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A Review of Eelgrass (*Zostera marina* L.) Transplanting Projects in the Pacific Northwest

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Introduction

Eelgrass (*Zostera marina*) meadows (Fig. 1) cover much of the lower intertidal and subtidal space in Northwest estuaries. There is a growing awareness of the critical ecological role of eelgrass meadows in nearshore food webs (Phillips 1984; Thom 1987).

Because eelgrass meadows occur in very shallow water, they have been subjected to degradation and loss due to shoreline development and pollution. The Clean Water Act and other federal, state, and local regulations probably have slowed the loss of eelgrass. However, pressure to develop marinas and navigation channels, and dispose of dredged material continues. In order for projects to proceed, mitigation for the loss of eelgrass has been attempted through construction of eelgrass meadows in areas adjacent to the development (Fonseca, Kenworthy, and Thayer 1988). Meadow construction generally consists of transplanting plants from a donor stock into the mitigation site.

Transplantation of sea grasses (a group of approximately 50 species worldwide to which *Z. marina* belongs) has been carried out in many areas of the world (Phillips 1980). The majority of the work in the United States has focused on shoalgrass (*Halodule wrightii*) and *Zostera marina*. The U.S. Army Corps of Engineers, through research on establishing vegetation on dredged material, has developed efficient methodologies for transplanting as well as estimating the cost of conducting the transplant work (e.g., Fonseca et al. 1979; Kenworthy et al. 1980; Fonseca, Kenworthy, and Thayer 1982; Fonseca et al. 1984; Fonseca et al. 1985; Fonseca et al. 1987). This work has largely been performed on the East Coast by Mark S. Fonseca, W. Judson Kenworthy, and Gordon W. Thayer (National Marine Fisheries Service Laboratory, Beaufort, North Carolina). In addition, extensive numbers of small (e.g., one m^2) experimental

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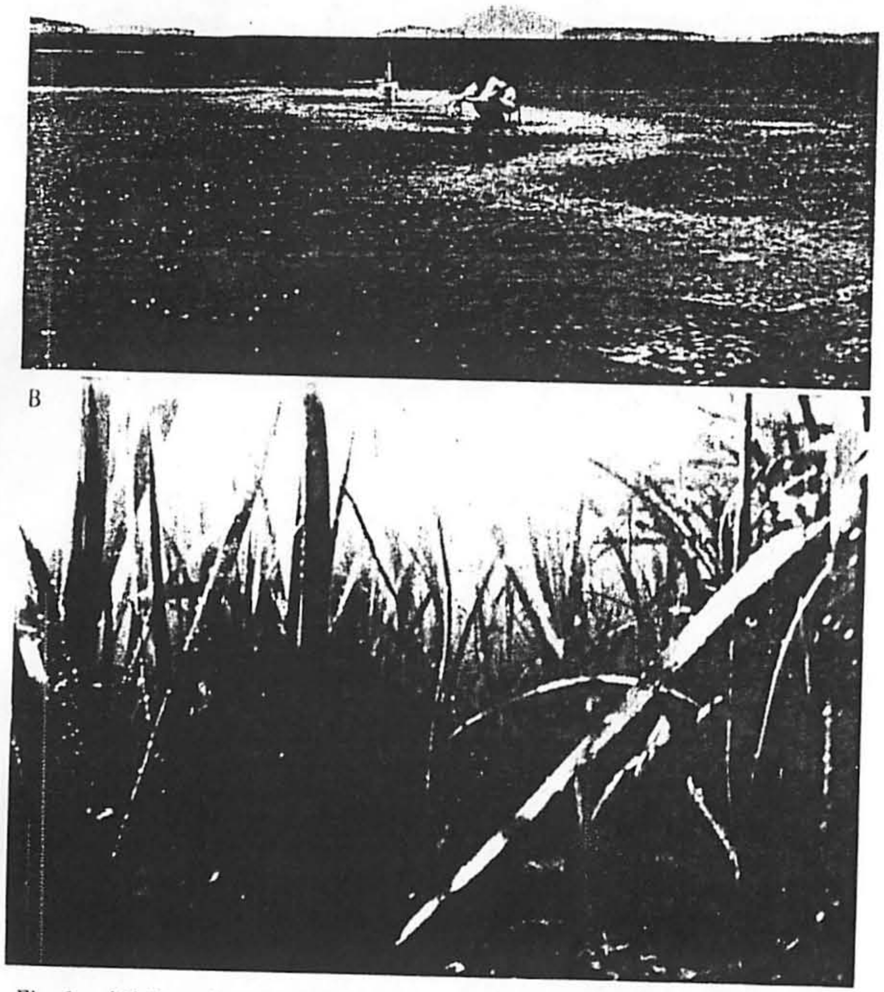

Fig. 1. (A) Sampling the eelgrass meadow at Padilla Bay, Washington. This meadow covers approximately 3,500 ha of the flats in the bay. Photo by Ron Thom. (B) Underwater photograph of eelgrass in Padilla Bay. Photo by C. Simenstad. The shoots can be in excess of 2 m long in Padilla Bay.

transplant plots (review below) have been used on the West Coast for research purposes. These studies were done primarily by Ronald C. Phillips (Seattle Pacific University, Seattle, Washington) and Paul G. Harrison (University of British Columbia, Vancouver, British Columbia).

Can functioning eelgrass meadows be successfully constructed? New information indicates general poor success of seagrass mitigation by transplantation (e.g., Fonseca, Kenworthy, and Thayer 1988), so this question became a focal point during federal and state agency evaluations of a marina proposed for Lummi Bay, Washington (122° 41'W 48° 47'N). Construction of the marina and access channel would result in a loss of 3.6 ha (8.8 acres) of eelgrass (U.S. Army Corps of Engineers 1988). Furthermore, eelgrass beds in the vicinity of the project have been documented by the Washington Department of Fisheries (WDF) and the Lummi Indian Tribe as spawning grounds for Pacific herring (*Clupea harengus pallasi*) (Thom Hooper, Fisheries Biologist, WDF, Olympia, Washington, conversation, 1989). Efforts proposed to lessen the impact of destruction (i.e., mitigate) of eelgrass and herring spawning habitat involved establishment of new beds in the area through transplanting (U.S. Army Corps of Engineers 1988). Significant concern remained, however, among WDF biologists regarding (1) whether eelgrass could be successfully transplanted; and, (2) if the new bed would serve as herring spawning habitat (Kurt Fresh, Fisheries Biologist, WDF, Olympia, Washington, pers. comm., telephone call, 1989).

Although the technology for successfully establishing seagrass beds has been developed, enthusiasm for applying the technology has recently waned on a national basis. The reason for this, according to Fonseca, Kenworthy, and Thayer (1988), is that all seagrass mitigation projects have resulted in a net loss of habitat. This lack of success was primarily due to poor site selection. Furthermore, Fonseca, Kenworthy, and Thayer found no data that documented how transplanted beds functioned relative to the natural beds they replaced. Lacking these data, they felt that conclusions regarding the functional equivalency of transplanted beds were insupportable.

Projects that could impact eelgrass meadows continue to be proposed in the Northwest, and transplantation of eelgrass is being proposed to mitigate project impacts. Therefore, a better understanding is required of the relative success of previous eelgrass transplanting efforts in the region. The purpose of this paper is to summarize the results of previous eelgrass transplanting projects in order to provide part of the basis upon which to judge the possibility of eelgrass transplanting success in the Northwest. To provide the most relevant picture, only projects conducted in the region encompassing northern California through British Columbia were considered in detail.

Methods

The study area extended from San Francisco Bay through British Columbia. Available published literature, unpublished reports, and personal communications (i.e., telephone conversations) were used to gather information on past projects. In general, the information gathered included the: (1) project location; (2) project purpose; (3) site selection criteria and site description; (4) transplanting methods; (5) monitoring plans and results; (6) relative success; and, (7) recommendations. The interviews were useful in acquiring additional information on other related projects. The full names of the people contacted are listed in the acknowledgments section at the end of the paper.

Results of Previous Work

Seventeen discrete eelgrass transplant projects have been carried out in the study area since 1974 (Table 1). Several other projects were mentioned by the investigators, however these were usually very small in scale and were not monitored sufficiently.

Previous projects can be classified as either experimental studies or mitigation efforts. The experimental projects included investigations into the technology of transplanting eelgrass (e.g., Roberts Bank, Padilla Bay, Richmond Harbor) and studies on the biology of the species (i.e., Backman 1984; Phillips 1972, 1980). The transplanted area was difficult to ascertain in many cases (e.g., plantings were performed in linear rows as opposed to square blocks). Total documented plot sizes ranged from 0.1 m^2 to 11,000 m^2. The smaller plots were generally for experimental manipulations. Some of these small plots (e.g., Backman 1984) were placed within existing natural eelgrass meadows. Transplanting methods included plugs of various sizes, individual shoots that were anchored or planted directly into the substrata, and bundles of shoots (i.e, planting units; Fonseca, Kenworthy, and Thayer 1982). Planting density varied from 0.3 to 1 m spacing. The most commonly used standard for monitoring the eelgrass bed was shoot density, which served as a measure of plug, shoot, or bundle survival. Percentage cover also was used in some cases to indicate the area of bottom covered by the plants. Monitoring duration varied widely from a few months to five years (Table 1). The intensity of monitoring also varied. A few studies frequently measured several physical and biological parameters for a long period, whereas many studies relied simply on short-term survival of transplants as an indication of project success.

Available data on percentage survival are provided in Table 1 as an objective indication of the success of the project. Data on the area planted, plant survival, and total area covered are useful in determining the long-term dynamics of a project. For example, 8,000 m^2 were planted in Sequim Bay. By the fifth year, approximately 10% of the originally barren area contained plants. The vegetation was abundant in this latter area, however (J. Walton, Professor, Peninsula College, Port Townsend, Washington, telephone call, 1989).

Investigators reported good success in three of four studies that provided only relative indications (i.e., low, moderate, high) of success (Table 1). In the Bodega Harbor, California, project, one of the most well-documented large-scale projects, 40% survival of transplants on the tideflats and 90% bottom coverage was documented after two years (Connors 1986). Harrison, Backman and Phillips all reported successful transplant results in relatively small plots located in several areas in the Strait of Georgia and Puget Sound. Percentage survival in these studies ranged from 90 to 100%.

Opinions about the best transplanting technique (i.e., shoots, shoot bundles, plugs) varied. Plugs disturb roots and rhizomes less than shoot bundles, which may reduce transplant shock (Fonseca et al. 1985). However, plugs were heavier than shoot bundles due to sediment associated with the root/rhizome mass; therefore they are more difficult to transport. Plants at the edge of the existing eelgrass bed may be better adapted for colonization than are interior plants (S. Wyllie Echeverria, University of Alaska, Fairbanks, Alaska, telephone call, 1989).

Recommendations

If eelgrass is not naturally occurring at the potential transplant site, there must be a reason. In these cases, it was recommended that studies of the sites which include the physical characteristics (i.e., substrata quality, depth, light regime, etc.) be conducted and the conditions be compared to those of natural eelgrass beds occurring in the vicinity. Table 2 summarizes principal physical and chemical characteristics of areas where eelgrass meadows occur. Some of the conditions (e.g., light, salinity, water temperature) require frequently repeated sampling throughout an annual cycle. The interaction of the environmental factors also must be understood. For example, the optimal depth for eelgrass is dependent upon light penetration, which is in turn affected by wave action and local sedimentation processes. Areas of enhanced nutrients may have

TABLE 1. Summary of eelgrass transplant projects, San Francisco Bay to British Columbia, 1974–1989.

Location	Start dates	Purpose	Planting		
			Habitat	Approx. area	Technique
Hidden Harbour Marina, B.C.	April 1987	Mitigation for dredging	Mud, subtidal	1,900 m^2	Shoots
Gibsons Harbour, B.C.	May 1985	Experiment	Gravel, cobble, subtidal	—	Several
Roberts Bank, B.C.	1981–1983	Experiment	Intertidal and subtidal (three sites)	—	Several
Blaine Marina, WA	1987	Experiment	Intertidal sand/mud	—	10-cm diameter plugs at 1-m spacing
Padilla Bay, WA	1988	Experiment; donor site recovery; survival of potted plants	Intertidal sand/mud	70 m^2	Planted shoots in pots and in plots
Dakota Creek, WA	Spring 1988	Mitigation for dredging	Intertidal (+0.5 to +1.0 m MLLW)	60 m^2	Shoots
Sequim Bay, WA	1985	Mitigation for marina dredging	Intertidal sand/mud	8,000 m^2	a) shoot bundles b) plugs c) shoots

TABLE 1. Extended.

Location	Planting	Monitoring		Success	Conclusions (reference)
	Density	Plan	Duration		
Hidden Harbour Marina, B.C.	Approx. 2 m^{-2}	Shoot density; total area of bed	1 year+	28% shoot survival; 23% decrease in transplanted area	Eelgrass can survive in marina, but lush vegetation not expected (Harrison 1988; Harrison, 4/21/89, pers. comm.)
Gibsons Harbour, B.C.	—	Shoot density	4 years+	Low in gravel, cobble; moderate in fine sands	Substrata is critical; water clarity critical (Harrison 1988; Harrison, 4/21/89, pers. comm.)
Roberts Bank, B.C.	—	Shoot density; rhizome growth	5 years+	Good in most areas	Eelgrass survived best in areas with standing water at low tide (Harrison 1988; Harrison, 4/21/89, pers. comm.)
Blaine Marina, WA	Approx. 10 shoots per plug	Shoot density	8 months	8% of plugs evident after 8 months	Steep slope reduced survival; deepest plugs had best growth (Thom et al. 1988)
Padilla Bay, WA	—	Shoot density	1 year+	Up to 100% survival of shoots in pots; 20% survival of shoots in plots	Donor plots recovered rapidly; potted shoots survived well (Pritchard, 4/19/89, pers. comm.)
Dakota Creek, WA	1 shoot per 0.3-m space	Shoot density; epibenthos density; infauna	1 year	80% survival at lowest elevations; <30% survival at higher elevations	Coarse substrata; high elevation of tideflat and disturbance by boats affected survival (IES Associates 1988; Van Wormer, 4/18/89, pers. comm.)
Sequim Bay, WA	1 unit at 0.75-m spacing; 11,000 shoots planted	Bed area; shoot density	5 years+	800 m^2 of bed remains after 5 years; very dense in surviving area; total shoot abundance = 200,000	Planting methods gave similar results; finer substrata and deeper areas with standing water had greatest survival (Walton, 4/26/89, pers. comm.)

TABLE 1. Extended.

Location	Start dates	Purpose	Planting: Habitat	Planting: Approx. area	Planting: Technique
Bangor, WA	1987	Mitigation for dredging	Intertidal and subtidal sand	46 m^2 (total of 5 plots)	—
Anderson Pt., Battle Pt., Manchester, WA	1977	Experiment	Eelgrass beds	Several 1-m^2 plots per site	a) 20-cm diameter plugs b) unanchored shoots c) anchored shoots
Smith Cove, WA	1987, 1988	Experiment	Intertidal sand/mud	230 m^2 (total of 147 plots)	Plugs
Magnolia Bluff, WA	1988	Experiment	+0.1 to +0.5 m MLLW	260 m^2	—
Seacrest, WA	1988	Experiment	Subtidal in planter boxes	50 0.6-m^2 planters	Shoots
Puget Sound, WA (several sites)	1974	Experiments	Intertidal and subtidal	Various plots, 0.1–1.5 m^2	a) plugs b) anchored shoots c) unanchored shoots

TABLE 1. Extended.

Location	Planting: Density	Monitoring: Plan	Monitoring: Duration	Success	Conclusions (reference)
Bangor, WA	—	Shoot density; fish use; epibenthos	1 year+	4 of 5 plots died; remaining plot is subtidal	Steep slope of intertidal area (where planted) may cause losses (Marino, 4/21/89, pers. comm.)
Anderson Pt., Battle Pt., Manchester, WA	—	Shoot density; leaf width; flowering	2.5 years	Good survival	Techniques give good survival if planted in proper habitat (Backman 1984)
Smith Cove, WA	0.5-m spacing	Shoot density	2 years+	No survival by March 1989	Drifting sand and silt covered plots (Pritchard, 4/19/89, pers. comm.)
Magnolia Bluff, WA	—	Shoot density	1 year	No survival by April 1989	Drifting sediment covered plots (Pritchard, 4/19/89, pers. comm.)
Seacrest, WA	—	Shoot density	2 years	Some plants survived in some boxes	(Pritchard, 4/19/89, pers. comm.)
Puget Sound, WA (several sites)	Up to 500 m^{-2}	Percent cover	5–11 months	25–100% cover	Small plots placed in appropriate habitat do well; disturbance by waves reduced survival; all techniques worked well; long-term success of large-scale projects unproven (Phillips 1980; Phillips, 4/89, pers. comm.)

TABLE 1. Extended.

Location	Start dates	Purpose	Planting		
			Habitat	Approx. area	Technique
Siuslaw River, OR	1976, 1977	Experiment	Intertidal sand; swift tide currents	290 m^2 (total of 5 plots)	Shoots (3 per hole at 0.15-m spacing)
Humboldt Bay, CA	1982	Mitigation for dredging	−0.75 to +0.75 m MLLW	—	Shoots in rows over elevation range
Bodega Harbor, CA	Nov.–April 1984	Mitigation for dredging	Shallow subtidal flat and channel blank	11,000 m^2	Shoot bundles
Richmond Harbor, San Francisco Bay, CA	April 1985	Experiment	Intertidal sand/mud in eelgrass beds	9-m long linear plots (total no. plots = 25)	Shoot bundles

TABLE 1. Extended.

Location	Planting	Monitoring		Success	Conclusions (reference)
	Density	Plan	Duration		
Siuslaw River, OR	133 m^{-2}	Percent survival	1 year	90% survival	Low fencing around plots reduced flows and helped survival; standing water at low tide over plots helped survival (Ternyk, 4/21/89, pers. comm.)
Humboldt Bay, CA	—	Shoot density; below-ground growth	Several months	Good survival in first several months; severe storms destroyed plots	Transplanting success is enhanced if below-ground production of shoots is good (Wolcott, 4/21/89, pers. comm.; Wyllie Echeverria, 4/14/89, pers. comm.)
Bodega Harbor, CA	1 bundle per 0.65–0.8 m	Percent cover; shoot density; infauna; crabs; sediment characteristics; currents; light	2 years	40% survival and 90% cover on tidal flat; 5% survival and 10% cover on channel banks	Low current, low disturbance, low turbidity areas did best (Connors 1986; Connors, 4/14/89, pers. comm.)
Richmond Harbor, San Francisco Bay, CA	1 bundle per 1 m	Shoot density; flowering; biomass; recruitment; temperature; salinity; water transparency	13 months	Approx. 100% mortality by end of study	Mature transplants did the best; transplant shock may have contributed to losses (Fredette et al. 1987; Wyllie Echeverria, 4/14/89, pers. comm.)

TABLE 2. Physical and chemical characteristics of areas where eelgrass occurs along the North Pacific coast.

Characteristic	Condition	Note	Reference
Depth	0.0 to −6.6 m MLLW	optimal	reviewed in Phillips (1984)
Light	20–30% of surface irradiance	max. biomass recorded	Mukai, Aioi, and Ishida (1980)
	70–175 μE m^{-2} s^{-1}	saturates photosynthesis; temp. affects saturation point	summarized in Dennison (1987)
	0.95 × mean annual Secchi depth (m)	max. depth limit	Dennison (1987)
Nutrients	ample inorganic nitrogen and phosphate	growth can be nutrient limited; sources are sediment and water column; excess nutrients can reduce growth due to high epiphyte biomass	reviewed in Day et al. (1989)
Salinity	10–30 ppt	optimal	reviewed in Phillips (1984)
Sediment	mixed sand and mud	optimal	reviewed in Phillips (1984)
Slope	flat to very slight incline	optimal	present review
Temperature	10–20° C	optimal	reviewed in Phillips (1984)
Waves	none or very small and infrequent	optimal	present review

abnormally high phytoplankton production, which will reduce water clarity and light transmittance. Finally, even if all characteristics are shown to fall within the optimal ranges at a particular site, transplant success is not ensured.

Experimental transplanting should be conducted, when possible, under conditions where the full transplant project will take place. This will help to further evaluate the probability of plants actually surviving and growing in the proposed transplant site. Modifications of the physical characteristics of the site (e.g., introducing appropriate substrata, restricting wave action) would have to be made prior to the experimental transplanting effort. Previous data suggest that poor sites will have no survival of transplants in less than 12 months. Observations from the longest-term study (Sequim Bay) indicated that the system will exhibit significant changes for at least five years following transplanting. If a poor site is chosen it probably will be evident in a short period of time, and modifications of the site (as dictated by the results of a monitoring program) possibly can be made to improve conditions. However, the expense of making site modifications may be great on a full mitigation scale. In contrast, the results from sites that show good success after two years do not necessarily indicate a long-term stable condition of the meadow. The potential mitigation site should be pre-tested to make sure it satisfies performance criteria prior to development. Afterwards, monitoring of the newly-constructed site for at least two years is strongly recommended (Fonseca, Kenworthy, and Thayer 1988). This is perhaps the best alternative given the uncertainties associated with eelgrass meadow construction.

The actions and conditions that can increase the probability of success can be summarized as follows:

1. Select sites with low turbidity to allow adequate solar energy (see Table 2) to support primary production. Sites with high turbidity have generally yielded poor results.
2. Select transplant sites with medium-grained sand and moderate organic matter content. Although eelgrass does have a wide tolerance for sediment characteristics, transplants appear to be most successful on the recommended substrate type.
3. Select transplant sites with low disturbance from boat wakes, waves, sediment movement, etc.
4. Plant on flat areas rather than steep slopes.
5. Plant in areas that form pools at low tides. Eelgrass occurs naturally in these areas, and transplants seemed to survive best in areas where the water remained over the tideflats at low tide.
6. Transplant eelgrass into an area larger than the target area desired for mitigation. In all previous projects reviewed, areas of successful transplantation were smaller than the areas originally planted.
7. Minimize the holding time of the donor stock. Eelgrass is very sensitive, and donor plants should be planted within a few hours (maximum 24 hours) after removal from the donor site. The plants should be kept under water during transport, if possible.
8. Understand the ecosystem (see Table 2) into which the transplants are to be placed and the ecosystem from which the donor stock was taken. Natural selection in eelgrass populations creates populations of variable tolerances (e.g., to light, temperature, and wave action).
9. Conduct experimental transplanting to evaluate the effectiveness of a potential site. This could consist of planting plots

(e.g., 10 × 10 m) in the area where the full mitigation meadow will be planted. At minimum, the number of shoots present and the area occupied by eelgrass should be monitored quarterly for two years to evaluate potential success.

Conclusions

Key factors that influenced the success of an eelgrass transplant project were primarily related to the site (e.g., Phillips 1980; Fonseca, Kenworthy, and Thayer 1988). These factors include substrata, depth, current or wave disturbance, light energy, scale or size of the plot, salinity and temperature. Other factors cited were proximity to a natural bed, quality of donor stock, time between removal from bed and transplanting, mode of spreading (i.e., seeds or rhizome), grazing by animals, and unusual weather events (e.g., severe storms, freezes).

No investigator concluded that eelgrass meadow establishment by transplanting was impossible. All investigators voiced reservations, however, and recommended caution when developing an eelgrass transplanting effort. I view 11 of the 17 (65%) projects as successful. That is, during the observation period eelgrass survived and flourished in at least part of the site.

Survival and growth of transplants does not necessarily mean that a functionally performing meadow has been achieved. Only two large-scale and long-term projects provide adequate documentation of functional equivalency: Sequim Bay and Bodega Harbor. Functional equivalency in the case of Lummi Bay is defined in terms of the amount of herring eggs found on the transplanted plants as compared to adjacent naturally established plants (K. Fresh, WDF, Olympia, Washington, conversation, 1989). There was no apparent attempt to document herring spawning among the 17 projects. Other functional performance criteria might include the densities of animal populations (that are food sources for fish) in the sediment (infauna) or on the surface of the sediment or eelgrass leaves (epibenthos).

The time required for the transplanted meadow to function at a level insignificantly different from a natural meadow is important and also should be considered. Obviously, data on the functional performance of constructed meadows are needed. Phillips (telephone call, 1989) stated that construction of eelgrass meadows as mitigation is an interesting concept. However, creating a large-scale meadow that functions like a natural system is not proven as yet. Phillips indicated that we cannot yet predict with reasonable confidence the final rate of success.

Review of the past projects does provide us with information that will aid in the design of transplant projects. The results seen on the East and Gulf coasts (Fonseca, Kenworthy, and Thayer 1988) appear to coincide with those seen in the Northwest. The smaller the project, the greater the success. Many of the small projects were carried out by eelgrass experts (Harrison; Backman; Phillips) for purposes of investigating the biology of the plant. Using their intimate understanding of the requirements of the plants, and knowing that successful transplanting was critical to their work, they took great care in establishing the small plots. It was clear that plots receiving adequate light and protection from wave disturbance were the most successful. Fonseca, Kenworthy, and Thayer (1988) did an extensive review of seagrass transplanting projects on the East and Gulf coasts, and emphasized the importance of assessing these factors during the site selection process.

The technology for transplanting eelgrass is in the trial-and-error stage in the Northwest. Research is needed. Through my involvement in the mitigation planning process, I have found that resource agencies are reluctant to fund this research because it is the developer who impacts the ecosystem and must be responsible for mitigating the impact through scientifically justified means. The burden of proof is on the developer regarding the mitigation plan, whether it is based on actual experiments or up-front (pre-project) mitigation, followed by verification of performance through appropriate monitoring. The developers are not interested in conducting research, primarily due to the cumulative effects of costs and time delays on the project's cost-benefit ratio. Based on the present survey, performance monitoring was highly variable among their projects, was generally very limited in scope and time scale. Quantitative information on the projects was either missing or not easily accessed.

The failures of mitigation involving eelgrass transplanting are probably, in part, the direct result of lack of information. The present way of gaining information for the purpose of advancing transplanting technology in the Northwest is non-rigorous and inefficient. The net result is that the ecosystem probably suffers. Pressure to develop shorelines will continue, and eelgrass will be a major concern. It is premature to conclude that eelgrass tranplanting can reliably mitigate for impacts on natural eelgrass meadows, but if the technology is to succeed, it depends upon carefully conceived and executed research.

For agencies and developers to consider eelgrass transplanting a viable alternative, it is in the public interest to develop a strong data base gained through a comprehensive research program in the Northwest. In this regard, perhaps the best approach would involve collaboration to include major land developers of estuaries (e.g., port authorities), public resource and regulatory agencies, and universities as directors and funders of the research program. In lieu of a comprehensive program, it is probably wise to evaluate the site through measurements of environmental factors and experiments done at the site before full-scale planting. The best approach for the ecosystem, however, would be a strong regional data base coupled with site specific studies.

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