undertaken since 1990, and held a workshop of practitioners and resource managers to discuss their experience with these and other projects, and provide a summary of recommendations. The attendees provided insight into factors that could improve project success based on their experiences. We developed these insights into a set of recommendations and future actions. Although we compiled a set of data on specific projects, we found that summarizing the results were difficult because of project-to-project variations in restoration methodology, monitoring scope and duration, performance criteria, and data interpretation. Our general null hypothesis is that eelgrass can be restored to match natural eelgrass meadows in terms of structure and function.

Methods

The principle source of information was comments by practitioners at a workshop held in May 2007. Prior to the workshop, eelgrass restoration project reports, papers, and responses to a questionnaire were submitted by practitioners and those knowledgeable about restoration projects in the region. The workshop involved 12 practitioners plus 19 representatives from federal and state agencies (Table 1).

At the workshop we collected information organized to follow the components of a restoration project (e.g., Diefenderfer et al. 2005). These 10 components included:

- Goals – what were overall project goals?
- Project objectives – what were the principle project objectives and performance criteria?
- Conceptual model – was a conceptual model developed and how was it used?
- Site selection – how was this accomplished?
- Restoration strategy – was this a creation, restoration, or enhancement project, and how was the future of the site ensured?
- Performance measures – what metrics were employed and why?
- Implementation – what actions were taken to "construct" the project?
    - Donor material and collection methods – what was the source of the donor material, and how was it handled?
    - Seeds – were seeds used and how were they distributed?
    - Planting – what planting method was used?
- Monitoring design – what was the design employed for monitoring performance?
- Adaptive management – was anything done to improve success after monitoring the results of the initial action?
- Dissemination of results – how were the results distributed?

We also asked if there were impediments during the seagrass planting process (e.g. permits, property access, property acquisition, donor material). As a summary to the workshop, the question was posed – *Based on what you know and what you have heard, can eelgrass meadows be reliably restored in the region?*

Study Results

Reports, Papers, and Personal Communication Results

Although participants identified on the order of 30 known projects, only 14 eelgrass transplant/mitigation projects (Figure 1) had enough information to provide input to topics addressed in the workshop. All but one of the projects were conducted to mitigate for impacts of a development project. The total size of project area ranged from 2.5 m^2 (Curtis Wharf; Gayaldo et al. 2001) to 62,726 m^2 (Drayton Harbor). The projects were conducted in square plots, with plantings done in rows or within quadrats (e.g., 1.0 m^2). Planting density varied based on different planting techniques from 1 to 200 shoots m^{-2}.

Harvesting and planting techniques varied among projects. Most projects removed donor material by hand. These projects usually indicated that care was taken to avoid long lasting damage to donor stands by only removing a small percentage (i.e., 10%) of the shoots. The Sequim Outfall project was the only project that used a clamshell dredge to remove eelgrass sod from the location of a new outfall trench and transferred it directly without removing it from the water into prepared receiving locations adjacent to the construction corridor (Kyte and Evans 2002). In all cases, donor material was handled carefully to avoid desiccation and heat stress. Common planting techniques included plugs of eelgrass shoots with intact sediments and eelgrass shoots without sediments (bare roots) held in place with metal staples, washers, or rebar.

Pre-planting and post-planting monitoring was conducted on most projects. Along with quantitative sampling of eelgrass, some post-planting monitoring included seasonal efforts to observe physical and biological disturbances that may have disrupted planted plots. Monitoring duration varied extensively from a minimum of two (i.e., before-after) sampling efforts to annual assessments over a 10-year period.

The majority of the studies used shoot density as the principle performance metric, which was often compared against densities in reference plots. Other metrics included presence of planting units and salmon prey densities (e.g., bundles of shoots; Thom et al. 2001; Houghton et al. 2007). Because of variations among projects in site preparation, planting methods, performance assessment methods, project age, and data interpretation, it was decided that a quantitative comparison of project success would not be reliable. This latter finding generally limited the ability to draw conclusions and recommendations from a summary of past projects.

Workshop Results

Workshop participants provided verbal responses based on research and field experience to focused questions posed relative to each restoration project component. What follows is our summary of the discussion in response to the 10 components of a restoration project (Table 2).

Goals

Workshop participants discussed three aspects of the formulation of a goal statement: 1) define *specific* goals based on a proposed restoration action; 2) understand how the goals should be applied to address project requirements (e.g. meet mitigation requirements); and 3) employ an ecosystem-based approach toward achieving goals. Of the numerous goals that were discussed (Table 2), the overarching theme was to restore natural processes that control and sustain eelgrass populations. Specific eelgrass restoration goals included providing functioning habitat for fish and other organisms, increasing biodiversity, generating no net loss of reproductive capacity, and minimizing anthropogenic stressors.

Project Objectives

The discussion on project objectives centered on physical actions used to enhance an area that has been recommended for restoration (Table 2). Additional discussion dealt specifically with eelgrass stressors and controlling factors. Ecosystem stressors are "out of the ordinary" natural and unnatural inputs to the system that disturb the controlling factors, structure, and processes in the ecosystem. Controlling factors are the basic environmental conditions, such as light, temperature and salinity ranges, that are required by eelgrass.

Conceptual Model

A conceptual model captures the knowledge about how critical factors such as temperature, salinity, substrata, nutrients, and water motion affect eelgrass abundance and growth. In addition, other factors that must be considered include competition, natural and anthropogenic disturbance, requirements of transplanted shoots, historical presence of eelgrass, and slope or elevation. Although practitioners agreed that conceptual models are useful in the organization and understanding of conditions and factors that affect eelgrass, models were not explicitly employed in most projects. However, practitioners always considered many of these factors when evaluating a site for restoration. Conceptual models were used by the Clinton Ferry Terminal project to determine effects of the terminal expansion and ferry boat operations (e.g., propeller wash) on eelgrass and to focus efforts on actions (e.g., reduction of terminal width by making the terminal longer, and thereby moving propeller wash offshore, and reducing shading; Thom et al. 2005) (Figures 2-3). Mumford (2007) provides a general model for reducing stressors to eelgrass for the purposes of restoration (Figure 4).

Another issue relevant to a conceptual model (and site selection) would be landscape position/context. For example, in Fidalgo Bay (in northern Puget Sound) project proponents propose to dredge an existing eelgrass bed adjacent to the northwestern shoreline and mitigate for this action by depositing dredge material (from another source) offshore in the bay to create elevations suitable for eelgrass growth. Such a change in location of an eelgrass bed brings into question landscape context issues (e.g., will the same organisms be capable of using the beds, are specific life history stages disadvantaged by position of the bed, how will physical factors such as tidal currents affect use of the new location, etc.).

Site Selection

For site selection, practitioners noticed that it is important to determine how site selection fits in with the restoration agenda (i.e., local coastal management plan) in a given area or how it can be combined with larger restoration efforts (e.g., coastal watersheds). Further, information on the temporal dynamics of eelgrass abundance in the vicinity of the potential site is useful in assessing how variable the conditions for newly planted eelgrass might be. Another consideration is the history of disturbance at the proposed restoration site, and whether the site will be protected from future development or disturbance. In addition, practitioners concluded that it is necessary to examine nearshore processes (e.g., sediment delivery to the meadow by natural erosion of bluffs) to be certain that the processes are functioning in a manner that will ultimately support eelgrass.

Restoration Strategy

Restoration, enhancement, and creation were the three “management” strategies discussed. Restoration, returning a system to a semblance of its former undisturbed state, worked best in situations where eelgrass was formerly present and where the factor responsible for the loss were understood and alleviated. Enhancement was advised where eelgrass distribution was limited, but a site assessment indicated that eelgrass distribution and/or density could be increased through removal of obstructions (e.g., overwater structures, sunken logs, anchor chains). Finally, creation, the bringing into existence a habitat not formerly present, was demonstrated to be possible if site conditions (e.g., bathymetry) were modified to accommodate eelgrass.

Planting mature, terminal shoots was generally used to initiate eelgrass colonization under all three restoration strategies. Selection of appropriate sites for donor plant material is an important consideration. In particular, practitioners discussed the importance of harvesting plants from an area that is in close proximity to the restoration site, and at the same depths, to increase the potential that the stock will be adapted to the local environmental conditions. Seeding by several methods has been experimented within several projects with some success. It was generally viewed as experimental at this point, with considerations of the source and amount of seed available for distribution at the site. In general, low flowering shoot densities are recorded from natural meadows in the Northwest, which limits the sources of seeds required for large projects (Phillips 1984). Seed viability can commonly be below 10% (Phillips 1984), which adds to the need for vast quantities of seeds for large restoration sites. Practitioners did note that expansion and filling of unplanted areas at some sites was the result of both rhizome growth and natural seed recruitment.

Performance Measures

Performance measures are quantifiable or observable parameters used to track the progress of a system in meeting project goals. Restoration practitioners discussed performance measures for eelgrass transplants and habitat qualities, and concluded that it is important to keep performance measures simple, yet quantifiable, so that progress can be objectively assessed at a site over time. Performance measures for eelgrass transplants included area extent (m^2 of transplants), survival within the planted area, shoot density, shoot abundance, shoot morphology (e.g., leaf length, leaf width), above ground versus below ground biomass, and seed production metrics. Performance measures for functions included salmonid use of eelgrass beds, density of juvenile salmon epibenthic prey, sedimentation, and herring spawn on reference and transplant sites. Often, performance metrics were compared to nearby reference sites. In one case (Clinton Ferry terminal), the performance of the transplants were judged by the total abundance of plants in all of the plots, which indicated that the plants were spreading and that there was more eelgrass than had existed at the site previously (Thom et al. 2005).

Issues with comparing restoration sites to reference sites were noted. For example, reference plots at depths slightly different than the planted plots provided consistently different results (e.g. shoot density), which complicated comparisons (Vavrinec et al. 2007). Furthermore, although most reference and planted plots can show similar trends in density on an annual basis, there were examples where reference plots died or either transplant or reference plots showed much greater variation than their counterpart plots (Houghton et al 2007).

Implementation

Restoration practitioners discussed a list of proposed physical activities used to prepare a site for planting regarding substrate, elevation, and nutrients. In terms of site condition, it was deemed important to restore site conditions as close as possible to pre-disturbance conditions. This may require manipulating site elevation through dredging or filling (e.g., Drayton Harbor), clearing debris (e.g., Clinton Ferry terminal), or removing structures (e.g., Maritime Center Dock) that inhibit eelgrass growth.

Donor Material and Collection Methods

It was concluded that more research is needed to determine the appropriate percentage of a donor site that can be harvested and used for restoration. Based on experience, participants suggested that harvest of 10% of the donor stock plants would not permanently harm the donor meadow. This suggestion is presently being evaluated experimentally at one site (Brightwater), but requires more study at additional sites. To minimize damage and understand effects, participants recommended spreading donor harvests over a wide area (e.g., removing one to three shoots m^{-2}). Monitoring the donor site shoot density, morphology and flowering shoot density relative to the transplant site was also recommended.

When harvesting eelgrass it was important to keep eelgrass cool, shaded, and submerged (or at least very moist). The Holmes Harbor project had good success in developing donor material by collecting approximately 1,500 fresh drift eelgrass shoots and placing the material in sediment in large flowing seawater tanks. Because this material contained numerous flowering shoots, recruitment by seed was suspected to be a major factor contributing to the expansion by approximately 20,000 shoots within one year. This material was then used to restore eelgrass at the site. Other projects (Clinton Ferry Terminal, Hood Canal Bridge, Brightwater outfall) have developed planting stock by harvesting plants from the site prior to the impact from the development project, placing these plants in large flowing seawater tanks for 1-2 years to allow natural development of five to 15 times more shoots (A. Borde). For the new Midway sewer outfall corridor, eelgrass from the corridor was stockpiled in baskets anchored in water near the site until planted following backfilling of the corridor (Kyte 2007).

Seeds

Restoration practitioners have used numerous methods to establish seeds in a given location. Some have experienced that after a large germination event, seeds do not establish well because they are washed away by tides, waves, and currents. Others had used mats or mesh to keep seeds in place. However, the use of seeds has not been a highly successful method to establish eelgrass in the Pacific Northwest. Research continues on the use of seed buoys (Pickerel et al. 2005) in the Northwest and elsewhere.

Planting

Various methodologies have been used to transplant eelgrass (Phillips 1974, Fonseca et al. 1998). Planting plugs of eelgrass with sediment associated with the rhizosphere was used rarely and generally was most appropriate for planting small areas. Most often, bundles of bare-root (i.e., sediment free) plants were inserted into the sediment, often secured by an anchor of some sort. Common methods (Figure 5) include using metal turf staples to anchor the shoots, staking plants to metal rebar, and tying mature shoots to solid frames with biodegradable cord and staking the frames in the sediment (see Phillips 1974, Fonseca et al. 1998, Short et al. 2002b). To plant extensive areas for 20+ projects in the region, one of us (C. Durance) has successfully employed a method that involves attaching individual rhizomes to metal washers. The washer/rhizome-shoot unit is dropped from a boat while traversing transects through the site. Divers then followed transects and planted the washers and rhizomes into the sediment by hand in groups of 10. As mentioned above, a clamshell dredge, operated from a floating barge, was used to transplant large sections of eelgrass turf from the Sequim Sewage Treatment outfall corridor to adjacent areas (Kyte and Evans 2002).

Monitoring Design

The overarching principle for the design of a monitoring program hinges on the questions that are being asked. In developing the specifics of the monitoring program, practitioners considered the project goals, project scope, and scale (e.g., the size of the project). Other considerations are monitoring duration and frequency. The majority of workshop participants advised that monitoring should continue for at least 5 years, with numerous variations on the theme. Some projects (e.g., Clinton Ferry Terminal; Drayton Harbor) had longer monitoring programs primarily driven by the size and uniqueness of the projects. In the case of the Clinton Ferry Terminal and the Drayton Harbor Eelgrass Restoration Project there were specific uncertainties associated with the projects that required longer and more intense monitoring. For Clinton, the survival of plantings very near the terminal was questionable. The Drayton Harbor project involved planting on top of fill. This had not been attempted at such a large scale (62,726 m^2) in the Northwest.

Qualitative and quantitative data for pre- and post-restoration conditions were strongly recommended to document changes. Quantitative surveys of eelgrass in transplant plots often involved use of randomly placed quadrats (0.25 to 1.0 m^2) or set transects that are repeatedly examined and quantified over time (repeated measures). Monitoring most often took place during summer when eelgrass biomass and density were greatest. Qualitative observations made throughout the year of the restored plots were often helpful in explaining the condition of the eelgrass plots during summer quantitative surveys. For example, winter storm-driven waves can often move sediment and gravel onto eelgrass plots as well as erode eelgrass. However, the sediment sorting process that occurs between winter and summer tends to make physical conditions appear suitable and mask the severity of the winter disturbances on eelgrass.

Adaptive Management

Throughout the course of an eelgrass restoration project, project managers have three adaptive management options to increase restoration success (Thom 1997, 2000):

- Do nothing - stay with the status quo and allow the site to develop naturally;
- Do something - implement a corrective action to change a piece of the restoration project. This requires a trigger (e.g. no success after a specified amount of time triggers replanting) based on the monitoring criteria and project goals; or
- Change goal - implemented if it has been determined that the site may not ever achieve its original goal(s). This option requires feedback to the planning, implementation, and monitoring phases of the project and needs to have a sound scientific and statistically rigorous basis.

In the case of restoration for mitigation purposes, inaction (do nothing) when performance criteria are not met is often not viewed as an option. Corrective actions are often requested with wide latitude in the measures that may be employed. At this point, an understanding of the inherent reasons for not meeting performance criteria is essential in order to choose and implement a corrective measure that will yield positive results. In the case of the Everett Rail/Barge transfer facility, sediment characteristics within the initial eelgrass planting-site had become less suitable for eelgrass transplant success within the first year after planting. This likely was due to resorting of the restored beach face in another section of the project. The corrective action employed was to change location and then replant as opposed to just replanting (Houghton et al. 2007).

Although not desired, particularly by regulatory agencies, changing the goal or the performance objectives might be in order. Thom et al. (2005) explained how the specific use of paired transplant-reference plot comparisons was inadequate in evaluating restoration success at the Clinton Ferry Terminal once a better understanding of spatial patterns and factors controlling eelgrass density was achieved through monitoring. In this case, a new performance metric was created based on total number of shoots in restored plots to replace the comparative density estimates. Restoration practitioners agreed that it is important to incorporate statistically rigorous experiments and monitoring metrics into the monitoring plan as appropriate to investigate uncertainties. An experiment might involve planting in some areas that may be outside the natural local depth range of eelgrass distribution to test whether eelgrass meadows could be expanded. Planting at various densities and patch sizes using different transplanting methods to evaluate rates of bed development versus cost was also suggested. Although costly, workshop participants noted that one must often measure large set of parameters to better understand the reasons for eelgrass restoration failure. Using a conceptual model to focus these investigations on potential causal factors and appropriate parameters was recommended. Finally, it was suggested that periodic (e.g., annual) meetings with interested parties, where project data was reviewed and decisions were made on what to do if performance was not meeting predictions, would be a simple yet functional way to conduct project-level adaptive management.

Dissemination of results

The workshop participants agreed that there is a need for a clearinghouse (e.g., database) of eelgrass restoration and monitoring results that compiles summaries of regional eelgrass mitigation efforts. This clearinghouse of information would serve to provide information on current and completed projects, and would facilitate communication of what has been done to the next generation. Other ideas for providing information to larger audiences are gray literature reports, presentations at meetings and conferences, journal articles, regional databases, and programs such as SeagrassNet, a global seagrass monitoring network (www.seagrassnet.org). Results from individual projects should be ultimately placed in the larger context of eelgrass restoration in the region to better inform the practitioner community and managers. To that end, workshop participants recommended establishing regional reference sites so that the results of individual restoration projects could be assessed collectively among numerous projects.

Lesson learned

Practitioners provided a set of lessons learned from their experiences conducting eelgrass restoration projects. These range from large scale and general, to very specific and highly applied lessons. The top (highest priority) lessons learned are as follows:

- Understand why eelgrass does not occur at a potential restoration site before attempting to transplant
- Choose multiple reference sites carefully, making sure they are close match to transplant sites both physically and ecologically
- Do not replant areas that show obvious problems during the first year following planting

- Understand the processes that form and maintain eelgrass, and assure that the potential restoration site possesses these processes
- Monitor projects for at least five years; longer if significant uncertainties exist
- Remove donor material in close proximity to the restoration site, and from the same depth and sediment conditions
- Understand or assess periodic disturbances such as boat wakes, deposition of debris, etc., that might kill eelgrass
- Construction contractors must follow permit conditions (e.g., reduced success at Midway because of allowed permit excursions)
- Government agencies must agree and use “best available science” for conditioning permits
- Test planting methods; what works in one environment may not work in another

Discussion

In a national review of seagrass restoration projects, Fonseca et al. (1998) concluded that seagrass planting is now a proven management tool for mitigating losses of seagrass. “However, planting will not succeed unless managers appreciate and emphasize the extreme importance of site selection, care in planting, and incorporation of plant demography into the planting and planning process.” (Fonseca et al. 1998, page 141). Based on a review of eelgrass restoration projects in the Pacific Northwest region, numerous entities have reported similar conclusions on the state of eelgrass restoration science and have addressed information gaps. One of the major issues is whether or not success can be predicted for a given restoration project. Although there have been many successful projects, the general response to the workshop summary question (*Can eelgrass meadows be reliably restored in the NW region?*) indicated that success is inconsistent. Some believed that the question should be *Can we avoid failures?*, but failures are often difficult to explain. Where conditions appear ideal, and planting is handled using standard methods, plots will sometimes die out completely or remain very sparse. To improve eelgrass restoration success workshop participants agreed that baseline information and models of eelgrass requirements need to be improved. We, as yet, cannot predict accurately the final stable density of a planted bed given a set of environmental conditions. Also, it is important to identify the gaps in eelgrass restoration science which include monitoring designs, potential regional reference sites, historical and baseline information, natural interannual variability, value of one site compared to another, and eelgrass genetic diversity to gain a better understanding of the overall eelgrass restoration effort in the Pacific Northwest.

Stamey (2004) found that only 13% of projects in the Pacific Northwest achieved or exceeded success in all metrics. Practitioners noted that they often saw a decline in eelgrass density the year following planting. In subsequent years, eelgrass density increased. For example, the density one year following planting at the Clinton Ferry Terminal project was a poor predictor of long-term density, although it did indicate that plots were viable for support of eelgrass. Density of plots in year five, however, was a strong predictor of longer-term (e.g. average year 6-10) eelgrass density (Vavrinec et al. 2007).

Although we sought to arrive at an estimate of project success rate based on a review of projects, we felt uncomfortable at making this assessment for several reasons. First, we were not sure if the projects that were submitted for review was a random sampling of all projects that had been done since 1990. We knew of many more projects, and we could not determine if our sample was unbiased. Second, variations in monitoring methods, performance criteria, age of projects and a variety of other differences made it very difficult to draw conclusions from the project data set. Finally, in a point made both at the workshop and after the workshop, the interpretation of success can be biased. For example, where the practitioner may conclude that the project was successful, a regulator may conclude that project failed because it did not meet all the performance criteria established in the mitigation plan or showed such high variability between sampling events that the results were considered inconclusive. Since nearly all eelgrass restoration projects are presently done within a regulatory framework as part of a compensatory mitigation effort, adaptive approaches to assessing overall success are problematic. A variety of factors, including both regulatory constraints and scientific uncertainty need to be adequately addressed before the science of eelgrass restoration can effectively progress toward more informed approaches. We provide some recommendations below in this regard.

Over the decades there have been large-scale losses in eelgrass populations, but the factors that are driving the losses are not completely understood (e.g., Westcott Bay, San Juan Island; southern Hood Canal; Holmes Harbor (Dowty et al. 2007). Efforts to understand the declines are underway, but have been conducted in a piece-meal fashion because of poor funding. Our review indicates that one major need is for more collaborative research. Particularly, 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 effort.

Many themes emerged during the workshop discussion, but the following three were most pronounced. First, uncertainties are inherent in eelgrass restoration and establishment of an adaptive management plan can be used to help deal with uncertainty. A comprehensive monitoring program that is built into the adaptive management plan can help to identify habitat parameters important to increasing restoration success.   Second, criteria used to evaluate the performance of eelgrass restoration should be kept simple and easily quantifiable (e.g., mean eelgrass percent cover, shoot density or total eelgrass shoot abundance relative to a benchmark like previous eelgrass cover, density or abundance). This is important for evaluating whether or not the trajectory of restoration meets project goals (Evans and Short 2005) or if adaptive adjustments are necessary. Finally, knowledge gaps exist such as historic and baseline data, appropriate monitoring design, and truly representative reference sites making it challenging to completely understand the dynamics of eelgrass restoration. In order to fill in the gaps we need to know why aspects of projects have failed in the past and make sure we are assessing the correct performance measures. Monitoring of a consistent set of site attributes using statistically rigorous methods is particularly important to resource agencies who are tasked with deciding whether or not the overall project performance meets the no net loss criteria. Lack of sufficient and/or robust data has hampered such determinations for several projects in Puget Sound.

Summary of Restoration Recommendations

In Table 3 we provide a summary list of recommendations from earlier reports from the Northwest (i.e., Phillips 1984, Thom 1990, Stamey 2004), a national review (Fonseca et al. 1998) and a very early document (Addy 1947; see also Appendix A). Although the emphasis of the reports vary (e.g., Addy was focused on “how to”, whereas Stamey provided overarching recommendations), there is obvious overlap among the various reports. All reports gave specific suggestions for planting/establishing eelgrass in transplant areas, although these suggestions varied in each paper. The most often mentioned recommendation for the restoration process was the need to evaluate, understand, and document both the donor and transplant sites. Of the six early recommendations of Addy (1947), half were mentioned in other reports. This suggests that these recommendations could be critical to improving the success of projects. Our consensus recommendations are provided in the sixth column of Table 3. We have also added recommendations that deal with issues of planning, site selection, donor material, planting methods, monitoring and dissemination, as well as adaptive management.

Finally, large-scale variation should also be taken into account. For example, climate variation has been shown to dramatically affect eelgrass abundance in Northwest systems (Thom et al. 2003). So although annual variation in winter storm damage can be significant, variations in mean sea surface temperature and sea level can also contribute to large differences in eelgrass density between years.

Conclusions

As has been stated for sixty years, eelgrass can be restored if the site contains appropriate conditions, plants are taken from local areas, and transplants are handled and planted following recommended procedures. It appears that several methods for planting will work, and that planting in higher densities may provide a better start for the transplant effort (Thom et al. 2005). However, monitoring is not consistent among projects, there is very limited and often confusing communication on results, and there is no way to easily synthesize what information has been gathered. Funding for monitoring is generally very poor because funders often do not recognize its importance. Finally, personal bias can affect the conclusions drawn about a project. This is a serious fact that must be overcome before we can consistently and objectively evaluate eelgrass restoration projects.

There is a vast array of studies on eelgrass worldwide, and similar diversity for eelgrass restoration projects in the region. Even for experts it is difficult to keep up with this information. If eelgrass restoration is to be a continued focus of mitigation efforts as well as large-scale restoration programs in the region, then eelgrass restoration information should be organized in a central location. A centralized database will facilitate learning, allow resource managers and practitioners to obtain the latest guidance, and allow ready synthesis of results in a timely fashion.

Emphasis must be placed on reducing uncertainties through focused studies, and the results must be communicated. Further, performance assessment must be unbiased and reported in a simple, clear and consistent format. To this end we have the following recommendations:

- Develop a standard protocol for eelgrass monitoring, including a standardized set of attributes and appropriate statistical tests, to document performance of restoration efforts
- Implement a research program focused on improving success and understanding the variability in success among projects
- Implement a clearinghouse of eelgrass transplant monitoring data from all restoration projects in the region
- Implement an annual meeting of eelgrass restoration practitioners, regulatory and resource agency personnel, researchers and others involved in the restoration process to capture the lessons learned from the ongoing projects
- Every three-five years revise the monitoring protocols, restoration guidance, and other relevant documents based on a synthesis of the information from annual meetings

- Because this document reflects the current state-of-the-science in the Pacific Northwest; consider the information and recommendations holistically to serve as a foundation for current and future eelgrass restoration projects

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Table 1. List of workshop attendees, their affiliations, who are contacts from projects shown in Figure 1.

Name	**Affiliation**	**Project in Figure 1**
Bloch, Phil	WSDOT	
Borde, Amy	PNNL	Brightwater Clinton ferry terminal Hood Canal Bridge Port Townsend Maritime Center Dock Sequim Bay West Eagle Harbor
Boyle, Matthew	Grette Associates	Drayton Harbor Brightwater
Brooks, Rhonda	WSDOT	
Bulthuis, Doug	DOE	
Carman, Randy	WDFW	
Cereghino, Paul	NOAA	
Cziesla, Chris	Jones and Stokes	
Durance, Cynthia	Precision Identification	Nanaimo Harbor, BC Pender Harbor, BC Sooke, BC
Gaeckle, Jeff	WDNR	
Gower, Eric		
Guerry, Anne	NOAA	
Krueger, Kirk	WDFW	
Kyte, Michael	ENSR/AECOM	Sequim Outfall Midway
Marion, Carey	WSDOT	
Mumford, Tom	WDNR	
Quinn, Tim	WDFW	
Ruckelshaus, Mary	NOAA	
Rumrill, Steve	South Slough National Estuarine Research Reserve	
Sasha, Visconty	WSDOT	
Schlenger, Paul	Anchor	
Stutes, Jason	PENTEC/Hart Crowser	Everett Rail/Barge Transfer Facility
Tear, Lucinda		
Thom, Ron	PNNL	
Vecht, Sharon	WSDOT	
Wagner, Paul	WSDOT	
Ward, Carl	WSDOT	
Weitkamp, Don	Parametrix	
Williams, Brian	WDFW	
Wones, Andy	Jones and Stokes	Holmes Harbor
Ziegler, Ellie	WSDOT	

Table 2. Summary of input from practitioners at the May 2007 workshop regarding eelgrass restoration as organized within ecosystem restoration topics (Diefenderfer et al. 2005).

Goals

- Provide functioning habitat for juvenile salmonids and other organisms
- Understand natural variability with established plots
- Develop transplant sites equivalent to the donor/natural site
- Match primary production of adjacent natural bed
- Restore *Zostera marina* to fit into the natural ecosystem landscape
- Net ecosystem improvement – after an impact how the system be improved?
- Reestablish ecological function
- Restore natural ecological processes that control and maintain *Zostera marina*
- Sustainable development
- Enhance carbon sequestration
- Minimize anthropogenic stressors
- Increase biodiversity

Project Objectives

- Emulate sediment grain size and topography (grade)
- Adjust site elevation to support *Zostera marina*
- Insure that there is ample light penetration
- Control chemical or physical disturbance to *Zostera marina*
- Facilitate natural recolonization
- Removal of overwater structures and wood debris to allow more light
- Improve water quality conditions
- Remove substrata for competitors (unless it’s part of the natural mosaic)

Components of Conceptual Models

- Light
- Temperature
- Salinity
- Substrata
- Nutrients
- Water motion
- Competition
- Historical presence of seagrass
- Physical, natural and anthropogenic disturbance

Site Selection

- Minimize impact so that compensatory mitigation is minimal. Look at the trajectory of eelgrass abundance and performance over time
- Understand the habitat qualities of an existing site
- Combine eelgrass site selection and restoration with the larger restoration agenda
- Sites should be areas that are protected from future development/disturbance
- Consider construction impacts to determine timing of planting
- Potentially establish *Zostera marina* restoration banks
- Make sure nearshore processes are functioning well to support *Zostera marina*
- Test transplant to help determine large-scale restoration sites

Restoration Strategy

- Long-term protective covenants on the site
- Stockpile plants and/or material that would otherwise be destroyed
- Harvest plants from adjacent areas as those plants would likely be adapted to similar conditions
- Don’t move plants too far from place of harvest (risk of out-breeding depression)

Performance Measures

- Area extent- specific survival within a predetermined area
- Total abundance of shoots (= shoot density x area)
- Shoot morphology- can be equated to productivity relative to pre-existing conditions, or conditions at adjacent site
- Above ground versus below ground biomass
- Flowering and seed production metrics
- Rhizome metrics (internode length)
- Habitat utilization (juvenile salmon usage)
- Sign of sedimentation/exposed rhizomes (erosion)
- Patchiness metrics

Implementation – ***Site Preparation Activities***

- Dredge or fill to get desired elevation
- Clear shell hash and debris
- When restoring a disturbed site, allow new or existing sediment to settle out before replanting
- Get conditions at disturbed site as similar to pre-disturbance conditions as possible (e.g. sediment grain size)
- Disturbance of rhizomes may spur growth
- Use bivalves to add nutrients to the substrate

Implementation – ***Donor Material and Collection Methods***

- Spread shoot collection over a wide area, 1-3 shoots m^{-2} or 10% of donor bed, store in cool seawater, handle in water, keep them moist
- Monitor in first 6 months and then every 6 months thereafter
- Evaluate fungal communities and compare to the reference site

Implementation – ***Harvesting and Donor Meadow***

Techniques (shoot description)

- Individual shoots
- Harvest mat
- Harvest with rhizomes intact
- 3 nodes or 3 inches – whichever is longer

Tools

- Hand excavation of mat
- Clamshell dredge
- Aerated pitchfork
- Large sheets of steel
- Light snow shovels
- Plugs or cores

Implementation – ***Seeds***

- Huge germination at first, but it all washes away suggesting plants can’t get established (i.e., lack of persistence).
- Seed bags method – limited success too much material, not enough flowering shoots
- Mat or mesh used to keep seeds in place
- Collecting wrack – seedlings and mature plants
- Seeding buoys and other methods

Implementation – ***Planting***

- Length of rebar with plants tied on (with degradable ties) to ~1 cm diameter metal washers (not galvanized), 1 plant per washer, 10 per patch planted on 1m centers. Plant squares to rectangles because it is easier to monitor. Timing – 12 months of the year
- Metal turfs staple, 4 shoots per anchor with rhizomes in opposing directions, planting configuration – uniform pattern, clump 20 plants (i.e., five planting units) together to minimize crab disturbance.
- Range of densities of 1-200 shoots m^{-2}, planted in spring and summer
- Turfs staple method, circular pattern, increased density at center of patch, 9.3 m^{2} patches, 1.7m ft radius, use a string to keep distance correct

Monitoring Design

- Develop a statistically robust monitoring design
- Use of remote sensing may be a good way to improve monitoring in a cost effective way
- Pool regional reference sites and use remote sensing to categorize reference sites
- Use monitoring protocols based on questions and goals of the project
- Use of reference and control sites are not always necessary but typically underutilized
- Use co-variates in experimental design (depth, light penetration, etc.) and look for differences in residuals
- Total abundance in a transplant plot compared to a similar area in a reference plot

Monitoring Frequency

- As often as possible
- Quarterly
- Twice a year, winter/summer, peak and low biomass
- Monitor more frequently up to year five and then annually
- Quarterly: quantitative monitoring once a year and qualitative monitoring the other three sampling trips.
- Ideally monthly but to be cost effective…6 months after planting, after another 6 months, then annually for a few years, then if plants are well established wait until year 5 to do additional monitoring.
- 3 times (February, mid summer, November)

Monitoring Duration

- 10 years on some projects and the data have been used to determine the 5 year duration is needed.
- Pre-construction monitoring as baseline
- Monitor for 5 years

Adaptive Management

- Helped minimize uncertainty in *Z. marina* restoration
- Do nothing based on successful performance
- Do something- need a trigger (e.g. no success after 12 months) and need a plan forward
- Adaptive management can include experiments to evaluate significant uncertainties prior to full planting effort

Dissemination of Results

- Evident that there needs to be a clearinghouse for eelgrass information and monitoring results
- Communicate what has been done to the next generation
- Grey literature reports
- One-pagers
- Meeting presentations
- Journal articles
- Regional databases
- Global SeagrassNet Program
- Pacific Estuarine Research Society meetings
- Eelgrass session at Puget Sound Research Conferences

Table 3. General summary of recommendations from past reports and project phases where recommendations fit as defined in the present paper. Specific recommendations from the various reports can be found in Appendix A. ✓ = recommended in report. Project phases: P = planning; I = implementation; M = monitoring; AM = adaptive management.

Recommendations	**Adey (1947)**	**Phillips (1984)**	**Thom (1990)**	**Fonseca et al. (1998)**	**Stamey (2003)**	**Present Review**
Address all permitting requirements well ahead of planting				✓		P
Identify goals of project early in process, ensure that work is done, allow for mid-course corrections, and learn from projects to improve future projects				✓		P, I, AM
Evaluate, document, and understand donor and transplant sites (sites should be similar)	✓		✓	✓		P
Emphasize quality of transplant site		✓			✓	P
Specific suggestions for habitat requirements	✓	✓	✓			P
Conduct experimental plantings to evaluate transplant site		✓	✓			P
Transplant a greater area than proposed as end result			✓			P, I
Plant shoots densely				✓	✓	P, I
Specific suggestions for planting methodology	✓	✓	✓	✓	✓	I
Plant on clear calm days during March, April, May	✓					I
Maximize genetic diversity of donor stock				✓		I
Donor stock should be taken from extensive beds	✓					I
Plant where there will be a benefit to shellfish and waterfowl	✓					I
Develop and monitor a consistent set ecological attributes					✓	P, M
Specifically define restoration success and monitor for metrics					✓	P, M
Monitor quarterly for first year, then biannually for next four years				✓		M
Create and maintain a central data base on eelgrass restoration projects					✓	AM
If two plantings following the initial planting fail, managers should consider abandoning the site				✓		AM
Understand factors that affect wide between-project variability in success					✓	P, AM

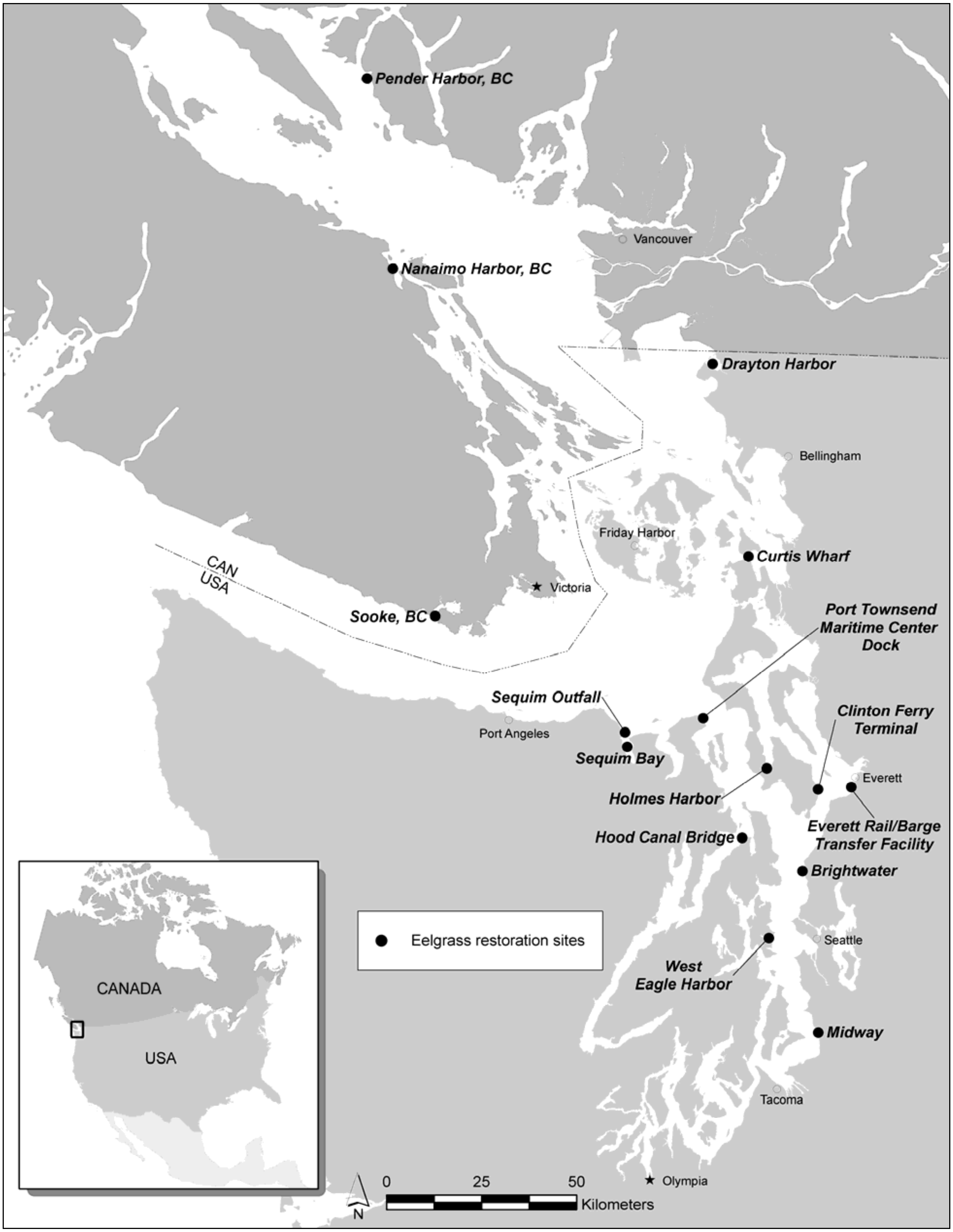

Figure 1. Map of locations of eelgrass projects we reviewed.

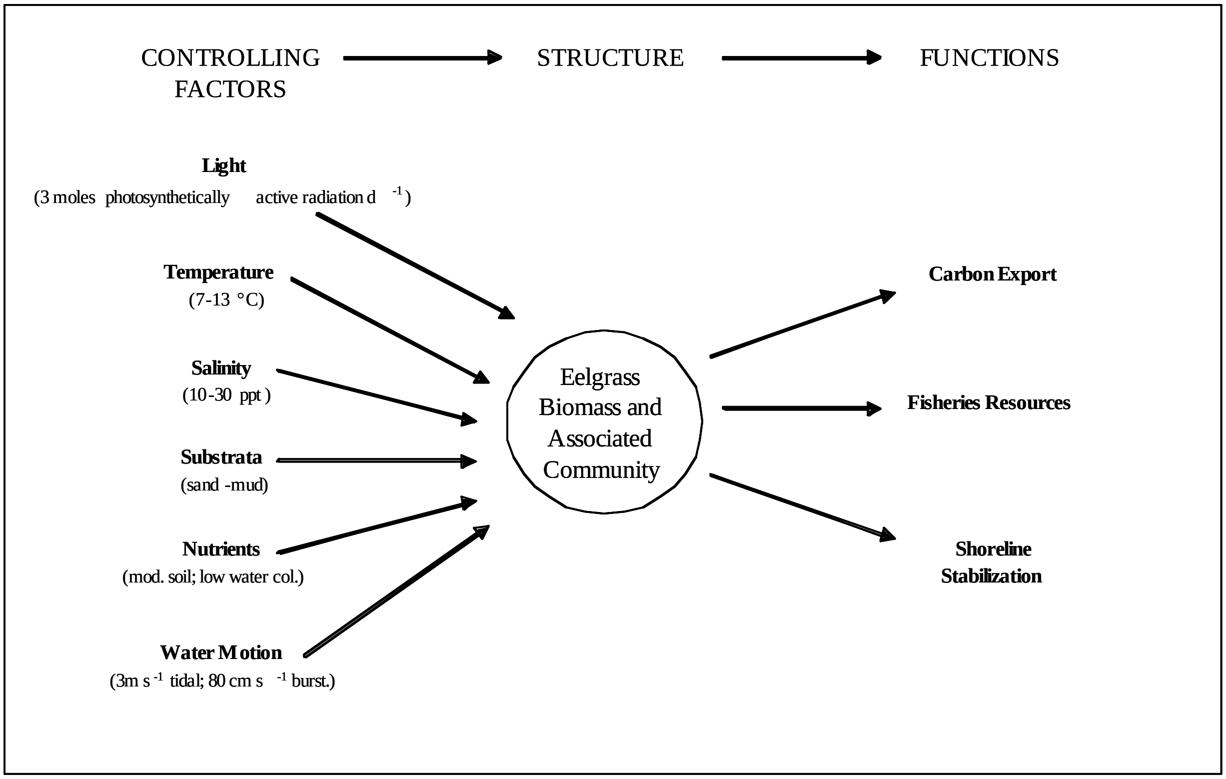

Figure 2. General eelgrass conceptual model (from Thom et al. 2005).

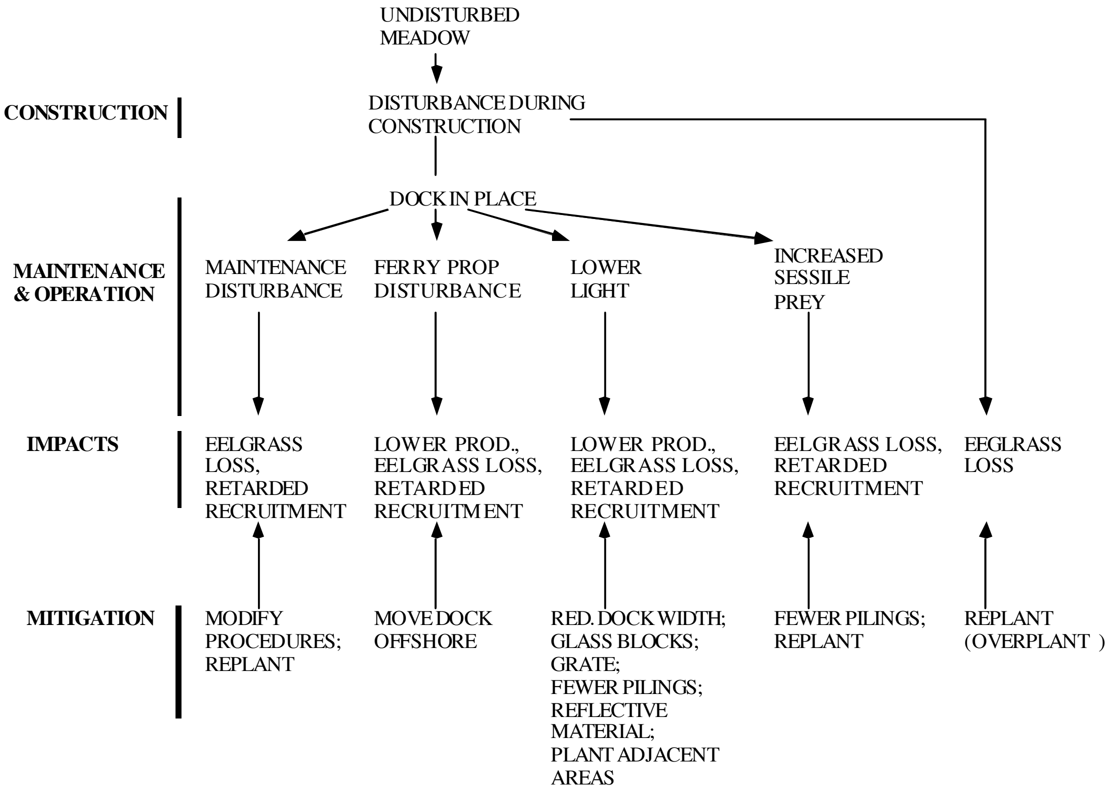

Figure 3. Conceptual model used to identify stressors from a ferry terminal and potential mitigation/restoration actions (from Thom et al. 2005)

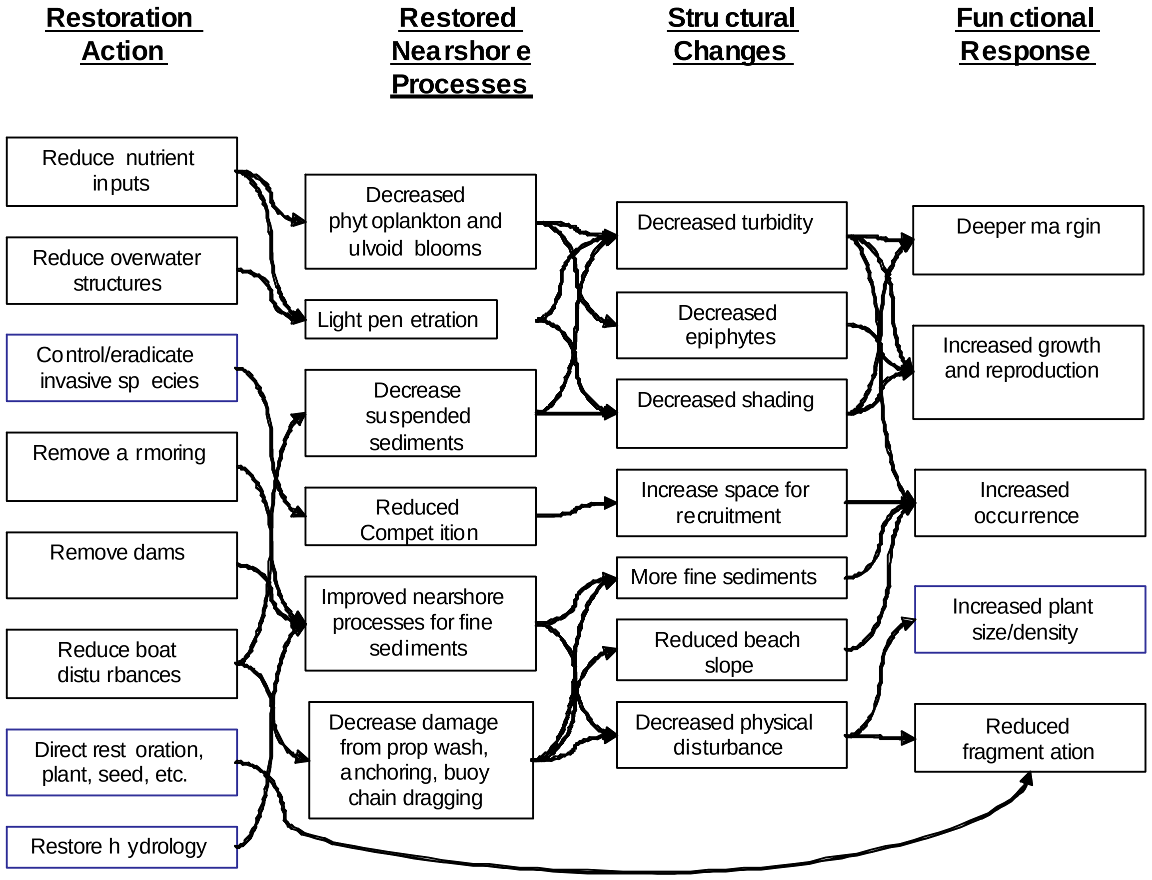

Figure 4. Conceptual model of eelgrass restoration using a set of potential actions (from Mumford 2007).

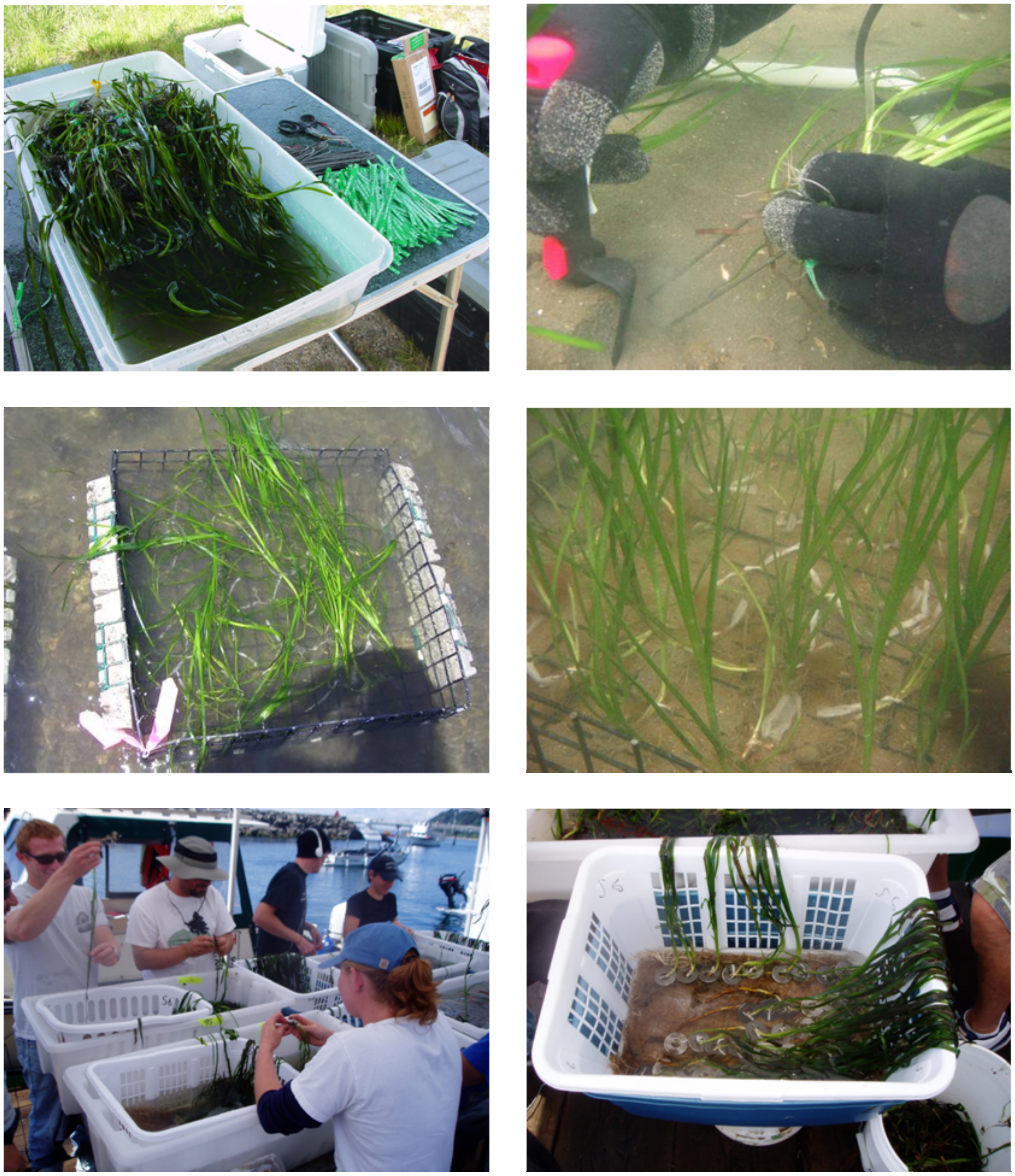

Figure 5. Photos illustrating common methods for transplanting eelgrass: Top - bundling plants on sod staples using degradable twist ties, and using divers to excavate sediment and insert bundles; Middle - TERF (Transplanting Eelgrass Remotely with Frames) method developed by Dr. Fred Short (University of New Hampshire) for attaching eelgrass to a wire frame with biodegradable paper and burying the frame and roots in the sediment (photos courtesy of R. Thom); Bottom - preparing eelgrass shoots on metal washers for planting by divers (M. Kyte).

Appendix A. Detailed recommendations from previous reports (paraphrased for space) used to compile Table 3.

Addy (1947)

Transplant stock should be taken only from extensive beds
Plant where there will be a benefit to shellfish and waterfowl
Bottom should be similar to that of the donor stock
Bottom should be of mud containing a moderate amount of sand
Plant at an elevation where plants will be covered by water on most low tides
Plant on clear calm days during March, April, May
Dig up shovel-sized sod, handle carefully, cover with wet burlap, plant in shovel-sized depressions, press lightly around edges with foot
Place stems with seed in container with screen for 1-2 months, sow seeds in early fall, or over-winter and sow in following year

Phillips 1984 (verbatim)

Determine planting methods best suited for a particular growth phase in a particular set of substrate – current conditions
Determine planting methods best suited for the creation of new seagrass meadows, and for the replenishment of meadows damaged by perturbations
Determine the limits of ecotypic differentiation and phenotypic plasticity of the species
Determine the presence and/or extent of physiological races in seagrasses
Determine the most successful conditions of transporting seagrasses, i.e. how long they can be kept out of water, the need for soil around the root system, and the maximum latitudinal or geographic distance to retain survival

Thom (1990)

Select sites with low turbidity
Select sites with medium grained sand and moderate organic matter
Select sites with low wake disturbances and sediment movement
Plant on flat areas, not steep slopes
Plant in pools that form at low tide
Transplant an area larger than target area expected
Minimize holding time of donor stock
Understand the donor and transplant ecosystems
Conduct experimental plantings to evaluate site

Fonseca et al. (1998)

Determine if the bed has been injured, how much has been disturbed, what constitutes adequate remediation
Consider life history of species, geographical variation, seasonality, consequences of local regimes (e.g. temperature, bioturbators)
Maximize genetic diversity of donor stock
Conduct site surveys to document disturbances and seagrass distribution
Identify project goals early in process
Address all permitting requirements well ahead of planting
Coordinate permitting protocols among all regulating agencies
Evaluate sites for factors affecting seagrass growth and survival
Select donor site to best mimic transplant site conditions
Planting units should - have intact meristems, contain enough short shoots per long shoot to facilitate growth after planting, minimize stress to planting units
Planting methods showing success are plugs, staples, peat pots
Plant dense enough to spread as quickly as desired and minimize loss by disturbances
Define success as beds that persist unaided, at or above the desired acreage and shoot density for five years following planting; or show a trajectory of spread for slow growing species
Monitor quarterly for one year, biannually for the next four years. If replanting is needed, then restart the cycle
If two plantings following the initial planting fail, managers should consider abandoning the site
Ensure that contacted work was performed to specifications, allow for mid-course corrections, learn from

projects to improve future projects
Stamey (2004)
Create and maintain a central data base on eelgrass restoration projects Develop a consistent set of biological and ecological attributes for monitoring Monitor ecological attributes (e.g., epibenthic zooplankton) Understand factors that affect wide between-project variability in success Transplant densely to maximize survival Emphasize the quality of the transplant site Plant using turfs or bare root methods