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Kelp and Eelgrass in Puget Sound

Prepared in support of the Puget Sound Nearshore Partnership

Thomas F. Mumford, Jr
Washington Department of Natural Resources
Aquatic Resources Division

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Kelp, which are large brown seaweeds, attach to bedrock or cobbles in shallow waters, especially in areas with moderate to high waves or currents. Eelgrass, which is a flowering plant adapted to the marine environment, roots in sand or mud in shallow waters where waves and currents are not too severe. Both kelp and eelgrass need fairly high light levels to grow and reproduce, so they are found only in shallow waters of nearshore ecosystems. They provide variety of ecological functions, and are are highly productive, annually producing large amounts of carbon that fuel nearshore food webs. Shellfish, such as crabs and bivalves, use eelgrass beds for habitat and nursery areas. Fishes such as juvenile salmonids use eelgrass beds as migratory corridors as they pass through Puget Sound; the beds provide both protection from predators and abundant food.

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Valued Ecosystem Components Report Series

Puget Sound Nearshore Partnership

RESTORING OUR ECOSYSTEM HEALTH

The Puget Sound Nearshore Partnership (PSNP) has developed a list of valued ecosystem components (VECs). The list of VECs is meant to represent a cross-section of organisms and physical structures that occupy and interact with the physical processes found in the nearshore. The VECs will help PSNP frame the symptoms of declining Puget Sound nearshore ecosystem integrity, explain how ecosystem processes are linked to ecosystem outputs, and describe the potential benefits of proposed actions in terms that make sense to the broader community. A series of "white papers" was developed that describes each of the VECs. Following is the list of published papers in the series. All papers are available at *www.pugetsoundnearshore.org.*

Brennan, J.S. 2007. Marine Riparian Vegetation Communities of Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-02. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Buchanan, J.B. 2006. Nearshore Birds in Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-05. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Dethier, M.N. 2006. Native Shellfish in Nearshore Ecosystems of Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-04. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Eissinger, A.M. 2007. Great Blue Herons in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-06. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Fresh, K.L. 2006. Juvenile Pacific Salmon in Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-06. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Johannessen, J. and A. MacLennan. 2007. Beaches and Bluffs of Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-04. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Kriete, B. 2007. Orcas in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-01. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Leschine, T.M. and A.W. Petersen. 2007. Valuing Puget Sound's Valued Ecosystem Components. Puget Sound Nearshore Partnership Report No. 2007-07. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

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Front Cover: Bull kelp (Nereocystis). (Photo courtesy of Washington Sea Grant.)

Back Cover: Eelgrass, left (courtesy of Jeff Gaeckle, Washington Department of Natural Resources); bull kelp, right (courtesy of Tom Mumford, Washington Department of Natural Resources).

Contents

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The Puget Sound Nearshore Partnership Steering Committee initiated the concept of this paper and the others in this series. The Nearshore Partnership Project Management Team (PMT) — Tim Smith, Bernie Hargrave, Curtis Tanner and Fred Goetz – oversaw production of the papers. The Nearshore Science Team (NST) played a number of roles: they helped develop conceptual models for each valued ecosystem component (VEC), in collaboration with the authors; individual members were reviewers for selected papers; and members were also authors, including Megan Dethier, Tom Mumford, Tom Leschine and Kurt Fresh. Other NST members involved were Si Simenstad, Hugh Shipman, Doug Myers, Miles Logsdon, Randy Shuman, Curtis Tanner and Fred Goetz.

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For further information or printed copies of this report, contact Curtis Tanner, Local Project Manager, Puget Sound Nearshore Ecosystem Restoration Project, Washington Department of Fish and Wildlife, 600 Capital Way North, Olympia, Washington 98501-1091.
curtis_tanner@fws.gov.

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"Only a favored few, however, have experienced the sensation of viewing at close range a field of *Macrocystis* or *Nereocystis* far out from shore, the long sinuous dusky, shadowy fronds flowing with the current in the gloomy depths of the water. Not everyone has peered into clear rock pools at the hour of dawn, when the tide is at its lowest ebb, and recognized in the dusky shadowy forms of the young kelps, living creatures belonging to a far distant past. Only the fortunate few can know the true meaning of the Greek word *phaios* and fully appreciate its beauty."

Josephine Tilden, 1935. *The Algae and Their Life Relations*

Executive Summary

Kelp and eelgrass are photosynthetic marine organisms of sufficient importance in Washington's waters to be afforded some protection by statutes. Kelp, which are large brown seaweeds, attach to bedrock or cobbles in shallow waters, especially in areas with moderate to high waves or currents. Kelp includes both floating and non-floating species. Eelgrass, which is a flowering plant adapted to the marine environment, roots in sand or mud in shallow waters where waves and currents are not too severe. Both these organisms need fairly high light levels to grow and reproduce, so they are found only in shallow waters (mostly less than 20 meters for kelp, and 10 meters for eelgrass). Hence, they are totally dependent on the nearshore environment. This paper does not include discussion of the more than 600 other species of seaweeds, although many of their ecological functions and stressors are similar.

Both kelp and eelgrass serve a wide variety of ecological functions in nearshore ecosystems, and are critically linked to other Valued Ecosystem Components (VECs). Both are highly productive, annually producing large amounts of carbon that fuel nearshore food webs, principally through detritus pathways. Both also provide critical three-dimensional structure in otherwise two-dimensional environments, and many other marine organisms use this structure. Shellfish, such as crabs and bivalves, use eelgrass beds for habitat and nursery areas and feed indirectly on the carbon fixed by the plants. Fishes such as juvenile salmonids use eelgrass beds as migratory corridors as they pass through Puget Sound; the beds provide both protection from predators and abundant food, such as the small crustaceans associated with eelgrass. The Great Blue Heron and other marine-associated birds feed extensively on the many small invertebrates and fishes that inhabit eelgrass beds. Some forage fish species, critical in other nearshore food webs, lay their eggs selectively on eelgrass. Kelp similarly provide food and refuge for a wide variety of invertebrates (including valued sea urchins and abalone) and fishes, especially juvenile rockfishes. Even orca whales are seen foraging in kelp beds, presumably consuming salmon there.

Kelp and eelgrass are broadly distributed in Puget Sound. Both are found primarily in the shallow subtidal zone, although some plants can be found low on the shore (Table 1). Kelp is found almost anywhere where there is hard substrate in shallow water, including pilings and other artificial surfaces. It grows especially well where water movement brings nutrients past it and removes sediment, which can readily smother the microscopic stages. Human impacts on kelps probably consist largely of processes that increase sedimentation in shallow waters. Competition with invasive species is also an issue in Puget Sound. Eelgrass is found in sediments ranging from mud to clean sand; its upper limit is set by desiccation (in the intertidal zone) and its lower limit by light limitation (in the shallow subtidal zone). It is not found in south Puget Sound, perhaps because of the extreme tidal range or seasonal lack of nutrients. A variety of human impacts affects eelgrass growth. These include docks, which shade the bottom; increased nutrient inputs to the nearshore, which can cause plankton blooms or excess growth of eelgrass epiphytes (both of which can reduce the ability of eelgrass to get enough light); and numerous aquaculture activities, which compete for space. Toxics, such as metals and crude oil, directly impact eelgrass and kelp. Low oxygen and the related high sulfide levels in sediments also impact eelgrass.

Table 1. Habitat requirements for kelp and eelgrass, by life stage.

Species	Bull Kelp (*Nereocystis*)		Giant Kelp (*Macrocytis*)		Non-Floating Kelp (*Laminaria, Costaria*, etc.)		Eelgrass[1]		
Life Stage	Sporophyte	Gametophyte	Sporophyte	Gametophyte	Sporophyte	Gametophyte	Sed Germinatin (Range/optimum)	Vegetative Growth (Range/optimum)	Flower state (Range/optimum)
Tidal (Water) Elevation (MLLW in meters)	MLLW to - 20 (higher in tidepools)	Mostly unknown, but has been found in subtidal areas	MLLW to - 20 (higher in tidepools)	Mostly unknown, but some in shallow subtidal	MLLW to - 20 (higher in tidepools)	Mostly unknown		See SVMP	
Salinity (PSU)							4.5-9.1	Freshwater - 42/10-30	Same as veg. growth
Temperature (°C)							--/5-10	-6 – 40.5/10-20 7/12 (Thom et al, 2003)	--/15-20
Dissolved Oxygen (mg/L)	?	?	?	?	?	?		hypoxia for more than 3 weeks lethal (Terrados, 1999)	
Nutrients (total N, mg/L)								>10 mM (Denison et al., 1993)	
Chlorophyll a (mg/I)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tidal Range (meters)		Not known		Not known		Not known	Not known	Less than 10.1 ft. tidal amplitude in south Puget Sound	Not known
Velocity (cm/sec)							Unknown	Waves and currents to 3.5 knots. Currents from propellers erode.	Unknown
Exposure	Moderate to high	Unknown	Moderate to high, narrower range than bull kelp	Unknown	Low to very high	Unknown	Moderate to low	Unknown	Unknown
Sediment Grain Sie (diam. mm)		Unknown					Unknown	Pure firm sand to pure soft mud/ mixed sand and mud; >70% silt/ clays	Unknown
Suspended Sediment		Spores and gametophytes very sensitive to sediment on the surface (Shaffer and Parks, 1994)		Spores and gametophytes very sensitive to sediment on the surface (Shaffer and Parks, 1994)		Spores and gametophytes very sensitive to sediment on the surface (Shaffer and Parks, 1994)	Not known but germling cannot be buried	>15 mg/l will block light and reduce growth or depth distribution	Not Known
Light Penetration								1.5 Kd; m-1 (Dennison et al.,1993) 0.48 (0.31-0.60) (Thom et al., 2003)	

[1]**(*Zostera marina*) (Phillips, 1984, Table 6, unless otherwise noted.)**

Preface

Kelp and eelgrass, while less in the public eye than organisms such as orca whales and salmon, have long been recognized as culturally and ecologically valuable. In some situations, they are also directly valuable economically — and the ecological values translate indirectly into economic value, for example via the linkage to highly valued salmon.

There is an extensive literature on the ecosystem values of kelp, (although little work has been done specifically in Puget Sound.) Worldwide, kelp provides an enormous amount of primary production in nearshore waters; the productivity of kelp beds is comparable to alfalfa fields (Duggins et al. 1989). Some of this plant mass is consumed directly, by urchins, for example, but most makes it way into particulate or dissolved organic matter or into detritus (Figure 1). Kelp plants that are torn from the substrate often wash ashore where marine or terrestrial-based scavengers and decomposers may consume them. Much of this carbon may then wash back down into the nearshore zone to contribute to food webs there. Kelp may also sink into deep water, such as the deep basins of Puget Sound, and provide an important food source in those ecosystems. Carbon fixed by kelp is critical in supporting nearshore food webs; in at least some areas, it is a far more important source of carbon than is phytoplankton. A variety of commercially important organisms in Puget Sound, including sea cucumbers, crabs and other shellfish, may thus depend directly or indirectly on the carbon produced by kelp.

A very different role for kelp stems from the three-dimensional structure of its growth. Many organisms take advantage of the physical spaces provided by kelp forests, whether these are the floating, stipilate of prostrate species. These organisms may include juvenile rockfish, juvenile salmon, and other fishes (Thom 1987). As demonstrated by Eckman et al. (1989), kelp can also affect its physical environment by modifying current and wave energy. Both kelp and eelgrass provide important refugia microhabitats for a large number of often specialized organisms. These include snails (*Lacuna*, *Margarites*) and other species that live in kelp holdfasts, burrow in the stipe or are endophytic or endozooic in the plant tissue. They are important prey items and can also impact the health of the host plants. Also, nine species of seaweeds are known to be highly associated with or only occur on eelgrass.

Eelgrass provides many similar critical ecosystem functions (Thayer and Phillips 1977). First, it is an important primary producer, fixing carbon that then enters nearshore food webs (Thom 1990a). Relatively few organisms directly consume eelgrass; the major exceptions are brant (Wilson and Atkinson 1995, Baldwin and Lovvorn 1994) and a few invertebrates. Most eelgrass biomass enters the food web through detritus, as the ends of blades slough off and whole plants break or are uprooted. Some eelgrass detritus probably sinks into deeper water, but the fate and importance of this carbon source is unknown.

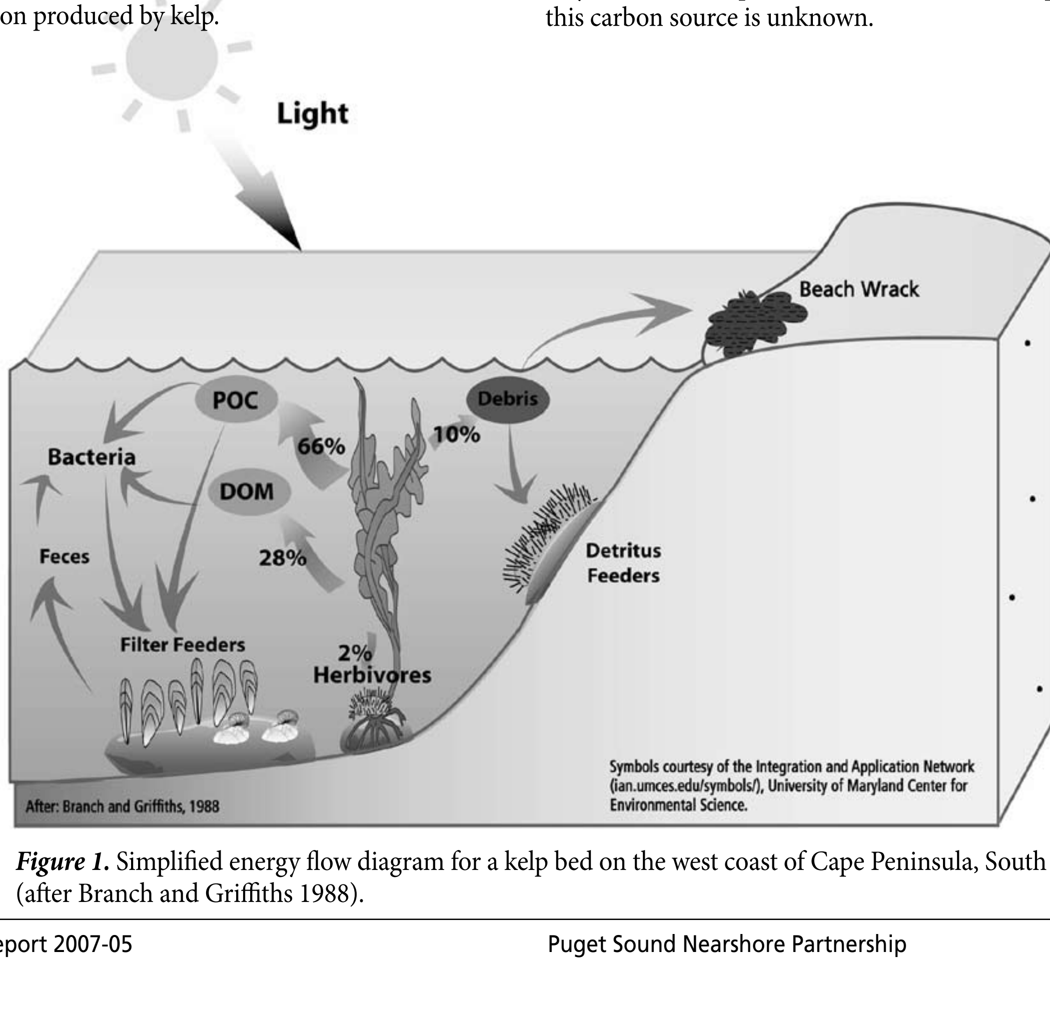


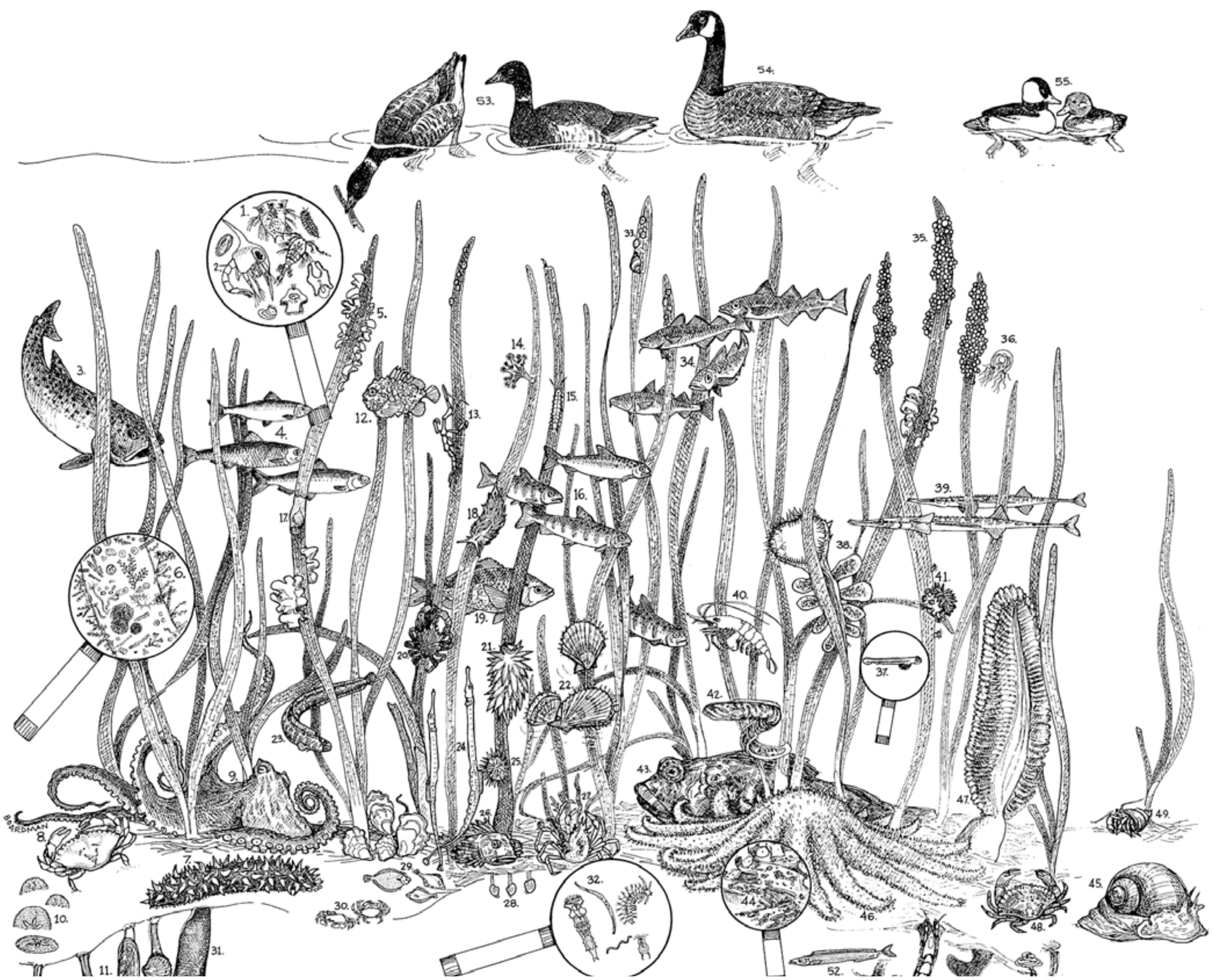
Figure 1. Simplified energy flow diagram for a kelp bed on the west coast of Cape Peninsula, South Africa (after Branch and Griffiths 1988).

A more important role of eelgrass beds in nearshore ecosystems stems from the three-dimensional structure that the plants provide in an otherwise two-dimensional (sand or mud) environment (Figure 2). The blades slow water currents and dampen waves, thereby trapping sediments, detritus and larvae. The roots of eelgrass stabilize the sediment via the matting effects of their dense, interlocking rhizomes. In addition, the rhizomes strongly influence geochemical conditions in the sediments (Kendrick et al. 2005). The blades, and to some degree the rhizomes, also act as substrate for various organisms that otherwise would not be found on soft sediments; for example microalgae and macroalgae and invertebrates such as copepods, amphipods and snails. During parts of the year, the blades are so overgrown that they appear ragged or dirty.

Most importantly, a wide variety of mobile organisms use eelgrass beds, including many commercially important species (Blackmon et al. 2006; Figure 2). Great Blue Herons feed extensively there (Eissinger 2007). Dungeness and red rock crab use eelgrass as a place for settlement of larvae, refuge from predators for juveniles and general habitat for adults. Adult crabs can find many of their preferred food items in eelgrass beds, including bivalves and other crustaceans (Dethier 2006). Eelgrass is an important spawning substrate for Pacific herring (Penttila 2007). The extensive relationship between eelgrass beds and salmonids is described in Fresh (2006) and others (Shreffler et al. 1992, Shreffler and Thom 1993, Thom 1987, Boström et al. 2006). Other species, including shrimp, flatfishes, and at least some stage in the life histories of most important Puget Sound fishery species, use eelgrass beds for feeding, refuge from predators, and nursery areas (Figure 2). Because of these fisheries connections, Costanza et al. (1997) calculated eelgrass to be worth $19,004 per hectare per year. Virnstein and Morris (1997) calculated the annual fisheries value of seagrasses in Indian River Lagoon (Florida) to be approximately $1 billion ($30,890 per hectare per year).

Both kelp and eelgrass also have diverse commercial and cultural values (Kuhnlein and Turner 1991). Kelp is used for food, chemicals, medicine, energy (Flowers and Bird 1984), and construction materials. Native Americans used kelp beds to help direct migrating adult salmon to nets (Stewart 1977) and used eelgrass as ceremonial material, orally passing the practice of collecting and processing eelgrass through many generations. The coastal Salish people also value continuous meadows as hunting grounds (Suttles 1951). Asian countries extensively use various species of kelp for food and flavoring. While commercial harvest is prohibited in Washington, recreational harvest in April and May is widespread. Herring commonly deposit their eggs on kelp; the herring-roe-on-kelp fishery is no longer active in Washington but continues to be highly valued in British Columbia and Alaska. Kelp contains significant amounts of iodine; the Republic of China grows large quantities (more than 100,000 dry mt/year) to prevent and treat goiter. Kelp is also widely used in the American health food market to provide micronutrients. In many parts of the world, kelp is harvested commercially for alginic acid, which is used as a stabilizing agent in foods, latex paint, and printing inks. Historically, kelp was the primary source of potash and soda used in the glass industry and as fertilizers.

The Eelgrass Meadow — A World of Microhabitats



1. Zooplankton
2. Larval crab
3. Salmon
4. Herring
5. Epiphytic macroalgae
6. Epiphytic microalgae, Hydozoa, and bryozoa
7. Sea cucumber
8. Dungeness crab
9. Octopus
10. Sand dollars
11. Clams and cockles
12. Pacific spiny Lumpsucker
13. Caprellid amphipod
14. Stalked jellyfish
15. Eelgrass isopod
16. Juvenile salmon
17. Bubble shell
18. Opalescent nudibranch
19. Perch
20. Juvenile kelp crab
21. Alabaster nudibranch
22. Scallop
23. Gunnel
24. Bay pipefish
25. Sea urchin
26. Juvenile sculpin
27. Decorator crab
28. Juvenile clams
29. Juvenile flounder And sole
30. Juvenile crab
31. Geoduck
32. Sediment microfauna
33. Snail and snail eggs
34. Juvenile cod, tomcod And wall-eyed pollock
35. Herring eggs
36. Jellyfish
37. Larval fish
38. Melibae-hooded nudibranch
39. Tubesnout
40. Shrimp
41. Brooding anemone
42. Prickleback
43. Sculpin
44. Bacteria on detritus
45. Moonsnail
46. Sunflower seastar
47. Sea pen
48. Red rock crab
49. Hermit crab
50. Worms
51. Ghost shrimp
52. Sand lance
53. Black Brant
54. Canada Goose
55. Bufflehead

Figure 2. The eelgrass meadow: A world of microhabitats (© permission Port Townsend Marine Science Center, Port Townsend, WA).

General Biology

Kelp

Kelp is the term applied to a group of large seaweeds belonging to the order Laminariales in the phylum Ochrophyta, class Phaeophyceae (sometimes treated as phylum Phaeophyta), the brown algae. Twenty-three species in 12 genera are found in Puget Sound, making it one of the most diverse kelp floras in the world (Druehl 1969) (Table 2). Recent discovery of a species (*Chorda filum*) in Hood Canal raises the specter of the first possible invasive species of kelp in the area (Mumford, unpubl.). Another highly invasive kelp species, *Undaria pinnatifida* (know as *wakame* in Japan), is not yet in Puget Sound, but has been found in California and many other temperate areas and will likely invade here in time (Silva et al. 2002).

When some sort of solid substrate is present in the lower intertidal and subtidal zones, kelp is a dominant species, forming dense canopies with its often-wide blades. These canopies are generally in three layers: floating, stipitate and prostrate canopies (Figure 3; Britton-Simmons, pers. comm.; Dayton 1985). Two local species, *Macrocystis integrifolia* and *Nereocystis luetkeana*, have evolved floats that enable the photosynthetic blades to remain at or near the surface to obtain maximum light, forming a floating canopy. Other kelp species, found in the lower intertidal and subtidal zones, do not have floats but are raised off the bottom by rigid stipes (examples include *Pterygophora*, *Laminaria complanata*). Other species have short stipes and create a canopy near the bottom, creating cover for a complex understory community of shade-loving, desiccation-intolerant species (examples include *Agarum* spp., *Costaria costata*, *Saccharina subsessile*) (Dayton 1985).

All kelp species are characterized by a life history with a striking alternation of dissimilar generations. The large plant is the diploid sporophyte. This phase produces small spores that swim in the water as plankton for some period of time, and then settle down on the bottom. They germinate into small filamentous gametophyte (haploid) plants, often only a few cells in size. Gametophytes are poorly understood; they appear to live on rocky bottoms, where they are vulnerable to grazers and siltation, but have also been found growing inside the tissue of red algae (Hubbard et al. 2004). Under the proper environmental conditions, the gametophytes produce eggs or sperm (Lüning and Dring 1975). The non-motile eggs produce a pheromone that attracts the motile sperm. The fertilized egg then grows, often rapidly, into the large sporophyte. Thus, the habitat requirements for kelp include not only those conditions needed for the large kelp plant, but also for the tiny and cryptic gametophytes, for induction of reproduction, and for fertilization (Foster and Schiel 1985, Dayton 1985, Druehl and Wheeler 1986).

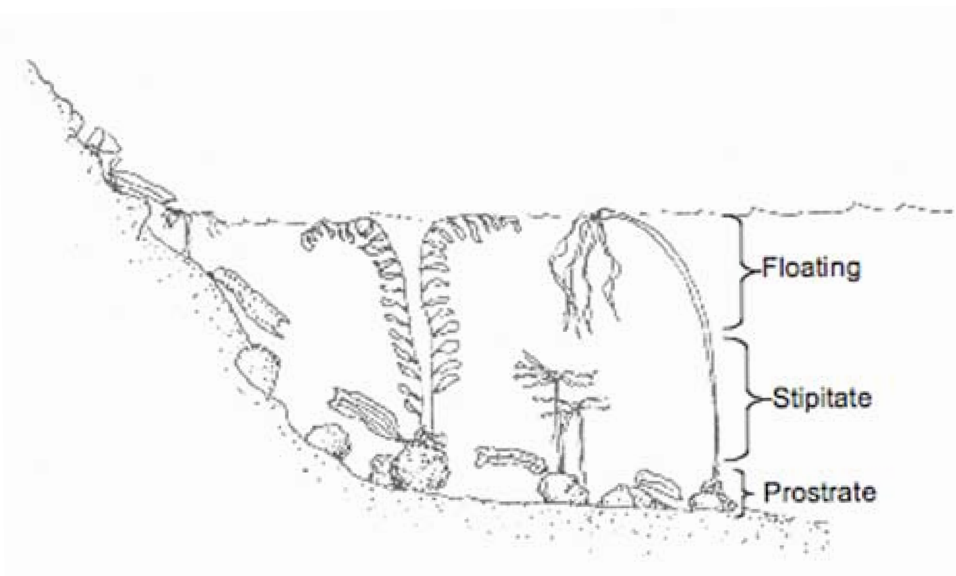


Figure 3. Canopies (floating, stipitate, and prostrate) found in kelp beds in Washington state.

Eelgrass

Eelgrass is the common name for the perennial, rooted vascular plant *Zostera marina* (hereafter *Zostera*). While it is a flowering monocot, it is not a true grass but instead belongs to the family Potamogetonaceae, the pondweed family (Moore and Short 2006). *Zostera* flowers, fertilizes and sets seeds underwater (Ackerman 1997, Cox 1988). Flowering begins in spring, and seeds are released into the water in mid-summer (Churchill et al. 1985, Phillips et al. 1983). Seeds overwinter and germinate the following spring (DeCock 1980). Plants can also spread through vegetative growth. Rhizomes (underground stems) branch and produce a tangled mat within the bed (Setchell 1929, Phillips 1974, 1982, 1984, Moore and Short 2006). They spread horizontally through the substrate, with an apical set of blades reaching through the surface. The blades are up to 2.0 meters in length, with longer blades found in deeper subtidal populations. Blade width varies with depth. The blades from deeper plants are one to two cm wide, while intertidal plants are from two to five mm. Roots from the rhizome serve as the main means of nutrient uptake from the substrate (Short and McRoy 1984).

Mycorhizal associations have been found in some Puget Sound populations of *Zostera* rhizomes. Given the recognition that mycorhizal associations play a critical role in terrestrial plants, much work remains to be done on elucidating the presence of these fungi in seagrass systems (Rodriguez et al. 2005).

Ruckelshaus (1994, 1996, 1998) studied the population genetics of Puget Sound *Z. marina*. She found that there is very high genetic homogeneity, possibly because seeds are distributed by rafting of reproductive shoots and/or by seeds being transported in the guts of birds such as brant. Bachman (1984), in his studies of populations using reciprocal transplants, showed that there may be several species or subspecies of *Z. marina* in Puget Sound.

Other marine vascular plants in Washington include the invasive species *Zostera japonica*, three species of the surfgrass *Phyllospadix*, and widgeon grass, *Ruppia maritima*. *Z. japonica* was probably introduced with oyster spat from Japan. It was first found in the 1930s in northern Puget Sound, and since then has spread to almost all areas of central and south sound and outer coastal estuaries. It occupies a higher tidal elevation than the native *Z. marina*. *Z. japonica* is not discussed in detail here. The surfgrasses are found attached to rocks in high-wave-energy environments.. *Ruppia* is found mostly in low-salinity environments such as channels in marshes or on the freshwater side of tide gates (Wyllie-Echeverria and Ackerman 2003). These species are not included in this discussion

Table 2. Species of kelp found in Washington state (From: Gabrielson et al. 2006).

Family	Genus	Species	Puget Sound- Geographic Distribution	Habit	Sporophyte Annual or Perennial	Canopy Form (floating, stipitate, prostrate)
Chordaceae	*Chorda*	*C. filum* (Linnaeus) Lamouroux1	Great Bend area, southern Hood Canal	On small pebbles, gravel in sheltered areas, at lower limit of eelgrass beds, -10’	Annual	Floating- has small internal air spaces and floats vertically in water but does not form canopy.
Alariaceae	*Pterygophora*	*P. californica* Ruprecht	Common in straits and San Juan archipelago; also rare in central and southern PS	*Abundant, on rocks in the subtidal to a depth of 30 ft, in fully sheltered to moderately exposed habitats or in areas of high currents	Perennial	Stipitate
	Alaria	*A. marginata* Postels *et* Ruprecht	In straits and San Juan archipelago	Abundant, in pools and on rocks in the low intertidal and upper subtidal in fully sheltered to fully exposed habitats.	Perennial	Prostrate
		A. nana Schrader	Open exposed coast, in outer Strait	Uncommon, on rocks and wood in the upper intertidal, in the subtidal in fully exposed areas.	Annual	Prostrate
	Lessoniopsis	*L. littoralis* (Tilden) Reinke	Open exposed coast, in outer Strait	Abundant, in the low intertidal on the most wave exposed solid rock surfaces.	Perennial	Stipitate
	Pleurophycus	*P. gardneri* Setchell *et* Saunders *ex* Tilden	In straits and San Juan archipelago, west side of Whidbey I.	Uncommon, on rocks in pools, as isolated individuals in the upper subtidal, throughout the range.	Annual	Prostrate
Laminariceae	*Macrocystis*	*M. integrifolia* Bory	In strait westward from Low Point	Open exposed coast.	Perennial , 2-5 years	Floating
	Nereocystis	*N. luetkeana* (Mertens) Postels *et* Ruprecht	Throughout	Abundant, on upper subtidal rocks to 10–25 feet, in fully sheltered to fully exposed habitats.	Annual	Floating
	Postelsia	*P. palmaeformis* Ruprecht	In beds, on rock in shallow subtidal and very low intertidal, exposed to moderately exposed.	Abundant, in the low and mid intertidal on rocks exposed to heavy surf, in moderately to fully exposed habitats.	Annual	Stipitate

	Cymathaera	*C. triplicata* (Postels *et* Ruprecht) J. Agardh	In Straits and San Juan archipelago, west side of Whidbey I.	*Locally common, on rocks in the upper subtidal in moderately exposed habitats.	Annual	Prostrate
	Laminaria	*L. complanata* (Setchell *et* Gardner) Setchell	Friday Harbor, San Juan archipelago	*Uncommon, on rocks and pilings in the low intertidal and upper subtidal, on moderately exposed beaches.	Probably perennial	Stipitate
		L. ephemera Setchell		*Uncommon, on subtidal rocks.	Annual	Prostrate
		L. longipes Bory	Only at Salmon Bank, Strait of Juan de Fuca	Uncommon, on rocks, subtidal	Probably perennial	Prostrate
		L. setchellii Silva	Outer straits	*Abundant, on rocks, in the low intertidal and upper subtidal in moderately sheltered to fully exposed habitats.	Perennial	Stipitate
		L. sinclairii (Harvey *ex* Hooker f. *et* Harvey) Farlow, Anderson *et* Eaton	Open exposed coast	*Abundant, in pools and on rocks in the low intertidal and upper subtidal, in moderately sheltered, sanded-in habitats.	Perennial	Stipitate
	Saccharina (formally *Laminaria* or *Hedophyllum* spp.)	*Saccharina latissima* (Linnaeus) C. E. Lane, C. Mayes, Druehl *et* G. W. Saunders, comb. nov.	Throughout PS	*Abundant, in pools and on rocks, shell, and wood in sheltered places in the low intertidal and upper subtidal, known in the subtidal in exposed surfy areas.	Annual	Prostrate
		Saccharina groenlandica (Rosenvinge) C. E. Lane, C. Mayes, Druehl *et* G.W. Saunders, comb. nov.	Central Puget Sound northwar	Abundant, on rocks in upper subtidal	Annual	Prostrate
		Saccharina sessile (C. Agardh) Kuntze 1891, Revisio generum plantarum p. 915. (*Hedophyllum sessile*)	West side San Juan archipelago, straits	*Common, on rocks in pools and in the mid and low intertidal and upper subtidal in moderately sheltered to fully exposed habitats.	Perennial	Prostrate

Table 2. continued

Family	Genus	Species	Puget Sound- Geographic Distribution	Habit	Sporophyte Annual or Perennial	Canopy Form (floating, stipitate, prostrate)
Lessoniaceae	*Egregia*	E. *menziesii* (Turner) Areschoug	Exposed sites, strait, San Juan archipelago, west side Whidbey I.	*Abundant, on rocks, in pools, in the low intertidal and upper subtidal in fully sheltered to fully exposed habitats.	Perennial	Floating
	Eisenia	*E. arborea* Areschoug	Not confirmed for Washington; found on Vancouver I. side of strait	*Locally abundant, on rock, in subtidal to 10 ft in exposed to fully exposed habitats	Perennial	Stipitate
Costariaceae	*Costaria*	*C. costata* (C. Agardh) Saunders	Throughout PS	*Common, in pools and on rocks and wood in the low and mid intertidal and upper subtidal in fully sheltered to fully exposed habitats.		Prostrate
	Agarum	*A. clathratum* Dumortier	San Juan Island	*Uncommon, on rocks of the upper subtidal zone to at least 5 fathoms in moderately sheltered to fully exposed habitats.		Prostrate
		A. fimbriatum Harvey	Throughout PS	*Common, subtidal to 60 fathoms, on stones, other algae, piles, and old wood in moderately sheltered to moderately exposed habitats.		Prostrate
	Dictyoneurum	*D. californicum* Ruprecht.	Straits	*Uncommon, in pools and on rocks in the low intertidal and upper subtidal, fully exposed to surf		Prostrate

*From "DeCew's Guide to the Seaweeds of British Columbia, Washington, Oregon, and Northern California." Available at *http://ucjeps.berkeley.edu/guide/*

[1]The presence of *Chorda* in Hood Canal, Washington (Mumford, pers. com.) lends support to earlier records.

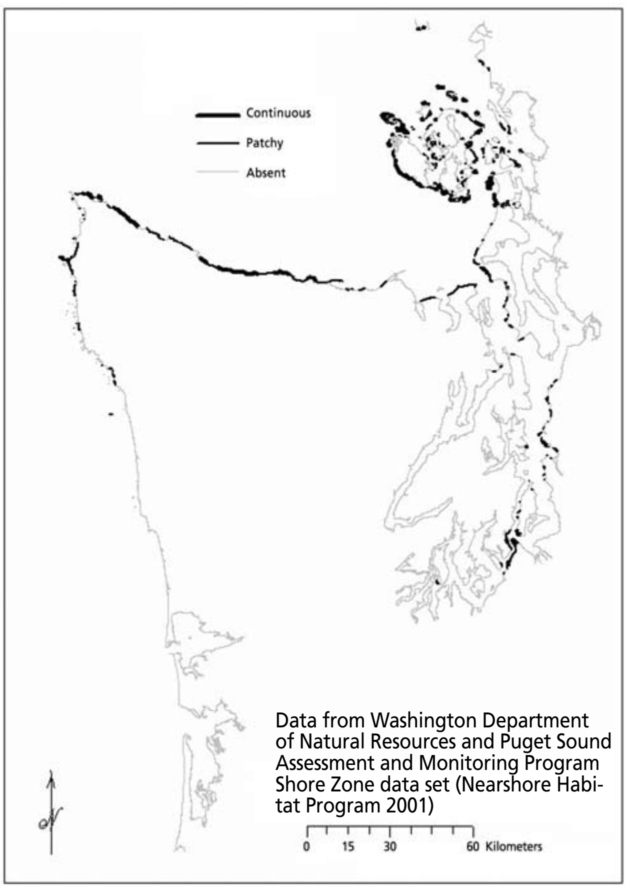
Distribution and Abundance within Puget Sound

Kelp plants, besides requiring moderate to high water movement and energy levels, are most likely limited by the availability of suitable substrate. The distribution of substrate materials is influenced by a number of nearshore processes involving sediment movement. The abundance and location of floating kelp beds appear to be persistent; in many cases, kelp beds mapped in 1912-15 (Rigg 1912, 1915) have not substantially changed. Floating kelp distribution (both *Nereocystis* and *Macrocystis*) is shown in Figure 4 (Nearshore Habitat Program 2001). Detailed data exist for two species, discussed below.

Bull Kelp *(Nereocystis luetkeana)*

Sporophytes of bull kelp are always found attached to bedrock or to large cobbles in the subtidal zone, especially in areas of considerable water movement (either wave exposure or tidal currents). Plants that attach to small cobbles (< 10 cm) tend to lift their substrate off the bottom in any water movement, and thus be carried to the shore or into deeper water. The plants attach by holdfasts, which, unlike roots, do not penetrate the substrate or carry nutrients to the rest of the plant. Bull kelp in Puget Sound occurs from the extreme low tide level to a depth of 10-30 meters, depending on water clarity. Their reliance on areas of considerable water movement may stem from the tiny gametophyte phase's intolerance of being covered with silt (Schiel et al. 2006). The sporophytes, which can reach 40 meters in length, are annuals, growing from the bottom starting in early spring, reaching the surface by April or May, and being swept away by fall and winter storms. In Washington, bull kelp is found in discrete beds on the outer coast northward from Copalis Rocks (the southernmost extent of suitable substrate) and throughout the Strait of Juan de Fuca (including on offshore shallow banks) and the San Juan archipelago. It is also found in high-current areas in central Puget Sound and to a lesser degree in southern Puget Sound. The southernmost bed is near Squaxin Island. Little is known about the effective dispersal distance for sori and gametophytes in *Nereocystis*, but it is likely large, given the widespread distribution of fertile plants in wrack (Schoch and Chenelot 2004).

The ecology of *Nereocystis* gametophytes is poorly understood, although extensive culture work has been done. The relationship of growth and survival to toxics and to light quantity and quality is well understood (Vadas 1972, Foreman 1984). Light quantity is limiting below about 30 meters.



Data from Washington Department of Natural Resources and Puget Sound Assessment and Monitoring Program Shore Zone data set (Nearshore Habitat Program 2001)

Figure 4. Distribution of floating kelp species (*Nereocystis* and *Macrocystis*) (Nearshore Habitat Program 2001).

Giant Kelp *(Macrocystis integrifolia)*

The sporophytes of the giant kelp *Macrocystis* are found attached to bedrock and large boulders in the lower intertidal and shallow subtidal zone to a depth of four meters. In Washington, this species is found on the outer coast north of Copalis Rocks and in the Strait of Juan de Fuca west of Low Point but never in Puget Sound proper (probably because of seasonally low salinity; see below). Plants tend to inhabit somewhat less energetic environments than bull kelp. Sporophytes are perennial, living two to five years and growing up to six meters long, but little is known about the ecology of the gametophyte phase. Interannual variation of canopy cover is up to 30 percent (Foreman 1975, North 1987, Dayton 1985, Berry et al. 2005).

In California, it has been shown that *Macrocystis* beds expand and contract in bed area, depending on water quality attributes (temperature and nutrients linked to upwelling and El Niño/La Niña), but that the core areas remain in the same location. Whether the interannual variation in kelp bed area in Washington is linked to these large-scale forcing events is not known, but the beds do center on core areas (H. Berry, WDNR, unpubl. data).

Non-floating kelp species

Beside the two species of floating canopy kelp, another 21 kelp species (Table 2) inhabit Washington marine waters (Gabrielson et al. 2006). They are found in a variety of intertidal and subtidal habitats, but all require some sort of solid substrate for growth — bedrock or rocks as small as pebbles, as well as a variety of artificial substrates such as boat bottoms, floats, docks and mooring buoys and chains. They tend to grow in areas of high to moderate wave energy or currents, and are abundant wherever there is suitable substrate (see Figure 5 for distribution map). There are both annual and perennial species, and most form blades one to two meters long. The importance of these smaller kelps is often underestimated in comparison to the floating species, even though they cover larger areas of the subtidal zone and provide valuable habitat functions (Dayton 1985). Their total contribution to the food web (Figure 1) through direct consumption, detritus, and dissolved organic carbon is probably larger than the floating species (Duggins 1987, Duggins et al. 1989).

Eelgrass *(Zostera marina)*

Beds of *Zostera marina* are found throughout Puget Sound, except for south of Anderson Island and Carr Inlet in southern Puget Sound (Figure 6). *Z. marina* grows in lower and shallow intertidal areas in muddy to sandy substrates and low to moderately high-energy environments. In the higher energy areas, such as Salmon Bank, it may grow in the finer substrates trapped between cobbles and boulders. It grows in areas from +1.8 to -8.8 meters, with an average maximum depth of -3.5 meters (relative to MLLW). Beds are most abundant at about 0.0 meters. Deepest beds are found in the Strait of Juan de Fuca and the San Juan Islands (Berry et al. 2003).

Z. marina grows in several bed configurations or patterns (Bell et al. 2006). In areas where conditions are thought to be most suitable, beds are solid or continuous. In other areas there may be persistent patchy beds, often at the ends or edges of solid beds. Continuous beds are often found in extensive tideflats, and more fragmented beds in areas

Non-floating Kelp in Intertidal and Shallow Subtidal Areas

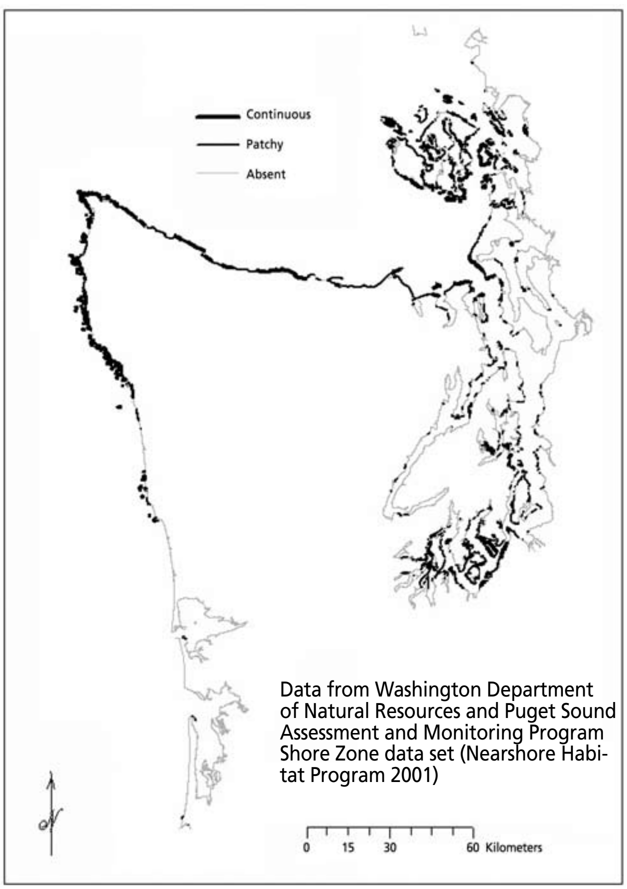


Figure 5. Distribution of intertidal and shallow subtidal non-floating kelp species, as visible from aircraft at low tide (Nearshore Habitat Program 2001).

Eelgrass (Z. marina) Presence

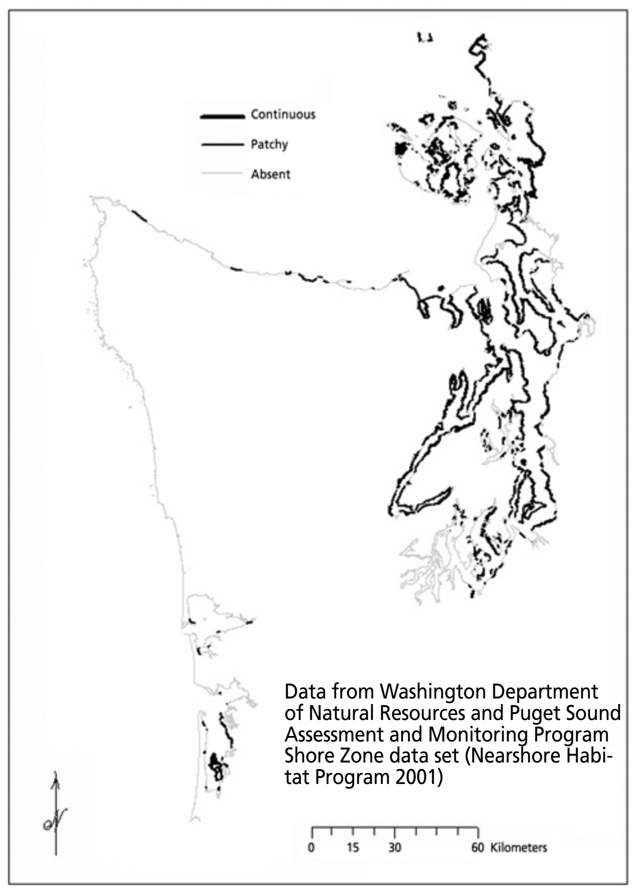


Figure 6. Distribution of eelgrass (*Z. marina*) (Nearshore Habitat Program 2001).

fringing linear shorelines (Berry et al. 2003). Little is known about interannual variation in bed area, but it appears to be less than 10 percent (Berry et al. 2003, Dowty et al. 2005).

Z. japonica is found throughout Puget Sound north of Nisqually Reach. It occurs in the mid- to high-intertidal area, often above *Z. marina* (above 1.8 meters MLLW), with little overlap in their distribution. It also grows in muddy to sandy substrates.

Z. marina shows several interesting landscape distribution attributes. First, the lack of beds in southern Puget Sound is similar to the distribution in Long Island Sound, which is attributed to a combination of high tidal amplitudes and timing of low tides during the summer (Koch and Beer 1996). During low tide events, especially during hot summer middays, desiccation/heat stress limits the upper distribution, while at high tides, enough water covers the plants to limit net photosynthesis at depth. At the point where tidal amplitude is enough to cause the lower limit to be the same as the upper limit, eelgrass will not grow. The author (Mumford) hypothesizes that a similar situation occurs in southern Puget Sound; the limit of distribution corresponds to the 10.1-foot tidal amplitude isobar. The problem is exacerbated by the fact that the timing of extreme low tides in southern Puget Sound is in midday, when temperatures are the highest. In contrast, on the outer coast and straits, low tides are early in the morning, before the heat of the day.

Both the author and C. Simenstad (University of Washington, pers. comm.) have noted that in northern Puget Sound and in Hood Canal, the most luxuriant, dense and continuous beds are distributed along the cusp at the margins of river deltas, not along the delta face itself, nor along stretches of beach far away from river mouths. It is likely that at that point, sedimentation and water turbidity are not high enough to block light or smother or bury the eelgrass, but there is enough sediment to supply nutrients and create a fertile "soil" for optimal growth. Eelgrass requires or does best in a particular soil, an attribute not solely associated with water quality or wave energy.

As noted elsewhere, the lower depth distribution of eelgrass is related to overall water clarity. The Submerged Vegetation Monitoring Program (SVMP, Dowty et al. 2005) has found that the lowest depth limits of eelgrass are in northern Puget Sound and the straits, along an axis from southern Puget Sound to Cape Flattery (Table 3) (Dowty et al. 2005). Recent SVMP analyses are showing a slight but significant difference in lower depth limits between "flats" (areas of large eelgrass beds in embayments that extend deeper than "fringes") and the more linear beds found along shorelines (Dowty et al. 2005).

Table 3. Range of maximum and minimum *Z. marina* depths by region in 2000-2004 (MLLW) (modifications per 2003-2004 data are bolded) (from: Table 3-3. Dowty et al. 2005).

	Minimum Depth (m)		**Maximum Depth (m)**	
Region	Absolute	Range in Site Means	Absolute	Range in Site Means
North Puget Sound	1.4	+0.6 to **-3.3**	**-8.4**	**-2.3** to -6.6
San Juan/Straits	+1.5	+0.4 to **-5.4**	**-10.5**	-0.4 to **-8.3**
Saratoga/Whidbey	+1.3	+0.5 to **-1.2**	-8.0	-0.3 to -4.4
Hood Canal	+1.8	+1.1 to -1.4	**-7.3**	-2.3 to **-4.4**
Central Puget Sound	+1.6	+1.1 to -1.3	**-10.1**	-0.5 to **-6.3**

Nearshore Habitat Requirements

Table 1 (in Executive Summary) lists the known physical habitat requirements for kelp and eelgrass. Note that while these habitat requirements are listed singly, plants integrate and compensate for multiple factors, often in a non-additive or non-linear fashion. These values are also given as optimal levels; distribution may often be limited by acute or extreme values. Requirements may be changed by disease or herbivory, which in turn are influenced by factors non-lethal to the plants themselves.

Kelp

Because kelp is photosynthetic and unable to root in soft sediments, it requires a fairly well-defined set of physical conditions: high ambient light, hard substrate, minimum sediment in the water that could block the light or smother the tiny gametophyte stages, and fairly low marine water temperatures and moderate to high salinities. Thus, they are completely confined to nearshore habitats. These physical parameters apply to both the floating-canopy and the non-floating species, although there are little data on specific tolerances of physical stresses. Kelp in quiet water can attach to hard surfaces ranging from bedrock to small pebbles, but in areas with greater water movement, attachment sites need to be more stable: large cobbles or bedrock, especially for the larger floating species. Since all kelp start life on the bottom (as a gametophyte, then small sporophyte), they cannot attach in deep water because of inadequate light for these young stages, even if as adult plants they can grow to the surface. The lower limits of kelp vary with species and with water clarity, but in Puget Sound most occur shallower than 20 meters, and often reach their greatest biomass in the shallow subtidal zone.

Druehl (1981) found that most kelp species in the northeast Pacific require a combination of fairly high (>25 psu) salinities and fairly low (<15^{o}C) temperatures. Low salinities can be tolerated by some species, but only if coinciding with low temperatures. *Macrocystis*, for example, is not found in areas with considerable snowmelt runoff, which can lower salinity when seawater temperatures are relatively warm. Thus, low salinity probably is the factor that excludes this kelp from the inside waters of Washington (Druehl 1979). Some kelps (e.g., *Saccharina latissima* (*Laminaria saccharina)*) have a higher tolerance of low salinities, regardless of temperature; the kelp species that extend into southern Puget Sound probably share these tolerances. *Nereocystis* tolerates a wide range of salinities but not areas of high sedimentation (e.g. Shaffer and Parks 1994), perhaps because of smothering of the microscopic gametophyte phase (Schiel et al. 2006, Devinney and Volse 1978).

Competitors of kelp in Puget Sound include any shallow, subtidal-space-occupying organism; the tiny gametophytes and small sporophytes can be out-competed for space or light by a variety of algae and sessile invertebrates. Because of the difficulty of studying these small organisms *in situ*, we know little of their ecology. Once grown out of these small stages, however, kelps can outcompete most other seaweeds and sessile invertebrates because of their rapid elongation (10 cm per day in *Nereocystis*) and large adult size. Even the smaller, non-floating kelps can overtop and shade other algae. The one local exception is the invasive brown alga *Sargassum muticum*, which competes for space with non-floating laminarians and can have a negative impact on their abundance (Britton-Simmons 2004). Kelps also compete with each other. At least in some regions, *Nereocystis* is an early-successional kelp, growing in temporarily open patches until gradually displaced by the perennial *Laminaria* spp. (Duggins 1987).

Kelp is also vulnerable to a variety of herbivores, especially when the plants are small. Depending on the herbivore species and density, many grazers (mollusks, urchins, etc.) can consume gametophytes and small sporophytes, so kelps tend to get established in refuges from grazing (e.g., on cobbles surrounded by sand that grazers will not cross, or in crevices) (Dayton 1985). Urchins are among the few herbivores that can consume adult kelps, in some cases even crawling up their unstable stipes. Kelp beds often establish in areas where urchins have been removed by high wave energy, natural predators (such as sea otters) or human harvesters (Duggins 1987, Foster and Schiel 1985). The abundance of kelp is also mediated indirectly by the presence or absence of sea otters; the otters eat the herbivores, leading to an increase or shift in kelp species (Estes et al. 1978, Duggins 1980). The phenomenon of urchin barrens cycles over decades between an overabundance of urchins (removing kelp and other fleshy seaweeds and leaving only crustose coralline algae) and fewer urchins (leaving more kelp). The persistence of urchin barrens influences habitat for fisheries and otters that has been intensively studied in the Maritime Provinces but has not been observed in Washington.

Eelgrass

Competitors of eelgrass in Puget Sound include the introduced brown seaweed *Sargassum muticum* (Britton-Simmons 2004), the sand dollar (*Dendraster excentricus*) and possibly the newly discovered kelp species in Hood Canal, *Chorda filum*. In situations where there are excessive nutrients, algal species such as sea lettuce (*Ulva* spp.) will overgrow eelgrass. Excessive nutrients also can cause overgrowth by epiphytes on the blades, blocking light, nutrients and gas exchange. Several herbivores (the snail *Lacuna* spp. and the marine isopod *Idotea* spp.) can control epiphyte density and thereby benefit the underlying eelgrass (Williams and Ruckleshaus 1993; Nelson and Waaland 1997).

Direct herbivory on eelgrass is usually not significant. Crabs are known to uproot eelgrass (Simenstad et al. 1997), and the sand dollar (*Dendraster excentricus*) also disturbs the substrate to a degree that excludes eelgrass. However, the Black Brant (*Branta bernicla nigricans*), a small sea goose, feeds on eelgrass in large quantities, especially in areas such as Dungeness, Padilla and Samish bays (Baldwin and Lovvorn 1994). The isopod *Synidotea* also feeds on eelgrass. Eelgrass can be buried and killed by sand overwash from storms.

Human Effects on Habitat Attributes

As a rooted plant, eelgrass responds to a wide variety of stressors, which can be thought of as the human effects on habitat attributes. The results of many studies make the relationships between eelgrass and stressors relatively well known (see Larkum et al. 2006, Short and Wyllie-Echeverria 1996). As a result, eelgrass has been widely used as a broad-scale environmental indicator in areas such as the Chesapeake Bay, Florida, the Baltic Sea and Australia (Corbett et al. 2005, Dennison et al. 1993, Duarte 2002, Orth 1985, Short and Wyllie-Echeverria 1996, Krause-Jensen et al. 2005).

Stressors that affect marine plants such as kelp and eelgrass include those that affect the amount of light available to the plant, the direct and indirect effects of high or low nutrient levels, toxics, and physical disturbances. Plants can also be stressed from chronic and acute stressful levels in salinity, temperature and oxygen, and from temporary or permanent changes in types of substrate. Light levels are often decreased by an increase in suspended sediments, i.e., turbidity, or by overwater structures such as piers, docks, and moored boats. Sedimentation from upland runoff or re-suspension can prevent kelp spores or zygotes from attaching and cause injury from smothering and light blockage (Schiel et al. 2006).

Nutrient levels can affect kelp and eelgrass by being insufficient for growth. There are no data to suggest this is an issue in Puget Sound, but eelgrass may be limited in areas such as southern Puget Sound inlets, with dramatic summer stratification and very low surface nutrient levels. Low nutrient levels during El Niño episodes decrease floating kelp standing crop in California (Foster and Schiel 1985). Excess nutrients may commonly have a negative effect by changing the competitive advantage toward phytoplankton and ulvoids. Eutrophication then impacts eelgrass through smothering and decreased light from shading by ulvoids and epiphytes (Hemminga and Duarte 2000, Short and Wyllie-Echeverria 1996).

Toxics such as various oil products are known to affect bull kelp by causing tissue damage/death, especially in the growth regions, and by lowering photosynthesis and respiration (Antrim et al. 1995, Dean et al. 1998, Steele and Hanisak 1977, Thursby et al. 1993). Metals such as cadmium and toxics such as high sulfide levels in sediments adversely impact eelgrass growth and reproduction (Thursby et al. 1993).

Other direct stressors to eelgrass include harrowing or roto-tilling for on-ground oyster culture and damage from propellers and high-energy boat wakes. Similarly, harvesting of kelp, if done by cutting below the meristem, or growing region, will result in the death of the entire plant.

Important indirect stressors include hypoxia, eutrophication and changes in tropic structure from harvest of competitors, herbivores or predators of herbivores. Effects from global climate change include rising seawater temperatures and change in depth from increased sea levels. High temperatures may cause loss of eelgrass in embayments already experiencing near-lethal temperatures.

Protection and Restoration

Kelp restoration has been practiced extensively in California, but only a few projects have been attempted in Washington (e.g., Elliott Bay Marina mitigation, see Carney et al. 2005). Merrill and Gillingham (1991) wrote a manual for *Nereocystis* cultivation, aimed at mitigation and farming.

Eelgrass restoration for mitigation projects has been highly problematic in Puget Sound. Gayaldo (2002) researched the optimal characteristics of the substrate. Thom (1990b) and Carlisle (2004) reviewed transplanting projects and found poor success. Stamey (2004) found both high variability and a moderate level of overall success (13-80 percent), stating that eelgrass transplantation has not reached a point where it can be reliably used as a compensatory mitigation technique in Puget Sound. However, 13 percent of the projects reviewed achieved or exceeded success in all the metrics that were applied, demonstrating that eelgrass transplantation can be successful in some cases. Eelgrass restoration costs are extremely high, at between $100,000 and $1 million per acre (Fonseca et al. 1998).

Because of the uncertainty surrounding methods involving transplanting whole eelgrass plants into the substrate (Fonseca et al. 1998, Calumpong and Fonseca 2001, van Diggelen et al. 2001), two new techniques are being developed, although they have not been widely used in Puget Sound. The first involves the use of seeds (Pickerell et al. 2006). The second is the use of whole plants tied to frames (TERFS, transplanting eelgrass remotely with frame systems; available at *www.edc.uri.edu/restoration/html/tech_sci/restsea.htm*). To overcome what is viewed as the highest source of uncertainty in transplanting, Short et al. (2002) developed a model for selecting eelgrass restoration sites (available at *www.edc.uri.edu/restoration/html/spatial/habmodel.htm*), although it has not been parameterized or tested in Puget Sound. Evans and Short (2006) have begun to assess the success of restoration not just by the presence of eelgrass shoots, but also by the beds actually functioning as habitat or the amount of primary production.

As summarized by Stamey (2004) and others (Hershman and Lind 1994, Fresh 1994), both kelp and eelgrass are given regulatory protection under a variety of federal, state and local laws. Both eelgrass and kelp are designated as critical habitat under the Critical Areas Ordinance. These protections are in flux and are being shifted from the Growth Management Act jurisdiction to the Shoreline Management Act as counties revise and get approval for the Shoreline Master Plans. Thus, protection will vary by county. Commercial harvest of seaweed from aquatic lands (including privately owned tidelands) is prohibited. With mutual approval from the Washington departments of Natural Resources (WDNR) and Fish and Wildlife (WDFW), however, *Macrocystis* may be commercially harvested for use in the herring spawn-on-kelp fishery (RCW 79.96.210). Personal-use harvest of seaweeds is limited to 10 pounds per person, unless otherwise limited by WDNR and WDFW. It is illegal to harvest seaweed if herring eggs are attached. Most Washington State Park beaches are closed to seaweed harvest, and harvest methods are regulated to minimize permanent damage to the plants and allow them to regrow. Regulations are detailed at *http://wdfw.wa.gov/fish/regs/2006/2006sportregs.pdf* (accessed June 5, 2006). Currently, eelgrass is not harvested and has no direct commercial value in Washington, although it was recently added to the state definition of "seaweed" (WDFW 2006), so up to 10 pounds wet per day can be harvested with a license.

Ecosystem Processes Supporting Habitat Attributes

Nearshore ecosystem processes can be broken into three scales of influence (C. Simenstad, University of Washington, pers. comm.). Regional processes influence all ecosystems across hundreds of kilometers and often produce dramatic change. These include precipitation, solar, wave and wind energy inputs, earthquakes, tidal movements, sea level rise, volcanic inputs, glacial processes, and freshwater inflow. These processes influence kelp and eelgrass via nutrient and light inputs, and thus depth distribution. Local processes are embedded within regional influences but vary considerably in scale, from kilometers to a fraction thereof. These include tidal movements, freshwater inputs from streams and rivers, localized wind energy inputs, and erosion, deposition, and movement of sediments. These processes influence the local distribution and abundance of kelps and eelgrass. Finite processes operate on the scale of meters and are spatially and temporally complex. They include biogeochemical conversions, nutrient cycles, primary production, primary consumption, respiration, decomposition, reproduction, recruitment, competition, symbiosis and behavior. These strongly influence very small-scale abundance and distribution.

Simplified conceptual models linking management measures, ecosystem processes and healthy populations of eelgrass and kelp are shown in Figures 7 and 8. Management measures are linked to restored nearshore processes. Restoration then results in structural changes in kelp and eelgrass habitats that in turn change their functional response. Management measures include reducing nutrient inputs, reducing overwater structures, controlling invasive species, removing armoring, removing dams, practicing direct restoration measures, and restoring hydrology.

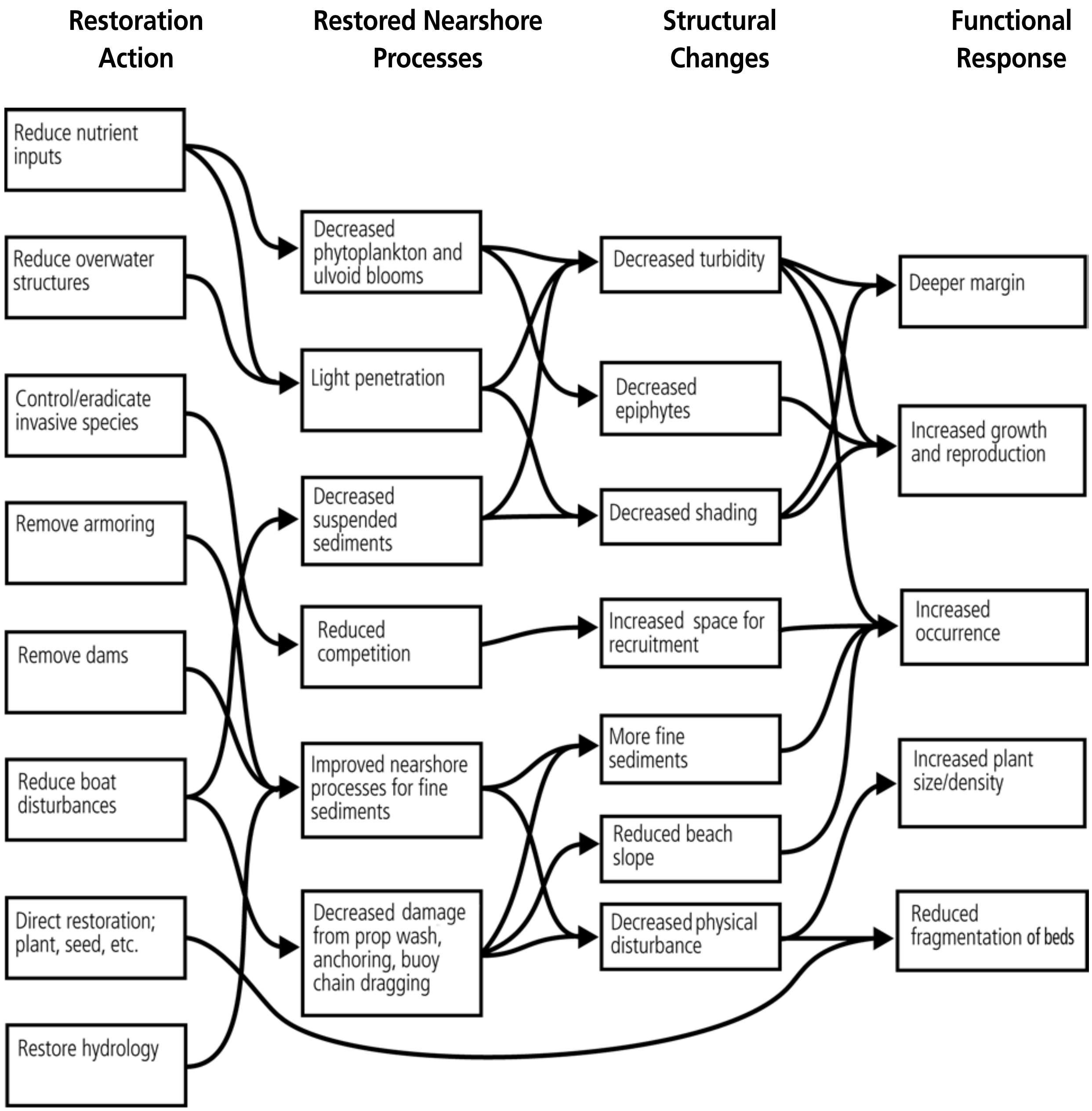


Figure 7. Conceptual model for eelgrass (*Z. marina*).

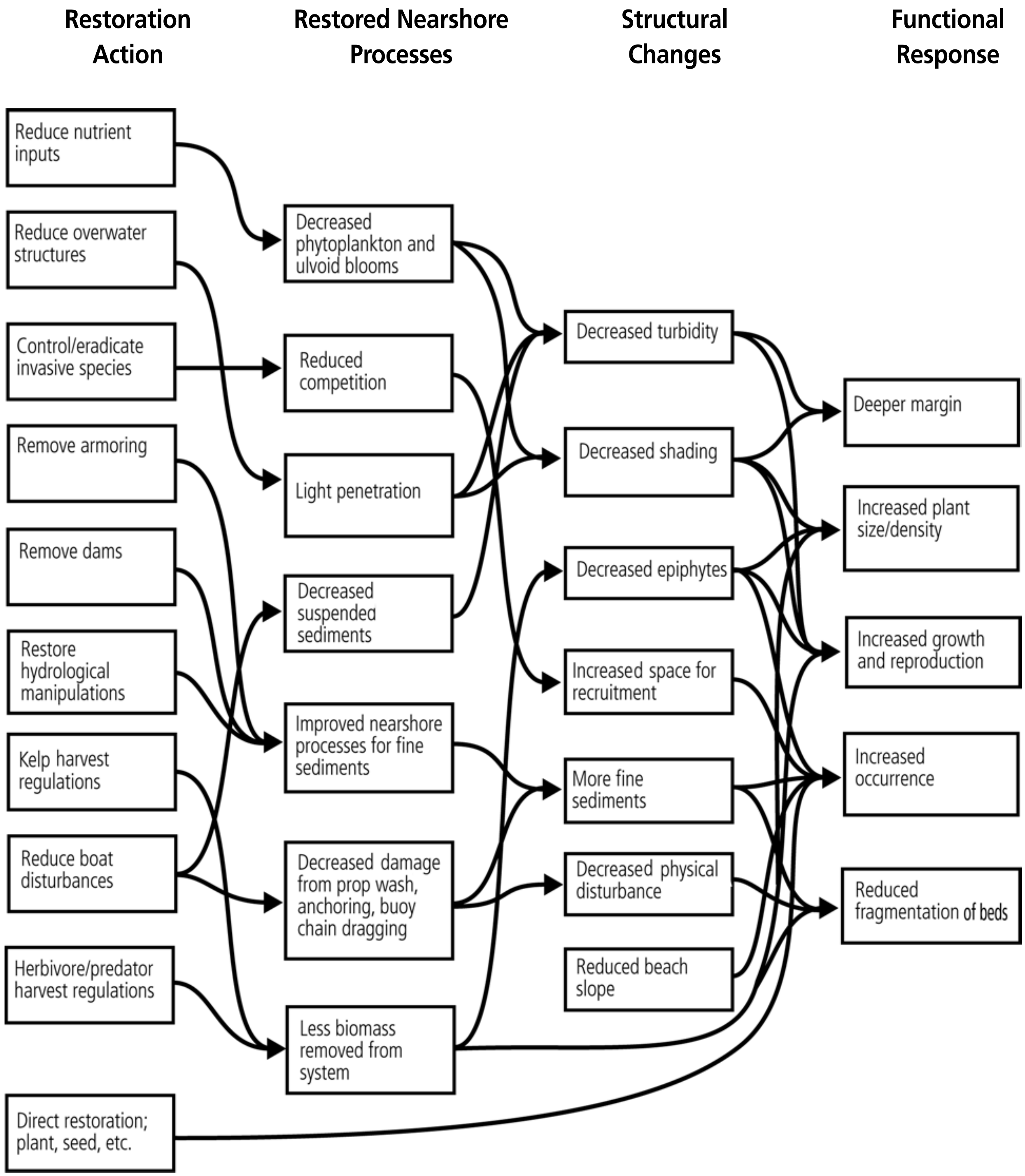


Figure 8. Conceptual model for kelp species.

Status and Trends

Kelp

The only data available on the status and trends of kelp in Puget Sound are for the two canopy-forming (floating) kelp species, and then only for their sporophyte phases. The subtidal habitat and lack of surface expression of the non-floating species prevent cost-effective monitoring of their populations, although use of towed video arrays holds promise. Thus, while these smaller kelps may play a larger role than the canopy kelps in the Puget Sound ecosystem because of their broad distribution and likely high abundance, at this time we have no way to quantify either their status or trends.

Thom and Hallum (1990) reviewed several sources of historical data and found evidence that floating kelp increased by 58 percent since the first European mapping in the 1850s, although they noted anecdotal evidence for losses in central Puget Sound. The author has also been contacted by several concerned citizens about losses of kelp beds around Marrowstone, Bainbridge and Fox islands. The author (personal observations) also noted the loss of small kelp beds in southern Puget Sound at Itsami Ledge, Devils Head and Dickenson Point.

Kelp beds have been mapped by the WDNR and published in the ShoreZone database (Nearshore Habitat Program 2001). Floating kelp is found along 11 percent of the shoreline of the state (Table 4). Maps showing the distribution of kelp are in Figures 4 and 5.

Table 4. Length of shoreline with eelgrass, floating and non-floating kelp by Puget Sound counties (data from ShoreZone, Nearshore Habitat Pro-gram 2001).

County Name	Total Miles	Percent of Shoreline with Aquatic Vegetation			
		Eelgrass	Floating Kelp	Non-floating kelp	Sargas-sum
Clallam	254	20%	40%	80%	1%
Grays Harbor	187	5%	> 1%	6%	> 1%
Island	214	63%	10%	18%	8%
Jefferson	254	58%	7%	33%	18%
King	123	62%	13%	27%	25%
Kitsap	254	48%	> 1%	21%	21%
Mason	232	28%	> 1%	24%	33%
Pacific	276	22%	> 1%	1%	> 1%
Pierce	239	26%	7%	44%	19%
San Juan	408	41%	31%	63%	47%
Skagit	229	51%	12%	26%	15%
Snohomish	133	22%	1%	1%	3%
Thurston	118	4%	> 1%	24%	4%
Whatcom	147	55%	7%	18%	34%
Total	3067	37%	11%	31%	18%

Since 1989, WDNR has gathered data by aerial coverage of floating kelps throughout the waters of the state, using photographs taken at the same time each year (van Wagenen 1989-2004). Berry et al. (2005) show that during this period, kelp canopy area has increased over the study area as a whole, especially on the outer coast and in the Strait of Juan de Fuca. In smaller-scale shoreline sections where a change through time was discernable, kelp canopy area generally increased. Kelp losses could be explained by:

- Substrate changes, loss of cobble and exposed bedrock
- Loss of detritus feeders, such as sea cucumbers, that remove silt and debris from the substrate, allowing sporeling attachment
- Increase of herbivores
- Decreases in water quality
- Harvest; illegal but can be substantial.

Examples of these key changes include growth of the coastal and straits populations of sea otters, which consume urchins and thus have a positive effect on kelp abundance. Human harvest of sea urchins may have similar effects. Other possibilities include methodological artifacts, changes in habitat characteristics, algal community shifts and climate change. The large *Nereocystis* bed on Dallas Bank, north of Protection Island in the Strait of Juan de Fuca, has almost totally disappeared since 1989. The cause of this change is not known.

Eelgrass

As with kelp, there is little long-term or broad-scale information that can be used to judge trends in eelgrass populations in Washington. Thom and Hallum (1990), after examination of early "T" and "H" sheets from the 1800's, could not make any definitive statements about long-term changes in eelgrass distribution. They did find evidence of significant losses in several major embayments (Bellingham and Snohomish River delta) and some evidence for a huge increase in the amount of eelgrass in Padilla Bay, currently the largest bed in Washington.

More recent, local surveys are numerous, although largely unanalyzed. Mapping efforts were made in the mid-1960s by Ron Phillips in Hood Canal using SCUBA and towing sleds. Phillips recorded more than 30 diving transects through Puget Sound in 1962-63 and reported depths, plant density and size. He stated that there was a "continuous eelgrass bed all around Hood Canal" (pers. comm.). Eelgrass and kelp beds were mapped from small aircraft in the late 1970's and published in the Coastal Zone Atlas (WDOE 1980, Youngmann 1977). The results are shown in Table 5. Table 5 also contains data supplied to Thom and Hallum (1990) by Dan Penttila, WDFW, from surveys he had made from 1975-89 during his herring spawn surveys.

More recently, eelgrass was mapped by the WDNR and published in the ShoreZone database (Nearshore Habitat Program 2001). Eelgrass was located on 37 percent of the shoreline (Table 6). A map showing the distribution of eelgrass is in Figure 6.

Hydraulic permit applications and shoreline permits require eelgrass surveys and thus constitute a significant amount of distribution data, but these are not published. WDFW has also encountered eelgrass while surveying for herring roe since 1974. These data were gathered by raking at depths up to about -4.6 meters (MLLW) and include the presence of eelgrass or macroalgae on the rake and whether there was herring spawn on the eelgrass. This could be a major detailed source of long-term data on eelgrass presence/absence, but only a few sites have been analyzed.

Table 5. Length of shoreline occupied by eelgrass based on surveys by Washington Department of Fisheries (WDF) (D. Penttila, pers. comm.) and by the Washington Department of Wildlife for the Coastal Zone Atlas (CZA). Total coastline lengths for each region are given in parentheses. The percent of coastline surveys by WDF is shown in parentheses under eelgrass distribution. (From: Thom and Hallum 1990, Table 8).

Region	WDF (1975-1989)		CZA (1977)	
	Eelgrass Distribution (km)	Coastline with eelgrass (%)	Eelgrass Distribution (km)	Coastline with eelgrass (%)
Straits (1,044 km)	206 (80%)	19.8	243	23.3
N. Sound (331 km)	38 (55%)	11.6	141	42.4
Hood Canal (295 km)	96 (~100%)	32.5	104	35.2
Main Basin (455 km)	53 (78%)	11.7	146	32.1
S. Sound (497 km)	~0 (~0%)	~0	25	5.1
Total (2,622 km)	393 (64%)	15.0	659	25.1

By far the most valid estimates of eelgrass distribution and trends have been made by the WDNR in its statistically-rigorous SVMP under the aegis of the Puget Sound Assessment and Monitoring Program. WDNR began monitoring five regions within Puget Sound during 2000 and has now published results of six seasons (Berry et al. 2003, Dowty et al. 2005). The report estimates 200 km^2 of *Z. marina* in Puget Sound. At the soundwide scale, over the past six years, eelgrass abundance, as measured by bed area, has not significantly changed. However, there is high variability in bed area with time at the scale of the five regions. In general, this variability has taken the form of short-term oscillations and not persistent trends. Of the five regions, only Hood Canal has shown a significant change in abundance: a persistent decline observed over four years (2001-2004). In addition, at the smallest (site) scale, SVMP identified fourteen sites that have strong or very strong evidence of declining *Z. marina* (Table 6). These results are from random transects within 1,000-meter segments, not from returns to precise sampling points, so the power of repeated sampling is somewhat lessened, but the ability to extrapolate is greater.

In addition, a set of small embayments in the San Juan archipelago is of concern. Wyllie-Echeverria et al. (2003) used aerial photographs from 1965 to the present to document the total loss of eelgrass in the Westcott/Garrison Bay complex and significant losses in several other bays. Five embayments in particular have experienced strong declines (Figure 9) (Wyllie- Echeverria et al. 2005a, 2005b, Reeves et al. 2005, Dowty et al. 2005).

For these small embayments, Mumford (in Wyllie-Echeverria 2003) hypothesized a variety of possible causes for the eelgrass decline:

- Increased sediment load or re-suspension
- Change in water circulation
- Hypoxia
- Eutrophication
- Overgrowth by macroalgae (ulvoids)
- Shading by phytoplankton
- Shading by epiphytes
- Shading by over-water structures
- Change of depth from dredging/fill
- Toxics
- Thermal or salinity stress
- Bird grazing (brant)
- Bioturbation
  - Ghost shrimp (*Neotrypaea californiensis, Upogebia sp.*)
  - Dungeness crab (*Cancer magister*)
- Boating anchors/prop scarring
- Disease (wasting disease- *Labyrinthula zosterae*).

However, to date there is no clear explanation (Wyllie-Echeverria et al. 2003). At these sites, these changes are probably not due to the construction of overwater structures and shading, but more likely to changes in water quality, disease or unknown invasive species.

Table 6. Eelgrass sampling sites in Puget Sound identified by multi-parameter assessment as having declined in area; considered are area, maximum and minimum depth, and patchiness. (Dowty et al. 2005).

Category	Site Code	Site Name	Region	Remains in sample in 2005?
very strong evidence of decline	flats18	Similk Bay	**Saratoga - Whidbey**	yes
	flats53	Wescott Bay	**San Juan - Straits**	no
	hdc2239	Hood Canal NE	**Hood Canal**	yes
	sjs0081	Broken Point (Shaw Is.)	**San Juan - Straits**	yes
	swls1625	S. of Tulalip Bay	**Saratoga - Whidbey**	yes
strong evidence of decline	core006	Burley Spit	**Central Puget Sound**	yes
	cps1686	Fort Lawton	**Central Puget Sound**	no
	flats37	Wing Point	**Central Puget Sound**	yes
	flats43	Dabob Bay	**Hood Canal**	yes
	flats62	Swifts Bay	**San Juan - Straits**	no
	hdc2359	Lynch Cove Fringe	**Hood Canal**	yes
	nps0654	Yellow Cove (Guemes Is.)	**North Puget Sound**	yes
	nps1363	Village Point (Lummi Is.)	**North Puget Sound**	no
	swh1556	NW Camano Island	**Saratoga - Whidbey**	no

Major Gaps/Critical Uncertainties

Although widely assumed, the functions, goods and services provided by kelp and eelgrass as habitat are poorly documented. Research needs to done to determine the degree to which herring spawning is dependent on eelgrass versus other types of vegetation, the degree to which salmon juveniles (by species) require or use eelgrass as a habitat, the degree to which adult salmon species directly or indirectly use kelp and eelgrass beds in their feeding and migratory behavior, and the degree to which fish and crab (and other invertebrate) larvae and juveniles require eelgrass and kelp as critical habitat.

Landscape studies need to include testing spatial models at various scales, studying plant responses to landscape patterns, and examining patchiness not only in regard to eelgrass but to other biotic metrics (other flora and faunal inhabitants).

Kelp

Little is known about the autecology of the gametophyte half of the kelp life history. This enigmatic phase may be crucial to kelp populations.

For the sporophytic (macroscopic) phase, we need a better understanding of the substrate requirements, such as size of boulders required, and the effects of burial and sediment or detritus coatings on adhesion and survival.

Because of possible loss of kelp in portions of central Puget Sound, we need to investigate the degree of loss and the effects of water quality changes on these losses.

Little is understood about the contribution of kelp to Puget Sound food webs, both in detrital and dissolved organic matter pathways. Research is also needed on the relationship of kelp to other primary producers, especially phytoplankton, and to other seaweeds, particularly ulvoids.

In some systems, kelp beds are more influenced by top-down effects (herbivory) than by bottom-up effects (nutrients, etc.) (Steneck et al. 2002, Halpern et al. 2006). We need to investigate the effects of fisheries on kelp forests, especially the effects of declines in sea urchins, cucumbers, abalone, sea otter, crab and fish.

Eelgrass

Effects of eutrophication in the Puget Sound system on eelgrass are not well understood and are in urgent need of research.

Eelgrass may have specific substrate requirements and may be sensitive to sedimentation rates. We need to investigate tolerances of burial and erosion and how those rates vary near river deltas and other sediment/nutrient sources.

The role of degraded water quality on plants and their functions is not clear. What attributes in water quality have changed? Is eelgrass sensitive to direct toxic effects or indirect effects that change the amount of available light?

Little is understood about the contribution of eelgrass to Puget Sound food webs, both in detrital and dissolved organic matter pathways. Research is also needed on the relationship of eelgrass to other primary producers, especially phytoplankton, and to other seaweeds, particularly ulvoids.

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PSNERP and the Nearshore Partnership

The Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) was formally initiated as a General Investigation (GI) Feasibility Study in September 2001 through a cost-share agreement between the U.S. Army Corps of Engineers and the State of Washington, represented by the Washington Department of Fish and Wildlife. This agreement describes our joint interests and responsibilities to complete a feasibility study to

"…*evaluate significant ecosystem degradation in the Puget Sound Basin; to formulate, evaluate, and screen potential solutions to these problems; and to recommend a series of actions and projects that have a federal interest and are supported by a local entity willing to provide the necessary items of local cooperation.*"

The current Work Plan describing our approach to completing this study can be found at:

http://pugetsoundnearshore.org/documents/StrategicWorkPlanfinal.pdf

Since that time, PSNERP has attracted considerable attention and support from a diverse group of individuals and organizations interested and involved in improving the health of Puget Sound nearshore ecosystems and the biological, cultural, and economic resources they support. The **Puget Sound Nearshore Partnership** is the name we have chosen to describe this growing and diverse group, and the work we will collectively undertake that ultimately supports the goals of PSNERP, but is beyond the scope of the GI Study. Collaborating with the Puget Sound Action Team, the Nearshore Partnership seeks to implement portions of their Work Plan pertaining to nearshore habitat restoration issues. We understand that the mission of PSNERP remains at the core of our partnership. However, restoration projects, information transfer, scientific studies, and other activities can and should occur to advance our understanding and, ultimately, the health of the Puget Sound nearshore beyond the original focus and scope of the ongoing GI Study.

As of the date of publication for this Technical Report, our partnership includes participation by the following entities:

- King Conservation District
- King County
- National Wildlife Federation
- NOAA Fisheries
- NOAA Restoration Center
- Northwest Indian Fisheries Commission
- Northwest Straits Commission
- People for Puget Sound
- Pierce County
- Puget Sound Partnership
- Recreation and Conservation Office
- Salmon Recovery Funding Board
- Taylor Shellfish Company
- The Nature Conservancy
- U.S. Army Corps of Engineers
- U.S. Department of Energy
- U.S. Environmental Protection Agency
- U.S. Geological Survey
- U.S. Fish and Wildlife Service
- U.S. Navy
- University of Washington
- Washington Department of Ecology
- Washington Department of Fish and Wildlife
- Washington Department of Natural Resources
- Washington Public Ports Association
- Washington Sea Grant
- WRIA 9

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Puget Sound Nearshore Partnership

RESTORING OUR ECOSYSTEM HEALTH

Puget Sound Nearshore Partnership/
Puget Sound Nearshore Ecosystem Restoration Project

c/o Washington Department of Fish and Wildlife

Mailing Address: 600 Capitol Way North,
Olympia, Washington 98501-1091

Contact: *pugetsoundnearshore@dfw.wa.gov*
or vist our website at: *www.pugetsoundnearshore.org*