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OVERWATER STRUCTURES: MARINE ISSUES

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Overwater Structures: Marine Issues

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16. ABSTRACT

This paper synthesizes 30 years of literature documenting the potential effects specific overwater structures pose to important estuarine and nearshore marine habitats for juvenile salmon and other fishes in the Pacific Northwest. While the fish and shellfish species discussed are known to specifically use nearshore habitats, we also examine potential impacts at the broader scale of the nearshore ecosystem.

Overwater structures have been proved to pose potential mortality and fitness risks to these animals and their ecosystems. Mechanisms of impact are characterized as changes in light, wave energy, and substrate regimes. Modifications to these regimes by the construction of, presence of and operations around overwater structures have been found to produce significantly different distributions of invertebrates, fishes, and plants in under-dock environments than in adjacent non-shaded vegetated habitats.

Effects of light limitation (shading) from overwater structures on migratory organisms such as juvenile salmon have been characterized as 1) behavioral barriers that can deflect or delay migration; 2) reduced prey resource production and availability (i.e. "carrying capacity"), and 3) altered predator-prey relationships associated with high intensity night lighting alterations to the nighttime ambient light regime. This paper identifies known visual thresholds associated with light limitation for salmonids and other juvenile fishes.

Empirical findings indicate that the cumulative impacts of overwater structures can have significant impacts on ambient wave energy patterns and substrate types. Given what is known concerning biota and substrate relationships and shoreline geomorphology (drift cell) processes determining those substrates, the basic unit of measurement for establishing change thresholds to identify overwater structure effects is likely related to drift cell characteristics and scale. At this time, drift cell thresholds are not established; however, we conclude that thresholds are needed to avoid and mitigate cumulative effects. Further studies are recommended to determine plant and animal behavioral thresholds and the nature and extent of direct and cumulative effects.

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Information Web Sites

Information Web Site	URL Location
UW Fisheries Research Institute	http://www.fish.washington.edu/Publications/frireps.html
NOAA Regional Library	http://www.wrclib.noaa.gov/lib/
WDFW - Homepage	http://www.wa.gov/wdfw/
WDFW - Forage Fish	http://www.wa.gov/wdfw/fish/forage/forage.htm
NOAA Northwest Fisheries Science Center	http://research.nwfsc.noaa.gov/pubs/nwfscpubs.html
National Marine Mammal Laboratory	http://www.nmfs.noaa.gov/prot_res/PR2/Stock_Assessment_Program/sars.html
Dept of Ecology-Publications Page	http://www.ecy.wa.gov/pubs.html
Dept. of Ecology Water Quality Data	http://www.ecy.wa.gov/programs/eap/mar_wat/mwm_intr.html
Dept. of Ecology-Environmental Assessment Bibliography	http://www.wa.gov/programs/eap/biblio/index.html
UW Urban Water Resource Management- Salmon Information Database	http:// http://depts.washington.edu/cuwrm
PSWQAT-Puget Sound Health 2000	http://www.wa.gov/puget_sound/Publications/pshealth2000/index.html
UW Library	http://catalog.lib.washington.edu/search~/
NMFS Status Reviews: chum coho chinook sockeye pink steelhead	http://www.nwfsc.noaa.gov/pubs/tm/tm32/index.html http://www.nwfsc.noaa.gov/pubs/tm/tm32/index.html http://www.nwfsc.noaa.gov/pubs/tm/tm35/index.htm http://www.nwfsc.noaa.gov/pubs/tm/tm33/tm33.html http://www.nwfsc.noaa.gov/pubs/tm/tm25/tm25.html http://www.nwfsc.noaa.gov/pubs/tm/tm27/tm27.htm
WSDOT-Research Reports Ferry Terminal Impacts on Juvenile. Salmon - Phase I & II	http://www.wsdot.wa.gov/ppsc/research/rpage.htm
NOAA Coastal Cutthroat	http://www.nwr.noaa.gov/1salmon/salmesa/cuttorc.htm
USFWS Endangered Species Page	http://endangered.fws.gov/
WDFW Habitat Guidelines	http://www.wa.gov/wdfw/hab/salguide/salguide.htm

Information Web Site	URL Location
Puget Sound Research '98	http://www.wa.gov/puget_sound/Publications/98_proceedings/index.html
Dept. of Ecology -Shorelands and Wetlands	http://www.ecy.wa.gov/programs/sea/shorelan.html
NOAA Protected Resources - Marine Fish	http://www.nwr.noaa.gov/1salmon/salmesa/marfish.htm
NOAA Fisheries Protected Species Status Reviews	http://www.nwr.noaa.gov/1salmon/salmesa/pubs.htm
Wa. Dept. of Health Shellfish PSP Hotline	http://www.doh.wa.gov/ehp/sf/biotox.htm

Overview of Aquatic Habitat Guidelines Project

As part of the process outlined in Washington's *Statewide Strategy to Recover Salmon: Extinction is Not an Option* the Washington Departments of Fish and Wildlife, Ecology, and Transportation were charged to develop Aquatic Habitat Guidelines employing an integrated approach to marine, freshwater, and riparian habitat protection and restoration. Guidelines will be issued, as funding allows, in a series of manuals addressing many aspects of aquatic and riparian habitat protection and restoration.

This document is one of a series of white papers developed to provide a scientific and technical basis for developing Aquatic Habitat Guidelines. The white papers address the current understanding of impacts of development and land management activities on aquatic habitat, and potential mitigation for these impacts. The following topics are addressed in the white paper series:

- Over-water structures - marine
- Over-water structures - freshwater
- Over-water structures - treated wood issues
- Water crossings
- Channel design
- Marine and estuarine shoreline modification issues
- Ecological issues in floodplain and riparian corridors
- Dredging - marine
- Dredging and gravel removal - freshwater

Individual white papers will not necessarily result in a corresponding guidance document. Instead, guidance documents, addressing management and technical assistance, may incorporate information from one or more of the white papers. Opportunities to participate in guidelines development through scoping, workshops, and reviewing draft guidance materials will be available to all interested parties.

Principal investigators were selected for specific white paper topics based on their acknowledged expertise. The scope of work for their projects requested a "comprehensive but not exhaustive" review of the peer-reviewed literature, symposia literature, and technical (gray) literature, with an emphasis on the peer-reviewed literature. Readers of this report can therefore expect a broad review of the literature, which is current through late 2000. The coverage will vary among papers depending on research conducted on the subject and reported in the scientific and technical literature. Analysis of project specific monitoring, mitigation studies, and similar efforts are beyond the scope of this program.

Each white paper includes some or all of these elements: overview of the Aquatic Habitat Guidelines program, overview of the subject white paper, assessment of the state of the knowledge, summary of existing guidance, recommendations for future guidelines, glossary of technical terms, and bibliography.

The overarching goal of the Aquatic Habitat Guidelines program is to protect and promote fully functioning fish and wildlife habitat through comprehensive and effective management of activities affecting Washington's aquatic and riparian ecosystems. These aquatic and riparian habitats include, but are not limited to rearing, spawning, refuge, feeding, and migration habitat elements for fish and wildlife.

Overview of Overwater Structures: Marine Issues Paper

This paper presents the results of an extensive literature review that included peer-reviewed journal articles, books, theses/dissertations, technical reports, unpublished manuscripts, and interviews with resource managers and leading experts on the effects overwater structures can pose to fish and shellfish habitats in the marine environment. Through the presentation of existing information, empirically supported evidence, and scientific uncertainties, this paper identifies existing data gaps in need of further exploration, and recommends methods to reduce habitat loss. Those species identified in this paper are representative of fish and shellfish species with life history strategies most closely associated with marine and estuarine nearshore habitats where dock structures and associated activities are most likely to occur.

Estuarine and shallow marine nearshore habitats provide passage for fish and shellfish, larvae, ocean water, and human transportation. These habitats are important sources of prey resource production, refugia, and spawning substrates for the region's Pacific salmon, groundfish, and forage fish. Overwater structures can pose alterations to key controlling factors, such as light, wave energy and substrate regimes, that determine the habitat characteristics that support these critical functions. The scientific literature has identified plant light requirement levels, light reduction levels under and near overwater structures, and methods to minimize light reduction impacts through the use of particular construction materials, such as glass blocks and grating that reduce light limitation effects, and structural design specifications, such as height, width, and sun orientation.

The literature also reflects that fish migrating along the shoreline have consistently shown behavioral responses upon encountering docks. These responses include pausing, school dispersal, and migration directional changes. The significance of these behavioral effects and methods to avoid such responses require further investigation.

The design and placement of docks and marinas requires an understanding of the specific substrate, wave energy, and light regimes supporting critical habitat in a given area in order to minimize deleterious effects on fish and shellfish, and loss and degradation of their habitats. In addition to impacts associated with the dock structures, activities associated with docks can also pose risks to the quality and quantity of habitat through prop scour, groundings, contaminant introduction to the marine environment, and structural interferences with shallow nearshore habitats with the placement of ramps and haul-outs in nearshore areas. This paper recommends: 1) structural designs and materials known to minimize light limitation effects; 2) operational practices to minimize effects; 3) further research to understand the significance of fish behavioral changes upon encountering piers; 4) further research to identify ecological effects such as reduced prey resources; 5) further research on light mitigating techniques such as the use of artificial under-pier daytime lighting, and 6) the development of cumulative assessment tools to better predict cumulative thresholds to improve design and location of overwater structures.

Assessment of the State of Knowledge

Methods

The databases used in this literature search included Aquatic Sciences and Fisheries Abstracts (ASFA), University of Washington Fisheries Research Institute (UW-FRI) reports, the National Technical Information Service (NTIS), UW Urban Water Resource Management and the Seattle Aquarium Salmon Information Center databases, and the University of Washington (UW) library system catalog. The ASFA database has limited on-line membership access but is available on compact disc in the University of Washington library system. The ASFA database includes literature dating back to 1982 covering science, technology, and management of marine and freshwater environments. It includes 5,000 international sources in the form of primary journals, source documents, books, monographic series, conference proceedings, and technical research reports. The UW-FRI reports, UW Water Resource Management, Seattle Aquarium Salmon Information Center, UW library, and NTIS electronic databases have unlimited internet access. Access to the UW library is at http://catalog.lib.washington.edu/search~/. Access to the UW School of Aquatic and Fisheries Sciences UW-FRI report and citations database is at http://www.fish.washington.edu/Publications/database.html. This database includes over 500 reports pertaining to research conducted by Fisheries Research Institute (FRI) personnel from 1973 to the present. The UW Urban Water Resource Management and Salmon Information Center databases are accessible at http://depts.washington.edu/cuwrm/. Information pertinent to life history strategies of specific species are also available on-line through the Washington Department of Fish and Wildlife (WDFW) at http://www.wa.gov/wdfw/fish-sh.htm, the NOAA Regional Library at http://www.wrclib.noaa.gov/lib/, and the Northwest Fishery Science Center (NWFSC) at http://research.nwfsc.noaa.gov/pubs/nwfscpubs.html.

Overview of Ecological and Habitat Issues

Definition of Estuarine and Nearshore Marine Habitats

Estuarine and nearshore marine plant and animal assemblages are primarily distributed along substrate types, elevation, salinity, and wave energy gradients influencing the functional outcome and distribution of species predominant to particular habitat types. In order to identify the factors controlling plant and animal distribution, this paper adopts the dominant assemblages and habitat characteristics identified in the Washington State Department of Natural Resources (WDNR) Washington Natural Heritage Program Marine and Estuarine Habitat Classification System (Dethier 1990) and incorporates the basic habitat functions and characteristics identified in the Estuarine Habitat Assessment Protocol (Simenstad et al. 1991a). Although other classification systems, such as the Cowardin/National Wetland Inventory System (NWI), are often used to classify habitats, this paper uses the above systems in order to incorporate the variations in dominant species across varying substratum and wave energy regimes specific to Puget Sound and the estuaries and coastal waters of Washington State. Region-wide use of the above classification systems provides a consistent statewide framework for existing data and future inventory work and enables reasonable predictability as to the presence of dominant plant and animal species in a given habitat (Dethier 1990; Simenstad et al. 1991a).

This paper limits the description of habitat impacts to those impacts associated with overwater structures occurring within ecosystems between the tidal levels of mean high water spring (MHWS) and -15 meters below mean lower low water (MLLW) (see Figure 1). Table 1 provides definitions of intertidal and subtidal ecosystems using both the NOAA tidal datum and the WDNR classification systems. See Appendix A for definitions of the terms used in the WDNR system and the plant and animal species associated with particular habitat subsystem classifications.

Table 1. Intertidal Definitions (adapted from Dethier (1990), NOAA (2000), Kosloff (1983)

Intertidal Ecosystems	Depth Classifications	NOAA Tidal Datum Classifications
Habitats affected only by higher tides, may not often be wet except from spray or rain	Supralittoral backshore	Above MHWS In the San Juan Archipelago, the lower limit is 2.1 m (7 ft) above MLLW (0). In Puget Sound, the lower limit is about 2.7 m (9 ft) above MLLW
Habitats regularly inundated and uncovered by the tides	Eulittoral	Between MHWS and MLLW
Habitats rarely, if ever, completely uncovered by low tide	Shallow subtidal	15 meters or less below MLLW

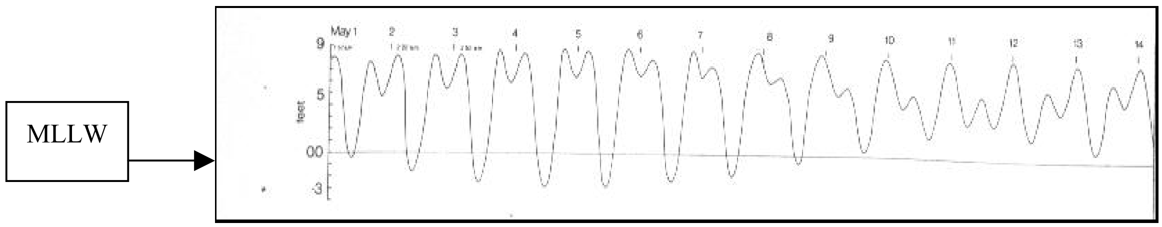


Figure 1. Illustration of Mean Low Low Water (MLLW) tide levels (Kozloff 1983)

Fish and Shellfish Nearshore Habitat Use

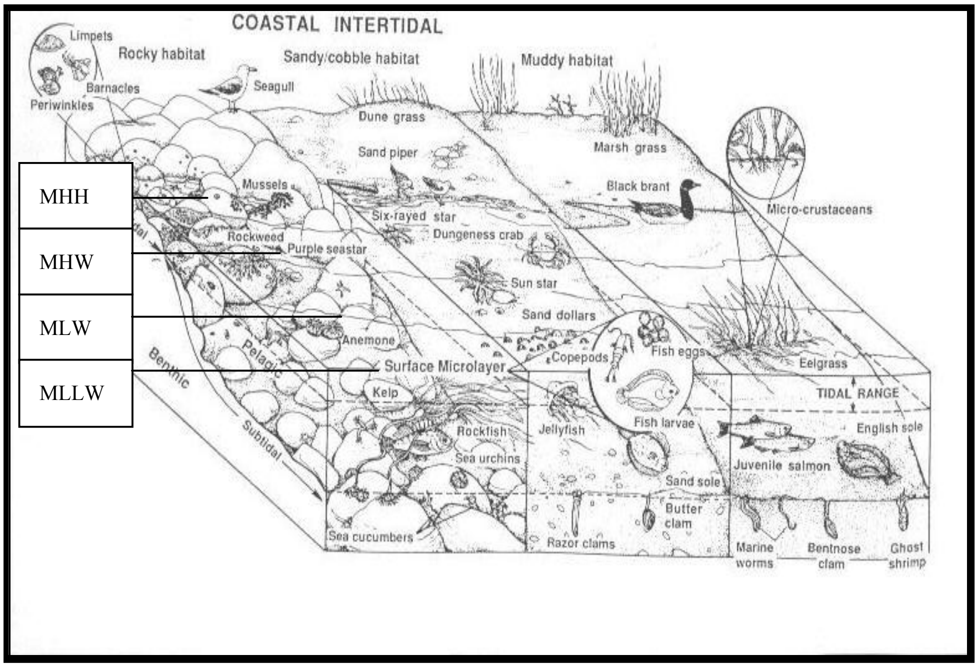
Prey resource production, refugia, and reproduction are key ecological functions important to the recruitment and survival of the region's fish and shellfish species provided by nearshore habitats (Cordell 1986; Fernandez et al. 1993; Haldorson and Richards 1987; Matthews 1989; McMillan et al. 1995; Miller and Borton 1980; Palsson 2000; Penttila 2000a; Simenstad et al. 1979, 1980, 1982; Wissmar and Simenstad 1988).

Knowledge of spatial and temporal patterns of habitat use, food web relationships, and predator-prey relationships provide an ecological framework to predict the ecological effects of habitat alteration upon members of associated fish and shellfish assemblages. The fluctuating physical environment of the intertidal zone in conjunction with the biological needs of individual species serves to constrain fish and shellfish use of shallow nearshore habitats both spatially and temporally. Fish and shellfish residency patterns in these habitats reflect the physical dynamics shaping those habitats (Dethier 1990; Simenstad et al. 1979, 1991a; Williams 1994).

This paper describes fish assemblages by their nearshore habitat residency patterns. For this purpose, the functional use of nearshore habitats by nearshore fish assemblages are categorized as **resident, seasonal resident, migratory, or transient species** (Table 2). Estuarine and nearshore marine habitat functions are categorized by the general functions of juvenile rearing, spawning, or adult residency. Figure 2 depicts the distribution of nearshore habitats along tidal elevations and some of the assemblages of plants and animals that are typically found in those habitats in the Pacific Northwest (Krukeberg 1991).

Table 2. Fish Nearshore Habitat Use

	Rocky-Kelp	Rocky-Cobble	Shallow Exposed Gravel-Cobble	Sand-Gravel	Mud/Sand - Eelgrass
MHHW +4 meters	**Rearing:** resident & transient fishes	**Rearing:** resident fishes	**Rearing:** resident fishes	**Spawning:** transient **Rearing:** transient fishes	**Rearing:** resident, transient & migratory fishes
MHW +2 meters	**Rearing:** resident & transient fishes	**Rearing:** resident, juvenile migratory & transient fishes	**Rearing:** resident, juvenile migratory & transient fishes	**Spawning:** transient fishes	**Rearing:** resident, transient & migratory fishes
MLW +1 meter	**Rearing:** resident & transient fishes	**Rearing:** resident, juvenile, migratory, & transient fishes	**Rearing:** resident, juvenile migratory transient fishes	**Spawning:** transient fishes	**Rearing:** resident, transient & migratory fishes
MLLW 0.0 and below	**Spawning:** transient fishes **Rearing:** resident & transient fishes	**Rearing:** migratory & transient fishes	**Rearing:** resident & transient fishes	**Spawning:** transient fishes	**Spawning:** transient fishes **Rearing:** resident, migratory & transient



(Artist Sandra Noel, adapted form Krukeberg 1990)

Figure 2. Nearshore Habitats and Tidal Elevations

Characterizing Nearshore Habitats

Fish density variations correlate both to seasonal variations in vegetative cover and wave exposure (e.g. wave and current energy) in combination with the varying life-history needs of particular species that determine the spatial and temporal extent of their habitat use. Fish species dependent upon these nearshore habitats have developed complex life history strategies utilizing seasonally available refugia and resources (J.A. Shaffer 1995; Carr 1989; Love et al. 1991).

In early spring, increased sunlight and vegetation correlate with increased abundances of larval and juvenile fish taking advantage of the abundant nearshore prey resources and refugia associated with vegetation. Each habitat possesses distinctive fish species adapted to the physical characteristics and the associated flora and fauna of that habitat. Fish densities in particular habitats are seasonally dependent. For example, high densities are found in rock/kelp habitat in spring and declining fish densities are found in fall and winter (Miller et al. 1976). Seasonal fluctuations in wave and low tide exposure can result in some habitats, such as shallow cobble habitats, being more physically stressed than other, more protected habitats (Miller et al. 1976). Similarly, Miller et al (1976) found rockfish and Pacific tomcod to migrate out of such habitats in fall and early winter with populations of kelp greenling, sculpins, perches, and tubesnouts becoming more prominent in the winter. Table 2 classifies fish habitats as rocky-kelp, rocky-cobble, shallow exposed gravel-cobble, sand-eelgrass (*Zostera marina*), and mud-eelgrass habitats. These classifications are consistent with the nearshore food web and fish community studies of Miller et al. (1976) and Simenstad et al. (1979) that documented fish habitat associations based upon scientific inventorying and analysis. The following habitat descriptions are a very general and simplified characterization of nearshore habitat types because these habitat characteristics are found to vary significantly depending upon specific geomorphologic and wave energy characteristics along with seasonal variations in prey resources specific to a given region (Miller et al. 1976; Simenstad et al. 1979; Cross 1981).

Rocky-kelp habitats are predominantly subtidal habitats. These habitats are characterized by well-flushed steep gradients. Although these habitats are generally not as capable of supporting the large numbers of infaunal species found in soft-sediment environments, epibenthic and epiphytal shrimps, crabs, mysids, gammarid amphipods, isopods, and copepods are able to occupy the kelp holdfast and macroalgae understory microhabitats. The food web organized around this environment supports bottomfish that feed on these organisms. These bottom and small demersal fishes, in turn, support harbor seals, larger demersal fish, sea lions, and orcas (Simenstad et al.1979).

Rocky-cobble habitats include exposed intertidal rocky and cobble habitats, seaweed, and the extensive beneath-rock habitat provided by intertidal cobble beaches. In the intertidal rocky kelp habitat, detritus production is sustained by the senescence of annual macroalgae and herbivores such as chitons, limpets, sea urchins, and snails that graze and release macroalgae from the substrate (Simenstad et al. 979). Seasonal fluctuations are prominent in this habitat, particularly those associated with the annual die-off macroalgae and the massive recruitment of barnacles and mussels.

Shallow exposed gavel-cobble habitats are characterized by gravel-cobble beaches exposed to wave action. This environment largely restricts the presence of macroalgae or eelgrass and results in a less diverse food web structure. Detritus is transported and accumulated in unconsolidated sediments which serve to bind the detritus and enable its utilization by detritus grazing epibenthic crustaceans, such as gammarid amphipods, cumaceans, harpacticoid copepods, mysids, and isopods supporting fishes, birds and marine mammals (Simenstad et al.1979).

Sand-eelgrass habitats are protected habitats typically characterized by shallow, semi-enclosed embayments with low to moderate energy beaches. These environments allow for the accumulation and stabilization of sand, mixed fine gravels, and the colonization of eelgrass. The stable substrates of the protected environment provide rich benthic infaunal and epibenthic communities and provide prey resources for juvenile fishes seeking protection in the eelgrass beds. The eelgrass shoots serve to increase the substrate available for epiphytic algae and associated fauna. They also reduce wave and current action, trap sediments and detritus, and maintain high dissolved oxygen concentrations through photosynthetic activity. Through shading at low tides, the eelgrass also minimizes temperature fluctuations that would otherwise occur with direct sunlight. The detritus resulting from eelgrass dieback provides detrital carbon energy directly to important detritivores such as harpacticoid copepods, gammarid amphipods, and isopods and indirectly to those carnivores preying on benthic organisms (Simenstad et al. 1979).

Mud-eelgrass habitats are characterized by fine mud and sandy-mud substrates in a protected area. They are most expansive in estuarine mudflat habitats. Epibenthic crustaceans have been found to be much denser in these habitats than in the sand eelgrass habitat by as much as five times. This could be due to the ability of fine substrates to entrain organic matter input from vascular salt marsh plants that are transported into the estuary by way of spring runoff and spring tides (Simenstad et al. 1979).

Marine riparian habitats in the upland areas above MHHW along the shoreline likely provide some of the same functions that freshwater riparian areas provide (Desbonnet et al. 1994) as well as additional functions unique to nearshore systems (Brennan and Culverwell, In Prep; Cedarholm 2000; Gonor et al. 1988). In addition to bank stability, riparian functions contributing to nearshore ecosystems include water quality protection; microclimate regulation of temperature, precipitation, and moisture retention; shade to control temperature on beach spawning substrates (Penttila 2000a); nutrient and prey input from overhanging vegetation, and the addition of large woody debris (LWD that provides roosting, nesting, foraging, spawning and attachment substrate for invertebrates and plants. LWD can also serve to stabilize beaches and help build berms and backshore areas (Brennan and Culverwell, In Prep).

Resident and Seasonal Resident Fishes

The **resident fishes** remain in nearshore habitats throughout their various life-history stages with some species, such as the saddleback gunnel and sculpins, remaining in the intertidal area throughout even the daily tidal cycles. In contrast, the **seasonal residents**, such as Pacific herring, Pacific cod, walleye pollock, lingcod, and English sole reside in nearshore habitats only seasonally and often associated with specific life history stages (e.g. as juveniles or for spawning). For all of these intertidal residents, available refuge often determines their low tide distribution and their feeding, recruitment, and colonization functions (Williams, 1994; Gibson 1982; Mayr and Berger 1992).

Table 3 associates fishes always residing in the eulittoral and shallow subtidal zones with the general habitats they use and Table 4 identifies their vertical distribution. This is a representative list of such fishes and is not an exhaustive list of intertidal fishes in Washington State marine waters. An exhaustive list would include over 200 species. Tables 5 and 6 list a representation of priority fishes characterized as **seasonal residents** of these nearshore zones. Table 7 lists those fish classified as **migratory fishes** utilizing the nearshore zone, which are the salmonids characteristic of this region, and Tables 8 and 9 lists examples of priority species classified as **transient fishes** for the purposes of this paper. These tables also include a general description of life-history stages and annual timing of their use of these nearshore habitats.

Table 3. Resident Fishes - Habitat Use

Intertidal Resident Fish			Nearshore Habitat Use				
Family	Scientific Name	Common Name	Rocky Kelp	Rocky and Cobble	Shallow Exposed Gravel-Cobble	Sand Eelgrass	Mud Eelgrass
Gobiesocidae	*Gobiesox maeandricus*	northern clingfish		X			
Stichaeidae	*Anoplarchus purpurescens*	high cockscomb		X			
	Xiphister atropupureus	black prickleback		X			
	Phytichthys chirus	ribbon prickleback		X			
	Xiphister mucosus	rock prickleback		X			
	Lumpenus sagitta	snake prickleback			X	X	X
Pholidae	*Apodichthys flavidus*	penpoint gunnel	X	X		X	X
	Pholis laeta	crescent gunnel	X	X		X	X
Hexagrammidae	*Hexagrammos decagrammus*	kelp greenling	X				
Syngnathidae	*Syngnathus leptorhynchus*	bay pipefish				X	X
Cottidae	*Jordania zonope*	longfin sculpin	X				
	Artedius fenestralis	padded sculpin			X		X
	Ascelichthys rhodorus	rosylip sculpin		X			
	Artedius lateralis	smoothhead sculpin		X			
	Clinocottus acuticeps	sharpnose sculpin		X			X
	Blepsias cirrhosus	silverspotted sculpin			X	X	X
	Enophrys bison	buffalo sculpin			X	X	X
	Leptocottus armatus	Pac. staghorn sculpin			X		
	Clinocottus embryum	calico sculpin		X		X	X
	Clinocottus globiceps	mosshead sculpin		X			
	Oligocottus maculosusu	tidepool sculpin		X	X		
	Artedius harringtoni	scalyhead sculpin	X				
	Oligocottus snyderi	fluffy sculpin		X			
Embiotocidea	*Cymatogaster aggregata*	shiner perch			X	X	X
	Rhacochilus vacca	pile perch				X	
Cyclopteridae	*Liparis florae*	tidepool snailfish			X		
Gasterosteidae	*Aurlorhynchus flavidus*	tube-snout		X		X	
Bothidae	*Citharichthys stigmaeus*	speckled sanddab				X	

Adapted from and Cross 1982 and Simenstad et al. 1979

Table 4. Resident Fishes - Water Column Use

Intertidal Resident Fish			Nearshore Habitat Use			
Family	Scientific name	Common name	Spawning Habitat	Eggs	Larvae	Adult Habitat
Gobiesocidae	*Gobiesox maeandricus*	northern clingfish	demersal	demersal	pelagic	demersal-rock
Stichaeidae	*Anoplarchus purpurescens*	high cockscomb	demersal	demersal	pelagic	demersal
	Xiphister atropupureus	black prickleback	demersal: rock	demersal	pelagic	demersal intertidal
	Phytichthys chirus	ribbon prickleback	unk	unk	unk	demersal
	Xiphister mucosus	rock prickleback	demersal	demersal	pelagic	demersal
	Lumpenus sagitta	snake prickleback	unk	unk	unk	demersal
Pholidae	*Apodichthys flavidus*	penpoint gunnel	demersal	demersal	pelagic	demersal
	Pholis laeta	crescent gunnel	demersal	demersal	pelagic	demersal
Hexagrammidae	*Hexagrammos decagrammus*	kelp greenling	demersal: rocky	demersal	pelagic	demersal
Syngnathidae	*Syngnathus leptorhynchus*	bay pipefish	unk	unk	unk	inshore protected areas
Cottidae	*Jordania zonope*	longfin sculpin	unk	demersal	unk	demersal
	Artedius fenestralis	padded sculpin	demersal: rocks	demersal	pelagic	demersal
	Ascelichthys rhodorus	rosylip sculpin	unk	unk	unk	demersal
	Artedius lateralis	smoothhead sculpin	demersal	demersal	pelagic	demersal
	Clinocottus acuticeps	sharpnose sculpin	demersal	demersal	pelagic	demersal
	Blepsias cirrhosus	silverspotted sculpin	demersal	demersal	pelagic	demersal
	Enophrys bison	buffalo sculpin				
	Leptocottus armatus	Pac. Staghorn sculpin	unk	demersal	pelagic	demersal
	Clinocottus embryum	calico sculpin	unk	unk	unk	demersal
	Clinocottus globiceps	mosshead sculpin	unk	unk	unk	demersal
	Oligocottus maculosusu	tidepool sculpin	demersal	demersal	pelagic	demersal
	Artedius harringtoni	scalyhead sculpin	unk	unk	pelagic	demersal
	Oligocottus snyderi	fluffy sculpin	unk	unk	unk	demersal
Embiotocidea	*Cymatogaster aggregata*	shiner perch	pelagic nearshore			pelagic nearshore
	Rhacochilus vacca	pile perch	pelagic nearshore			pelagic nearshore
Cyclopteridae	*Liparis florae*	tidepool snailfish	unk	unk	unk	demersal
Gasterosteidae	*Aurlorhynchus flavidus*	tube-snout	demersal	demersal	pelagic	pelagic
Bothidae	*Citharichthys stigmaeus*	speckled sanddab	unk	unk	pelagic	demersal

Adapted from Garrison & Miller 1982

Table 5. Seasonal Resident Fishes – Habitat Use

Seasonal Resident Fish			Nearshore Habitat Use				
Family	Scientific Name	Common Name	Spawn	Juvenile Rearing	Adult Res.	Habitat Type	Timing
Clupeidae	*Clupea harenus pallasi*	Pacific herring	X	X	X	1) protected sand-gravel eelgrass shallow subtidal 2) mud eelgrass 3) subtidal 4)rocky/cobble/kelp	Juvenile: year-round Adult: spring-summer
Gadidae	*Gadus macrocephalus*	Pacific cod		X		1) enclosed 2) sand-eelgrass 3) cobble 4) gravel	summer-fall
	Theragra Chalcogramma	Walleye pollock		X		1) shallow exposed gravel-cobble 2) mud eelgrass 3) sand eelgrass	Juvenile: spring-winter
Hexagrammidae	*Ophiodon elongatus*	lingcod		X		Juvenile 1) gravel 2) mud eelgrass Adult subtidal rocky/kelp	Juvenile: summer Adult: year round
Pleuronectidae	*Pleuronectes vetulus*	English sole		X	X	1) shallow exposed gravel-cobble 2) mud eelgrass 3)sand eelgrass	year round - Juvenile recruitment Jan-Feb and April-May on coast and Dec- March and May to July in Puget Sound

X indicates extensive use
Adapted form Garrison & Miller 1982; Miller et al. 1976; Shi 1987; Simenstad et al. 1979

Table 6. Seasonal Resident Fishes - Water Column Use

Seasonal Resident Fish			Water Column Distribution			
Family	Scientific Name	Common Name	Spawning Habitat	Eggs	Larvae	Adult Habitat
Clupeidae	*Clupea harenus pallasi*	Pacific herring	demersal	pelagic	pelagic	Demersal
Gadidae	*Gadus macrocephalus*	Pacific cod	semi-demersal	demersal	pelagic	semi-demersal
	Theragra Chalcogramma	Walleye pollock	pelagic	pelagic	pelagic	demersal or pelagic
Hexagrammidae	*Ophiodon elongatus*	lingcod	demersal on rocks and rocky crevices	demersal	pelagic	demersal: rock & algae
Pleuronectidae	*Pleuronectes vetulus*	English sole	demersal	pelagic	pelagic	demersal: moderate depths

Adapted from Garrison and Miller 1982; Matthews 1987

Pacific Herring (*Clupea harenus pallasi*)

Pacific herring *(Clupea harenus pallasi)*, the predominant species in Northern Puget Sound's neritic fish assemblages (Fresh 1979), typically utilize shallow subtidal habitats for spawning and juvenile rearing. Although there is variation region-wide in spawning times specific to particular beaches, Pacific herring generally spawn in early spring from January through early April. Typically females deposit eggs on nearshore vegetation, such as kelp and eelgrass, between the mean higher high tide line (MHHW) and out to depths of -40 feet below (MLLW) (Penttila 2000). However, there are variations in spawning behavior. Some populations spawn on vegetation found in upper intertidal regions along the outer edges of salt marshes, on exotic cordgrass (*Spartina* spp.) and native macroalgae, (*Fucus* sp. and *Ulva* sp.), fucus and ulva. These spawnings in the upper intertidal upon *Fucus* and *Spartina*, typically at +1m above MLLW, demonstrate a larger spatial range for herring spawning habitat than previous descriptions. Previously it was commonly thought that herring typically spawn subtidally. Herring have also been found to spawn above MHHW on such substrates as pickleweed (*Salicornia* sp.) and pilings; however, these latter represent an anomaly that does not likely show signs of viable hatchlings (Penttila 2001). The viability of these spawns is compromised by atmospheric exposure during low tide. Some stocks are thought to migrate annually from inshore spawning grounds, such as Puget Sound, to open ocean feedings areas. Studies in Northern Puget Sound (Simenstad et al. 1979) have found juvenile Pacific herring to be feeding principally on epibenthic organisms, with harpacticoid copepods comprising 82% of their diet. Pacific herring are an important prey item for many marine organisms. Pacific herring have been found to comprise the following diet percentages of specific fish species: Pacific cod (42%), walleye pollock (32%), lingcod (71%), Pacific halibut (53%), coho and chinook salmon (58%) (Environment Canada 1994).

Pacific Cod (*Gadus macrocephalus*)

Pacific cod *(Gadus macrocephalus)* are found throughout Washington's inside marine waters. Juvenile cod (Miller and Borton 1980) settle to shallow vegetated habitats, such as sand-eelgrass, in late summer where they find shelter and rich abundances of prey resources in the form of copepods, amphipods, and mysids (Matthews 1987). Adult Pacific cod live near the bottom over soft sediments. They feed on Pacific sand lance, Pacific herring, walleye pollock, sculpins, flatfishes, and invertebrates, such as euphausids, crabs, and shrimp (Albers and Anderson 1985; Jewett 1978; Blackburn 1986; and Westrheim and Harling 1983). They spawn in the winter and following spawning, migrate to feed in deeper, cooler waters. In Puget Sound, Pacific cod have been found to concentrate in shallow embayments such as Port Townsend Bay and Agate Passage but disperse to deeper waters during the remainder of the year (Walters 1984; Bargmann 1980). For example, Walters (1984) found that following winter hatching, Pacific cod in Port Townsend Bay showed a tendency to remain in the shallow areas until June. Westrheim (1982) distinguished four Pacific cod stocks in the inland marine waters of British Columbia that included three resident stocks and one highly migratory stock with migration and straying occurring between British Columbia and Washington waters. Stomach content analyses have demonstrated that Pacific herring are the main prey items of Pacific cod (Palsson 1990). Water temperature and the presence or absence of Pacific herring have been found to affect Pacific cod recruitment and abundance in British Columbia (Palsson 1990). Walters et al. (1986) found that when Pacific herring abundances are low, cod are likely to move to other feeding grounds or suffer from reduced egg production due to the lack of prey resources.

Pacific Hake (*Merluccius productus*) and Walleye Pollock (*Theragra chalcogramma*)

Pacific hake *(Merluccius productus)* and walleye pollock (*Theragra chalcogramma)* are midwater, cold-water schooling fishes that undergo northward feeding migrations in the summer and return to southerly waters for winter spawning (West 1997). As juveniles, they migrate to inshore, shallow habitats for their first year and move back to deeper waters in their second year. Walleye pollock juveniles are semi-demersal and are very adaptable to a variety of substrate types (Matthews 1987). As adults, both Pacific hake and walleye pollock are midwater schooling codfishes with the Pacific hake population migrating from California and Baja in the summer to feed in Washington and British Columbia (West 1997). Simenstad (1979) and Walters (1984) found juvenile walleye pollock to eat mysids, calanoid and harpacticoid copepods, gammarid amphipods, and juvenile shrimp. A small, genetically distinct, resident population in northern Puget Sound migrates seasonally between Port Susan and Saratoga Passage that has experienced a severe decline in recent years (West 1997).

Lingcod (*Ophiodon elongatus*)

Lingcod *(Ophiodon elongatus)* typically have a relatively small home range. They spawn between December and March, laying eggs in rocky crevices in shallow areas with strong water motion. Eggs are then fertilized and vigorously defended by the males. After dispersing from their nests, larvae spend two months in pelagic habitats as surface-oriented larvae. In late spring to early summer, juveniles move to benthic habitats settling in shallow vegetated habitats (Buckley et al. 1984; Cass et al. 1990; West 1997). It is likely that juveniles use nearshore habitats for both refuge and feeding. In their first fall season, juveniles move to flat shoals and other uncomplex, bottoms where they will spend a year or two growing to a size large enough to avoid predation by other reef-dwelling species (i.e. rockfish, cabezon, larger lingcod). They will then move to their adult rocky reef habitat.

English Sole (*Pleuronectes vetulus*)

English sole *(Pleuronectes vetulus),* a common offshore species and the most abundant flatfish in Puget Sound, utilizes a variety of nearshore habitats as juveniles. Miller et al (1976) found juveniles in gravel, sand-eelgrass, and mud-eelgrass habitats. Larvae were found in nearshore habitats between March and May and juveniles were found throughout the year in eelgrass habitats feeding on annelids. English sole spawn offshore along the coast between September and April (Kruse and Tyler 1983). Gunderson and Miller report that English sole in Puget Sound from January to April. Shi (1987) reports two recruitment peaks for juveniles with one occurring in January-February and another in April-May. Two influxes of juveniles have also been observed in Puget Sound, one in winter (December - March) and one in summer (May - July). Following a pelagic early larval stage, they move into the benthos of coastal and estuarine areas where they assume a demersal existence for the remainder of their lives (Tasto 1983; Stevens and Armstrong 1984; Krygier and Pearcy 1986; Boehlert and Mundy 1988). English sole larvae of 15mm total length (TL) settle to the substrate and at times burrow into it. Gunderson et al. (1990) found that as the fish reached 55mm in length, the majority was found in estuarine waters with migration from the estuaries beginning at 75-80 mm TL. Shi (1987) found that as fish reached 100 mm TL they migrated out of estuaries and into open coastal areas. Similarly, Gunderson et al. (1990) found fish greater than 125 mm TL to have migrated from the estuaries with the migration in and out of estuaries to be length-dependent. The estuaries provide juveniles with prey resources and refuge. The disproportionately high settlement in estuaries and larval distribution patterns suggest an active migration or directed transport to estuarine areas for settlement (Reilly 1983; Boehlert and Mundy 1988; Jamieson et al. 1989). This finding is consistent with a wide variety of studies of fishes and crustaceans that have demonstrated the importance of specific larval behavior patterns and interactions with physical processes that assure recruitment to estuaries (Gunderson et al. 1990; Rothlisberg 1982; Rothlisberg et al. 1983; Epifano et al. 1984; Johnson, D.R. et al. 1984; Sulkin and Epifano et al 1986; Boehlert and Mundy 1988; Epifanio 1988; Shenker 1988). Gunderson et al (1990) states that clearly prey availability is of major significance in evaluating the advantages of an estuarine existence. In studies off the Oregon Coast, English sole 17-35 mm TL fed primarily on polychaete palps, juvenile bivalves, and harpactiocid copepods. Juveniles 35-82 mm TL fed on the larger amphipods and cumaceans (Hogue and Carey 1982). Toole (1980) found English sole, less than 50 mm TL, to feed almost exclusively on harpacticoid copepods and the diets of 66-102 mm TL sole to be dominated by polychaetes. Similarly, Buechner et al (1981) found the diets of English sole in Grays Harbor to be dominated by harpacticoid copepods and gammarid amphipods from April and August and polychaetes predominating in October.

Migratory Fishes

These species utilize nearshore habitats as they continue along their migratory corridor to their adult habitats. Their adult habitats are primarily not in nearshore areas. Juvenile salmonids are examples of migratory fish that utilize nearshore habitats along their migratory corridor. Table 7 lists salmonid use of nearshore habitat in Washington's inland waters. Many of these species utilize estuarine and marine nearshore habitat along their migratory corridor to the open-ocean or deeper pelagic waters. Juveniles of these species are characteristic of shallow gravel-cobble, mudflats, and vegetated estuarine and marine nearshore habitats. The classifications used as Preferred Habitat Types describe habitat types in terms of wave energy defined by the WDNR classification system (Appendix A).

Pacific Salmon *(Oncorhynchus* spp.)

Pacific Salmon *(Oncorhynchus* spp.) depend upon a wide range of habitats throughout their life cycle (Groot and Margolis 1991). Upon emergence from the gravel redds of their natal streams, various species and life-history types of salmon exhibit wide variation in the extent of their use of various freshwater and saltwater habitats. Some species rear in their natal stream for a year or longer, others migrate immediately to the estuary, and some migrate to lakes. Some remain in freshwater throughout their entire lifespan while others engage in long outmigrations to the open

Table 7. Migratory Fishes - Habitat Use

Migratory Fish			Nearshore Habitat Use			
Family	Scientific Name	Common Name	Adult	Juvenile Rearing & Size	Preferred Habitat Types	Timing
Salmonidae	*Oncorhynchus keta*	chum		X 30-50mm	1) enclosed 2) channel/slough	Feb-June
	Oncorhynchus gorbuscha	pink		X 33-40mm	1) enclosed 2) channel/slough	Feb-June (even yrs.)
	Oncorhynchus tshawytscha	chinook		X 30-120mm	1) enclosed 2) channel/slough	Feb-mid-Sept
	Oncorhynchus kisutch	coho			1) open	March-August
	Oncorhynchus nerka	sockeye			1) open	early June
	Oncorhynchus clarki clarki	coastal cutthroat	X		1) open	year round (as smolts, sub-adults, and adults)
	Oncorhynchus mykiss	steelhead			1) open 2) deep	March-June with outmigration March-May
	Salvelinus confluentus	bull trout	X	X 150mm+	1) shallow nearshore	year round (as smolts, sub-adults, and adults). Dec-Feb freshwater overwintering.

X indicates extensive use

sea. Others limit their outmigration to only the estuarine waters of Puget Sound. Some chum, pinks, and ocean-type chinook salmon outmigrate very soon following emergence from their natal stream gravels at sizes as small as 25 and 35+ mm fork length (FL).

The stresses young fry encounter upon entering estuarine waters are immense. The entry of fry into saltwater triggers a series of hormonal and rapid physiologic changes that transform them into smolts and adapt them to saltwater. Due to their dependence upon vegetated habitats, limitations to the extent of vegetated habitats pose a potential risk of reducing their ability to meet critical growth needs and counter predation risks.

Species that outmigrate at such small sizes have a strong reliance upon shallow-water habitats, especially those vegetated with algae and eelgrass, for important prey resources and shelter from predation. Shallow nearshore habitats provide important shelter from the size-selective predation by larger fish, which are most often found in deeper waters. In this way, shallow nearshore habitats are critical to the survival of such species (Healey 1982a; Naiman and Seibert 1979; Simenstad 1979,1980, 1982; Johnson et al. 1997). For salmonids, mark and recapture studies in Hood Canal have identified this period of estuarine residence as one of critical growth and high mortality risk with estimated daily mortalities to be in the range of 31-46% (Bax 1983; Whitmus 1979, 1985). This reliance on nearshore estuarine habitats may also make them particularly susceptible to productivity changes in those habitats when their growth determines their vulnerability to predation.

Studying migrating juvenile chum in Hood Canal, Simenstad (1979,1980) found chum to selectively prey on harpacticoid copepods found in very high densities in eelgrass beds. The study findings suggested links between the availability of harpacticoid crops, migration speed, and fish sizes. Smaller densities of harpacticoids appeared to link to faster migration speeds and smaller fish sizes. It was found that harpacticoid crops in eelgrass meadows at times averaged eight times the magnitude found in other nearshore habitats (Simenstad et al. 1979,1980). The affinity of the harpacticoid for eelgrass lies in the rich prey resources provided by epiphytic communities on and around the eelgrass shoots and rhizomes. The harpacticoid feeds on the diatoms, detrital, and microbial communities that make up the brown epiphytic felt accumulating on its shoots (Cordell 1999). Substrate type, depth, and wave energy are also important determining factors in prey abundance.

Chum (*Oncorhynchus keta*)

Timing of Salt Water Entry

Chum fry emerge from their natal gravels in early spring and outmigrate immediately to salt water throughout spring and early summer. Chum populations outmigrate as summer run, fall and winter runs. Of these runs, the summer-run chum fry outmigrate the earliest. Depending upon local temperature conditions, summer chum have been found to outmigrate as early as February and at sizes as small as 35 mm FL (Johnson 2001). With some variation between individual fish that are spawned at varying times throughout a run's spawning period, chum outmigration from their natal streams is an immediate outmigration to salt water (Simenstad

2001). In the case of summer chum, as the adults typically spawn relatively low in both large and small river systems, the fry outmigration to salt water is often a brief journey. This pattern of early outmigration places the summer chum in estuaries prior to many other salmonids (Johnson 2001). Their outmigration from freshwater is only a few days, and their subsequent stay in the estuary is estimated to be from one to a few weeks (Simenstad 2001).

Adult chum spawners also utilize nearshore areas as "staging" areas as they prepare for their migration to freshwater. This "staging" occurs in the proximity of the mouth of their natal stream. Quilcene Bay data suggests that summer chum mill about the mouth of the natal stream for 10-12 days before entering freshwater. This is thought to relate to maturation timing and acclimation to freshwater, but may also be affected by stream flows (WDFW/Point No Point Treaty Tribes 2000). Adult summer chum are known to return between August and October (Johnson 2001, Simenstad 2001). Later fall and winter runs are known to return through January (Simenstad 2001).

Estuarine Habitat and Prey Characteristics

Upon their arrival in tidal waters, chum fry inhabit shallow estuarine habitats, such as delta marshes, and flats, particularly those with dense eelgrass habitats, before starting to migrate along more narrow marine shorelines (Schreiner 1977, Bax 1982, Bax 1983, Whitmus 1985; Groot and Margolis 1991; Levy and Northcote 1981). During this period, when they are fry <50 mm FL, juvenile chum restrict their movement to shallow waters ~0.5-1 m deep and often occur in dense schools during the day. At night, the schools are less cohesive and the fish appear to move offshore (Prinslow et al. 1988; Schreiner 1977). Their vertical distribution has been found to be concentrated in the top few meters of the water column (Bax 1983b). Egan (2000) found that chum fry in Puget Sound tend to reside in the top 2-3cm of surface waters during their first few weeks. They tend to form loose aggregations during daylight hours and show a strong affinity for shorelines and low salinity waters (Schreiner 1977, Bax 1983, Whitmus, 1985).

The fry appear to prefer quiescent shoreline waters. In studies of juvenile chum in Puget Sound marinas, Heiser and Finn (1970) found smaller chum fry (35-45 mm FL) to be reluctant to leave shorelines, while larger fry (50-70 mm FL) being observed to move offshore into deeper water upon encountering piers and bulkheads. During daylight hours, Kaczynski et al (1973) found chum fry in water less than one meter deep and within 3 m of Puget Sound beaches. During nighttime, Schreiner (1977) and Bax (1982) found Hood Canal chum to move away from the shoreline. Tyler (1963) found young chum in the Snohomish estuary to be within one meter from the surface and newly emergent fry a few centimeters from the surface. Healey (1980) determined that fry have an affinity to congregate close to shorelines in depths of only a few centimeters during their early residence in estuarine waters. This is followed by a subsequent move to offshore waters as they reach sizes of 45-55mm (Healey 1982). Weitkamp (2000) reported juveniles to be primarily found in protected shoreline areas near the surface in waters less than one meter deep. Taylor and Willey (1997) observed chum 50-80 mm FL in size within 2 to 15 feet from dock structures and vertically located between the surface and depths of 3 m (10 feet). Consistently, juveniles appear to prefer shallow, low velocity waters. Schools of chum fry and other salmonids are found in marinas throughout the region (Taylor and Willey 1997;

Heiser and Finn 1970; Weitkamp 1980, 1981, 1982; Weitkamp and Shadt 1982; Penttila and Aguero1978). In a study of juvenile salmon behavior associated with the Naval Fuel Pier at Manchester in Puget Sound, Dames and Moore (1994) found most chum migrating through the nearshore to be 60-80mm FL, while those migrating further offshore measured 90mm FL.

Tynan (1997) reports that as summer chum reach a threshold size of 50 mm FL, they begin a seaward migration at a rate of 7-14 kmd^{-1}. Rapid seaward movement possibly reflects a response to low food availability, predator avoidance, or a strong, prevailing south/southwest weather system accelerating surface flows (Bax et al. 1978,Simenstad et al. 1980, Bax 1982, Bax 1983). At a rate of 7 kmd^{-1}, southernmost outmigrating fry in Hood Canal would leave the Canal in 14 days (WDFW/Point No Point Treaty Tribes 2000). The food web of chum fry <50mm FL occupying shallow water habitats is based principally upon detritus (i.e. dead plant material). Detritus provides the organic matter base for bacteria and other microbes that support epibenthic prey resources, such as the harpacticoid copepod. Certain taxa of harpacticoids appear to be commonly preferred of chum fry in estuarine environments (Kaczynski et al. 1973; Simenstad et al. 1980; Simenstad and Salo 1982; Simenstad et al. 1982). Naiman and Sibert (1979) estimated that more than 5 million fry require 3,850 kg of prey during their estuarine residence.

Pink (*Oncorhynchus gorbuscha*)

Timing of Salt Water Entry

Pink fry, among the earliest of outmigrators, arrive in estuarine habitats at very small sizes 25-30 mm FL in early spring. Similar to chum, they migrate immediately from spawning gravels very near to the estuary. Pinks have two-year life cycles with spawning occurring every other year. Depending upon the region, they will spawn in even or odd years. The predominant spawning pattern in Washington is the odd year pattern with most pink juveniles found in estuaries during even years. Although they basically use the same nearshore habitats as chum and small ocean-type chinook, it is likely that they may move offshore sooner spending less time in estuarine waters.

Estuarine Habitat and Prey Characteristics

During their early sea life, their estimated growth rate is 5% to 7.6% body weight per day (LaBrasseur and Parker 1964). It is estimated that this high growth rate requires an average daily food ration of 10-12% of their body weight (LaBrasseur 1969). Pinks are both opportunistic and generalized feeders that, upon occasion, may specialize in specific prey items. Along shallow cobble-sand and mud substrate beaches with low gradient shorelines, harpacticoid copepods are an important prey. In boulder and bedrock substrates with steeper gradient shorelines, calanoids and pelagic zooplankters are more important. Tidal currents are believed to play a significant role in the food delivery to these habitats. In addition to copepods, pinks have also been found to feed upon barnacle nauplii, mysids, amphipods, euphausiids, decapod larvae, insects, larvaceans, eggs of invertebrates and fishes, and fish larvae (Groot and Margolis 1991). Peak feeding appears to occur at dusk (LaBrasseur 1974).

Chinook (*Oncorhynchus tshawytscha*)

Timing of Salt Water Entry

Chinook show considerable variability in their outmigration timing. They share with sockeye the highest variability in habitat use. Chinook life-history structure divides into two races (ocean- and stream-type) (Healey 1991). In general, these are differentiated by ocean-type, showing an early outmigration to estuarine waters as subyearlings and the stream-type, who outmigrate from their natal stream only after their first year or longer. In addition to this general race distinction, there is considerable variation within each race that is believed to reflect uncertainties in juvenile survival and productivity within their respective freshwater and estuarine nursery habitats. They appear to spread the risk of mortality across years and habitats (Stearns 1976; Real 1980; Groot and Margolis 1991; Gilbert 1913, Reimers 1973; Schluchter and Lichatowich 1977; Fraser et. al.1982).

Ocean-type chinook enter saltwater at varying sizes along a continuum from early juvenile salt water entry as "Immediate" fry who migrate to the ocean soon after yolk reabsorption at 30-45 mm FL (Lister et al. 1971, Healey 1991), fingerlings who migrate out at varying sizes, 60-90 mm FL (Johnson 2001, Grette 2001), and yearlings, who remain in freshwater for their entire first year and outmigrate during their second or third spring (Myers et al. 1998). Both environmental and genetic factors underlie these differences in juvenile life history (Randall et al. 1987). Migration timing is believed to be linked to the distance of migration to the marine environment, stream stability, stream flow, temperature regimes, stream and estuary productivity, and general weather regimes. Due to their early outmigration to estuarine waters, ocean-type chinook more extensively utilize estuaries and coastal areas for juvenile rearing. In general, the younger (smaller) juveniles are at the time of emigrating to the estuary, the longer they are expected to reside in the estuary (Kjelson et al. 1982, Levy and Northcote 1982, Healey 1991). Although the majority of Puget Sound chinook generally outmigrate to the ocean as subyearlings, there is great variation across watersheds and tributaries. Twenty-seven recognized chinook stocks are found in the rivers of this region. These include 8 spring-run, 4 summer run, and 15 summer/fall and fall-run stocks (WDF 1993). Timing into the estuary can vary considerably depending upon the rearing environment. In the Sacramento-San Joaquin River estuary, fry were observed from January to March (Kjelson et al. (1981, 1982). In the Fraser River delta, fry were observed predominately in April and May (Levy and Northcote 1981, 1982). In the Puget Sound area, fry have been observed in estuarine habitat during the period from February to mid-September unpubl., K. Fresh, WDFW).

Estuarine Habitat and Prey Characteristics

In the estuarine environment, chinook tend to feed on a variety of prey resources depending upon their position along the estuarine gradient, from aquatic insects and mysids in tidal freshwater and brackish zones and more benthic/epibenthic amphipods in euryhaline to euhaline habitats; benthic amphipods, chironomid larvae, aquatic insects, mysids cladocerans, copepoda, and dipterans are their primary prey but certain taxa, such as *Corophium* spp. amphipods may be particularly selected in some habitats. Their diet reflects seasonal changes in prey abundance. Evidence suggests growth rate variations between estuaries correlate with food supply with departure from the estuary being size-related. In the intertidal areas, chinook fry tend to prefer slightly larger prey organisms than similar sized salmonids. Their diets include larval and adult insects and various amphipods. Dunford (1975) suggests that chinook are more efficient predators of chironomid larvae than chum, and able to eat prey that chum are unable to capture. In estuaries, chinook fry are generally shoreline oriented spending most of their time within 20 meters of shorelines (Weitkamp 2000). They have been observed utilizing nearshore areas including areas along shoreline structures, such as riprap, piers, and log rafts (Kask and Parker 1972; Ledgerwood et al. 1990; Meyer et al. 1980; Weitkamp et al. 1981; Weitkamp and Schadt 1982; Taylor and Willey 1997). In Fraser River tidal marshes, chinook have been observed using the high tide to reach the highest points along the shoreline. They were observed moving into tidal channels and creeks as the tide receded. With the incoming tide, they would again disperse along marsh edges (Healey 1980, 1982; Levy and Northcote 1981, 1982; Levings 1982).

Coho (*Oncorhynchus kisutch*)

Timing of Salt Water Entry

In North America, coho largely spend one winter in freshwater and migrate downstream as yearling smolts (Groot and Margolis). Variations in outmigration range from the general pattern of populations that remain one, two or three years in their natal stream to those streams from which outmigration begins as fry. This latter group is an "ocean-type" coho that does not rear in their natal stream, but rather outmigrates as fry to brackish estuarine regions where it is presumed that they rear for extensive periods in tidal sloughs (Simenstad et al. 1992, 1993).

Estuarine Habitat and Prey Characteristics

Upon first entering salt water, coho feed upon marine invertebrates. As juveniles in nearshore habitats, they have been found to feed on copepods, mysids, epibenthic amphipods, and crab larvae (Miller et al. 1976; Simenstad et al. 1979). With growth, they soon become more piscivorous and become important predators on chum and pink fry (Parker 1971; Slaney et al. 1985). Their documented prey include fish such as Pacific sand lance, surf smelt, anchovy, and a variety of crab larvae. Smaller fish are found in shallow shoreline areas and larger fish are found in deeper channel areas of estuaries (Dorcey et al. 1978; Meyer et al. 1980; Durkin 1982; Argue et al. 1985; Dawley et al. 1986; Ledgerwood et al. 1990; Thom et al. 1989).

Sockeye (*Oncorhynchus nerka*)

Timing of Salt Water Entry

The majority of sockeye rear in lakes and tend to migrate as smolts during their second or third years of life. However sockeye have demonstrated several life-history pathways in adaptation to varying estuarine and nearshore conditions. Wissmar and Simenstad (1988) report that a common but not necessarily predominant strategy observed in the Fraser and Stikine Rivers is that of rapid migration to estuaries from fresh water and extensive estuarine rearing (Sandercock 1991; Wood et al. 1988; (Gilbert 1918, 1919; Schaefer 1951). Levy and Northcote (1981) also document sockeye fry rearing with pink, chum, and chinook fry in Fraser River marshes. It is believed that these varying life history strategies reflect responses to varying nearshore conditions and that these conditions are responsible for differences in marine survival between cohort populations (Groot and Cook 1987; Straty 1974; Straty and Jaenicke 1980). Although river/sea-type sockeye salmon have been rarely reported in rivers south of the Stikine River in Alaska (Gustafson et al. 1997), they have been reported in Southern British Columbia 1950, 1951; Birtwell et al. 1987; Levings et al. 1995). Halupka et al. (1993) suggested that the lack of reported river/sea-type sockeye salmon stocks south of the Stikine River and Fraser River populations, may be due to a lack of sufficient colonists with the genetic capacity for developing this life-history pattern, a lack of habitat suitable for development of this life-history pattern, or their presence being overlooked. Eiler et al. (1992) indicated that riverine spawning has been reported,(if only sometimes anecdotally, throughout the range of sockeye salmon (Gustafson et al. 1997). It is presently not known if this life-history strategy occurs in Washington State.

Steelhead (*Oncohynchus mykiss*)

In general, steelhead migrate as smolts through estuaries in the second and third year of life, remaining in relatively deep water and moving rapidly through the system (Dawley et al. 1986; Ledgerwood et al. 1990). Although they are not found in large numbers along shoreline areas, they have been found in the Columbia River plume in May and early June. Individuals have also been caught in beach seines likely feeding on small fish migrating and rearing in nearshore habitats (Shreffler and Moursund 1999).

Coastal Cutthroat (*Oncorhynchus clarki clarki*)

The coastal or sea-run cutthroat life history is very complex and little understood. Although most anadromous cutthroat trout enter seawater as two or three year olds, some may remain in fresh water for up to five years before entering the sea (Giger, 1972; Sumner, 1972). Still other cutthroat trout may not outmigrate to the ocean, but remain in small headwater tributaries. Other cutthroat trout may migrate only within freshwater environments despite having access to the ocean (Tomasson, 1978; Nicholas 1978; Moring et al. 1986; Johnson et al. 1999). Similar to sockeye, cutthroat are large and tend to occupy relatively deeper waters. However, individuals are observed and caught in nearshore areas likely foraging on small salmonids and forage fish present in nearshore habitats.

Bulltrout (*Salvelinus confluentus*)

In the northern Puget Sound region, bull trout populations show considerable variation in migration and rearing strategies (Kraemer 2001). There are populations that spend their entire lives in headwater streams, populations that spend one or more years in the main stem larger rivers, and populations that spend one or more years rearing in lakes.

The anadromous populations are characterized by fall spawning between September-November, depending upon the weather. As temperatures drop in fall to around 8 degrees C, they begin their move from the estuary to upriver over-wintering sites with spawning being triggered by falling water temperatures. Sexually mature fish can begin leaving the marine waters as early as late May with most fish back into freshwater by late July. They reach spawning staging areas one to four months prior to spawning. They tend to spawn in headwaters as far as 200km upstream from the river mouth. Sexual maturity occurs in the second fall with spawning occurring at age 4 or 5. Non-spawners return to over-winter in their natal stream, typically in the lower 40-50 km of the river and spawners return to spawn and over-winter in the headwaters. Consequently few fish are in the estuary between December and February (Kraemer 2001).

Timing of Salt Water Entry

Post spawning adults begin to re-enter marine waters around the first of January with older fish re-entering the estuary earlier and all spawners returned to the estuary by March. A smolt trap at the Skagit River indicated that the bulk of downstream migration of smolts and outmigrating adults occurred in spring with 95% outmigration between April 1st and July 15th and a peak in mid may to early June. There were variations in size. However, in general, they were 150mm in length (Kraemer 2001).

Estuarine Habitat and Prey Resources

During their nearshore residence, they are typically found along the shoreline in less than 3 meters of water. They are often seen actively foraging in less than 1/2 meter of water. Although, they clearly can and do cross deep water, as smolts, subadults, and adults, they appear to spend most of their time in the estuary in shallow water. They also tend to remain within tens of miles from their natal stream mouth. These shallow shoreline oriented fish primarily forage upon baitfishes and they are capable of foraging on fish 35-45% of their own body size.

Transient Fishes

Transient species (Tables 8 and 9) move from subtidal to intertidal habitats to feed (Miller and Dunn 1980; Wolff et al. 1981; Rozas and Lasalle 1990; Van der Veer and Witte 1993), spawn, or avoid predation (Kneib 1987; Ruiz et al. 1993). These fishes share a dependence upon nearshore intertidal and subtidal habitats for one or more of their life-history stages but use deeper habitats in other stages. Table 8 also identifies the habitat type they depend upon and the life-history stage supported by a specific habitat type. Their use of the nearshore varies seasonally and consistently with each species' life-history strategies. Pacific sand lance, surf smelt, and rockfish species are examples of transient species that use nearshore eulittoral habitats on a temporally limited basis depending upon their life-history phase. Although, they use pelagic habitats as adults, they use eulittoral habitats for both spawning and rearing. Although Pacific sand lance and surf smelt share some similarities with juvenile salmon in their migratory utilization of nearshore habitats en route to the sea or to adult neritic habitats, for the purposes of this paper,

Table 8. Transient Fishes – Habitat Use

Family	Scientific Name	Common Name	Spawn	Juvenile. Rearing	Adult Res.	Habitat Type	Timing
Osmeridae	*Hypomesus pretiousus*	surf smelt	X	X	X	1) protected sand-gravel eelgrass shallow subtidal 2) mud eelgrass 3) subtidal 4) rocky/kelp-adults & larvae only	Juvenile: spring-summer adults: year round
Ammodytidae	*Ammodytes hexapterus*	Pacific sand lance	X	X	X	1) protected sand-gravel eelgrass shallow subtidal 2) mud eelgrass 3) subtidal 4) rocky/kelp	Juvenile: spring-summer adults: year round
Scorpaenidae	*Sebastes (*spp.*)*	rockfish		X		Juvenile 1) shallow gravel 2) shallow subtidal sand eelgrass adult: 1) subtidal rocky/kelp 2) gravel	Juvenile: spring-summer adults: year round

X indicates extensive use
adapted from Matthews 1989, 1990; Miller et al. 1976; Simenstad et al. 1979; Penttila 2000,b,c, 2001)

Table 9. Transient Fishes – Water Column Use

Transient Fish			Water Column Distribution			
Family	Scientific Name	Common Name	Spawning Habitat	Eggs	Larvae	Adult Habitat
Osmeridae	*Hypomesus pretiousus*	surf smelt	demersal	demersal	pelagic	pelagic
Ammodytidae	*Ammodytes hexapterus*	Pacific sand lance	demersal on sand	demersal	pelagic	pelagic
Scorpaenidae	*Sebastes* (spp.)	rockfish			pelagic juveniles	semi-demersal

Adapted from Garrison & Miller 1982

their obligate dependence upon nearshore habitat for spawning places them in the transient fishes classification. Rockfishes are classified as transient due to their combined dependence upon nearshore habitat for only part of their juvenile life stage and their move to adjacent deeper adult habitats. Their use of nearshore habitat is very transient in nature. Rockfish juveniles migrate and settle into nearshore habitat for a brief period of their existence to take advantage of the shelter and prey resources provided in those habitats (Haldorson and Richards 1987; Norris 1991; Love et al. 1991; Miller et al. 1976; Simenstad et al. 1979; Kuzis 1987; Matthews 1989). Upon reaching larger sizes, they move out to deeper adult habitats. Their adult home area is quite small (i.e. 50 m^2 or less). Their life-history strategy is not that of migrating through an area but rather, in the case of the nearshore, migrating into the area of the nearshore and moving back out to adjacent deeper waters utilizing floating, unattached nearshore vegetation as a transportation corridor to adult habitat.

Surf smelt (*Hypomesus pretiousus*)

Surf smelt *(Hypomesus pretiousus)* spawn at the highest tide lines at high slack tide near the water's edge on coarse sand or pea gravel. Egg development is temperature dependent with marine riparian vegetation serving to maintain lower temperatures during high temperature periods (Penttila 2000a). The smelt life span is thought to be five years (Penttila 2000c). The adults feed primarily on planktonic organisms but their movements between spawning seasons are basically unknown. However, they are known to be a significant part of the Puget Sound food web for larger predators. Recent surveys document 195 miles of surf smelt habitat in Puget Sound (Penttila 2000b). Inside Puget Sound (PS), they spawn at the higher high water line, while on the coast, they spawn at lower tidal elevations corresponding to access to fine gravel substrates. In Washington, smelt spawning grounds are geographically distinct with significant differences in temporal use. Spawning in northern Puget Sound occurs year round, while spawning in central and southern Puget Sound occurs in fall and winter. For populations along the coast and straits, spawning occurs in summer months. As 80% of all Washington spawning has been found to occur in coarse sand and pea gravel, it is likely that substrate type and size may be the primary factor in spawning location. The limited extent of surf smelt spawning grounds makes them quite vulnerable to shoreline development and construction activities with some spawning grounds being mere remnants of their historical extent (Penttila 2000a). Their spawning grounds have been mapped and are protected by the Washington Administrative code (WAC) Hydraulic Permit Approval (HPA) rules.

Pacific Sand Lance (*Ammodytes hexapterus*)

Pacific sand lance *(Ammodytes hexapterus)* spawn at high tide in the upper intertidal area on sandy gravel beach material. Their ability to spawn at a given location is determined by the availability of sandy material. The fine sandy beach material coats the eggs and likely serves to assist in moisture retention when they are exposed during low tides. It also serves to conceal the eggs from predators. In Puget Sound, the spawning season is November 1 through February 15 with larvae commonly found between January and April in the Puget Sound area (Garrison and Miller 1982). Upon hatching, larvae and young-of-the-year rear in bays and nearshore waters.

Although the metamorphosis of Pacific sand lance from larvae to juvenile stages has not yet been described, Smigielski et al. (1984) found that with the cogener *A. americanus* a complete metamorphosis occurs between 30-40 mm FL with burrowing behavior to escape predation occurring between 35-40mm and movement to deeper waters occurring at 50mm size length (Tribble 2000). At Friday Harbor, Washington, Tribble (2000) found sand lance larvae and juveniles to feed in the upper water column during the day upon prey items similar to juvenile salmon, such as copepods, crab larvae, amphipods and diatoms. Tribble (2000) found swimming speed appearing to maximize at the 45mm size during the period they are residing in nearshore waters. Similarly, Tribble (2000) found indications of critical visual development occurring in the nearshore as they become adapted to the visual world of pelagic waters that they will move into as adults. These findings indicate the importance of available prey resources, light, and fine substrates in nearshore habitats for critical rearing and refugia functions.

Adult movement and age structure are currently unknown. They feed in open water in daylight and burrow into the bottom substrate at night to avoid predation. They are a significant dietary component of many economically important resources in Washington, such as juvenile salmon. It has been found that 35% of juvenile salmon diets are known to be Pacific sand lance (Environment Canada 1994). They are particularly important to juvenile chinook with 60% of the juvenile chinook diet represented by Pacific sand lance. Their habit of spawning in upper intertidal zones of protected sand and gravel beaches makes them particularly vulnerable to the direct and cumulative effects of shoreline development. Their spawning habitat is also protected by the WAC HPA rules. Loss of spawning habitat likely limits their net total stock recruitment success (Penttila 2000a).

Rockfish (*Sebastes* spp.)

Rockfish *(Sebastes* spp*.)* inhabit rocky reef habitats as adults but use nearshore habitats to rear as juveniles. As adults, they do not venture outside of 50 m^2 from their preferred habitat. Born around April as free-swimming pelagic larvae, rockfish spend four months in open water (DeLacey et al. 1964). During their first year, juveniles settle into shallow habitats vegetated by bull kelp, macroalgae, and eelgrass to meet critical juvenile rearing needs (Haldorson and Richards, 1987; Matthews, 1990; Miller et al 1976, 1978; Norris 1991; Phillips 1984; Stober and Chew, 1984). These nearshore habitats provide juvenile rockfish shelter from predation and increased access to prey resources. Survival is likely dependent upon the availability of suitable refuge habitat provided by nearshore environments (Norris 1991). The particular nearshore habitats most utilized by juvenile rockfish are gravel habitats that provide benthic crustacean prey resources (Miller et al.1976). Copper, quillback, and brown rockfish species generally eat small fishes and epibenthic prey with their seasonal distribution likely reflecting prey presence. Summer feeding plays an important role in providing food for storing fat reserves for winter maintenance. They reproduce pelagically and as a viviparous species (also considered ovoviviparous by some classification systems), they give birth to live young. It is suggested that the availability of juvenile habitat may play a more important role than even the size of local adult fish density in predicting local recruitment success. These early nursery habitats likely play a determining role in fish stock density through prey resource access and protection from mortality during vulnerable juvenile stages. Limited availability of such habitat is thought to impose a demographic bottleneck on stock recruitment (Norris 1991; West et al. 1995). The seasonal variation in vegetated habitat is reflected in dramatic density differences (Buckley, R.M. 1997). Matthews (1989) found the highest fish densities occurred in the summer, in low-relief rocky reef and sand-eelgrass habitats with fish density declines in those habitats consistent with dieback of vegetation. This is likely due to the lack of places for fishes to hide in these habitats when vegetation is lost (Matthews 1989; Quast 1968; Stephens et al. 1984; Ebeling and Laur 1988). Winter high fish densities in high-relief habitat likely correlate to the presence of holes and crevices in these habitats for fishes to hide in. Temperature has been found to affect juvenile rockfish growth during their first year with warmer temperatures, such as those found in the nearshore areas, found to produce higher growth rates and possibly increased food assimilation efficiency (Buckley, 1997; Love et al. 1991).

Juvenile rockfish also occur with drift habitat formed by macrophytes and seagrass for both prey resources and refugia while they move between pelagic and nearshore habitats (Bohlert 1977; Buckley 1997; Shaffer 1995).

Dislodged nearshore vegetation may provide a link between pelagic and nearshore systems by providing a transportation corridor in the form of refuge and prey resources for small fishes settling into or exiting the nearshore environment. Under the influences of tide, wind, and ocean-current-driven convergent zones, detached intertidal and subtidal vegetation form floating mats that move into open water pelagic systems. These floating mats provide cover for small rockfishes along with high densities of planktonic organisms associated with the vegetation (Gorelova and Fedoryako1986). This nearshore and pelagic mix creates a unique habitat offering components of both the nearshore vegetated habitats and open water pelagic system. Depending on the season, such vegetation mats have been shown to provide higher abundances of species diversity and richness than is usually found in open water systems. In this way, it acts as a nutrient, larvae, juvenile fish, and pollutant distribution system between nearshore and benthic habitats (Johnson and Richardson 1977; Kulczycki et al. 1981; Kingsford and Choat 1986; Shanks and Wright 1987; Kingsford 1992; Shaffer 1995). Such drift habitat may be a critical resource for many fish species in Washington coastal waters for such species as juvenile chum, pink, chinook, and coho salmon, surf smelt, Pacific herring, and northern anchovy (Simenstad et al. 1991a).

Shellfish

Shellfish are an economically important resource in Washington State and are harvested for recreational purposes as well as by commercial industries**.** Shellfish habitat varies across estuarine and marine nearshore habitat. Shellfish rely on a variety of intertidal habitats specific to the life-history strategies of each species. Of particular concern is their proclivity, as filter feeders, to incorporate contaminants in their tissues and pass those contaminants to their predators in the marine food web. Filter feeding makes shellfish particularly susceptible to ingesting contaminants from the water in which they live. These accumulated water and sediment contaminants can then be passed through the food chain to shellfish predators.

Bivalves

Bivalves (clams, mussels and oysters) feed by filtering large quantities of water through ciliated gills drawing water into the mantle cavity and passing it back out. By drawing water over the gills, microscopic food becomes trapped in mucus and moved along cilia covered pathways to the mouth (Kozloff 1983).

In the lower reaches of the intertidal zone, substrate preferred by bivalves is composed largely of gravel mixed with sand or mud, which is an ideal habitat to support littleneck clams (*Protothaca* spp.). The bent-nose and other clams of the genus *Macoma* reach peak abundances in muddy sand. Similarly, the large gaper and horse clams of the genus *Tresus* generally live in sandy mud, or a mix of mud, gravel, and shell. The heart cockle, *Clinocardium*, appears to prefer quiet bays with fine muddy sand substrates. Soft-shell clams, *Mya arenaria*, are found typically in sand and mud or in mud and gravel habitats in areas where there is reduced salinity due to fresh water seepage. Other bivalaves, such as oysters and mussels require a hard substrate to which they attach. The large geoduck (*Panopea* spp.) is rather scarce intertidally (Kozloff 1983).

Crabs and Shrimp

Crabs and shrimps are the arthropods of the class Crustacea. These are the copepods, isopods and amphipods, crab and shrimp (Kozloff 1983).

Dungeness Crab (Cancer magister)

Dungeness crab (*Cancer magister)* rely on eelgrass beds, shell deposits, oyster culture, and macrolagae habitats of the intertidal zone during their developmental stage of 'settlement'. The life-cycle of this species is complex, with shifts in habitat location depending on age of the individual, although rate of growth is highly variable (Botsford 1984). In Washington, along the coastal waters, the Dungeness crab breed from May to June, with the fertilized eggs extruded in September to October. Around January through March, the meroplanktonic larvae are released by broadcast manner to the waters. The larvae develop through five zoel stages to a megalopa stage, taking approximately 120 to 150 days. After the megalopa stage, the young crab settle to the benthos around May to June (McConnauaghey et al 1995). Nearshore habitat in shallow embayments and inland waters provide crab nursery sites that are rich in prey resources, predation shelter, and warmer water temperatures to meet important growth needs. Crabs settling or residing in estuaries and shallow embayments are found to have significantly higher growth rates than their cohorts of the same year-class settling in coastal environments. The Dungeness crab is considered a benthic predator and feeds for rapid growth during its residence in estuaries and offshore communities (Stevens and Armstrong 1984). Stevens et al (1982) reports the diet of small crabs (average size - 39.7 mm carapace width) is dominated by small bivalves and crustaceans, while adult crab consume bivalves, fish, isopods, amphipods and crangon shrimp (Gotshall 1977; Bernard 1979).

The highest abundance of juvenile Dungeness crab is found in the intertidal zone during late summer (July through September) with a lower, more constant density in winter and early spring at this zone. Juvenile growth is correlated to water temperatures with the higher temperatures of late summer giving rise to peaks in growth rates, whereas during the colder periods, between November and March, less growth was found to occur. Growth increases begin again after March and peak in August (McMillan et al. 1995). In a study of northern Puget Sound intertidal habitat, McMillan et al. (1995) found the highest crab densities were consistently found in the gravel-algae and eelgrass habitats while significantly lower densities were found in open sand habitat.

Survival rates for the Dungeness crab were found to differ between habitats with high survival in gravel-algae and lower survival in eelgrass and open sand habitats. Increased survival rates are attributed to the gravel-algae habitat areas where the substrate is more reticulated and there is an overstory of attached or drifting macroalgae. In contrast, crab survival rates are lower in areas with small stands of eelgrass and open sand habitat. A correlation was found whereby crab densities increase in areas where there is an increase in percent eelgrass cover. Studies by Nelson (1981) and Heck and Thoman (1984) determined that a minimum, or threshold, vegetation density is required for significant reduction of predation impacts. These distribution shifts are consistent to predation-influenced patterns known for other crustacean fauna in vegetated aquatic habitats (Nelson 1981; Heck and Orth 1980; Heck and Thoman 1984; Summerson and Peterson 1984; Orth and van Montfrans 1987; Wilson et al. 1987) and other seagrasses (Heck and Wetstone 1977; Nelson 1981; Orth et al. 1984; Leber 1985; Heck and Wilson 1987).

Juvenile Dungeness crab settle in northern Puget Sound from June through September, while coastal settlement occurred only during May and June (Stevens, and Armstrong 1984; Gunderson et al. 1990; Dumbauld et al. 1993). Upon reaching approximately 30 mm in size, *C. magister* migrate from eelgrass habitat to deeper unvegetated subtidal areas. Gunderson et al. (1990) found that during the spring, following settlement, the majority of those juveniles initially settling off the coast migrated into estuaries to join those (now larger) members of the same year class that had moved into estuaries at an earlier age. This movement substantially increases the abundance of one-year old crabs in estuaries compared to adjacent coastlines. Predation is a major contributor to mortality during this time therefore, refuge availability provided by eelgrass, shell material and macroalgae is particularly important. At the Gray's Harbor area, mature female crabs tend to leave the harbor to offshore areas for spawning (Stevens and Armstrong 1984). Armstrong et al. (1987) found virtually all of the ovigerous female population at Ship Harbor to be located in the eelgrass zone from about 0.5 to 4.0 m depth buried in the substrate. The availability of intertidal habitat and refuge are important contributing factors to maintaining a viable crab population (McMillan et al. 1995).

Even though predators of *C. magister* are found in higher concentrations in estuaries than off the coast, the Dungeness crab will spend up to two years in the estuarine environment (Gunderson et al. 1990). It is believed that crabs utilize estuaries, despite the risk of increased predation, because of the advantage of increased food availability, which greatly enhances their growth rates (Gunderson et al. 1990). Predators of *C. magister* include coho and chinook salmon who prey heavily on *C. magister* megalopae (Reilly 1983). In Humboldt Bay, Prince and Gotshall (1976) found *C. magister* megalopae and postlarval instars to be the most important food items for copper rockfish *Sebastus caurinus* (Fernandez et al. 1993). Armstrong (1991) reports that over 50% of a settling crab year-class could potentially be lost by sculpin predation. Jacoby (1983) and Gotshall (1977) report cannibalism among young-of-the year and by larger crabs on smaller crabs as also a factor of predation rate.

Dungeness crab recruit to the fishery at 3.5 to 5 years after settlement. The earlier 3.5 recruitment year is possible when young crab have ideal habitat conditions with adequate food, proper salinity levels and the right temperature regime during their early growth period (Armstrong, et al 1987).

Sand Shrimp (Crangon **spp.***)*

Sand shrimp (*Crangon* spp.), live in shallow water areas and burrow under the sand. *Crangon* spp. are an important prey source to many estuarine organisms including Dungeness crab (Armstrong et al 1981). The ghost shrimp, *Callianassa californiensis,* burrows in the substrate as well, only it prefers the more muddy sand areas with high amounts of clay or organic matter (Kozloff 1983).

Habitat Impact Mechanisms

Alterations to the nearshore light, wave energy, and substrate regimes alter the nature of nearshore food webs important to a wide variety of marine finfish and shellfish (Armstrong et al.1987; Beal 2000; Burdick and Short 1995; Cardwell and Koons 1981; Fresh and Williams 1995; Kenworthy and Haunert 1991; Loflin 1995; Olson et al. 1997; Parametrix and Battelle 1996; Penttila and Doty 1990; Shafer 1999; Simenstad et al. 1978, 1979, 1980, 1988; Thom and Shreffler, 1996; Weitkamp 1991). Alarming declines in plant and animal populations in Washington's inland marine waters highlight the need to identify and avoid stressors to the region's marine resources (West 1997; Wright 1999). Fish populations suffering from significant anthropogenic stresses include Pacific salmon, Pacific herring, Pacific cod, walleye pollock, Pacific hake, and three species of demersal rockfish (West, 1997; Wilson et al. 1994). As the region's highest density of overwater structure development occurs largely within Washington's inland marine waters, this paper will have a special focus on habitats endemic to those inland waters. The combined forces of volcanic activity, glacial scour, and fluvial processes have created the present fjord bathymetry of the inland marine waters. The bathymetry is one consisting of deep troughs, exceeding 250 meters in depth in the central basin, surrounded by a narrow fringe of shallow vegetated habitat (Strickland 1983). It is the highly productive capacity of this vegetated fringe that provides critical functions for juvenile salmon and many of the region's important finfish and shellfish (Miller et al. 1978, 1980; Simenstad 1979). At some point in their juvenile rearing stage, each of the above-named species, and the forage fish that support them, rely on nearshore vegetated, gravel, or mudflat habitats to meet critical rearing needs. This reliance upon nearshore habitat for important rearing needs combined with the natural geomorphologic limitations in habitat extent and the proximity of these habitats to human transportation corridors magnifies the importance of protecting these habitats from further loss and degradation (Doty and Landry 1990; Norris 1991).

The Conceptual Framework for Identifying Impacts

As overwater structures are typically located in intertidal areas from above the area submerged by the mean higher high tides and out to 15 meters below the area exposed by the mean lower low tide, this paper focuses upon habitats located within those tidal elevations. The primary physical processes controlling habitat attributes (i.e. plant and animal assemblages) and functions are depth (elevation), substrate type, wave energy, light, and water quality. These are the most important factors influencing the development and distribution of nearshore habitats (Thom, in press.). Figure 3 models the conceptual framework this paper uses to define overwater structure impacts to nearshore habitat.

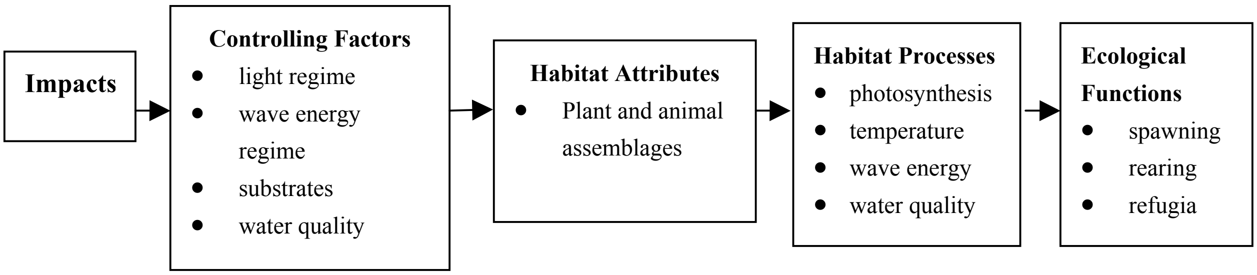


Figure 3. Conceptual Framework Model

Habitat Processes and Impact Mechanisms

Overwater structures and associated activities can impact the ecological functions of habitat through the alteration of habitat controlling factors. These alterations can, in turn, interfere with habitat processes supporting the key ecological functions of spawning, rearing, and refugia. The matrix presented in Table 10 identifies the potential mechanisms of impact overwater structure can pose to nearshore habitats. Whether any of these impacts occur and to what degree they occur at any one site depend upon the nature of site-specific habitat controlling factors and the type, characteristics, and use patterns of a given overwater structure located at a specific site.

Table 10. Overwater Structure Habitat Impact Mechanisms

Habitat Controlling Factors	Overwater Structures and Activities	Habitat Impact Mechanisms	Habitat Impacts
Light Regime	• Docks • Floats • Pilings • Moored vessels	• Reduced light levels • Altered ambient light patterns	• Limited plant growth and recruitment • Altered animal behavior and assemblages
Wave Energy Regime	• Floats • Breakwaters • Prop wash • Marina	• Altered wave energy patterns	• Altered plant and animal assemblages • Altered substrate type • Altered sediment transport & distribution
Substrate	• Prop and anchor scour • Pilings, breakwaters and floats	• Altered substrate characteristics	• Altered sediment transport and distribution • Altered substrate type • Altered plant and animal assemblages
Water Quality	• Discharges • Boat and upland run-off	• Increased exotics, toxics, nutrients and bacterial introductions	• Altered plant and animal assemblages • Limited growth and recruitment • Exotic species replacement of natives

Figure 1 in Appendix A identifies habitat impact mechanisms attributed to the various types of overwater structures and associated activities and Figure 2 in Appendix A indicates what is known specific to dock, pier, and float habitat.

Ambient Light Regime

By virtue of light refraction from the water's surface, the underwater light environment is by nature a light- reduced environment. Overwater structures enhance this light reduction through an increased loss of underwater light energy. Figure 4 depicts under-pier light energy loss has been found to fall below threshold amounts for the photosynthesis of diatoms, benthic algae, eelgrass and associated epiphytes, and other autotrophs. These photosynthesizers are an important part of nearshore habitat and the estuarine and nearshore marine food webs supporting juvenile ocean-type salmon and other fishes in estuarine and nearshore marine environments.

Vegetation and Light

Light, which drives the photosynthetic process controlling plant growth and survival, is the single most important factor affecting plants (Govindjee and Govindjee 1975). Plant growth, survival, and depth of penetration are directly related to light availability (Dennison 1987; Kenworthy and Haunert 1991). The maximum depth of plant survival increases with increasing light penetration into the water column (Dennison et al. 1993). The level of light penetration is dependent upon water depth, water clarity, and light absorption by plant material in the water column. Water clarity is a determining factor influencing the level of light penetration into the water column as dissolved particulates serve to reflect, refract, absorb, and scatter incident radiation. Organic and inorganic particulates washed into marine waters from surrounding surfaces or suspended from bottom deposits can also enhance the growth of phytoplankton and epiphytic algae. This increased abundance of phytoplankton and algae increases the light absorption by these plants and decreases the light available for the submersed rooted vegetation such as *z. marina*. Phytoplankton and epiphytic algae in the water column above the rooted vegetation can also change the spectral character of underwater light. By changing the spectral character of transmitted light, phytoplankton and algae can interfere with the ability of rooted plant pigments to use the transmitted light energy (Bulthuis and Woelkerling 1983; Dennison et al. 1993; Kemp et al. 1983; Olinger et al 1975; Orth and Moore 1983).

Plant Light Requirements

Determined by genetics, the pigments of each of the plant species absorb and utilize particular light spectral ranges. Each plant's light harvesting pigments absorb a genetically defined spectrum of light wavelengths which is transferred to reaction centers where oxidation and reduction reactions occur converting water and carbon dioxide to carbohydrates and oxygen. For example, phytoplankton requires 1 percent surface irradiance (Strickland 1958), freshwater macrophytes require 10 percent (Sheldon and Boylen 1977), and eelgrass requires a minimum of 10 to 20 percent (Duarte 1991; Dennison et al. 1993). For marine submersed aquatic vegetation,

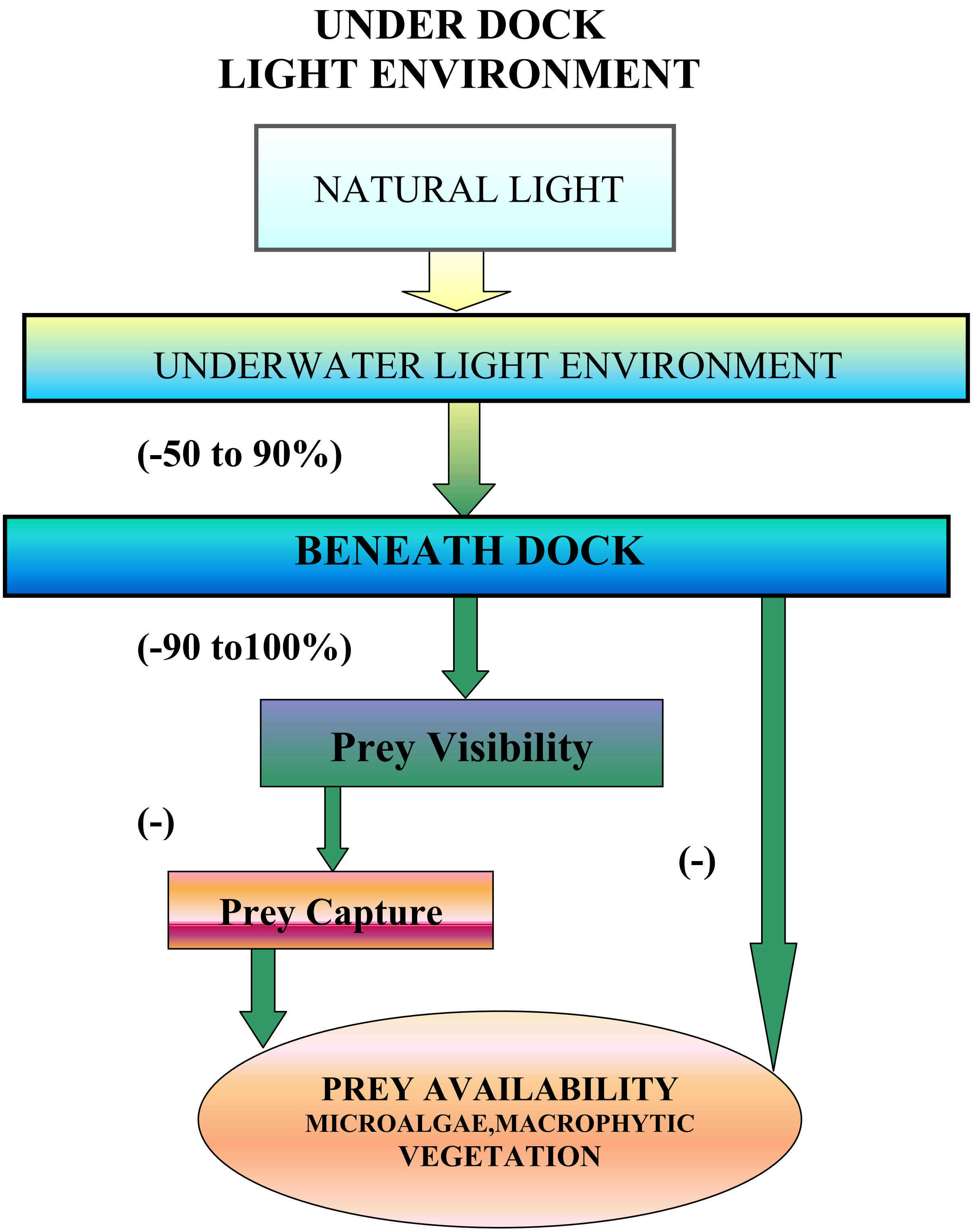


Figure 4. Under Dock Light Environment (Simenstad et al. 1999)

the average minimal light requirement is 10.8% (Duarte 1991). The average minimal light requirement for light energy transmitted below its threshold amount limits a plant's photosynthetic capacities. Estuarine primary producers such as diatoms, algae, and macrophytes that support the prey and refugia base for fish and shellfish rely on light transmitted through the water's surface. The minimum light required for persistence of a plant species is defined by the percentage of surface irradiance ($\%I_0=[I_z*100]/I_0=e^{-kz}$) reaching the lower depth limit for the particular plant species (Dennison et al. 1993; Zimmerman and Alberte 1991; Zimmerman et al. 1991). The level of irradiance or quantity of light required to saturate a particular plant species correlates to the habitat of that plant. Intertidal macroalgae species require 400-600 $uMm^{-2}s^{-1}$ and deeper sublittoral macroalgae species require less than 100 $uMm^{-2}s^{-1}$ (Luning 1981). Higher plants, such as seagrasses, require higher levels of radiant energy than the diatoms and epiphytic bacterial forms utilizing their shoots as substrates. In Puget Sound, Thom and Shreffler (1996) found that eelgrass is light limited at levels below 300 $uMm^{-2}s^{-1}$.

Absorption and utilization of radiant energy by plant material in the water, such as phytoplankton, diatoms, and other plants, depend upon the pigments they contain. Plant pigments such as chlorophylls, carotenoids, and phycobiliproteins provide each plant with light absorbing characteristics particular to that plant group and its environment. Photosynthetic pigments in plants include chlorphyll *a* plus a variety of other pigments arranged in the plant's reaction center. These pigments are the plant's light harvesting pigments. Each plant group has an array of pigments with characteristic absorption spectrums at given wavelengths. Their rates of photosynthesis depend upon irradiance levels with their respective rates of photosynthesis following the curve of absorption spectrum. The light energy absorbed by these pigments is then transferred to reaction centers where the oxidation and reduction reactions occur to convert water and carbon dioxide to carbohydrates and oxygen.

Based upon differences in pigment and chloroplast structures and the use of the sun's radiant energy, underwater plants can be grouped into seven categories: 1) diatoms, 2) phytoplankton, 3) green algae, 4) blue-green algae, 5) brown algae, 6) red algae, and 7) higher green plants. Table 11 identifies chlorophylls and absorption peaks characteristic to particular algal and diatom groups in Puget Sound (Kozloff 1983). However, it is important to remember that in their respective environments, plants are able to acclimate to a variety of differences in both light quantity and quality.

This higher irradiance requirement limits macrophyte and seagrass survival beyond those depths with correspondingly low irradiance levels. To the degree that epiphytic forms absorb light wavelengths, they limit light to the seagrass plant. Similarly, turbid waters attenuating the shorter wavelength levels and transmitting longer, low-energy wavelengths could transmit the energy required for bacterial and algae growth without transmitting the specific wavelengths activating eelgrass growth and reproduction. The increase in epiphytic and bacterial growth increases the shoot surface area covered by epiphytes and inhibits the photosynthetic capacity of the seagrass plant (See Table 11). Epiphyte abundance can be reduced by herbivorous epiphyte grazing isopod and amphipod populations. Studies have found that eelgrass biomass declined with decreasing epiphyte-grazing populations (Wetzel and Neckles 1986; Orth and Van Montfrans 1984; Williams and Ruckelshaus 1993).

Table 11. Puget Sound Algal Pigment and Wavelength Relationships.

Plant Phyllum	Alga Common to Puget Sound Docks, Pilings, *Zostera* Shoots and Rocky Shorelines	Chief Pigments	Wavelength Rim Absorption Peak
Cyanophyta	Blue-Green Algae (*Calothrix*)	chlorophyll *a,* carotenoid (*phycoerythrin*)	550 435
Chlorophyta	Green alga (U*lva, Cladophora, Bryopsis, Derbesia, Blidingia, Halicystis Entrophorpha,Ko rnmannia, Codium*)	chlorophylls *a,b*	435,480
Bacillariophyta	Diatoms (*navicula* spp.)	chlorophylls a,c,and carotenoid (*fucoxanthin*)	435, 650,740
Phaeophyta	Brown Algae and Kelps (*laminaria, Desmarestia, Costaria, Agarum, Vymathere, Egregia,Pterygophora,, Alaria, Nereocystis,Sargassum, Cystoseira)*	chlorophyls *a,c* carotenoid (*fucoxanthin*)	435, 650, 740
Rhodophyta	Red Alga *(Antithamnion, Antithamnionella, Hollenbergia, Scagelia, Polysiphonia, Polyneura, Iridaea, Delesseria, Membranoptera, Callophyllis, Smithora, Porphyra, Phyllospadix, Lithothamnium,Corallina, Calliarthron, Boxxiella,Constantinea,Gigartina,Iridaea, Odonthalia,Thodmela, Colpomenia,Hymenena, Botryoglossum,Erythrophyllum, Opuntiella, Prionitis,Laurencia, Plocamium, Pterochondria, Microcladia, Callithammnion)*	chlorophyll a, d carotenoid (*phycoerthrin*)	435, 760

Adapted from Kozloff 1983

Overwater Structure Effects

Without proper precautions, docks, piers, and pilings can cast shade upon the underwater water environment thereby limiting light availability for plant photosynthesis. Distributions of invertebrates, fishes, and plants have been found to be severely limited in under-dock environments when compared to adjacent vegetated habitat in the Pacific Northwest not shaded by overwater structures (Fresh et al. 1995, 2000; Ludwig et al. 1997; Orth and Moore 1983; Parametrix and Battelle 1996; Thayer et al.1984; Thom et al. 1996, 1997). Light reduction by overwater structures is also well documented (Burdick and Short 1995; Fresh et al 1995, 2000; Loflin 1993; Ludwig et al. 1997; Olson 1996, 1997; Penttila and Doty 1990; Thom and Shreffler 1996; Thom et al. 1996, 1997). Similar findings have also been reported in California, New York, Massachusetts, Florida, Alabama, and Australia (Able et al. 1998; Backman and Barilotti 1976; Burdick and Short 1999; Duffy-Anderson 1999; Loflin 1993; Ludwig et al. 1997; Shafer 1999; Short and Wyllie-Echeverria 1996; Walker et al. 1989).

Each dock defines a shade footprint specific to its structural specifications. Dock height, width, construction materials, and the dock's orientation to the arc of the sun are primary factors in determining the shade footprint that a given dock casts over the submerged substrates (Burdick and Short 1995; Fresh et al. 1995,2000; Olson 1996,1997). Burdick and Short (1999) found underwater light availability and eelgrass bed quality under docks to be primarily dependent upon dock height, followed in importance by dock width, and dock orientation relative to the arc of the sun. Burdick and Short (1999) also found light to be the most important variable affecting canopy structure (i.e. shoot density and height) and eelgrass bed quality. To the degree that a shade footprint limits plant photosynthesis, it decreases the extent and quality of habitat that supports a wide variety of fish and shellfish populations. Penttila and Doty (1990) found that construction of even partially shading types of structures, floating or on pilings, could be expected to largely eliminate existing eelgrass and other macroflora with little chance for replacement plant growth.

Animals and Light

Prey Capture and Visual Acuity

Teleost fishes, a classification that includes all fish identified in this paper, depend upon sight for feeding, prey capture, and schooling. For these fishes, sight is of tremendous importance for spatial orientation, prey capture, schooling, predator avoidance, and migration. For example, Figure 5 depicts light conditions found to determine juvenile salmon schooling, predator avoidance, feeding, and migratory behavior. The underwater light environment determines the ability of fishes to see and capture their prey.

Juvenile and larval fish are primarily visual feeders with starvation being the major cause of larval mortality in marine fish populations. Early life history stages are likely critical determining factors for recruitment and survival, with survival linked to the ability to locate and capture prey and to avoid predation (Britt 2001). Tribble (2000) found the swimming and feeding behavior of juvenile and larval sand lance, *Ammodytes hexapterus,* to be reduced with low light levels. Similar to other juvenile fishes with cone-based vision, larval sand lance retinal cells are found to fall in the violet to green range with limited visual acuity in low light environments. Their visual acuity increases with growth as their cone pigments shift from violet to blue sensitivity with an eventual development of rod vision that provides them with vision in light limited environments. Rods appear to develop at 24mm and full adult visual acuity develops at 35mm. This visual development prepares them for their transition to deeper waters. Tribble (2000) reports sand lance visual development to be reflective of the respective habitats they occupy at given total lengths. At 50mm in size, they will begin to move into deeper pelagic waters where the light environment changes and their light requirements for prey capture change in response to the light wavelengths characteristic of that habitat. Many juvenile fishes utilizing nearshore habitats, such as sand lance (Tribble 2000), perch, salmonids (Ali 1946), and lingcod (Britt 2001) share this sensitivity to UV wavelengths reflected in shallow nearshore marine habitats. Similar to salmonids, yellow perch and sand lance have been found to lose ultraviolet sensitivity with growth. Brownan and Hawryshyn (1994) report this loss of UV sensitivities to be size rather than age dependent and to likely correlate with the time such fishes move from shallow to deeper water and move from feeding on small crustaceans and other zooplankton to larger food items. As zooplankton reflect short wavelength light, such as UV, this provides an advantage for juvenile fishes with UV sensitivity feeding upon zooplankton in shallow nearshore waters. The ability of zooplankton to reflect UV is likely due to high concentrations of amino acids that protect them from the damaging effects of UV radiation (Zagarese and Williams 2000).

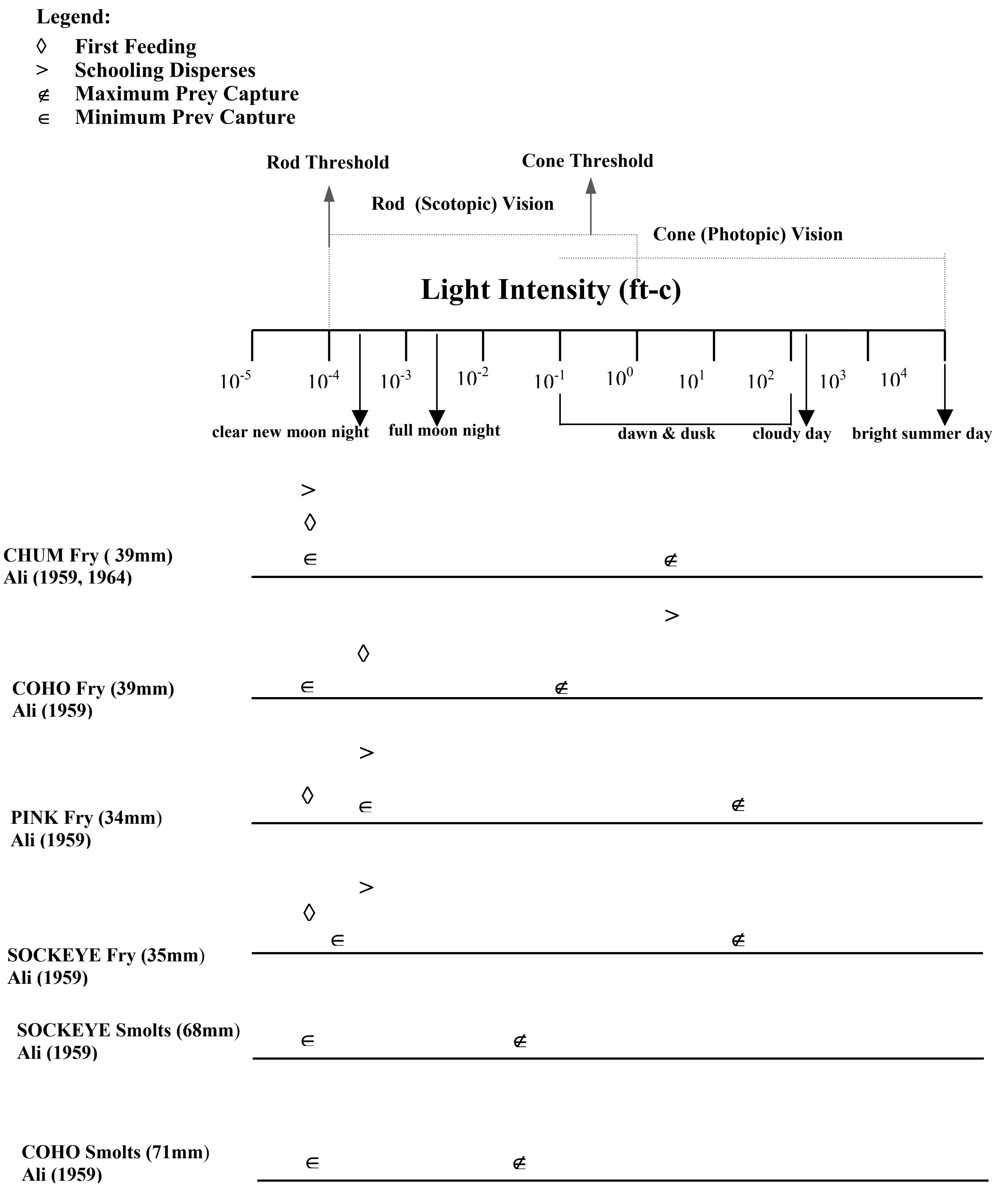


Figure 5. Measured juvenile salmon behavior patterns related to light intensities

Prey abundance and prey capture are both factors in the carrying capacity of a given habitat. In New York Harbor, Able et al (1998) found juvenile fish abundance to be reduced under piers when compared to open-water or areas with only piles but no overwater structure. This is likely due to both limitations in prey abundance and prey capture. In a New York study of pier impacts to fish growth and prey resource abundance, Duffy-Anderson and Able (1999) compared growth rates of caged juvenile fish under municipal piers to those of fish caged at pier edges and open waters beyond piers. Those fishes caged under the piers showed periods of starvation potentially making these individuals more vulnerable to predation, physiological stress and disease. Along the pier edge, they found growth rate variability to be very high and to be likely light related. They concluded that light availability is likely an important component of feeding success. They concluded that large piers do not appear to be suitable habitat for some species of juvenile fishes and that increased sunlight enhanced growth.

Light perception is dependent upon the light transmission qualities of the water environment coupled with the spectral qualities of the fish retinal visual pigments (Ali 1959; 1976; Brett and Groot 1963; Fields 1966; Hoar 1951; Hoar et al 1957; McDonald 1960; McFarland 1975; Mork & Gulbrandsen 1994; Nemeth 1989).

Habitat and genetics determine the light absorption capacities of fish visual pigments. Capacities differ across the solar spectral compositions specific to the species' habitats (Wald et al. 1957; Wald 1960). In the case of salmonids, as they move from fresh to salt water their retinal pigment changes. These habitat changes trigger changes in their visual sensitivity from the red-yellow hues of freshwater streams to the blue color of estuarine and ocean waters. Figure 6 shows the visual cell layers of the juvenile chum eye.

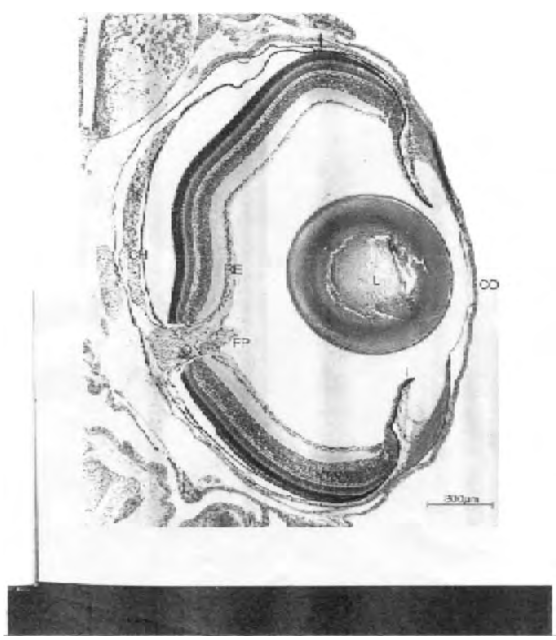


Figure 6. Transverse Section Through the Eye of a Juvenile Chum Salmon (RE=retina) (From Ali and Anctile 1976)

Light is received along the external limiting membrane of the retina (RE) with visual cell layers of the retina responding to varying intensities of light reception. The visual cell layers consist of two types of photoreceptors, rods, and cones. These retinal pigments have different light thresholds and respond to light and dark with changes in their relative positions. When the light intensity is above the retinal pigment and cone thresholds, the eye assumes the light-adapted state. In this state, the cone cells contract to be near the source of light, while the rod cells elongate away from the light. When the light intensity falls below threshold values, the cones expand away from the light source while the rod cells contract toward the light in direct proportion to the logarithm of the light intensity (Ali 1959). In freshwater laboratory studies, Ali (1959) found that when the light drops below the rod threshold, the school disbands and feeding by visual means ceases, with the extent of expansion and elongation being dependent upon ambient conditions (Ali 1975).

The time period for such physiologic changes in response to light variations vary across species and life stages. At the juvenile stage, the time required for light-adapted chum and pink fry to fully adapt to dark conditions was found to range from 30 to 40 minutes. However, the time required for dark-adapted fry to adapt to increased light conditions was found to range from 20 to 25 minutes (Brett and Ali 1958; Ali 1958; Protasov 1970). During these periods of transition, the juvenile chum's visual acuity ranges from periods of blindness to a slightly diminished capacity, depending upon the magnitude of light intensity contrasts. As the animals become older, the time required for light adaptation generally shortens. The time necessary to adapt to the dark, on the other hand, tends to increase with age. The progression of retinal changes from one state to another is influenced by the intensity of the introduced light and the intensity of light to which the fish have been previously exposed (Ali, 1962; 1975; Fields 1966; Protasov 1970; Puckett and Anderson 1987).

Contrasts in light levels determine the progression of changes the eye undergoes with previous light levels affecting the speed of transition. Fish previously exposed to higher light intensities become dark-adapted more slowly than those previously exposed to lower light intensities (Ali, 1962). A review of the literature on juvenile salmon behavioral responses to ambient and artificial light also revealed behavioral differences between species. Species that occupy and defend stream territories, such as coho, tend to be quiescent at night while species that disperse to estuaries, such as chinook, pink and chum typically school, show nocturnal activity, and demonstrate negative phototaxis (i.e. an aversion to light) (Godin 1982; Hoar 1951). Like salmon, most marine fish in Puget Sound, Hood Canal, and Strait of Juan de Fuca rely on vision for survival. Duffy-Anderson (2001) reported that studies of fish behavior under large dock and apron structures in New York Harbor revealed that although prey resources existed under these terminals, the fish were unable to capture and feed on those resources. This was likely due to the very dark conditions found under the pier aprons.

Overwater Structure Effects

Overwater structures can create sharp underwater light contrasts by casting shade in ambient daylight conditions. They can also produce sharp underwater light contrasts by casting artificial light in ambient nighttime conditions. The impacts of altered underwater light environments upon juvenile salmonid physiology and behavior are well documented (Ali 1958, 1962; Browman et al. 1993; Coughlin and Hawryshyn 1993; Dera and Gordon 1968; Fields and Finger 1954; Hawryshyn and Harosi 1993; Nemeth 1989; Novales-Flamique and Hawryshyn 1996; Puckett and Anderson 1987). Changes to ambient underwater light environments pose a risk of altering fish migration behavior and increasing mortality risks. Heiser and Finn (1970) first documented an observed reluctance of juvenile salmonids to pass under docks. Since that time, findings have demonstrated that fishes responses to piers are ambiguous with some individuals passing under the dock, some pausing and going around the dock, schools breaking up upon encountering docks, and some pausing and eventually going under the dock (Pentec 1997; Weitkamp 1979, 1982). The Taylor study (1997), at the Pier 64/65 guest moorage facility in Elliott bay, Seattle, and the Weitkamp study (1981) of Shilshole Bay fish resources both reflected a distribution of juvenile salmon along the outer bulkheaded parameters of the marinas without significant distribution under or around the floating piers. In Weitkamp's (1982a) study of Port of Seattle Piers 90 and 91, fish under-pier distribution appeared to be affected by light. Studies in the Puget Sound region have suggested that under-pier light limitations could result in the following behavioral changes: 1) migration delays due to disorientation; 2) loss of schooling in refugia due to fish school dispersal under light-limited conditions, and 3) increased size-selective predation risk due to changes in migratory routes to deeper waters to avoid light changes. In an experimental release at the Port Townsend Ferry Terminal, Shreffler and Moursund (1999) found released chinook fry ceasing their migration at the terminal's shadow line rather than immediately continuing under the terminal. Continued video monitoring and surface observations verified that the fry consistently swam from the dock shadow line into the light followed by their immediately darting down and back into the light-dark transition area again. As the sun dropped along the horizon and the shadow line moved in under the terminal dock, the chinook school appeared to follow the shadow line staying with the light-dark transition area (Shreffler and Moursund 1999).

Daytime Light Regime: Shading

Daytime light reduction caused by dock shading poses a risk of changing daytime behavior and driving the migration of juveniles into deeper waters during daylight hours. Such a move to deeper waters likely increases the risk of predation by larger predators occupying pelagic waters. Ratte (1985) found that light levels reducing ambient light by 2-4 orders of magnitude were still sufficient for feeding and schooling of juvenile salmon.

Scientific evidence supporting these contentions is highly uncertain. Only meager quantitative assessment of predation around overwater structures has been attained. In an attempt to verify whether or not there was enhanced predation associated with overwater structures, Ratte (1985) documented limited predation. However, it was relatively insignificant and limited to only one or two species. Few studies have actually validated the incidence of observed predation events with stomach content analysis. Also, the significance of predation to the migrating population has, to our knowledge, never been assessed empirically. Simenstad et al. (1999) found no studies attributing predation mortality to overwater structures.

Nighttime Light Regime: Artificial Lighting

Just as docks can create sharp underwater light contrasts by casting shade under ambient daylight conditions, they can also produce sharp underwater light contrasts by casting light under ambient nighttime conditions. These changes to the nighttime ambient light regime pose a risk of impacting fish migration behavior and placing them at increased mortality risk also. These light induced behavioral changes are consistent with behavioral observations documented around docks throughout the Puget Sound (Prinslow et al 1979; Weitkamp 1982a & b; Ratte and Salo 1985; Taylor and Willey 1997; Pentec 1997; Fields 1966; Johnson et al 1998).

Ambient light patterns changed by nighttime artificial lighting on dock structures can change fish species assemblages and pose increased risk of predation by subsequent changes in nighttime migration, activity, and location of predators. Prinslow et al. (1979) observed chum congregating below security lights. Significantly greater light intensities (200-400 lux) appeared to attract and delay chum. No large-scale aggregation of chum appeared to result from security lighting. However, predators known to feed on chum were not observed being measurably affected by wharf security lighting. However, dogfish, important herring predators, were attracted to security lighting. Thirty-nine predators were observed with lights on, while only two were observed with lights off. Few tests were conducted. Prinslow (1979) also suggests that lighting may provide increased feeding opportunities at night for chum. Prinslow suggests that after several years of continuous lighted use, the wharves at Bangor might harbor increased populations of predators. Studies in the Columbia, Snake and Sacramento Rivers and in marine waters in British Columbia have demonstrated significant predation on salmonids (e.g. squawfish waiting for outmigrants at fish ladders or below spillways and an instance of significant marine mammal predation of salmonids under a lighted bridge) with the assistance of artificial nighttime lighting. The level of intensity of artificial night lighting appears to influence the behavior of fishes. Prinslow (1980) found that lighting of 2-13 lux did not their fish catches. However, lighting of 200-400 lux did appear to attract salmonids at times but not consistently. How the response of apparent attraction of high intensity night lighting has not been fully explored and warrants further exploration to test for the extent of predator attraction to nightlighting and varying alterations to ambient nightlight conditions.

In addition to the above potential lighting effects on predation patterns, the reduced availability of vegetative cover due to light limitation serves to reduce refugia resources for juvenile salmonids and other small nearshore fishes and shellfish during vulnerable juvenile life stages. Reduced cover poses the risk of increasing their susceptibility to size-selective predation.

Prey Resources

The nature of the plant species present in a given location determines fish and shellfish prey resource composition and production and ultimately fish distribution and growth rates. An example of this was reported by Thom et al. (1988) in the Drayton Harbor study of epibenthos densities and fish assemblages. During the study period from Sept. 10, 1987 to Oct. 1988, juvenile salmon density was by far the highest on April 29th at the eelgrass habitat site which was also found to support, by far, the highest salmon prey density and the highest epibenthos density on that date. Similarly, total fish density increased dramatically immediately following a peak in maximum epibenthos and the most rapid increase in *Zostera* biomass (Thom et al. 1988). These epibenthic prey assemblages of copepods, such as the harpactioids, are known to feed upon bacteria, epiphytes, plant detritus, and diatoms (Cordell 1998). It is consistently documented that the vegetation assemblages associated with eelgrass, in particular, support increased magnitudes of juvenile salmonid epibenthic prey (Thom et al. 1988,1990; Simenstad et al. 1980, 1988a). Within the harpacticoid taxon, the *Harpacticus uniremus,* has been found to be primarily associated with epiphytic plants growing on algae and eelgrass while the *Tisbe* is associated more with detritus. Similarly, the *Harpacticus* is less likely to be found in low light conditions while the *Tisbe* tends to be found in areas high in detritus irrespective of light levels. Simenstad (1994) describes seagrass communities as the "marine analog to tropical rain forests in structural complexity, biodiversity, and productivity". Studies of eelgrass communities in Padilla Bay show *Harpacticus uniremis,* and *Zaus* spp. and *Tisbe* to be unique to the eelgrass epiphyte assemblage and the principal prey of juvenile chum salmon (*Oncorhynchus keta*), Pacific herring, Pacific sand lance, and surf smelt (Simenstad et al. 1988a). The complex structure of eelgrass communities and their associated epifauna and epiflora are also thought to limit the success of predators that typically associate and feed in unvegetated communities (Heck and Orth 1980; Heck and Thoman 1981; Miller et al. 1980). In addition to serving as substrates for epibenthic prey resources and spawning and rearing of Pacific herring and shellfish, *z. marina* exports a tremendous amount of organic material to pelagic and open-ocean waters. Studies using stable carbon isotopes as biomarkers show that organic matter generated by *Z.. marina* is strongly represented by the C-enriched autotrophs of the *Z. marina* habitat rather than the C-depleted organic matter of terrestrial plants or neritic phytoplankton (Simenstad 1994). Eelgrass beds have also been found to be responsible for the trapping and consumption of organic matter transported into the eelgrass habitat itself (Phillips 1984).

Overwater Structure Effects

Light is considered to be the primary factor limiting the survival and distribution of eelgrass (Dennsion et al. 1993). Given the strong association of important fish prey resources with eelgrass, limitations in the extent of eelgrass pose a potential risk of reduced prey resources. Prey resource limitations likely impact migration patterns and the survival of many juvenile fish species. For smaller fish less than 50mm in length, residence times along particular shorelines are thought to be a function of prey abundance (Simenstad et al. 1980). In Hood Canal studies on outmigrating juvenile chum, Simenstad et al. (1980) found juvenile chum fry (30-45mm) to feed extensively upon small, densely distributed harpacticoid copepods selecting for the largest copepods available. Similarly, Miller et al. (1976) reported that juvenile chum fed predominantly on epibenthic harpacticoid copepods in April and May and later. As the fish grew in size, their diet content became composed more of larger epibenthos and pelagic crustaceans. Consistent with other studies, the highest densities of harpacticoid copepods occurred in magnitudes 4-5 times higher in eelgrass stands than in sand habitat without eelgrass. Similarly, although shells and other substrates can provide cover for juvenile Dungeness crab, Stevens and Armstrong (1984) found the largest abundance of first post-larval stage crabs of 0+ age in eelgrass beds. This was also consistent with studies by Butler (1956) at Graham Island, Canada with the highest abundances in early crab instars found in eelgrass beds. Specific habitat needs vary across species and life history stages. The above-referenced studies also report that standing stocks of gammarid amphipods, a principal prey of larger (45-60mm) chum, chinook, and sole appeared to be higher in more current swept habitats with coarser substrates in marine macroalgae (*laminaria, ulva*) dominated areas. Weitkamp (1991) found non-apron stations to have significantly higher total epibenthos and juvenile salmonid prey epibenthos than the apron stations. Variations in substrate and slope also appeared to influence prey abundance.

Wave Energy and Substrate Regimes

Wave Energy, Substrates and Prey Resource Availability

The abundance and types of epibenthic prey available for juvenile salmonids and other small nearshore fishes appear to be closely linked to bottom elevation and gradient and wave and current exposure. The elevation ranges of main concern for salmon prey is +8 to -8 feet MLLW. In early parts of the growing season, high elevation bottoms in protected waters have been found to have high concentrations of epibenthic prey due primarily to the greater sunlight and plant productivity occurring there. In later seasons, they have smaller abundances than lower elevations. Similarly, sampling of bare sand and kelp-covered cobble at the Elliott Bay Marina (1990) showed prey density ratios to range from 1:11 to 1:16 (sand:kelp) with the higher prey densities attributed to increased plant production in the kelp-covered cobble habitat. Wave energy conditions are also an important component in the suitability of habitat for *z. marina* colonization and propagation and the utilization of that habitat by epibenthic copepod communities that support juvenile fish (Simenstad et al 1988b). Phillips (1972, 1978, 1984) reports that moderate current speeds appear to enhance *z. marina* growth. It is believed that currents make nutrients and CO_2 more readily available to the plant by breaking down the leaf surface diffusion gradient. The plant does not appear to grow in the presence of regular wave shock with too much current tearing the leaves, eroding the supporting substrate, and burying the plant (Bulthuis and Woelkerling 1983; Harlin et al. 1982; Phillips 1974). However, currents too slow will allow dominant algae colonization on *z. marina* leaves that will compromise seagrass survival (Sand-Jensen 1977; Phillips et al. 1978; Sieburth and Thomas 1973). *Z. marina* tends to grow in protected conditions and has a dampening effect on wave action as the leaves have been found to reduce current velocity and turbulence (Fonseca 1981; Fonseca et al. 1982; Ginsburg and Lowenstam 1958).

In addition to plant growth, substrate size and slope have been found to play an important role in the production and trapping of the detritus and bacteria that is consumed by epibenthic prey and, consequently, the abundance of epibenthic prey. Wave and wind exposure and beach slope influence substrate stability and plant propagation with epibenthic prey abundances found to be three to ten times greater in protected habitats than exposed areas and three times greater in gentle versus steep slopes. Extreme exposure and steep slopes also likely limit access by juvenile salmonids. Protected water has been found to have one to four times the epibenthic densities of unprotected water and algae-covered rocks have been shown to have 11-17 times the epibenthos of wave-washed sand (Jones and Stokes 1990). Similarly, in a study of epibenthos at Drayton Harbor in Blaine, a protected mudflat habitat, was found to support higher microalgae biomass, which supported higher juvenile salmon prey density, compared to a mudflat exposed to wind driven waves. Plant biomass and prey density also peaked four weeks earlier on the protected mudflat compared to the exposed mudflat and maximum fish densities in the eelgrass habitat were found to exceed mudflats habitat by 2.4-2.8 times (Thom et al. 1988). Consistently, the Simenstad et al. (1988b) study of nearshore communities in Neah Bay, found epibenthic harpacticoids to be particularly high in eelgrass beds at the head of the bay with lower abundances found in those eelgrass beds receiving higher wave energy. Jones and Stokes (1990) reported substrates at tidal elevations below +2 ft MLLW to have an average of four times the abundance of prey animals compared to substrates at higher elevations and eight times the prey abundance found at elevations below -3 ft. Weitkamp (1991) found that sand and gravel substrates had increased epibenthic production compared to rock riprap substrates. In a review of gravel mitigation projects in Puget Sound, Jones and Stokes (1990) summarized the findings of projects in highly developed estuarine areas such as the Port of Bellingham, Port of Seattle, Port of Tacoma and two recreational facilities in Elliott Bay and Gig Harbor. Table 12 summarizes key controlling factors influencing epibenthic prey standing crop or "habitat value" in those highly developed urbanized habitats.

Overwater Structure Effects

Wave energy and water transport alterations imposed by docks, bulkheads, breakwaters, ramps, and associated activities alter the size, distribution, and abundance of substrate and detrital materials required to maintain the nearshore detrital-based food web. Alteration of sediment transport patterns can present potential barriers to the natural processes that build spits and beaches and provide substrates required for plant propagation, fish and shellfish settlement and rearing, and forage fish spawning (Parametrix and Battelle 1996; Penttila 2000a; Thom et al. 1994, 1997; Thom and Shreffler 1996). For example, experimental investigations by Shteinman and Kamenir (1999) demonstrate how the construction of jetties and other in-water structures can partially or completely disrupt the longshore transport process. In a natural hydrodynamic regime, size separation of sediments proceeds along the bottom slope with wave flow impact, steep sloped bottoms move larger sediments towards the shore accumulating a thin near-shore strip along the shoreline. While smaller sediments were found to move towards deeper areas where they accumulate or were transported further by currents, the opposite was found to occur on gentle bottom slopes where smaller size sediments accumulated near the shore and coarser sediments were moved towards the deeper areas (Shteinman and Kamenir (1999). Such changes in wave energy across substrates determine the size and distribution of sediments and associated detritus. Throughout Puget Sound, Hood Canal, and Washington's coastal estuaries, variations in the interface between bottom slopes, wave energy, and sediments build beaches, nearshore substrates, and habitats unique to the climate, currents, and conditions of specific sites. Although the specific characteristics of the factors at play vary with the geology of each region or subsystem, it is important to remember that changing the type and distribution of sediment will likely alter key plant and animal assemblages. Wave and current interactions in shallow water (i.e. depths <1.0m) are particularly important to intertidal flora and fauna. For example, along the shallow edge of the tidal water, high suspended sediment concentrations may flow over a mudflat. This passage across the intertidal area potentially deposits large quantities of suspended sediment and nutrients on upper mudflat areas, particularly at slack water (Christie and Dyner

Table 12. Controlling Factors of Epibenthic Fish Prey Abundance in Developed Urban Estuaries in Puget Sound

Factor Type	Characteristic	Habitat Value	Factors Increasing Habitat Value	Factors Decreasing Habitat Value
Substrate Size	Mud/silt	Good to best value	Little or no gradient and relief, tidal pools and open protected waters, with eelgrass, macroalgae or diatom cover	Moderate to steep gradient and smooth relief, exposed, shaded and with no vegetative cover
	Sand	Same as above (coarser sands less productive)	Same as above	Same as above
	Gravel to cobble	Same as above with potential for increased production	Gentle to moderate gradient, uneven rounded rock surface, protected conditions for smaller gravels, to open waters for cobbles, macroalgae and diatom cover--with algae becoming more important for cobble cover	Steep gradients, smooth relief with crushed rock, exposed shaded and with no vegetative cover
	Boulder/riprap	Usually lowest value and production	Same as for cobble above, but suited for steep gradients	Exposed, shaded and with no vegetative cover
Gravel Substrate Type	Angular crushed rock	Good, but tends to pack down; best on steeper slopes	Algae cover, uneven surface, open protected to moderately protected areas	Same as above
	Rounded river rock	Best, but not as good on steep slopes	Middle to low elevations, algae cover, uneven surface, gentle gradient, open protected waters	Exposed, with steep shaded slopes, and no vegetative cover
Substrate Relief	Smooth surface	Good	Middle to low elevations, algae or eelgrass cover, gentle gradient	High elevations, shaded waters, and no vegetative cover
	Irregular or pitted surface	Best in all cases	Same as above, should improve enhancement performance versus smooth surface at higher elevations and/or steeper slopes	Shaded waters and no vegetative cover
Bottom Elevation	High -- +10 to +3 feet	Usually lowest	Algae cover, no shading, uneven surface, protected, gentle gradient; likely to have increased production versus lower elevations early in spring	No vegetative cover, exposed, steep slope, shaded; likely to have lower production versus lower elevations form mid-spring through summer
	Medium- +3 to -3 feet	Moderate to high	Algae cover, protected to semi-protected, gentle gradient, unshaded	Same as above
	Low - -3 to -10 feet	Usually highest	Algae or eelgrass cover, gentle gradient, unshaded	Same as above
WindWave Protection	Protected	Usually best production	Algae or eelgrass cover, middle to lower elevations, unshaded gently sloping beaches	No algae cover, shaded
	Exposed	Usually lower production	Algae cover, middle to lower elevations, unshaded, gravel to cobble substrate	Sand or easily displaced substrate, no algae cover; shaded

Source: Jones & Stokes 1990

1998). These are part of the sedimentation and water transport processes that shape the geomorphology and consequently the plant and animal communities relying on the shallow soft sediment habitats of mud and sandflats. Depending on the geomorphology, current transport processes, and climatic conditions of a specific area, overwater structures have the potential to alter these important habitat-building processes.

Dock pilings have also been found to alter adjacent substrates with increased shellhash deposition from piling communities and changes to substrate bathymetry (Penttila 1990a; Shreffler 1999). Similarly, dock uses and construction activities are known to limit underwater light and redistribute sediments through prop scouring, vessel shading, and pile driving (Parametrix and Battelle 1996; Thom et al. 1996). These changes in substrate type can change the nature of the flora and fauna native to a given site. In the case of pilings, native dominant communities typically associated with sand, gravel, mud, sand, and seagrass substrates are replaced by those communities associated with shell hash substrates.

Other Mechanisms

Water Quality

Marinas as Habitat

Marinas have been found to attract large populations of juvenile salmon and baitfish and provide permanent habitat for a variety of other fish (Cardwell et al. 1978; Heiser and Finn 1970; 1980; Penttila and Aguero, 1977; Thom et al. 1988; Weitkamp 1981). This attraction is likely due to the low hydraulic energy similarities between a marina environment and an embayment (Cardwell and Koons 1981). This magnifies the importance of maintaining water circulation at levels that move and mix water layers thereby maintaining healthy dissolved oxygen and temperature levels for fish and shellfish.

Contaminant Loading

Studies demonstrate that contaminants introduced to the marine water and ingested by marine organisms are passed along through the marine food web and can ultimately interfere with animal reproductive viability and population sustainability (Jones, 1996; Johnson et al. 1991, 1993, 1994, 1995; Lee 1985; O'Neill 1995; 1996; West 1996,1997, 2000). Nutrient and contaminant loading from vessel discharges, engine operation, prop scouring, bottom paint sloughing, boat washdowns, haulouts, boat scraping, painting, and vessel maintenance activities pose water quality degradation and sediment contamination risks (Cardwell et al. 1980; Cardwell and Koons 1981; Eisler 1998; Hall 1988; Krone et al. 1989a, 1989 b; Waite et al. 1991). Creosote and other wood preservative products used on dock structures also pose additional water quality and sediment contamination risks of contaminant leaching. See the accompanying white paper (Poston 2001) on treated wood products for further information on this topic.

Nutrient Loading

Although the duration, intensity and availability of PAR light lies at the core of determining plant productivity and distribution patterns, plant productivity also depends upon the combined forces of temperature, salinity, wave action, and nutrient conditions. The rate of plant photosynthesis depends upon numerous factors, including inorganic carbon and nitrogen supplies, temperature, pH, circadian rhythms, and plant age (Lobban et al. 1985).Although all primary producers require nitrogen and phosphorous for growth and metabolism (Raymond 1980), plants differ in their nutrient requirements. Nutrient conditions that favor the production of phytoplankton and algae over higher plants, such as seagrasses, may produce algae to such an extent so as to reduce the light available for eelgrass growth. For example, the addition of nitrogen forms, such as NO3 and NH4 would likely increase algal growth until another factor, such as phosphorous, light, or oxygen becomes a limiting factor.

Variations in these key environmental factors lay the groundwork for biological interactions and competitions that can impact growth and reproduction patterns across varying plant species. This includes the relationship between higher plants and epiphytic bacteria, fungi, algae, sessile animals, and predation by herbivores (Lobban et al. 1985).

Physical Structure Effects

A growing body of literature, accumulated over the past 30 years, documents what is known about the impacts of overwater structures to important habitats for juvenile marine fishes and juvenile salmon migratory corridors in the Pacific Northwest. In this section, we identify those information sources and present the scientific uncertainties and empirically supported evidence presented in those sources pertaining to how specific types of overwater structures and associated activities can create physical and behavioral barriers to migrating juvenile salmon and other marine fish and shellfish populations. This paper also identifies data gaps and makes recommendations for further research. The paradigm under which we present these findings can be stated as:

Overwater structures have been documented to pose the following potential risks for increasing the mortality of juvenile fishes utilizing shallow estuarine and nearshore marine habitats.

- "Behavioral barriers" that can deflect or delay migration
- Prey resource production and availability (i.e. "carrying capacity") limitations
- Altered predator-prey relationships associated with high intensity night lighting changes to the nighttime ambient light regime

Reflective of this paradigm, we have classified our findings on the overwater structure effects due to light, wave energy, and substrate regimes as due to:

- Light Reduction
  - Vegetation Responses
  - Animal Responses
  - Migration
  - Predation
- Wave Energy and Substrate Changes
- Other Mechanisms
  - Water Quality

Fixed Piers and Pilings

Throughout the region, numerous studies over the past 30 years have documented the effects of fixed piers and pilings to fish and plant assemblages. Table 13 captures findings from these sources.

Table 13. Dock Study Findings

Study	Animal Responses		Vegetation Responses	Findings
	Migration	Predation	Prey Resources	
Burdick & Short 1995 Massachusetts			• Dock features impact light availability and eelgrass quality. • Sediments scoured by prop scouring.	• Dock Height is #1 variable for predicting light avail. & eelgrass quality. • Docks should be over 3 m above bottom; N-S orientation, and placed in deep waters.
Cardwell, et al. 1980 Skyline Marina, Anacortes				• Oysters in marina were high in copper and zinc concentrations. Likely due to bottom paint leaching. • Marina water significantly warmer and more oxygenated than the bay. Surface zooplankton less dense and rich in marina.
Dames & Moore 1994 Manchester Naval Pier	• Migration dependent upon preferred prey resource avail. Most catches and observations were nearshore.	• No determination of pier causing increased or decreased predation.		• Pier design diminishes its shade impact on prey resources.
Duffy-Anderson & Able 1998 New York Harbor			• Juvenile fish (flounder & Walbaum) unable to feed on prey resources in dark aproned areas.	• Although prey resources were present under pier aprons, fish held in under-dock environments were in starved condition. Light limitation is believed to limit prey capture.
Fresh et al. 1995 Bellingham San Juans			• Reduced plant growth from shade dependent upon dock design & use. Docks & pilings changed community structure and substrate.	• Shading is the major reason for decreased eelgrass around and under docks. Docks significantly reduce eelgrass density. Size of shading dependent upon dock characteristics.
Heiser & Finn 1970 Puget Sound	• Juv. Pinks and chum concentrated inside marinas were reluctant to leave shoreline for bulkheads or breakwaters. Sizes 50 – 70mm moved offshore to deeper waters in response to large pier.	• Unable to derive actual predation rates. Predation appeared to be discouraged due to human presence.		• Very little evidence of predation.
Loflin 1993 Charlotte Harbor			• Seagrass reduced by dock shadow	• Docks contribute substantially to seagrass loss.

Table 13. Dock Study Findings (continued)

Study	Animal Responses		Vegetation Responses	Findings
	Migration	Predation	Prey Resources	
Miller 1980 Seattle Terminal 91 & 37	• Fish abundance in the Terminal 91 area is only 20% as large as comparable shallow-mud sand habitats without piers.			• Riprap and pilings act as artificial reefs attracting surfperch and rockfish w/ surfperch being dominant. • Common species: Eng. Sole, rock sole, flathead sole, Dover sole, speckled sanddab, shiner perch, pile perch, brown and quillback rockfishes.
Olson et al. 1997 Ferry Terminals			• Assuming summer condition plant adaptation, there is insufficient light at all stations. Assuming winter plant adaptation, there is sufficient light at all stations.	• Dock shade footprint is measurable. • Shade footprint dependent upon dock dimensions, bathymetry, piling configs., lat/longs. and time of day
Pentec 1997 Everett Harbor	• Fish encountering piers milled around w/ schools breaking up. Most fish along shoreline w/fewer fish seen at piers. Smaller schools at piers. Most pierside observations were at shoreline end of piers.	• Observed: cormorant and larger salmonid preying on juveniles.	• Higher abundances of juv. salmon observed along riprapped and bulkheaded shores rather than along piers. Feeding only observed along riprap shoreline.	• Unable to assess net effect of juv. salmon encountering piers. Schools dispersed and fish moved around piers upon encountering piers. Inferences on under- pier behavior were not empirically supported.
Penttila & Aguero 1978 Birch Bay Marina	• Marina heavily utilized by juv. marine fishes. Likely due to adjacent spawning areas outside marina. Chinook,chum, pinks, sockeye, and trout found in marina. Marina may trap fish in it.	• Predation is a concern due to the many co-occurring sizes and species of marine fishes. Steep sided marina basin provides little protection. Evidence of predation is minimal.	• Prey resources may be compromised by the co-occurring juveniles that share specific prey resource species such as calanoids and harpacticoids.	• Most abundant marine fish were Pacific herring. Most widely distributed were smelt. Followed by 3-spine stickleback, anchovies, and sand lance were also in abundance. Other marine species include sculpins, penpoint gunnels, pile perch, surfperch, pipefish, poachers, tubesnouts, and Dungeness crab.
Penttila & Doty 1990 Anacortes & Hood Canal			• Net loss in veg. due to shade. Fixed docks can reduce eelgrass densities to zero depending on dock features. Pilings alter community structure, bathymetry, and substrates.	• Dock shading in littoral zones largely eliminated existing macroflora. Dock designs can mitigate some impacts.

Table 13. Dock Study Findings (continued)

Study	Animal Responses		Vegetation Responses	Findings
	Migration	Predation	Prey Resources	
Prinslow et al. 1979 Bangor, Hood Canal	• Artificial lighting can delay migration at high intensities while lower intensities did not.	• Insignificant predation detected. < 4% of predators contained salmonid remains. Few implicated predators observed.		• Too few tests to conclude migration delay cause.
Ratte and Salo (1985) Commencement Bay	• Coho and pink appear to prefer dark under-pier habitat during early marine life-history	• No evidence of predator aggregations in under dock habitat		• Effect of artificial lights on fish abundance is inconclusive under piers.
Roni and Weitkamp (1996) Manchester Naval Fuel Pier	• 1996 beach seines findings showed juv. chum were not travelling out around the end of the pier but likely passing under the pier.		• Juvenile chum salmon remained in shallow, nearshore areas with cover and fed on epibenthic organisms upon their first entry into saltwater.	• Pier design (i.e. structural design and materials) reduced light limitation effects. Chum salmon size data indicated that smaller chum were feeding nearshore and moving offshore as they got larger
Salo et al. 1980 Bangor, Hood Canal	• Offshore movement of small juv. chum around piers appeared to occur.. Outmigration speed decreased as migration period progressed. • Movement from the epibenthic zone to the pelagic zone occurred at night.	• No significant predation observed.		• Small fry were found further offshore when they were around piers than in habitats that did not have piers. • Juv. chum yearly changes in location preferences likely reflected pier construction activities.
Taylor & Willey 1997 POS Pier 66 Bell Harbor	• Juv. salmon appeared to migrate through facility N-S pattern using fish passage opening, shorelines and edges of dock structures.	• No unusual congregation of predators observed. On occasion grebes & mergansers seen catching fish.		• Fish migrated through the facility using shorelines and edges of facility structures. Considerable predation not observed. No avian predation at peak migration.

Table 13. Dock Study Findings (continued)

Study	Animal Responses: Migration	Animal Responses: Predation	Vegetation Responses: Prey Resources	Findings
Thom et al. 1997 Bremerton, Kingston, Southworth and Vashon Ferry Terminals			• Bremerton, the least vegetated habitat had far fewer fish. All sites except Bremerton had substantial eelgrass beds. Damage to eelgrass beds was observed from construction, shading and prop wash. Large stands of drifting ulvoid algae observed.	• Causes of bare patches are unknown but believed to be related to prop wash, shading and terminal construction. Further study of restoration potential is needed.
Thom et al. 1996 Vashon Pass.- Only Ferry			• Light limitations, substrate erosion from vessel shading and prop wash.	• Benthic communities impacted by sediment and light changes.
Thom & Shreffler 1996 Clinton, Edmonds, Port Townsend Ferry Terminals			• Benthic plant taxa absent or severely limited under terminals	• Substrate changes observed from shell hash accumulation associated with piling communities. Substrate changes due to prop scour. Terminal construction appeared to eliminate eelgrass in places without recovery. Annual maintenance activities with tugs and barges disturb bottom sediments and eelgrass.
Thom et al. 1988 Blaine Marina	• Salmon densities in Mudflat:eelgrass habitat = 1:8		• Light energy correlated to increased primary production. Epibenthos and fish density correlated to vegetation types.	• Fish assemblages in eelgrass habitat showed increased species richness over mudflat habitat. 14 acres of high intertidal mudflats = 3 acres of eelgrass habitat based on prey resource abundance.
Weitkamp & Shadt 1980 Duwamish Waterway	• 30-49mm salmon fed on nearshore epibenthos. 50-89mm fish fed on pelagic zooplankton. 80+mm fish fed entirely on pelagics.			• Chinook – mid May peak w/size 71-74mm and used shallow shoreline. Chum April (39-40mm) with steady increase to 81mm. Peaks in early April & May; coho in May only. Pinks 40-47mm in late April-May.

Table 13. Dock Study Findings (continued)

Study	Animal Responses		Vegetation Responses	Findings
	Migration	Predation	Prey Resources	
Weitkamp 1982 Seattle Terminal 91	• Juv. chum and chinook seen feeding on west side of piers and near log booms. Juv. reluctant to pass under piers except where piers were open to light.			• Fish distribution appeared to correlate to light availability.
Weitkamp 1981 Shilshole Bay Marina	• 38-53mm chum migrated along bulkheaded shoreline. 120-127mm coho found in open waters of the marina.		• Predation not observed.	• Large schools of Juv. chum (38-53mm) observed migrating along bulkheaded shoreline only. Not found under floating docks or riprap breakwater. Large school of coho (120-127mm) found in open waters of marina. Herring found along bulkheaded shoreline. Cabezon, greenling perch, flatfish and rockfish were also along bulkheaded shoreline and breakwaters.
Williams & Weitkamp 1991 Sitcom & Blair Waterways		• No predators observed	• Non-apron sites had higher total epibenthos than apron sites.	• Riprap is less productive than finer substrates. Results on substrate and slope effects to prey densities were inconclusive. Harpacticus densities were significantly reduced under aprons.

Light Reduction

Vegetation Responses

Light regimes under fixed docks show considerable variation depending upon the characteristics of the structure itself. Burdick and Short (1995) found dock height over the marine bottom to be the most important variable for predicting the relative light reaching the eelgrass and hence eelgrass bed quality under the docks. Increased dock height diminishes the intensity of shading by providing a greater distance for light to diffuse and refract around the dock surface before reaching the eelgrass canopy. A north-south dock orientation has been shown to increase underwater light availability by allowing varying shadow periods as the sun moves across the sky. This movement of the shade footprint decreases the stress imposed on eelgrass (Burdick and Short 1995; Olson et al.1996,1997; Fresh et al 1995). In studies at ferry terminals in Puget Sound, Thom and Shreffler (1996) found the level of photosynthetically active radiation (PAR) to be substantially reduced under terminal docks with PAR levels increasing rapidly in locations away from the edges of the terminals. In the laboratory component of these under-dock studies, Thom and Shreffler (1996) found PAR variations to also affect epiphyte production. Similarly, in studies of ferry docks at Clinton, Bainbridge, Southworth and Clinton, Blanton et al. (2001) found east/west dock orientation to decrease light availability to the bottom to an extent that precluded the light requirements for eelgrass survival. The study also suggested that macroalgae density could also decrease light and out compete eelgrass at some sites.

Piling density and construction material also determine the extent of light limitation that can alter plant production. Increased numbers of pilings used to support a given dock, increase the shade cast by pilings on the underwater environment. The piling material (i.e. concrete, wood, or steel) also determines underwater light as concrete and steel pilings refract more light to the underwater environment than light-absorbing wood piles. An open-pile structure offers many fish and shellfish benefits over filled structure. A filled structure intrudes on more habitat area, can produce a darker underwater light environment that limits plant growth, and will likely alter fish distribution and migratory behavior. Adequate spacing between piles is important to reduce light limitations to the underwater environment and prevent interference with water and sediment movements (Fresh et al. 1998). Minimizing the number of pilings, using construction materials that reflect light, and increasing the space between pilings can minimize habitat impacts.

Animal Responses

Light is a determining factor in both fish migration and prey capture. Salmon fry are known to use darkness and turbidity for refuge. However, they tend to migrate along the edges of shadows rather than penetrate them (Simenstad et al. 1999). Studies in the northwest have documented this behavioral tendency to use shadow edges for cover during migration (Shreffler and Moursund 1999; Taylor and Willey 1997; Pentec 1997). The underwater light environment also determines the ability of fishes to see and capture their prey. Able et al (1998) found juvenile fish abundance to be reduced under piers when compared to open-water or areas with only piles but no overwater structure. Similarly, Weitkamp (1991) found non-apron stations to have significantly higher total epibenthos and juvenile salmonid prey epibenthos than the apron stations. Variations in substrate and slope also appeared to influence prey abundance. In a New York study of pier impacts to fish growth and prey resource abundance, Duffy-Anderson and Able (1999) compared growth rates of caged juvenile fish under municipal piers to those of fish caged at pier edges and open waters beyond piers. Those fishes caged under the piers showed periods of starvation potentially making these individuals more vulnerable to predation, physiological stress and disease. Along the pier edge, they found growth rate variability to be very high and to be likely light related. They concluded that light availability might be an important component of feeding success. They concluded that large piers do not appear to be suitable habitat for some species of juvenile fish and that increased sunlight enhanced growth. Evidence suggested that this could have been related more to reduced light levels reducing prey capture rates.

In addition to structural light reduction effects, increased turbidity from pile driving and associated construction is likely to reduce primary productivity, interfere with fish respiration, alter the suitability of spawning areas, reduce bottom habitat diversity, and smother benthic organisms (Mulvihill et al. 1980). Sediment disturbance from vessel prop scour is an additional source of turbidity (Thom et al 1996).

Migration

Fixed piers supported by piles vary in habitat impacts. Large, densely located pier aggregations such as the industrial shipping areas in Elliott Bay, Seattle and Commencement Bay, Tacoma contain shorelines lined with large piers and aprons 75 and 130 feet wide and often 2400 feet in length with light levels reduced by 2 -4 orders of magnitude. Based upon light behavior criteria identified by Ali (1959), light levels in areas under the industrial docks near the outer edges are found to be high enough to facilitate feeding and schooling. However, areas nearer to dock bulkheads and at times of ship presence have shown reduced light levels where cessation of feeding and schooling would occur (Ratte and Salo 1985). In studies in the Port of Seattle's Terminal 91, Weitkamp observed juvenile chum and chinook using the zone bordering the large piers in comparably equal abundances to the number using adjacent shoreline areas. He also observed that juvenile salmon were reluctant to pass beneath the pier aprons into darkened areas. Studies have consistently documented a tendency for juvenile salmon to avoid entering shaded habitats (Pentec 1997; Weitkamp 1982; Heiser and Finn 1970). Similarly, Feist (1991) and Feist et al. (1992) found that although salmon fry appeared to be attracted to in-water objects such as piles, they were rarely seen to pass under floating objects. Rather they would pause or move around them. In studies of juvenile salmonid behavior around Port of Seattle Terminals 90 and 91, Weitkamp (1982) observed very marked, significant, and consistent differences between the numbers of juveniles observed on the east side of the piers compared to the west side and between the juveniles observed under a west sun-exposed opening compared to the east opening with predominant distribution occurring in the more sun-exposed west side. Salo et al. (1980) observed that chum salmon appeared to shift from nearshore migration routes to offshore areas upon encountering a wharf in Hood Canal. Similarly, in a pilot study of ferry terminal impacts, Shreffler and Moursund (1999) found that within 5 minutes, released chinook fry stopped their migration at the dock shadow line instead of continuing under the terminal. For approximately one hour of observation, chinook fry were observed and video taped as they repeatedly swam from the dock shadow line to the surface to apparently feed during this period of migratory pause. As the sun dropped lower on the horizon and the shadow line moved under the terminal, the school appeared to follow the shadow line remaining near the light-dark transition area. Similarly, in the Pentec (1997) study of juvenile salmonid behavior in Everett Harbor, juvenile chum were observed milling around with no net gain for periods ranging from 30 minutes to 2 hours in duration. Fewer and smaller schools were observed at piers while the greatest number and largest schools were observed along riprapped shorelines. Similarly, feeding was observed along these shorelines and not under piers. The study concluded that the net effect of juvenile salmon encountering overwater structures was impossible to assess given the available data but that upon encountering piers, fish split up and moved around the piers. Similarly, the Dames and Moore (1994) study of the Manchester Naval Fuel Pier reported most catches of juvenile chum to occur nearshore with fish movement believed to be dependent upon prey resources in adjacent eelgrass beds. The physical design (height, width, orientation, etc.) reduced the shadow cast by the Navy pier and likely diminished its impact on prey habitat.

However, in other instances juvenile chum appeared to be attracted to wharves during daylight hours. Ratte's (1985) findings suggest a preference for dark areas for some species. Based on laboratory studies of juvenile chinook behavior in turbid versus clear conditions, shade at the edge of a dock presents the possibility of juvenile fish using it as cover. Gregory and Northcote (1993) suggest that turbidity can be used by juvenile salmon as a protective cover. Fish responses in Gregory's study supported such a "turbidity as cover" model. Consistently studies of fish behavior around piers have identified the breaking-up of schools upon encountering the shade cast by an overwater structure (Pentec 1997). Taylor and Willey (1996) found that fish tended to use the shoreline and edges of structures in their migration through a marina facility. These studies reflect that the level of darkness does inhibit their ability to pass under the dock. The extent this factor impairs their migration (and potentially their fitness) has not been quantified.

Predation

Overwater structures could increase the exposure of juvenile salmon to potential predators by:

- Providing predator habitat near salmon refugia, such as eelgrass beds
- Reducing refugia, such as eelgrass
- Diverting juveniles into deeper waters upon encountering docks (i.e. migration alteration)
- Altering prey detection through alterations to light and turbidity

However, there is very little empirical evidence to support the above possibilities of increased predation. Lists of potential predators have been cited through the literature of the past 30 years with very little empirical validation. Table 14 identifies suspected predators and the types of empirical validation in existing overwater structure studies.

Table 14. Potential, Observed, Questionable, and Validated Predators of Juvenile Salmon

Fresh et al. (1978) [validated][1]	Prinslow et al. (1982)[2] [validated]	Ratte and Salo (1985) [validated]	Dames and Moore and Biosonics (1994) [not validated]	Taylor and Willey (1997) [not validated][3]	Pentec Environmental (1997) [not validated]
spiny dogfish	spiny dogfish	Cutthroat	Trout	western grebe	cormorants[6]
ratfish	cutthroat[5]	steelhead	steelhead	belted kingfisher	40-cm salmonids
coho	chinook	Dolly Varden	*Pacific tomcod*	red-breasted merganser	
chinook	coho	Coho	Pacific hake	common merganser	
cutthtroat	Pacific hake	Chinook	*buffalo sculpin*		
steelhead	"cottids"	Pacific cod	Great sculpin		
walleye Pollock		Walleye Pollock	Pacific staghorn sculpin		
copper rockfish		Pacific hake	*shiner perch*		
quillback rockfish		*Pacific tomcod*	*striped perch*		
Pacific staghorn sculpin[4]		Prickly sculpin	*C-O sole*		
Great sculpin		Pacific staghorn sculpin	*English sole*		
cabezon		brown rockfish	rock sole		
rock sole			starry flounder		
starry flounder					

Normal typeface = potential predators
Double underline = validated by stomach contents or unambiguous observation
Italicized = questionable.
(Simenstad et al. 1999)
1. Validated by stomach contents analysis on all species in this list of potential predators
2. In Prinslow and Bax (Chap. 2)
3. No stomach contents analysis or otherwise unambiguous determination; observation only
4. Stomach contents analysis: n=2, 50% (1/2) frequency; chum fry
5. Stomach contents analysis: n=60, 3.3% (2/60) frequency; percent total Index of Relative Importance=1.1%
6. Unambiguous observation

Simenstad et al. (1999) reports that the significance of predation to migrating populations has never been empirically assessed. No studies have examined mortality due to predation much less that mortality is attributable to overwater structures. Upon narrowing down the above list to only those empirically validated predators implicated with overwater structures only cormorants, cutthroat, and Pacific staghorn sculpin remain on the validated predator list without any indication that there were aggregations of these predators. In contrast, inference from existing literature suggests piscivorous fishes, birds, or marine mammals do not aggregate around docks. A more comprehensive evaluation of the issue of predation requires further exploration of predator responses to dock structures and effects, such as nighttime artificial lighting. In ferry terminal studies in Puget Sound, Simenstad et al. (1999) reported the most common and abundant species under terminals to be such species as pile perch (*Damalichthys vacca*), sanddabs (*Citharichthys* spp.) unidentified flatfish (*Bothidae and Pleuronectidae*), identified sculpins (*Cottidae*), English Sole (*Pleuronectes vetulus*), and saddleback gunnels (*Pholis ornata*). Species common but only moderately abundant included striped perch (*Embiotoca lateralis)*, copper rockfish (*Sebastes caurinus*), chinook salmon smolts (*Oncorhynchus tshwaytscha*), and ratfish (*Hydrolagus colliei*).

Fresh and Cardwell (1978) listed 17 potential predators of juvenile salmon in the southern Puget Sound region finding only three (maturing chinook, copper rockfish, and staghorn sculpins) to prey extensively on nearshore fishes. Their analysis of food habits by stomach contents showed only staghorn sculpins having juvenile salmon in their stomach contents. Their study around the dock did not show staghorn sculpins in greater abundance than elsewhere in the study area. Ratte (1985) found sea perch and pile perch to be the most abundant fish under docks. These fish are not potential predators of juvenile salmon. Ratte's data suggested that there was no indication that predatory fish aggregated in under-pier habitat. In fact, the most often reported predators were other salmonids. Ratte's data indicates predators to be less abundant in shaded habitat. There was no evidence of predatory fish targeting juvenile salmonids during the spring outmigration period and gut contents of potential predators did not show a single juvenile salmonid prey item. Similarly, Heiser and Finn (1970) noted that predation in marina areas was less than expected. Weitkamp (1982a) also observed no fish preying on juvenile salmon at Pier 91 at Port of Seattle. Similarly, Salo et al (1980) found less than 4% of the total diet of suspected predatory species (i.e. cutthroat, trout, staghorn sculpins and Pacific cod) to be juvenile salmon.

Alteration of Shoreline Energy Regime

Pilings

Substrate Changes

Pilings provide surface area for encrusting communities of mussels and other sessile organisms such as seastars that prey upon the shellfish attached to the dock. Such changes in substrate result in large depositions of shellhash on the adjacent substrates and changes in the biologic communities associated with those substrates. The introduction of piling communities also impacts eelgrass production. The reef effect of docks enhances seastar and Dungeness crab populations. As shellhash accumulates at the piling base due to seastar predation on piling shellfish populations, the substrate becomes piled high with shellhash. It also becomes a prime settling habitat for Dungeness crab. Both crab and seastar foraging activity can disrupt eelgrass and retard recruitment. In the presence of large crab populations, crabs burrowing into the substrate to avoid predation may significantly inhibit eelgrass recruitment (Thom and Shreffler 1996). Such disturbance of seagrass meadows by animal foraging is also reported elsewhere (Camp et al 1973; Orth 1975; Williams 1988; Baldwin and Lovvorn 1994).

The driving and insertion of pilings alters the substrate area previous used by biota. Ratte (1985) and Penttila and Doty (1990) also found that pilings changed the flow of water around the pilings and over the substrate thereby changing the bathymetry of the substrate and the flow of water in the immediate area. Open pile structures tend to interfere less with sediment transport.

Water Quality

Disturbance and relocation of bottom sediments during pile-driving and removal and from prop scouring can recontaminate the water column and substrate surfaces. It is likely that fishes may also be attracted to construction sites due to the increased suspension of benthic organisms. This magnifies the importance of not contaminating such sites.

Noise

Noise is a documented influence on fish behavior. Fish are known to detect and respond to sound and use sound for prey, predator detection and social interaction (Hawkins 1986; Fay 1988; Kalmijn 1988; Cox et al. 1988; Myrberg 1972; Myrberg and Riggio 1985; Wisby et al. 1964; Nelson 1965; Nelson et al 1969; Richard 1968). Feist (1991, Feist et al. 1992) found that based upon the known range of salmonid hearing, pile-driving noise would be expected to be heard by salmonids within a radius of least 600m from the noise source. Throughout the study of pile driving effects on juvenile pink and chum salmon at Everett Homeport, Feist (1991) found pile-driving operations to affect the distribution and behavior of fish schools around the site. The presence of fish schools during non-pile driving days was two-fold. Salmonids have been observed engaged in "startle" behavior characterized by sudden swimming bursts. Blaxter (1981) found Atlantic herring to show an avoidance response to sound stimuli and Schwarz and Greer (1984) found similar responses on the part of Pacific herring. Sound has been shown to affect growth rates, fat stores, and reproduction (Meier and Horseman 1977; Banner and Hyatt 1973). High intensity sounds can also permanently damage fish hearing (Popper and Clark 1976; Enger 1981; Cox et al 1987). Although pile-driving is not at the same levels of sound as these particular studies, it is considered conceivable that pile-driving sounds can damage salmonid hearing (Feist 1991; Feist et al. 1992). Auditory masking and habituation to pile driving sounds may also decrease the ability of salmonids to detect approaching predators (Feist 1991, Feist 1992).

Floating Docks, Covered Moorages, Houseboats, and Boathouses

Light Reduction

Over the past 15 years, studies in the Pacific Northwest and on the East Coast of North America have identified the effects of light reduction caused by floating structures. Consistently, studies have demonstrated dock height to be the most important dock characteristic to correlate with underwater light reduction (Burdick and Short 1999; Fresh et al. 1995). This is due to the fact that floating docks when compared to fixed docks have the lowest deck height above the bottom with no light cast between the dock and the water's surface. The higher the dock is over the submerged bottom, the more diffuse the shadow. Light diffusion between the bottom of the dock and the water surface result in greater light under the dock. The biological response to reduced light levels on the part of submerged vegetation is basically a reduction in primary productivity. This response reverberates through the nearshore food web. This is due to the functions served by primary producers in the food web. These functions include providing: 1) a primary source of fixed organic matter contributing to the nearshore detritus pool; 2) a substrate for epiphytes and associated animals, as a microhabitat of preferred prey such as harpacticoid copepods and gammarid amphipods, and 3) refugia that offers juvenile fishes shelter from potential predators. This is well documented for animals such as teleost fishes as vision is their primary sense. This strong reliance upon vision and light for migration, rearing, and refuge could make such fishes very vulnerable to changes in the ambient light regime.

Vegetation Responses

Burdick and Short (1999) report that both under dock light and eelgrass bed quality are primarily determined by dock height. Although other characteristics such as width, dock orientation to the arc of the sun, and dock movement also impact light levels, dock height has been found consistently to be the primary light determining characteristic of docks.

Burdick and Short (1995,1999) found floating docks to have severe impacts to eelgrass. Three of the four floating docks they studied having no rooted eelgrass under them. Increased dock height above the bottom was identified to be the most important dock characteristic correlating to eelgrass bed quality. Similarly, the Kalikow Dock study in Montauk N.Y. (Ludwig et al. 1997) reported the exclusion of eelgrass near a floating pier due to insufficient light in the float's impact zone. Their study showed light readings documented at 269 and 284 $uEm^{-2}s^{-1}$ occurring at areas where eelgrass had disappeared. In contrast, stations with readings between 486-580 still had eelgrass presence. These light thresholds are consistent with light threshold findings in the Puget Sound region. Thom and Shreffler (1996) found eelgrass in Puget Sound to be light-limited at levels below $300nMm^{-2}s^{-1}$. Table 15 outlines study findings pertaining to vegetation and floats.

For further discussion on overwater structure impacts to ambient light regimes. see the*Habitat Impact Mechanisms/Ambient Light Regime/Animals and Light*section of this paper.

Covered moorages, houseboats, and boathouses enlarge the shade footprint due to the increased water surface area covered by the structure itself. Weitkamp (1980) noted that the limitation of light transmission under such structures and between docks, extends the cumulative impact or areal extent of the shadow footprint. Since most slips are at least 12 feet wide and often more, a covered moorage would shade the 12 feet between the floats, as well as the area under the floats. Moored vessels alongside floats also enlarge the shadow footprint and increase eelgrass impacts. Such shading impacts to eelgrass can be seen to occur in as little as 18 days (Backman and Barilotti 1976). Another impact specific to floats is float grounding. Fresh et al. (2000) found that a float grounding on eelgrass likely leads to the total loss of eelgrass at one Pacific Northwest study site. Light reduction capacity varies dependent upon combinations of both dock and environmental factors. For example, Penttila and Doty (1990) found no apparent eelgrass loss due to shading under a floating dock secured by anchors and chains. In that case, it was thought that given the winds and current of that site, the degree of movement allowed by the anchor-chain system resulted in no area beneath the dock being continuously shaded, thereby eliminating the stress of shade upon the eelgrass bed. Further study of the formulas combining dock structural characteristics and site-specific environmental factors need to be explored in an effort to limit negative impacts to critical habitat such as eelgrass.

Table 15. Study Findings Pertaining to Vegetation and Floating Docks

Study	Pacific Northwest Location	Dock Impact Findings	Recommendations
Penttila & Doty 1990	Hood Canal, (Twanoh State Park)	• Due to the flexible nature of this chained-anchor float no evidence of negative impact on the stature of eelgrass on or near the float.	• Float was moored with a north-south orientation and with a flexible mooring system that moved with the wind and current resulting in no underdock area being continuously exposed to shade.
Burdick & Short 1995	Massachusetts	• Dock height was the most important variable for predicting under dock light. levels and quality of vegetation • Shoot density increased with distance from dock. • Strongest impact adjacent to docks from prop scouring. • Controlling for dock height, increased under dock light was associated with reduced dock width. • Dock orientation to the sun determines light availability.	• Narrow docks over 3 meters from the marine bottom and oriented north-south had the least impact. • Best dock design is a high dock, north-south orientation, extending to the edge of a navigable channel too deep for eelgrass. • Further study in areas of greater tidal variation is warranted.
Fresh et. al. 1995	Bellingham Bay, San Juan Islands, Hood Canal	• Regular dock movement increased under-dock light and reduced impacts. • 4 out 5 floats studied following construction declined in eelgrass density and 1 increased w/the increase under the dock was only a fraction of the increase in a comparable reference area • Length, height over the bottom, design orientation and environmental conditions influence impacts. • Gratings can reduce light limitation impacts. • Moored vessels increase the shade footprint with vessels moored for only a few days having a negative impact.	• Site-specific factors such as current patterns are an importance influence. • Dock height, design, and orientation affect impacts. • Pilings change substrate type and bathymetry.
Fresh et al. 2000	Puget Sound, San Juan, Whatcom County	• Significant changes in eelgrass shoot density occurred at 6 of 9 sites. A significant increase was not detected at any site. Impact findings with significance included: • Strong relationship between N-S float orientation in reducing shade impact. • Float shape. • 50% grating reduced under-dock impacts to adjacent eelgrass but not necessarily to eelgrass directly under the dock.(grating up to 50% by itself does not predictably avoid eelgrass impacts. • Seasonality of float significantly reduced shade impacts to eelgrass.	• Dock orientation, float removal impacts require further study. • Grating combined with float orientation and seasonal dock removal show potential reduced impacts. • Further study of site-specific float and environ. attributes required for design of an orientation, percent grating, and seasonal float removal formula for avoiding impacts.

Animal Responses

Migration

Fish distribution studies in Puget Sound marinas have well documented the affinity of small juvenile fish for protected embayments, which include marinas. Studies of juvenile salmon in marinas with floating docks report small juvenile salmon (<50mm FL), such as chum, to be distributed not under the floating docks but rather along the riprap and bulkheaded shorelines around the shallower edges of marinas, or along the edges of docks with fish demonstrating a reluctance to pass under the docks (Weitkamp 1981; Taylor 1997; Feist 1991). These shorelines appeared to offer prey resources, light for migration and, shadow edge for cover. This consistency in juvenile distribution around marina shorelines likely reflects juvenile fish reliance upon shallow nearshore habitats and their avoidance of dark under-dock areas. Further study specific to floating docks is required to confirm this apparent lack of passage and presence under floating docks.

The vast majority of fishes in Puget Sound and the Straits are teleosts that rely primarily on their sense of vision for prey capture, migration direction, and predator avoidance. Laboratory and field studies have consistently reported that sharp contrasts in underwater light can bring fish prey capture to cessation, disperse fish schools, and change the direction of their migration to avoid light contrasts that temporarily reduce their ability to see. Concerning studies of under-dock environments in New York, Duffy-Anderson 2001) reports that in very dark under-dock environments, fish were not able to feed. Even when prey resources were available under the dock, the fish were not able to capture the prey. Similarly, in fish behavioral studies at the Port Townsend Ferry Terminal, Shreffler and Moursund (1999) found small juvenile chinook and chum to pause as they encountered the shadow cast by the dock. For further findings and discussions pertaining overwater structures and migration see the *Habitat Impact Mechanisms/Ambient Light Regime/Animals and Light* section and also the *Physical Structure Effects/Fixed Piers and Pilings/Light Reduction* section of this paper.

For young outmigrants such as juvenile chum, pinks and ocean-type chinook, prey availability is an important component to migration behavior. The loss of important nursery habitat, such as eelgrass beds, likely reflects a loss in the quantity of available prey resources. Although, floating docks support a large number of organisms, they are not the preferred prey of juvenile salmon. They can also support kelp and other substrate for Pacific herring spawn. Table 16 reports study findings pertaining to fish behavior around or near floating docks in the Puget Sound area.

Predation

There is no empirically supported evidence that floats promote predator aggregations. Species known to prey on juvenile salmon and who are typically present under docks in Washington's marine waters are not likely of the size to prey on juvenile salmon. Evidence from the Pentec 1997 study of Everett Harbor and Hesier and Finn (1981) suggests that there does exist a possibility that light limitation may move migrating fishes out into deeper waters and therefore increase the risk of predation by larger pelagic fishes that occupy adjacent deeper waters. The studies of floats by Weitkamp (1981) and Taylor (1997) at the Port of Seattle's Shilshole Bay and Pier 94/95 marinas did not show evidence of increased aggregation of predators. Taylor (1997) found no aggregation of avian predators during the peak juvenile chum outmigration. Similarly, Weitkamp (1981) reported no significant evidence of predation of juvenile salmonids occurring during the peak chum outmigration. Weitkamp (1981) found suspected predators (i.e. large 127 mm FL) present at slightly different times than the chum and present in different areas of the marina. Consistent with these findings, Penttila and Aguero (1978) found no empirical evidence of predation amongst the marina floats in Birch Bay. Rather they found evidence of competition between fish species for mutually preferred prey resources (i.e. the calanoid and harpacticoid copepods). For further findings and discussions pertaining overwater structures and predation see the *Habitat Impact Mechanisms/Ambient Light Regime/Animals and Light* section and also the *Physical Structure Effects/Fixed Piers and Pilings/Light Reduction* section of this paper.

Table 16. Study Findings pertaining to Fish Behavior Around Floating Docks

Study	Animal Responses		Vegetation Responses	Findings
	Migration	Predation	Prey Resources	
Penttila & Aguero 1978 Birch Bay Marina	Marina heavily utilized by juv. marine fishes. Likely due to adjacent spawning areas outside marina. Chinook, chum, pinks, sockeye, and trout found in marina. Marina may trap fish in it.	Predation is a concern due to the many co-occurring sizes and species of marine fishes. Steep sided marina basin provides little protection. Evidence of predation is minimal.	Prey resources may be compromised by the co-occurrence of nulti-species juveniles that share specific prey resource species such as calanoids and harpacticoids.	Most abundant marine fish were herring. Most widely distributed were smelt. Followed by 3-spine stickleback, anchovies, and sand lance were also in abundance. Other marine species include sculpins, penpoint gunnels, pile perch, surf perch, pipefish, pachers, tubesnouts, and Dungeness crab.
Taylor & Willey 1997 POS Pier 64/65 Facility	Juv. salmon appeared to migrate through facility N-S pattern using fish passage opening, shorelines and edges of dock structures.	No unusual congregation of predators observed. On occasion grebes & mergansers seen catching fish.		Fish migrated through the facility using shorelines and edges of facility structures. Considerable predation not observed. No avian predation at peak migration.
Weitkamp 1981 Shilshole Bay Marina	38-53mm chum migrated along bulkheaded shoreline. 120-127mm coho found in open waters of the marina.		Predation not observed.	Large schools of Juv. chum (38-53mm) observed migrating along bulkheaded shoreline only. Not found under floating docks or riprap breakwater. Large school of coho (120 127mm) found in open waters of marina. Herring found along bulkheaded shoreline. Cabezon, greenling perch, flatfish and rockfish were also along bulkheaded shoreline and breakwaters

Alteration of Wave Energy and Substrate Regimes

Substrate Changes

Floating piers are known to affect beach sand movement and are not recommended in areas of significant littoral transport and longshore current (Coastal Plains Center for Marine Development Service 1973). In southern California, Reish (1961) observed a succession of attached organisms occurring on marina floats with an apparent climax community of the *Mytilus* mussel and *Ulva* algae after the floats were in the water for 6 months. In the presence of particular dinoflagellates such as *Gonyaulax catenella,* the *Mytilus* can be very poisonous. In abundance, *Ulva* spp., an opportunistic green macroalgae, is known to reduce light and oxygen, and create an anoxic environment (Hull 1987; Hernandez et al 1997). Through shading, the algae *Ulva* is capable of triggering habitat shifts resulting in declines of eelgrass and concomitant increases in *Ulva* (Wilson and Atkinson 1995; Wilson 1993). The Puget Sound Expedition, Cohen et al (1998), survey of non-indigenous species specifically sampled dock-fouling organisms on floats at 26 marinas throughout the entire Puget Sound region identifying 39 non-indigenous species on marina floats throughout the region. In general, the biotic communities on the floats were encrusting, often dominated by *mytilus*, with *ulva* present. With the exception of the pile perch, the float community survey did not reflect habitat rich in prey resources for juvenile salmon and many other nearshore fishes. The effect such climax plant and animal communities could have on eelgrass survival, non-indigenous species proliferation, and nearshore ecology is unknown at this time.

Float communities are known to support the prey resources of such intertidal resident species as sculpins, perches, and tubesnouts. The prey resource habitat advantages offered by the proliferation of communities on float surfaces would likely be for those species who tend to feed in the water column near the point of surface contact or in the water column along a supportive structure such as a piling. Whereas epibenthic feeders, such as salmonids, are more likely to suffer disadvantages due to the shading impacts that would limit their visual acuity and could limit the primary production supporting their preferred prey resources. The magnitude of the shade effect would be dependent upon depth, structure size and characteristics, and water clarity.

Other Mechanisms

Water Quality

Houseboats, boat houses, and covered moorages are typically associated with parking lots and transportation corridors that can result in contaminated storm-water runoff with Polyaromatic hydrocarbons (PAH's) and other contaminants known to become incorporated in fish tissue and consequently the marine food web. In addition, the houseboat, as a place of residence, subjects adjacent waters to potentially more frequent exposure to household cleaning, pesticide, and herbicide products that pose special risks to the marine food web. Similarly, boathouse uses, such as storage of boat paint and maintenance products, can pose an increased risk of contamination to the marine food web through accidental spillage.

Marinas

Light Reduction

Vegetation Responses

A marina, as a collection of individual piers located behind a breakwater, has a much larger cumulative biologic impact due to the increased area of light reduction and to structurally introduced changes in wave energy and longshore sediment transport. These changes result in alterations of both sediment and vegetation distribution and type. Biological impacts due to the various structures within marinas vary depending upon the type of structures located in the marina (See sections within this paper addressing floating docks, covered moorages, houseboats, fixed docks, and pilings). Through marina design, construction materials, and site location the extent of such impacts can be significantly reduced. Without mitigating biologic changes due to reduced light, a marina extends the area of light limitation impact to vegetation. See the *Habitat Impact Mechanisms* section of this paper for discussions regarding overwater structures and light limitation effects. See Table 13 for study findings pertaining to Shilshole Bay, Edmonds, Des Moines, Kingston, Pier 64/65, Blaine, and Birch Bay Marinas. Figure 7 depicts the basic marina configurations of the Shilshole Bay, Edmonds, Des Moines, and Kingston marinas in Puget Sound. Figure 8 depicts the Port of Seattle Pier 64/65 marina with special fish migratory passageway built into the design.

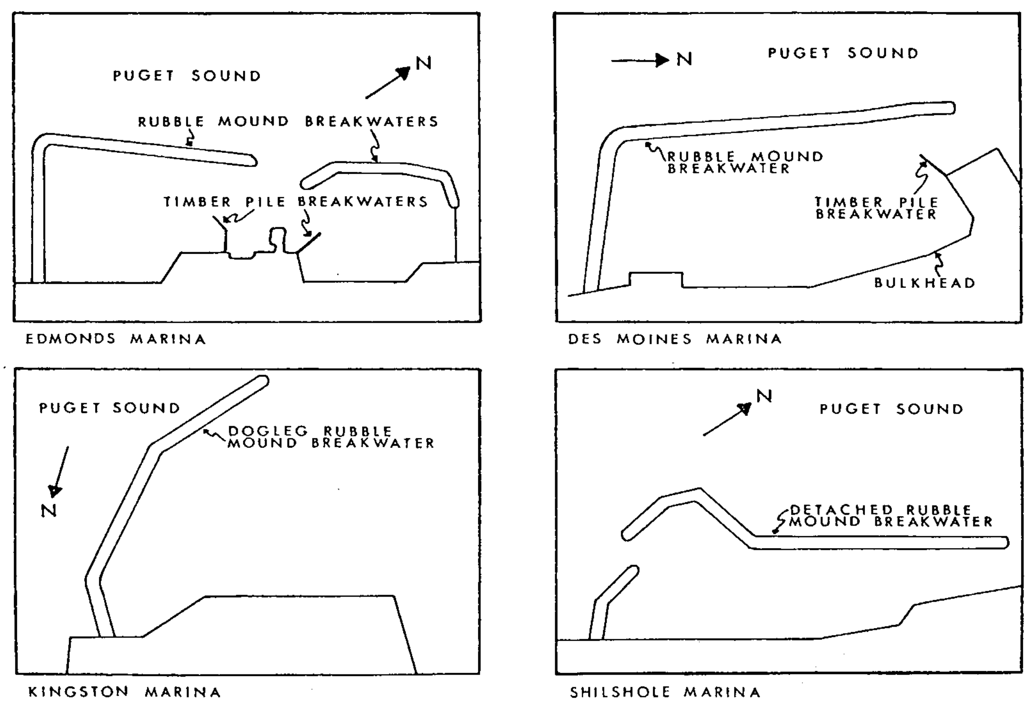


Figure 7. Four Marina Designs in Puget Sound, Washington
(Diagrams are not to scale) (Source: Mulvihill 1980)

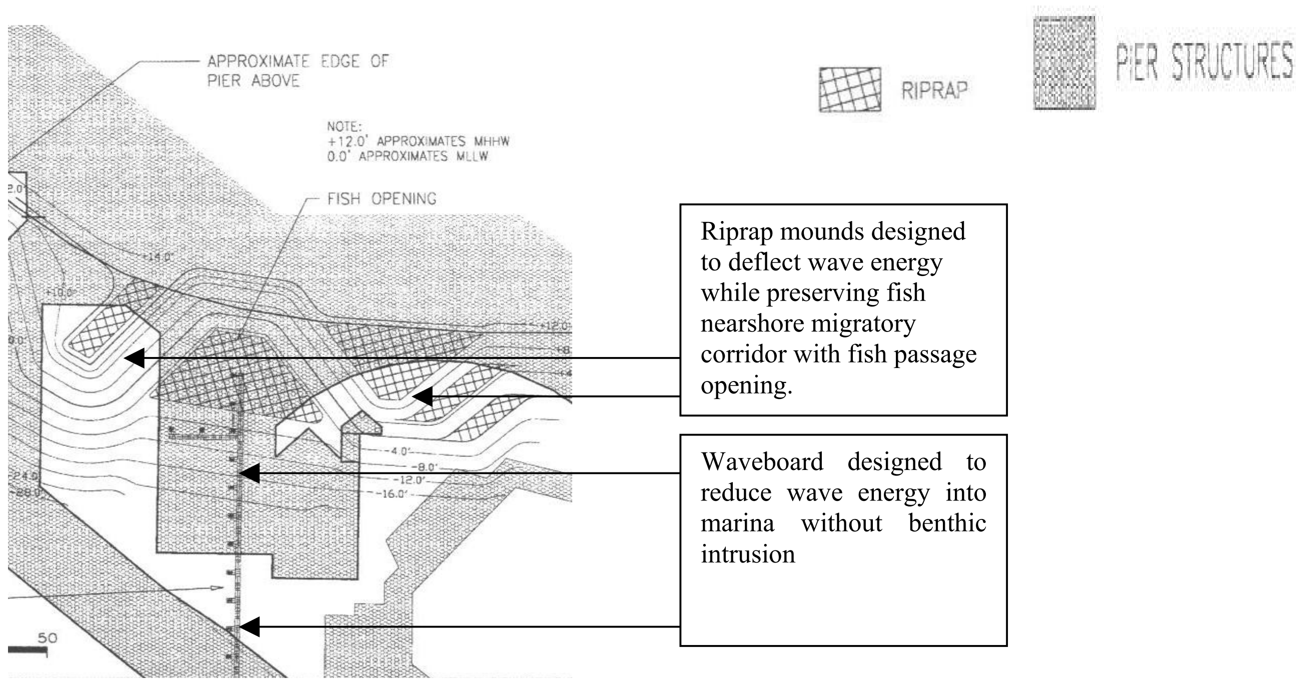


Figure 8. Port of Seattle Pier 66 Bell Street Marina Fish Passage

Animal Responses

Migration

Fish distribution studies have well documented the affinity of small juvenile fish for protected embayments that include marinas (Penttila and Aquero 1978; Taylor and Willey 1997; Weitkamp 1981). Studies of juvenile salmon in marinas with floating docks report small juvenile salmon, such as (<50 mm FL) chum, to be distributed not under the floating docks but rather along the riprap and bulkheaded shorelines around the shallower edges of marinas, or along the edges of docks with fish demonstrating a reluctance to pass under the docks (Weitkamp 1981; Taylor 1997; Feist 1991). In a study of Shilshole Bay fish resources, Weitkamp (1981) found larger coho out in the deeper more open waters of the marina that were hypothesized to be feeding on small fish associated with the general marina basin environment. Depending upon their particular life-history strategy, different fish species utilize environments associated with overwater structures. At Shilshole Bay Marina, a school of 800 herring were seined along the shoreline bulkhead, English sole and starry flounder were caught along the breakwater, and larval baitfish were common along the breakwater. Striped perch, pile perch, greenling, and flatfish were documented as common along the shoreline bulkhead, the breakwater, and under a large fixed standing pier located approximately 12 ft above the waters surface on MLLW. Cabezon, greenling, and a few rockfish were also identified within the marina along the bulkheaded shoreline. The shoreline perimeter of Shilshole Bay has very little shadow other than the bulkhead itself. The floating piers begin approximately 20 feet from the bulkhead with only grated ramps extended from the bulkheaded parking lot to the floating docks. The only fish caught within the open water of the marina were coho (127 mm FL) while the smaller fish were caught at the outer perimeters of the marina along riprap shorelines, breakwaters and shoreline bulkheads. The bulk of small juvenile salmonids present in the marina occurred between April 22 and May 19th with larger chinook and chum following later. On April 29, approximately 8000 juvenile chum (38-53 mm FL) were counted along bulkheaded shoreline and 4300 were observed along the marina riprap, south of the marina. No juvenile chum fry were observed along the breakwater. These juveniles, remained 2 to 20 feet from the riprapped shorelines inside and outside of the marina. By May 6th, they had essentially disappeared from the marina area. However, large schools of coho, approximately 5000 fish (120-127mm FL) moved into the marina. These larger fish were distributed throughout the open waters of the marina. Also, on May 12th, smelt larvae occurred along the inside of the breakwater and small schools of chum were seen once again along the marina's shoreline bulkhead. This outmigration timing for juvenile chum was also consistent with the observations of Taylor at the Port of Seattle's Pier 66/Bell Street Harbor Marina in Elliott Bay (Taylor and Willey 1997; Weitkamp 1981). These shorelines appeared to offer prey resources, light for migration and, depending on the time of day, shadow edge for cover. This consistency in juvenile distribution around marina shorelines likely reflects juvenile fish reliance upon shallow nearshore habitats and their avoidance of dark under-dock areas. Further study specific to floating docks is required to confirm this apparent lack of presence under floating docks.

Four marinas in the Puget Sound region, Shilshole, Des Moines, Kingston, Edmonds, and Pier 66/Bell Harbor Marina demonstrate examples of marina designs producing varying levels of impacts. The Shilshole Bay Marina is designed with a detached rubble mound breakwater. This design provides openings at both ends for good tidal exchange and surface water movement (Mulvihill 1980). The marina design of the Kingston Marina includes a dogleg rubble mound breakwater extending from the north shore and angling out to protect the marina front. This angling shape provides the south side of the marina with a large entrance. This large entrance facilitates water circulation by allowing adequate tidal exchange with northerly winds (Heiser and Finn 1970). In 1970, Heiser and Finn observed large concentrations of pink salmon fry within this marina. Fry moving north towards the open ocean would likely enter the marina using the shorelines south of the marina, follow the riprap shoreline along the north side of the marina, follow the east side of the breakwater going south, continue around the corner of the breakwater, and migrate along the east face of the breakwater under the adjacent ferry dock towards the natural shoreline just north of the ferry dock. In June 2000, this author observed a large school of small approximately 35mm salmonids migrating along the eastern face of the Kingston Marina breakwater. Upon encountering a small fishing pier, there was some disruption in the schooling behavior, with some fish pausing, and some fish moving out into deeper waters. However, most fish moved quickly under the pier. This particular pier provided a shadow line but had enough height to allow considerable light to the underwater environment particularly given the western exposure to the afternoon sun. Some fish appeared to travel out into deeper waters, pass under the idling ferry, and became disoriented with a consequent movement in the direction of deeper waters but the bulk of small fishes continued along a path parallel to shoreline and moving under the ferry terminal dock.

The breakwater designs at both Des Moines and Edmonds marinas are examples of restrictive breakwaters that significantly reduce tidal exchange and hence water quality in the marina (Heiser and Finn 1970). The design of these marinas could result in longer residence times for fry given the circular migration they would need to follow and the longer period of exposure to contaminated waters (should the marina waters become contaminated with fuel spill, bilge water discharge or sewage discharge). Heiser and Finn (1970) observed a small three-foot diameter culvert near the Edmonds marina that appeared to repel small chum and pink fry. They also experimented with culverts to test if juveniles would pass through the culvert to get to a natural Heiser and Finn (1970) found coho fry in the one culvert and due to fish avoidance of these culverts concluded these were predatory situations for juveniles. It could also be the case that the significant change in light conditions brought on the avoidance response. Figure 8 depicts the Port of Seattle Pier 66/Bell Harbor Marina designed with features to minimize intrusion on the nearshore environment and maintain a nearshore fish migratory corridor beach area, but the fish consistently avoided the culvert. The Pier 66/Bell Street Harbor Marina in Elliott Bay is specifically designed to facilitate fish migration with a fish passage opening built into the north end of the facility. This way small juvenile salmonids migrating north out to the open ocean can migrate into the marina at the south end, follow the riprap shoreline north to the fish passage, and exit the marina area through the fish passage at the north end. Taylor (1997) observed salmonids utilizing that shoreline, migrating out and around the outer edges of the marina and the breakwater, and utilizing the fish passage opening. The Pier/66/Bell Strate Marina fish passageway allows fish to migrate along the nearshore without exposing the marina to incoming wave energy. This was accomplished using rock mounds to absorb incoming wave energy while still allowing fish access through the passage.

Predation

No aggregation of predators has been observed or empirically validated to occur around floating or fixed dock structures (Simenstad et al. 1999). Both Weitkamp (1981) and Taylor (1997) have studied the question of the aggregation of avian predators at the Port of Seattle floating dock facilities at Shilshole Bay and Pier 64/65 with no indications of predator aggregation. However, Prinslow et al.(1979) reported the possibility that changes to the ambient nighttime light regime may pose risks of aggregating predators due to change in underwater ambient light patterns caused by dock night lighting. For further findings and discussions pertaining overwater structures and predation see the *Habitat Impact Mechanisms/Ambient Light Regime/Animals and Light* section and also the *Physical Structure Effects/Fixed Piers and Pilings/Light Reduction* section of this paper.

Alteration of Shoreline Energy Regime

Substrate Changes

Marinas are designed to protect boats from wave energy. The breakwaters serving this purpose interfere with longshore sediment transport processes changing adjacent beach substrate types. These changes in wave energy patterns also change the circulation and water quality of such embayments. Mitigation of impacts to water quality and fish passage can be built into the design of the marina. Carlisle (1977) reported marinas to be generally characterized by a lack of normal benthic succession, poor substrate, and poor water quality. Poor water circulation can create dead water areas leading to a buildup of organic sediments and low dissolved oxygen concentrations (Wick 1973).

Other Mechanisms

Water Quality

The dredging required for marina development and vessel navigation deepens subtidal zones and often converts intertidal into subtidal habitats. This has a profound impact on the plant and animal assemblages associated with those areas. These impacts include mortalities and loss in the extent of intertidal habitat. The white paper on dredging addresses dredging habitat effects to estuarine and marine habitat.

Carlisle (1977) characterized marinas as potential water traps creating suitable conditions for dinoflagellate blooms. Such bloom die-offs decrease dissolved oxygen (DO) concentrations and can result in massive fish kills exacerbating existing depleted oxygen level conditions.

Water quality impacts are dependent upon the level of use and design of the marina and the level of tidal exchange within the marina. Increased tidal exchange and surface water movement can reduce water quality impacts. Increased dock usage levels can pose risks to water quality through the introduction of sloughing bottom paints, vessel engine exhausts, fuel spillage, sewage discharge, paint and cleaning product contamination, and increased stormwater introduction of contaminants from automobile traffic and asphalted parking lots adjacent to a marina. These effects can be avoided through filtration, best management practices, and marina design. For suggested techniques, see the discussions on long-term structural effects in the *Habitat Protection and Mitigation for Long-Term Structural Effects* section of this paper.

Floating Breakwaters and Wave Boards

The use of floating breakwaters or wave boards can avoid the profound impacts of a fixed mound breakwaters and the associated maintenance dredging often required by the mound structure's interference with littoral drift cells. With the use of floating breakwaters, fish entrapment is less likely as they can pass under the floating breakwater along their nearshore migratory corridor. However, due to the weather patterns in the Pacific Northwest and the expanse of our inland waters, the combined forces of exposure to severe northerly winds and considerable fetch results in high energy, long-period waves. Such high-energy waves limit the feasibility of the floating breakwater in the Pacific Northwest to a seasonal use. For marinas and anchorages that are only in operation seasonally, a floating breakwater offers protection from summer wind and vessel activity waves with very minimal impact to fish and substrate. The use of wave boards have the advantage of providing marinas with shelter from direct swell in areas with large fetch while minimizing interference with littoral drift and benthic environments.

Light Reduction

Vegetation Responses

To the extent that a floating breakwater shades subtidal and intertidal vegetated habitat, it reduces the extent of such habitat for a variety of shellfish and finfish utilizing vegetated habitat during critical life history stages. The floating breakwater can present some of the same shading impacts as a floating dock unless it is in deep enough water that it does not shade the bottom. These shade impacts can be reduced through structural design that limits the width and uses construction materials that transmit light to the underwater environment. For findings and discussions concerning floating docks see the *Physical Structure Effects/Floating Docks, Covered moorages, Houseboats, and Boathouses* section of this paper.

Animal Responses

To the extent that a floating breakwater provides passageway under the structure, it can enhance fish migration. With the ability to migrate under the floating breakwater, the fish are not required to expend additional migration energy, experience disorientation, or become entrapped behind a solid breakwater structure with only one entrance and exit point. To the extent that it provides light under the structure, it allows shoreline migrants to pass under the structure that is likely to be attached to the shoreline at one point. It provides an advantage for benthic dwellers and deep bottom dwelling fish as it does not limit the natural extent of their habitat by burial or the presence of a solid breakwater structure. A breakwater that is intermittently attached to pilings with the majority of its bottom area, the area between securing pilings, being open to fish passage at the base of the structure offer the advantage of withstanding Northwest wind and wave conditions and allowing fish passage. See the accompanying Marine and Estuarine Shoreline Modification Issues white paper (Thom and Williams 2001) for further discussion of types of solid breakwaters.

Alteration of Shoreline Energy Regime

Substrate Changes

Floating breakwaters or intermittently piling-secured breakwaters have much less influence on littoral drift (Harris and Thomas 1974; U.S. Corps of Engineers 1973). However, a floating breakwater poses impacts similar to floating docks in its ability to provide a substrate for encrusting communities and therefore shellhash and organic debris accumulation across the benthos. Depth, tidal currents, and construction materials together determine the extent of this type of impact.

Barges, Rafts, Booms, and Mooring Buoys

Vegetation Responses

Williams and Betcher (1996) found mooring buoys anchored to substrates to alter vegetation through substrate scouring by the fastening chains. Barges, rafts, and booms anchored to substrates pose this risk to surrounding biota. They also pose risks of increased light limitations, which can effect plant reproduction within an 18-day duration (Backman and Barilotti 1976). In addition to light limitation, barge, raft, vessel, and boom groundings can also cause animal mortalities through smothering or crushing, limit the extent of available benthic substrates for plant and animal assemblages, and disturb substrates and consequently eelgrass growth. In studies at multiple ferry terminals in Puget Sound, Thom et al. (1996) reported that required annual maintenance of wood ferry terminals pose the risk of barge groundings, anchorage scouring, and propeller scars from tugs and work boats. The rate of eelgrass recolonization following such disturbances is still unknown in the Puget Sound region. Through careful strategizing, the above effects can be avoided with careful location of booms, barges, and rafts in deeper areas and employment of anchoring techniques to avoid scouring. Light limitation effects due to a particular vessel or barge anchorage will depend on the time duration of light limitation, which would be influenced by depth, vessel or barge design, currents, and vessel wind conditions at a given location. Table 17 captures the results of mooring buoy system studies in the Pacific Northwest and Perth, Australia. The factors that influence the significance of impact of mooring buoy systems include tide, water depth, water current, prevailing wind/wave patterns, marine vegetation types, anchor types, and moorage time.

Table 17. Study Findings Pertaining to Mooring Buoy Systems

Study	Mooring System	Impacts	Findings
Williams & Betcher 1996 (Pac. NW)	Mid Line Float	Least Impact	Float keeps line from resting on the bottom. Float placement is calculated based on extreme tides.
	All Rope Lines	Minor Impacts	Key factor is the type and size of line used. Smaller and more buoyant lines have less impact on vegetation.
	Rope to Chain Lines	86% disturbed marine vegetation	Size of chain and rope determines impact magnitude.
	All Chain Lines	93% disturbed vegetation	Size of chain determines impact magnitude of impact- heavier chain produces larger impact.
	Mid Line Float with Counterweight	Potential impacts depending upon wind conditions	If currents disturb the counter weight, additional bed disturbance occurs. Location of mid-line float also influences the magnitude of disturbance.
	Stainless steel cable, rods and tires	100% impacted	All moorings in this category caused disturbance
Walker et al. 1989 (Perth, Australia)	Cyclone Moorings: 3 anchors and a swivel	Least impact	The most effective anchoring system to protect the integrity of seagrass beds.

Low tides present the greatest risk of contact with the bed and disturbance to marine vegetation. Incorporation of extreme tidal elevations is required to calculate minimum water depth and effectively prevent contact with bed. Installing moorings in water depths beyond the limits of marine vegetation is an effective way to avoid vegetation disturbance. The horizontal force of water currents depends upon the geographic location of the buoy respective to the tides. Usually, tidal changes pivot the moored boat in different directions respective to the varying tides and winds. If a heavy line is used between the anchor and buoy that is permitted to drag along the bed, significant damage can occur. Mooring buoys in high current areas have been shown to have a greater potential for disturbing vegetation than moorings in sheltered bays. In areas where movement of the buoy is dominated by current, vegetation disturbance assumes a circular pattern around the anchor. Moorings with heavy lines that make contact between the anchor and buoy located in areas where prevailing wind/wave patterns override current effects, vegetation disturbance takes on a "V" configuration. The magnitude of impact is also influenced by the type of vegetation present. Laminaria may be more resistant to disturbance than eelgrass and ulva due to its tendency to lie prone to the bed. The length of time mooring occurs also influences the magnitude of impact. Design of the mooring buoy system is the most significant variable in preventing the anchor to surface line from contacting the bed.

Animal Responses

Walter et al. 1989 found that scouring in seagrass canopies by anchoring systems had far greater impacts to bed integrity than impacts to the edge of the seagrass meadow. The risk of grounding on low tides poses risks to benthos and intertidal biota. Grounding of large objects poses the risk of smothering and crushing shellfish populations, scouring vegetation and changing the quality of the substrates with perhaps increased organic material with lower dissolved oxygen levels. The overall effect poses the risk of reducing habitat quality for a variety of shellfish and fish species. The area of the bottom covered by a large object equates to reduced fish habitat for fishes in the intertidal area during the period of time this object is stationed in a specific area. Intertidal resident fish species, such as sculpins, gunnels and even juvenile English sole are morphologically adapted for occupation of small interstitial spaces even when the cobbles are exposed on the lower tides.

Alterations to Shoreline Energy Regimes

Substrate Changes

Substrate type and size could be impacted by light limitation, chain scouring and vessel grounding depending on the extent of the grounding and the duration of time the barge, vessel, or raft is anchored in a given location. An anchored barge or raft can have the same effects as a float on both light limitation and substrate type depending on wind, depth, and water circulation at a given site (See the short term construction effects and long-term structural effects sections for avoidance of such effects.) The bottom of an anchored barge or raft can become a surface for encrusting communities (See the section on floats for a description of potential encrusting community effects on substrates and surrounding biota).

Prop scouring of sediments and vegetation limits the extent of rooted vegetation and epibenthic communities associated with plant and sediment substrates. To the extent that vegetation and substrates are scoured, is likely to the extent that fish and shellfish prey resources are lost at that location. Similarly, vessel or barge groundings can result in smothering, burial, or crushing of crabs and other shellfish and intertidal resident fish, such as gunnels and sculpins, utilizing that habitat. Such groundings also damage vegetation and likely result in a loss of larvae that have settled in that particular intertidal zone. The above barge and vessel impacts can be avoided by securing vessels and barges in deep waters where they will not touch the bottom substrates. The number of such occurrences in a given locale or region magnifies the cumulative extent of such impacts. The cumulative total of each area of intertidal habitat loss will likely result in smaller recruitment for those species dependent upon nearshore habitat during their critical juvenile rearing stages.

Boat Ramps, Hoists, and Launches

A launch typically slopes continuously from above the high waterline to below the low water line. In general, ramps are constructed where there is fairly deep water close to shore and protection from wind and waves. Ramps usually take the form of poured concrete with most of the structure submerged during higher tides and revealed during lower tides. Ramp presence can reduce the extent and continuity of the intertidal area available for forage fish spawning and burrowing organisms. Depending on the site selected for the ramp, ramp presence may eliminate once present vegetation, thereby, reducing protective prey and refugia habitat for nearshore fishes. It may also eliminate habitat for fishes, such as the sculpin, gunnels and other juvenile species particularly adapted to using rock and gravel habitats in the nearshore zone. Moulton (2000) reported that placement of a ramp across a spawning beach on Lopez Island was serving to break up the continuity of the beach habitat and reduce available habitat for spawning forage fish. A ramp can also alter adjacent habitat through interference with drift cell processes feeding sediments to adjacent beaches. Ramp usage and associated parking areas also determine the extent of additional impacts to wave energy and water quality. These types of habitat changes can be avoided by strategic placement of ramps in already impacted areas.

Light Reduction

Vegetation Responses

Although a single ramp without an associated dock is not an overwater structure, it is conceivable that activities at the ramp could create turbidity and result in light limitation at the site (Mulvihill et al. 1980). Such effects include substrate scouring due to propeller wash and boat groundings, poor ramp site selection that interferes with drift sector processes and results in increased sediment deposition in adjacent habitats. Increased sedimentation, nutrient and pollution run-off from adjacent upland surfaces such as associated parking lots available for ramp use can pose light limitation risks. To the extent that ramp construction replaces vegetation without mitigation for that loss, it will decrease the net extent of vegetation. The ramp also poses the risk of rearranging the distribution of vegetation around the ramp structure itself. The additions of docks for vessel tie-up or haulout pose the additional risks associated with floating docks. For futher discussion of effects on vegetation see the *Physical Structure Effects/Fixed Piers and Pilings* section and the *Physical Structure Effects/Floating Docks, Covered Moorages, Houseboats, and Boathouses* section of this paper.

Animal Responses

The ramp alters the substrate and vegetative structure of nearshore habitat for migrating fish species, such as salmonids, and decreases the extent of habitat available for resident nearshore species utilizing rock and cobble substrate for protective cover. For discussions pertaining to prey resources and substrates see the *Habitat Impact Mechanisms/Ambient Light Regime/ Animals and Light* section, the *Habitat Impact Mechanisms/ Wave Energy and Substrate Regimes* section, the *Habitat Impact Mechanisms/Other Mechanisms* section, *Physical Structure Effects/Fixed Piers and Pilings/Light Reduction* section, and the *Physical Structure Effects/Fixed Piers and Pilings/Alteration of Shoreline Energy Regime* section of this paper.

Alteration of Shoreline Energy Regime

Substrate Changes

To the extent that the ramp interferes with littoral drift cells, it also poses the risk of interference with the deposition of fine sediments to adjacent beaches supporting beach spawning forage fish, such as surf smelt and sand lance. The limitation of fine sediments to adjacent beaches also poses the risk of limiting the establishment of rooted vegetation, such as eelgrass, along submerged areas of adjacent shorelines. In this way it reduces available habitat for fish and shellfish species reliant upon such vegetated habitats for spawning and rearing. The degree to which a ramp is used will determine additional effects of wave energy from vessel traffic and pollutant distribution from vessels and adjacent shoreline structures. For discussions pertaining to prey resources and substrates see the *Habitat Impact Mechanisms/Ambient Light Regime/ Animals and Light* section, the *Habitat Impact Mechanisms/ Wave Energy and Substrate Regimes* section, the *Habitat Impact Mechanisms/Other Mechanisms* section, the *Physical Structure Effects/Fixed Piers and Pilings/Light Reduction* section, and the *Physical Structure Effects/Fixed Piers and Pilings/Alteration of Wave Energy and Substrate Regimes* section of this paper.

Other Mechanisms

Hoist and launch areas can pose reduced benthos and habitat area due to additional piers for travel-lift operation and increased water quality risks due to the nature of boat maintenance activities performed in those areas. Water quality impacts can be reduced with the implementation of stringent operational best management practices and appropriate stormwater catchment and filtering systems. For discussions of avoiding long-term effects see the *Habitat Protection and Mitigation for Long-Term Structural Effects* section of this paper. For further findings and discussion on water quality concerns see the *Habitat Impact Mechanisms/Other Mechanisms/Water Quality* section of this paper.

Habitat Protection and Mitigation for Long-Term Structural Effects

Fixed Piers and Pilings

Placement

Using eelgrass as an indicator for light transmission standards in the protection of submerged vegetation and aquatic habitats, Burdick and Short (1996) provide guidance on protecting ambient light conditions under docks. They found the most important variable determining eelgrass bed quality under docks was dock height, followed in importance by dock orientation and width. Based upon field data, descriptive equations for eelgrass bed quality suggest that a north-south running dock with a height above the bottom of 1.7m will support 50 % of the eelgrass of surrounding beds. Using the same model, an east-west running dock would need to be 1.8m above the bottom. Using mesocosm data to predict light levels, regardless of orientations, the dock must be 2.0m above the bottom for light levels to reach 20% (i.e. 10-20% is the reported light level required for eelgrass survival) under a 1 m wide dock at noon. The predictive production equation from these mesocosm studies was: production (g/m^2/day)=-2.85+3.18*log (%light) with r^2=0.856. Using this equation, at 30% light relative to full light would produce 50% eelgrass relative to full light (Short and Burdick 1995; Short and Burdick 1996). Other considerations include placing docks in deep water to avoid substrate scouring and light limitations from vessel props and vessel grounding. Further study on specific light limitations to other marine plant and animal species are needed to further delineate the impact of shading on fish prey and refugia resources in nearshore areas.

Construction Materials

To avoid light limitation, the use of light-transmitting glass-centered concrete blocks, reflective material, or quartz halogen lamps has been found to allow light into the under-pier aquatic environment. Olson (1997) reported findings that photosynthetic active radiation (PAR) was 60 % of ambient light and that PAR measured under reflective foil was 60% greater than values under wooden docks without foil. The use of quartz halogen lamps demonstrated that eelgrass photosynthesis occurred at magnitudes as high as five times greater than under ambient light. The use of such materials at strategic areas under the dock can allow more light to support fish migration and submerged vegetation under the docks.

Creosote coated pilings pose an additional risk of leaching contaminants into the water column that eventually could settle and adsorb to bottom sediments and subsequently become part incorporated into the marine food web. Use of alternative materials, such as concrete and metal, are recommended as alternatives to creosote or other preservatives used to protect wood from boring organisms (See the Poston white paper on wood treatment products). The use of these alternative materials has also been found to reflect more light into the under-pier aquatic environment (Thom and Shreffler 1996).

Operations

Bottom paint sloughing, vessel exhaust, parking lot runoff, vessel gray water discharge, sewage discharge, spillage, and boat maintenance and repair activities unique to docks and marinas that pose the risk of introducing contaminants into the water column. To avoid the introduction of contaminants from vessel maintenance and repair activities, all wash-downs, and discharges, must be undertaken over a catchment system for proper filtering and treatment of contaminants before release into marine waters. Placing docks in water deep enough to avoid grounding and propeller (prop) wash disturbance of bottom substrates can also avoid a recirculation of existing contaminants that may have adsorbed to bottom substrate particles and avoid further penetration of contaminants into the substrate. Stormwater filtering and treatment will avoid contaminant run-off from entering marine waters from adjacent upland sources. Similarly, in areas of limited flushing, the collection, filtration, and dispersal of disposed fish waste from sports or commercial fishing activities avoids organic matter overloading to the marine ecosystem. Limiting the placement of garbage containers to supervised areas will reduce the potential for litter to enter the marine ecosystem.

Cumulative Effects

The type and extent of alterations is dependent upon site characteristics and structure types. Two primary effects will likely include shading and substrate changes from piling community shellhash. Increasing the number of docks increases the overall area with light limitations and substrate changes and consequently the ability of that habitat to support the native plant and animal communities. Without precautions to avoid adverse biological impacts, the resulting cumulative habitat effects are most likely to be reduced habitat area.

An important alternative to the proliferation of docks and pilings for both residential and commercial use are the establishment of multiple, community-use docks. Carefully placed community docks engineered to avoid light limitation, vessel grounding, and substrate change impacts can provide human transportation with the least amount of adverse effect to the aquatic environment. By limiting the impact to one area, many other areas remain undisturbed with intact ecosystems.

Floating Docks, Covered Moorages, House Boats, and Boathouses

Placement

Placement of floating docks, covered moorages, houseboats, and boathouses along marine shorelines also impose likely impacts to both the extent and quality of nearshore habitats. Placement to avoid those changes and losses include avoiding the placement of floating docks in shallow areas susceptible to grounding on low tides, and avoiding the placement of covered moorages and larger structures that enlarge the shade footprint. Placing floating docks in deeper waters can avoid such habitat disturbances and losses as: crushing, burial, smothering, disturbance to substrates, and damage to vegetation that is triggered by float groundings.

Burdick and Short (1995, 1999) found dock height to be the most important variable affecting light availability under docks. Although increasing dock height is not an option, placement in deeper waters can be an option. In the case of floating docks, a carefully selected structural specification formula that includes dock width and orientation and attachment to the uplands that allows for movement with currents and wind (i.e. chains) can reduce the duration of light limitation upon shallow nearshore habitats. It can also avoid vessel and dock disturbance to substrates and vegetation.

Materials

The incorporation of gratings or glass inserts into the dock structure will allow increased light to the under-pier habitat and avoid shade effects to aquatic habitats (Fresh et al. 2000). Fresh et al (2000) found that the percentage of grated dock area required to avoid light limitation impacts to eelgrass was over 50% of the dock area. Gratings must also be kept clean of drifting vegetation that can attach to the gratings and reduce underwater light.

Operations

Bottom paint sloughing, vessel exhaust, vessel gray water discharge, sewage discharge, spillage, and vessel maintenance and repair activities pose the risk of introducing contaminants into the water column. Vessel maintenance and repair byproducts, vessel wash-down wastewater, and other vessel discharges discharged into a catchment system will provide proper filtering and treatment to avoid the introduction of contaminants into the marine food web. Stormwater filtering and treatment will also avoid contaminant run-off from entering marine waters from upland sources. Similarly, the treatment of disposed fish waste from sports or commercial fishing activities can also be filtered and dispersed to avoid nutrient overloading to the marine ecosystem in areas of limited flushing. Limiting the placement of garbage containers to supervised areas will reduce the potential for litter to enter the marine ecosystem.

Cumulative Effects

Increasing the numbers of floating docks and structures with adverse effects to the marine environment magnifies the extent of adverse impacts. To the degree that each dock structure alters the light, substrate, and wave energy regimes of nearshore habitats, directly influences to what degree the system will suffer cumulative effects. Although presently it has not been quantified, it is likely that each local geographic subsystem has a threshold over which the nearshore habitat will no longer be able to support the biologic assemblages native to it.

Marinas

Placement

Pre- and post-project site suitability analysis taken over an extended period of can result in design features that avoid habitat degradation or loss. A combination of studies identifying: current and circulation patterns, water quality, bathymetric and topographic features, vegetation and fish distributions, and substrate features will identify those factors supporting habitats. Through such identification, steps in design and construction can be taken to protect habitats from loss. The time span of the pre-project study should include all annual seasonal variations and compile existing information identifying interannual climate variations. This information will assist in predicting the short and long term effects of any proposed marina project and plan for any potential enhancements and identify plant species present in one season but not in another. It was recommended that post-project monitoring should cover one year to capture construction disturbance impacts, and a second and third year to identify structural and use-related impacts (Deis 2000). This will help avoid unexpected long-term results to local geomorphology and habitat. For example, Bauer (1976) describes the arbitrary and uninformed location of a marina entrance and jetty in Birch Bay, Whatcom County, at a site between a barrier spit and feeder bluff drift-supply source, as an alteration to the shoreline energy regime that de-activates the natural system feeding the barrier spit. He suggests that this de-activation of the natural system could have been avoided by placing the marina entrance at the terminal end of the spit. Similarly in Whatcom County, he identified a groin-acting jetty and dredged channel at a marina entrance as representing an absolute barrier to long-shore drift. This drift had previously provided berm building and gravel maintenance material. In another example, Bauer describes the combination of excavation of the Sandy Point Spit core for the marina and canals with the spits' tidal water influence as posing an inundation and possible wave hazard to the dwellings along the eastern coast. He also describes the open design of the harbor entrance, as presenting a potential for imminent harbor erosion that is likely to require jetty maintenance and stability problems (Bauer 1976). Pre-project studies of such shoreline processes can avoid these types of risks. Pre- and post-project studies can also identify unexpected changes as they arise and will allow for adaptation to those changes in order to maintain a healthy ecosystem.

Assessment of site characteristics that include seabird and fish uses coupled with identification of benthic ecosystems, often particularly rich in shallow nearshore areas, will also contribute to the knowledge inventory of the natural resources of the region. These assessments can reflect the use of such habitats for fish spawning and juvenile fish and shellfish rearing.

Fish and shellfish populations in shallow areas are highly dependent upon substrate qualities including vegetation and the presence of loose sediments and stones in which organisms burrow, hide, or in the case of forage fish such as surf smelt and Pacific sand lance, spawn. It is believed that loss of such habitats translates to loss of these fish stocks (Penttila 2000). Understanding water circulation and sediment transport processes are key to selecting marina sites that do not interfere with critical fish and shellfish habitat supported by existing the existing wave energy and substrate regimes. Changes marinas can pose to circulation, sediment transport, and the nature of biological habitat in one area can have a profound affect on the specific site and adjacent habitats. Often it is the nature of adjacent habitats that also influences the viability of a given area to support the diversity of animals native to an area. This includes, but is not limited to, the need to provide a continuous migratory corridor for juvenile fish, such as salmonids and Pacific herring. To avoid mortality risks, fishes, such as ocean-type salmon, require continuity in the extent of prey and refugia availability along their migratory corridor to adult habitat. For discussions of marina configurations and fish behavior see the *Physical Structure Effects/Marinas* section of this paper..

Design and Materials

The following marina designs could minimize habitat loss and interference with the natural physical and biologic processes that determine nearshore habitat functions.

- Use upland boat storage as an alternative to in-water boat moorings
- Excavate uplands to create marina basin rather than dredging shallow nearshore areas
- Use natural deep water areas to minimize or preclude the need for dredging and avoid changing light, wave energy, and substrate regimes in nearshore areas
- Place marinas in areas of low biological abundance and diversity
- Place marinas in areas that will not interfere with natural wave energy and littoral drift processes to avoid starving adjacent habitats of sediments and wave energy

The construction materials and designs for docks and pilings, described in the *Habitat Protection and Mitigation for Long-Term Structural Effects/Floating Docks, Covered Moorages, House Boats, and Boathouses* section and the *Habitat Protection and Mitigation for Long-Term Structural Effects/Marinas* section of this paper, are known to decrease light-reduction impacts to plant and animal assemblages. Recent examples of designing marinas top avoid impacts to fish species is the Elliott Bay Marina in Seattle and the Port of Seattle Pier-64/65 Guest Moorage Facility. Both of these facilities are designed to benefit fish passage by including designed features such as fish passages to enable fish to exit the marina in a direction consistent with their migratory corridor. Taylor (1997) found fish utilizing the fish passage at the Port of Seattle facility. Similarly, in a study of salmon migration at Manchester Naval Fuel Pier in Manchester, Washington, Dames and Moore (1994) found that the docks at that facility did not significantly stall migratory salmonids or cause them to move offshore to pass around the pier. It is very likely that the physical design of the pier (i.e. the pier height, wide, and piling number and type) did not cast a significant shadow on the underwater habitat. Most fish were observed to be moving along nearshore stations and very few were found at the offshore stations. The fish were within 60-80 mm FL.

Operations

Storm water runoff from urban areas and surrounding impervious surfaces such as parking lots can introduce contaminants. Boat discharges can introduce excess nutrients and pathogens, bottom paint sloughing will likely introduce toxic contaminants to bottom sediments. Depending on the situation, a marina can improve sediment and water quality if it improves stormwater discharges that tend to add to siltation problems, changing substrates, nutrient, and contaminant levels.

Cumulative Effects

A marina produces cumulative effects by virtue of the fact that it has multiple docks, serving multiple purposes over an extended area. However, it does reduce the overall impacts to a given region through its service as a community dock that can reduce or eliminate the need for individual docks that would otherwise fragment habitat along a longer stretch of shoreline. The extended size of a marina and its requirement to serve as a haven from year-round wind will require some type of energy dissipation barrier. The location of the marina, its structural features, and the selection of wave energy barrier features will determine the extent to which the marina will interfere with littoral sediment transport processes feed adjacent beaches that support spawning forage fish, eelgrass beds, and mud flat habitats that are rich fish and shellfish habitat. The cumulative effects of such interference with drift cell processes pose a special planning challenge due to the extended duration of time and other compounding variables, such as other piers and structures that produce effects over a very long time range.

Floating Breakwaters

Placement

The wave barrier selection design requires assessment of site bathymetric and wave energy characteristics. Wave climate could be counteracted by increasing the structural design of piers, floats, vessels mooring systems, and other harbor features. This is particularly appropriate for harbors designed for large ships that are able to withstand higher energies. Smaller vessels could be hauled out during the winter high wind energy seasons, thereby reducing the extent of need for breakwaters. Minimizing the use of solid mound breakwaters can minimize associated dredging activities (Mulvihill et al. 1980). Using deeper waters for the placement of marinas and floats can also reduce the dredging impact of converting intertidal to subtidal habitat with a concomitant reduction in the extent of overall nearshore habitat available to intertidal fish and shellfish assemblages. (See the dredging white paper for further discussions on this issue). Floating breakwaters are biologically preferable to fixed breakwaters due to their significantly reduced impact to intertidal flora and fauna. Selection of wave barrier location, type, and shape require full assessment of bathymetric, wave energy, current, drift cell, and nearshore ecological components for estimation of wave energy requirements pertaining to a specific site. Testing all options for impacts specific to a location would represent a comprehensive and precautionary approach to reduce negative habitat effects. (See the above section on marina placement.).

Materials

Selection of materials based upon their ability to reduce wave energies specific to the site for the combined purposes of harbor safety and avoiding impacts to fish and shellfish habitats can be accomplished with pre-project tests using equipment to simulate wave energy spectrums known to exist at a specific site. Over-building a breakwater for wave energy events that do not occur in a given area could significantly and unnecessarily undermine the general biological characteristics supporting the marine food web in a given region. The Jamieson et al. (1995)

studies in Aukland, using machine and laboratory controlled variables, compared sloping (i.e. 11.5 degree slope) versus rectangular non-sloping breakwater modules. The sloping top breakwater, at an 11.5-degree angle incident to waves, resulted in wave energy transmissions reduced by 18% with variation depending on size of the wave. Energy transmission varied with width, wave period, and length with wider breakwaters significantly reducing wave energy. The addition of porous sheets was found to significantly reduce energy transmission (Jamieson et al. 1995).

Operations

Floating breakwaters likely require periodic cleaning to clear marine growth and trash from collecting at the breakwater. Such cleaning will prevent further light limitation to fish and submerged vegetated habitats under and adjacent to the breakwater. Monitoring changes to flora have been recommended to take place over a minimum of 3 subsequent years (Dies 2000). This will identify biologic changes occurring in response to physical changes in light availability and sediment transport.

Cumulative Effects

The extent of cumulative impacts is built upon the careful selection of breakwater characteristics appropriate to each site. Individual breakwaters will change the wave energy and light availability factors determining underwater habitat characteristics. However, the extent of that impact is determined by the selection of wave barrier placement, design, and materials. Cumulative impacts can be significantly minimized through stringent application of site and design selection criteria.

Barges, Rafts, Booms, and Mooring Buoys

Placement

Moorings of rafts, barges, booms and vessels place a shade footprint over the bottom that varies with the size and shape of the floating object. However, the movement of the floating object around the buoy in response to currents and winds reduce the light limitation stress to vegetation due to the shadow moving with the arc of the sun. It is likely that the larger risk lies in the actual contact of the floating object with the bottom substrate at low tides or the scouring of the substrate vegetation by the anchoring system itself. Studies in the Pacific Northwest and Perth, Australia have identified the specific mechanisms of impact from mooring buoys (Williams and Betcher 1996; Walker et al. 1989). Williams and Betcher (1996) found that zostera marina may be more susceptible to such disturbances due to its vertical position in the water column whereas laminaria appears to be more resistant to such disturbances. For further details on identified impacts of buoy systems see the *Physical Structure Effects/Barges, Rafts, Booms, and Mooring Buoys* section of this paper.

Operations

Vessel groundings could be significantly reduced by limiting tie-ups to those areas not subject to low tide contact with the substrate. The monitoring of mooring buoy system design with owners required to use those systems showing the least impact to marine vegetation could reduce local and cumulative effects. Williams and Betcher (1996) grouped buoy designs into 6 different categories: 1) midline float, 2) all rope lines, 3) rope to chain lines, 4) all chain lines, 5) other, to include stainless cable, steel rods, tires, etc., and 6) midline floats with counterweight. They found properly installed midline float systems to have the least impact on marine vegetation with midline float preventing the anchor to surface line from contacting the bed. The all-rope designs demonstrated minor impacts to marine vegetation with only 14% disturbing marine vegetation. The weight and diameter of lines used and growth on the lines also determines its success in preventing disturbance. Eighty- six percent of the rope to chain design disturbed marine vegetation with the magnitude of impact depending upon chain size and weight of rope material. Midline float with a counterweight appeared to have the potential for significant impacts to vegetation given current, tidal height, wind, and wave regimes. Moorings using designs 1 and 2 demonstrated little or no impact whereas 93/% of designs 3,4, and 5 demonstrated impacts. Design 6 appears to have the greatest potential for significant marine vegetation impact if improperly installed. The effectiveness of designs 1 and 2 rely on using the proper rope lengths relative to maximum water depth, sizes and types of rope used.

Cumulative Effects

A single mooring surface line scouring the bed can impact marine vegetation. Depending upon the amount and type of mooring buoys, the cumulative impact of permanent or seasonal mooring buoy installations in marine waters could be significant. Mooring buoy installation design, tides, water, depths, water currents, prevailing wind/wave patters, and marine vegetation type are variables that determine the shape and extent of these disturbances.

Groundings of floating rafts, barges, and booms, although temporary, are also likely to have negative impacts on the biota with the extent of the cumulative impacts depending on the duration of the event. The number of occurrences of permanent or seasonal floating rafts, docks, or booms occurring in a given region likely presents a significant cumulative impact to the total net nearshore fish and shellfish production and available habitat. Although a short-term effect of only groundings over a period of a week would be considered a temporary event, with far less significance to the net total cumulative impacts, it would still adds to the impact and should be avoided whenever possible.

Boat Ramps, Hoists, and Launches

Placement

Launching ramps built to allow boat launching across the intertidal area under varying tidal levels are typically installed in low energy areas to provide access to deep areas just beyond the intertidal area. As intrusive structures in the intertidal area, ramps can split and reduce intertidal spawning and rearing areas. Typically ramps extend into the water perpendicular to the shoreline at a 12-15 % slope. Slopes steeper than 15% can be dangerous to drivers (Dunham and Finn 1974) while ramps with a less than 12% slope will require trailer wheel hubs to be submerged (Mulvihill 1980). Ramps placed in quiet areas will minimize the biological intrusion of additional protective structures. By placing ramps in well-flushed areas, pollutant and excessive nutrient buildups will be avoided. Siting ramps within marinas could serve to encourage the use of specific ramp and haulout facilities to serve smaller boats and serve to limit the number of small boats requiring year-round moorage. This will also restrict ramp development to existing disturbed sites and reduce regional cumulative intertidal habitat loss due to additional ramp structures in unimpacted areas.

Design and Materials

Alternative ramp structures that reduce habitat losses include:

- Elevated railway launches
- Hoist or lift launches
- Natural substrate ramps
- Elevated ramps

The above designs will minimize the impact to nearshore habitats by elevating the ramp structure above the intertidal. When it is necessary to place a ramp across the intertidal, using materials similar to the surrounding natural environment will reduce impacts to water clarity and decrease the input of contaminants into the marine environment. The above designs can minimize the loss of spawning and other intertidal habitat functions by minimizing the extent of disturbances and interference with the ambient natural physical processes that determine adjacent habitat functions.

Operations

All vessel washdowns should occur over a washdown system specifically designed for washdown water or for drainage into a sewer system for treatment and not returned directly back to the marine waters. Otherwise, engine oils and other contaminants will likely be introduced into marine and estuarine ecosystems. Shoreline parking facilities require proper stormwater filtration or treatment to reduce further negative biological impacts through the introduction of contaminants.

Cumulative Effects

A ramp replaces benthic and epibenthic habitat utilized by fish and shellfish populations. The number of ramps in a given area extends the area of such intertidal habitat fragmentation and loss. Community ramps should be required or encouraged in order to limit the biological intrusions and loss resulting from such structures.

Cumulative Effects

Scientific evidence increasingly indicates that the most devastating environmental effects are most likely not the direct effects of a particular action, but the combination of individually minor effects of multiple actions over time (CEQ 1997). In general, as the number of overwater structures increase in a given area, impacts will accrue producing a net loss in vegetation production and a concomitant reduction in epibenthic and benthic nearshore habitat. The type and extent of each of these alterations depends upon specific site characteristics and structure types. The bathymetry of Washington's inland waters, that of a fjord surrounded by a narrow strip of shallow vegetated habitat, magnifies the need to protect the integrity and continuity of this limited area of nearshore habitat because of the concentrated zone of potential impact.

Cumulative Effects along Rural and Natural Shorelines

To what degree a given system is likely subjected to adverse effects is dependent upon its existing habitat characteristics. The existing habitat functions and the cumulative effects of additional overwater structures are determined in part by the degree to which an existing shoreline is in a relatively natural state or it is already impacted by urban development with many shoreline modifications that have accumulated over time. To the extent a natural shoreline supports fish and shellfish spawning, rearing, and refugia is to the extent adverse ecosystem effects to those habitats can result in loss of fish and shellfish carrying capacity supported by those shorelines. This is largely due to the habitat value of the existing environment. The habitat value of an environment that directly supports the recruitment of fish and shellfish stocks is magnified by its overall importance in stock recruitment. Its value is intrinsic to its location but its loss to stocks and the larger ecosystem reaches beyond its specific location. In short, protection of habitats critical to important survival and recruitment needs of fish and shellfish magnify the importance of controlling any adverse effects to them. Economically, it is far less expensive and more productive to protect existing critically important habitat than to restore lost or degraded habitats. The factors controlling habitat characteristics and the biologic assemblages that have evolved are endemic to the geologic and biologic history specific to a geographic location and region. Perhaps more significantly, the linkages among these ecosystem components are not fully understood.

Cumulative Effects along Urban Industrialized Shorelines

An urban industrialized shoreline area may have, over a long period of time, lost its native vegetation and suffered major changes to its historical substrates and other controlling factors (e.g., wind/wave energy, estuarine circulation). In the urbanized environment, the addition of a new structure may pose a qualitatively different set of cumulative effects than the effects of a new structure in a rural or more undisturbed natural environment. The potential detrimental effects of cumulative changes could include a depletion of existing prey resources. The possible impacts such prey loss can pose on salmonid migration and survival is likely reflected in the studies of chum fry migration in Hood Canal (Simenstad et al. 1980). The Hood Canal (Simenstad et al. 1980) suggests that outmigration speed is likely directly related to the availability of prey resources. The study demonstrated that when epibenthic resources are significantly depleted in areas along the migratory corridor, it appears that small juveniles (30-60mm) will migrate more rapidly to other shallow sublittoral habitats where adequate prey resources exist (Simenstad et al. 1980). Similarly, Healey (1979) and Sibert (1979) found the residence and productivity of chum fry in the Nanaimo River estuary to be linked to the production of specific prey resources, such as the harpacticoid copepod H. uniremis. The trade-off for faster outmigration in the face of limited prey resources could be a sustained exposure to size-selective predation as a product of swimming longer distances with less energy input. It is theorized that the associated energy costs of migration with limited prey resources result in those fish in depleted resource environments remaining at smaller sizes for longer periods of time and therefore extended risk of predation.

Prey resource productivity in urban industrialized areas is often compromised by light limitation and substrate modifications that limit plant and animal productivity. Large shipping facilities with dock construction specifications that are constrained by load-bearing requirements and vessel maneuverability may preclude the same types of design considerations and mitigations that residential, recreational boating and commercial fishing facilities can employ. As light limitation poses both the risks of barriers to migration and limited prey resource production, mitigating to offset light limitation through the manipulation of every possible light-carrying vector carries the potential of increasing the corridor's carrying capacity. These vectors could include the use of light reflective paint on dock undersides, building in light-allowing areas through the intermittent use of blocks and grates intermittently along the migratory corridor, and using low level intermittent under-dock artificial light during daytime hours to allow ambient light into underwater environments. Weitkamp (1982a) identified the presence of salmonids around areas of light such as a hole in Pier 91, which is consistent with the notion that fish do not require continuous light but they depend upon contrasts and shadows created by varying light patterns underwater.

For urban industrialized areas, a landscape ecology approach combining increased light in under-pier environments with adjacent areas of enhanced prey production could begin to rebuild a higher carrying capacity migratory corridor for juvenile fishes, such as salmonids, that typically suffer higher mortality. To compensate for the lack of under-dock lighting, prey resource enhancement in adjacent beach areas could increase the productivity available under the dock, depending on the water transport of detrital matter, and in the immediate enhanced habitat area. In this way, habitat enhancement of areas available for increased plant and prey resource production interspersed with intermittent under-dock light enhancement strategies could rebuild a nearshore migratory corridor for very small fish. This landscape ecology approach could hold a particularly important place in salmon recovery for the region given that urban shorelines are typically along salmonid migratory corridors that support numerous salmon runs (Shreffler and Thom 1994; Simenstad 2000).

Cumulative Effects of Invasive Species

International shipping has brought to the region the invasion of numerous non-native marine species that may be capable of out-competing native species. The ecosystem of the San

Francisco Bay estuary has been modified by an estimated 95% by the invasion of exotic biotas that are believed to be largely transported by ship ballast water. Oil tankers in Prince William Sound have also been implicated with an identified 24 species of invasive species in Alaskan waters (Hines et al. 2000). A 1998 rapid assessment survey of invasive species identified 39 invasive species found on floating docks in the Puget Sound region (Cohen 1998). In 1997, Ruiz and Hines identified 67 non-indigenous marine species in the shared inland waters of British Columbia and Washington. The ensuing changes to the food web may be profound and permanent. State regulations to be implemented in 2001 will prohibit the release of ballast waters while ships are at dock or anchor in Puget Sound. Exotics can also be transported on the hulls of recreational vessels that move about inland waters. Precautions, such as wash downs, can be taken to keep vessel hulls clean of species acquired in one water body from being boat-transported to other water-bodies where they are not indigenous.

Conclusions

Light and Animals

Empirical findings support the notion that overwater structures can have measurable effects on the distribution and abundance of marine resources. Based on the existing state of the knowledge and the fact that light levels are measurable and variable with each structure and location, we conclude that light limitation assessment and mitigation in the development of overwater structures is integral to ecosystem-based resource management. Fish feeding and migration abilities are closely linked to the predominant ambient light wavelengths of the natural marine environment. To the extent that under-dock environments block important wavelengths, they diminish prey and directional orientation visibility levels and cause behavioral changes. Laboratory studies have shown that the threshold for the lowest levels of maximum prey capture for juvenile chum and pink salmon occurs between 10^{-1} and 1 foot-candles which is partially equivalent to 0.5 (PAR) Photosynthetically Active Radiation. This represents the lowest end of light levels characterizing dawn or dusk which ranges from 10^{-1} to 100 ft-candles. Measurements of light levels under ferry terminals have identified under-dock areas that drop below the threshold even in the high light conditions of summer. When light intensity falls below this threshold, the fish must "dark adapt" to rod vision. During this time they are in a state of blindness with visual adaptation taking between 35 to 50 minutes. This "dark adapt" process is likely what is reflected in fish pause or directional change behavior. We conclude that during daylight hours, at very minimum, under-dock light levels must be maintained at levels above 0.5 PAR to avoid this behavioral interference. This lower threshold of light level, however, only addresses the issue of migration delays and behavioral alterations associated with required visual adaptation to light intensity variations and transitions from cone to rod vision. Cone vision is often the only form of vision for larval marine fishes. Fish visual development takes place on varying levels. Within juvenile cone vision development stages, there are also varying levels of sensitivity to the full spectrum of ultraviolet wavelengths. As visual development proceeds, juvenile marine fishes are known to behave and feed in response to specific ultraviolet wavelengths. They are known to respond to the full spectra of ultraviolet light contained in outdoor light as compared to forms of artificial light, such as fluorescent lights. Such artificial lighting does not contain both UV-A and UV-B spectra. Evidence reveals that juvenile fish, such as salmonids, feeding in shallow nearshore waters utilize ultraviolet wavelengths for prey capture. Therefore, we also conclude that allowing the transmission of increasing levels of natural light to the under-dock environment to include the transmission of required ultraviolet light spectra will reduce structural interference with fish ability to capture under-dock prey.

Light and Plants

Light thresholds for vegetation vary with species. Eelgrass in Puget Sound is light limited at levels below the photosynthetically Active Radiation (PAR) level of 300 nm; while intertidal macroalgae species may require 400-600 nm and sublittoral macroalgae may require less than 100nm. We conclude that overwater structures can minimize negative impacts to prey resources and habitats if the PAR levels required by vegetation native to the given site are provided by the overwater structure. Overwater structures that reduce light levels below these thresholds limit the growth of these plants and the abundance of prey resources and refugia associated with them. Given the known light threshold needs of plants and fishes in marine nearshore environments, the degree that (PAR) light levels between 300-550 nm are maintained is to the degree that both plants and animals will not be light limited in under-dock environments.

Wave Energy and Substrate Type

Empirical findings support the notion that overwater structures can pose significant impacts to ambient wave energy patterns and substrate types. Given what is known concerning biota and substrate relationships and the drift cell processes determining those substrates, the basic unit of measurement for establishing change thresholds to identify overwater structure effects is likely based in the drift cell. At this time, drift cell thresholds are not established. However, we conclude that such thresholds are needed to mitigate impacts. We also conclude that such thresholds will require development on a corridor and drift cell-specific basis.

Cumulative Effects

Given the apparent increasing demand for overwater structures, structural design to allow maximum light transmission and to mitigate energy and substrate changes are required to protect the ecosystems marine fishes rely upon. Given what is known concerning overwater structure impacts to marine and estuarine ecosystems, we conclude that multiple placements of overwater structures in marine waters can pose substantive risks of significant changes to the immediate and surrounding marine and estuarine ecosystems. These risks require the assessment of existing cumulative light limitation effects and wave energy and substrate effects to the shoreline environment. These risks require assessment at the drift cell level before considering the addition of new structures.

Recommendations

Assessing Individual and Cumulative Impacts of Overwater Structures

The existing scientific knowledge clearly identifies a range of potential impacts on fish and shellfish from overwater structures, depending upon shoreline habitat and setting and the type, size, and orientation of the structure.

Approaches Mitigating Impact of Overwater Structures

Fixed Docks

- Increase height to allow light transmission in under the dock
- Decrease dock width to decrease shade footprint
- Align dock in North-South orientation to allow arc of sun to cross perpendicular to dock to reduce duration of light limitation
- Place dock in deep waters to avoid intertidal and shade impacts
- Insert glass blocks to allow under-dock light transmission across the
- Insert dock gratings to allow under-dock light transmission across the intertidal
- Explore the effects of under-pier artificial lighting during daylight hours to avoid fish behavioral changes due to interference with ambient light conditions
- Use reflective paint on underside of dock to reflect light to under-pier areas

Pilings

- Use materials (i.e. concrete or metal) that reflect light as opposed to dark wood
- Use the fewest number of pilings necessary to allow light into under-pier areas
- Drive piles using environmental windows that include protection for spawning periods and periods of presence of juvenile salmonids, forage fish and groundfish.

Floats

- Use chains to attach dock to land to allow dock movement and decrease sustained duration of light reduction
- Minimize dock width to decrease under-dock shadow area

- Place floats in deep water to avoid light limitation and grounding impacts to the intertidal
- Align floats in North-South orientation to allow ace of sun to cross perpendicular to dock to reduce light limitation
- Remove docks during the season of low use

Marinas

- Place marina where it does not interfere with drift sectors determining adjacent habitats
- Place marina where maintenance dredging to keep waterways open to navigation will not require maintenance will not be required
- Avoid impacts to wave energy that determines characteristics of adjacent habitats
- Encourage only seasonal use of docks and off-season haul-outs
- Assure marina access to surrounding community to minimize need for additional facilities and single-family docks
- Use upland boat storage to minimize need for overwater structures
- Excavate uplands to create marina basins rather than converting intertidal or shallow subtidal to deeper subtidal for basin creation
- Place marinas in natural deep water areas to minimize or preclude dredging and groundings
- Place marinas in areas of low biological abundance and diversity
- Leave marine riparian buffers in place to enhance intertidal microclimate and nutrient input
- Build in fish passageways to allow fish in and out of the marinas

Floating Breakwaters

- Use floating breakwaters whenever possible, removing them during periods of low dock use
- Use waveboards to minimize effects on littoral drift and benthic habitats
- Avoid use of solid breakwaters whenever possible
- Use alternative wave energy buffer designs that serve both human and fish uses
- Minimize use of breakwaters whenever possible

Barges and Rafts

- Anchor work barges and boats in deep water to avoid groundings of barge and work boats and avoid damage to intertidal fish, shellfish and vegetation

Ramps and Haul-outs

- Avoid placing ramps across spawning substrates
- Use elevated railway launches
- Use hoist or lift launches to minimize disturbance in intertidal areas
- Use natural substrate materials for ramps to maintain integrity and continuity of intertidal area
- Use elevated ramps to minimize to reduce area of disturbance in the intertidal
- Place all parking lots associated with ramp and marina areas upland connecting them with storm run-off catchment and run-off systems to minimize contaminant inputs into marine waters

Research Required to Address Significant Gaps in Knowledge

Throughout this synthesis, we have acknowledged that there are significant gaps and uncertainties in the extent of scientific knowledge about impacts of overwater structures on estuarine and nearhsore marine biota. Some of these gaps are very basic to understanding the ecology and life history of potentially impacted species, such as those defining the extent and "ecological dependence" of shoreline habitat use by certain biota. Examples of knowledge gaps include understanding why certain forage fishes such as surf smelt and Pacific sand lance choose certain beaches to spawn or understanding the significance of plant and animal responses to shoreline structures. We consider the following to be fundamental gaps in our knowledge base that are required to effectively assess the impact of shoreline structures and mitigate for the potentially significant impacts.

Determine the conditions for and the significance of avoidance of shoreline structures by migrating juvenile salmon

Presently, although we know that under some conditions small juvenile salmon will delay or otherwise alter their shoreline movements when encountering an overwater structure, the conditions under which this behavioral modification is significant to the fishes' fitness and survival is relatively unknown. Such behavioral responses may be short-term lasting from minutes to hours, based on sun angle and tidal stage, or may persist into diel or nocturnal periods. The consequence to juvenile salmon under these different scenarios needs to be examined in terms of increased vulnerability to predation, reduced foraging, and other potential acute and chronic impacts to their migration and survival.

Further measure the effects of using artificial lights in under-pier environments to avoid interference with natural ambient light patterns in shallow nearshore habitats

If behavioral avoidance of mobile biota, such as juvenile salmon, is the primary mechanism of response to overwater structures, reducing the shadow contrast beneath structures may mitigate that response and promote fish passage.

Further quantify the effects of overwater structures on salmonid prey resource abundance

The effect of overwater structures on juvenile salmonid prey resources has yet to be rigorously examined. However, the WSDOT Research Office is presently supporting on-going graduate student study[1] of the influences of overwater structures on juvenile salmon prey resources at three WSDOT ferry terminals in Puget Sound. Information from this study, available in early 2002, should significantly improve our understanding of this issue.

Develop a scientifically based approach to determining cumulative impact thresholds

We suggest that the ultimate assessment of impact of overwater structures likely rests in determining the cumulative impacts of multiple structures along a shoreline segment or the relative sensitivity of certain ecologically significant regions of shorelines. This, in part, rests in understanding how estuarine and nearshore marine shorelines are organized and maintained by phsyiochemical processes, such as shoreline geology, gemorphology, and physical and chemical oceanography, and how these processes influence ecological functions. The scientific basis for understanding both the biophysical organization of shoreline habitats and how to determine impact thresholds of cumulative shoreline development, such as overwater structures is sorely deficient.

Because estuarine ecological functions are determined by diverse and dynamic physiochemical processes that interact across landscape elements, we recommend a landscape ecology approach for identifying impact thresholds. Using the definition of a landscape as a geographic area encompassing diverse yet connected habitats that contain a pool of materials and energy transferred between component ecosystems (Simenstad 2000; Leibowitz1992), a shoreline drift cell (sector) could constitute a reasonable landscape unit, within which materials and energy are transferred as a result of a variety of ecological processes. The ecological processes of bluff erosion, wave energy, and littoral transport provide sediments to the drift cell ecosystem that maintains shoreline habitats that support viable fish populations. We recommend that development of a scientifically based cumulative assessment include the following steps:

- Develop a landscape scale model of shoreline processes that create and maintain biological habitats
- Develop assessment indices for identifying ecological responses to overwater structures within the context of the model

[1] Ms. Melora Haas, Wetland Ecosystem Team, School of Aquatic and Fishery Sciences, University of Washington

- Identify landscape-level sub-units, such as shoreline drift cells (sectors)
- Identify landscape elements in terms of connectivity and homogeneity using the fundamental definitions of corridors, matrices, patches and other landscape attributes in order to guide the design and placement of specific types of overwater structures

To some degree, the first element in this sequence is presently being developed under Washington Sea Grant funding within the context of the Nearshore PRISM Working Group at the University of Washington.

Summary of Existing Guidance

Regulatory Framework Governing Overwater Structures in Marine Ecosystems

Construction of overwater structures in marine waters of Washington State require compliance with the rules of the state Hydraulic Code (WAC 220-110). In addition, other local, state, and federal regulations apply to such projects. For example, rules under the Shoreline Management Act (WAC 173-27) and the applicable local Shoreline Master Program (jointly administered by the Department of Ecology and the local jurisdiction) apply to overwater structure proposals, as well as, federal rules (implemented by the U.S. Army Corps. of Engineers). Each of these agencies requires certain types of permits depending on the scope and nature of the proposal. In addition, an Aquatic Lands Lease license from Washington Department of Natural Resources may be required. All of these permits can be concurrently processed by the various applicable agencies when the Joint Aquatic Resource Permit Application ("JARPA") form is used. Most overwater structure projects are also subject to the rules of the State Environmental Policy Act (WAC 197-11).

Available Guidance Materials for Construction and Operation of overwater structures in marine ecosystems

Note: The Shoreline Management Act although not included in the following list of guidance materials would also apply.

HYDRAULIC CODE RULES

WAC 220-110-020 Definitions

WAC 220-110-250 Saltwater Habitats of Special Concern

In the following saltwater habitats of special concern, or areas in close proximity with similar bed materials, specific restrictions regarding project type, design, location and timing may apply as referenced in WAC 220-110-270 through 220-110-330. The location of such habitats may be determined by a site visit. In addition, the department may consider all available information regarding the location of the following habitats of special concern.

1. Information concerning the location of the following saltwater habitats of special concern is available on request to the habitat management division of the department offish and wildlife. These habitats of special concern may occur in the following types of areas:

2. Surf smelt (*Hypomesus pretiousus*) spawning beds are located in the upper beach area in saltwater areas containing sand and/or gravel bed materials.

3. Pacific sand lance (*Ammodytes hexapterus*) spawning beds are located in the upper beach area in saltwater areas containing sand and/or gravel bed materials.

4. Rock sole (*Lepidopsetta bilineata*) spawning beds are located in the upper and middle beach area in saltwater areas containing sand and/or gravel bed materials.

5. Pacific herring (*Clupea harengus pallasi*) spawning beds occur in lower beach areas and shallow subtidal areas in saltwater areas. These beds include eelgrass (*Zostera* spp.) and other saltwater vegetation and/or other bed materials such as subtidal worm tubes.

6. Rockfish (*Sebastes* spp.) settlement and nursery areas are located in kelp beds, eelgrass (Zoster spp.) beds, other saltwater vegetation, and other bed materials.

7. Lingcod (*Ophiodon elongatus*) settle and nursery areas are located in beach and subtidal areas with sand, eelgrass (Zostera spp.), subtidal worm tubes, and other bed materials.

8. Juvenile salmonid (family *salmonidae*) migration corridors, and rearing and feeding areas are ubiquitous throughout shallow nearshore saltwater areas of the state.

9. The following vegetation is found in many saltwater areas and serves essential functions in the developmental life history of fish or shellfish:

    - Eelgrass (*Zostera* spp.);
    - Kelp (Order *laminariales*);
    - Intertidal wetland vascular plants (except noxious weeds).

WAC 220-110-270 Common Saltwater Technical Provisions

1. Use of equipment n the beach area shall be held to a minimum and confined to specific access and work corridors.

2. Bed material, other than material excavated for bulkhead footings or placement of bulkhead base rock, shall not be utilized for project construction or fills. The department may allow placement of dredged material in areas for beneficial uses such as beach nourishment or cleanup of contaminated sediments.

3. Wet concrete shall be prevented from entering water of the state. Forms for any concrete structure shall be constructed to prevent leaching of wet concrete. Impervious material shall be placed over any exposed concrete not lined with forms that will be come in contact with waters of the state. Forms and impervious material shall remain in place until the concrete is cured.

4. Beach area depressions created during project activities shall be reshaped to preproject beach level upon project completion. Hydraulic clam harvesters shall comply with hose conditions specified in WAC 220-52-018.

5. No debris or deleterious material shall be disposed of or abandoned waterward of the ordinary high water line except at an approved in-water site.

6. All debris or deleterious material resulting form construction shall be removed form the beach area or bed and prevented from entering water of the state.

7. No petroleum products or other deleterious materials shall enter surface waters.

8. Project activities shall be conducted to minimize siltation of the beach area and bed.

9. All piling, lumber, and other materials treated with preservatives shall be sufficiently cured to minimize leaching into the water or bed.

10. Wood treated with preservatives trash, waste, or other deleterious materials shall not be burned below the ordinary high water line. Limited burning of untreated wood or similar material, subject to timing restrictions or other provisions may be allowed.

11. Project activities shall not degrade water quality to the detriment of fish life.

12. If a fish kill occurs or fish are observe din distress, the project activity shall immediately cease and the department granting the HPA shall be notified immediately.

WAC 220-110-271 Prohibited Work Times in Saltwater Areas

Work waterward of the ordinary high water line shall be prohibited or conditioned for the following times and areas. These timing restrictions shall be applied to projects in the following saltwater areas except when allowed under subsection 96) of this section or WAC 220-110-285 (Single family residence bulkheads in saltwater areas).

The prohibited times and areas for protection of migrating juvenile salmonids, surf smelt, and Pacific herring spawning beds are listed in Table 18.

Table 18. WAC Timing Restrictions

Tidal Reference Area	Juvenile Salmonid Migration Feeding and Rearing Areas	Surf Smelt Spawning Beds	Herring Spawning Beds
1	March 15-June 14	–	January 15-March 31
2	March 15-June 14	July 1-March 31	January 15-March 31
3	March 15-June 14	October 1-April 30	January 15-March 31
4	March 15-June 14	October 1-April 30	January 15-April 14
5	March 15-June 14	September 1-March 31 in all areas except Eagle Harbor and Sinclair Inlet. Year round in Eagle Harbor and Sinclair Inlet	January 15-April 30
6	March 15-June 14	–	–
7	March 15-June 14	Year round	February 1-April 14
8	March 15-June 14	Year round	February 1-April 14
9	March 15-June 14	Year round	February 1-April 14 south of a line running due west from Governor's point: February 1-June 14 north of a line running due west from Governor's point
10	March 15-June 14	Sept 15-October 31 in Kilisut Harbor; October 15-Janaury 14 in Dungeness Bay; May 1-August 31 in Twin Rivers and Deep Creek; Year round in San Juan Islands	January 15-April 30
11	March 15-June 14	September 15-March 1	January 15-March 31
12	March 15-June 14	–	February 15-April 14
13	March 15-June 14	October 15-January 31	January 15-April 14
14	March 1-June 14	–	–
15	March 1-June 14	–	–
16	March 1-June 14	–	–
17	March 1-June 14	–	February 1-March 14

Fixed docks and piers, floating docks, piers, barges, rafts, booms, boathouses, houseboats and associated moorings, and mooring buoys

WAC 220-110-300 Saltwater Piers, Pilings, Docks, Floats, Rafts, Ramps, Boathouses, Houseboats, and Associated Moorings

Piers, pilings, docks, floats, rafts, ramps, boathouses, houseboats, and associated mooring projects shall incorporate mitigation measures as necessary to achieve no-net-loss of productive capacity of fish and shellfish habitat. The following technical provisions apply to piers, pilings, docks, floats, rafts, ramps, boathouses, houseboats, and associated moorings in saltwater areas. In addition, these projects shall comply with technical provisions and timing restrictions in WAC 220-110-240 through 220-110-271,

1. Floats and rafts shall not ground on surf smelt, Pacific herring, Pacific sand lance, and rock sole spawning beds. In all other areas, no more than twenty percent of the float or raft within the beach area shall ground at any time. Those portions of the float or raft that will ground shall be constructed to align parallel to the shore and provide a minimum of eight inches clearance between the beach area and nongrounding portions of the float.

2. Floats, rafts, and associated anchoring systems shall be desidgned and deployed so that the bed is not damaged.

3. Piers, docks, floats, rafts, ramps, boathouses, houseboats, and associated moorings shall be designed and located otavoid shading of eelgrass (Zostera spp.).

4. Kelp (Order laminariales) and intertidal wetland vascular plants (except noxious weeds) adversely impacted to to construction of piers, docks, floats, rafts, ramps, boathouses, and houseboats shall be replaced using proven methdology.

5. Mitigation measures for piers, docks, floats, rafts, ramps, and associated moorings shall include, but are nto limited to, restircitons on strcuture width and/or incorportion of materials that allow adequate light penetration (i.e. grating) for structures located landward of -10.0 feet MLLW.

6. Piers, docks, floats, rafts, ramps, boathouses, houseboats, and associated moorings shall be designed and located to avoid adverse impacts to Pacific herring spawning beds and rockfish and lingcod settlment and nursery areas.

7. Piers, docks, floats, rafts, ramps, boathouses, houseboats, and associated moorings shall be designed and located to avoid adverse impacts to juvenile salmonid migration routes and rearing habitats.

8. Floatation for the strcuture shall be fully enclsoed and ocntained ot prevent the breakup or loss of the floatation material in the water.

9. Boathouses and houseboats and covered moorage sshall not be located landwoard of -10.0 feet MLLW.

10. Pilings and dolphins

Marinas

WAC 220-110-330 Marinas in Saltwater Areas

Marina construction projects shall incorporate mitigation measures as necessary to achieve no net loss of productive capacity of fish and shellfish habitat. The following technical provisions apply to marina projects. In addition, these projects shall comply with technical provisions and timing restrictions in WAC 220-110-240 through 220-110-320 except WAC 220-110-285.

1. The construction of marinas is prohibited on or over Pacific herring spawning beds and lingcod and rockfish settlement and nursery areas.

2. Marinas shall be designed, located, and constructed to avoid adverse impacts to surf smelt, Pacific sand lance, and rock sole spawning beds, and eelgrass (Zostera spp.).

3. Open-type construction, utilizing floating breakwaters and open pile work, shall be used whenever practical.

4. Physical modeling, numerical models, or other information that demonstrates adequate water exchange and circulation may be required.

5. All navigation channels and breaches shall be maintained at or below marina depth to provide adequate fish passage.

6. Isolated breakwaters beyond the line of extreme low tide shall be constructed of permanent material. No slope restrictions apply.

7. The following provisions apply to marina construction shoreward of the existing ordinary high water line:
    a) A single entrance may be required.
    b) The entire inner shoreline shall be in conformance with bulkheading provisions in WAC 220-110-280.

8. The following provisions apply to marina construction waterward of the ordinary higher water line:

   a) The beach area inside the marina may be protected in accordance with bulkheading provisions in WAC 220-110-280. Between the elevation of the toe of the bulkhead and MLLW the beach face shall not exceed a slope of 1.5 feet horizontal to one foot vertical.

   b) For a single entrance or breach marina, the breakwater structure shall not exceed a 1.5-foot horizontal or one foot vertical slope inside and outside the marina.

   c) The following provisions apply when a marina includes breaches that form shore breakwaters (jetties) and detached breakwaters:

      i. The toe of the shore breakwaters (jetties) may extend seaward to MLW, but shall not extend seaward more than 250 feet form MHHW.

      ii. The shore breakwaters shall have a minimum slop of 1.5 feet horizontal to 1 foot vertical throughout.

      iii. The breaches between the shore breakwaters and the detached breakwaters shall be not less than 20 feet in width measured at the toe of the slope.

   d) Boathouses, houseboats, and covered moorages shall not be located landward of -10-feet MLLW.

Boat ramps, hoists, and launches

WAC 220-110-290 Saltwater Boat Ramps and Launches

Boat ramp projects shall incorporate mitigation measures as necessary to achieve no net loss of productive capacity of fish and shellfish habitat. The following technical provisions apply to saltwater area boat ramp and launch projects. In addition, these projects shall comply with technical provisions and timing restrictions in WAC 220-100-240 through 220-110-271.

1. Railway-type boat launches shall be designed to cause minimal interference with tidal currents and littoral drift.

2. Boat ramps shall be designed and located to avoid adverse impacts to surf smelt, Pacific sand lance, rock sole, and Pacific herring spawning beds, rockfish and lingcod settlement and nursery areas, and eelgrass (Zostera spp.).

3. The side slopes of boat ramps shall be no steeper than 1.5 feet horizontal to one foot vertical.

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APPENDIX A

Estuarine and Marine Classification Definitions, Dominant Plant and Animal Assemblages, and Overwater Structure Impacts

Table A-1. Estuarine and Marine Classification Definitions- Natural Heritage Program (adapted from Dethier 1990)

System	Subsystem	Substrate	Wave Energy	Depth
Marine	Intertidal	• Consolidated: bedrock, boulder, hardpan • Unconsolidated: cobble, mixed coarse, gravel, sand, mixed fine, mud, organic	• Exposed • Partially Exposed • Semi-Protected • Protected	• Eulittoral: Areas between MHWS and ELWS • Backshore: Areas above MHWS but receiving marine influence through spray or irregular flooding
Marine	Subtidal	• Consolidated: bedrock, boulder, hardpan • Unconsolidated: cobble, mixed coarse, gravel, sand, mixed fine, mud, organic	• High: exposed to oceanic swell or very strong currents • Moderate: exposed to only wind waves and moderate tidal currents • Low: exposed to only very weak or no currents with little wave action	• Shallow: 15 m or less below MLLW • Deep: over 15m below MLLW
Estuarine	Intertidal	• Consolidated: bedrock, boulder, hardpan • Unconsolidated: cobble, mixed coarse, gravel, sand, mixed fine, mud, organic	• Open: exposed to moderate to long fetch, windwaves and/or current • Partly Enclosed: partially enclosed with minimal wave action • Lagoon: Protected, largely enclosed embayment • Channel/Slough: inlets submerged with tidal backup water at high tide	• Eulittoral: Areas between MHWS and ELWS • Backshore: Areas above MHWS but receiving marine influence through spray or irregular flooding
Estuarine	Subtidal	• Consolidated: bedrock, boulder, hardpan • Unconsolidated: cobble, mixed coarse, gravel, sand, mixed fine, mud, organic	• Open: exposed to moderate to long fetch, windwaves and/or current Partly Enclosed: partially enclosed with minimal wave action • Lagoon: Protected, largely enclosed embayment • Channel/Slough: inlets submerged with tidal backup water at high tide	• Shallow: 15 m or less below MLLW • Deep: over 15m below MLLW

Table A-2. Dominant Plant and Animal Assemblages in Washington State Marine Intertidal and Shallow Subtidal Habitats

Marine Intertida eulittoral)	Rock	Exposed; Partially Exposed; Semi-protected	Rockweed, Algae, Kelps, Surfgrass Coralline Algae	Sea Perch, Sculpins, Rockfish, Cod, High Cockscomb, Sculpins, Clingfish, Prickleback	Mussels, Barnacles, Crab, Limpets, Chitons
	cobble	partially exposed	Algae	herring spawn, sculpins, clingfish, gunnels	barnacles, clams, crab, shrimp
	mixed-coarse	semi-protected protected	seasonal drift algae		shrimp, clams
	gravel	partially exposed	none	shiner perch, juv. tomcod Eng. sole, starry flounder, gunnels, sculpins, surf smelt spawn, sand lance larvae	amphipods, shrimp
	gravel	semi-protected	algae	shiner perch, juv. Eng. sole, flounder, sculpins	clams, crab
	sand	exposed partially exposed	None	sole, flounder, Pac. sand lance, Pac. tomcod, perch, sculpins, gunnels, sturgeon poachers, Pac. herring, surf smelt	clams, shrimp
	sand	semi-protected protected	eelgrass, algae,	sole, juv.salmonids, sculpin, surf smelt, sand lance and candlefish larvae	clams, shrimp
	mixed fines	semi-protected protected	eelgrass, algae, drift algae	juv. Pac. tomcod, lingcod, tube-snout, pipefish, perch, prickleback, gunnels, sculpin, poacher, sanddab, surf smelt, juv. Eng. sole flounder	clams, crabs, shrimp
	mud	protected	eelgrass, algae	flounder, juv. Eng. sole, tube-snout, perch, pipefish, gunnel, goby, sculpins, herring spawn	
Marine Shallow Subtidal	rock & boulders	mod to low energy	surfgrass, eelgrass, algae	greenlings, rockfish, sculpins, cabezon, gunnels, perch	crabs, scallops, chitons, abalone, snails, urchins
	gravel	high & low energy	algae	greenlings, rockfish, sculpins, cabezon, gunnels, perch, flatfish	snails
	mixed-fines	moderate to high energy	algae	juv. Eng. sole, sole, flounder, juv. Pac. tomcod, poachers, sculpins, perch	bivalves, scallops, crabs, snails, geoducks, clams
Estuarine Intertidal eulittoral	mixed-coarse	open	algae; often eelgrass beds lie just subtidally of these beaches	sculpins, juv. salmon, trout, blennies, gunnels, clingfish, perch, surf smelt, sole, stickleback, herring spawn	bivalves, clams, crabs, oysters, limpets
	gravel	open	ulva, algae	juv. Eng. sole, perch, cabezon, flounder sculpins, greenling, gunnels, poachers	

Table A-2. Dominant Plant and Animal Assemblages in Washington State Marine Intertidal and Shallow Subtidal Habitats (continued).

Marine Intertida eulittoral)	Rock	Exposed; Partially Exposed; Semi-protected	Rockweed, Algae, Kelps, Surfgrass Coralline Algae	Sea Perch, Sculpins, Rockfish, Cod, High Cockscomb, Sculpins, Clingfish, Prickleback	Mussels, Barnacles, Crab, Limpets, Chitons
eulittoral & marsh	gravel	partly enclosed	pickleweed, saltwort, rockweed, sedge, martima		
open	sand	open	eelgrass, gracilaria, drift algae	juv. salmon, flounder, goby, sculpin, Eng. sole,	clams, shrimp
Estuarine Intertidal	sand mixed-fine mud	partly enclosed lagoon	vascular plants, bulrush,sedge, pickleweed (depending on salinity)	perch, juv. salmon, cutthroat, stickleback	clams, crabs
	mud	partly enclosed enclosed	eelgrass		
lagoon, marsh, backwaters	Organic sand mixed-fine mud	partly enclosed	sedge, grasses, vascular plant (depending on salinity) marsh plants,ulva, eelgrass	Pac. herring, Pac. sand lance, tube-snout, juv. Eng. sole, flounder, sculpins, stickleback, pipefish, prickleback, gunnels, surf smelt, perch, juv. salmon	shrimps, crabs, moon snails, oyster,
	mixed-fines mud	channel/slough	Eelgrass, lined with marsh plants	juv. salmon, stickleback, flounder, sculpin	clams, crabs
Estuarine Shallow Subtidal	Rock	open	algae		chitons, limpet, crabs, snails
	cobble	open	eelgrass		crab, clams
	mud	open	eelgrass, algae, ulva, kelp	sculpins, sole	bivalaves
	mud	partly enclosed		Pac. tomcod, flounder, sole, sculpin, smelts	bivalves, geoducks
	Sand mud	channels		Eng. sole, sanddab, sculpins, prickleback, Pac. tomcod, perch, peamouth, juv. salmon, flounder	crab, shrimp

(Adapted from Dethier 1990)

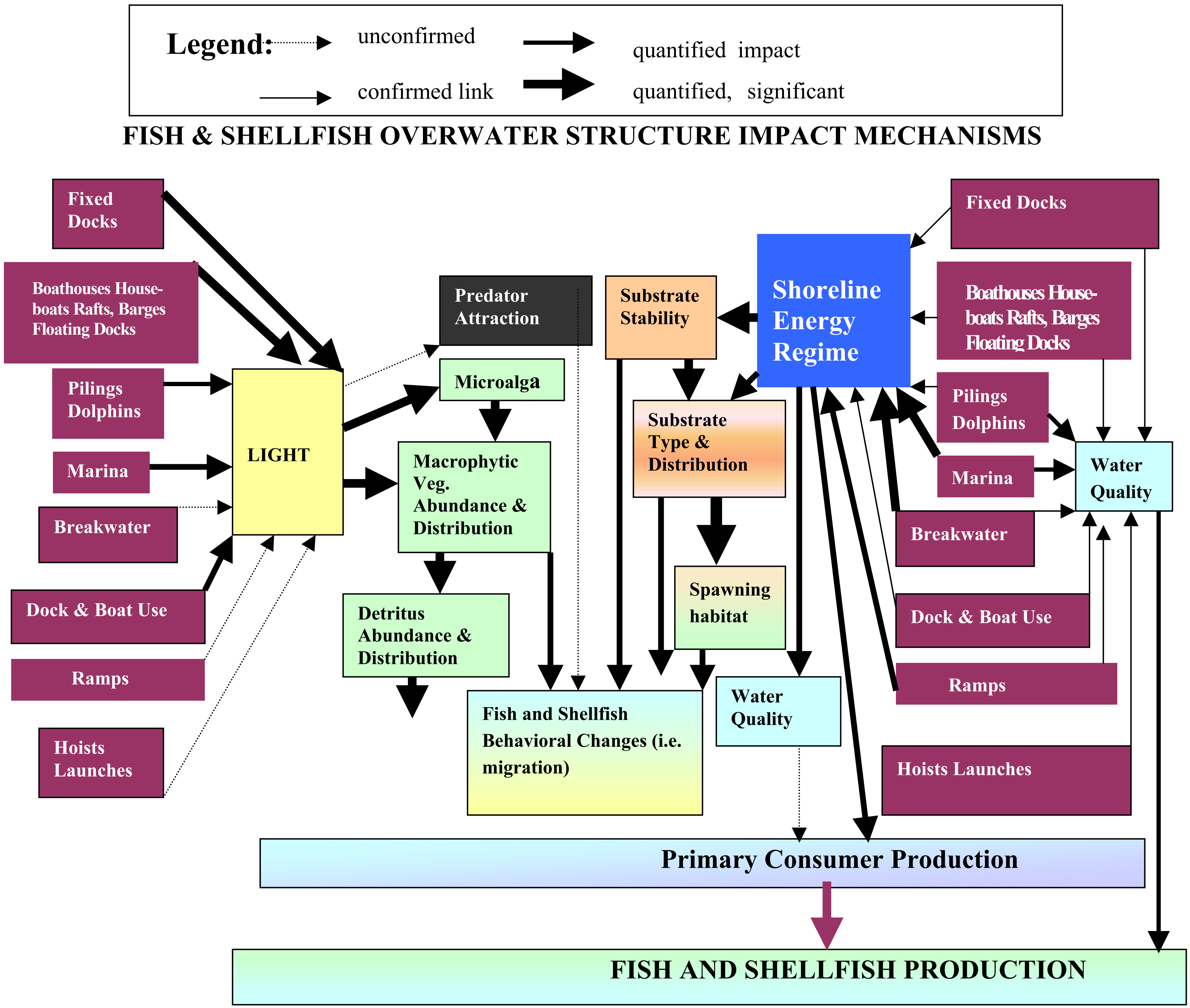

Figure A1. Habitat Impact Mechanisms

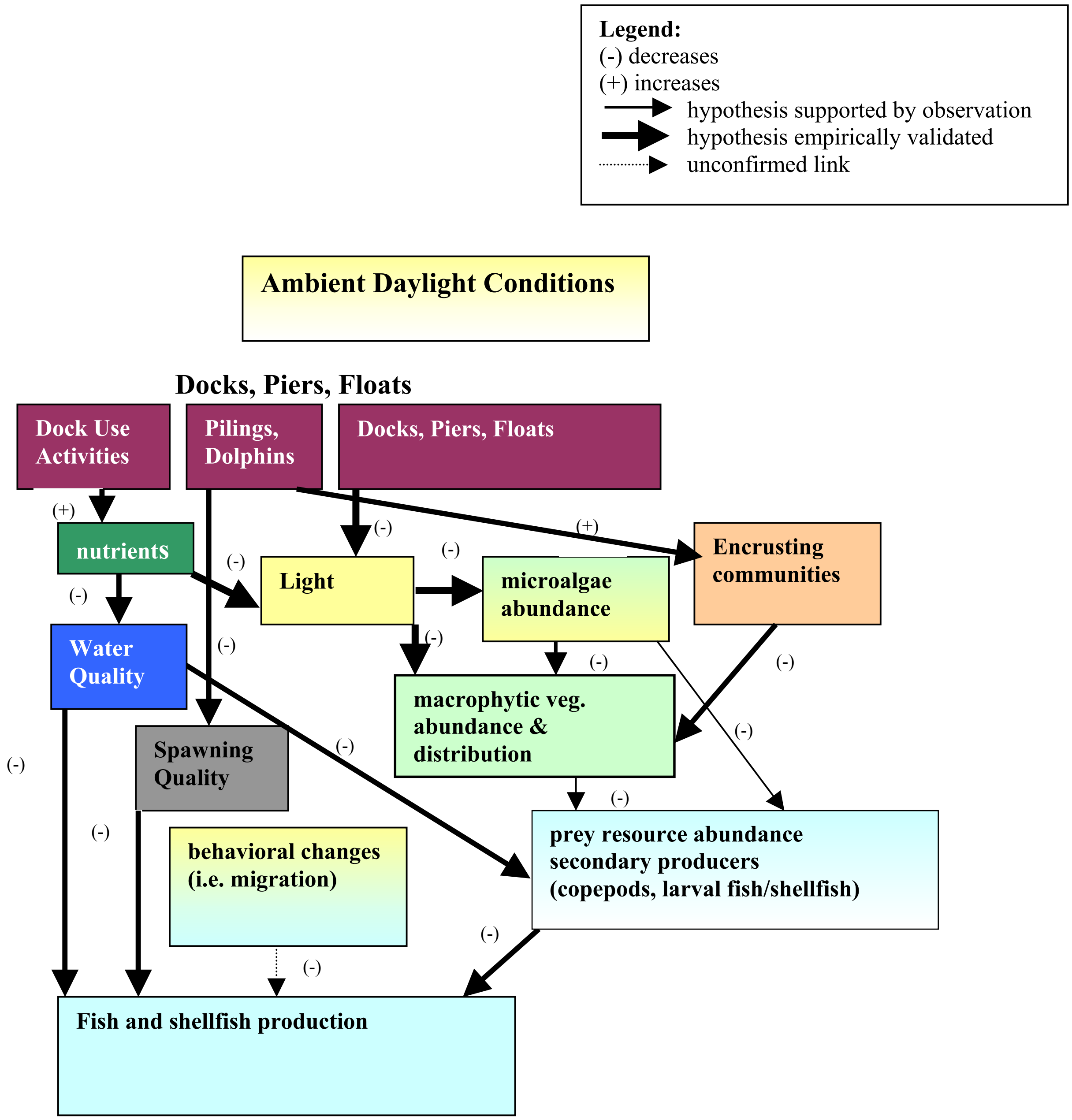

Figure A2. Dock, Pier & Float Impacts

APPENDIX B

Glossary of Terms

Glosary of Terms

ABIOTIC—the non-living factors of a given area, such as temperature, wind, substrate

ALGAE—simple plant form having no true roots, stems or leaves; ranging in size from microscopic, single-celled plants (microalgae) to seaweeds (macroalgae)

ALLUVIUM—unconsolidated mineral material moved by water and deposited in a fan shape at streams, river beds, floodplains, lakes, estuaries, and at the base of mountain slopes

AMPHIPOD—crustaceans in the Order Amphipoda, of subclass Malacostraca

ANADROMOUS FISH—species that are born in fresh water, spend a large part of their lives in the sea and return to freshwater rivers and streams to reproduce (e.g., salmon)

AQUATIC ENVIRONMENT—the geochemical environment in which dredged material is submerged under water and remains water saturated after disposal is completed.

AQUATIC ECOSYSTEM —bodies of water, including wetlands that serve as the habitat for interrelated and interacting communities and populations of plants and animals.

ARTIFICIAL REEF—an artificial made structure designed to simulate a natural reef.

ASSEMBLAGE—the group of species generally associated with a given habitat type.

BACKSHORE—the area wetted by storm tides but normally dry between the coastline and the high tide line. It may be a narrow gravel berm below a sea bluff or a broader complex of berms, marshes, meadows, or dunes landward of the high tide line

BANK—a land surface above the ordinary high water line that adjoins a body of water

BAR—a shore form similar to a spit or a hook, though generally not attached to the mainland during periods of high water.

BARRIER BEACH—an accretion shore form of sand and gravel that has been deposited by longshore drift in front of bluffs, bays, marshes, or estuaries, and functions like a storm barrier.

BEACH—the zone of unconsolidated material that is moved by waves, wind and tidal currents, extending landward to the coastline.

BEACH FEEDING—a process by which beach material is deposited at one or several locations in the updrift portion of a driftway. The material is then naturally transported by a wave's down drift to stabilize or restore eroding beaches or berms

BEACH RESTORATION AND ENHANCEMENT—the alteration of terrestrial and tidal shorelines or submerged shorelines for the purposes of stabilization, recreational enhancement, or aquatic habitat creation or restoration.

BEST AVAILABLE TECHNOLOGY—the most effective method, technique, or product available which is generally accepted in the field, and which is demonstrated to be reliable, effective and preferably low maintenance.

BEST MANAGEMENT PRACTICE (BMP)—method, activity, maintenance procedure, or other management practice for reducing the amount of pollution entering a water body. The term originated from the rules and regulations developed pursuant to Section 208 of the federal Clean Water Act (40 CFR 130).

BIODEGRADABLE—materials that are capable of being readily decomposed by biological means

BAITFISH (also called prey fish)—group of fish that are important to aquatic predators such as salmon, marine mammals and seabirds as food items. Examples of prey fish include: herring, sandlance and surfsmelt

BATHYMETRY—the measurement of depths of water in oceans, seas, and lakes. Also, information derived

BENEFICIAL USES—placement or use of dredged material for some productive purpose. Beneficial uses may involve either the dredged material or the placement site as the integral component of the beneficial use
BENTHIC —pertaining to the bottom substrate or the bottom of the water column

BERM—nearly horizontal part of beach or backshore formed of material deposited by wave action

BIOACCUMULATION—the accumulation of contaminants in the tissues of organisms through any route, including respiration, ingestion, or direct contact with contaminated water, sediment, or dredged material.

BIOPHYSICAL—the biological and physical attributes of an ecosystem.

BIOTA—the animal and plant life of a region

BIOTECHNICAL—method of shoreline stabilization that utilizes natural materials to enhance slope stability and resist erosion This may include use of bundles of stems, root systems, or other living plant material, soft gabions, fabric or other soil stabilization techniques, and limited rock toe protection where appropriate. Biotechnical projects often include fisheries habitat enhancement measures in project design (e.g., anchored logs, root wads, etc.). Such techniques may be applied to creeks, rivers, lakes, reservoirs, and marine waters. Biotechnical may also be applied in upland areas away from the immediate shoreline.

BIVALVE—An aquatic invertebrate animal of the class Bivalvia. Bivalves, such as clams and oysters, have two shells (valves) and most are filter feeders.

BRACKISH—water with a very low salt content (see oligohaline waters)

BREACHING—the breaking of a dike to allow re-entry of tidal flooding to tidal wetlands; can be caused naturally or artificially

BREAKER ZONE—zone of shoreline where waves break

BREAKWATER—an offshore structure generally built parallel to the shore that may or may not be connected to land. Its primary purpose is to protect a harbor, moorage, or navigational activity from wave and wind action by creating a still water area along the shore. A secondary purpose is to protect the shoreline (e.g., beaches and bluffs) from wave-caused erosion. Breakwaters may be fixed (e.g., rubble mound or rigid wall), open pile or floating. Most breakwaters in the Pacific Coast area are rip-rapped, mound construction. Several include ancillary sand by-passing operations.

BUFFER—a strip of land that is designed and designated to permanently remain vegetated in an undisturbed and natural condition to protect an adjacent aquatic or wetland site from upland impacts

BULKHEAD—a wall usually constructed parallel to the shore with the primary purpose of containing and preventing the loss of soil caused by erosion or wave action. Bulkheads may also be termed "seawalls," however in common usage, the term seawall in generally reserved for massive public works structures along the open coast. By contrast, bulkheads are typically lighter in structure and may be either private or public. Both bulkheads and seawalls are usually constructed of poured-in-place concrete, steel or aluminum sheet piling, wood or wood and structural steel combinations. They may be either thin structures penetrating deep into the ground, or more massive structures resting on the surface.

CALANOID COPEPODS—crustaceans in the Order Calanoida, of the Subclass Copepoda

CHANNEL—a natural or artificial waterway of perceptible extent which either periodically or continuously contains moving water, or which forms a connecting link between two water bodies

CHLOROPHYLL—green pigments essential to the process of photosynthesis, found primarily in plants; chlorophyll *a* is a specific type of chlorophyll pigment often used as an indicator of plant biomass

CHRONIC TOXICITY—any toxic effect on an organism that results after exposure of long duration (often 1/10th of the life span or more). The end result of a chronic effect can be death, although the usual effects are sublethal (e.g., inhibited reproduction or growth). These sublethal effects may be reflected by changes in the productivity and population structure of the community.

COASTAL ZONE—includes coastal waters and the adjacent shorelands designated by a State as being included within its approved coastal zone management program. The coastal zone may include open waters, estuaries, bays, inlets, lagoons, marshes, swamps, mangroves, beaches, dunes, bluffs, and coastal uplands. Coastal-zone uses can include housing, recreation, wildlife habitat, resource extraction, fishing, aquaculture, transportation, energy generation, commercial development, and waste disposal

COLIFORM BACTERIA—a type of bacteria that is coil or helix shaped. Fecal coliform bacteria are those coliform bacteria that are found in the intestinal tracts of mammals. The presence of high numbers of fecal coliform bacteria in a water body can indicate the recent release of untreated wastewater and/or the presence of animal feces. These organisms may also indicate the presence of pathogens that are harmful to humans. High numbers of fecal coliform bacteria therefore limit beneficial uses of water such as swimming and shellfish harvesting.

COMMUNITY—association of plants and/or animals in a given area or region in which various species are more or less dependent upon each other

CONTAMINANT—a chemical or biological substance in a form that can be incorporated into, onto, or be ingested by and that harms aquatic organisms, consumers of aquatic organisms, or users of the aquatic environment.

COPEPOD—crustacean in the subclass Copepoda; includes both pelagic (Calanoida, Cyclopoda) and benthi/epibenthic (Harpacaticoida)

COVERED MOORAGE—boat moorage, with or without walls, that has a roof to protect the vessel.

CREST—the seaward limit of a berm; Also, the highest part of a wave

CROSS-SHORE—sediment traveling up or down the profile of a beach

CUMULATIVE EFFECTS—the combined environmental impacts that accrue over time and space from a series of similar or related individual actions, contaminants, or projects. Although each action may seem to have a negligible effect, the combined effect can be severe.

CURRENT—a flow of water

DEPOSITION—the deposit of sediment in an area, can be by wave action, currents; or through mechanical means

DESICCATION—critical loss of fluids; drying out

DELTA OR RIVER DELTA—those lands formed as an aggregation feature by stratified clay, silt, sand and gravel deposited at the mouths of streams where they enter a quieter body of water. The upstream extent of a river delta is that limit where it no longer forms tributary channels

DEMERSAL—pertaining to an organism, such as a fish, living close to or on the bottom of a body of water; describing the habitat close to or on the bottom

DENSITY—the number of organisms per unit of area or volume

DEPOSITION—the deposit of sediment in an area through natural means such as wave action or currents; may also be done by man through mechanical means.

DIKE (also see LEVEE)—a wall or mound built around low-lying area to control flooding

DISCHARGE, DIRECT OR INDIRECT—the release of wastewater or contaminants to the environment. A direct discharge of wastewater flows directly into surface waters while an indirect discharge of wastewater enters a sewer system.

DISSOLVED OXYGEN—oxygen that is present (dissolved) in water and therefore available for fish and other aquatic animals to use. If the amount of dissolved oxygen in the water is too low, then aquatic animals may die. Wastewater and naturally occurring organic matter contain oxygen-demanding substances that consume dissolved oxygen.

DISPOSAL SITE OR AREA—a precise geographical area within which disposal of dredged material occurs

DREDGING—the removal of earth, sand, gravel, silt, or debris from the bottom of a stream, river, lake, bay, or other water body and associated wetlands. Dredging is normally done for specific purposes or uses such as constructing and maintaining canals, navigation channels, turning basins, harbors and marinas, for installing submarine pipelines or cable crossings, or for dike or drainage system repair and maintenance. Dredging may also be used to mine for aggregates such as sand and gravel.

DREDGED MATERIAL (previously called DREDGE SPOIL)—the minerals and associated material removed by dredging, or material excavated from waters of the United States or ocean waters. The term dredged material refers to material, which has been dredged from a water body, while the term sediment refers to material in a water body prior to the dredging process

DRIFT CELL, DRIFT SECTOR OR LITTORAL CELL—a segment of shoreline along which littoral, or longshore, sediment movement occurs at noticeable rates. It allows for an uninterrupted movement, or drift, of beach materials

DRIFTWAY—that portion of the shore process corridor, primarily the lower backshore and upper intertidal area, through which sand and gravel are transported by the littoral drift process. Each drift sector includes: a feed source that supplied the sediment, a driftway along which the sediment can move, an accretion terminal where the drift material is deposited, and boundaries that delineate the end of the drift sector.

DUNE—a hill or ridge or sand piled up by the wind and/or wave action

ECOLOGICAL—the interrelationship of living things to one another and to their environment

ECOLOGICAL FUNCTIONS—those natural physical, chemical, and biological processes that contribute to the proper functioning and maintenance of aquatic and terrestrial ecosystems means those shoreline areas that retain the majority of their natural shoreline functions and values, as evidenced by vegetation and shoreline configuration. Generally, but not necessarily, ecologically intact shorelines are free of structural shoreline modifications, structures, and intensive human activities. In unmanaged forested areas, they generally include native vegetation with a diversity of species, multiple canopy layers, and large woody debris available for recruitment. Recognizing that there is a continuum of ecological conditions ranging from near natural conditions to totally degraded and contaminated sites, this definition is intended to delineate those shoreline areas that provide valuable functions for the larger shoreline ecosystem which would be lost by significant human development. Whether or not a shoreline is ecologically intact is determined on a case-by-case basis using best available science. The term "ecologically intact shorelines" applies to all shoreline areas meeting the criteria ranging from larger reaches that may include several properties, to small areas located within a single property. For example, in establishing boundaries for Natural environment designations as called for in Washington Administrative Code, as amended, the term "ecologically intact" may apply to continuous, multi-parcel sections of shorelines. In applying shoreline stabilization standards to an individual property, the term may apply to a portion of the property.

ECOLOGICALLY INTACT SHORELINES—means those shoreline areas that retain the majority of their natural shoreline functions and values, as evidenced by vegetation and shoreline configuration. Generally, but not necessarily, ecologically intact shorelines are free of structural shoreline modifications, structures, and intensive human activities. In unmanaged forested areas, they generally include native vegetation with a diversity of species, multiple canopy layers, and large woody debris available for recruitment. Recognizing that there is a continuum of ecological conditions ranging from near natural conditions to totally degraded and contaminated sites, this definition is intended to delineate those shoreline areas that provide valuable functions for the larger shoreline ecosystem which would be lost by significant human development. Whether or not a shoreline is ecologically intact is determined on a case-by-case basis using best available science. The term "ecologically intact shorelines" applies to all shoreline areas meeting the criteria ranging from larger reaches that may include several properties, to small areas located within a single property. For example, in establishing boundaries for Natural environment designations as called for in Washington Administrative Code, as amended, the term "ecologically intact" may apply to continuous, multi-parcel sections of shorelines. In applying shoreline stabilization standards to an individual property, the term may apply to a portion of the property.

ECOSYSTEM—the organization of all biotic and abiotic factors in an area

EELGRASS (HABITAT)—intertidal and shallow subtidal, unconsolidated sand to mud shores that are colonized by aquatic, submerged rooted vascular angiosperms (seagrasses) of the genus *Zostera*. Two species predominate in the Pacific Northwest: *Zostera marina*, the endemic eelgrass, and *Z. japonica*, an introduced cogener

EFFLUENT—water that is discharged from a confined disposal facility during and as a result of the filling or placement of dredged material

EMERGENT MARSH—intertidal shores of unconsolidated substrate which are colonized by erect, rooted herbaceous hydrophytes, excluding mosses and lichens

EMBANKMENT—artificial bank such as a mound or dike, generally built to hold back water or to carry a roadway

ENCRUSTING BIOTA—animal or plant life that attaches itself to a given substrate or object, such as a barnacle or mussel

ENTRAINMENT—when an organism is trapped in the uptake of sediments and water being removed by dredging machinery

ENVIRONMENTAL IMPACT STATEMENT (EIS)—a document that discusses the likely significant impacts of a development project or a planning proposal, ways to lessen the impacts, and alternatives to the project or proposal. EISs are required by the national and Washington state environmental policy acts.

EPIBENTHIC—pertaining to the benthic boundary layer habitat at the interface between the bottom surface and the overlying water column, or to the organisms living in the habitat

EPIBENTHOS—organisms that live on the surface of the bottom sediment. (see also epibenthic)

EPIPELAGIC—pertaining to organisms which, through associated with the bottom, actively migrate off it into the water column, sometimes to the surface in shallow depths

EROSION—the wearing away of land by natural forces; on a beach, the carrying away of the beach materials

ESTUARY—the region near a river mouth where fresh water mixes with salt water and is influenced by the tide of marine waters

EUHALINE—waters with a salinity range of 30-40 ppt

EULITTORAL—The area between high and low tides, which is uncovered periodically.

EUPHAUSIIDS—crustaceans in the Order Eusphausiacea, of the subclass Malacostraca

EUPHOTIC ZONE—the surface waters of the oceans that receive sufficient light for photosynthesis to occur

EXTREME LOW TIDE—the lowest line of the land reached by a receding tide.

FAUNA—animal life (see also Flora)

FECAL COLIFORM see COLIFORM BACTERIA

FEEDER BLUFF OR EROSIONAL BLUFF—any bluff or cliff experiencing periodic erosion from waves, sliding or slumping that, through natural transportation, contributes eroded earth, sand or gravel material via a driftway to an accretion shoreform. These natural sources of beach material are limited and vital for the long-term stability of driftways and accretion shoreforms (e.g., spits, bars, and hooks).

FETCH—the distance over unobstructed open water on which waves are generated by a wind having a constant direction and speed

FISH AND WILDLIFE ASSEMBLAGES—groups of species that are representative of all fish and wildlife species that commonly utilize specific estuarine habitats; not inclusive of all species, but each use, such as feeding, reproduction, etc. is represented; not guilds

FIXED PIER—a fixed structure supported by pilings

FLOATING PIER (FLOATS)—a floating structure that is moored, anchored, or otherwise secured in the water, but which is not connected to the shoreline.

FLORA—plant life (see Fauna)

FORESHORE—part of the shore lying between the crest of a seaward berm and ordinary low water mark.

GABION—means a mass of rock, rubble, or masonry tightly enclosed in wire mesh, forming massive blocks that are used to form walls on beaches to prevent wave erosion or as foundations for breakwaters or jetties.

GEOTECHNICAL ANALYSIS—means a scientific study or evaluation conducted by a qualified expert that includes a description of the site hydrology and geology, the affected landform and its susceptibility to mass wasting, erosion, and other geological hazards or processes. The evaluation also includes conclusions and recommendations regarding the effect of the proposed development on geologic conditions, the adequacy of the site to be developed, the impacts of the proposed development, alternative approaches to the proposed development, and measures to mitigate potential site-specific and cumulative impacts of the proposed development, including the potential adverse impacts to adjacent and down-current properties. Geotechnical reports must conform to accepted technical standards and must be prepared by qualified engineers or geologists who are knowledgeable about the regional and local geology.

GRAVEL-COBBLE (HABITAT)—intertidal shores that have substrates composed of a mixture of cobble and gravel where the habitat tends to be formed as beaches and bars, due to wave and current action, and seldom flats

GROIN—means a wall-like structure extending seaward from and usually perpendicular to the shore into the intertidal zone. Its purpose is to build or preserve an accretion beach on its updrift by trapping littoral drift. A groin is relatively narrow in width but varies greatly in length. A groin is sometimes built in a series as a system and may be permeable or impermeable, high or low, and fixed or adjustable. See also, "weir," and "rock weir."

GROUNDFISH-fish (also known as bottomfish) that live on or near the bottom of water bodies, for example, English sole.

HABITAT—interacting physical and biological factors, which provide at least minimal conditions for one organism to live or for a group of organisms to occur together. The specific area or environment in which a particular type of plant or animal lives. A habitat provides all of the basic requirements for the maintenance of life for an organism, a population or a community. Typical coastal habitats include beaches, marshes, rocky shores, bottom sediments, mudflats, and the water itself

HARBOR AREA—area of navigable tidal waters as determined in Section 1 of Article 15 of the Washington State Constitution, which is forever reserved for landings, wharves, streets, and other conveniences of navigation and commerce.

HEIGHT—a measurement from average grade level to the highest point of a structure. Television antennas, chimneys, and similar appurtenances are not used in calculating height, except where they obstruct the view of a substantial number of residences, or where this Master Program provides otherwise. Temporary construction equipment is not used in calculating height.

HARPACTICOID COPEPODS—crustaceans in the Order Harpacticoida, of the Subclass Copepoda

HAZARDOUS WASTE—any solid, liquid or gaseous substance which, because of its source or measurable characteristics, is classified under state or federal law as hazardous and is subject to special handling, shipping, storage and disposal requirements. Washington state law identifies two categories, dangerous and extremely hazardous. The latter category is more hazardous and requires greater precautions.

HYDRAULIC—pertaining to water

HYDRAULIC PROJECT APPROVAL (HPA)—permits issued by the Washington Department of Fish and Wildlife (WDFW) under chapter 77.55 RCW (formerly 75.20 RCW) to any person, organization, or government agency proposing to conduct activities, which change, obstruct, divert or use the bed or flow of fresh and salt waters of the state. An HPA is either approved, conditioned, or denied based solely on protection of fish life under rules promulgated under chapter 220-110 WAC. Fish life includes all fish and shellfish at all stages of development.

HYDROLOGY—the dynamics of water movement through an area, as either surface (exposed) waters or subsurface (ground) waters

HYDROPHYTES—any macrophyte that grows in water or in a substrate that is at least periodically deficient in oxygen as a result of excessive water content; plants typically found in wetlands and other aquatic habitats

HYDROSTATIC PRESSURE—pressure in a system from water collection, may be gravitational or chemical.

IMPACT—an action producing a significant causal effect or the whole or part of a given phenomenon.

IMPERVIOUS SURFACE—a surface that cannot be easily penetrated. For instance, rain does not readily penetrate asphalt or concrete pavement.

IMPOUNDMENT—the retention or trapping of sediment in a location, either by natural or structural means

INDUSTRY—production, processing, manufacturing, or fabrication of goods or materials. Warehousing and storage of materials or production is considered part of the industrial process

INFAUNA—those organisms living within the sediments underlying a body of water

INFILTRATION—water flow into the soil to replenish aquifers

INNER HARBOR LINE—a line located and established in navigable tidal waters between the line of ordinary high tide and the outer harbor line and constituting the inner boundary of the harbor area

INTERSPECIFIC COMPETITION (see also Intraspecific competition)—competition for resources between different species

INTERTIDAL—the area exposed at low tides and inundated at high tides; defined as the area between Extreme Low Tide and Extreme High Tide

INTRASPECIFIC COMPETITION (see also Interspecific competition)—competition for resources among individuals of the same species

INVERTEBRATES—animals that lack a bony or cartilaginous skeletal structure.

ISOPODS—crustaceans in the Order Isopoda, of the Subclass Malacostraca

JETTY—a structure generally perpendicular to the shore, extending through or past the intertidal zone. Jetties are built singly or in pairs at a harbor entrance or river mouth mainly to prevent accretion from littoral drift in an entrance channel, which may or may not be dredged. Jetties also serve to protect channels from storm waves or cross currents and to stabilize inlets through barrier beaches. On the Pacific Coast, most jetties are of rip-rapped, mound construction.

LAND USE—the way land is developed and used in terms of the types of activities allowed (agriculture, residences, industries, etc.) and the size of buildings and structures permitted. Certain types of pollution problems are often associated with particular land-use practices, such as sedimentation from construction activities.

LARVAE—the immature form of an animal which is unlike the adult form and which requires fundamental changes before reaching the basic adult form

LEACHATE—water or any other liquid that may contain dissolved (leached) soluble materials, such as organic salts and mineral salts, derived from a solid material. For example, rainwater that percolates through a confined disposal facility and picks up dissolved contaminants is considered leachate

LIMNETIC—waters in the salinity range of 0 – 0.5 ppt

LITTORAL—the benthic environment or depth zone between high water and low water, or pertaining to the organisms of that area

LIVEABOARD—those using a boat, other than a houseboat, as a primary dwelling.

LOADING—the total amount of material entering a system from all sources.

MACROFAUNA—animals with lengths between 0.5 mm and 5 cm

MANAGEMENT ACTION—those actions or measures that may be considered necessary to control or reduce the potential physical or environmental impact of proposed or existing operations, structures, etc.

MARINA—a public or private facility providing boat moorage space, fuel, or commercial services. Commercial services include but are not limited to overnight or live-aboard boating accommodations.

MARINE—waters associated with the ocean and that contain high salt content, as opposed to freshwater.

MARINE SANITATION DEVICE (MSD)—a device installed on a boat to treat or hold sewage. Section 312 of the federal Clean Water Act requires all vessels with installed toilets to have approved MSDs. Federal regulations describe three types of MSDs: Type I and Type II MSDs are treatment devices, while Type III MSDs are holding tanks.

MARSH—an area which is frequently or continually inundated with water, is generally characterized by herbaceous vegetation adapted to saturated soil conditions.

MEAN HIGHER HIGH WATER (MHHW)—height of the highest tidal waters, at a particular location, of each day averaged over a 19-yr period

MEAN LOW WATER (MLLW)—height of the lowest tidal waters, at a particular location, of each day averaged over a 19-yr period

MEIOFAUNA—animals (e.g., epibenthic, benthic) between 0.063 mm and 1.0 mm long

MESOHALINE—waters with a salinity range of 3 –10 ppt

METABOLISM—all chemical processes occurring within an organism, including both synthesis and breakdown of organic materials.

METALS—metals are elements found in rocks and minerals that are naturally released to the environment by erosion, as well as generated by human activities. Certain metals, such as mercury, lead, nickel, zinc and cadmium, are of environmental concern because they are released to the environment in excessive amounts by human activity. They are generally toxic to life at certain concentrations. Since metals are elements, they do not break down in the environment over time and can be incorporated into plant and animal tissue.

MICROBIOTA—animals less than 0.063 mm long

MICROCLIMATE—the climate generally observed in a small, specific region such as an estuary or under a rock.

MICROLAYER, SEA-SURFACE MICROLAYER—the extremely thin (usually estimated as 50 microns) layer at the top of the water. Contamination of this layer is of concern because many contaminants, such as oil, grease, organic toxicants and pathogens, are buoyant in seawater and therefore may concentrate at much higher concentrations in the microlayer than in the water column. The atmospheric deposition of toxicants into the microlayer is also of concern. These contaminant concentrations may pose a danger to fish eggs and other organisms that may come into contact with the water surface.

MICROORGANISMS—microscopic organisms, (e.g., bacteria, viruses and protozoans) that are not visible to the unaided eye. Some cause diseases in humans, animals and plants; some are important because they are involved in breaking down and stabilizing sewage and solid waste.

MIGRATION—the seasonal travel of an animal between habitats.

MIGRATORY CORRIDOR—the physical pathway through which animals migrate.

MIGRATORY FISH—those species utilizing nearshore habitats as they continue along their migratory corridor to the open-ocean to deeper pelagic waters. Their adult habitats are primarily not in nearshore areas. These include: chum, pink, chinook, coho, sockeye, coastal cutthroat, steelhead and bull trout.

MITIGATION—the process of avoiding, reducing, or compensating for the environmental impact(s) of a proposal, including the following:

A. Avoiding the impact altogether by not taking a certain action or parts of an action;

B. Minimizing impacts by limiting the degree or magnitude of the action and its implementation by using appropriate technology or by taking affirmative steps to avoid or reduce impacts;

C Rectifying the impact by repairing, rehabilitating, or restoring the affected environment;

D. Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action;
E. Compensating for the impact by replacing, enhancing, or providing substitute resources or environments; and
F. Monitoring the impact and the compensation projects and taking appropriate corrective measures.

MIXOHALINE—waters with a salinity range of 0.5 – 30 ppt

MOORING BUOY—anchored devices in water bodies used for the mooring of watercraft.

MUDFLAT—intertidal shores not vegetated by macrophytes, with unconsolidated sediment particles smaller than stones, predominately silt and is flooded at high tide and uncovered at low tide

MUNICIPAL DISCHARGE—effluent from a municipal sewage treatment plant.

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES)—a part of the federal Clean Water Act, which requires point-source dischargers to obtain discharge permits. These permits are referred to as NPDES permits and are administered by the Washington Department of Ecology.

NATURAL ENVIRONMENT or SHORELINE—ecologically intact and currently performing an important, irreplaceable function or ecosystem-wide process

NATURAL VARIABILITY—error associated with estimates of populations which is attributed to their natural fluctuations, heterogeneous distribution or dispersal in the environment

NEARSHORE—the beach, intertidal and subtidal areas along the shore of marine waters

NEARSHORE SUBTIDAL—subtidal (depths > ELLW and ,20 m) zone adjacent to the shoreline or within an estuary

NONPOINT SOURCE POLLUTION—pollution that enters water from dispersed and uncontrolled sources (such as surface runoff) rather than through pipes. Nonpoint sources (e.g., forest practices, agricultural practices, on-site sewage disposal, and recreational boats) may contribute pathogens, suspended solids, and toxicants. While individual sources may seem insignificant, the cumulative effects of nonpoint source pollution can be significant.

NOURISHMENT—process of replenishing a beach; naturally by longshore transport or artificially by deposition of dredged material. (beach nourishment)

NUTRIENTS—essential chemicals needed by plants or animals for growth. If other physical and chemical conditions are optimal, excessive amounts of nutrients can lead to degradation of water quality by promoting excessive growth, accumulation, and subsequent decay of plants, especially algae. Some nutrients can be toxic to animals at high concentrations.

OFFSHORE—the sloping subtidal area seaward from the low tideland

OLIGOHALINE—waters in the salinity range of 0.5 – 3 ppt

OPEN-WATER DISPOSAL—placement of dredged material in rivers, lakes, estuaries, or oceans via pipeline or surface release from hopper dredges or barges

OVERTOPPING—passing of water over the top of a structure as a result of wave run-up or surge action

OVERWASH—that portion of the uprush that carries over the crest of a berm or of a structure.

OXYGEN-DEMANDING MATERIALS—materials such as food waste and dead plant or animal tissue that use up dissolved oxygen in the water when they are degraded through chemical or biological processes. Biochemical oxygen demand (BOD) is a measure of the amount of oxygen consumed when a substance degrades.

PARALYTIC SHELLFISH POISONING (PSP)—an illness, sometimes fatal to humans and other mammals, caused by a neuro-toxin produced by a type of plankton called Gonyaulax. During certain times of the year and at certain locations, these organisms proliferate in "blooms" (sometimes called red tides) and can be concentrated by clams, mussels, and other bivalves. The nervous system of affected shellfish is unaffected. Consumption of the shellfish can cause acute illness in humans and other mammals.

PATHOGEN—an agent such as a virus, bacterium or fungus that can cause diseases in humans. Pathogens can be present in municipal, industrial and nonpoint-source discharges to the Sound.

PELAGIC—pertaining to the water column or to an organism living within the water column

pH—the degree of alkalinity or acidity of a solution. A pH of 7.0 indicates neutral water while a pH of 5.5 is acid. A reading of 8.5 is alkaline or basic. The pH of water influences many of the types of chemical reactions that will occur in it. For instance, a slight decrease in pH may greatly increase the toxicity of substances such as cyanides, sulfides and most metals. A slight increase may greatly increase the toxicity of pollutants such as ammonia.

PHOTIC ZONE—the surface waters of the ocean that receive light; where plants can photosynthesis

PHOTOSYNTHESIS—the process by which plants use light energy to make simple sugars and carbohydrates from carbon dioxide and water.

PHYSICOCHEMICAL—the physical and chemical properties of water.

PIER—a fixed, pile-supported structure secured to the shoreline

PLANKTON—small plants (phytoplankton) and animals (zooplankton) that are suspended in the water and either drift with the currents or swim weakly.

POINT—a low profile beach promontory, generally of triangular shape whose apex extends seaward

POINT SOURCE—a source of pollutants from a single point of conveyance such as a pipe. For example, the discharge pipe from a sewage treatment plant or a factory is a point source.

POLLUTANT—a contaminant that adversely alters the physical, chemical or biological properties of the environment. The term includes pathogens, toxic metals, carcinogens, oxygen-demanding materials, and all other harmful substances. With reference tononpoint sources, the term is sometimes used to apply to contaminants released in low concentrations from many activities which collectively degrade water quality. As defined in the federal Clean Water Act, pollutant means dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal and agricultural waste discharged into water.

POLYCHAETE—segmented worms of the phylum Annelida

POLYCHLORINATED BIPHENYLS (PCBs)—a group of manufactured chemicals including about 70 different but closely related compounds made up of carbon, hydrogen and chlorine. If released to the environment, they persist for long periods of time and can biomagnify in food webs because they have no natural usage in the food web. PCBs are suspected of causing cancer in humans. PCBs are an example of an organic toxicant.

POLYCYCLIC or POLYNUCLEAR AROMATIC HYDROCARBONS (PAHs)—a class of complex organic compounds, some of which are persistent and cancer-causing. These compounds are formed from the combustion of organic material and are ubiquitous in the environment. PAHs are commonly formed by forest fires and by the combustion of gasoline and other petroleum products. They often reach the environment through atmospheric fallout and highway runoff.

POLYHALINE—salinity level of 10-17 ppt

PORTS—centers for waterborne commerce and traffic.

PRIORITY HABITAT—a habitat type with unique or significant value to one or more species. An area classified and mapped as priority habitat must have one or more of the following attributes:

A. Comparatively high fish and wildlife density;
B. Comparatively high fish and wildlife species diversity;
C. Important fish and wildlife breeding habitat;
D. Important fish and wildlife seasonal ranges;
E. Important fish and wildlife movement corridors;
F. Limited availability;
G. High vulnerability to habitat alteration; or
H. Unique or dependent species.

A priority habitat may be described by a unique vegetation type or by a dominant plant species that is of primary importance to fish and wildlife (such as, oak woodlands, eelgrass meadows). A priority habitat may also be described by a successional stage (e.g., old growth and mature forests). Alternatively, a priority habitat may consist of a specific habitat element (such as, consolidated marine/estuarine shorelines, talus slopes, caves, snags) of key value to fish and wildlife. A priority habitat may contain priority and/or non-priority fish and wildlife.

PRIORITY SPECIES—fish and wildlife species requiring protective measures and/or management guidelines to ensure their perpetuation. Priority species are those that meet any of the following criteria:

A. State-listed or state candidate species. State-listed species are those native fish and wildlife species legally designated as endangered (§232-12-014 WAC), threatened (§232-12-011 WAC), or sensitive (§232-12-011 WAC). State candidate species are those fish and wildlife species that will be reviewed by the department of fish and wildlife for possible listing as endangered, threatened, or sensitive according to the process and criteria defined in §232-12-297 WAC.

B. Vulnerable aggregations. Vulnerable aggregations include those species or groups of animals susceptible to significant population declines, within a specific area or statewide, by virtue of their inclination to congregate. Examples include heron rookeries, seabird concentrations, marine mammal haulouts, shellfish beds, and fish spawning and rearing areas.

C. Species of recreational, commercial, and/or tribal importance. Native and non-native fish, shellfish, and wildlife species of recreational or commercial importance and recognized species used for tribal ceremonial and subsistence purposes that are vulnerable to habitat loss or degradation.

D. Species listed under the Endangered Species Act as either threatened or endangered. Federal candidate species are evaluated individually to determine their status in Washington and whether inclusion as a priority species is justified.

PRODUCTION—the amount of organic matter generated per unit of time or area by a plant or an animal

PRODUCTIVITY—the rate at which plants or animals generate organic matter

RAMP—a slab, pad, plank, rail, or graded slope used for launching boats by means of a trailer, hand, or mechanical device.

REEF—an offshore chain or ridge of rock or ridge of sand at or near the surface of the water.

REFUGE—habitat area that provides protection from predators or disturbance.

REGULATIONS—in the context of the Marine Protection, Research, and Sanctuaries Act, means those regulations published in the Code of Federal Regulations, Title 40, Parts 220-227, and Title 33, Parts 209, 320-330, and 335-338 for evaluating proposals for dumping dredged material in the ocean. In the context of the Clean Water Act, refers to regulations published in the Code of Federal Regulations, Title 40, Parts 230, 231, and 233, and Title 33, Parts 209, 320-330, and 335-338 for evaluating proposals for the discharge of dredged material into waters falling under the jurisdiction of the Clean Water Act

RELIEF—the elevational features of a surface.

REMINERALIZE—process through which nutrients are broken down into their original inorganic structure, and are made available for biological use.

RENOURISHMENT—the follow-up nourishment of a beach nourishment or fill project, often required in high-energy environments

RESIDENT FISHES – those fishes who remain in nearshore habitats throughout all of their life-history stages

RESTORATION—the recovery of original ecological functions through measures such as native revegetation, removal of intrusive shoreline structures and removal or treatment of toxic materials.

RILL—a very small drainage channel on a beach caused by seaward flow of water.

RIP CURRENT—a strong surface current flowing seaward from the shore.

RIPARIAN HABITAT—riparian ecosystems include the transitional areas between aquatic and terrestrial environments and contain all of the environmental elements that directly contribute to the structural and functional processes of a body of water..

RUNOFF—the liquid fraction of dredged material or the surface flow caused by precipitation on upland or nearshore dredged material disposal sites.

SALINITY—a measure of the concentration of dissolved salts in water, usually expressed as parts per thousand (ppt.) or as practical salinity units (psu)

SALMONID—a fish of the family Salmonidae (as distinct from a salmonid which is merely a fish that resembles a salmon). Fish in this family include salmon and trout. Most Puget Sound salmonids are anadromous.

SANDFLAT—intertidal shores not vegetated by macrophytes, with unconsolidated sediment particles smaller than stones, primarily sand substrate and is flooded at high tide and uncovered at low tide.

SEASONAL RESIDENT FISHES—fishes that move in and out of the eulittoral and shallow subtidal zones based on season and life-history strategies. nearshore zones. These include: Pacific herring, Pacific cod, walleye pollock, lingcod, and English sole.

SEDIMENT—material, such as sand, silt, or clay, suspended in or settled on the bottom of a water body. Sediment input to a body of water comes from natural sources, such as erosion of soils and weathering of rock, or as the result of anthropogenic activities, such as forest or agricultural practices, or construction activities. The term dredged material refers to material that has been dredged from a water body, while the term sediment refers to material in a water body prior to the dredging process.

SEDIMENT DYNAMICS—the physical processes that sediment particles are subject to in an area, such as longshore drift

SEEP—location where groundwater rises above the land surface, or exits the soil on a slope

SHELLFISH—an aquatic animal, such as a mollusc (clams and snails) or crustacean (crabs and shrimp), having a shell or shell-like exoskeleton**.**

SHELLFISH CONTAMINATION—the contamination of certain bivalves (clams, mussels, oysters), which filter water to feed and tend to collect or concentrate waterborne contaminants in their tissues.

SHORELINE DEVELOPMENT—as regulated by the Shoreline Management Act (Chapter 90.58 RCW) the construction over water or within a shoreline zone (generally 200 feet landward of the water) of structures such as buildings, piers, bulkheads, and breakwaters, including environmental alterations such as dredging and filling, or any project which interferes with public navigational rights on the surface waters.

SPIT—a narrow point of land extending into a body of water.

STRUCTURE—a permanent or temporary edifice or building, or any piece of work artificially built or composed of parts joined together in some definite manner on, above, or below the surface of the ground or water, except for vessels.

SUBTIDAL—the area deeper than the line of Extreme Lower Low Water (ELLW)

STORM DRAIN—a system of gutters, pipes or ditches used to carry storm water from surrounding lands to streams, lakes or Puget Sound. In practice storm drains carry a variety of substances such as sediments, metals, bacteria, oil and antifreeze that enter the system through runoff, deliberate dumping or spills. This term also refers to the end of the pipe where the storm water is discharged.

STORM WATER—water that is generated by rainfall and is often routed into drain systems in order to prevent flooding.

SUSPENDED SOLIDS—organic or inorganic particles that are suspended in water. The term includes sand, silt, and clay particles as well as other solids, such as biological material, suspended in the water column.

TERRITORIAL SEA—the strip of water immediately adjacent to the coast of a nation measured from the baseline as determined in accordance with the Convention on the territorial sea and the contiguous zone (15 UST 1606; TIAS 5639), and extending a distance of 3 nmi from the baseline.

TIDAL CHANNEL—a channel through which water drains and fills intertidal areas

TOMBOLO—a causeway-like accretion spit connecting an offshore rock or island with the main shore

TOXIC—poisonous, carcinogenic or otherwise directly harmful to life.

TOXIC POLLUTANT—pollutants, or combinations of pollutants, including disease-causing agents, that after discharge and upon exposure, ingestion, inhalation, or assimilation into any organism, either directly from the environment or indirectly by ingestion through food chains, will, on the basis of information available to the Administrator of the U.S. Environmental Protection Agency, cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions, or physical deformations in such organisms or their offspring.

TOXIC SUBSTANCES AND TOXICANTS—chemical substances such as pesticides, plastics, detergents, chlorine and industrial wastes that are poisonous, carcinogenic or otherwise directly harmful to life.

TOXICITY—level of mortality or other end point demonstrated by a group of organisms that has been affected by the properties of a substance, such as contaminated water, sediment, or dredged material.

TRANSIENT FISHES—fishes that use nearshore eulittoral habitats on a temporally limited basis depending on their life-history phase. These fishes share a dependence upon nearshore intertidal and subtidal habitats for one or more of their life-history stages but use deeper habitats in other stages. These include: surf smelt, Pacific sand lance, and rockfish.

TRIBUTYL TIN (TBT)—an organic-metal compound used as an additive in many marine antifoulant paints used to prevent algal and barnacle growth. Tributyl tin is highly toxic to many marine organisms.

TURBIDITY—a measure of the amount of material suspended in the water. Increasing turbidity levels of water decreases the amount of light that penetrates the water column. Abnormally high levels of turbidity can be harmful to aquatic life.

UPLANDS—the area above and landward of a wetland or the intertidal shoreline

UPLAND ENVIRONMENT—the geochemical environment in which dredged material may become unsaturated, dried out, and oxidized.

URBAN INDUSTRIALIZED SHORELINE—shorelines subjected to intense development, shoreline modifications and urban growth

URBAN GRWOTH—growth that makes intensive use of land for the location of buildings, structures, and impermeable surfaces to such a degree as to be incompatible with the primary use of land for the production of food, other agricultural products, or fiber, or the extraction of mineral resources, rural uses, rural development, and natural resource lands designated pursuant to §36.70A.170 RCW. A pattern of more intensive rural development, as provided in §36.70A.070(5)(d) RCW, is not urban growth. When allowed to spread over wide areas, urban growth typically requires urban governmental services. "Characterized by urban growth" refers to land having urban growth located on it, or to land located in relationship to an area with urban growth on it as to be appropriate for urban growth.

VESSEL—a ship, boat, barge, or any other floating craft that is designed and used for navigation

WASHINGTON ADMINISTRATIVE CODE (WAC)—Contains all state regulations adopted by state agencies through the rulemaking process. For example, Chapter 173-201 WAC contains water quality standards.

WATER COLUMN—the water in a lake, estuary or ocean that extends from the bottom sediments to the water surface. The water column contains dissolved and particulate matter, and is the habitat for plankton, fish and marine mammals.

WATERSHED—the geographic region within which water drains into a particular river, stream or body of water. A watershed includes hills, lowlands and the body of water into which the land drains. Watershed boundaries are defined by the ridges of separating watersheds.

WATERWAY—a river, channel, canal, or other navigable body of water used for travel or transport

WETLANDS—areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support and that, under normal circumstances, do support a prevalence of vegetation typically adapted for life in saturated-soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas (40 CFR Part 230).

WETLANDS RESTORATION—returning a wetlands ecosystem to a close approximation of its condition prior to disturbance or other disruption of natural functions

YOUNG-OF-THE-YEAR—animals at 0 + years of age (i.e. less than one year of age)

ZONING—to designate, by ordinances, areas of land reserved and regulated for specific land uses.

ZOOPLANKTON—the group of small, primarily microscopic, passively suspended or weakly swimming animals in the water column.