Technical Report 2007-02

Marine Riparian Vegetation Communities of Puget Sound

Prepared in support of the Puget Sound Nearshore Partnership

James S. Brennan
Washington Sea Grant

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.

Mumford, T.F. 2007. Kelp and Eelgrass in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-05. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Penttila, D. 2007. Marine Forage Fishes in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-03. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

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Contents

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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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Executive Summary

Riparian vegetation along marine shorelines serves a variety of critical ecological and social functions. Coastal trees and other vegetation on backshore areas, banks, and bluffs help stabilize the soil, control pollution entering marine waters, provide fish and wildlife habitat, and modify stressful physical conditions along shorelines. Riparian areas are transitional, providing connections between and affecting both adjacent aquatic and terrestrial systems.

Geological history, soils, climatic conditions, and various types and degrees of disturbance affect riparian vegetation along the shores of Puget Sound. Although quantitative historical data on vegetation types and locations are mostly lacking, riparian areas have been heavily disturbed through timber harvest, urban development, roads, railroads, and other infrastructure and activities. The historical climax communities in marine riparian areas were likely forests of western hemlock and Douglas fir, intermixed with western red cedar and a variety of associated understory species. In areas of frequent disturbance, early successional trees, such as red alder and maple, dominated coastal forests. Douglas fir is currently the most common conifer in relatively undisturbed sites. Today's shorelines are often dominated by maple, alder, and non-native species, which colonize rapidly after many types of disturbance, including logging, fire, soil erosion and other anthropogenic impacts. Madrone forests are found on dry, sunny sites with relatively nutrient-poor soils. Other, more specialized riparian communities include prairies, dune-grass associations, salt marshes, and tidal or surge-plain communities; losses of most of these habitats have been extensive in Puget Sound.

Prior to European colonization, marine coastal vegetation in Puget Sound was probably a mosaic, with natural disturbances such as fire, wind, and landslides removing the climax community in patches and "resetting" succession. Variation in physical conditions, such as soil moisture and local rainfall, also would have caused different plant communities in different parts of the sound, but the data suggest that dense, coniferous forests covered most of the lowlands. Today, natural disturbances, such as fire, are suppressed, while anthropogenic ones, such as logging and urbanization, act in a different fashion. The introduction of invasive plant species means that natural succession is disrupted when disturbances do occur.

Restoring native riparian vegetation will be a slow task because of the time required to establish and grow mature forests, although early successional trees, shrubs, backshore, and salt marsh vegetation could be regenerated fairly quickly. Protecting remnants of existing native coastal vegetation is the most cost-effective and rapid management option for regaining some of the lost functions of these habitats. Removing non-native plants and physical obstructions (such as shoreline armoring), and allowing natural succession to occur, can take place on a larger scale but will be very slow in achieving results. Restoration (e.g., by actively planting native forest species) will be difficult but could ultimately provide the greatest benefits.

Preface

Riparian vegetation along marine shorelines provides ecological, economic, social and cultural functions and benefits. The recognition of these values has prompted managers to incorporate riparian vegetation into ecosystem management practices, providing increased shoreline protection. Riparian areas are part of the transition zone between aquatic and terrestrial systems. They affect exchanges of matter and energy between these systems and provide climatic differences from inland areas, important wildlife habitats and improvements in water quality. The importance of marine riparian areas typically falls into two categories: ecological functions and social values. Ecological functions include pollution control, fish and wildlife habitat, soil stability, sediment control, microclimate, shade, and inputs of nutrients and large woody debris. Societal values include human health and safety, as well as cultural and aesthetic qualities. These values overlap. For example, if good water quality were not valued by society, it would likely not be considered an important function. Similarly, soil stability functions provided by riparian vegetation become a human safety issue if development occurs on or near unstable slopes. A summary of each of these functions and values is provided below. Additional discussion may be found in Brennan and Culverwell (2004) and in the references provided at the end of this manuscript.

Pollution/Sediment Control

Vegetated riparian areas are efficient and cost-effective tools for pollution control. Many contaminants from urban and rural areas bind to sediments that, when washed into waterways, constitute large masses of pollutant loadings. These contaminants include most forms of nitrogen and phosphorus, hydrocarbons, PCBs, most metals, and pesticides. In addition, fine sediments themselves can adversely affect aquatic organisms by clogging the gills of fishes and invertebrates, smothering eggs and larvae, altering substrates, and burying benthic organisms. Riparian vegetation can slow the rate of runoff, retain sediments, absorb nutrients, and remove or break down many pollutants, preventing them from contaminating waterways. Effectiveness depends on vegetation composition, depth, density and continuity.

Fish and Wildlife Habitat

Riparian areas tend to promote higher fish and wildlife species diversity, owing to their complexity and adjacency to water. Resident and transitory wildlife species use these areas for rearing, feeding, reproduction, refuge and migration. Riparian vegetation also influences the health of adjacent water bodies and thus the fish and wildlife that live there. The alteration or removal of historical vegetative structure has undoubtedly resulted in the loss or fragmentation of riparian wildlife habitat and the consequent loss of wildlife species. In addition to living vegetation, large woody debris (LWD), often derived from riparian forests, is an important part of estuarine and oceanic habitats. Structurally, LWD in the marine environment provides potential roosting, nesting, refuge and foraging opportunities for wildlife; foraging, refuge and spawning substrate for fishes and aquatic invertebrates; and attachment substrate for algae. Logs high in the intertidal zone may become imbedded and form beach berms, which may influence sediment and wrack deposition patterns and establishment of beach vegetation. As trees are removed from riparian areas for development and view corridors, their potential recruitment to the beach is eliminated, or they are replaced with smaller and shorter-lasting deciduous trees.

Soil Stability

Intact riparian communities act as natural sponges. They intercept precipitation with their canopy, build absorbent soils with their litter, bind soils with their root structure, and retain moisture. Thus, riparian vegetation, once established, provides self-perpetuating and increasingly effective erosion control. For all shorelines (particularly those in areas with steep bluffs), native vegetation is usually the best tool for keeping the bluff intact.

Microclimate

Riparian vegetation creates small-scale microclimates upon which plants, fish, and wildlife depend, especially climate-sensitive species such as amphibians and upper intertidal invertebrates. Removing vegetation in upland and riparian areas increases exposure of the land and water to sun and wind. This increases desiccation rates, reduces organic matter, alters soil conditions, increases runoff and creates a stressful environment for organisms that are dependent upon cool, moist or shaded conditions. Cleared areas become more homogeneous and are often colonized by invasive plants that do not provide the same structure and ecological functions as native vegetation.

Shade

Solar radiation leads to increased temperatures and desiccation and plays an important role in determining the distribution, abundance, and species composition of intertidal organisms. Along Puget Sound shorelines, distinct differences in substrate moisture, air and substrate temperature exist between shaded and unshaded beaches. For example, Penttila (2001) and Rice (2006) have determined that significantly higher mortality of smelt (forage fish) eggs occurs on unshaded beaches, apparently because of reduced substrate moisture and direct solar radiation.

Nutrient Inputs

Riparian vegetation may support substantial populations of insects, which are important in the diet of marine fishes such as juvenile salmonids. In areas with healthy riparian communities, terrestrial insects in marine waters are diverse and abundant. Some marine invertebrates, such as mysids and amphipods, are also connected to riparian vegetation by detritus-based food webs. As riparian vegetation is eliminated, the food supply and carrying capacity of the nearshore ecosystem are likely to be reduced.

Introduction

Northwest Washington state is one of the most ecologically diverse areas in the nation and contains some of the most productive forests in the world. The Puget Sound region is a centerpiece of that diversity and productivity. The mosaic of forests and vegetation communities in this region are the product of thousands of years of evolution; their composition, structure, and functions are influenced by multiple factors, including geology, climate, topography and disturbance. These influences have resulted in patterns of forest types and vegetation communities segregated into distinct zones and community associations, which vary with regard to management issues and ecological and economic values. The Puget Sound Area Zone is one of the most distinctive and important because of its glacial history, ecological linkages to the marine waters of the region, and management challenges resulting from post-European settlement and modification of the natural landscape. The areas adjacent to the marine waters of Puget Sound are distinguished as riparian areas: transitional areas between the aquatic and terrestrial systems, or ecotones, where the interactions and influences between these two environments create gradients in the biophysical conditions and distinctive ecological processes and biota. Vegetation is one of the primary features used to distinguish riparian areas and evaluate ecological functions and values, although some riparian areas support limited vegetation owing to natural disturbances. The riparian vegetation communities that have evolved around the shores of Puget Sound are very diverse, and they play an important role in the ecological health of the terrestrial and aquatic ecosystems, and as terrestrial aquatic ecosystems are recognized as some of the most valuable and indicative ecosystems in the world, (NRC 2002, NRC 2004, MEA 2005). Yet little information exists on the species composition, distribution, associations, or alterations of marine riparian vegetation communities. This paper is an attempt to assemble the available information on marine riparian vegetation communities and summarize some of the ecological conditions necessary for their existence and role in the nearshore ecosystem.

As with any study of the living landscape, vegetation zones and community types may be distinguished at various spatial or temporal scales, or both. Forest zones and their associated vegetation community types are diverse. For example, Franklin and Dyrness (1973) list more than 350 plant community types or subtypes for Oregon and Washington. Within the Puget Sound Area, there are more than 50 types or subtypes. At the larger scale (e.g., from sea level to the mountain tops), forest types are broken into zones, represented by the dominant canopy (tree) species, or climax community, with various subtypes distinguished by subdominant tree and shrub associations. As distance from the shore and elevation increase, changes in soil, moisture, temperature, precipitation, and other factors combine to create conditions that are suitable for different plants. For northwest Washington, there are five major forest zones identified by Franklin and Dyrness (1973): the Sitka Spruce, Western Hemlock, Puget Sound Area, Pacific Silver Fir, and Mountain Hemlock zones (Figure 1). The Puget Sound Area Zone is embedded in the Western Hemlock Zone, but is distinctive in its plant associations because of differences in climate and soils. In the coastal areas of northwest Washington, there are three dominant forest types (Box 1). The Pacific Silver Fir and Mountain Hemlock zones are found at higher elevations along the western slopes and crest of the Cascade Range and in the Olympic Mountains, and they are not characteristic of coastal forests. The Pacific Silver Fir Zone lies between the Western Hemlock Zone of the lowlands and the subalpine Mountain Hemlock Zone.

Within each zone, there is also vertical stratification of vegetation types, including dominant canopy tree species, understory trees and shrubs, and groundcover. Different vegetation community types evolve over time, depending upon climate, soils, local disturbances and other conditions. Plants that are better adapted to one set of conditions are typically less tolerant of other conditions and will therefore be less abundant as conditions change. The diverse set of environmental conditions, including the ways in which different plants interact (e.g., understory vegetation with canopy species), sets the stage for the development of different vegetation associations, or community types. For a more complete description of forest zones and community types, refer to Franklin and Dyrness (1973) and Chappell (2005).

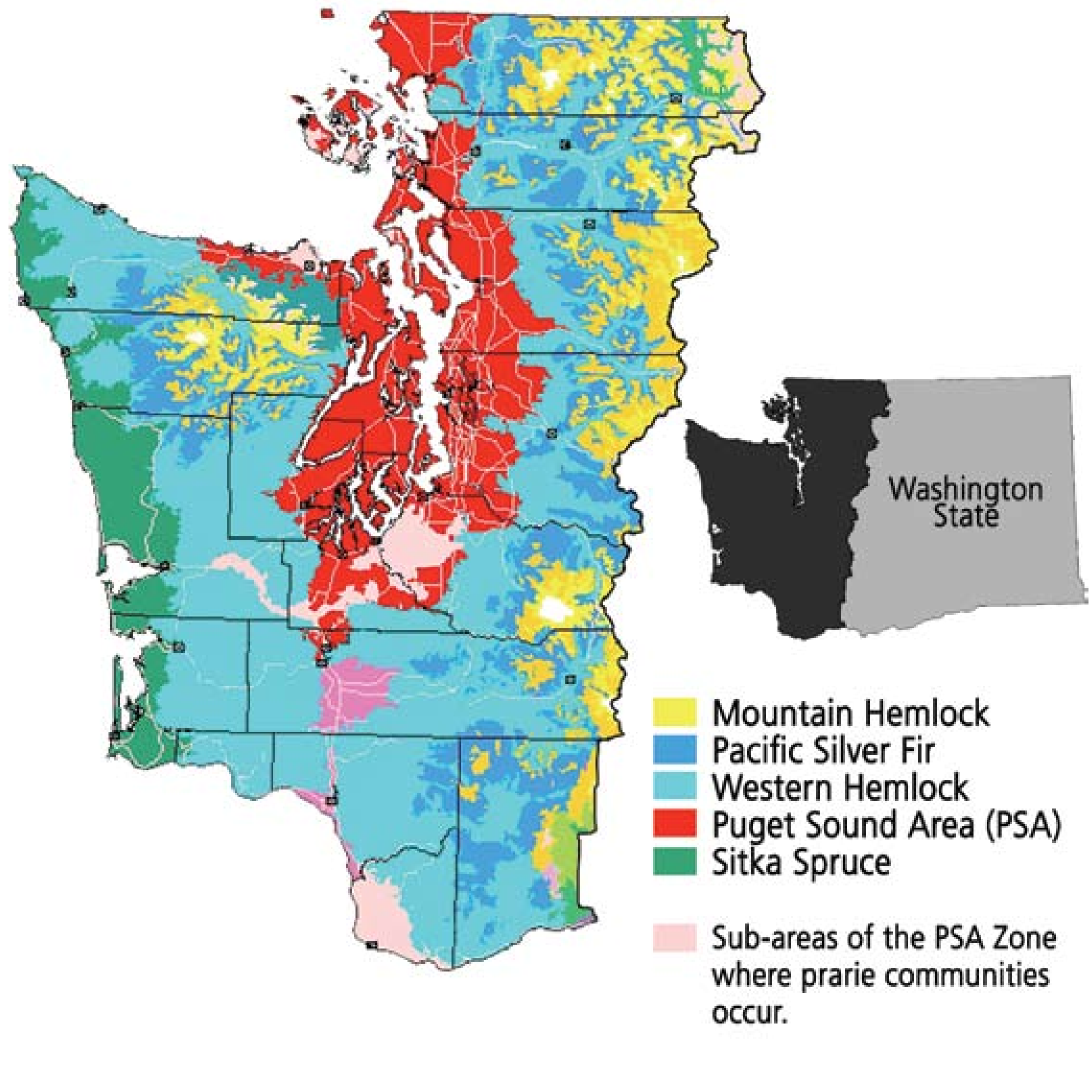

Figure 1. Major forest zones in northwestern Washington. Adapted from image acquired from the University of Washington (*http://depts.washington.edu/natmap/images/modimage/www_zone.jpg*).

More readable color versions of this and all other graphics in this series are available at *www.pugetsoundnearshore.org/*.

Distinguishing forest zones and ecological communities serves multiple purposes, including the identification, quantification and management of harvestable forest products, fish and wildlife, and conservation efforts. Numerous state and federal agencies, such as the U.S. Forest Service, U.S. Fish and Wildlife Service, U.S. Geological Survey, and the Washington departments of Natural Resources and Fish and Wildlife, have mapped and studied various aspects of forest zones, community types, fish and wildlife interactions, harvest impacts, recreation, and management strategies. Similarly, private forest landowners and conservation groups (e.g., The Nature Conservancy) have expended substantial time and financial resources to study forests and develop management strategies for harvesting commercial products and conserving ecological communities. These efforts have become particularly important in recent decades, following many decades of poor development and forestry practices that have resulted in the loss or fragmentation of important ecological communities, individual species, and associated ecological goods and services.

Marine riparian vegetation communities are particularly important because they exhibit greater biodiversity than inland vegetation communities, influence the health and integrity of marine habitats and species, and are an integral part of nearshore ecosystems. Riparian areas maintain local biodiversity, and their ecological functions provide the basis for many valued fisheries, in addition to bird and other wildlife habitat (National Research Council 2002). Unfortunately, riparian systems have historically been heavily disturbed through timber harvest, urban development, and other anthropogenic activities, which have reduced their ability to provide "ecological goods and services." The extent of modification and loss of coastal forests and riparian areas serves as a strong indicator of reduced forest and nearshore ecosystem health. Their demise has also led to reduced air and water quality; a loss of commercial, cultural, recreational and aesthetic resources; and a disruption of ecological processes needed to maintain nearshore ecosystems.

The recognition of marine riparian areas as an integral part of marine nearshore ecosystems, and the importance of their ecological and social benefits, is a fairly recent occurrence. As a result, we lack directed studies to develop a more thorough understanding of these systems and regulatory or nonregulatory standards to protect them. Although regional forests and plant communities, defined as aggregations of species (Kruckeberg 1991), have been classified and mapped at various spatial scales by different entities (e.g., U.S. Forest Service, U.S. Geological Survey, Washington Department of Natural Resources [WDNR]), marine riparian vegetation communities of the Puget Sound region have not. General information on forest classifications, plant biology, plant associations and their life-history requirements and ecology are available from multiple sources (e.g., Franklin and Dyrness 1973, Kruckeberg 1991, Grossman et al. 1998, Jennings et al. 2004, NatureServe 2004, Chappell 2005), and limited mapping information is also available. However, historical data, which would help in determining the extent of change, are lacking, and current vegetation community types are not well mapped at the smaller scale. Nonetheless, available information is adequate to determine that riparian vegetation communities are significantly changed from historical conditions, primarily owing to settlement patterns in the region, timber harvest and subsequent development practices. Protecting, enhancing or restoring riparian forests will require large-scale and long-term strategies and commitments and an ecosystem-based approach to managing nearshore systems and coastal communities of Puget Sound.

Box 1. The three dominant coastal forest types and their characteristics.

Examples of Western Washington Coastal Forest Zone Communities

(Adapted from Franklin and Dyrness 1973)

Sitka Spruce (*Picea sitchensis*) Zone

The Sitka Spruce Zone extends from northern California, coastal Oregon and along the outer Washington coast into the Strait of Juan de Fuca to approximately Port Angeles. It is generally found below elevations of 150 meters, but goes to 600 meters where mountain masses are immediately adjacent to the coast. This zone's climate is considered uniformly wet and mild because of its proximity to the ocean. Annual precipitation averages 2,000–3,000 mm, but frequent fog and low clouds during the summer ensure minimal moisture stress. Wind is a primary disturbance factor along the coast. Average annual temperatures range from 10.3° to 11.3° C. Soils are typically acidic (pH 5.0–5.5) and high in organic matter. Coniferous forest stands in this zone are typically dense, tall, and highly productive. Constituent tree species are Sitka spruce, western hemlock, western red cedar, Douglas fir, grand fir, and Pacific silver fir (the first three are the most common). Mature forests have lush understories with dense growths of shrubs and ferns. One distinctive variant in this zone in northwest Washington is the Olympic rainforest.

Western Hemlock (*Tsuga heterophylla*) Zone

The Western Hemlock Zone is the most extensive vegetation zone in western Washington and Oregon and the most important in terms of timber production. It extends from British Columbia through the Olympic Peninsula, Coast Ranges, Puget Sound, and both Cascade physiographic provinces in western Washington. This zone has a wet, mild, maritime climate. Precipitation averages 1,500–3,000 mm per year. Average annual temperatures in this zone range from -3.7° to 29.4° C, with a mean of 8–9° C. There is a great deal of climatic variation throughout this zone, associated with latitude and elevation. Soils are also variable and influenced by forest cover type, underlying geology and slope. Constituent tree species are Douglas fir, western hemlock, and western red cedar. Grand fir, Sitka spruce, and western white pine occur sporadically. Both western white pine and shore pine occur on glacial drift in the Puget Sound area. Hardwoods, such as red alder and big leaf maple, are not common, except in disturbed sites or specialized habitats (e.g., riparian areas). Madrone and Oregon white oak may be found on drier, lower elevation sites. Western red cedar is associated with wet sites on lower slopes and stream terraces. Although this is called the Western Hemlock Zone, based upon potential climax species, large areas are dominated by forests of Douglas fir (particularly drier sites). Much of the zone has been logged or burned, or both, during the last 150 years, and Douglas fir is usually dominant (often sole dominant) in the seral stands that have developed. There are many variations of the community pattern throughout this zone, generally in response to moisture, soils and disturbance.

Puget Sound Area (PSA) Zone

The Puget Sound Area Zone falls within the greater Western Hemlock Zone but is noteworthy because it has characteristics and its own variations that distinguish it as a separate vegetative zone. The PSA extends from approximately Port Angeles, in the Strait of Juan de Fuca, around the lower eastern side of the Olympic range and throughout the Puget Sound lowlands, up into British Columbia. A portion of the area lies in the rain shadow of the Olympic Mountains. Annual precipitation averages 800–900 mm in the Puget lowlands, but drops as low as 460 mm on the northeastern side of the Olympic Peninsula and in the San Juan Islands. Average annual temperatures in the lowlands range from approximately 3.3° to 19° C (temperatures are lower in higher elevations). The fact that the terrestrial environment is adjacent to large bodies of water has a great influence on climate. Similarly, because this area is glaciated, the glacial outwash and terrain influence the diverse array of vegetative communities. Plant communities are generally typical of the Western Hemlock Zone, but major constituents include Douglas fir and grand fir. There are also pine forests, oak groves, prairies, swamp and bog communities, and deciduous forests in areas where disturbance occurs with some regularity.

Vegetation Characteristics And Conditions

The forests and other vegetation communities that line the shores of Puget Sound evolved in a manner similar to all other life forms following the end of the last glacial period, some 13,000 years ago. On the terrestrial side, the process of succession from grasses and shrubs to mixed conifer and deciduous forests continues today, where the vegetation characteristics (e.g., type, age structure, extent) continue to be influenced by the forces of both nature and man. In general, the major natural forces that control what types of vegetation become established in a particular location are the interacting influences of atmosphere (air), lithosphere (soils), and hydrosphere (moisture). Even though the greater Puget Sound basin is considered to be one ecoregion, local variations in soils, exposure to sun and wind, precipitation, topography, soil stability, tidal inundation, and microclimate cause small-scale variations in vegetation community types.

Puget Sound lowland vegetation is generally classified in the Western Hemlock, or Western Hemlock/Sword Fern Zone, recognizing the climax tree canopy species (western hemlock) and the associated, dominating presence of the sword fern on the forest floor (Franklin and Dyrness 1973, Kruckeberg 1991). Kruckeberg (1991), recognizing the historical climax community, classifies the dense conifer forests in the Puget Sound lowland as the Western Hemlock/Western Red Cedar Forest Zone, indicating dominance of hemlock–cedar in late successional phase. This large-scale view overlooks marked local variations in the plant and animal communities. For example, Douglas fir often dominates the present lowland forests that would nevertheless be included in the Western Hemlock Zone (Kruckeberg 1991), and its current dominance indicates the lack of climax forest communities. In fact, some authors (e.g., Kricher and Morrison 1993, Chappell 2005) identify this northwest forest zone as being dominated by Douglas fir, which is now true, particularly in drier, more exposed and well drained areas, but this does not recognize the climax species. Although fire was historically pervasive across the region and reset the ecological clock in terms of seral communities, present-day forests and vegetation communities differ significantly in their composition and succession patterns because of anthropogenic influences that now serve as the major controlling factors.

Other species are common cohabitants with western hemlock and sword fern, including Douglas fir, western red cedar, and understory shrubs such as red huckleberry, Oregon grape, trailing blackberry, and salal (Kruckeberg 1991). Other common trees in this zone include big leaf maple, vine maple, red alder, black cottonwood and madrone. A list of the most common plants of the Western Hemlock Zone, along with information on their relative abundance and habitats, may be found in Kruckeberg (1991). A more extensive species list may be found in Franklin and Dyrness (1973). A list of the more common native trees, understory, and salt-tolerant vegetation found in marine riparian areas was compiled for this paper (Table 1).

Within the Puget Sound Area, a number of smaller-scale plant associations illustrate the diversity and complexity within this ecoregion. A classification for plant associations in the Puget Sound Area has been developed by the Natural Heritage Program (Chappell 2005) and provides details on distribution, status, environmental characteristics, disturbance/succession and terrestrial plant species associations.

Table 1. Vegetation species list (common and standard names) for some of the more common species found in marine riparian areas.[1]

Western hemlock	*Tsuga heterophylla*
Douglas fir	*Pseudotsuga menziesii*
Western red cedar	*Thuja plicata*
Pacific madrone	*Arbutus menziesii*
Bigleaf maple	*Acer macrophyllum*
Vine maple	*Acer circinatum*
Red alder	*Alnus rubra*
Salal	*Gaultheria shallon*
Oceanspray	*Holodiscus discolor*
Oregon grape	*Mahonia spp.*
Indian plum	*Oemleria cerasiformis*
Salmonberry	*Rubus spectabilis*
Snowberry	*Symphoricarpos spp.*
Sword fern	*Polystichum munitum*
Huckleberry	*Vaccinium spp.*
Nootka rose	*Rosa nutkana*
Gumweed	*Grindellia integrifolia*[2]
Saltweed	*Atriplex patula*[2]
Saltgrass	*Distichlis spicata*[2]
Pickleweed	*Salicornia virginica*[2]
Fleshy jaumea	*Jaumea carnosa*[2]
Seaside arrowgrass	*Triglochin maritimum*[2]
Seaside plantain	*Plantago maritima*[2]
Dune wildrye	*Elymus mollis*[2]

[1]*Please refer to Franklin and Dyrness (1973) for a more complete plant species list, and Chappell (2005) for plant species associations.*

[2]*Salt tolerant, typically associated with salt marsh, beach strand, or other wetlands.*

Each of these plant associations is characterized by the dominant types of vegetation (primarily dominant trees), and then by associated vegetation (other trees and understory vegetation). The western hemlock and Douglas fir associations are the most common and widespread, with approximately 33 association subtypes. The Natural Heritage Program surveys (Chappell 2005) have determined that some of these associations are widespread, some are rare and only found in specific areas within the Puget Sound Area, and others may be found in patches. The details (maps and descriptions) of these associations may be found in Chappell (2005), but it is important to keep in mind that these are terrestrial plant associations, and no attempt has been made to map or characterize vegetation on shorelines.

No surveys or characterizations exist for forest or other vegetation associations and community types found specifically on Puget Sound shorelines. However, vegetation communities found in the Puget Sound Area that are less likely to occur on shorelines include oak woodlands and lodgepole and ponderosa pine forests, which are often associated with savannas or plains and occur as early- to mid-seral stage forests in areas disturbed by fires (Chappell 2005). Fire suppression has greatly influenced these communities' distribution and abundance. Although these tree species may occur along shorelines in association with others, they are not considered the dominant or characteristic species. There are, however, unique and uncommon patches of uncharacteristic tree species in some locations around the region — such as oak woodlands (Oak Bay, Jefferson County), aspen (Sucia Island, San Juan Island, San Juan County) (Paula Mackrow, North Olympic Salmon Coalition, pers. comm., Jim Agee, University of Washington, pers. comm.) and Douglas maple (Tom Mumford, WDNR, pers. comm.) — but they have not been mapped or formally described.

Available characterization information for the various community types, and some knowledge of local conditions, indicates that some community types are more likely than others to occur along shorelines—for example, Douglas fir, western hemlock and deciduous (maple, alder) associations. Less common, but worth mentioning, are the madrone associations. Madrone typically occurs on dry, sunny sites with relatively nutrient-poor soils. They are also relatively fire and drought resistant, which has allowed them to persist under natural fire disturbance regimes (e.g., they resprout well after fire). Fire suppression, timber harvest/clearing, and other development activities have resulted in the fragmentation of madrone forest communities, an increase in disease and a decline in historical abundance (Chappell 2005).

Douglas fir forests are likely the most common forest communities found along Puget Sound shorelines today. Shrubs and deciduous trees would dominate where these fir stands have been disturbed by natural or anthropogenic influences. Douglas fir forests are the most diverse of the local forest types, with varying distribution patterns and associations. With some exceptions, and in the absence of natural or anthropogenic disturbance, most fir forests in moist areas would likely become dominated by hemlock and red cedar if left undisturbed for hundreds of years, because they are considered mid-late seral-stage forests. Although the varieties of this community type are well described by Chappell (2005), surveys of shoreline distribution and abundance, continuity/fragmentation, density, age structure, and other characteristics are not available. Clearly, however, very few if any of these forests look and function as they did before European settlement, when these undisturbed forests likely were dominated by western hemlock and Douglas fir. Where natural disturbance occurred and along open edges, Douglas fir dominance would follow the early seral communities of shrubs and deciduous trees. Localized conditions, influenced by soils, moisture, aspect, types and frequency of disturbance and other factors, would ultimately result in a plant community adapted to these conditions. Intense and more frequent physical disturbances, such as fire or soil movement, would result in disturbance-adapted vegetation communities, such as alder, maple, black cottonwood and madrone.

Alder and maple (vine and big leaf) forest communities are a common occurrence along the shores of Puget Sound. Naturally, they occur in a limited habitat, located on steep slopes (Chappell 2005). Alder colonizes a disturbed area rapidly and is prolific but short-lived (about 80–100 years). Maples are also strongly associated with soil movements and appear capable of surviving small or slow mass movements, sprouting vigorously after major damage to a mature stem, unlike conifers and alder (Chappell 2005). They are characteristically adapted for early succession (e.g., reduced shade canopy) and physical disturbance. Because most of the bluffs around Puget Sound experience soil movement at intervals shorter than those needed for the development of a climax forest, these "fringe" forests often have a higher composition of disturbance-adapted vegetation. In addition to soil movement, disturbances such as wind, salt spray, timber harvest, development, and other anthropogenic activities have resulted in the conversion of conifer forests to vegetation communities dominated by alder, maple, and non-native species, making these forest communities much more common and widespread today than they were historically.

Specialized Communities

A variety of other specialized community types are also found along the shores of Puget Sound: the forest and prairie communities of Sequim and the San Juan Islands; "ocean-front" communities (Franklin and Dyrness 1973) such as sand dune, strand or salt marsh communities; and communities associated with flood or tidal surge plain areas (i.e., tidal estuaries). These vegetation communities are included in this discussion because they are a distinct part of the transition between marine and terrestrial systems, have unique characteristics and adaptations, and play an important ecological role in the nearshore ecosystems. These beach and salt marsh communities add to the diversity of habitats and vegetation community types in the region and are highly susceptible to disturbance from anthropogenic activities along the shoreline. Additional specialized communities may be found along the shores of Puget Sound, but like those being described here, none have been well studied or mapped; also, these three community types were simply selected to serve as examples of the diversity and specialization exhibited by some of these plant communities.

Sequim and the San Juan Islands are situated in the rain shadow of the Olympic Mountains and, as a result, include some of the driest sites encountered in western Washington (Franklin and Dyrness 1973). The exposed, south-facing slopes of Whidbey and the San Juan Islands are occupied by grassland vegetation and open woodlands, composed of Douglas fir and madrone. Other tree species include white oak, shore pine, and juniper. More sheltered areas support more dense forests of Douglas fir, mixed with grand fir and western red cedar. This illustrates the diversity of community types that may be found in close proximity to each other and the strong influence of aspect, wind exposure and moisture. The drier climate, free-draining soils and exposure also support unique prairie communities, such as those found in Sequim and on the southwest side of San Juan Island. Unlike most other shorelines in Puget Sound, trees are a minor component, and those that do occur exhibit stunted growth and stress from wind exposure (and likely salt spray).

Beach and salt marsh plant communities contain highly specialized plant species that are tolerant of salt, relatively dry and free-draining soils or soils of high organic content, and disturbance from wave action, tidal inundation and shifting substrate. Most of what is known about beach vegetation communities comes from studies of outer-coastal dune areas; in Puget Sound they occur at a much smaller scale than the broad and continuous dunes of the outer coast. "Strand" communities inhabit the backshore, or beach berm, with its accumulation of sediments, relatively narrow band of stranded logs and salt-tolerant vegetation. Larger accumulations of logs and vegetation typically occur in sediment accretion areas, such as points, spits and estuaries, which are capable of supporting large and more diverse vegetation communities. Salt marsh communities may also occur in the strand, but typically occur in larger patches, on broad flats, or within stream and river estuaries and embayments that are regularly inundated by tides; these communities are more easily recognized and classified as a wetland "type" (see Cowardin et al. 1979, Dethier 1990). Regardless of the size and dimensions, many of the same vegetation types exist along shorelines, and all are technically wetlands, providing similar ecological functions and influenced by many of the same processes.

Some of the more common plant species in these areas include dune grass (dune wildrye), sedges, rushes, seaside arrowgrass, seaside plantain, saltgrass, pickleweed, gumweed, saltweed (fat hen), fleshy jaumea, beach pea, tufted hairgrass and shore lupine. Their ability to tolerate wind, waves, saltwater inundation and shifting sediments enables them to survive in such harsh environments. They are an important part of the nearshore food web, provide habitats for fishes and wildlife, and they help to stabilize beaches, reducing erosion of fine sediment and contributing to the development of beach berms.

The vegetation communities that occur in tidal or surge plain areas (i.e., river-mouth estuaries) are often substantially different from the typical open shoreline of Puget Sound, primarily due to the reduced energy, freshwater and sediment input within these areas. As river flows come up against tidal forces over time, sediments and organic matter carried downriver or on incoming tides settle out, creating broad deltaic and mudflat formations. These become colonized by vegetation communities adapted to varying levels of salt and inundation from tidal and river flows. The vegetation itself becomes a trap for additional sediments and provides organic matter that builds the marsh and contributes to many of its important ecological functions. Salt marsh communities become a dominant feature in lower areas with saltwater inundation, giving way to less salt-tolerant species as elevation and freshwater input increases. The vegetation types within these tidal wetlands have been described generally as emergent marsh or scrub/shrub, but precise surveys of plant species composition are lacking. In addition, early settlers began converting much of this marshland for agriculture, ports and industrial or residential uses. These conversions have continued, and little is known about what has been lost. Several studies have determined that the loss of tidal marsh and riparian habitat is extensive (Bortelson et al. 1980, Thom and Hallum 1991, Levings and Thom 1994), and an historical reconstruction of tidal marshes (Collins and Sheikh 2005) indicates that tidal wetlands now amount to about 17-19 percent of their historical extent. Unfortunately, none of these assessments was able to identify specific vegetation community types, because the original data (e.g., General Land Office surveys) lacked such detail. So even though we can estimate the spatial extent of loss, we know little about plant species composition. However, some available data on tree species in the historical estuarine streamside forest, tidal-freshwater streamside forest, and freshwater streamside forest do quantify major tree species frequency and basal area (Collins and Sheikh 2005). For example, "spruce forests" have been described along the lower reaches of some estuarine streamside forests. Spruce is not considered a dominant tree species in this region. This likely indicates specialized community types and adaptation to historical conditions along lower river/estuarine areas. The documented tree species composition offers a good picture of historical conditions, and it is likely that some of the gaps in knowledge of other vegetation and community types could be filled in with further analysis.

Factors Controlling Riparian Vegetation Communities

Elevation, climate, precipitation, soils, disturbance and hydrology are among the factors that control forest zones, vegetation communities and successional patterns. Available seed source, aspect, wildlife interactions, competition, and other natural or anthropogenic influences also play a role in the evolution of community types. The details and complexity of these influences are beyond the scope of this paper, but a brief description of some of these factors is provided below to help in understanding how riparian vegetation community types evolve.

Succession

The classification of the Western Hemlock Zone, in recognition of the climax species, provides a broad, generalized picture of the dominant tree and associated vegetation community that would occur within this zone over a time scale of hundreds of years. Within this timeframe, one would find earlier seral plant communities and different dominants, depending upon local environmental conditions, disturbances and available seed source. In a mature forest, for example, when the tree canopy is removed due to age, disease, fire, logging, or other natural or anthropogenic influences, an opportunity exists for other plants, which may not be shade tolerant, to thrive. Over time, the early settlers (e.g., grasses and shrubs) give way to deciduous trees and conifers, and the understory ultimately consists only of shade-tolerant vegetation. On dry, well-drained sites, hemlock may be absent or rare, with the dominant conifer being Douglas fir. On heavily disturbed sites, such as erosional areas, the vegetation types may be dominated by early-to-mid seral communities, characterized by species such as maple, alder and salal, or nonnatives, such as Himalayan blackberry and Scotch (Scot's) broom.

Information on successional patterns for western hemlock forests comes primarily from studies of commercial forests, following traditional clearcut, slash and burn methods. Note that successional patterns under all circumstances have not been well studied, and the type of disturbance to a site or area may result in different successional patterns. General information on western Washington and Oregon forests, with some limited details, may be acquired from the WDNR Natural Heritage Program (Chappell 2005), Franklin and Dyrness (1973), Kruckeberg (1991), and Proctor et al. (1980). However, as noted earlier in this paper, some distinct plant community types do exist in the Puget Sound Area and have their own successional patterns based on various controlling factors. For example, the "prairie" communities that occur in the south sound are more typical of open grasslands with invasions of Douglas fir and oaks and are quite dissimilar from the successional patterns seen in the typical hemlock community. Similarly, early- to mid-successional communities become established along very actively eroding bluffs and those composed of well-drained soils and a southern exposure, excluding or reducing the abundance of many of the characteristic hemlock seral communities due to limitations in stress tolerances for drier, more disturbed sites.

Climate

Climatic conditions in the Puget Sound region greatly influence vegetation types, patterns of distribution and ecological processes, structure and functions. In general, climate is defined by temperature, precipitation and humidity, which are all affected by the geomorphology (local terrain) of the region, the Pacific Ocean, cloud cover and other atmospheric conditions. The cool marine waters and air that flow into Puget Sound from the Pacific Ocean act as the region's thermostat and generator of moisture-laden air. The mountain ranges and other topographic features influence precipitation and cloud cover patterns throughout the region, causing variations in weather within short distances. For example, Sequim, in the rain shadow of the Olympic range, receives an average of only 432 mm of rain per year, whereas Olympia receives more than 1,270 mm yearly (Kruckeberg 1991).

Land that lies close to marine waters experiences temperatures that are cooler in the summer and warmer in the winter than uplands. At lower elevations, precipitation comes mainly as rain; in Puget Sound, more than 75 percent of it falls between the beginning of October and the end of March (Kruckeberg 1991). Humidity follows the temperature and precipitation patterns. The variable and combined effects of temperature, moisture, and humidity result in conditions that are suitable for the types of vegetation communities found throughout the region. At the regional scale, coniferous forests are dominant, but the high degree of variability that exists in the smaller-scale patterns of coastal forests and vegetation communities results from variations in more localized climatic conditions. For example, a tree canopy may be dominated by madrone or deciduous trees on some drier sites, and the associated understory shrubs would likely be dominated by salal rather than swordfern, which require more shaded, moist conditions. Trees and other vegetation in close proximity to marine waters are also likely to be more exposed to wind, salt, and fog.

Soils

The geologic history of the Puget Sound region is particularly important for understanding soils and topography, which are important determinants of plant associations and successional patterns. The soils of the northern Puget Trough Province are generally well described by Franklin and Dyrness (1973) and have been mapped in the Coastal Zone Atlas by the Washington Department of Ecology (WDOE 1977–1980). The glacial legacies (geology, soils, and topography) of the region are described by Downing (1983), Franklin and Dyrness (1973), Burns (1990), and

Kruckeberg (1991). Aside from plate tectonic influences, in general, the geology and topography of the Puget Sound basin resulted from a lobe of the cordilleran icecap, which pushed into the area from the north during the Pleistocene epoch (the Vashon glaciation being the most recent). The deposits left by glacial advance and retreat range from very porous gravels and sands to a hard, cemented till in which substantial clay and silt are mixed with coarser particles (Franklin and Dyrness 1973) or are in stratified layers, varying in sediment composition. Over time, organic contributions from decomposing vegetation have also created a layer of humus-enriched topsoil in many areas. Soil organisms, such as mycorhizae-forming fungi, also play an important role in soil condition and nutrient acquisition by plants.

These variations in soil types have a strong influence on vegetation. For example, soils with low permeability may become quickly saturated or create standing water, which promotes growth of tree species like hemlock and red cedar that are more tolerant of wetter conditions. In contrast, free-draining soils in more exposed areas would support Douglas fir and madrone. Many shoreline areas retain water or have springs and seeps that often provide localized conditions for plants that are tolerant of, or thrive in, wet soils, while excluding plants that have a low tolerance for wetter soils or are capable of surviving in drier soils (e.g., madrone). The close proximity of vegetation to the water also creates more moist conditions due to the cooling effect of Puget Sound, fog and condensation on riparian plants and soils.

Areas with soils high in organic material support vegetation associations that thrive in nutrient-rich soils (e.g., Douglas fir–western hemlock/Oregon grape/sword fern association [Chappell 2005]). Such vegetation would be absent or less common in areas where soils are nutrient poor (e.g., Douglas fir–western red cedar/Pacific rhododendron association [Chappell 2005]). Higher organic composition in the topsoil also sets the stage for greater microbial activity, a process that is strongly linked to nutrient availability and plant health. Many of the controlling factors for the various vegetation associations may be found in Chappell (2005). The major controlling factors for the major tree species have been summarized in this paper (Table 2).

Topography

For the purposes of this report, topography refers to both elevation and relief (i.e., slope height and angle). As mentioned earlier, changes in temperature and other weather conditions at different elevations are a strong influence on forest zones. For coastal forests within the Puget Sound lowland, however, atmospheric conditions and proximity to marine waters are the primary controllers of the local climate, and minor elevation changes have little influence.

The variability in topographic relief and stability of steep slopes greatly influence vegetation community types and add to the diversity and complexity of forest/vegetation communities within the region. The complex of hills, valleys, plains, ravines, steep bluffs, and low- to no-bank shorelines exhibits various community types. Shorelines with steep slopes and unconsolidated soils that experience soil movement at relatively frequent intervals are dominated by deciduous trees and associated vegetation communities. On more stable slopes, particularly those with lower relief, there is less exposure to wind and less soil movement over greater periods of time, allowing for dominance of slower-growing and longer-lived conifers.

Table 2. Physical characteristics and tolerances for six of the more common marine riparian trees.[1]

PHYSICAL CHARACTERISTICS	Western Hemlock	Douglas Fir	Western Red Cedar	Pacific Madrone	Bigleaf Maple	Red Alder
Age (yrs)	400+	750+	1,000+	N/A	300+	100
Diameter (cm)	90-120	150-220	150-300	35	50	55-75
Height (meters)	50-60	70-80	60+	30	15	30
TOLERANCES						
Soil Moisture	High	Low	High	Low	Medium	Medium-High
Shade	Very High	Low	High	Low	Medium	Low
Rocky/Sandy Soil	Medium	Medium	Low	High	Medium	Medium-High
Physical Damage/ Disturbance	Low	Medium	High	High	Very High	Medium[2]

[1]Developed from several sources, including Franklin and Dyrness (1973), Hanley and Baumgartner (2002), Chappell (2005).

[2]Physical damage to tree low, but generally tolerant and quickly recolonizes disturbed areas.

Disturbance

Disturbance is a natural process in riparian ecosystems that usually occurs in episodic events over large time scales. Forest fires, disease, insect blight, windstorms, volcanic eruptions, seismic events, landslides and storm surge can have large-scale effects on a forest. Any major disturbance of the plant community would normally be followed by a regular succession of plant communities until a steady state is again established, in the form of the climax community (Figure 2). Anthropogenic disturbances also have a significant impact on forest ecosystems, but forests are often converted and controlled to a point that few undergo natural succession.

Fires can devastate hundreds of acres of forest that take centuries to regenerate into a climax community. Intentional clearing and burning for timber harvest and the development of agricultural and urban lands have also removed thousands of acres of forest and caused major shifts in vegetation communities. Consequently, much of these forests is prevented from regenerating, or is replanted with monocultural stands of Douglas fir for future harvest. Native people deliberately burned forest areas to maintain openings in the forested landscape. These areas were an important source of specialized plants for food and technology (e.g., building and clothing materials) and also provided good forage for game animals (Jefferson County Historical Society 1992, Kruckeberg 1991). Today, natural, episodic fire events are suppressed, disrupting natural selective and successional processes in Puget Sound forests. A reduction of fire-resistant species, increased invasions of nonnative plants, and a change in abundance and dominance patterns from historical forest conditions are all attributed to current fire suppression practices (along with other modifications of natural disturbances) (Brown and Smith 2000, Smith 2000).

Anthropogenic disturbances are the greatest threat to riparian areas today. Starting with historical logging practices and early urbanization and continuing through modern times, riparian vegetation communities have not only been altered, but vast areas have been and continue to be permanently converted to urban and agricultural lands. Intensive logging over the past 150 years has significantly reduced the volume of timber that existed prior to European settlement. For example, the 1840 estimate of timber for all of Washington was 578 billion board-feet, reduced to an estimated 60 billion board-feet of old growth and 100 billion board-feet of second growth in 1973 (Kruckeberg 1991) (note: no data exist for riparian forests). Clearcutting, slash and burn, and replanting with monocultural tree species have significantly changed the landscape and ecological functions of forests. Commercial and residential development along the shores of Puget Sound begins with vegetation removal, or thinning, and tree removal to improve views, often followed by replacement with impervious surfaces, artificial landscaping, fill, armoring, and other modifications of the soils and vegetation. These disruptions and conversions interfere with natural riparian processes, structure and functions, setting the stage for invasions of nonnative species, losses of natural habitats and native species, reductions in water and air quality, and an increase in other risks to human health and safety. The literature is replete with evaluations and warnings of the potential and known consequences of these modifications (e.g., Puget Sound Water Quality Authority 1990; WADOE 1994, 1995; Williams et al. 2001; Brennan and Culverwell 2004). Considering the linkages between healthy riparian areas and the health of fishes and wildlife that depend upon them, the recent listings of numerous habitats and species under various state and federal regulations, including the Endangered Species Act listings of salmon and orca, are strong indicators of an ecosystem out of balance owing to anthropogenic influences.

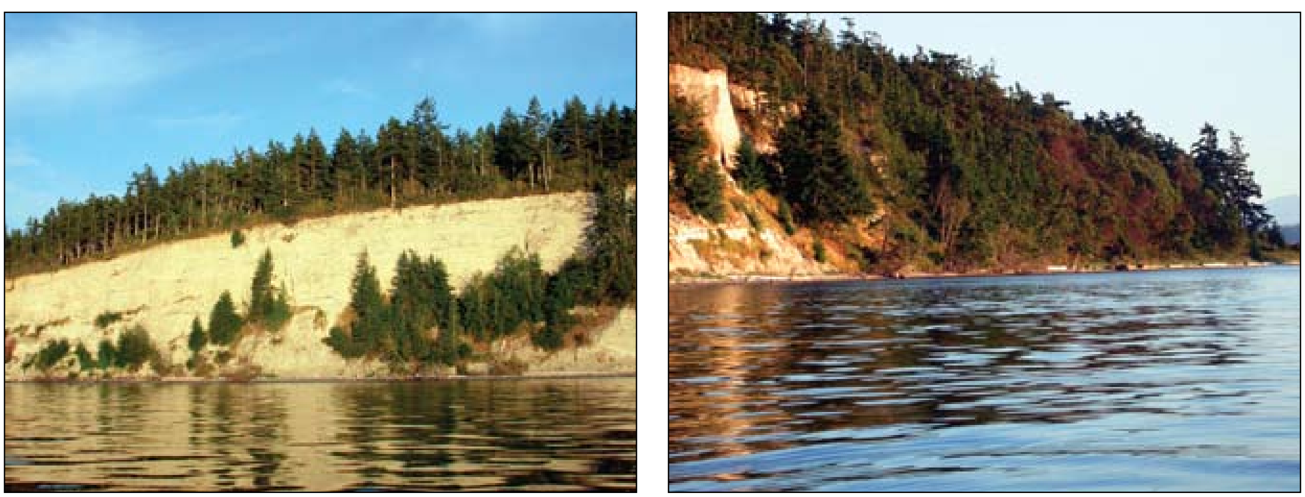

Figure 2. Photos depicting natural erosion (left) and vegetation patterns (right) on a steep bluff.

Aspect, Wind, Saltwater Inundation and Spray

A number of other factors also influence riparian vegetation communities and, similar to many of the other controlling factors, are not well studied or documented for marine riparian areas in Puget Sound. However, observation alone reveals patterns in vegetation that are likely controlled by aspect, wind, and saltwater inundation and spray. Aspect (compass direction and exposure) plays an important role in the amount of solar radiation and wind exposure riparian vegetation receives. Trees and understory plants that thrive in dry, exposed conditions (e.g., Douglas fir, madrone, oak) will compete better on shorelines with a southern exposure. However, where wind is a major influence (e.g., highly exposed points, south/southwest sides of San Juan and Whidbey Islands), trees become less of a component of the vegetation community, and growth may be stunted or distorted (e.g., broken or twisted trunks and limbs) (Figure 3). Although sun exposure provides increased opportunity for photosynthesis, wind has a desiccating effect on plants and soils. Terrestrial plants not well adapted to saltwater inundation and spray exhibit signs of salt "burn" (drying, desiccation and death of stems and leaves) if they are in close proximity to the water's edge. These effects have been well studied on outer-coastal forests and dune communities, but have not been studied in Puget Sound.

Links to Other VECs

There are a number of direct and indirect linkages between riparian vegetation and other valued ecosystem components. Most of these are in the form of "functional benefits." For example, in pollution abatement, riparian vegetation retains, filters, or processes contaminants that run off the land and can contaminate marine organisms via uptake through physical contact (i.e., water or sediments) or through the food web, where contaminants accumulate in prey and are passed along to the consumer. Riparian vegetation also provides structural benefits that influence many physical and biological processes, such as bluff erosion, sediment distribution, and providing habitat structure for fish and wildlife feeding, refuge and reproduction. Riparian areas are a major source of primary and secondary production, providing organic material for the detritus-based food web and insects that serve as prey for salmon and terrestrial wildlife. Some of the easily identifiable linkages to the other VECs have been summarized in Table 3.

Figure 3. Shoreline prairie community on San Juan Island (left) and wind-stressed trees (right).

Table 3. Linkages between marine riparian vegetation and other VECs in terms of a stronger, more direct linkage (yes), an indirect or weaker linkage (maybe), or no apparent link (no) between the linkages (listed across the top row) and the VECs (listed down the first column)..

	Slope stability	Food web	Water quality	Habitat structure	Fine sediment reduction	Sediment control (metering/deposition)
Beaches and bluffs	**Yes** (root structure, drainage control)	**Yes** (soil health, structure, biomass, biological productivity)	**Yes** (contaminant & sediment trapping, filtration)	**Yes** (standing and down wood/vegetation)	**Yes** (biological activity/ productivity)	**Yes** (rates of erosion, deposition)
Shellfish	**Maybe**	**Yes** (detrital/organic inputs)	**Yes** (contaminant trapping, filtration)	**Maybe**	**Yes** (burial, respiration)	**Yes** (sediment volume, type)
Salmon	**Maybe**	**Yes** (prey production)	**Yes** (contaminant trapping, filtration)	**Yes** (LWD, sediment, and living vegetation) (feeding, refuge, migration)	**Yes** (respiration, water clarity)	**Yes** (sediment volume, type)
Forage fishes	**Maybe**	**Yes** (prey production)	**Yes** (contaminant trapping, filtration)	**Yes** (LWD, sediment, and living vegetation) (feeding, refuge, migration)	**Yes** (respiration, water clarity)	**Yes** (sediment volume, type)
Great Blue Heron	**Maybe**	**Yes** (prey production, primary and secondary	**Yes** (contaminant trapping, filtration)	**Yes** (Trees, sediment, and living vegetation) (feeding, refuge, roosting, reproduction)	**No**	**No**
Marine birds	**Maybe**	**Yes** (prey production)	**Yes** (contaminant trapping, filtration)	**Yes** (LWD, sediment, and living vegetation) (feeding, refuge, roosting/resting, reproduction)	**Maybe**	**Maybe**
Orca		**Yes** (prey production, secondary)	**Yes** (contaminant trapping, filtration)	**No**	**Maybe**	**No**
Kelp and eelgrass	**Maybe**	**No**	**Yes** (contaminant trapping, filtration)	**Yes** (waterlogged logs - potential attachment substrate)	**Yes** (burial, photosynthesis)	**Maybe** (sediment volume, type)

Status and Trends

Available literature has shown that as little as 150 years ago the Puget Sound lowland was covered with dense coniferous forests. Kruckeberg (1991) describes the experience of early explorers to the region as having "encountered on our shores an evergreen forest of majestic and awesome dimensions." Most forests likely were climax communities of the western hemlock/western red cedar/Douglas fir associations. Accurate historical data on the vegetation along shorelines is very limited, but some information can be gleaned from early survey maps and written records (e.g., General Land Office and U.S. Coast & Geodetic Survey topographic sheets [T-Sheets]). These data could be used to develop a historical reconstruction similar to that in tidal estuaries by Collins and Sheikh (2005). Such an analysis may provide a basis for quantifying changes in riparian communities since European settlement and evaluating how changes in riparian forests have affected the health and integrity of riparian and nearshore ecosystems.

A number of recent marine nearshore assessments have evaluated the types and extent of modifications to the nearshore ecosystem. Although riparian forest composition is likely the most modified component of the Puget Sound nearshore environment, this has not been quantified. Anthropogenic disturbances, such as filling, diking, armoring, overwater structures, upland structures, roads, ports, and other activities along shorelines have resulted in the fragmentation and loss of the diversity and abundance of shoreline plant communities (Figure 4). Several assessments give indications of the amount of change. For example, estimates based upon evaluation of 11 major deltas in Puget Sound indicate at least a 76 percent loss in tidal marshes and riparian habitat (Levings and Thom 1994). Coastal urban areas have lost 90-98 percent of their estuarine wetlands, and water quality is in good condition in only 35 percent of Washington's estuaries (WDNR 1998). The WDNR's ShoreZone inventory (WDNR 1999) indicates that riparian vegetation overhanging the intertidal zone is relatively rare in Puget Sound, occurring at only 440 of the nearly 2,500 shoreline miles of Puget Sound (Redman et al. 2005). Riparian forests were the first areas to be extensively logged, because they were easily accessed, and logs could be rafted and floated to mills around the region. Since mature hemlock/Douglas fir forests take hundreds of years to develop, it is likely that where these forests occurred naturally, there are few, if any, nearshore riparian forests remaining in pristine condition, with the possible exception of areas where natural disturbance was frequent and persistent enough to maintain early seral communities. Therefore, it is logical to assume that altering the vegetation structure and disrupting natural processes has resulted in a shift in or loss of riparian vegetation, community types, and ecological functions.

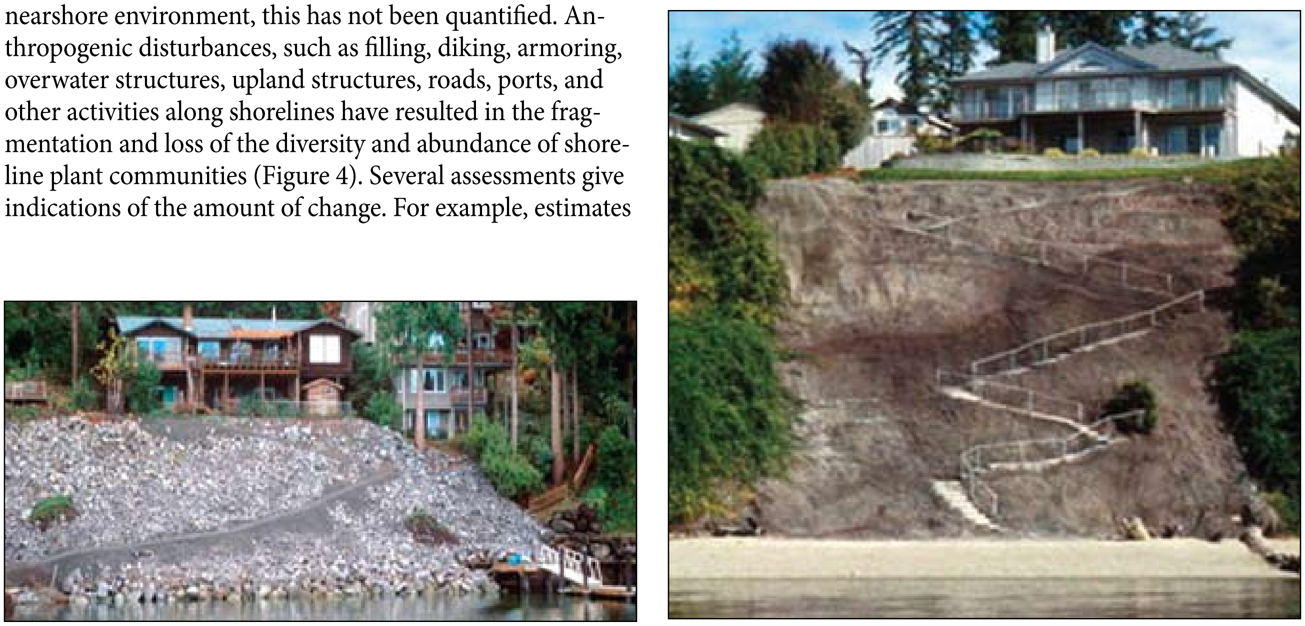

Figure 4. Examples of anthropogenic disturbances that result in changes (left) or elimination (right) of natural vegetation on shorelines.

Ecosystem Processes

The primary purposes of focusing on an individual component of the nearshore ecosystem include providing an improved understanding of how the system and each component works and what can be done to improve conditions or prevent further degradation. Conceptual models are often used to better explain the linkages between various management actions and potential outcomes for ecological improvement. The PSNERP has developed a conceptual model for the nearshore ecosystem to determine the suite of actions that, combined, will preserve or restore the full ecosystem. But the finer detail of each component of the ecosystem is needed to identify problems and develop management actions at that scale. The conceptual model developed for marine riparian vegetation (Figure 5) is designed to meet this need. It identifies some of the important linkages between management actions and expected outcomes. It can be plugged into the larger-scale model, which illustrates the linkages in a simplified diagram, to enhance understanding and management of the nearshore ecosystem. This model does not identify all management measures, restored processes, structural changes or functional responses, but simply attempts to identify some of the more important actions and expected outcomes. Using this model will assist scientists, resource managers and policy makers in deciding which actions would be the most effective, beneficial and important for preserving, protecting, enhancing or restoring the nearshore ecosystem. For example, by protecting existing riparian vegetation, or establishing undisturbed vegetation buffers that require separation between upland development and the water, we would expect that many of the natural processes (e.g., hydrology, sediment transport/deposition, plant growth and succession) would not be impaired. Further, these processes would then allow for the development of the natural structure (forests, wetlands/salt marsh/strand communities, beaches), and functions (pollution abatement, feeding, breeding, migration, refuge) of the nearshore ecosystem.

Conditions Required to Maintain, Enhance, or Restore Healthy Marine Riparian Vegetation

Given that coastal forests in the Puget Sound nearshore environment have been significantly modified throughout the brief 150-year post-European settlement of the region, there are three management actions that should be implemented, in concert, to improve forest conditions and realize the benefits of associated ecological functions.

First, existing shoreline forests must be protected to allow them to mature into the types of stable climax communities found historically. This is the most important and cost-effective management action, but it will require an inventory and assessment of current forest conditions, prioritization of areas to be protected, and restrictions on development activities that would modify or degrade shoreline vegetation communities. Buffers are one of the most effective management tools available for protecting shoreline vegetation. Although marine shoreline buffers are not well studied in the Puget Sound region, the results of studies in other marine and freshwater systems are transferable and can be used until studies on buffer effectiveness for multiple functions are established for Puget Sound shorelines.

Second, for areas that are already modified as a result of urbanization, enhancement and rehabilitation are the most logical approaches for reestablishing some ecological functions. Removing nonnative plants and physical obstructions (e.g., armoring, impervious surfaces, nonessential structures) and replanting with native species would improve existing conditions if done at large-enough temporal and spatial scales. Results likely will not be realized quickly because plant growth, functional responses, and the natural succession of native plant communities occur over decades and centuries. However, this understanding of their biology should be part of the management strategy and a focus of public education and outreach. Removal or relocation of some roads, railroads, bulkheads, overwater structures, dikes and other obstructions wherever possible would also help in reestablishing the linkages between riparian areas and the aquatic environment.

The third action—restoration of coastal forests and riparian areas—is likely to be the most difficult, costly, and time-consuming management action, but could provide some of the greatest benefits, depending on the scale of restoration and commitment to long-term goals. Much could be learned in the restoration process if efforts were monitored and the results made available to coastal managers. Many restoration efforts likely would occur piecemeal, at the site scale, and should therefore be a part of a larger restoration strategy. Similarly, efforts to protect, enhance or restore any nearshore habitats should take a more holistic approach and consider riparian conditions and influences as a part of their project evaluation and implementation.

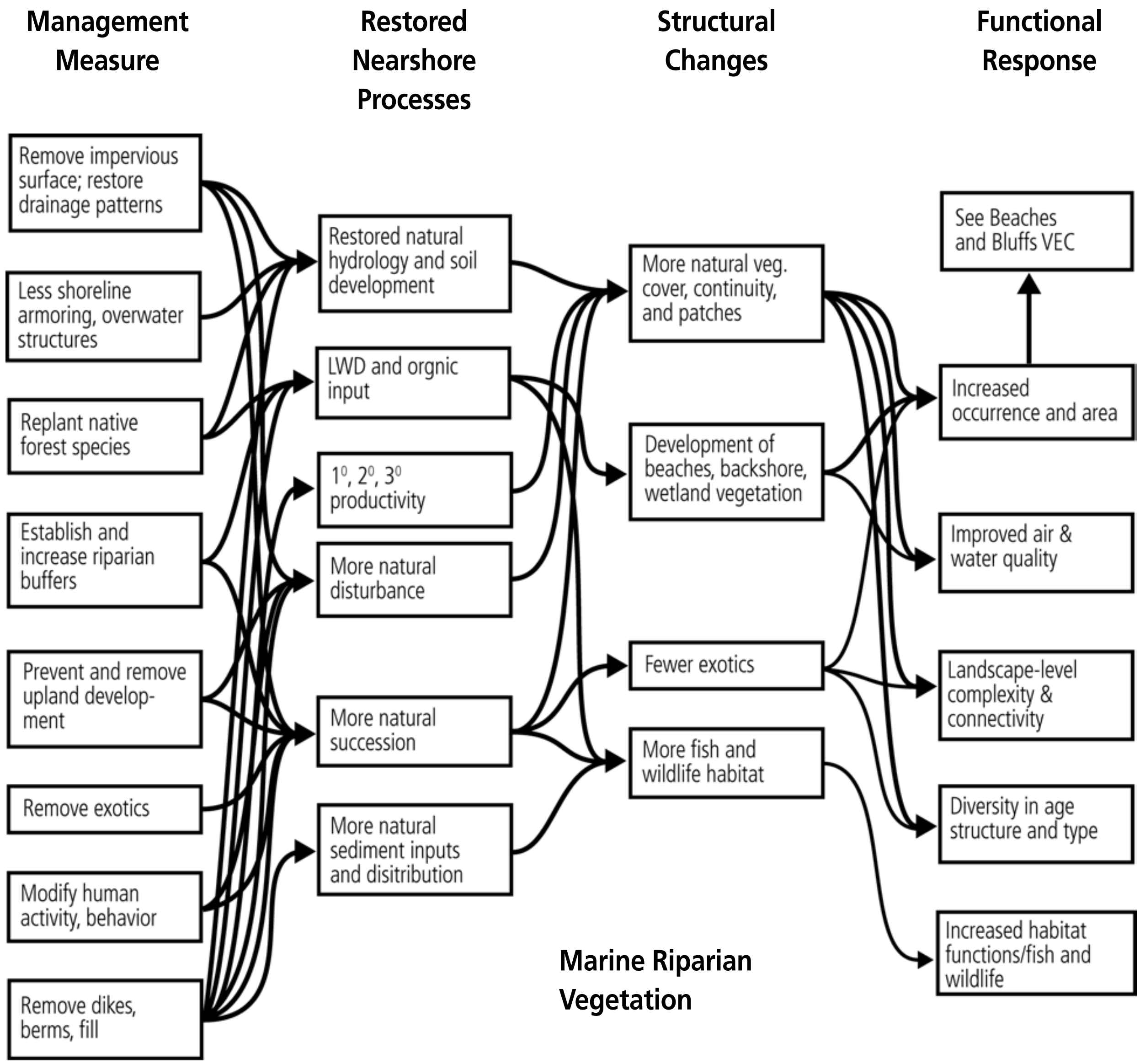

Figure 5. Conceptual model of the marine riparian vegetation VEC, illustrating the linkages between management measures, restored processes, structural changes, and functional responses.

Major Gaps/Critical Uncertainties

- Studies/data on marine riparian functions for the Puget Sound region are very limited.
- Inventories (types, locations, size) of shoreline vegetation and community types or associations are lacking, and there is no monitoring or assessment of modification and loss.
- Protection, enhancement, and restoration standards for marine riparian vegetation are limited.
- Fish and wildlife inventories and dependencies on marine riparian areas are not well documented.
- Appropriate buffer widths and setbacks for protecting marine riparian and marine aquatic systems are poorly understood and inconsistently applied (if applied at all).
- An improved understanding of the exchanges (e.g., energy, matter) across and within these riparian transition areas is needed.
- Food web data are limited.
- Study of the potential effects of climate change and sea-level rise on marine riparian systems is lacking.

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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.*"

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, which ultimately supports the goals of PSNERP but is beyond the scope of the GI Study. We understand that the mission of PSNERP remains at the core of the Nearshore 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, the Nearshore Partnership enjoys support and participation from the following entities:

- King Conservation District
- King County
- Lead Entities
- National Wildlife Federation
- NOAA Fisheries
- 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 – Pacific Northwest National Laboratory
- 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

Information about the Nearshore Partnership, including the PSNERP work plan, technical reports, the Estuary and Salmon Restoration Program, and other activities, can be found on our Web site at: *www.pugetsoundnearshore.org*.

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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*