Washington DNR Technical Memorandum

Aquatic Vegetation: Potential Impacts of Covered Activities and Buffer Recommendations

This technical memorandum was created in support of the development of performance standards for the Aquatic Lands Habitat Conservation Plan (HCP) and only addresses those conservation measures and impacts associated with submerged aquatic vegetation. Additional conservation measures and strategies are addressed in the HCP and other documents related to the HCP. In addition to defining minimum light requirements for the vegetation and impacts associated with specific types of structures, this document also presents recommendations for activity/structure specific vegetative buffers and conservation measures.

Four groups of native aquatic vegetation are considered here for protection as habitat for covered species: saltwater plants (submerged and emergent); kelps (macroalgae in the Order Laminariales); complex freshwater algae (stoneworts and brittleworts); and rooted freshwater plants (submerged, floating and emergent).

1. Background

Similarly to terrestrial vegetation, submerged, floating and emergent vegetation provides three-dimensional structure to shallow water benthic habitats; slows erosion and wave energy (Fonseca and Cahalan 1992); and converts carbon dioxide (CO_2) into oxygen and plant biomass (Hemminga and Duarte 2000). Aquatic vegetation biomass is a major source of food for herptofauna, birds, fish and invertebrates either as a result of direct consumption of the vegetation or of species that shelter in vegetation (e.g., zooplankton, larval/juvenile fish) (Moore et al. 2004; Alvarez and Peckarsky 2005; Hilt 2006). Species may also use vegetation for egg attachment, nursery/rearing areas, and/or for refuge from predation (Love et al. 1991; Webb 1991; Kendall and Mearns 1996; Sampson 1996; Munger et al. 1998; Shaffer 2004; Mumford 2007; National Marine Fisheries Service 2008).

While in- and overwater structures affect submerged and emergent aquatic vegetation through physical disturbance and changes to sediment chemistry, perhaps their most significant impact may be a reduction in the amount and/or quality of submerged aquatic vegetation as a result of shading (Pease 1974; Burdick and Short 1999; Rumrill and Poulton 2004).

There is little documentation as to how many plants, shoots, or thalli comprise a patch of aquatic vegetation, or many are required to support the patch's ecological function. As a result, Washington DNR has chosen to apply the precautionary principle and define a patch of aquatic vegetation as three or more plants, shoots, or thalli per square meter (m^2) of substrate. The standard of three individuals was chosen because it is the smallest number for which a standard error can be calculated. The extent of a patch is further defined as the point where density decreases below three individuals/m^2 (Precision Identification 2002; Geostreams Consulting

2004). An exception to the three-individual definition of a patch may be made at sites with historic evidence (documented or anecdotal) of aquatic vegetation, or at sites determined to have potential habitat and where colonization/re-colonization is possible. At such sites a single individual may be considered a patch.

2. Types of vegetation and function

2.1 SALTWATER

Aquatic vegetation in the saltwater ecosystem of Washington State is composed of salt marsh plants, a wide array of seaweeds and six species of seagrass. Both the native and introduced eelgrasses (*Zostera marina* and *Z. japonica* respectively) inhabit soft bottom or sandy flats, with three native species of surfgrass (*Phyllospadix* spp.) found in wave-exposed areas of the rocky intertidal. The remaining native species of seagrass, widgeon grass (*Ruppia maritima*), is uncommon in Washington State, and inhabits high intertidal areas with brackish water (Green and Short 2003). Among the native seaweeds, the kelps (Phaeophyta, Order Laminariales) form canopies that provide a three-dimensional habitat useful to covered species such as juvenile salmonids and juvenile rockfish (Love et al. 1991; Sampson 1996; Mumford 2007; National Marine Fisheries Service 2008).

Eelgrass and kelp populations impact their immediate environment in several important ways. Both kelp and eelgrass beds slow wave energy (Fonseca and Cahalan 1992; Mumford 2007). Eelgrass beds reduce current speeds by as much as 85 percent (Peterson et al. 2004). Slower-moving water allows finer sediment particles to settle out, thereby helping to reduce turbidity in the water column (Daby 2003). Eelgrass beds also increase recruitment of larval invertebrates such as crabs and bivalves by slowing water currents to increase colonization (Reusch and Chapman 1995) and by stabilizing the sediment to reduce burial of newly settled larvae (Webster et al. 1998). Eelgrass plants alter sediment chemistry by adding oxygen to sediment that is often anoxic. The oxygen is formed during photosynthesis and transported through internal air passages to the rhizomes where 50 to 60 percent of it diffuses into the sediment (Kraemer and Alberte 1995; Goodman et al. 1995). The small zone of oxygenated soil surrounding seagrass rhizomes supports aerobic bacteria that participate in the nitrogen cycle (Iizumi et al. 1980; Flindt et al. 1999). Eelgrass further alters its immediate environment through the uptake of nutrients from both the sediment and the water column (Thursby and Harlin 1982). Kelps are able to survive such high levels of nitrate and ammonium and remove them from the water column at such a rate they have been recommended for use as a biofilter for netpen aquaculture (Ahn et al. 1998).

In addition to their physical and chemical functions, both seagrasses and kelps serve as a direct food source for a number of invertebrates and birds. Eelgrass is the primary food source for black brant (*Branta bernicla nigricans*) (Wilson and Atkinson 1995) and supplements the diet of other waterfowl, including the common loon (*Gavia immer*) (McIntyre and Barr 1997), American widgeon (*Anas americana*), northern pintail (*A. acuta*) and the mallard (*A. platyrhynchos)* (Baldwin and Lovvorn 1994). Similarly, kelp is a direct food source for abalone (*Haliotis* spp.) and sea urchins (*Strongylocentrous* spp.) (Shaffer 2000).

Seagrasses, kelps and salt marsh plants also provide habitat and refuge for a variety of juvenile fish (e.g., rockfish, *Sebastes* spp.; salmonids, *Oncorhynchus* spp.) (Congleton and Smith 1976; Congleton et al. 1981; Dean et al. 2000; Pastén et al. 2003; Shaffer 2004; Guido et al. 2004; Mumford 2007; Semmens 2008) and invertebrates (e.g., Dungeness crab, *Cancer magister*) (Armstrong et al. 1988; McMillan et al. 1995), with northern pinto abalone (*H. kamtschatkana*) preferentially inhabiting kelp beds (Shaffer 2000; Sloan 2004). Salt marsh plants and eelgrass are particularly important to juvenile pink, Chinook and chum salmon while they adapt to oceanic conditions (Congleton and Smith 1976; Congleton et al. 1981; Love et al. 1991; Webb 1991; Sampson 1996; Fresh 2006). Chinook juveniles display a strong preference for native eelgrass habitat and have higher survival rates when eelgrass beds are available (Semmens 2008). In Washington, Pacific herring (*Clupea harengus pallasii*) spawn predominantly within eelgrass meadows (Barnhart and Moran 1988; Rooper and Haldorsen 2000).

2.2 FRESHWATER

Aquatic vegetation in Washington's rivers and lakes is comprised of a wide array of vascular plants and freshwater algae. Freshwater plants can be categorized as rooted or unrooted, with rooted plants further classified as submerged, floating or emergent. Among the freshwater algae, only the stoneworts (*Chara* spp.) and brittleworts (*Nitella* spp.) achieve the size and structural complexity necessary for providing habitat to covered species.

Freshwater plants, stoneworts and brittleworts have similar impacts on their immediate environment. Their presence helps reduce wave energy and stabilize the sediment; with van den Berg et al. (1998) reporting that maximum sediment resuspension rates within stonewort meadows was two orders of magnitude lower than within adjacent unvegetated areas. All three groups also remove nutrients from the water column, reducing eutrophication and further improving water clarity (van den Berg et al. 1998; Hietala et al. 2004). Plants and algae also diffuse oxygen into the water column (Findlay et al. 2006) and the sediment (Laskov et al. 2006).

In addition to their physical and chemical functions, stoneworts, brittleworts and freshwater plants are also an important food web component. Species that directly consume freshwater vegetation include amphibian tadpoles, the western (Pacific) pond turtle (*Clemmys marmorata*) (Bury 1986), snails (Elger et al. 2007), insects (Lamberti and Resh 1983; Alvarez and Peckarsky 2005), birds (Weisner et al. 1997), and fish (Hilt 2006). In turn some of these primary consumers are a valuable food source for adult amphibians (e.g., Columbia spotted frog, *Rana luteiventris;* northern leopard frog, *Rana pipiens;* western toad, *Bufo boreas*) and reptiles (e.g., western pond turtle); birds (black tern, *Chlidonias niger*; common loon; harlequin duck, *Histrionicus histrionicus*); and both juvenile and adult fish (white sturgeon, *Acipenser transmontanus;*).

Freshwater vegetation also provides refuge and breeding habitat for a variety of species. Kopp et al. (2006) reported that frog tadpoles used the habitat complexity provided by aquatic vegetation to hide from carnivorous water bugs. Other animals that use freshwater vegetation to avoid predation include numerous aquatic insects (Hornung and Foote 2006). The Oregon spotted frog (*R. pretiosa*) hibernates in the roots of emergent plants (Watson et al. 2003). The Columbia spotted frog, northern leopard frog, western toad, Olympic mudminnow (*Novumbra hubbsi*) and the western long-toed salamander (*Ambystoma macrodactylum)* lay their eggs on or within freshwater vegetation (Howard and Wallace 1985; Kendall and Mearns 1996; Davis and Verell 2005).

3. Light Requirements

Like terrestrial plants, aquatic vegetation requires light within the photosynthetically active light spectrum (400 to 700 nanometers). However, water absorbs and scatters light and turbidity caused by particles in the water such as sediment grains or single-cell plankton absorbs and scatters light even more. Researchers at Battelle Marine Sciences Laboratory showed that 64 percent of surface photosynthetically active radiation (PAR) was lost within the top meter of the water column within John Wayne Marina in Sequim Bay (Washington DNR 2005). Light availability clearly limits the distribution of aquatic vegetation to shallow water (Zimmerman et al. 1991), but even in shallow water light limitation is still one of the most important factors regulating the survival of aquatic vegetation (Dennison 1985; Binzer et al. 2006). The amount of light reaching aquatic vegetation depends both on the clarity of the water and the amount of light blocked by overshadowing structures or terrestrial plants. Growth rates, reproductive rates, shoot density and biomass of aquatic plants decline with decreasing light levels until a threshold light level is reached below which a given species cannot survive (Backman and Barilotti 1976; Short et al. 1995). This survival threshold, the minimum light requirement, is a conservative estimate of the light requirements of vegetation. The minimum light requirement varies by species and ranges from 0.1 percent to 30 percent of ambient surface light (Table 1).

Other factors influencing the survival of aquatic vegetation include toxins such as hydrogen sulfide (Goodman et al.1995; Holmer and Bondgaard 2001) and physical removal through clipping, sediment erosion or dredging (Burdick and Short 1999; Eriksson et al. 2004).

Table 1. Minimum light requirements in percent of surface light for selected freshwater and saltwater vegetation found in Washington State.

Vegetative species	Minimum light requirements (percent ambient light)	Literature source
Freshwater species		
Willow moss (*Fontinalis antipyretica)*	1.7	Sand-Jensen and Madsen 1991
Buttercup (*Ranunculus* spp.	1-10	Sheldon and Boylen 1977; Sand-Jensen and Madsen 1991
Coontail (*Ceratophyllum demersum)*	2	Meyer and Heritage 1941; Sand-Jensen and Madsen 1991

Vegetative species	Minimum light requirements (percent ambient light)	Literature source
Awlwort *(Subularia aquatica)* Big spore quillwort (*Isoetes macrosporea)* Pondweed (*Potamogeton* spp.) Slender water-nymph (*Najas flexilis)* Water lobelia (*Lobelia dortmanna)* Water star-grass (*Heteranthera dubi)*	10	Sheldon and Boylen 1977; Goldsborough and Kemp 1988
Brittleworts (*Nitella* spp.)	10-30	Schwarz et al. 2002
Stoneworts (*Chara* spp.)	20-30	Schwarz et al. 2002
Canadian waterweed (*Elodea canadensis*)	2-10	Sheldon and Boylen 1977; Sand-Jensen and Madsen 1991
Saltwater species		
Kelps	0.1-0.5	Luening 1980
Eelgrass (*Zostera marina)*	19-29	Dennison 1987; Duarte 1991; van Katwijk et al. 1998

4. Potential impacts of covered activities

4.1 OUTFALLS

Outfalls impact aquatic vegetation directly through increases in turbidity, discharge of nutrients and contaminants, altering nearshore/littoral profiles, and scouring vegetation within the plume (Dickman and Prescott 1983; Lim 1995; Smith 1997; Bryars and Neverauskas 2004). The structure may also indirectly affect vegetation through alteration of wave energy and currents, further increasing erosion (Smith 1997). The eroded area can reach 0.1 to 4 meters (0.3 to 13 feet) in width depending on the diameter of the outfall pipe (Lim 1995; Smith 1997).

4.2 OVERWATER STRUCTURES

Docks, Rafts, Boat Lifts, Nearshore Buildings, Marinas, Shipyards & Terminals

Potential impacts to aquatic vegetation from these activities are related to structural shading and other reductions in the amount of light reaching the vegetation. Shading that reduces light levels below the minimum requirement may result in the complete loss of vegetation throughout the footprint of the structures (Loflin 1995; Burdick and Short 1999; Shafer 1999; Beal and Schmit 2000; Fresh et al. 2006), with the effect being most severe with structures that float directly upon the water. Burdick and Short (1999) reported that three out of four floating docks in Massachusetts had no aquatic vegetation beneath them and recommended dock height as the most important factor for increasing the amount of light reaching aquatic vegetation. Unfortunately, little work has been done on the effects of dock height on shade intensity in the larger tidal prism of Puget Sound.

The shadow cast by a structure does not just impact the footprint of the structure. Based on the angle of the sun, the shadow produced by overwater structures actually extends beyond the footprint of the structure, moving as the sun moves. This moving shadow impacts areas adjacent to the footprint of the structures, causing a decline in nearby vegetative abundance and biomass (Loflin 1995; Fresh et al. 2006). Work done by Battelle Marine Sciences Laboratory determined that the area shaded by docks ranged from four times the total surface area of the dock to ten times the total surface area of the dock with the exact area of alteration depending on the orientation of the dock and the season (Washington DNR 2005). North/south oriented docks produce a shadow that moves more quickly around the impacted area throughout the day as opposed to the relatively immobile shadow produced by east/west oriented docks (Burdick and Short 1999). The movement of the shadow around north/south oriented docks means that no one area adjacent to the dock is shaded for long periods. Shafer (1999) reported that eelgrass growth rates were higher adjacent to north/south oriented docks than east/west oriented docks.

In addition to impacts associated with shading, rafts and floating docks can also directly impact aquatic vegetation by grounding out at low water, thereby crushing vegetation (Nightingale and Simenstad 2001) and docks can also impact aquatic vegetation through alterations in sediment transport.

Impacts to aquatic vegetation may also occur as a result of associated vessels. Not only do boats moored at a dock increase the area of shading around the dock, boat propellers can also clip off leaves (Eriksson et al. 2004) and uproot plants through prop scour (Burdick and Short 1999). Sediment suspension through prop scour increases turbidity in the water column and therefore decreases the amount of light reaching aquatic vegetation (Eriksson et al. 2004). Prop scour and prop dredging occur when boaters motor through water too shallow for their draft so prop scars are most prevalent in water less than 2 meters deep, a common location for aquatic vegetation (Sargent et al. 1995). Loflin (1995) reported that propeller scars were especially common close to docks with lifts, most likely caused by boat operators maneuvering their boat to line up with the lift. However, even docks without propeller scars lost an average of 7 square meters of seagrass due to prop scour. Prop scour doesn’t just occur next to the dock. As the boats turn when arriving at or leaving the dock, prop scour can occur at any point in that turning circle. The turning circle of a boat varies widely based primarily on the shape of the hull and the rudder. In general, turning circles range from the length of the boat to seven times the length of the boat.

Floating Homes

Similarly to other overwater structures, floating homes directly impact aquatic vegetation by creating shade. As with docks, the shadow thrown by houseboats extends beyond the footprint of the boat. Hertler et al. (2004) reported that houseboats in the La Parguera Reserve in Puerto Rico produced a shadow that extended 10 to 20 meters beyond the boat. However, little is known about the impacts of a second or third story on the length or intensity of the shadow thrown.

Mooring Buoys

Mooring buoys are defined here as a combination of the float, the anchor line and the anchor. Shading associated with mooring buoys is generally the result of the boat rather than the buoy itself with the extent of shading factored by the size of the vessel and the length of time the vessel is moored. The swing of the boat around the buoy is a lessening factor in the extent of shading by the boat as it causes the shadow to move, but no studies have been done on the effect of boat swing on shading intensity. Mooring buoys also directly impact aquatic vegetation by physically removing it or crushing it. The anchor line of the buoy can scour the sediment clear of seagrass to a 1 to 10 meter radius (Walker et al. 1989). Hastings et al. (1995) determined that the exact radius of damage depended on the type of anchoring system used and the degree of water energy present at the mooring site. All-rope systems with buoyant rope avoid scouring the bottom when clean, but tend to be come fouled with marine organisms and lose buoyancy without regular maintenance. A mid-line float system, that holds the mooring buoy anchor line above the bottom and does not require regular cleaning causes the least damage to aquatic vegetation. Solid anchors, such as concrete blocks crush or displace vegetation. An embedded anchor avoids these effects and so causes the least damage to aquatic vegetation. Mooring buoys also indirectly affect aquatic vegetation through their association with boats and the subsequent potential for increased water turbidity and prop scour and the crushing of aquatic vegetation through the grounding-out of boats at low water.

4.3 LOG BOOMING AND STORAGE

In addition to affects from shading (Pease 1974; Sedell and Duval 1985), log booming in shallower waters may directly affect aquatic vegetation by crushing or uprooting vegetation during low tides as well as by compaction of the sediment through the weight of dropped or sunken logs or debris and loss of habitat through coverage of the substrate with bark (Sedell and Duval 1985; Picard et al. 2003). Log booming also affects aquatic vegetation indirectly by the loss of bark and other organic materials that fall to the bottom, crush or displace vegetation, and then cause the production of hydrogen sulfide gas (H_2S) a by-product of anaerobic decomposition (Sedell and Duval 1985). Hydrogen sulfide is a toxin that when present in the sediment slows growth in aquatic plants (Holmer and Bondgaard 2001) especially in low light situations (Holmer et al. 2005). Goodman et al. (1995) determined that sediment hydrogen sulfide concentrations greater than 400 micro-moles/liter are sufficient to slow the growth of eelgrass. Because the area impacted by debris from log booming can extend 20 to 60 meters beyond the footprint of the site (Pease 1974), it is likely that the crushing and displacing effects and hydrogen sulfide production also extend 20 to 60 meters beyond the footprint of the site.

4.4 AQUACULTURE

For the purposes of the HCP, aquaculture on state-owned aquatic lands includes, but is not limited to, the farming of introduced Atlantic salmon (*Salmo salar*), mussels (*Mytilus* spp.), introduced Pacific oysters (*Crassostrea gigas*) and Kumamoto oysters (*Crassostrea sikamea*), native littleneck clams (*Protothaca staminea*), and introduced Manila clams (*Tapes philippinarum*). Methods utilized include netpens, rafts, on-bottom culture, longlines, bag culture, stakes, and fixed or floating racks. Potential impacts of aquaculture on aquatic vegetation vary with the aquaculture method.

Finfish

Although finfish aquaculture occurs in both fresh- and saltwater, freshwater sites are uncommon on state–owned aquatic lands. The most prevalent finfish aquaculture method uses netpens, with effects to vegetation occurring both as a result of shading and the degradation of sediment quality associated with fecal material and uneaten food (Karantzi and Karakassis 2006). Hall et al. (1990) determined that 70 to 78 percent of carbon fed to rainbow trout (*Oncorynchus. mykiss*) in netpens was lost to the environment with 18 percent being deposited in the sediment. High organic carbon levels lead to bacterial formation of hydrogen sulfide and the sediment underneath and adjacent to the netpens often have increased hydrogen sulfide levels (Hargrave et al. 1993). Hydrogen sulfide bubbles have been seen rising from the sediment underneath salmon netpens (Brooks and Mahnken 2003). Elevated organic carbon levels in the sediment have been reported 50 to 200 meters from netpens (Ye et al. 1991, Carroll et al. 2003), and sediment hydrogen sulfide levels greater than 400 micro-moles/liter (the toxic level for aquatic vegetation) have been reported 60 to 150 meters from netpens (Brooks and Mahnken 2003).

Shellfish

Common shellfish culture methods include on-bottom, longlines, rafts, stakes, and racks (fixed to the bottom or floating) and in-bottom. Impacts to aquatic vegetation occur as a result of shading by suspended culture methods; physical removal of eelgrass through harrowing or rototilling prior to seeding; trampling during seeding/installation/maintenance; smothering or removal when gravel is added to increase natural recruitment (Thompson 1995); and as a result of removal during harvest (Simenstad and Fresh 1995). Bishop et al. (2005) reported that the dredge harvesting of bay scallops using a commercial scallop dredge removed 5.76 square meters of eelgrass every 10 minutes. Neckles et al. (2005) found that the dredge harvesting of blue mussels (*Mytilus edulis*) removed 86% of the eelgrass in one dredge transect, leaving small, scattered, patches (average length, 1.03 meters). Based on measured colonization rates in the dredged areas, recovery of eelgrass density was predicted in 9-11 years depending on the degree of eelgrass removal in each transect. On-bottom shellfish culture also competes with aquatic vegetation for space. Tallis et al. (2006) reported that even a sparse shellfish percent coverage of 20 percent led to a significant reduction in vegetative cover.

Suspended methods of aquaculture (e.g., longlines, stakes, and rafts) shade out vegetation beneath and adjacent to them, with the degree of shading dependent on the size and spacing of the structures. Rumrill and Poulton (2004) determined that oyster longlines in northern California spaced 1 meter apart contained 5.5 percent of the eelgrass density measured outside aquaculture operations while longlines spaced 2 meters apart contained 43.7 percent and longlines spaced 3 meters apart contained an eelgrass population almost identical to areas outside aquaculture operations. Everett et al. (1995) found that stake aquaculture methods in Oregon increased sedimentation and could bury aquatic vegetation while fixed racks altered water flow and increased erosion of sediment and vegetation. Under both methods vegetation decreased to less than 25 percent of the vegetative cover measured outside aquaculture operations.

Aquaculture rafts contain a large number of individuals in a relatively small area, with effects to vegetation occurring both as a result of shading and degradation of the water and sediment quality associated with the deposition of pseudofecal material. Finer sediment particles and significantly higher organic carbon and total nitrogen levels have been reported underneath mussel rafts (Otero et al. 2005). Stenton-Dozey et al. (1999) determined that the rate of organic carbon and total nitrogen deposition was 3 times higher and 2 times higher, respectively under mussel rafts. Biodeposits can build up under rafts to a depth of 20-150 cm over time (Stenton-Dozey et al. 1999; Otero et al. 2005) and the benthic invertebrate community has been found to change from predominantly suspension feeders to predominantly deposit feeders (Otero et al. 2005). High organic carbon levels lead to bacterial formation of hydrogen sulfide. Sediment underneath and adjacent to finfish netpens often have increased hydrogen sulfide levels (Hargrave et al. 1993). Hydrogen sulfide bubbles have been seen rising from the sediment underneath salmon netpens (Brooks and Mahnken 2003). Elevated organic carbon levels in the sediment have been reported 50 to 200 meters from finfish netpens (Ye et al. 1991; Carroll et al. 2003), and sediment hydrogen sulfide levels greater than 400 micro-moles/liter (the toxic level for aquatic vegetation) have been reported 60 to 150 meters from netpens (Brooks and Mahnken 2003).

In-bottom geoduck culture physically uproots aquatic vegetation during the harvesting process due to the use of a hydraulic jet of water that liquefies the sediment and makes the removal of geoducks easier. This water jet is sometimes used during the planting of geoducks as well to make the insertion of the predator-exclusion PVC tubes easier (Davis 2004). The turbation of the sediment leads to large sediment plumes in the water, especially when harvest and planting take place when the beds are immersed. Aquatic vegetation can also be crushed through the installation of kiddie pools for geoduck spat nurseries.

Oysters, mussels and some species of clams are filter feeders that remove phytoplankton from the water column. Phytoplankton in the water column block light and increase light limitation for aquatic vegetation (Giesen et al. 1990). The removal of phytoplankton should therefore decrease light limitation and the installation of oyster reefs has been suggested as a possible remediation method for eutrophic estuaries such as the Chesapeake Bay (Cerco and Noel 2007; Fulford et al. 2007). However, studies done to test the effectiveness of oysters at decreasing turbidity have shown that the filtering effects of oysters only extend a short distance and are insufficient to significantly affect the growth and survival of eelgrass unless the eelgrass is in close proximity (Cerco and Noel 2007). It has also been shown that oyster beds can increase phytoplankton levels on a local scale by enriching the water column with their feces (Prins et al. 1998). In such a situation, the filtering effects of oysters would be merely undoing the damage done by oysters. Plus, the decrease in turbidity can have a positive effect on phytoplankton as well as on eelgrass, causing the phytoplankton to reproduce more rapidly and restore turbidity (Prins et al. 1998). There is also the possibility of a temporal mismatch - phytoplankton blooms take place in the spring and summer and the harvest of oysters in these seasons would remove their filtering capabilities just when those effects are needed (Fulford et al. 2007).

5. Recommended conservation measures

The conservation measures recommended here are focused on avoiding and minimizing shading, poisoning, and the physical removal of the protected groups of aquatic vegetation (saltwater plants, kelps, rooted freshwater submerged, floating and emergent plants, stoneworts, and brittleworts). Recommended conservation measures include avoiding all impacts to protected aquatic vegetation through the establishment of buffers between newly constructed covered activities/structures and all patches of protected aquatic vegetation and the minimization of impacts to protected aquatic vegetation through the modification of existing activities/structures.

5.1 AVOIDANCE MEASURES - BUFFER DISTANCES

Buffer distances for the covered activities are based on the potential effects of those activities as outlined in the literature.

Outfalls

New and reconfigured outfalls must be located to avoid impacts to existing native aquatic vegetation attached to or rooted in substrate. The diffuser or discharge point(s) for new or expanded outfalls must be located offshore and at a buffer distance beyond the nearshore/littoral area, to avoid impacts to those areas. This buffer distance shall be calculated as the extent of the mixing zone (including both the acute and chronic mixing zones) as defined in the current National Pollutant Discharge Elimination System (NPDES) permit for the leasehold. Leaseholds without a current NPDES permit must requisition a mixing zone analysis for the outfall from a qualified party and the analysis must follow protocols approved by Washington DNR science staff. The outfall pipe must be subsurface within the nearshore.

Docks, Rafts, Marinas, Shipyards & Terminals

Buffer distances for docks whether single or part of a marina or shipyard/terminal, and rafts, were based on the shade cast by the structure, the impacts of prop scour from the boats associated with the structure and the 8 meter (25 foot) buffer required by the U.S. Army Corps of Engineers (the Corps). There are several different buffer distances depending on site-specific factors.

- Buffer distance for docks, piers, wharves, rafts not associated with motorized watercraft is either 8 meters (25 feet) from the edge of the structure or the maximum distance shade will be cast by the structure, whichever is larger (see Appendix A).

- For docks, piers, wharves, and rafts associated with motorized watercraft, the horizontal buffer distance is 8 meters (25 feet) whenever there is a vertical buffer of 2 meters (7 feet) of water above the vegetative canopy at the lowest low water within the diameter of the turning circle. The buffer distance will be measured from the outside edge of the boat.

- For docks, piers, wharves, and rafts associated with motorized watercraft and without a sufficient vertical buffer, the horizontal buffer distance will be either 8 meters (25 feet), the maximum distance shade will be cast by the structure, or the diameter of the turning circle, whichever is longer. The buffer distance will be measured from the outside edge of the boat (see Appendix A).

For this measure the turning circle is defined as 3.5 times the length of the longest boat to use the structure.

Nearshore Buildings

Buffer distances for nearshore buildings are based on the potential shadow cast by these structures, a value strongly affected by the height of the building (the number of stories). The buffer distance for nearshore buildings is the maximum distance shade will be cast by the structure (see Appendix A).

Floating Homes

Washington DNR does not allow new floating homes on state-owned aquatic land, so an aquatic vegetation buffer is not necessary.

Mooring Buoys

There are no buffers for mooring buoys because the requirement that anchorage systems for mooring buoys include an embedded anchor and midline float will substantially reduce the impacts of mooring buoys on aquatic vegetation.

Log Booming and Storage

The buffer distance for log booming/storage and aquaculture rafts are based on estimations from the literature of how far beyond the footprint bark, or pseudofeces will be deposited, leading to crushing, displacement or potentially toxic hydrogen sulfide concentrations in the sediment. The buffer distance for log booming and storage is 60 meters (200 feet).

Aquaculture

Racks, on-bottom, longlines, stakes

Buffer distances for aquaculture racks, on-bottom culture, longlines and stakes are based on the potential shadow cast by these structures and the 8 meter (25 foot) buffer required by the Corps. The buffer distance for new or expanded racks, stakes, on-bottom culture or longlines is 8 meters (25 feet) from existing aquatic vegetation.

Geoduck Buffer distances for in-bottom geoduck culture are based on the sediment disruption during planting and harvesting and the impacts to light levels by the sediment plume raised during harvest. New geoduck aquaculture operations will be sited at a minimum buffer distance of 0.6 vertical meters (2 vertical feet) or 55 horizontal meters (180 horizontal feet) from the waterward edge of existing aquatic vegetation or 15 horizontal meters (50 horizontal feet) from the shoreward edge of existing aquatic vegetation.

Floating culture, netpens

The buffer distance for shellfish floating culture and finfish floating culture is based on the impacts to sediment chemistry from the buildup of carbon in the sediment. The buffer distance for new and expanded shellfish rafts and finfish netpens is 150 meters (492 feet) from existing aquatic vegetation.

5.2 ADDITIONAL AVOIDANCE MEASURES

Overwater Structures

Docks, Marinas, Shipyards & terminals

- New docks, marinas, shipyards & terminals should be located in water sufficiently deep to prevent the structure from grounding out at the lowest low water or stoppers should be installed to prevent grounding out.

- Boat mooring areas of docks, marinas, shipyards & terminals should be located where the water will be deeper than 2 meters (7 feet) at the lowest low water, to avoid prop scour.

Rafts

- New rafts should be anchored (if anchored) with an embedded anchor and a mid-line float system, which is recommended over the all-rope system because it does not require regular cleaning to maintain the buoyancy of the anchor line.

- New rafts should be located in water sufficiently deep to prevent the structure from grounding out at the lowest low water or stoppers should be installed to prevent grounding out.

- If used for boat moorage, new rafts should be anchored where the water will be deeper than 2 meters at the lowest low water, to avoid prop scour.

Aquaculture

- Longlines should not be spaced closer than 3 meters (10 feet).

5.3 MINIMIZATION MEASURES

Overwater Structures

Docks, Marinas, Shipyards & terminals

- Existing docks not located at the appropriate buffer distance from aquatic vegetation should be renovated over time to allow 30 percent of ambient light within the photosynthetically active range (400 to 700 nanometers) to reach the aquatic vegetation canopy.

- Boat mooring areas on existing docks should be moved to where the water will be deeper than 2 meters at the lowest low water, to avoid prop scour.

Rafts

- Existing temporarily anchored rafts should be moved to water sufficiently deep to prevent the structure from grounding out at the lowest low water.

- Existing temporarily anchored rafts not located at the appropriate buffer distance from aquatic vegetation should be relocated to the appropriate buffer distance or renovated to allow 30 percent of ambient light photosynthetically active range (400 to 700 nanometers) to reach the aquatic vegetation canopy.

- All rafts should be anchored with an embedded anchor and a mid-line float system, which is recommended over the all-rope system because it does not require regular cleaning to maintain the buoyancy of the anchor line.

- Existing permanently anchored rafts not located at the appropriate buffer distance from aquatic vegetation should be renovated over time to allow 30 percent of ambient light photosynthetically active range (400 to 700 nanometers) to reach the aquatic vegetation canopy.

Mooring Buoys

- Existing mooring buoys should be anchored with an embedded anchor and a mid-line float system, which is recommended over the all-rope system because it does not require regular cleaning to maintain the buoyancy of the anchor line.

- Existing mooring buoys not located in water deeper than 2 meters at the lowest low water should be relocated to deeper water, to avoid prop scour.

Aquaculture

- Existing longlines should be spaced a minimum of 3 meters apart.

- Geoduck aquaculture activities that disturb the substrate, such as hydraulic harvest, must be done only when the geoducks are exposed at low tide unless there is a minimum buffer distance of 0.6 vertical meters (2 vertical feet) or 55 horizontal meters (180 horizontal feet) from the waterward edge of existing aquatic vegetation or 15 horizontal meters (50 horizontal feet) from the shoreward edge of existing aquatic vegetation.

5.4 REDUCTIONS/EXEMPTIONS

HCP staff may reduce the buffer width or exempt an agreement from the vegetative buffer or other conservation measures on a case-by-case basis. The reasons for exemptions will be defined in the HCP Implementation Strategy and Procedures, but may include a structure being located in water too deep for aquatic vegetation, or in otherwise unacceptable habitat for the vegetation groups listed here or structural configurations that avoid impacts to vegetation.

6. Data Gaps

The conservation measures recommended in this technical memorandum are based on best available science. However, there are several factors contributing to the impacts of covered activities on aquatic vegetation that could not be quantified from published literature. These data gaps include, but are not limited to, the impact of dock height above the substrate on the area of alteration in the tidal prism of Washington State, the impact of the number of floors in floating homes or nearshore buildings on the area of alteration, the impact of prop scour from boats on the area of alteration, and the shading impacts of mooring buoys and their associated boats. These data gaps will be addressed through the adaptive management program in the HCP.

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Appendix A

Buffer distances for nearshore buildings and some docks are based on how far the structure will throw a shadow, on average. This distance can be determined using a right triangle (Figure 1) with the structure as the opposite side of the triangle (a) and the shadow cast by the structure as the adjacent side of the triangle (b). The height of the structure and the angle of the sun (Θ) above the horizon are known values and the distance the shadow is cast (b) can be determined using the trigonometric function of tangent whereby:

$$\tan(\Theta) = \frac{a}{b}$$

In this case the equation becomes $\tan(sunangle) = \frac{structureheight}{shadowlength}$

This can be solved for shadow length resulting in:

$$shadowlength = \frac{structureheight}{\tan(sunangle)}$$

Figure 1. The right angle triangle created by a nearshore building or dock, the angle of the sun above the horizon and the building's shadow.