Tidal Wetland Plants Distribution and Primary Control Factors in Commencement Bay

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Prepared for

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7600 Sand Point Way NE
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April, 2000

Table of Contents

Tables

Figures

Figures (continued)

Acknowledgements

This work was supported by the National Oceanographic and Atmospheric Administration (NOAA) Damage Assessment and Restoration Center Northwest. We sincerely appreciate the encouragement and help of the Commencement Bay Program Manager Jennifer Steger. Paul Farley of Battelle Marine Sciences Laboratory (MSL) provided technical guidance on survey methods. Ann Mullin, Associate Western University Program student, assisted with water quality sampling in April. Susan Thomas of MSL provided editorial comments.

Introduction

The Commencement Bay Natural Resource Trustees are responsible for implementing restoration in Commencement Bay as part of Natural Resources Damage Settlements. Restoration actions largely include the establishment of intertidal and shallow water habitats designed to benefit fish and wildlife resources. These habitats include tidal marshes, mud flats, cobble beaches, riparian and subtidal eelgrass meadow areas. Due to the significance of these restoration activities, a limited pilot project was implemented on the Middle Waterway, Commencement Bay. This pilot project has not achieved the anticipated performance of the Trustees for vegetation establishment, habitat function. Further, the project has not provided information on the species environmental requirements. Vegetation has either died or not established at an expected rate. This poor performance may have been due to the lack of species-specific requirements for growth and/or conditions may have changed following planting to prevent growth.

In Commencement Bay, a basic quantitative understanding of the physical and chemical factors that control the distribution and abundance of wetland plant species is needed. This information is necessary to design, create, and maintain planting areas. The purpose of the study reported here was to provide a quantitative description of the conditions under which intertidal wetland plant species presently occur and flourish in the bay.

Objectives

The specific objectives of the study were as follows:

1. Provide an accurate map (Geographic Information System [GIS] ArcView 3.1 format) of the location and species composition of existing intertidal natural vegetation by Habitat Focus Areas as determined by the trustees. Included in the GIS should be relevant existing information regarding the location of eelgrass beds. Eelgrass should be included based upon literature surveys and previous mapping exercises.
2. Provide survey information (GIS and tabular format) from natural and seminatural stands on the primary factors generally known to control community species composition, including elevation and slope (and therefore, degree and frequency of inundation), substrata/soil conditions (pore water characteristics [salinity], sediment characteristics [grain size, organic content]), physical description of energy regimes, temperature, and salinity.

3. Describe range and optimal conditions of environmental factors for each major wetland plant species and community types and provide recommendations on the factors that are critical for each community type and species.
4. Develop a framework in order to evaluate and interpret the data gathered above.

Methods

Field Studies

Sites. We conducted surveys of vegetation and soils at five sites representative of the habitat focus areas in Commencement Bay (Figure 1). The sites were selected based on discussions and recommendations of NOAA, and were designed to include the range of tidal marsh species that would normally be expected in Commencement Bay. Because of the highly altered state of the bay ecosystem and general lack of natural marshes, all but one of the sites (Nursery) were restored marshes. We also examined other sites of interest to NOAA, including the Meeker site and the Wasser Winter site. Neither of these sites contained marsh vegetation, and hence were not sampled for vegetation. We did, however, collect water properties data at these sites (see below).

Vegetation and Soils. At each of the sites, we delineated the portion of the site containing emergent wetland vegetation patches that we sampled using a Trimble Global Positioning System with a listed accuracy of <1 m. There were other patches of vegetation at most sites, but these were not delineated. In most cases, we collected position data at several points along the edge of the vegetation distribution. In some cases, the vegetation was so sparse that only points where vegetation occurred were surveyed. Elevations relative to a base point on the shore were collected using a Criterion 400 Laser Range Finder. This instrument has a manufacturer's-stated accuracy of ±0.2 degrees. The elevations were referenced to MLLW by recording the elevation of the water's edge along with the time, and correcting this elevation to data from that date at the NOAA tide gauge station located in Sitcum Waterway (Figure 1).

Vegetation parameters were sampled within each of the delineated areas at each site using a 1.0 m^2 quadrat. The quadrat was placed at even intervals along transects that spanned the distribution of the plants. At sites where vegetation was very sparse, the quadrats were placed directly over the patches of plants. Along with elevation and position, species cover (to the nearest 5%) was recorded.

Soil salinity was measured at a subset of points that were sampled for vegetation. To do this, a small core (ca. 1 cm diameter) of sediment was extracted, and several drops of water were extracted by squeezing the sediment core placed inside either several layers of heavy tissues or coffee filters. The salinity of the filtered water was measured using a calibrated refractometer, with an accuracy of ±1 part per thousand (ppt).

We collected a total of 10 surface sediment core samples for soil analysis. The samples were from areas representative of the distribution of the major plant taxa (i.e., *Carex, Deschampsia, Salicornia, Distichlis, Typha*) among all sites. Samples were placed in sealed glass jars and stored in a cool, dark container for shipment. The samples were analyzed by Applied Marine Sciences, Inc., for moisture, total organic carbon (TOC), grain size, nitrate+nitrite, total kjeldahl nitrogen, total phosphorus, and total solids.

Water Properties. We measured water properties at seven locations as close a possible to the vegetation and soils sites, and at the Meeker and Hylebos Creek (Wasser Winter) sites (Figure 1). All sites except Hylebos Creek were sampled by the filed crew lowering a Hydrolab Data Sonde 4 instrument package into water approximately 1m deep. The Hylebos Creek samples were collected by the field crew by lowering the instrument package from the Route 509 bridge. Sampling was conducted on 27 March 1999 and 3-4 June 1999. We measured water temperature, dissolved oxygen, salinity, and pH at the surface and bottom of the water column, where possible. Sampling was conducted near high slack tide in March. Sampling in June was concurrent with vegetation sampling and was conducted at lower tides.

Eelgrass Distribution Data

We obtained eelgrass (*Zostera marina*) distributional data from NOAA (unpublished data).

Geographic Information System Map Production

Base maps for the area were developed from a software package called TOPO! and placed on the MapInfo GIS system. The location data for vegetation areas and samples were entered into the GIS system as data layers. The data were converted to ArcView file format for transfer to NOAA.

Results and Discussion

Vegetation Distribution

The entire data set from the field sampling is provided in Appendix A. We recorded 15 taxa of marsh vegetation at the five study sites (Table 1). Based on the stratified sampling method, we used, which was highly biased toward areas that have vegetation cover, the most abundant taxa included *Distichlis*, *Carex*, *Salicornia*, *Deschampsia* and *Typha*. Among these, *Salicornia* and *Carex* occurred at the most sites; *Carex* occurred both at estuarine and freshwater sites. These five taxa have been the most successful at colonizing marsh areas in the bay, and are likely to be the most successful in new restoration sites planned for the bay. For these reasons, we restricted the analysis of the factors affecting the distribution of plants to these taxa. The Nursery and Gog-le-hi-te sites each contained seven taxa, and fewer taxa were recorded at the other sites. The Nursery site is one of the few remaining natural marsh areas in the bay. Gog-le- hi-te is a restored marsh system that was approximately 13 years old at the time of sampling. The remaining sites are all restored systems that are less than 5 years old. The perimeter of the wetland areas surveyed at each site are shown in Figures 2-6. The elevations of the sampling stations are provided on the maps along with the soil salinity values and the dominant vegetation taxa.

Table 1. The plant species and mean percent cover recorded at each of the five sites

Taxa	Nursery	Fairliner	Rhone Poulanc	Middle Waterway	Gog-Le-Hi-Te
Distichlis spicata	13.9%	0%	0%	11.9%	0%
Carex lyngbyei	55.3	0	0	0	15.5
?*Aster* sp.	3.6	0	0	0	0
Salicornia virginica	0.1	0	35.8	25.0	0
Plantago maritima	0.1	0	0	0.1	0
Triglochin maritima	0.03	0	0	0	0
Scirpus sp.	2.3	0.3	0	0	0.05
Jaumea carnosa	0	0.3	6.4	0	0
Spergularia marina	0	0	0.04	0	0
Deschampsia cespitosa	0	0	5.8	12.5	0
Atriplex patula	0	0	0	0.1	5.5
Typha spp.	0	0	0	0	15.0
Juncus bufonius	0	0	0	0	1.0
Elodea sp.	0	0	0	0	11.5
Eleocharis palustris	0	0	0	0	16.0

Nursery Site. At the Nursery site, a relatively lush natural marsh is distributed between about +11 and +14 ft MLLW (Figure 2, Appendix B). *Carex* dominated most of the site, and *Distichlis* occurring at higher elevations. Soil salinities were 13-14 ppt. We recorded freshwater inflow through a culvert located near the north end of the site, and we suspect that there is subsurface freshwater source at this site. Soils were relatively high in moisture content, organic carbon content, and gravels and sand (Table 2). Nitrogen and phosphate concentrations were relatively great at this site. The slope of the site was approximately 1.0 v:10.0 h (vertical to horizontal), which is steep for marshes in the region. The site has a maximum fetch of about 560 m, and it is open to wind driven waves from the southwest. A broad mudflat seaward from the marsh likely attenuates waves from this direction.

Table 2. Summary of sediment properties from the 10 samples collected at the sites

Site	Moisture (%)	TOC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Nitrite + Nitrate (mg/kg)	Total Phosphate (mg/kg)	Mean Soil Salinity (ppt)
Nursery	75.02	13.07	67.4	19.80	6.43	6.35	1.30	1300	14
	77.39	29.49	63.98	13.78	9.72	12.51	3.90	1900	
Fairliner	29.24	8.26	16.60	34.66	20.84	27.89	ND[1]	ND	ND
Rhone Poulanc	31.34	1.11	0.30	89.26	4.86	5.58	10.00	680	37
	12.98	0.72	0.69	87.66	6.69	4.96	0.40	630	
Middle WW	2.28	0.6	0.59	96.15	2.57	0.68	1.30	440	ND
Gog-le-hi-te	67.77	4.37	0.00	0.14	69.49	30.37	5.00	1800	3
	58.03	1.83	0.00	4.37	75.72	19.91	3.50	1200	
	39.94	2.77	0.00	7.00	75.34	17.66	1.40	1400	
	42.45	1.25	0.00	10.47	73.51	16.02	0.70	1200	

[1]ND = not determined

Fairliner Site. The Fairliner site was characterized as almost devoid of vegetation. Most of the few patches of extant vegetation were included in our samples and were found between elevations between +11.32 and +12.36 ft MLLW (Figure 3, Appendix C). The specimens of *Scirpus* and *Jaumea* that were present were sparse (Table 1) and appeared to be wilted and unhealthy. The sediment at the site is hard-packed, relatively low in moisture content, and dominated by silt and clay (Table 2). We were unable to obtain samples for salinity and nutrient analysis because of the dry and hard-packed nature of the soil. The slope is steep (1.1 v:10.0 h). Because it is located very near the shipping channel in Blair Waterway, the site likely receives substantial wakes from passing ships.

Rhone-Poulanc Site. This site is relatively newly restored with a developing marsh system. We surveyed the main marsh patch at the western portion of this site. A goose-exclusion fence surrounded the patch. According to the site manager, geese have removed a large portion of the marsh plantings from this site. The marsh vegetation is dominated at the lower elevations by relatively lush *Salicornia*, and at the higher elevations by clumps of *Deschampsia*. *Jaumea* is abundant in patches throughout the site. The vegetation extends from +11.74 ft MLLW down to +10.32 ft MLLW (Figure 4, Appendix D). Soil salinities were elevated, and ranged from 30 to 45 ppt. The soils were moderate in moisture content, and were dominated (>87%) by sand (Table 2). Nitrogen ranged widely from 0.4 to 10 mgN/kg. Phosphate was relatively low compared with the other sites. The site has a gentle slope of 0.2 v:10.0 h. This site is protected from wind-generated waves from the southwest. Ship wakes can reach the site, but they are probably minor factor affecting the vegetation because of the relatively narrow shape of the embayment in which the site is located.

Middle Waterway Site. The Middle Waterway site sits in a protected back bay portion of the waterway. A broad mudflat extends from the lower edge of the marsh to a narrow channel that forms at low tides in the middle of the waterway. Vegetation at the site is dominated by *Salicornia* and *Distichlis*, and is patchy but lush where it occurs. Vegetation occurs between +11.7 and +13.9 ft MLLW, and *Distichlis* occupies somewhat higher elevations than does *Salicornia* (Figure 5, Appendix E). The site is the remaining portion of a larger transplanted area in the general vicinity. Marsh vegetation also occurs as a narrow (ca. 5m wide) fringe to the west and south of the area we surveyed. The soils were dominated by hard-packed sand (96%) that contained very low moisture. We were unable to extract enough water at this site to make soil salinity measurements. Soil carbon, nitrogen, and phosphate values were among the lowest recorded during our study. The slope varies from moderate (0.4 v:10.0 h) in the *Salicornia* zone to steep (1.3 v:10.0 h) in the *Distichlis-Deschampsia* zone (Figure 5). Although the site is open across the waterway to winds and waves from the southwest, the presence of the mudflat and the probable lack of major ship traffic nearby, means that this site likely does not receive substantial wave disturbance.

Gog-Le-Hi-Te Site. This restored wetland lies in the tidal portion of the Puyallup River. *Typha* dominates the lush vegetation, with small patches of *Carex* and *Eleocharis* (Figure 6, Appendix F). Very low-growing aquatic vegetation consisting of *Elodea* and *Juncus bufonius* occurs on the mudflats seaward of the emergent marsh. *Typha* occurs at an elevation range of +7.9 to +11.4 ft MLLW, and *Carex* occurs between about +9.2 and +10.6 ft MLLW. Moisture content in the soils is great, and organic carbon is moderate. The soils are predominately silts and clays (Table 2). Soil nitrogen is moderate, and soil phosphate are relatively high. Soil salinity ranged from 2 to 5 ppt in the dense *Typha* stand. Soil salinity was lower (1.5 ppt) in the *Carex* stand, which was on a steeper slopes and closer to the mouth of the system. The site is protected from any significant wind waves and boat wakes by the river levee, which has a small (ca. 30 m-wide) connection to the river. The slope in the primary portion of the *Typha* marsh is a gentle 0.2 v:10.0 h.

Eelgrass Distribution

According to the data available, eelgrass occurs on the seaward end of the peninsula between the Puyallup River and the Middle Waterway (Figure 7). We have also observed eelgrass in small patches along the northern and southern shorelines of the bay.

Water Properties

The water property data provide a broad characterization of the conditions at the sites (Table 3). A more detailed study of these properties may be warranted if there is uncertainty about the conditions at a specific site. Dissolved oxygen, which ranged between 6.80 and 9.13 mg L^{-1}, and pH, which ranged from 7.52 to 8.06, exhibited no detectable trends among sites or depths, and are not presented in Table 3.

There are some notable differences among sites and between sampling dates in temperature and salinity. Temperature increased between April and June at all sites. Notable changes were the large increases at Fairliner, Gog-le-hi-te and at Hylebos Creek. The latter two of these sites are influenced by freshwater. In particular, Gog-le-hi-te receives primarily Puyallup River water that is fed from glaciers on Mount Rainier. In summer, the freshwater flow slows, and heating in the watershed likely causes temperatures in the river to rise. Fairliner is close to the mouth of Blair Waterway and the navigation channel and is therefore likely receiving colder bottom water from Commencement Bay. More protected sites and those with broad flats that heat up during low tides (e.g., Rhone Poulanc, Nursery) appear to have greater temperatures.

Salinity was very low at Gog-le-hi-te during both samplings, in concordance with the influence of the Puyallup River. Past studies have shown that salinity at this site can vary from near zero to about 7 ppt because of evaporation driven by heating of the flats (Thom et al. 1987). Salinity varied between samplings at the Hylebos Creek, with higher salinities in April and very low salinity in June. This may be related to heavier than normal rainfall in the area immediately prior to the June sampling. This rainfall event may also explain the general lower salinities at the sites in June as compared with April.

This limited data set from this study and that of others (Thom et al. 1987) indicates that Gog-le-hi-te and Hylebos are influenced by seasonal changes in salinity and temperature. The other sites are less subject to these variations. Fairliner may have a stronger "marine" influence than Commencement Bay. The other sites appear to be generally affected, albeit to a lesser degree, by either freshwater or bay water.

Factors Affecting Plant Distribution and Abundance

Elevation. Marsh vegetation was found between about +7 and +14.5 ft MLLW (Figure 8). The elevation range and elevation of peak cover varied among the five main species (Figure 9, Table 4). For example, *Distichlis* ranged from about +11.5 to +14.5 ft MLLW, with a peak at 13.2 ft MLLW. *Salicornia* occurred between 10.2 and 13.2 ft MLLW and peaked at about 10.5 ft MLLW. *Carex* cover was greatest at about +10.0 to +12.8 ft MLLW.

Table 3. Temperature and salinity data from the sites

Site	Depth	Temp. (°C) *April*	Temp. (°C) *June*	Salinity (ppt) *April*	Salinity (ppt) *June*
Hylebos	Surface	11.5	15.5	20.4	0.5
	Bottom	10.0	ND[1]	24.5	ND
Meeker	Surface	12.3	13.0	19.0	12.9
	Bottom	11.3	12.6	22.8	15.3
Nursery	Surface	15.0	ND	18.3	ND
	Bottom	13.5	ND	19.0	ND
Rhone Poulanc	Surface	10.0	13.4	21.4	21.8
Gog-le-hi-te	Surface	9.6	15.3	0.02	0.6
	Bottom	9.6	ND	0.02	ND
Middle Waterway	Surface	10.8	13.4	22.6	18.1
	Bottom	10.5	ND	19.6	ND
Fairliner	Surface	9.3	13.9	21.2	16.6
	Bottom	9.3	ND	21.6	ND

[1]ND = not determined

We emphasize that the elevations we present are relative to the Sitcum tide gauge. There is likely a slight variation in water level among all of the sites, as would be expected in any normal embayment.

Salinity. For the three sites where we were able to collect soil salinity samples, there was a strong relationship between salinity in surface waters in samples and soil salinity in June (Figure 10). Soils tended to accumulate salts, likely largely because of evaporation, at sites where water salinities were above about 20 ppt and below about 1 ppt. The Nursery site had intermediate soil salinities (Figure 2, Figure 10). As mentioned above, we noted a freshwater seepage very near the site that may have diluted salinities in the soils through a persistent flow both above and below ground.

The plants must deal with soil salinities through mechanisms that reduce internal salt concentrations. Cover of the five major plant species varied with soil salinity (Figure 11) and water column salinity (Figure 12). As evidenced by both water column and soil salinity data, *Salicornia* was the most salt tolerant, followed by *Distichlis* and *Deschampsia*. *Carex*, known to be a euryhaline species, exhibited the widest range of salinity tolerance.

Hutchinson (1989) reviewed salinity ranges and tolerances for wetland plant species in the Pacific Northwest. In general, the ranges we found in Commencement Bay agree well with the data in Hutchinson. Of note is that *Carex lyngbyei* has a wide range of tolerance to salinity but cannot tolerate soil salinities above about 20 ppt for extended periods. *Deschampsia* is also generally found in areas where salinities do not exceed 20 ppt, although it was recorded where we measured salinity as high as 23 ppt. *Distichlis* appears to be able to tolerate higher salinities, but generally dominates in areas where salinity ranges between 5 and 20ppt. *Salicornia* is recorded from areas with soils salinities as high as 45 ppt in the Pacific Northwest and even greater salinities in California. *Typha* is the least salt tolerant, rarely occurring in areas above about 10 ppt. This taxon normally occurs in freshwater-dominated sites but can withstand short periods during which salinities reach 8 ppt.

Summary of Factors. The summary of main factors correlating with the abundances of the five major species is shown in Table 4. Salinity was the primary factor that differed among the species, followed by elevation. Lowered soil salinities likely allowed *Carex* to reach a high abundance at the Nursery site in the zone receiving subsurface freshwater seepage. *Salicornia* occurred lowermost in the intertidal zone, and *Carex*, *Distichlis* and *Deschampsia* dominated the progressively higher elevations.

The species developed the best when soil moisture was generally greater than about 30% and the soils were sandy. The exception is the freshwater conditions at the Gog-le-hi-te site where soils were much finer, but had a high water content. Greater cover was associated with higher soil nitrogen and phosphate concentrations. Very dry and hard substrata, such as that recorded at Fairliner, were not conducive to the growth of vegetation.

The best plant development also occurred in sites that were protected from boat wake and substantial wind-driven wave action by either shoreline structures or broad flats. Gentler slopes favored stronger vegetation development. The slope in areas with highest plant cover ranged from 0.2 v:10.0 h to 1.0 v:10.0 h, and the latter value is very steep. The latter value was recorded at the Nursery site, which is protected from direct erosional forces by a broad mudflat.

We gathered no data on eelgrass during this study. We do know from other observations that eelgrass is generally confined to depths from about MLLW to -30ft MLLW in Puget Sound (Thom et al. 1998). It requires soft substrate that is not overly enriched with organic matter, which can cause toxic hydrogen sulfide buildup. It also requires adequate light for growth. Studies indicate that, at a minimum, eelgrass requires about 3 M m^{-2} d^{-1} of photosynthetically active radiation over extended periods in spring and summer (Thom et al. 1998). Turbidity, propeller wash and scour, high temperatures (e.g., above about 20 ^{o}C for extended periods), and eutrophication-generated ulvoid blooms will significantly harm eelgrass. Eelgrass grows under a salinity range of from 10 to 35 ppt, but appears to grow best at about 25-30 ppt (unpublished data).

Table 4. Summary of relationships between percent cover of the five major species and some measured environmental factors

Factor	*Distichlis*	*Carex*	*Salicornia*	*Deschampsia*	*Typha*
Elev. (ft, MLLW) *Maximum Cover*[1]	13.2	12.2	10.3	11.8 & 13.9	10.4
Elev. (ft, MLLW) *Range*[2]	11.5-14.6	10.0-12.8	10.3-13.2	11.6-14.5	7.9-11.4
Water Col. Salin. (ppt) *Maximum Cover*	17.8	0.02, 17.8	23.0	23.0	0.02
Water Col. Salin. (ppt) *Range*	17.8-22.6	0.02-17.8	17.8-23.0	18.1-23.0	0.02-0.6
Soil Salinity (ppt) *Maximum Cover*	14	1.5, 14	14	32	5
Soil Salinity (ppt) *Range*	13-14	1.5-14	13-45	30-45	2-5
Optimal Soil Grain Size	Gravel Sand	Gravel Sand (Silt Clay)[3]	Sand	Sand	Silt Clay

[1]Maximum cover = conditions where the species was maximum cover was recorded
[2]Range = gradient of conditions where the species was recorded
[3]Parentheses = *Carex* in the Gog-le-hi-te site

In terms of stressors to the marsh plants, grazing by geese has obviously been a factor in the loss of transplants at the restored sites. Goose exclusion efforts, consisting of crisscrossed ropes and strings, appeared to reduce the rate of grazing. Fences used in the Duwamish River appear to have had good success in excluding geese (C. Simenstad, personal communication, University of Washington). Planting in very dense and large clumps (e.g., turf), may also be an option. Many grazers tend to eat at the edges of habitats. Grazing and log and debris damage were observed to be resulting in damage to plants at many of the sites. The effects of contaminants on marsh vegetation has not been evaluated, but may be a factor in Commencement Bay. It is known, however, that marsh vegetation and associated soils and soil microorganisms can be very effective in remediating contaminated soils and sediments.

Recommendations

Based on the results presented here, we can make the following recommendations with regard to planting marshes in Commencement Bay:

- ***Consider those species that have been successful so far in Commencement Bay***. We have focused the analysis of vegetation distribution on five species because they have shown success at restoration sites as well as exhibited a wide range of occurrence in Commencement Bay. Restoration designers often recommend that species used for restoration purposes should be ones that have shown good success and those for which optimal growth conditions are understood. Restorationists also commonly recommend a simplified planting scheme involving only one or a few species known to be hardy or vigorous colonizers. This is opposed to "landscaping" the site by planting many species. In general, one or a few species that establish well will enhance the area for colonization of many species. At Gog-le-hi-te, one species (*Carex*) was initially planted. After five years, over 57 species of plants were noted in the system (Simenstad and Thom 1996). The other species noted at the sites in Commencement Bay may work also given the correct conditions. The data set on these other species is not as strong as for the five target species, and therefore, we hesitate to draw definitive conclusions regarding suitable conditions for their growth.

- ***Use the elevations described in this report as a guide.*** The elevation ranges for the five target species provided in Table 4 should be useful in site planning. For rarer species, consult the Appendix, which provides elevation data for all species including the rarer species.

- ***Design marsh benches with a gentle slope***. The best marsh development was documented in areas where the slope was very gentle (i.e., 0.2 v:10.0 h). Although marshes can establish on steeper slopes, their development depends on retention of water in the soils. Steep slopes will tend to result in quicker dewatering of soils.

- ***Protect the site from wind wave or boat wake disturbances***. Erosional forces were obviously affecting the development of marshes at some sites. The strongest development of marsh vegetation occurred where waves were likely to never exceed about 20cm in height.

- ***Use sediment dominated by sand***. Sandy sediments occurred where marsh development was the greatest with the exception of Gog-le-hi-te, where finer sediments dominated.

- ***Amend soils if needed to retain soils moisture***. Lush vegetation corresponded with relatively high soil moisture. Amendments of vegetative matter such as peat or hay have been used to help retain moisture as well as add nutrients to soils. Tilling to break up compaction coupled with a soil amendment would be effective in retaining moisture content. Once the roots dry out, the plants will succumb quickly.

- ***Amend sediments to incorporate nutrients, if needed***. Although experiments are needed to fully evaluate this recommendation, it is well known that the plants will require a large amount of nutrients to help them establish. Strategies that have proven successful include planting plugs or turf. Plugs and turf contain some of the soil material from the donor site. This method is often much more labor intensive than planting bare root material.

- ***Protect vegetation from goose grazing***. Although this is general knowledge, the study site with some protection and with suitable soils and elevation fared better than those without protection did.

- ***Protect vegetation from floating debris that might significantly harm the plants***. Logs and large floating debris are constant threats to newly developing marshes. Sites where debris did accumulated showed long-term damage to the marsh.

- ***Monitor new sites for vegetation and soil properties to more fully evaluate and refine these recommendations***. We strongly recommend further development of the database through monitoring of new restoration sites. This monitoring effort provides much needed information for adaptive planning and management of the systems in Commencement Bay.

In summary, site conditions for marsh development must:

- be protected from wave disturbances
- maintain a gentle slope over elevation +8 to +14.5ft MLLW
- foster the accumulation and maintenance of fine sands
- maintain high soil moisture and organic matter content
- be amenable for protection from goose grazing pressure
- have a free exchange of water with either a river or the bay.

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