RECOMMENDATIONS TO MINIMIZE POTENTIAL IMPACTS TO SEAGRASSES FROM SINGLE-FAMILY RESIDENTIAL DOCK STRUCTURES IN THE PACIFIC NORTHWEST

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INTRODUCTION

Seagrasses are widely recognized as one of the most productive and valuable habitats in shallow marine environments. Seagrass leaves are a major source of food in coastal ecosystems, either through direct grazing of leaves and epiphytes, detrital pathways, or export to adjacent communities (Zieman and Zieman 1989). They play an important role in nutrient cycling, through the production of detritus and transport of nutrients from the sediments to the water column (Kenworthy et al. 1982). Seagrasses also serve as nursery grounds, providing food and shelter for juveniles of many commercially important fish and shellfish species (Gilmore 1987). In the Pacific Northwest, eelgrass has been designated Essential Fish Habitat (EFH) for groundfish, coastal pelagic species and Pacific salmon. In addition to their importance to the biological community, seagrasses may also alter the physical properties of their environment. Dense stands of grasses function as a current baffle, retarding the flow of water, increasing sedimentation rates, and inhibiting resuspension of organic and inorganic deposits (Kenworthy et al. 1982). Roots and rhizomes of seagrasses form a dense mat which binds sediments and reduces erosion (Zieman and Zieman 1989).

Due to continuing rapid development in the coastal zone, there is a concern that the proliferation of dock structures will negatively impact seagrass meadows. Declines in seagrass coverage could have important consequences for those marine animals that utilize seagrass as habitat, and may also alter some of the physical properties of the habitat (e.g., changes in water circulation patterns, reduced sediment stability and retention). Loss of seagrass cover in areas under and adjacent to docks may result from shading, piling installation, and boat traffic (i.e., prop scarring). Although the area of seagrass loss associated with any individual dock can be relatively small, cumulative impacts and fragmentation of seagrass beds may be significant along highly developed shorelines. For example, in Palm Beach County, Florida, more than 50 acres of seagrasses are estimated to have been negatively impacted due to single family dock structures (Smith and Mezich, draft report 1999). In Puget Sound, substantial losses of eelgrass associated with shoreline development have been documented (Thom and Hallum 1990), although the amount of loss directly attributable to residential docks is unknown. With seagrass populations in decline in many areas, coastal resource managers are interested in the development of consistent, defensible guidelines to reduce additional dock-associated impacts to an already stressed resource.

The amount of available light is one of the most important factors affecting the survival, growth, and depth distribution of seagrasses (Bulthuis 1983; Dennison 1987; Abal et al. 1994; Kenworthy and Fonseca 1996). Although the seagrass response to light reduction has been documented in numerous studies using experimentally manipulated light levels (Bulthuis 1983; Neverauskas 1988; Abal et al. 1994; Gordon et al. 1994; Czerny and Dunton 1995; Fitzpatrick and Kirkman 1995), these experimental studies alone do not provide a basis for the development of guidelines to reduce dock shading impacts. The development and application of regulatory policy to address these impacts has been hindered by a lack of supporting data which directly links changes in seagrass characteristics with levels of light reduction associated with various types of overwater structures. Recent studies have documented the shading effects produced by these structures in Alabama (Shafer 1999), Florida (Molnar et al. 1989, Loflin 1995, Beal and Schmidt 2000), Massachusetts (Burdick and Short 1999), New York (Ludwig et al. 1997; Able et al. 1998) and Washington (Fresh et al. 1995, 2000; Thom and Shreffler 1996, Thom et al. 1997). The results of these studies can be used to provide a scientific basis for the development of guidelines and regulations for dock construction and protection of seagrass resources.

In the Pacific Northwest, there has recently been considerable interest in the effects of overwater structures in the marine environment, motivated largely by concerns related to potential habitat and/or behavioral alterations for Puget Sound chinook salmon and Coastal/Puget Sound bull trout, both federally listed species under the Endangered Species Act (ESA). Nightingale and Simenstad (2001) produced an excellent summary of the types and mechanisms of impacts associated with various types of overwater structures. Much of the research conducted in Puget Sound has been focused on the impacts related to the construction and operation of large ferry terminals (e.g. Thom et al. 1996; Thom and Shreffler 1996; Blanton et al. 2001). Although some of the results of these studies may also be applicable to small, single-family docks, there are issues of size, scale, and frequency of use that may require separate sets of standards or guidelines for large ferry terminals and residential piers.

This document provides a brief summary of current information on the potential impacts of single-family residential dock structures on seagrasses, with an emphasis on the issues and seagrass species of importance in the Pacific Northwest. Although potential impacts to marine fauna are recognized as a critical concern, this document will focus on the potential impacts to the seagrasses themselves. Five species of seagrass are known to occur in the Pacific Northwest. Three of these, in the genus *Phyllospadix*, grow on rocky substrate along exposed coasts (Phillips 1984). The remaining two species in the genus *Zostera*, grow in soft sediments along more protected shorelines. *Zostera marina* (eelgrass) is typically found from +1.8m down to -6.6m, while *Zostera japonica* is typically found from +1.2m to +2.4 m (Phillips 1984). *Z. japonica* is not native to the Pacific Northwest, and is believed to have been introduced as part of the oyster trade (Harrison and Bigley 1982) as early as the 1950's. Although much research has been conducted involving the ecology and physiology of *Z. marina*, comparatively little attention has been focused on *Z. japonica*.

The information in this document is organized into two major sections. The first provides background information on the minimum light requirements of seagrasses, and documents the effects of reduced light availability on seagrass biomass and density, growth, and morphology. The second provides suggestions on means to reduce potential impacts to seagrass resources associated with single-family residential docks.

EFFECTS OF REDUCED LIGHT AVAILABILITY ON SEAGRASS RESOURCES

In considering the reduction in ambient light associated with dock structures, there are two sources of light attenuation to consider. The first involves attenuation of light by the water column, which is highly variable over multiple time scales from hourly to seasonal. The second involves shading by the dock structure itself, which is less variable and more predictable. The primary mechanism for the changes in seagrass distribution, shoot density, or biomass associated with overwater structures is the reduction in ambient light caused by shading produced by the structures (Fresh et al. 1995). Therefore, most guidance intended to minimize seagrass impacts associated with docks has focused on various methods to increase light availability in the area beneath these structures. As a result, the information provided in this document will be focused on this topic. There are other sources of potential impacts, however, that need to be considered. Prop scouring in association with residential docks was noted by Burdick and Short (1999) and Shafer (1999a). Prop wash, scouring, and the associated increase in turbidity have been noted in studies of large ferry terminals (Thom et al. 1996). Growth of seagrasses around the base of pier pilings may be inhibited by changes in bottom topography or the accumulation of shell and debris (Fresh et al. 1995, Shafer and Lundin 1999). Other potential sources of impacts (not addressed in this document) include chemical contamination from leaching of treated wood products and leakage of petroleum products from moored vessels. See Table 10 (p. 34) in Nightingale and Simenstad (2001) for a summary of the habitat impacts and controlling factors related to overwater structures.

Light Requirements of Seagrasses

As photosynthetic vascular plants, seagrasses utilize light in the range of 400-700 nm (photosynthetically available radiation (PAR)) to supply energy for metabolic processes. Decreased ambient light typically results in lower overall productivity, which is ultimately reflected in lower shoot density and biomass. Predicting the potential impacts of dock shading on seagrass resources requires a knowledge of the minimum light requirements of the seagrass species as well as the nature of the light reduction produced by shading. In general, light requirements for submersed aquatic plants are higher than those of shade-adapted terrestrial plants (Dennison et al. 1993). Light requirements of seagrasses are often expressed as a percentage of light available at the surface. Estimates of the average minimum light requirement for seagrasses range from 4.4% to 29.4% of the light available at the surface (Dennison et al. 1993).

Methods for Estimating Seagrass Minimum Light Requirements

There are two general approaches to estimating the minimum light requirements of seagrasses. The first, known as the 'depth limits' approach, involves establishing the maximum depth of seagrass colonization for a particular area. Seagrasses at this depth are assumed to be existing at or near the minimum threshold light requirement. The amount of available light at that depth may be calculated based on an average value for light attenuation by the water column (Kenworthy and Fonseca 1996). An advantage of the 'depth-limits' approach is the direct connection it makes between the maximum depth of seagrass colonization and water column light attenuation. This enables managers to make predictions about the changes in seagrass distribution based on measurements of the diffuse attenuation coefficient (K_d), an index of the rate of light loss with increasing water depth. This approach has been used in the development of water quality standards and seagrass habitat restoration goals in Chesapeake Bay and other locations along the Atlantic and Gulf coasts (e.g. Kenworthy and Haunert 1991; Dennison et al. 1993). However, even frequent sampling of water column parameters are likely to miss periodic episodes of intense light attenuation which could be important to seagrass survival. Therefore, the actual seagrass depth limits are likely to differ from those predicted on the basis of average water column attenuation values. In addition, the extreme daily tidal fluctuation in water column depths in the Pacific Northwest may make this approach less applicable than in other areas with less tidal variation.

An alternative approach, known as the carbon balance model, involves estimating the minimum amount of light required to maintain a positive carbon balance. The principal advantage of this approach lies in the direct link between light conditions and plant photosynthesis. Two measures of the quality of the light environment are often used under this approach: the integrated irradiance (in moles photons per unit area per unit time), and the daily period of light-saturated irradiance in hours (H_{sat}). The saturation irradiance is the level of light at which the maximum rates of photosynthesis occur. Further increases in light intensity above the saturation point will result in no further increases in photosynthetic rate. H_{sat}, rather than instantaneous PAR, is the most important characteristic of the light environment affecting eelgrass photosynthesis, growth, and biomass (Dennison and Alberte 1986). The daily H_{sat} has been shown to be the best predictor of daily carbon gain in at least one west coast estuary (Zimmerman et al. 1994), and has been linked to the persistence of eelgrass at the lower depth limits (Dennison and Alberte 1982; 1985). The minimum H_{sat} requirement for an eelgrass population near Woods Hole, Massachusetts was estimated to be at least 6-8 hours (Dennison and Alberte 1985). Empirical data to establish the relationship between maximum eelgrass depth limits and H_{sat} for Pacific Northwest populations of eelgrass are lacking; in a recent literature review of the light requirements of eelgrass by Olsen et al. (1996), this was identified as a critical research need.

Simple carbon balance models may be constructed at the level of the leaf, or the whole plant. However, the minimum light requirements of seagrasses should not be predicted based on measurements of leaf tissue alone. This approach will severely underestimate the amount of light required to support the entire plant (Fourquean and Zieman 1991). Whole plant estimates of compensation irradiance for three seagrass species were at least twice as high as those based on measurement of leaf tissue alone (Fourquean and Zieman 1991).

The carbon balance approach is rarely used in a management context because it requires the use of more expensive equipment and the collection of continuous, time-series data. In practice, aspects of both approaches are often used in combination. Estimates of minimum light requirements using the carbon balance approach may be used to validate estimates obtained through the depth-limits approach (e.g. Dennison 1987).

Light requirements of Zostera marina

The light requirements of *Zostera marina* (18.2-29.4% of surface irradiance) appear to be at the high end of the range for most seagrasses (Dennison et al. 1993). There is a considerable amount of variability in the estimates of maximum depth limits and minimum light requirements reported from various regions (Table 1). Most research investigating the light requirements of eelgrass has been conducted along the Atlantic coast of the United States (e.g. Dennison 1987; Dennison and Alberte1982, 1985), California (e.g. Backman and Barrilotti 1976; Zimmerman et al. 1994), or northern Europe (e.g. Olesen and Sand-Jensen 1993) where the sun angle, tidal regime, climate, and other environmental factors differ from those in the

Pacific Northwest. Because of regional physiological adaptations, the light requirements of Pacific Northwest eelgrass populations may not be typical of those in other areas.

Table 1. Estimated depth limits mean light attenuation coefficients and minimum light requirements for *Zostera marina*. (Source: Dennison et al. 1993).

Location	Max. Depth Limit (m)	Diffuse Attenuation coefficient (K_d) (m^{-1})	Minimal Light Requirement (%)
Denmark	3.7-10.1	0.16-0.36	20.1 $\pm$ 2.1
Denmark	2.0-5.0	0.32-0.92	19.4 $\pm$ 1.3
Denmark	1.5-9.0	0.22-1.21	20.6 $\pm$ 13.0
Woods Hole, MA	6.0	0.28	18.6
Netherlands	2.5	0.49	29.4
Japan	2.0-5.0	0.38-0.49	18.2 $\pm$ 4.5

Until recently, published accounts of the light requirements of Pacific Northwest seagrasses were unavailable (Olson et al. 1996). Thom and Shreffler (1996) conducted a series of *in situ* growth measurements and mesocosm chamber experiments designed to determine the minimum light level for Pacific Northwest populations of *Zostera marina*. In the mesocosm experiments, plant mortality was observed when integrated light levels were below 3 M m^{-2} d^{-1} (expressed as number of photons per unit area per unit time) for approximately one week. In the long-term *in situ* growth studies, drastic reductions in growth rates were observed at light levels of 4-5 M m^{-2} d^{-1}. These data suggest a minimum threshold of at least 3 M m^{-2} d^{-1} is necessary for continued growth and survival of eelgrass (Thom and Shreffler 1996).

Seagrass Response to Shading

Changes in Biomass and Density

The ability to survive extended periods of light reduction varies greatly between species. Species with large rhizomes and proportionately large below-ground biomass (e.g. *Thalassia*) may take months to register an appreciable decline (Neverauskas 1988, Tomasko and Dawes

1989, Hall 1991, Czerny and Dunton 1995). Species with intermediate below-ground biomass (e.g. *Heterozostera tasmanica*) may respond over a period of weeks (Backman and Barilotti 1976, Dennison and Alberte 1982, Bulthuis 1983, Dennison and Alberte 1985). Small, shallow-rooted species (e.g. *Halophila*) may experience rapid declines after only a few days of shading (Williams and Dennison 1990). The effects of shading may be more pronounced during the warmer summer months when seagrasses are actively metabolizing and respiratory demands are higher. In a study of *Heterozostera tasmanica*, an Australian seagrass species, Bulthuis (1983) compared the results of various levels of shading initiated both in summer and in winter. For all light levels, the rate of decline in density was much more rapid for treatments initiated in summer than in winter.

Carbohydrate reserves stored in the rhizomes may play a critical role in the survival and regrowth of seagrasses after periods of unfavorable conditions (Olesen and Sand-Jensen 1993; Rey and Stephens 1996). The depletion of below-ground storage reserves could result in a lower root:shoot ratio for plants existing in a low-light environment. The root:shoot ratio has been interpreted as an indicator of plant health (Dunton 1996). By shifting resource allocation from below-ground to above-ground tissues, eelgrass plants were able to sustain continued growth over a period of several weeks, in spite of severe shading and loss of plant biomass (Olesen and Sand-Jensen 1993). This strategy would enable eelgrass to maintain low growth rates during the winter months, and may also help seagrasses to survive in the shaded conditions under docks.

In the northern Gulf of Mexico, *Halodule wrightii* was able to persist (at reduced density and biomass), under docks shaded at light levels of 19% and 16% surface irradiance, at shallow and deep sites, respectively (Shafer 1999). Seagrasses were not present under docks at light levels less than 14% surface irradiance. These data are in agreement with estimates of *in situ* compensation irradiance levels of 15-18% surface irradiance for meadows in Texas coastal waters (Dunton 1994; Onuf 1994; Czerny and Dunton 1995). Declines in eelgrass (*Zostera marina*) density in California were observed in as little as 18 days following the initiation of shading experiments in which the ambient light was reduced by 63%. After nine months of this treatment, eelgrass shoot density was reduced by 95% (Backman and Barilotti 1976). The density of flowering shoots was also reduced in shaded treatments.

Leaf Production and Growth

Growth rates in seagrasses typically exhibit seasonal patterns, which follow a general trend of increasing growth rates with increasing solar insolation during the spring and early summer, but these patterns may also be highly correlated with other environmental factors, such as water temperature, day length, etc. Zimmerman et al. (1989) suggest that seasonal patterns in growth and net photosynthesis may be largely controlled by changes in water temperature. Therefore, any differences in growth as a result of shading may be difficult to detect. This may explain the similarity in growth rates between shaded and unshaded plants reported by both Bulthuis (1983) and Czerny and Dunton (1995).

In the Pacific Northwest, Thom and Shreffler (1996) also observed strong seasonal patterns in eelgrass growth. Maximum *in situ* growth rates occurred at PAR levels of 3-5 M m^{-2} d^{-1}, although high growth rates were also observed at very low PAR levels. These results may provide further support for the influence of factors other than light on eelgrass seasonal growth patterns.

Other studies have reported dramatic declines in growth rates due to shading (Gordon et al. 1994, Fitzpatrick and Kirkman 1995). The ability to resume normal growth rates following cessation of shading also varied widely by species, and the extent and duration of the shading (Dennison and Alberte 1985, Gordon et al. 1994, Fitzpatrick and Kirkman 1995). Deep water populations of *Zostera marina* responded to light reduction by lowering the rate of leaf production (Dennison and Alberte 1982). Interestingly, leaf production rates in shallow water populations were not similarly affected (Dennison and Alberte 1982).

Because of the influence of factors other than shading on shoot production and leaf elongation rates (Czerny and Dunton 1995), and the ability of seagrasses to maintain growth rates in the presence of severe light limitation through re-allocation of below-ground resources (Olesen and Sand-Jensen 1993), measurement of seagrass growth rates may not be a reliable indicator of light stress.

Plant Morphology

A reduction in ambient light can produce changes in seagrass morphological characteristics such as blade length and width. Depending upon the species, blade length has been reported to either increase or decrease in response to shading. *Posidonia sinuosa* leaf length was reported to decrease in response to 80-99% reduction of light (Gordon et al. 1994). Blade width generally remained unaffected. Increases in *Z. marina* leaf length in response to experimental shading were reported by Short (1991). Similar increases were reported for *Heterozostera tasmanica* by Bulthuis (1983), and *Halodule wrightii* (Shafer 1999). This response has been interpreted as an adaptation to increase the amount of leaf surface area available for photosynthesis. Shafer (1999) suggested that seagrasses in the vicinity of docks may be able to use this mechanism to partially compensate for the reduction in light availability due to shading. Since west coast populations of *Z. marina* are highly morphologically variable (Backman 1991), a similar change in blade morphology in response to dock shading may also occur, but this response has not been documented.

MINIMIZING DOCK-ASSOCIATED IMPACTS

Seagrass Impacts Associated with Boat Moorings

It has been suggested that boat moorings be used in place of piers or docks in order to reduce seagrass impacts associated with these structures. If the moorings could be placed in deep water outside the depth limits of the seagrasses, then this strategy would be highly effective. If the moorings were placed in areas with seagrass, there is the potential for loss of seagrass cover. However, there are few reports that document the types of seagrass impacts associated with boat moorings. Only two published studies could be found, both from Australia (Walker et al. 1989; Hastings et al. 1995). Results of these studies are presented here in the absence of any comparable information for the Pacific Northwest region.

Walker et al. (1989) found that boat moorings can produce circular or semi-circular scoured areas within seagrass beds, ranging in size from 3 to 300 m^2 (Figure 1). The size of the scours was positively correlated with boat size. In areas with larger tidal ranges (> 1 m), the mooring chains will necessarily be longer, potentially causing more scouring action and damage. The scoured areas were generally 0.5 m to 1 m deeper than the surrounding seagrass beds (Walker et al 1989). Accumulation of seagrass detritus within these depressions is believed to be a limiting factor in the subsequent recolonization of the bare areas (Walker et al. 1989).

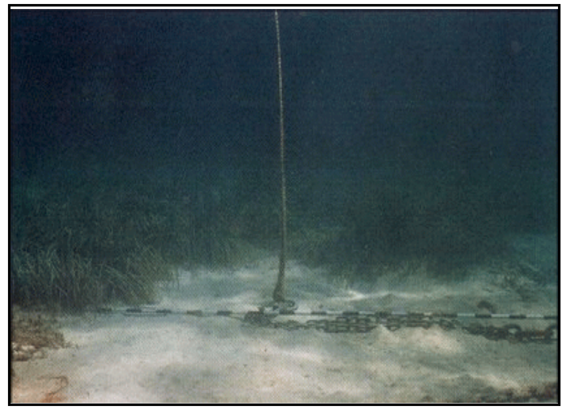

Figure 1. Bare area in seagrass bed produced by mooring chain scour.
Photo source: http://www.q-net.net.au/~amt/enviro.html

These studies indicate that the area of seagrass loss associated with boat moorings can be significant in some areas (Figure 2). For example, the area of seagrass loss directly attributable to moorings in a bay with a high concentration (344) of moorings was estimated to be 2.45 ha (Walker et al. 1989). In another area, 18% of the total seagrass area was lost due to moorings between 1941 and 1992. Thirteen percent of this loss occurred from 1981 to 1992, coincident with an increase in the number of moorings from 81 in 1977 to more than 190 in 1992 (Hastings et al. 1995). The loss of seagrass was not as dramatic in other bays, however, and seemed to be related to the degree of wave exposure and the sedimentary environment (erosional vs. depositional). Areas with a higher degree of wind and wave exposure and an erosional sediment environment appear to be more susceptible to damage from boat moorings than

Figure 2. Area of seagrass loss in a bay with a high mooring density.
Photo source: http:// www.q-net.net.au/~amt/enviro.html

more protected bays with a depositional sediment environment (Hastings et al. 1995).

Although the area of seagrass loss associated with boat moorings may represent only a small proportion of the total seagrass area, the effect is much greater than if an equivalent contiguous area was lost (Walker et al. 1989). In Rocky Bay, the length of exposed edge increased by more than 250% between 1981 and 1992 (Hastings et al. 1995). Increased fragmentation and loss of bed integrity may make the beds more vulnerable to erosion during storms.

The area of seagrass loss associated with moorings could be reduced through the use of low-impact designs that minimize scouring of the sea floor. Walker et al. (1989) found that cyclone moorings (triple-point) resulted in a smaller area of seagrass loss than swing (single-point) moorings. In response to this finding, the Rottnest Island Authority made a switch from single-chain moorings to 3-chain cyclone moorings. In an investigation of the effectiveness of this measure to reduce seagrass loss, Hastings et al. (1995) observed that in some cases, the cyclone type design resulted in a greater area of seagrass loss than the single-chain design.

Clearly, alternative designs that avoid scouring of the sea floor are needed. An internet search for seagrass-friendly mooring systems turned up a single company, based in Australia, that manufactures and sells a mooring system that claims to result in no impacts to seagrasses. However, the effectiveness of this system to reduce seagrass impacts in the Puget Sound region would need to be demonstrated through an experimental approach.

The area of seagrass in the Pacific Northwest that may be subject to potential damage from anchored mooring buoys is unknown. Aerial surveys combined with GIS analysis could be used to assess the extent of the impacted areas. Studies are needed in order to evaluate the impacts associated with various types of mooring systems in order to determine which system(s) will result in the least impacts to seagrass resources.

Minimizing Seagrass Impacts Due to Residential Dock Structures

Any overwater structure, however small, is likely to alter the marine environment in some way that could potentially affect seagrasses and their associated fauna. The only way to avoid impacts to eelgrass resources is to avoid placing these structures where eelgrass is present. In the event there is no other alternative, resource mangers need to focus on the development of some reasonable guidelines for the construction of docks and piers which will result in the least impacts to these resources.

The primary mechanism of impact to seagrass resources appears to be reduction in ambient light or shading produced by the structure itself (Fresh et al. 1995). This translates into a reduction in seagrass density or biomass in the area beneath the docks, or in severe cases, a complete loss of all seagrass cover (Fresh et al. 1995, 2002; Burdick and Short 1999). The fragmentation and loss of the physical integrity of the bed that results from complete elimination of seagrass may ultimately affect an area much larger than the original impact. Exposed edges of seagrass patches may be more vulnerable to erosion; these bare areas within seagrass beds may enlarge and 'migrate' across the bed (Patriquin 1975). Walker et al. (1989) also found that the bare patches produced by mooring chains may enlarge and become deeper than the surrounding sediments, limiting the ability of seagrasses to re-colonize the cleared areas. Although some reduction in seagrass density and/or biomass may be an unavoidable consequence of the placement of any dock or pier, complete loss of seagrass cover may be avoided in many cases through careful design and placement of the structures. This will reduce patchiness and fragmentation, and contribute to maintaining the physical integrity of the seagrass beds. If seagrass shoot density is reduced, but not eliminated, some evidence suggests that the individual shoots may be able to compensate in part by increasing blade length or width (Shafer 1999).

Based on the information currently available, some general guidelines are suggested to avoid or minimize seagrass impacts resulting from the construction of residential docks, piers, and floats. As previously noted, there are issues of size, scale, and frequency of use that may require separate sets of standards or guidelines for large ferry terminals and residential piers. The following recommendations are based on a limited number of observations and may require modification when results of on-going and future studies become available. Unfortunately, our current level of understanding does not allow us to make detailed recommendations or site-specific predictions concerning the potential effects of various alternative dock designs.

GENERAL RECOMMENDATIONS FOR DESIGN AND CONSTRUCTION OF RESIDENTIAL DOCKS

Avoidance. The placement and alignment of the dock/pier should be designed to avoid areas with seagrass cover to the fullest extent possible. In some situations, the length of the walkway portion of the pier may be increased so that the terminal platform or float is placed over water depths which are too deep to support the growth of seagrasses, as recommended by the Dade County, Florida Department of Environmental Resources (Molnar et al. 1989). Exceptions may be needed in those cases where this may result in an obstruction to navigation. If avoidance is not possible, impacts to seagrasses may be minimized by adopting the design principles suggested in the following sections.

Reduce cumulative impacts. In order to reduce the cumulative impacts associated with the placement of docks and piers, incentives could be used to encourage property owners to build shared facilities rather than multiple individual docks.

Orientation. The orientation of the structure has been noted in several studies as an important factor affecting the survival and density of seagrass. Docks/piers oriented in a north-south direction will produce less shading than those oriented in an east-west direction (Burdick and Short 1999; Shafer 1999; Fresh et al. 2002). Therefore, all overwater structures should be oriented in a north-south direction to the extent possible allowed by shoreline configuration.

Pier Width. The width of the dock or pier should be as narrow as possible without jeopardizing user safety. A maximum width of 4 ft for the walkway portion of the dock was adopted as part of the Florida regulatory guidelines for dock construction in areas where seagrass was potentially affected (Shafer and Lundin 1999).

Fixed Docks. Elevated fixed piers will allow greater light penetration to the underlying seagrasses than floating platforms. Therefore, elevated fixed structures should be used in preference to floating docks whenever possible. Burdick and Short (1999) reported height above the bottom was the single most important factor affecting seagrass bed quality. In Florida, seagrasses were able to persist under docks elevated 4 ft above MHW with a north-south orientation, although biomass and density were reduced by 40-60% (Shafer 1999). Current regulatory guidelines in use in Florida require docks to be built at least 5 ft above MHW (Shafer and Lundin 1999).

Floating Docks: In Puget Sound and other regions with large tidal ranges, the use of floating platforms for at least some portion of the structure may be a necessity. Floating platforms are likely to result in a greater reduction in seagrass density than fixed docks of comparable size. In Massachusetts, Burdick and Short (1999) reported a nearly complete loss of eelgrass cover under all floating platforms examined. A survey by WDFW in northern Puget Sound conducted in 1989-1990 found that seagrass was completely eliminated under three of the seven non-grated floats examined, and greatly reduced under the remaining four floats (Dan Pentilla, WDFW, cited in Fresh et al. 2002). In some situations, impacts may be reduced by lengthening the fixed elevated pier so that it extends out to a depth greater than the maximum depth of seagrass colonization, then attaching a float to the end of the fixed pier.

If the floats are allowed to rest directly on the sediments during low tide events, the physical abrasion of the sediment surface can result in direct removal or damage to seagrasses and other benthic and epi-benthic organisms. The installations of stoppers or other mechanisms to prevent grounding will reduce impacts associated with this type of disturbance.

Float Size and Shape. If a floating dock must be used, the size should be limited to the smallest footprint possible. In Florida, regulatory guidelines for dock construction limit the size of the terminal platform that may be placed at the end of the pier (Shafer and Lundin 1999). The maximum size of terminal platforms built with a grid surface deck is slightly larger than that allowed for wood construction, in order to encourage the use of grid material. For wood structures, the dimensions of the terminal platforms may not exceed 6 ft by 20 ft; the total area is limited to 120 sq ft. For grid structures, the dimensions of the terminal platforms may not exceed 8 ft by 20 ft; the total area is limited to 160 sq ft. In addition, terminal platforms placed over seagrasses may not be covered.

In areas where boats are to be docked, the Dade County guidelines require a minimum depth of -4 ft MLW at the terminal platform (Molnar et al. 1989). Establishment of a minimum water depth for terminal platform placement helps prevent prop scouring, and will also prevent grounding of floating structures.

Comparatively little attention has been focused on the effects of dock shape on seagrass survival. This was one of the factors examined by Fresh et al. (2002) in a study of grated floats in Puget Sound. For reasons that are not entirely clear, floats built in an "I" shape appeared to result in lesser impacts to seagrass density than floats built in a "T" or "L" shape, perhaps because of the smaller footprint size (Fresh et al. 2002). Further research is needed to elucidate the causal mechanisms behind these observed differences.

Alternative Construction Materials. The use of alternative construction materials to increase the amount of light received by the seagrasses below has been suggested as a mechanism to reduce loss of seagrass due to shading impacts. In a preliminary investigation of alternative decking materials which compared acrylic, acrylic with matting, lexan, aluminum grating and fiberglass grids, the Dade County (Florida) Department of Environmental Resources Management (DERM) concluded that only the fiberglass grid material showed promise (Molnar et al. 1989). DERM recommended that additional studies involving dock construction with fiberglass grids be conducted (Molnar et al. 1989). A recent study demonstrated that the docks elevated 4-5 feet above mean sea level using the fiberglass grid (Figure 3) for the entire dock surface allowed sufficient light penetration for continued seagrass survival under the conditions typical of St. Andrew Bay, Florida (Shafer and Robinson 2001).

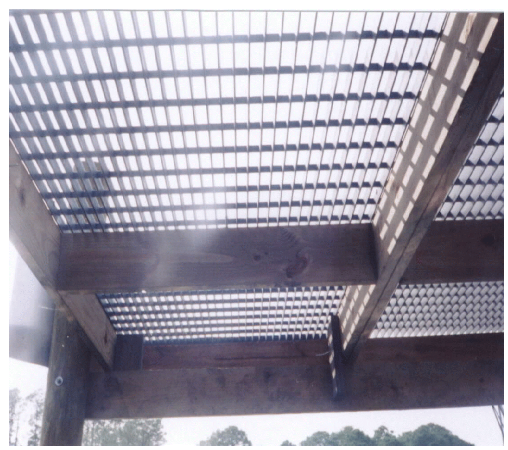

Figure 3. Light penetration through fiberglass grid dock surface.

Based on these results, regulatory guidelines in Florida for the construction of docks and piers in seagrass beds recommend the use of fiberglass grid materials.

A recent study by Fresh et al. (2002) evaluated the use of grate material for floats in Puget Sound, Washington. Fresh et al. (2002) reported that the grated floats were effective in reducing the impacts to eelgrass when compared to ungrated floats. Even if the entire float surface is composed of an open grate material, however, the solid pontoon floats beneath the grate surface may block up to 50% of the grate surface area. Floats should be designed so that the area of the pontoon represents the smallest footprint possible in order to maximize the area of open space available for light penetration.

Blanton et al. (2001) investigated several alternative means to increase the amount of available light under ferry terminals. These included glass prisms, glass blocks, a Sun Tunnel, metal halide lights, and reflective panels. Preliminary results indicated that all of these materials were effective at increasing light levels. However, these studies were conducted in an experimental darkened chamber, and did not take into account the effect of light attenuation by the water column. Similar studies involving construction of experimental docks in a seagrass environment are needed in order to determine which of these approaches are most likely to provide sufficient light for seagrass survival under *in situ* conditions.

In order to evaluate the effectiveness of the reflective panels, several panels were installed beneath a fixed dock located at the Port of Anacortes, Washington. The results indicate this approach was effective at increasing the ambient light levels from 1-3% to 9-11% (Gayaldo et al. 2002). Light levels of 9-11% of surface irradiance are within the range of the minimum thresholds for seagrass survival reported by Dennison et al. (1993). Although the exact location of the area affected by the reflective panels could not be delineated, it is likely that they contributed to the survival of the eelgrass transplants and seedling recolonization (Gayaldo et al. 2002).

The effectiveness of glass prisms to increase light levels beneath fixed piers was investigated in the Lower St. John's River system, Florida, by McKinney et al. (2002). The St. John's River is a low salinity, dark water system colonized by brackish and freshwater species of submerged aquatic vegetation such as *Valisneria americana*. The differences in average light levels beneath docks with and without prisms were statistically significant, but not large (25 µm m^{-2} s^{-1} vs. 18 µm m^{-2} s^{-1}). Nevertheless, preliminary results suggest that the additional light provided by the prisms had a positive effect on percent cover and canopy height. Differences in light levels between docks with prisms and those without were more apparent during the winter months than during the summer.

Piling Spacing. The presence of dock pilings results in potential impacts to seagrasses from both direct and indirect sources. Placement of pilings in seagrass beds results in the direct physical removal of seagrass during dock construction. The accumulation of debris and shell from barnacles, molluscs, and other marine organisms at the base of the pilings may inhibit the ability of seagrasses to recolonize the area surrounding the pilings (Fresh et al. 1995; Shafer and Lundin 1999). The presence of pilings can also alter sediment distribution and bottom topography, creating small depressions that preclude eelgrass growth (Fresh et al. 1995). In addition, shading is produced not only by the surface of the dock, but also by the pilings themselves. Therefore, the number of pilings should be limited to the minimum necessary, and the spacing of the pilings should be as far apart as possible, in order to maintain structural integrity of the pier.

Float Use: Seasonal vs. Permanent. Floats that are used only on a seasonal basis, and removed from the water for a portion of the year, appear to result in little change in seagrass shoot density. In an investigation of the attributes associated with seagrass impacts, Fresh et al. (2002) observed no declines in shoot density (compared to controls) beneath two floats that were removed from the water between October and April. Apparently, removal of the float during this period allows the seagrasses to recover from the light-limited conditions imposed by dock shading during the spring and summer. Because of the small sample size of seasonally removed docks available for the study, additional observations at other seasonally removed docks are needed to verify that these results are typical.

SUMMARY RECOMMENDATIONS

Recommendations for Dock and Float Design and Construction

- Encourage the use of shared dock facilities to reduce cumulative impacts.
- Relocate or realign the structure to avoid eelgrass beds.
- Extend the length of the walkway portion of the pier so that the terminal platform/boat mooring is located over water too deep to support eelgrass growth.
- If a deepwater location is not accessible, locate the terminal platform or float in water at least 4 ft deep to avoid grounding and prevent prop scarring.
- Orient all structures in a north-south direction to the maximum extent possible.
- Use elevated fixed piers at least 4-5 ft. above MHHW for the walkway portion, then attach a small float portion at the terminal end.
- Use alternative materials (e.g. grid surface for floats, reflective panels on fixed piers) to increase the amount of light penetration to seagrasses.
- Limit the width of the walkway portion of the pier to 4 ft.
- Limit the maximum size of the terminal platform or float.
- Use the minimum number of pilings required for structural integrity.
- Consider seasonal removal of the float.

Recommendations for Additional Study

The recommendations provided in this report were based on a limited number of observations and may require modification as results of on-going and future studies become available. Additional work in the following areas would improve our ability to make detailed recommendations or site-specific predictions concerning the potential effects of various alternative mooring system and dock designs.

- Measurements to determine the minimum number of hours of saturating irradiance (H_{sat}) required to maintain eelgrass survival and growth in Puget Sound.
- Investigate how float orientation, size and shape, and seasonality of use interact to affect seagrass bed health
- Compare the effectiveness of several alternative approaches to increasing light levels under docks (e.g. glass prisms, glass blocks, metal halide lights, Sun Tunnels, etc.) under *in situ* conditions through the construction of experimental dock units
- Comparison of different mooring buoy systems to determine which systems result in the least impacts to seagrasses.

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