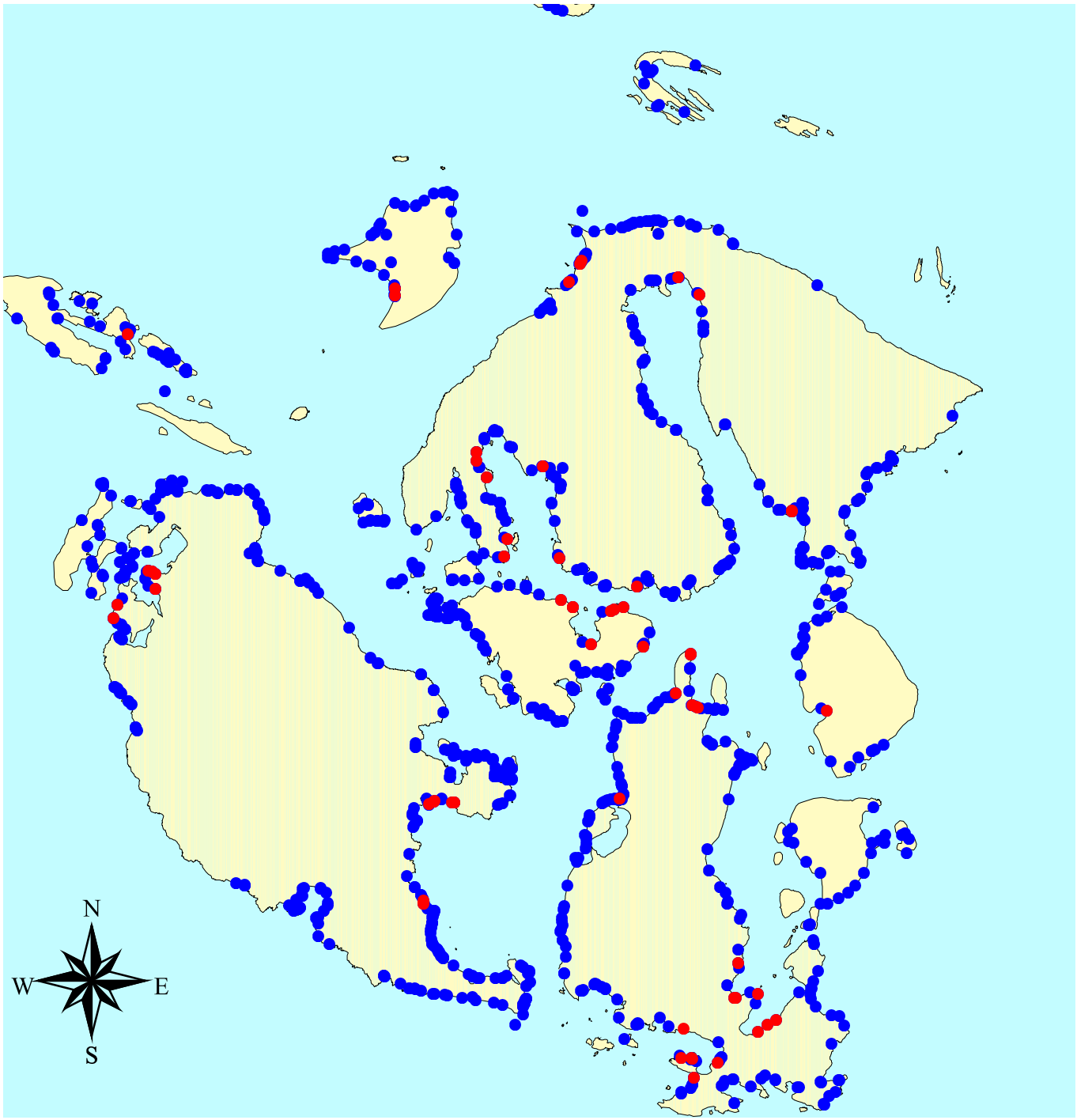
San Juan County Forage Fish Project

Marine Riparian Restoration Priorities for Forage Fish Habitat



High Priority

- Documented Spawn Sites with less than 50% Shading

Moderate Priority

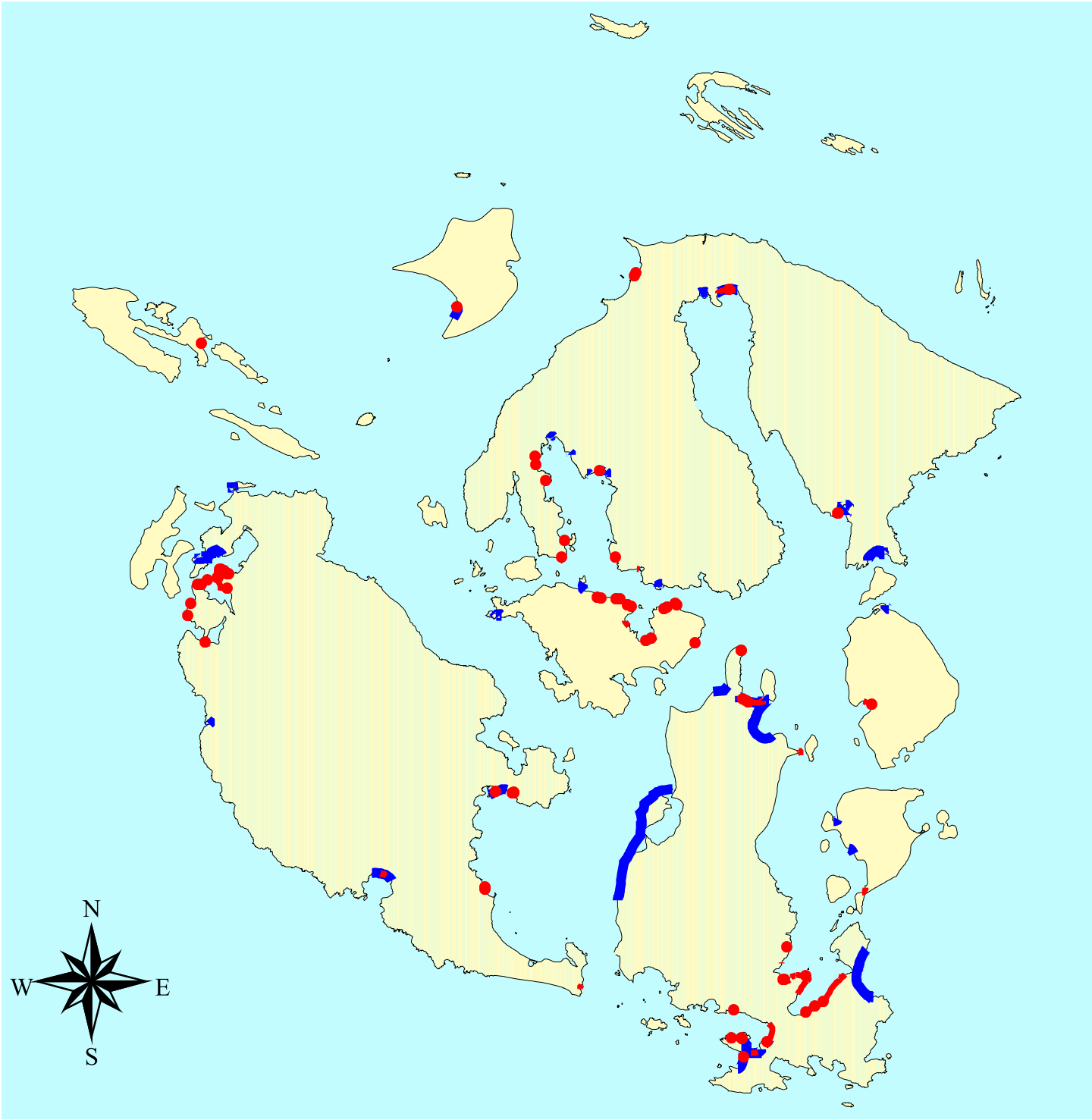
- Potential Spawn Habitat with less than 50% Shading

Figure 10

Note: Data from San Juan County Forage Fish Spawning Habitat Project Final Report

San Juan County Forage Fish Project

Potential and Documented Forage Fish Spawning Habitat in Close Proximity to Roads in San Juan County.



Documented Spawn Sites
Road Along Backshore

Figure 11

Note: Data from San Juan County Forage Fish Spawning Habitat Project Final Report

San Juan County Forage Fish Project

Stormwater Outflow Pipes in Potential or Documented Forage Fish Spawning Habitat

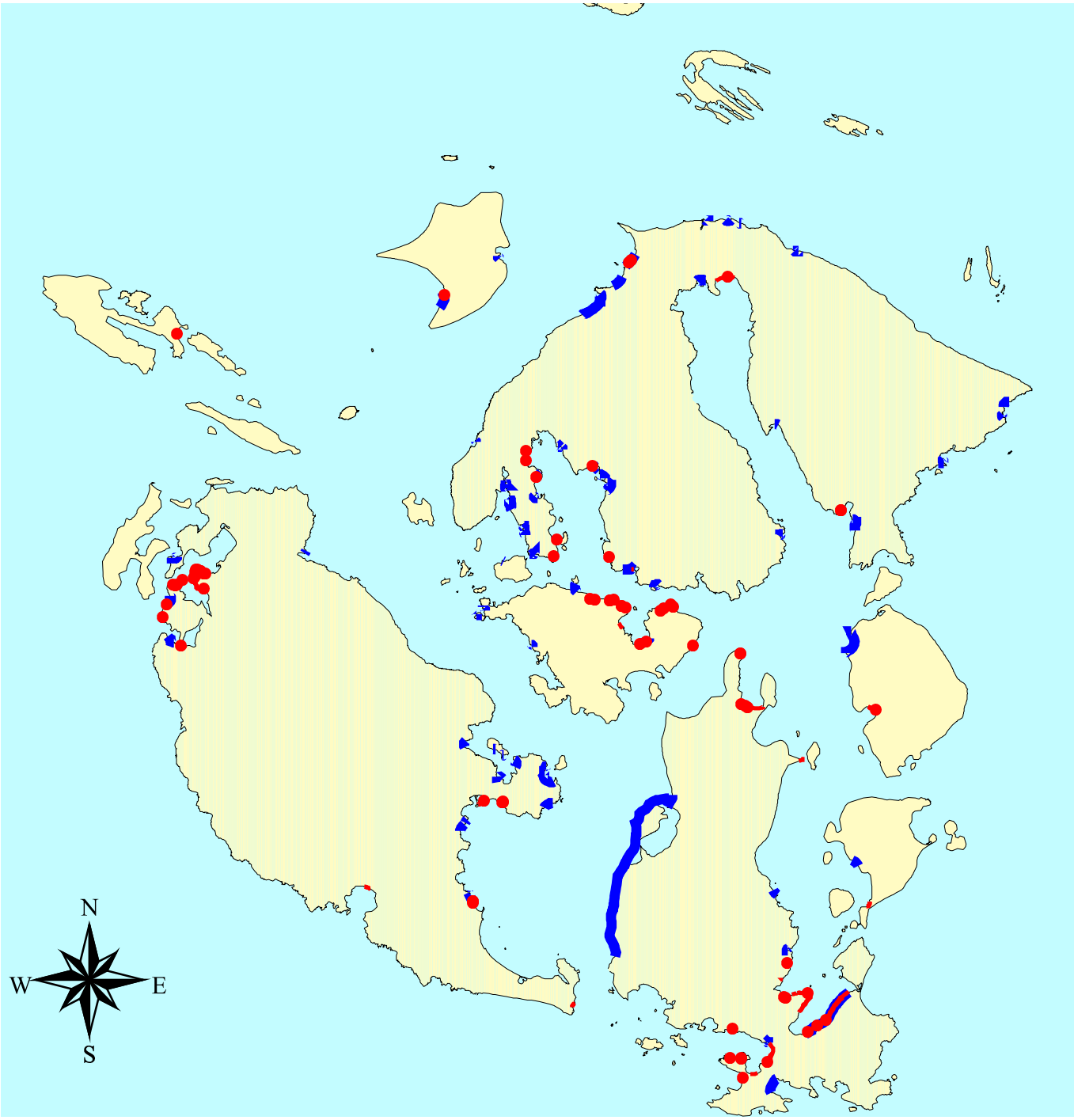
Outflow Pipes
Documented Spawn Habitat

Figure 12

Note: Data from San Juan County Forage Fish Spawning Habitat Project Final Report

San Juan County Forage Fish Project

Seawalls or Bulkheads on Potential or Documented Forage Fish Spawning Habitat



Documented Spawn Sites
Beaches with Seawalls or Bulkheads

Figure 13

Note: Data from San Juan County Forage Fish Spawning Habitat Project Final Report

Scoping Memorandum concerning the Pacific Gateway Terminal

The Marine Environment of the San Juans

Excerpt from: *Personal Watercraft Use in the San Juan Islands*

Prepared By: Aquatic Resources Conservation Group
For: The Board of County Commissioners
San Juan County, Washington

September 7, 1998

PERSONAL WATERCRAFT USE
IN THE
SAN JUAN ISLANDS

A Report Prepared for
The Board of County Commissioners
San Juan County, Washington

by the
San Juan County
Planning Department

Aquatic Resources Conservation Group
Seattle, Washington

Provisional Final Draft
September 7, 1998

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This document is a provisional final draft in fulfillment of a contract with the San Juan County Planning Department, signed on June 16, 1998. Peer review is still underway; when concluded, a final copy will be issued.

Aquatic Resources Conservation Group is a nonprofit, 501(c)(3) consulting organization specializing in marine and watershed resource issues.

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*The University of Washington was not involved in any manner whatsoever in this endeavor.

III. San Juan County's Marine and Coastal Environments

A. Setting

San Juan County is located in the northwest corner of Washington. The San Juan Islands and associated land masses comprise the southern end of the San Juan Archipelago, which extends across the United States' border into British Columbia, Canada. The county consists of 743 islands (428 at high tide),[1] 172 of which are named.[2] Approximately 375 miles of shoreline encompass the 150 largest islands at high tide,[3] and about 440 square miles of marine waters bathe the county's shores.

Sixty islands are inhabited by people, and four are served by ferries.[4] San Juan County's population in 1990 was 10,035, amounting to a density of fewer than 100 people per square mile.[5] The projected population for 2000 is 13,029.

San Juan County is fortunate to have prime lands set aside for public enjoyment. Public lands with shoreline access in San Juan County include twelve county parks located on Orcas, Shaw, Lopez, and San Juan Islands; fourteen state parks, including lands on Lopez and Orcas Islands; and two National Parks on San Juan Island. As evident from the map of San Juan County, a number of public roads access the shoreline, and several public boat ramps are located throughout the islands. (Appendix III., Figure 1. a. - c.)

A network of wildlife refuges and marine preserves and reserves established to protect and preserve the islands' plants, animals, and critical habitats augment the largely undeveloped public lands just described. In 1923, five marine preserves were established in which fishing (except for salmon and herring; and crabs in Parks Bay) and collection of marine plants and animals are prohibited. The preserves are located off of San Juan and Shaw Islands. (Appendix III., Figure 2.) San Juan County also has eight additional marine reserves with voluntary no-take zones closed to bottom fishing.[6] (Appendix III., Figure 2.) In addition, the San Juan Islands National Wildlife Refuge and Wilderness Area comprises 84 islands and rocks. (Figure 3)

The climate in the San Juan Islands is enjoyable year-round. Temperatures are moderate; the average summer high is 65 degrees Fahrenheit and the average winter low is 40 degrees Fahrenheit.[7] The islands receive moist air from the Pacific Ocean, yet their location in the rain shadow of the Olympic Mountains and Vancouver Island limit the average annual precipitation to 25 inches. The dry season begins in May and peaks in midsummer; the wet season begins in October and peaks in winter.

From a geological perspective, the San Juan Islands are part of the Puget Sound Basin, which comprises the northern end of the Puget Trough physiographic province.[8] The region's geological history is composed of three fundamental processes.[9] First, structural development occurred during the Cordilleran mountain-building process, which began about 200 million years ago. During this time, convergent interactions between two crustal plates resulted in the rise of the Olympic and Cascade mountain ranges of Washington and the Insular Mountains of Vancouver Island, in addition to other ranges in western North America. Next, during the Pleistocene Epoch, when the Puget Sound Basin was covered by an icecap to a depth of more than 700 meters, glacial activity shaped the region's topography and bathymetry. Erosive forces caused by the moving ice shaped and rounded the land, creating glacial plains and basins. Glaciers also deepened Haro Strait, East Sound, and Rosario Strait. The debris from this glacial sculpturing are evident today as glacial deposits such as sills and shoreline features located throughout the area. The most recent ice sheet retreated 12,000 to 13,000 years ago. Post-glacial changes in sea level, and riverine and marine shoreline erosion, shaped the region's beaches and shorelines. The San Juans' numerous narrow channels, protected estuarine bays, and multitude of islands are predominant features that resulted from millions of years of geological construction and destruction.

Furthermore, through their influence on the physical oceanography of the islands, these three features affect the diversity and distribution of marine plants and animals.

The region's geological features affect its oceanographic characteristics. The San Juan Islands are situated in the inland waterway estuarine regime, a region including the Strait of Georgia, Puget Sound, and Strait of Juan de Fuca, and extending from southern Vancouver Island to the mainland coasts of British Columbia and Washington.[10] This region is one of the largest expanses of protected, relatively shallow estuarine waters along the West Coast of North America.[11] The oceanography of the marine waters in the region is strongly influenced by water circulation and freshwater input. Four large channels encompass the islands: Rosario Strait and Haro Strait to the east and west, respectively, connect the Strait of Juan de Fuca south of the islands with the Strait of Georgia to the north. A network of narrow channels also provides routes for water flow around and between the islands. The narrow channels and shallow sills impede water circulation to remote bays, however, resulting in heterogeneous pockets of water that vary in salinity, temperature, organic nutrients, and other factors.[12]

Four fundamental forcing mechanisms affect water flow in the inland waterway. Estuarine (buoyancy-driven) flow is the dominant factor in this system.[13] Winter rainfall and summer snowmelt provide an influx of freshwater into the system, resulting in a net seaward outflow of brackish water on the surface and a net landward inflow of higher salinity marine water underneath. The Fraser River in British Columbia, Canada, contributes 80% of the mean annual discharge of freshwater into the Strait of Georgia, and this creates a net southerly transport of surface water through Haro Strait, Rosario Strait, and the San Juan Archipelago. Tides also act periodically on the system to change the direction and speed of water flow, with the intensity of tidal currents varying by location and time of day. The inland waters experience semidiurnal tides: there are two high tides and two low tides per day. Strong tidal currents passing through the narrow channels between the islands produce turbulent mixing, bringing nutrients and prey to the water's surface, thereby contributing to the area's high productivity.[14] Wind forcing is the third mechanism affecting water flow. In the San Juans, wave action is usually negligible except on the shores facing the Strait of Juan de Fuca that are exposed to intense waves during storms.[15] Coastal ocean forcing, including upwelling and reversals in estuarine circulation, is the fourth mechanism impacting the flow regime.

B. Marine Habitats

Long et al.[16] classify the marine environment into three areas, namely: intertidal/subtidal, nearshore, and offshore. The main differences between these areas are proximity to shore and water depth. Further partitioning of each area into habitat types is possible, with each habitat type having a characteristic flora and fauna. Definitions of each habitat type and examples of their associated biota are discussed below. Details on select species are addressed in Section III., Part C.

1. Intertidal/Subtidal

The intertidal and subtidal zones define the shoreline. The intertidal zone is the region of shoreline that is alternately covered and uncovered by the changing tides, whereas the subtidal zone is always covered by water. Habitats within the intertidal and subtidal zones can be further divided into three categories each, based on sediment type and exposure to wave action and tidal currents. Those categories are 1) exposed unconsolidated sediments, 2) protected unconsolidated sediments, and 3) rock. (Appendix III., Figure 4.)

The first intertidal/subtidal shoreline habitat type comprises **exposed unconsolidated sediments**, including gravel and coarse sand like the intertidal areas of Deadman Bay and Eagle Cove on the west side of San Juan Island. This habitat type is characterized by high wave or current action, mobile and

dynamic sediments, steeply sloping beaches, and absence of vegetation and relatively sessile animals such as clams and tube-dwelling worms. A few of the invertebrates commonly found in sandy habitats include moon snails, polychaete worms, mysids, and amphipods.[17] Phytoplankton and detritus provide the base of the food web; they are consumed by zooplankton, which attract fishes. Gravel and sand habitats, however, appear to support fewer fish species than habitats of any other type.[18] Among the species of fishes present here are Pacific staghorn sculpin, juvenile English sole, and juvenile Pacific tomcod. Migratory and nonmigratory birds are also found here, although the use of exposed unconsolidated sediments by shoreline foraging birds is relatively low in the San Juans due to the paucity of prey items. Bird species characteristic of these habitats include Bald Eagles, White-winged Scoters, Common Goldeneyes, Harlequin Ducks, Great Blue Herons, and various species of gulls. Harbor seals also frequent gravel and sandy beaches.

These habitats are susceptible to anthropogenic threats. Bacterial contamination and log storage threaten gravel habitats, while sandflats are declining in Puget Sound due to shoreline armoring and alterations to the environment such as filling and dredging.[19]

Protected unconsolidated sediments constitute the second shoreline habitat type. The dominant habitats include mud/gravel, mud/sand, and mud. This habitat type is typical of bays and harbors such as Garrison and Westcott Bays on San Juan Island, and Mud Bay on Lopez Island. It is characterized by the following features: protection from strong waves and currents; accumulation of fine sediments such as mud and silt; sediment stability; broad beaches with minimal slope; and backshore areas that occasionally have marshes. Relatively immobile infauna (animals living in bottom sediments) are also present, and some representatives are tube-dwelling polychaete worms; cockles; bent-nosed, hard-shell, and soft-shell clams; ghost and mud shrimp; and sea pens (limited to the subtidal).[20] Mud and mud mixtures are important habitats for birds and harbor seals. The seasonal species richness of birds is greater here than in any other intertidal or subtidal habitat type.[21] Common bird species include the Great Blue Heron, Black Brant, and Common Pintail; Bald Eagles and Harlequin Ducks are also present on occasion.

Eelgrass communities – of which *Zostera marina* is the native species – also thrive in these areas. This seagrass sends roots and rhizomes (horizontal stems) down into the soft sediments and projects erect, leafy shoots into the water column. Simenstad states that, "Seagrass communities likely rank with marine kelp (macroalgae) systems as the marine analog to tropical rain forests in structural complexity, biodiversity, and productivity."[22] Numerous species of algae, vertebrates, and invertebrates utilize eelgrass habitats for at least part of their lives. Examples of the diversity of invertebrates include hydroids, snails, nudibranchs, sea anemones, jellyfish, brittle stars, and crabs.[23] Eelgrass communities provide a wide assortment of services, primarily: habitat structure and stability; shelter from waves; refuge from predators; shade from the sun; nurseries for juvenile fishes such as salmon; spawning grounds for fishes (e.g., Pacific herring); vital links in the carbon, phosphorus, nitrogen, and sulfur cycles; oxygen via photosynthesis; and, finally, high production and growth rates that provide a foundation for marine food webs.[24] Bacteria feed on detritus from eelgrass beds, and then the bacteria are consumed by detrivores, the next link in the food chain. The distribution of eelgrass depends upon substrate composition, turbidity, light penetration, and physical disturbance from waves and currents.

Eelgrass beds and the protected unconsolidated sediments in which they grow are also vulnerable to human disturbance. These habitats may be physically disrupted by development, shoreline armoring, dredging, and filling; and scars from boat propellers and anchors are an additional concern for eelgrass beds. Physical, chemical and biological threats to eelgrass include decreasing water quality (including increases in turbidity, as well as oil and other toxic pollutants) and introduced species (e.g. *Zostera japonica* and *Spartina spp.*). Mudflats are declining in Puget Sound and, although estimates of previous abundance for eelgrass in Puget Sound are lacking, this seagrass may be also be declining.[25]

Rock is the third intertidal/subtidal habitat type. Three types of rocky habitats are protected solid rock, exposed solid rock, and cobble.[26] Lime Kiln State Park on San Juan Island and Iceberg point on Lopez Island are characteristic rocky shores. Features such as shoreline slope and physical disturbance that were used to define the previous intertidal and subtidal habitat types are highly variable for rocky shores. Tidepools and the epiflora and epifauna attached to rocky substrates are diagnostic features of this habitat type. Representative invertebrates that contribute to the diversity of rocky shorelines are sea anemones; a variety of worms, including nemerteans, flatworms, and polychaetes; numerous molluscs such as oysters, mussels, chitons, snails, limpets, and nudibranchs; many crustaceans, for example barnacles, crabs, hermit crabs, and shrimps; sea urchins, sea stars, and sea cucumbers, all of which are echinoderms; and tunicates (sea squirts) - some of our closest living invertebrate relatives![27] Macroalgae are significant contributors to the character of many rocky habitats. Like the eelgrass *Zostera marina*, macroalgal species such as *Laminaria*, *Egregia*, *Alaria*, *Fucus*, and especially *Nereocystis* (the bull kelp) serve multiple functions in rocky communities. Indeed, the functions provided by macroalgae are analogous to those listed previously for eelgrass. The geophysical differences between eelgrass and macroalgae habitats are reflected in each habitat's species assemblage. For instance, the mud and mud mixture habitats where eelgrass is found support high densities of birds, whereas the rocky habitats of macroalgae support relatively low densities of birds.[28] Harlequin Ducks, Bald Eagles, Greater Scaups, and Surf Scoters are a few of the bird species that frequent rocky habitats. In addition, harbor seals are the only species of marine mammal to frequent muddy habitats, whereas rocky habitats are commonly utilized by three species, namely Steller sea lions, California sea lions, and harbor seals. A few of the fish species characteristic of subtidal rocky habitat in the San Juans are copper and black rockfish, lingcod, and kelp greenling.

Rocky habitats may also be affected by human activities, including shoreline pollution, overharvest, introduced species, and trampling. The extent of kelp beds in Puget Sound has actually increased, probably due to accelerated erosion of soft sediments and associated increases in rocky habitats resulting from construction and development along the shoreline.[29]

2. Nearshore

The nearshore area, as designated by Long et al, consists of habitats in the water column from the high tide line to a depth of 20 meters offshore. They chose the 20 meter isobath as the boundary between nearshore and offshore areas because of the "relatively abrupt change in species composition, richness, and numbers" that occurs at that depth contour, "as exemplified by the birds."[30] The distribution of some nearshore bird species is related to the underlying substrate and it is therefore possible to define nearshore habitat types by substrate, analogous to the system presented above for the intertidal/subtidal area. For example, Marbled Murrelets and Pigeon Guillemots are found in nearshore waters over protected rock, and grebes are abundant nearshore over mud-gravel. When species distributions do not appear substrate-dependent, a single habitat may be considered, as is the case for many marine mammals and fishes. Harbor seals, harbor porpoises, and orcas are the most common nearshore marine mammals, although other species also venture close to shore. The diversity of fishes in the nearshore area is low, yet these are critical nursery habitats for some ecologically and economically important fishes - Pacific herring and salmon, for example.

3. Offshore

Waters deeper than 20 meters are designated offshore habitats.[31] Water dynamics, namely current velocity and tidal turbulence, are the principal factors dividing the different habitat types, which include bays, narrow passages, open waters, and broad passages. Open waters will not be addressed because they are not characteristic of the environment in the San Juans. As in the nearshore waters, the major

threats to offshore habitats are overharvest and biological and chemical pollution. Each habitat type is discussed separately below.

Narrow passages are exemplified by Speiden Channel and San Juan Channel. They have strong tidal currents and turbulence associated with tidal fronts, which tend to concentrate prey species. The prey species, in turn, attract predators. Narrow passages are important foraging habitats of both Steller and California sea lions. Seabirds forage on zooplankton and fish in these offshore waters; the Pacific Loon, Brandt's Cormorant, and Common Murre are piscivorous, whereas Bonaparte's Gull feeds on zooplankton, including pelagic fish eggs and larvae.

Haro Strait, Rosario Strait, the Strait of Juan de Fuca, and the Strait of Georgia are typical **broad passages**. They are characterized by very deep, open waters with noticeable tidal fronts that often have lower current velocity and less turbulence than narrow passages. Juvenile and adult Pacific herring and various species of adult salmon are representative of ecologically and economically important fishes that live in these offshore waters. Congregations of herring are important prey for seabirds such as Common Murres, Marbled Murrelets, cormorants, and gulls. Harbor porpoises, California sea lions, harbor seals, minke whales, and other marine mammals also feed on these schools of herring. Additionally, adult salmon are favorite prey of the resident orca pods.

The **deep-water bay** is the last offshore habitat type to be discussed. East Sound and West Sound on Orcas Island are representatives of this type of habitat. Of all the offshore habitats, deep-water bays usually support the lowest numbers of species.[32] Common Loons, Pacific Loons, Common Murres, and Marbled Murrelets use this habitat type during certain seasons, and harbor seals are the most common marine mammals found here.

C. Species Accounts

1. Marine Mammals

San Juan County provides primary habitat for several species of pinnipeds (seals and sea lions[33]) and cetaceans (whales, dolphins, and porpoises), and for river otters. Twelve diverse species of seasonally resident marine mammals frequent the islands: the river otter, harbor seal, northern elephant seal, Steller sea lion, California sea lion, harbor porpoise, Dall's porpoise, Pacific white-sided dolphin, orca, minke whale, humpback whale, and gray whale.[34] (Appendix III., Table 1.) All of these species depend upon the highly productive and relatively undisturbed marine environment of the San Juan Islands. For humpback and gray whales, the San Juan Islands are a rest area on their migrations between southern breeding and northern feeding grounds. For others, such as the California sea lion, Steller sea lion, and northern elephant seal, the San Juans mark the final destination of long annual journeys to haul out sites and productive feeding areas. Minke whales migrate to these waters to feed, and Pacific white-sided dolphins reside here during the summer and fall, corresponding to their breeding and calving seasons. The remaining species, the harbor porpoise, Dall's porpoise, harbor seal, river otter, and orca, are year-round residents, and therefore the marine habitats around the San Juans function as breeding, nursery, and feeding areas for them.

All marine mammal species are protected under the Marine Mammal Protection Act of 1972.[35] The Steller sea lion, harbor porpoise, and humpback whale are also protected by the Endangered Species Act of 1973.[36] Detailed descriptions for the orca (Appendix III., Figure 5.), harbor porpoise (III., 6.), minke whale (III., 7.), harbor seal (III., 8.), and California (III., 8.) and Steller sea lions follow.

a. Orca (*Orcinus orca*)

The orca is emblematic of the ecological and economical importance of marine mammals in the San Juans. It is the largest member of the dolphin family.[37] Orcas in British Columbia and Washington comprise two sympatric populations, termed "resident" and "transient."[38] These differ in a number of respects, primarily diet. Residents specialize on salmon (although occasionally eating bottomfish), whereas transients specialize on marine mammals – primarily harbor seals, but including Dall's and harbor porpoises, California and Steller sea lions, and elephant seals – and seabirds. Resident and transient populations are each composed of communities; communities are divided into pods; and certain subgroups within each pod are regularly seen together and are believed to be matriarchal family units.[39] The life history of orcas is characterized by a low reproductive rate, the gestation period being about 16 months with, on average, an eight-year calving interval. Female orcas become sexually mature at 13-17 years of age, while males reach sexual maturity at 15-19 years; the overall lifespan is at least 40-50 years.

The local transient population is composed of a single community and, although the exact population size is unknown, it is thought to number at least 160 animals.[40]

The resident population has two communities, northern and southern, and is one of the most studied cetacean populations in the world. Individual identification by photographic techniques provides researchers with the opportunity to investigate distribution, feeding, and life history characters of these cetaceans. Habitat ranges of the northern, southern, and transient orca communities overlap, although social and reproductive isolation has probably existed for many generations.[41] The center of the northern resident community's range is outside of the study area and therefore will not be discussed. The southern resident community, which consists of three pods, J, K, and L, has experienced annual population increases of 1.3-2.0% since 1977, when live-capture of orcas for the aquarium trade stopped.[42] Currently the southern resident community totals 89 individuals[43] and is larger than it was prior to 1962 when the live-capture practices began.[44] Orcas do not have a well-defined breeding season, but in Puget Sound most mating behavior occurs when the three resident pods meet and cooperatively feed on migrating salmon in the summer and fall.[45]

Orcas are present in the waters surrounding the San Juan Islands year-round. Transients range north to southern Alaska and south to Oregon, possibly California. They use all marine habitats at low densities, yet they are particularly common at major harbor seal haul outs. The southern residents occupy a smaller range, residing within a 200-mile radius of the islands; their distribution coincides with that of migrating salmon. Pods K and L regularly cruise the outer coast (the Pacific Ocean waters adjacent to the west coasts of British Columbia and Washington), while J-Pod frequents the inland waters and is therefore the focus of the following discussion. From late May through October, J-Pod is joined by K- and L-Pods in an area bordered by the eastern Strait of Juan de Fuca and the Fraser River, where migrating salmon congregate. The west side of San Juan Island is critical orca habitat; it has some of the greatest densities of orca sightings of all the marine waters in the San Juans. (Appendix III., Figure 5.) Rosario Strait, along the eastern sides of Lopez and Orcas is also frequented by resident orcas. Orcas use other offshore waters such as President Channel, San Juan Channel, and Boundary Pass, although less frequently.

Orca populations presently appear healthy. Their life history characters, however, are such that negative effects to the population may not be detected until considerable damage has been done. Therefore, continued monitoring of orca populations is crucial, especially as human activities in the area rise with the growing human population. In addition, measures should be taken to reduce the risk of threats such as human disturbance, pollution, and overharvest of salmon populations on the local orcas.

b. Harbor Porpoise (*Phocoena phocoena*)

Harbor porpoise distribution along the eastern North Pacific coast extends from Point Barrow, Alaska southward to Point Conception, California.[46] These porpoises are generally observed in groups of less than ten individuals,[47] and one to three individuals is the most common group size range in the inland waters.[48] Aerial surveys conducted over the inland waters in 1996 found that "harbor porpoise occurred throughout the study area with few breaks in their geographic distribution."[49] (Appendix III., Figure 6.) Furthermore, waters northwest of Orcas Island had the highest sighting rates (21 groups/100 km).[50] Increased sightings were also apparent with increased depths in the island regions (which includes the San Juan Islands and the Canadian Gulf Islands), although no clear trend was evident for all regions of the inland waters combined. No documentation of a strong seasonal migration exists for harbor porpoises in the North Pacific Ocean, although certain areas experience seasonal peaks in abundance. For instance, the largest annual concentrations of porpoises in Greater Puget Sound occur during the summer and early fall in the San Juans.[51]

Reliable trend data is lacking for harbor porpoise populations along the outer coast of Washington, Oregon, and British Colombia, and in Washington's inland waters. In Puget Sound, however, a substantial decrease is known to have occurred.[52]

> One of the most abundant cetaceans in Puget Sound four decades ago, the harbor porpoise was reportedly common enough to be seen on any day of the year throughout the inland waters of Washington State. Today, however, it appears only occasionally in Puget Sound proper, occurring primarily in the northern reaches around the San Juan Islands and the Strait of Juan de Fuca.[53]

Aerial surveys conducted in 1996 resulted in a population estimate of 1,616 harbor porpoises in the San Juans, and a total of 6,404 in the inland waters of Washington and British Columbia.[54]

With a lifespan of not more than 15-20 years, harbor porpoises are relatively short-lived cetaceans.[55] They reach sexual maturity at about age 4 and their gestation period is 11 months. These porpoises mate and calve in the transboundary waters of Washington and Canada.[56] Calving occurs during late spring or early summer, and the peak numbers in the summer and early fall may correspond to mating activity.[57] The primary prey for these cetaceans include squid and small fish such as herring and smelt. Small numbers of harbor porpoises are eaten by transient orcas.

The harbor porpoise is considered vulnerable to human disturbance.[58] Osborne et al. describe it as "a shy, retiring animal that may not be able to tolerate the increasing presence of humans on the inland waters."[59] Definite reasons for the decline are unknown, but possibilities include incidental mortality in gillnets, vessel traffic, human-generated noise, environmental contamination, unusual mortality events, and competition from an increasing abundance of Dall's porpoise.[60]

c. Minke Whale (*Balaenoptera acutorostrata*)

The minke whale is the most numerous and widely distributed baleen whale in the world.[61] It is also the most common baleen whale in the inland waters of Washington and Canada. Minke whales are found in the inland waters throughout the year, yet their population in the San Juans peaks from July through September.[62] Adults and subadults form the majority of the local population.[63] Although widely distributed in the inland waters, minke whales concentrate in four feeding areas in the San Juan Islands, with distinct populations returning to the same feeding area each year.[64] (Appendix III., Figure 7.) The minke whale feeding areas that have been identified are Hein Bank and Salmon Bank, located south of

San Juan Island; San Juan Channel, near Pear Point on San Juan Island; and south and west of Sandy Point on Waldron Island. Additional feeding areas may be present, but have yet to be identified.

Further monitoring is necessary to determine the population size and trends of minkes in the eastern North Pacific. Some information on the minkes that frequent local waters is provided by an 11-year study conducted in the San Juan Islands during the 1980's, which photo-identified 30 individual minke whales.[65] Up to 19 individuals were sighted in a single year. Minke whales are thought to reach sexual maturity at 3-8 years of age.[66] Females calve every 1-2 years, and they nurse their young for 4-6 months. Minke whale breeding or calving grounds have not been identified,[67] but they are believed to be located in lower latitude, warm waters.[68] Indeed, the conservation and management of this species would be facilitated by knowledge about their winter distribution, e.g., their calving and breeding grounds.

Minke whales feed on herring and sand lance, and individual whales appear to specialize on one of two different foraging strategies. The small-scale site fidelity exhibited by local minke whales may be one method of maximizing foraging efficiency: individuals specialize on the feeding strategy that results in the greatest catch given the topography and hydrodynamics of a specific feeding site.[69]

d. Harbor Seal (*Phoca vitulina richardsi*)

The harbor seal's geographic distribution spreads from Baja, California to the Aleutian Islands and Bering Sea.[70] The harbor seal is a year-round resident of the islands, and the only pinniped (seal or sea lion) species that breeds in Washington's inland waters.[71] It is also the most abundant marine mammal in these waters,[72] and the most abundant pinniped in Washington.[73] The estimated population of harbor seals in the inland waters during the 1996 pupping season was 17,036 individuals, with a peak count of 5,478 animals occurring during the first half of August. These numbers reflect a population increase of 6% between 1983-1996, and 10% for the more recent period of 1991-1996. Maximum life expectancy for these seals is approximately 30 years.[74] Harbor seal females mature between ages 3-5, and subsequently produce one pup per year. In the San Juan Islands, pupping occurs during June and July. Females mate approximately one month after giving birth to their previous pup, although implantation of the fertilized embryo does not occur for another two months. The duration of gestation from implantation to birth is nine months.

The results from 1996 aerial surveys over the inland waters of Washington and British Columbia concluded that "harbor seal sightings were common and occurred throughout the study area in the narrow passages as well as in open water."[75] Additionally, although harbor seals were most often sighted in shallow nearshore waters, they were also found "at all depths and distances to shore." Interestingly, 85% of the pups sighted in the aerial surveys were close to shore in the San Juan and Gulf Island regions. Harbor seal haul outs are located throughout San Juan County. (Appendix III, Figure 8. a.-c.) Areas with high concentrations of harbor seal haul outs include the southwest end of Lopez, in and around Davis Bay, Mackay Harbor, Iceberg Point, and Aleck Bay; the north and west sides of Shaw Island; the Wasp Islands located between Shaw and Orcas; islands and rocks around Patos, Sucia, Matia, Barnes, and Clark Islands, which border the north and east sides of Orcas; and the islands and rocks near Stuart, Spieden, and Johns Islands, north of San Juan Island. Some haul outs are also used as rookeries, where female harbor seals give birth to, and raise, their pups.

Harbor seals eat a variety of fishes, including hake, herring, pollock, sculpin, and tomcod.[76] Their position high on the food chain makes them especially susceptible to high levels of chlorinated hydrocarbons, which become concentrated at each trophic level.[77] Human disturbance is another potential threat to harbor seals. Calambokidis and Baird state:

> Harbour seals are one of the most wary pinnipeds to approach while hauled out, and typically enter the water upon approach….Potential impacts of disturbance include separation of mother and pups, interruption of nursing, and abandonment of haul-out areas.[78]

As the likelihood of human disturbance increases with increasing human population, it is essential to monitor these harbor seal populations.

e. Sea Lions

The California sea lion (*Zalophus californianus californianus*) and Steller (Northern) sea lion (*Eumetopias jubatus*) can be found in the San Juans during the non-breeding months, from early fall through late spring.[79] California[80] and Steller[81] sea lions have been known to congregate on Sucia Island, in northern San Juan County.[82] California sea lion haul out sites are shown in Appendix III., Figure 8. b. California sea lions breed south of here, on islands and on the mainland from central California to the tip of Baja, including the Sea of Cortez.[83] The majority of California sea lions present in the inland waters are males; females tend to stay closer to their breeding grounds year-round. The Steller sea lion's breeding range extends from southern California to the Bering Sea, but excludes Washington. Stellers are most abundant north of Washington, their core being in the central and western Gulf of Alaska and in the Aleutians.[84] Both species are polygamous, with males establishing territories on breeding grounds, and females typically producing one pup per year.[85] Both species are also primarily piscivores (fish-eaters). California sea lions prefer to eat hake and herring, and a group of locals have a notorious appetite for steelhead salmon. Steller sea lions eat a variety of fishes and invertebrates, principally walleye pollock, hake, herring, octopus, cod, rockfish, and salmon; they also occasionally eat other pinnipeds, such as harbor seals.[86]

The populations of these two sea lion species show opposite trends in abundance. The number of California sea lions in the inland waters has increased dramatically since the late 1970's,[87] and continued to rise until at least 1995.[88] Steller sea lions, by contrast, are listed as threatened under the Endangered Species Act.[89] Populations in core Steller area declined by 63% between 1985 and 1989,[90] and the range-wide estimate for 1989 was about 39-48% below that from 30 years prior.[91] This steep decline in Steller sea lion numbers is most likely due to low juvenile survival.[92] Changes in their prey resulting from competition with commercial fisheries or natural changes in the environment may have had a role in the recent declines.

2. Birds

A wealth of temporary or permanent residents totaling 291 species of birds have been recorded from the San Juan Archipelago,[93] and seabird colonies are located throughout the islands. (Appendix III., Figure 9.) The San Juan Islands foster approximately 37 species of birds that either depend on critical shoreline habitat for reproducing or feeding, or are common year-round and depend on the marine environment.[94] (Appendix III., Table 2.) An additional 61 species of birds are either fairly rare, relatively short-term visitors, or are non-nesting birds that exhibit low sensitivity to vessel traffic.

The birds in the San Juans exhibit a diversity of lifestyles. Loons and grebes use the islands as wintering grounds or as rest sites on their migration from northern breeding grounds to more southerly locations for the winter. Belted Kingfishers and Double-crested Cormorants are among the year-round fish-eating residents in the islands, both of whom breed here, although human disturbance is thought to have had negative impacts on the cormorant's breeding colonies.[95] The Peregrine Falcon is an endangered species that, in contrast to the Double-crested Cormorant, appears to be reclaiming historical nesting territories in

the San Juan Islands.[96] Foraging habitat ranges from the rocky intertidal used by American Black Oystercatchers to the narrow passages fished by Common Murres.

Among the 37 species listed in Table 2, all receive protection under the Migratory Bird Treaty Act of 1918[97]; the Marbled Murrelet, Common Loon, Bald Eagle, and Peregrine Falcon are covered by the Endangered Species Act; and the Bald Eagle receives further protection under the Bald and Golden Eagle Protection Act.[98] Below are detailed accounts of five species of local birds: the Marbled Murrelet (Appendix III., Figure 10.), Common Murre, Black Oystercatcher, Harlequin Duck, and Bald Eagle.

a. Marbled Murrelet (*Brachyramphus marmoratus*)

Marbled Murrelets are members of the family Alcidae. This species was listed as threatened under the U.S. Endangered Species Act in 1992, and its current population in Washington numbers about 5000 individuals.[99] These birds nest in trees within old growth forests adjacent to the ocean, where they feed on sand lance, sea perch, and other small crustaceans and schooling fish.[100] Currently there is not enough information to say definitively that Marbled Murrelets nest in the San Juans, although suitable habitat exists.

Marbled Murrelet distribution displays daily and seasonal variation due to the birds' breeding and foraging needs. Their foraging patterns are thought to be closely linked to tidal patterns, suggesting that they take advantage of spatial and temporal variability in prey distributions resulting from tidal activity.[101] Their proximity to shore also exhibits daily periodicity: by day they occupy nearshore habitats, generally within 500 meters of shore; at night, however, Marbled Murrelets move further offshore into areas such as the San Juan Channel and Rosario Strait.[102]

These birds are present in the San Juans year-round. The local population in the early summer includes both breeding and non-breeding birds, totaling approximately 500-800 individuals - about 20% of the state's breeding population. During this period, Marbled Murrelets are concentrated in two locations in the San Juans: the south end of Lopez Island, from Davis Bay to Point Colville, with a particularly high concentration at Iceberg Point; and along the west side of San Juan Island from Andrews Bay to False Bay. (Appendix III., Figure 10.) In mid-June the population increases to about 2000 birds as those who apparently spent the spring and summer (their breeding season) in the western Strait of Juan de Fuca and British Columbia return to the San Juans for the fall and winter. The migrants may come to the inland waters for more efficient foraging or to avoid harsh winter storms. This population of Marbled Murrelets, beginning to arrive in late summer, is distributed across a wider area than the early summer population. Of the early summer distribution, the south end of Lopez Island remains important as numbers increase threefold, but birds vacate the west side of San Juan Island. In addition, Marbled Murrelets expand their distribution into the following areas: the east side of Lopez Island from Shoal Bight up to Lawrence Point on Orcas Island, with particularly large numbers of birds near Decatur Head and Fauntleroy Point; the Wasp Islands; Cowlitz Bay off Waldron Island, which supports a high concentration of birds; the east side of San Juan Island from Limestone Point south to a location opposite Yellow Island; and many young
birds are present in Griffin Bay on San Juan Island.

Marbled murrelets are long-lived, have a clutch size of one, and are often found in pairs, suggesting that they mate for life. A consequence of this type of life history is that decreased survival or fitness of a relatively small number of individuals has severe implications for the population as a whole. The primary reason for concern about Marbled Murrelet populations is the loss of old-growth forests, which provide nesting habitat.[103] Incidental take in gillnet fisheries also contributes stress to Marbled Murrelet populations. Because of this, some gillnetting closures are currently in effect, but not all biologically

significant areas are protected. Human disturbance, oiling, and pollution also threaten these vulnerable populations of birds.

b. Common Murre (*Uria aalge*)

The Common Murre, like the Marbled Murrelet, is a member of the alcid family. Breeding populations of this species in Washington dropped precipitously from approximately 30,000 birds during 1979/1982 to 565 in 1993.[104]

Common Murres nest on cliffs along the outer coast, but they migrate to the inland waters to feed.[105] These birds arrive from the outer coast in late summer, staying in the islands until they return to their breeding grounds in April. Common Murres feed in deep water tide rips and channels[106] typical of San Juan Channel, Rosario Strait, and the south and west sides of Lopez and San Juan Islands.[107] Their primary prey are sand lance, herring, smelt, and bottomfish.

Multiple factors limit the recovery of Common Murres, including gillnet mortality, oiling, eagle-induced reduction in breeding success, anthropogenic disturbance, and El Nino events.[108] Mahaffy et al[109] note that, "Because of their depressed population, any additional mortality incurred from unnatural causes in the inner marine waters is cause for concern." Like Marbled Murrelets, Common Murres have a clutch size of one so any recovery for decimated populations will be slow.

c. Bald Eagle (*Haliaeetus leucocephalus*)

Bald Eagles are large raptors of the family Accipitridae. They are listed as threatened under the U.S. Endangered Species Act. In the San Juan Archipelago, Bald Eagles nest in greater concentrations than anywhere else in the contiguous United States.[110] The Bald Eagle population in Washington is doing well; nevertheless, long term habitat security for this species is uncertain.[111]. The number of nesting pairs has increased from approximately 250 in 1986 to over 580 in 1997. The majority of new territories were established along marine coastlines. San Juan County alone has 118 occupied nesting territories, which accounts for 1/3 of the total for King, Whatcom, Skagit, Snohomish, and Island Counties.[112] Although some Bald Eagles reside in the area year-round, during autumn the population declines as birds move north and inland to eat salmon spawning in streams and rivers; the population rebounds in the winter months as adults return to their breeding territories.[113]

Bald Eagles exhibit extreme fidelity towards their mates, remaining together for life. In the islands, they nest in old growth trees or mature trees with old growth characteristics such as those with broken or spiked tops. Bald Eagles are tenacious in defending an established territory during the breeding season. In the San Juans, almost all the nests are within 250 feet of shore, and there are very few places where shoreline is not part of eagle-defended territory.[114] It is common for a breeding pair to have more than one nest, including one favorite and one or more alternates. Nests are constructed of large sticks and lined with soft materials such as pine needles and grasses, and may measure over six feet in width and weigh hundreds of pounds.[115] During January and February the couple rebuilds their nests in preparation for nesting in the spring.[116] Females normally lay one or two eggs per year but occasionally lay three,[117] beginning in late Februray.[118] By the third week of March most of the egg-laying is complete,[119] and both parents incubate the eggs and care for the young.[120] The incubation period is thirty-five days and, if multiple eggs are present, the hatch interval is a few days. Often the first eaglet to hatch is the strongest and largest, and outcompetes its siblings for food; therefore, the oldest eaglet may be the only one to survive. In western Washington, young eagles normally spend 10-12 weeks in their nests before fledging, and may remain in their parents' home territories through their first summer, but then they are driven away to establish their own territories after obtaining breeding status at four to five years of age.[121]

These birds are opportunistic feeders, scavenging carrion when it is available, capturing marine birds, small terrestrial mammals, and fish at other times.

The most serious threat to Bald Eagles in the Northwest is logging and the continued development of shoreline areas. The continued loss of quality shoreline trees is especially disruptive. A typical nest or perch tree is often well over 100 years old. Commercial forest lands are now managed on a 60-80 year rotation. Cleared, landscaped lots eliminate forest regeneration and the few remaining large trees will eventually die or blow over. When trees do approach a size that is suitable to eagles, landowners often decide they are "danger" trees and have them removed. The net result of forest practices and residential development has been a virtual mining of suitable eagle habitat. If eagle populations are to remain viable 20-200 years from now, suitable and potential habitat must be protected.[122]

Human disturbance may also contribute to the loss of essential habitat for nesting, feeding, roosting, and perching. In addition, toxic contaminants and secondary poisoning from pesticides may have deleterious effects on some eagle populations in Washington.

d. **American Black Oystercatcher (*Haematopus bachmani*)**

The American Black Oystercatcher is the only representative of the family Haematopodidae in the San Juans.[123] These birds are more abundant in the San Juan Islands than in anywhere else in the Puget Trough[124]; a 1989 report estimated the number of breeding birds in the northern Puget Sound region to be 120.[125] Black Oystercatcher populations have been declining since the 1950s,[126] and this downward trend continues today throughout the Northwest.[127] They lay clutches of 1-3 eggs and may live to be over 30 years old.[128]

Black Oystercatchers are permanent residents in the San Juan Islands.[129] This species breeds, nests, and forages on clean, undisturbed rocky shorelines, preferring offshore rocks and islands to the more developed main islands.[130] During the breeding season in the spring these birds are highly territorial and do not form dense colonies, but from September to April they form flocks of up to several dozen.[131] They feed almost exclusively on invertebrates (e.g., mussels, limpets, chitons, crabs, and occasionally oysters) in the rocky intertidal zone.[132] Critical breeding habitat for Black Oystercatchers in San Juan County include the following locations: Patos and Matia Islands to the north of Orcas; Skipjack Island, north of Waldron; Flattop, Sentinel, Johns, Cactus, and Stuart Islands, located northwest of San Juan Island; Yellow Island, in San Juan Channel; the Wasp Islands; small rocks and islands south of Lopez, including Colville Island; Flower Island, Lawson Rock, and Pointer Rock surrounding the southern point of Blakely Island; Peapod Rocks in Rosario Strait, east of Orcas; and Clark Island and The Sisters to the northeast of Orcas.[133]

Black Oystercatchers are extremely sensitive to disturbance. Lewis and Sharpe assert that "all too frequently, uninformed boaters and fishermen inadvertently disturb the breeding birds and thus provide opportunities for the omnipresent gulls and crows to pilfer the temporarily unprotected nests."[134] Other concerns for the survival of this species include long-term degradation of the intertidal zone, and oil contamination.[135]

e. Harlequin Duck (*Histrionicus histrionicus*)

The Harlequin Duck is a candidate for listing under the U.S. Endangered Species Act. It is present year-round in the San Juan Islands.[136] The winter population consists of small, evenly dispersed groups. In late summer the local population is augmented by males returning from their breeding and nesting grounds in whitewater rivers of the Olympic, Cascade, and Rocky Mountains; in October, females and their young arrive in the islands.[137] In the marine environment, Harlequin Ducks inhabit offshore rocks

and reefs, and their diet includes a variety of invertebrates typical of rocky shores, for example, snails, limpets, crabs, chitons, and mussels.[138] They also occasionally eat fish. Areas of high concentration are found along San Juan Channel, particularly Turn Island and Turn Rock, and the southern end of Lopez Island.[139]

The migration of Harlequin Ducks resembles that of Pacific salmon in that they travel between breeding grounds in riparian areas (along the banks of rivers and streams), and marine feeding grounds. Therefore, these ducks are susceptible to many of the same threats that plague salmonids, namely loss of critical nesting habitat due to hydroelectric projects, road construction, logging, and mining. They also face pressures from overhunting by poachers and by hunters who confuse them for other species.

3. Fishes

The shared waters of Washington and British Columbia are inhabited by over 200 species of fishes,[140] all of which are ecologically important, and some, such as salmon, herring, flatfish, rockfish, and cod, are important components of commercial, recreational, or tribal fisheries. The adults of some species are migratory, as exemplified by salmonids, who swim great distances from productive marine feeding grounds to freshwater spawning grounds, recognizing no political boundaries on their journeys. Others, such as certain rockfish, travel very little and are therefore highly susceptible to local disturbance and fishing pressures. Many species utilize a variety of marine habitats at different stages in their lives. Developing eggs may be found on rocky or sandy substrates, on aquatic vegetation, or directly in the water column. After hatching, the larvae typically undergo a planktonic phase in which water currents disperse the new recruits to areas distant from their parental population. Juveniles may then occupy the same habitat type as adults, or wait until they are larger to move into adult habitat. A life history that involves a series of habitats, each one critical for a given stage, amplifies the number of anthropogenic and environmental threats that a fish experiences throughout its life. In addition, the degradation or destruction of a single habitat type may have consequences for the population as a whole by dramatically increasing mortality rates at a particular life stage. It follows that effective conservation and management of these ecologically and economically valuable fishes require preservation and maintenance of all marine habitats.

Pacific herring (Appendix III., Figure 11.), rockfish (III., Figure 12. and Table 3.), salmonids (III., 13.), lingcod (III., Figure 12. and Table 3.), and walleye pollock are discussed in greater detail below.

a. Pacific Herring (*Clupea harengus pallasi*)

Pacific Herring are the most abundant forage fish in the transboundary waters of Washington and Canada.[141] Adult herring return to the same location annually to spawn, and therefore each spawning ground is considered a discrete stock for management purposes.[142] The San Juan Islands foster the following stocks: Westcott and Garrison Bays on San Juan Island; East and West Sound on Orcas Island; Blind Bay on Shaw Island; and Mud and Hunter Bays on Lopez Island. (Appendix III., Figure 11.) The status of these stocks are unknown.[143] Pacific herring stocks typically exhibit fluctuations in spawner abundance due to variable natural mortality and recruitment.[144] Recently, however, there have been several indications that Puget Sound herring stocks may be in jeopardy: 1) four stocks (Cherry Point, Port Susan, Port Orchard, and Discovery Bay) are considered either “depressed” or “critical”; 2) the estimated natural mortality has risen from 30-40% before 1982 to 60-70% in 199_; 3) the number of age classes comprising the majority of the Puget Sound populations has decreased from five to two or three; and 4) changes in the schooling behavior of herring, in addition to increased sightings of harbor seals near herring schools at night, may be due to increased harbor seal predation on these fish.[145]

Most Pacific herring stocks undergo annual migrations to reproduce; some stocks in southern Puget Sound and the Strait of Georgia, however, are believed to be residents, never leaving the inland waters for the outer coast.[146] In Washington, most herring spawn in late January to early April; the Cherry Point stock is an exception, spawning from early April to early June.[147] Adults spawn in inshore waters, the females deposit adhesive eggs on algae and eelgrass.[148] The incubation period is temperature-dependent and lasts for about 10-21 days. Recently-hatched larvae subsist for six days on energy reserves provided by a yolk sack. The larval stage is a period of passive dispersal; planktonic larvae drift with the prevailing nearshore currents. After five weeks in the plankton, herring larvae metamorphose and begin active schooling in protected bays. Some fish migrate to the outer coast during their first winter, yet many delay their first migration until the following summer, traveling with groups of post-breeding adults and subadults. They remain in waters along the outer coast until age 2 or 3, and then join the inshore migration to spawning grounds in the fall. Throughout the winter and early spring herring form large congregations, but these divide around mid-February as the fish disperse to their spawning grounds. Once the spawning process is complete, the herring return to the outer coast to build energy reserves for the following year's reproductive effort. Although Pacific herring can live up to 15 years, in Puget Sound they typically do not live past age 5 or 6.[149] They provide prey for numerous species, including Pacific salmon, Pacific cod, Pacific hake, walleye pollock, lingcod, spiny dogfish, halibut, rockfishes, Common Murres, Tufted Puffins, Marbled Murrlets, Cormorants, gulls, harbor porpoises, California sea lions, and harbor seals. Herring also support a commercial fishery in Washington that is predominantly used for bait in salmon sport fishing.[150]

b. Rockfishes (*Sebastes spp.*)

Rockfishes comprise a group of approximately 100 species,[151] over 20 of which are found in north Puget Sound.[152] Four species present in the San Juans are copper (*Sebastes caurinus*), quillback (*S. maliger*), black (*S. melanops*), and yelloweye (*S. ruberrimus*) rockfish. The local distribution of rockfish and other groundfish is shown in Appendix III., Figure 12; further information is provided in Table 3. The geographical distribution of these four species extends from Alaska to California.[153]

Rockfish are long-lived species. Members of the genus *Sebastes* have estimated maximum lifespans of 20-140 years.[154] Copper and quillback rockfish may live up to 55 years,[155] black rockfish can live at least 36 years, and yelloweyes can reach 114 years.[156] Because of their longevity and the resulting generation overlap, rockfish populations are buffered to a certain extent against episodic failures in recruitment (the number of first-year fish added to the population each year).[157] The age at which rockfish mature varies by species and location, but copper and quillback rockfish in Puget Sound reportedly mature at ages 4 and 5, respectively, and black rockfish off central Oregon mature at age 5 for males and 6 for females.[158] Rockfish are iteroparous (adults have more than one opportunity to breed) and viviparous, internal fertilization is followed by the release of thousands of free-swimming pelagic larvae.[159] The timing of parturition (birth) varies by species, ranging from winter to summer.[160] Predation is highest on young fish and, therefore, relatively few survive to adulthood. Rockfish undergo deterministic growth: many have extremely low growth rates for up to 50% of their lives.[161] Juvenile rockfish eat plankton, and adults eat a variety of invertebrates (e.g. shrimp, crab, and octopus), and many species of fishes, including rockfish.

Habitat utilization varies by species and by life stage or season within a given species. Larval rockfish are pelagic, found in the water column as opposed to on the bottom of the ocean. Matthews studied the habitat utilization of rockfish in central Puget Sound, and she found that young-of-the-year rockfish seek protection and food in eelgrass beds and in algae on reefs with low currents.[162] Adult yelloweye and black rockfish are semi-demersal, they may be found either near the bottom or higher in the water column.[163] Black rockfish can be highly mobile, as is evident from the recovery of one tagged fish that traveled from Tillamook Hook, Oregon, to Mendocino, California – a distance of 345 miles.[164] By

contrast, adult copper and quillback rockfish are demersal, usually found on the bottom and closely associated with rock, vegetation, or artificial substrate.[165] Furthermore, copper and quillback rockfish are relatively sedentary, roaming very little as adults.[166]

Habitats that experience seasonal vegetation and subsequent structural changes - namely sand/eelgrass and low-relief rocky reefs – reportedly have the lowest densities of rockfish and the most dramatic differences in rockfish density over time.[167] Nevertheless, these low density areas are important temporary habitat in the summer when the vegetation is the most dense. Consistent densities of rockfish seem to utilize high-relief rocky reefs year-round; these are considered the highest quality habitats because they provide prey and shelter (rocks and crevices) even when vegetation is sparse. Matthews stated that the artificial reefs in her study seemed to represent an "anomalous habitat" because their rockfish assemblages were unlike those of any natural habitats, namely sand/eelgrass, low-relief rocky reefs, and high-relief rocky reefs. The dissimilarity of rockfish communities on artificial reefs and those on natural reefs creates doubts as to whether artificial reefs have the resources to replace lost natural habitats. Therefore, successful conservation and management of rockfish may necessitate the conservation and management of their natural habitats.

The conservation and management of sedentary and long-lived species like copper and quillback rockfish require a different approach than those used for migratory, short-lived fishes such as salmon and herring. These rockfish are easily overfished because many years must pass before another individual settles and grows to replace a large adult taken in recreational or commercial fisheries.[168] Furthermore, if a breeding population is not available to produce recruits, then the entire stock is vulnerable to extinction. In North Puget Sound, recreational fishers take over half of the recorded annual rockfish catch, and this fishery is considered fully utilized.[169] The commercial fishery for demersal rockfish is currently closed:

> Areas of high rockfish abundance have been closed to trawling, and gears designed specifically to harvest fish from rocky substrate (commercial bottomfish troll and jig gears) have been prohibited. Commercial landings of demersal rockfish are now limited to by-catch from trawling, and from setline and setnet fisheries targeting spiny dogfish (*Squalus acanthias*).[170]

Although recent catch rates in the recreational fishery are near the long-term average, there is concern for local rockfish populations because biological data show that the rockfish caught are smaller now than in the 1970s and that several species have become rare. Furthermore, a recent study comparing rockfish populations at Turn Island, which is open to fishing and is a short boat ride away from Friday Harbor, with those at San Juan Island's Shady Cove, a marine harvest refuge bordering San Juan Island, showed that copper rockfish in the refuge were significantly larger, more abundant, and had greater reproductive outputs than those in the fished area.[171] These data indicate that growth and recruitment overfishing have occurred. Growth overfishing "causes a depression of the average size of fish in a given population, as a result of chronically harvesting the largest fish," whereas recruitment overfishing "occurs when adult populations are reduced to such levels that production of progeny is insufficient to maintain stocks at desirable levels."[172]

The establishment of marine refuges can potentially be a very effective conservation and management tool that operates on the ecosystem level, incorporating both physical and biological aspects of the environment. In addition to increasing mean individual size and age, abundance, and reproductive output of target species within refuges, these protected habitats may compensate for overfishing of target species in neighboring areas by enhancing recruitment inside and outside of the refuges, maintaining genetic diversity of stocks, and increasing fishery yields in surrounding fishing grounds.[173] The benefits of marine harvest refuges are not limited to the target species, however; they can also potentially affect the

community ecology of the area by increasing species diversity, habitat complexity and quality, and community stability.

c. Salmonids (*Oncorhynchus spp.*)

Pacific salmon and steelhead are crucial components of local ecosystems and they comprise a substantial portion of commercial, tribal, and recreational fisheries in the Pacific Northwest. All salmon species are caught in fisheries surrounding the islands.[174] (Appendix III, Figure 13) Although the exact timing and location of anadromous salmon life history stages vary between species and between stocks within a given species, the general pattern is as follows: first, adults spawn in freshwater rivers, streams, or lakes; second, juveniles migrate to the ocean where growth and development occurs; finally, adults return to their natal watersheds to spawn.[175] These fishes are managed based on a stock system in which each stock represents a discrete population originating from and adapted to a specific watershed. Fisheries managers have not put much effort into identifying or monitoring salmon stocks originating in the San Juans because those runs are thought to contribute relatively few fish to fisheries. The 1992 Washington State Salmon and Steelhead Stock Inventory identifies only one native salmonid stock, Orcas Island Coho.[176] Other opportunistic runs may exist when water flow down creeks and streams is sufficient to permit adult access to spawning grounds.[177]

Some of the salmonids caught in local fisheries in the San Juans originate in Washington, whereas others come from British Columbia. Fraser River sockeye salmon form a significant component of Puget Sound fisheries,[178] and these stocks have been relatively healthy in recent years. The forecasted Fraser River escapement (number of fish surviving to reach spawning grounds, hatcheries, or in-river fisheries) for 1997 was between 11 and 73 million fish, and reflects increased production over the past several decades.[179] By contrast, many Puget Sound stocks of salmonids are in decline. The Nooksack, Samish, Skagit, and possibly Stillaguamish Rivers in Washington produce fish that are probably caught in fisheries in the San Juan Islands.[180] Coho salmon from the Puget Sound/Strait of Georgia are abundant, yet most existing populations have considerable hatchery contributions that may pose ecological, genetic, or sustainability risks to native stocks.[181] These coho stocks are not presently in danger of extinction, but are likely to become so in the foreseeable future. Chinook salmon from Puget Sound are also experiencing declines. The current overall abundance of chinook is substantially lower than historical counts, and both long- and short-term trends show declines.[182] Recent population trends for Puget Sound steelhead also exhibit declines, yet the two largest stocks (Skagit and Snohomish Rivers) are producing significant increases.[183] Chum and pink salmon stocks are relatively healthy, although recent declines in body length of odd-year pinks may signify reduced reproductive potential.[184]

Native salmon stocks are at risk due to a variety of factors. Chief among them are habitat loss, damage or modification resulting from hydropower, agriculture, logging, and other developments.[185] Other reasons for decline include overfishing and negative interactions with other fishes, such as hatchery-produced salmon and steelhead.

d. Lingcod (*Ophiodon elongatus*)

Lingcod are large predatory fish that inhabit rocky reefs as adults. Since 1992 the commercial lingcod fishery has been closed, and, therefore, recent stock indicators rely primarily on the recreational catch rate.[186] The North Sound lingcod stock encompasses most of the waters in the Strait of Juan de Fuca, the San Juan Archipelago, Bellingham Bay, and the U.S. Strait of Georgia. A 1994 video-acoustic survey estimated the abundance of North Sound lingcod to be at least 440,000 fish. This stock exhibits both long-term and short-term declines, and is considered depressed by the Washington Department of Fish and Wildlife. In addition, a recent study found that lingcod in the Shady Cove harvest refuge were larger, produced more eggs, and were present in greater densities than those found in the fished waters surrounding Turn Island.[187]

Like all of the fish accounts previously discussed, habitat utilization by lingcod varies with the life stage of the fish, thereby complicating conservation and management issues. Lingcod are found in nearshore habitats along the west coast of North America from Baja, California to the Shumagin Islands in Alaska.[188] They are present throughout the San Juan Islands[189] (Appendix III, Figure 12 and Table 3), and range in depth from 3-400 meters, although they are most common in waters 10-100 meters deep.[190] Adults are non-migratory, yet undergo localized seasonal movements to spawn. On average, males are sexually mature by age 2, and females mature between 3-5 years of age. In November - December, males aggregate in rocky, strong current areas 5-60 meters deep and establish nesting territories. Females generally remain in deeper waters except for brief periods to spawn. Females lay masses of large eggs that become cemented to the rocky substrate and to each other. Males guard the eggs until larvae hatch; hatching occurs synchronously after an average incubation period of 7 weeks. Lingcod dispersal occurs during the larval stage. Larvae rise to the surface waters in March – May; they are planktonic until juveniles settle to the bottom in late May - June. Kelp and eelgrass beds are critical habitat for juvenile lingcod. By September, juvenile lingcod have dispersed from these nearshore nurseries to flat bottom areas located at a wide range of depths. By age 2, lingcod begin to move into the rocky, high energy habitats typical of adults. Females are larger and longer-lived than males: the maximum reported age of lingcod on the west coast of Canada is 14 years for males and 20 years for females.

Lingcod diet composition changes with maturation, reflecting their change in habitat. Small larvae eat small invertebrates until they are large enough to consume larger invertebrates and other larval fish, such as Pacific herring. As juveniles, lingcod rely mostly on small fish - juvenile Pacific herring, sand lance, flatfish, and juvenile walleye pollock, for example. Juveniles also eat shrimp and prawns in lesser amounts. Pacific herring and Pacific hake are primary components of the diet of adult lingcod, although they also eat other fishes (including young lingcod) and invertebrates. As adults, lingcod have few predators aside from humans, sea lions, and harbor seals.

e. Walleye Pollock (*Theragra chalcogramma*)

The inland waters represent the extreme southern end of walleye pollock distribution, and this fish is much more abundant in the North Pacific Ocean at higher latitudes, including the Bering Sea and Gulf of Alaska.[191] The North Sound stock of walleye pollock frequents the Strait of Georgia,[192] and these fish have been found off of all the major islands in the San Juans.[193] This stock moves between U.S. and Canadian waters, and is one of the stocks that Washington shares with British Columbia.[194] Bottom trawl catch rate is the primary stock indicator for these fish, and low catches over the past several years suggest that this stock is declining and may be critically depressed. One limitation of using fishery statistics to determine population trends, however, is that low catch rates could be due to low fish abundance or to fisheries not catching available fish; for North Sound Walleye Pollock, it is not known why recent catch rates are low.

Walleye pollock adults are pelagic and semi-demersal, and are not clearly associated with any particular habitat.[195] They become sexually mature between ages 2-4, and may live to be greater than 17 years.[196] These fish are broadcast spawners, with females releasing eggs into the water column to be fertilized by schools of males nearby. Spawning occurs between February and April in local waters. The eggs are pelagic, and have been found at 100-300 meters deep in the Strait of Georgia. Larvae are found at the water's surface, where they eat small crustaceans.[197] Juveniles leave the surface of the water and move to eelgrass, gravel, or cobble habitats. Small juveniles eat crustaceans, and adults eat crustaceans and small fish, including juvenile pollock.

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[2] San Juan County, Wash., Ordinance No. 3-1996 (Jan. 30, 1996).
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[4] San Juan County Park Board, *supra* note 1.
[5] Puget Sound Water Quality Authority and Department of Natural Resources Division of Aquatic Lands, The 1992 Puget Sound Environmental Atlas Update, Region 2 (1992) [hereinafter PSWQA 1992].
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[8] *Id*.
[9] Edward R. Long, A Synthesis of Biological Data from the Strait of Juan de Fuca and Northern Puget Sound 3-12 (U.S. Environmental Protection Agency Report No. EPA-600/7-82-004, 1983) [hereinafter Long et al. 1983].
[10] Richard E. Thomson, Physical Oceanography of the Strait of Georgia - Puget Sound – Juan de Fuca Strait System, *in* Review of the Marine Environment and Biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait: Proceedings of the BC/Washington Symposium on the Marine Environment 1948 Can. Tech. Rep. Fish. Aquat. Sci. 36 (Jan. 13 & 14, 1994) [hereinafter Thomson 1994].
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[12] Eugene N. Kozloff, Seashore Life of the Northern Pacific Coast: An Illustrated Guide to Northern California, Oregon, Washington, and British Columbia 5 (1996) [hereinafter Kozloff 1996].
[13] Thomson 1994, *supra* note 10.
[14] Long et al. 1983, *supra* note 9.
[15] Kozloff 1996, *supra* note 12, at 116.
[16] Long et al. 1983, *supra* note 9, at 26-116. Long et al.'s classification system is presented in this report because it gives general characteristics of broad habitat types. For finer resolution, other habitat classification systems that are more detailed than Long et al.'s are used. For example, Dethier (reference follows) developed a marine and estuarine habitat classification system that is the standard for several government agencies in Washington State. Dethier considers more physical parameters in her classification scheme than Long et al. do, and therefore recognizes more habitat types than they do. Dethier acknowledges that one advantage to using a more detailed system is that "the more physical constraints considered, the greater the predictive power we gain about the organisms present." Megan N. Dethier, A Marine and Estuarine Habitat Classification System for Washington State (1990).
[17] Kozloff 1996, *supra* note 12, at 258-88.
[18] Long et al 1983, *supra* note 9, at 38.
[19] Colin D. Levings and Ronald M. Thom, Habitat Changes in Georgia Basin: Implications for Resource Management and Restoration, *in* Review of the Marine Environment and Biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait: Proceedings of the BC/Washington Symposium on the Marine Environment 1948 Can. Tech. Rep. Fish. Aquat. Sci. 336 (Jan. 13 & 14, 1994) [hereinafter Levings and Thom 1994].
[20] Kozloff 1996, *supra* note 12, at 288-339.
[21] Long et al 1983, *supra* note 9, at 40.
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[29] Levings and Thom 1994, *supra* note 19.
[30] Long et al. 1983, *supra* note 9, at 80-87.
[31] *Id*.at 97.

[32] Long et al. 1983, *supra* note 9, at 111.
[33] Walruses are also pinnipeds, but they are not found in the San Juan Islands.
[34] Memorandum from Richard Osborne, Curator of Science Services, The Whale Museum, to San Juan County Board of Commissioners (Jan. 15, 1996) (on file with San Juan County Prosecutor's Office) [hereinafter Osborne 1996].
[35] Marine Mammal Protection Act of 1972, 16 U.S.C.S. §§ 1361 – 1421h. (1984 & Supp. 1998)
[36] Endangered Species Protection Act, 1973, 16 U.S.C.S. §§ 1531 – 1554 (1984 & Supp. 1998)
[37] Richard Osborne et al., A Guide to Marine Mammals of Greater Puget Sound 29-42 (1988) [hereinafter Osborne et al. 1988].
[38] John Calambokidis and Robin W. Baird, Status of Marine Mammals in the Strait of Georgia, Puget Sound and the Juan De Fuca Strait and Potential Human Impacts, *in* Review of the Marine Environment and Biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait: Proceedings of the BC/Washington Symposium on the Marine Environment 1948 Can. Tech. Rep. Fish. Aquat. Sci. 282, 287-88 (Jan. 13 & 14, 1994) [hereinafter Calambokidis and Baird 1994].
[39] Osborne et al. 1988, *supra* note 37.
[40] Calambokidis and Baird 1994, *supra* note 38.
[41] Osborne et al. 1988, *supra* note 37.
[42] Calambokidis and Baird 1994, *supra* note 38.
[43] The Whale Museum, San Juan Island, Orca Adoption Program (visited Aug. 24, 1998) <http://www.whale-museum.org/adopt.html>.
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[52] Osmek et al. 1996, *supra* note 46 at 11.
[53] Osborne et al. 1988, *supra* note 37, at 25-27.
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[57] Osborne et al. 1988, *supra* note 37, at 25-27.
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[59] Osborne et al. 1988, *supra* note 37, at 25.
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[61] Osborne et al. 1988, *supra* note 37, at 77.
[62] Eleanor M. Dorsey et al., Minke Whales *(Balaenoptera acutorostrata)* from the West Coast of North America: Individual Recognition and Small-Scale Site Fidelity, (Special Issue 12) Rep. Int. Whal. Commn 357 (1990). Osborne et al. 1988, *supra* note 37, at 82.
[63] Calambokidis and Baird 1994, *supra* note 38, at 289. Eleanor M. Dorsey et al., Minke Whales *(Balaenoptera acutorostrata*) from the West Coast of North America: Individual Recognition and Small-Scale Site Fidelity, (Special Issue 12) Rep. Int. Whal. Commn 357 (1990).
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[67] Dorsey et al. 1990, *supra* note 65.
[68] Osborne et al. 1988, *supra* note 37, at 79.
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[73] Steven J. Jeffries et al., Assessment of Harbor Seals in Washington and Oregon, 1996, *in* Marine Mammal Protection Act and Endangered Species Act Implementation Program, 1996, at 83 (P. Scott Hill and Douglas P. DeMaster eds. Nov. 1997) (on file with the National Marine Mammal Lab Library).
[74] Osborne et al. 1988, *supra* note 37, at 103.
[75] Calambokidis et al. 1997, *supra* note 48.
[76] Osborne et al. 1988, *supra* note 37, at 103.
[77] Osborne et al. 1988, *supra* note 37, at 103. Calambikidis and Baird 1994, *supra* note 38, at 290.
[78] Calambikidis and Baird 1994, *supra* note 38, at 291.
[79] Everitt et al. 1980, *supra* note 70, at 18-22.
[80] Everitt et al. 1980, *supra* note 70, at 18.
[81] Osborne et al. 1988, *supra* note 37, at 120. Everitt et al. 1980, *supra* note 70, at 22.
[82] Telephone Interview by author Bricklemyer, with Patrick Gearin, Wildlife Biologist, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, National Marine Mammal Laboratory (Aug. 14, 1998). Gearin stated that very few Steller sea lion sites exist in the San Juan Islands. Recently, however, more Stellers are using the north side of Orcas Island, where he observed 50-100 individuals. Gearin also said that California sea lions move through the area and may utilize the waters, but the San Juans do not have important haul out sites for these pinnipeds. *See also* Telephone Interview by author Bricklemyer, with Steve Jeffries, Wildlife Biologist, Washington Department of Fish and Wildlife (Aug. 18, 1998). Jeffries said that the nearest Steller sea lion haul out is Race Rocks in British Columbia, but that he has observed Stellers feeding between the southeast end of Speiden Island and the north end of San Juan Island from December to May. Jeffries also mentioned that California sea lions use navigational buoys as haul outs in these waters.
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[87] Calambikidis and Baird 1994, *supra* note 38, at 284.
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[92] NMFS 1992, *supra* note 84.
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de Fuca Strait: Proceedings of the BC/Washington Symposium on the Marine Environment 1948 Can. Tech. Rep. Fish. Aquat. Sci. 256, 260 (Jan. 13 & 14, 1994) [hereinafter Mahaffy et al. 1994].

[97] Migratory Bird Treaty Act, 16 U.S.C.S. §§ 703 – 712 (1994)

[98] Bald and Golden Eagle Protection Act, 16. U.S.C.S. §§ 668, 668(a) – (d) (1994); *see also* Letter from Steve Negri, Wildlife Biologist, Washington Department of Fish and Wildlife to author Ferguson (Sept. 2, 1998) [hereinafter Negri Letter]. Negri states that the Bald Eagle is classified as a threatened species at both the state and federal level. The bird, egg, nest, and nest tree rules are strictly enforced by both state and federal authorities. General habitat protection is provided by the Wash. Rev. Code Ann. § 77.12.655 (West 1996) and Wash. Admin. Code § 232-12-292 (1997)

[99] Mahaffy et al. 1994, *supra* note 96, at 258.

[100] Tony Angell and Kenneth C. Balcomb III, Marine Birds and Mammals of Puget Sound 95 (1982) [hereinafter Angell and Balcomb 1982].

[101] Steven M. Speich and Terrence R. Wahl, Marbled Murrelet Populations of Washington – Marine Habitat Preferences and Variability of Occurrence, *in* Ecology and Conservation of the Marbled Murrelet 313 (U.S. Dept. Agriculture, Forest Service General Technical Report PSW-GTR-152, 1995).

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[103] James E. West, Protection and Restoration of Marine Life in the Inland Waters of Washington State 29 (Puget Sound/ Georgia Basin Environmental Report Series No. 6, 1997) [hereinafter West 1997].

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[105] Lewis and Sharpe 1987, *supra* note 93, at 122. Angell and Balcomb 1982, *supra* note 100, at 94.

[106] Mahaffy et al. 1994, *supra* note 96, at 261.

[107] Courtney 1998, *supra* note 102.

[108] West 1997, *supra* note 103, at 30.

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[112] Telephone Interview by author Bricklemyer, with Steve Negri, Wildlife Biologist, Washington Department of Fish and Wildlife (Aug. 7, 1998) [hereinafter Negri 1998].

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[117] Negri 1998, *supra* note 112.

[118] Watson and Rodrick 1998, *supra* note 116.

[119] Watson and Rodrick 1998, *supra* note 116.

[120] Lewis and Sharpe 1987, *supra* note 93, at 85.

[121] Negri Letter, *supra* note 98.

[122] *Id*.

[123] Lewis and Sharpe 1987, *supra* note 93, at 100.

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[129] Angell and Balcomb 1982, *supra* note 100, at 61.

[130] Speich and Wahl 1989, *supra* note 125, at 42.

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[146] Schmitt et al. 1994, *supra* note 140, 235.
[147] Stick 1994, *supra* note 142.
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[170] West 1997, *supra* note 103, at 37.
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[175] Schmitt et al. 1994, *supra* note 140, 219. *see also* Interview by author Ferguson, with Laurie A. Weitkamp, Fisheries Biologist, National Oceanic and Atmospheric Administration, National Marine Fisheries Service (Aug. 27, 1998). Weitkamp adds that some salmon (e.g., steelhead, sockeye, coho, and spring chinook) grow and develop in freshwater for at least one year before migrating to the ocean. Others (chum, pink, and fall chinook) enter the ocean the year they hatch.
[176] Washington Department of Fisheries et al., 1992 Washington State Salmon and Steelhead Stock Inventory 133 (Mar., 1993).
[177] Telephone Interview by author Bricklemyer, with Pete Castle, Fisheries Biologist, Washington Department of Fish and Wildlife (Aug. 5, 1998). Castle said that some coho and searun cutthroat may spawn in tributaries emptying into West Sound on Orcas Island, especially in years with above-average flow during October, November, and December. In addition, there may be a run of salmon at the south end of Lopez Island, near the town of Richardson, flow-permitting. Mackay Harbor on Lopez also occasionally hosts spawning salmon. Finally, False Bay on San Juan Island has coho runs during some years. *See also* Williams et al., A Catalog of Washington Streams and Salmon Utilization, at San Juan 01-04 and 101-104 (1975). This reference seems to agree with Castle's comments. It mentions several streams located throughout the islands that are used by spawning coho and chum salmon. It notes the following streams specifically: Cascade Creek on Orcas Island, draining Cascade and Mountain Lakes on the south side of Mount Constitution and entering East Sound; and two unnamed streams on San Juan Island, one draining from the Beaverton Valley area and entering on the east side of the island north of Friday Harbor, and the other draining the Trout Lake Cady Mountain area and entering False Bay. In addition to those streams already mentioned, it also adds: "intermittent spawning is expected in those island streams that provide access and suitable habitat, but only occasional adequate flows."
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[180] Weitkamp 1998, *supra* note 174.
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[183] Peggy J. Busby et al., Status Review of West Coast Steelhead from Washington, Idaho, Oregon, and California 165 (NOAA Technical Memorandum NMFS-NWFSC-27, 1996).
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[185] Schmitt et al. 1994, *supra* note 140, 222.
[186] Palsson et al. 1997, *supra* note 152, at 60.
[187] Palsson and Pacunski 1995, *supra* note 171.
[188] Alan J. Cass et al., Lingcod *(Ophiodon elongatus)* 109 Can. Spec. Publ. Fish. Aquat. Sci. 5 (1990) [hereinafter Cass et al. 1990].
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[193] Miller and Borton 1980, *supra* note 189, at 24.4.
[194] Palsson et al. 1997, *supra* note 152, at 40.
[195] Matthews 1987, *supra* note 191, at 22.
[196] Schmitt et al. 1994, *supra* note 140, 239.
[197] Matthews 1987, *supra* note 191.

Scoping Memorandum concerning the Pacific Gateway Terminal

Juvenile Salmon and Forage Fish

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Prepared for: San Juan County Department of Community Development and Planning and San Juan County Marine Resources Committee

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JUVENILE SALMON AND FORAGE FISH PRESENCE AND ABUNDANCE IN SHORELINE HABITATS OF THE SAN JUAN ISLANDS, 2008-2009: MAP APPLICATIONS FOR SELECTED FISH SPECIES

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Abstract

Fish presence probabilities for the San Juan Islands' shorelines were calculated for seven juvenile fish species or species groupings from results of 1,350 beach seine sets made at 80 different sites throughout the San Juan Islands in 2008 and 2009. The juvenile fish species evaluated were: unmarked (assumed wild) Chinook salmon (*Oncorhynchus tshawytscha*), chum salmon (*Oncorhynchus keta*), pink salmon (*Oncorhynchus gorbuscha*), Pacific herring (*Clupea pallasii*), Pacific sand lance (*Ammodytes hexapterus*), surf smelt (*Hypomesus pretiosus*), and lingcod/greenling (*family Hexagrammidae*).

Because juvenile salmon are known to be migratory in nearshore waters, our sampling plan was established to encompass the times of year when it is possible for juvenile salmon to be present within shoreline habitats of the San Juan Islands. Beach seining typically occurred at each site twice per month from March through October each year.

We hypothesized that space (i.e., where within the San Juan Islands) and habitat type differences would influence whether or not fish were present (or abundant) at specific locations within the San Juan Islands. Beach seine sites were selected to represent different regions within the San Juan Islands (SiteType2) and different geomorphic shoreline types (SiteType3). We also stratified by two coarser-scale variables for space and habitat type. The coarse variable for space has two possible values related to whether the site is located in "interior" or "exterior" areas of the San Juan Islands. The coarse scale variable for habitat was either "enclosure" or "passage." All 80 sites were characterized by these space and habitat type variables.

We used generalized linear models (GLM) to test whether our hypothesized variables of space and habitat type influence fish presence and abundance. We found strong support for both influences with no strong indication to weigh one variable over the other. Thus, we created two model versions to predict indices of fish presence probability based on fish presence rate results summarized by each of the 80 sites for each space and habitat type variable. Models were created for each of the seven juvenile fish species or species grouping. A high resolution model (HRM) multiplied fish presence values for SiteType2 by SiteType3. A lower resolution model (LRM) multiplied fish presence rate values for the coarse space variable by the coarse habitat type variable. For each model, the calculated fish presence probabilities could range between 0 and 1. The resulting fish probability of presence estimates relate to our beach seine sampling regime of twice per month from March through October. For example, a Chinook probability of presence value of 1 for a site means you are certain to find Chinook salmon present at the site if you beach seine twice per month from March through October.

We also found fish presence rates to be positively correlated with fish density for all fish species or species groupings in this report. This means sites with higher values of fish presence also have higher values of fish abundance. The strength and type (e.g., linear, exponential) of the correlated relationships varied.

Background and Purpose of Study

Estuary and nearshore habitats are occupied by juvenile salmon during their transition from freshwater spawning and rearing habitats to ocean feeding grounds. Duration of estuarine/nearshore residence and attributes of estuarine/nearshore habitats can be important limiting factors in recovery of salmon populations (Beamish et al. 2000 & 2004; Mortensen et al. 2000; Magnusson and Hilborn 2003; Greene and Beechie 2004; Greene et al. 2005; Bottom et al. 2005a & 2005b).

Chinook salmon populations originating from Puget Sound are now federally protected, and the subject of significant population rebuilding efforts (Federal Register 64 F R 14208, March 24, 1999; Federal Register 69 FR 33102, June 14, 2004). Chinook salmon are thought to be the most estuarine/nearshore dependent of the Pacific salmon species (Healey 1982 & 1991; Simenstad et al. 1982) and therefore the most vulnerable to human alterations of estuarine/nearshore ecosystems.

A major data gap apparent in efforts to develop a recovery plan for Puget Sound Chinook salmon is information on juvenile Chinook salmon use of estuarine/nearshore habitats in the mixed stock rearing environments such as those found in the San Juan Islands. To date, our ability to document differences between Chinook salmon populations in their use of estuarine/nearshore habitats has been limited to coded wire-tagged, hatchery-origin fish in the main basin of Puget Sound (Duffy 2003; Brennan et al. 2005; Fresh et al. 2006). Hatchery origin salmon do not necessarily represent wild salmon life history types and results from the main basin of Puget Sound do not represent other areas throughout Puget Sound. Much in the same way as for juvenile salmon, data gaps exist for the juvenile nearshore habitat associations of three forage fish species (Pacific herring, surf smelt, and Pacific sand lance), which are also identified in salmon recovery plans as important to protect and restore because of their key role in Puget Sound food webs.

This study helps fill these fish use data gaps for the San Juan Islands. Its results are inteneded to help San Juan County planners and salmon recovery staff know what nearshore areas are providing juvenile habitat opportunity to juvenile salmon and forage fish species. Coupled with shoreline type characterization in GIS (McBride et al. 2009), the fish use results were used to create models of fish probability of presence estimates for all San Juan County shorelines, including areas not sampled directly in this study. The mapped application of these models can be used to identify specific areas for restoration or protection through salmon recovery or environmental regulatory processes.

Methods

This study is based on a stratification scheme using *time* (year and month), *space* (area within the San Juan Islands), and *habitat type* (shoreline type). The conceptual foundation for this stratification is based upon results of research from throughout the Pacific Northwest demonstrating that juvenile salmon use of estuarine and inland coastal landscapes will vary with time period, region, and habitat type. For example, Zhang and Beamish (2000) found a bimodal seasonal abundance curve for wild sub-yearling Chinook salmon in Georgia Strait; each mode was potentially a different group of fish (e.g., different life history strategy). Similarly, Beamer et al. (2003) found that differences in time (season or month) and habitat type directly affect the relative abundance of juvenile Chinook salmon life history types within Skagit Bay.

In the San Juan Islands, few salmon can originate from spawners within local watersheds because of the limited amount of stream habitat in this region. Therefore, the majority of juvenile salmon using San Juan County's shorelines originate from areas outside of our study area (Figure 1). Thus, we hypothesize that juvenile salmon use of the San Juan Islands' nearshore will vary spatially and temporally because of differences in the migratory pathways and habitats potentially available to source salmon populations. Migratory pathways could be influenced by the shape and diversity of the landscape, distance from natal river mouths, water quality, and water currents. For example, the northern side of the San Juan Islands is in closer proximity to the Fraser River than southern Rosario Strait, which is closer to the Skagit and Samish Rivers. Differences between source population sizes (e.g., millions of smolts migrating from some natal rivers versus only a few thousand smolts migrating from other natal rivers) and source population characteristics (e.g., composition of life history types, such as many fry migrants verses many yearling migrants) could influence the composition of juvenile salmon populations within San Juan County's nearshore habitats. Thus, our study was designed to collect fish data to determine the spatial and habitat patterns of fish in the nearshore habitats throughout the San Juan Islands.

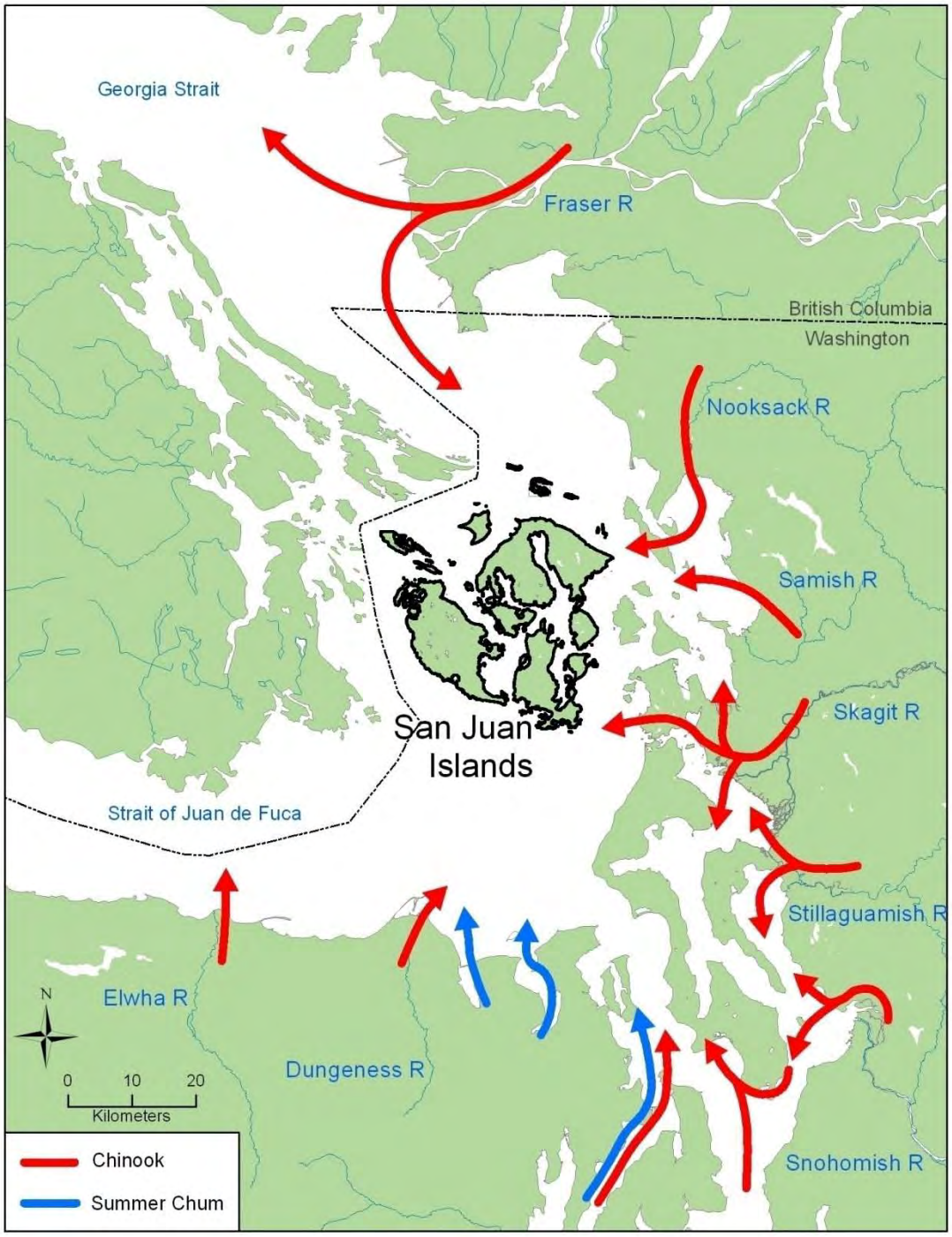

Figure 1. Location of San Juan Islands study area and conceptual varying migratory pathways for juvenile salmon coming from their source population rivers to mixed stock rearing areas within the southern Salish Sea.

Stratifying Variables

Time

Year: We sampled over a two-year period in order to capture the possibility of varying abundance levels of different fish species. For example, pink salmon abundance varies considerably between years due to their two year old life cycle. Adult pink salmon returning to river systems near the San Juan Islands (Fraser, Nooksack, Skagit, etc.) are much greater in abundance in odd-numbered years than in even-numbered years. Thus, the progeny of pink salmon, which migrate to sea as fry, are more abundant in even-numbered years than in odd-numbered years.

Month: We sampled over the entire period when juvenile salmon could be present in shoreline habitats of the San Juan Islands. Because juvenile salmon are migrating from their natal rivers to the ocean, we expect them to show some seasonal curve of absence to presence and again to absence. During their migration to the ocean, the different species of salmon are expected to transiently occupy and rear in nearshore habitats. As the fish grow in size they tend to be less associated with shoreline habitats. Logically, fish size and time of year are correlated with larger juvenile salmon occurring later in the season. To capture the seasonal patterns of use by juvenile salmon in nearshore habitats we sampled monthly from March through September or October each year. The sampling period was biased toward capturing the seasonal curve of juvenile Chinook salmon and was inferred largely from patterns known to occur in the Skagit estuary and its adjacent nearshore (Beamer et al. 2005). We hypothesized all the nearshore fish species we would encounter in this study have their own seasonal patterns of nearshore habitat use based on their unique life cycles.

Space

We defined fourteen (14) different areas within the San Juan Islands for this purpose; they are called "SiteType2" in the GIS (see Appendix B). Each area represents a subset of the San Juan Islands' nearshore habitat where juvenile salmon stock and species composition might be unique based on di fferences in salmon migration pathways and proximity to source population areas like the Skagit, Nooksack, or other rivers (Figure 2).

Because we were uncertain whether we could beach seine all areas of the San Juan Islands (i.e., all SiteType2s), we also defined a coarser scales for space within the San Juan Islands that is based on an area being in the interior or exterior of the San Juan Islands (Figure 3). The coarse binning of space is "Int_Ext" in the GIS analysis (see Appendix B).

Figure 2. Map of 14 areas within the San Juan Islands. These areas are our primary spatial strata (Sitetype2). Beach seine sampling occurred in 12 of the 14 areas.

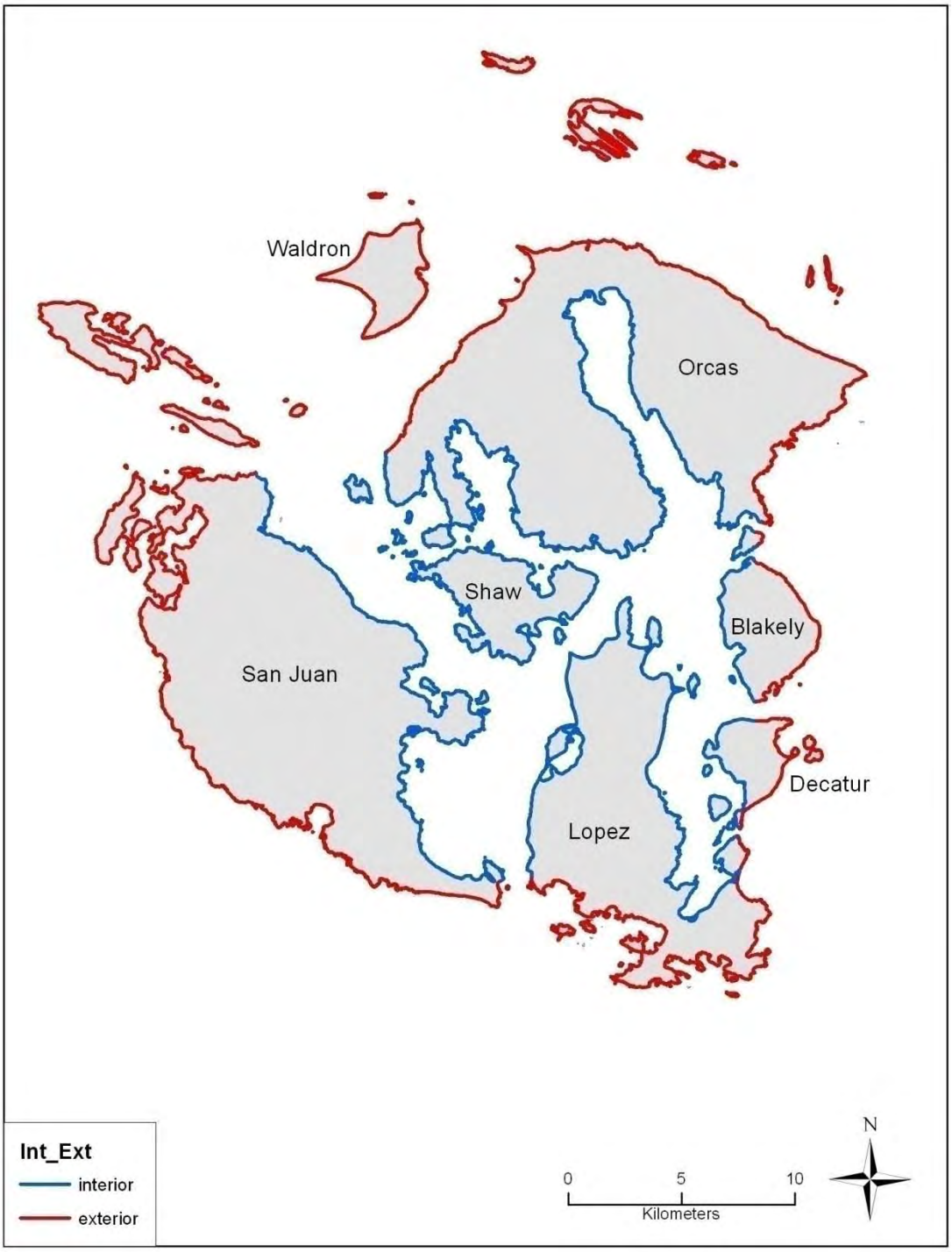

Figure 3. Interior and exterior areas within the San Juan Islands per our coarse space variable.

Habitat type

We created two habitat type variables: SiteType3 (shoreline type) and Enclosure/Passage.

SiteType 3: We chose to group geomorphic units based on similarities in beach form into five groups (described below) and applied the groupings to all shorelines of the San Juan Islands (Figure 4). The groupings are simplified geomorphic typology after the classification by McBride et al. (2009). Examples of shoreline types used in this study are shown in Appendix A along with a crosswalk table of classifications used by the RITT (Bartz et al. 2012) and SSHIAP. The SSHIAP program has a Puget Sound-wide GIS data layer using the McBride et al. (2009) method.

Barrier beach: The *barrier beach* group includes true barrier beaches, which are depositional landforms, and pocket closed lagoon and marsh units that look like barrier beaches even though these are erosional beaches (see *pocket beaches* below). The barrier beach group is characterized by low relief beaches with well developed backshore areas and leeward tidal and/or freshwater impoundments. The impoundments themselves are part of the *pocket estuary* group if there is a consistent surface connection to marine water.

Bluff backed beach*:* The *bluff backed beach* group includes erosional depositional beaches at the base of sediment bluffs. This group also includes sediment-covered rock beaches and seeps/small streams that enter the beach via the bluff rather than via a pronounced stream valley. Bluff backed beaches do not form lagoons (except as a sediment source to the barrier beaches that do form lagoons).

Pocket beach: *Pocket beaches* are a particular variation of a beach that can look like 'bluff-backed beach' at the base of rocky bluffs. Unlike bluff-backed beaches, however, pocket beaches have no adjacent sediment source from drift cells and thus are not part of drift cell systems. Beach sediments in pocket beaches are derived locally.

Pocket estuary like: The *pocket estuary like* group includes all the impoundments behind spits or other barrier beaches, and those habitats impounded behind pocket beaches. They also include stream estuaries not partially enclosed by lagoons/barrier beaches (deltas, drowned channels and tidal deltas). Most pocket estuaries have freshwater inputs because most are created by streams or as a result of a stream or glacial valley intersecting the shoreline. The shoreline forms an indentation at valleys. These valley indentations are often crossed and then partially enclosed by beach sediments moving across the indentation opening, creating lagoons. Lagoons can also form parallel to bluffs, when tides encroach into the backshore. These cases of pocket 'estuaries' may not have a freshwater input. Pocket beach lagoons also may not have a freshwater input. In both of these salty cases, we have observed that freshwater does accumulate in the impoundments during the wet season. The estuarine character of these sites needs to be determined on a site by site basis. A third salty pocket

‘estuary’ is the tidal channel marsh that forms where tides encroach into coastal lowlands.

Rocky shoreline: The *rocky shoreline* group includes both the low-to-medium gradient rocky shorelines and plunging rock cliffs.

Some shorelines were so heavily modified that we could not determine their shoretype. These were by default classified as ***modified*** and were not included as potential beach seine sites.

Enclosure/Passage: We defined Enclosure/Passage as an intermediate-scale variable for habitat type based on s horeline length, shape, and watershed area contributing to the shoreline length. We mapped enclosure and passage area for all shorelines within the San Juan Islands (Figure 5).

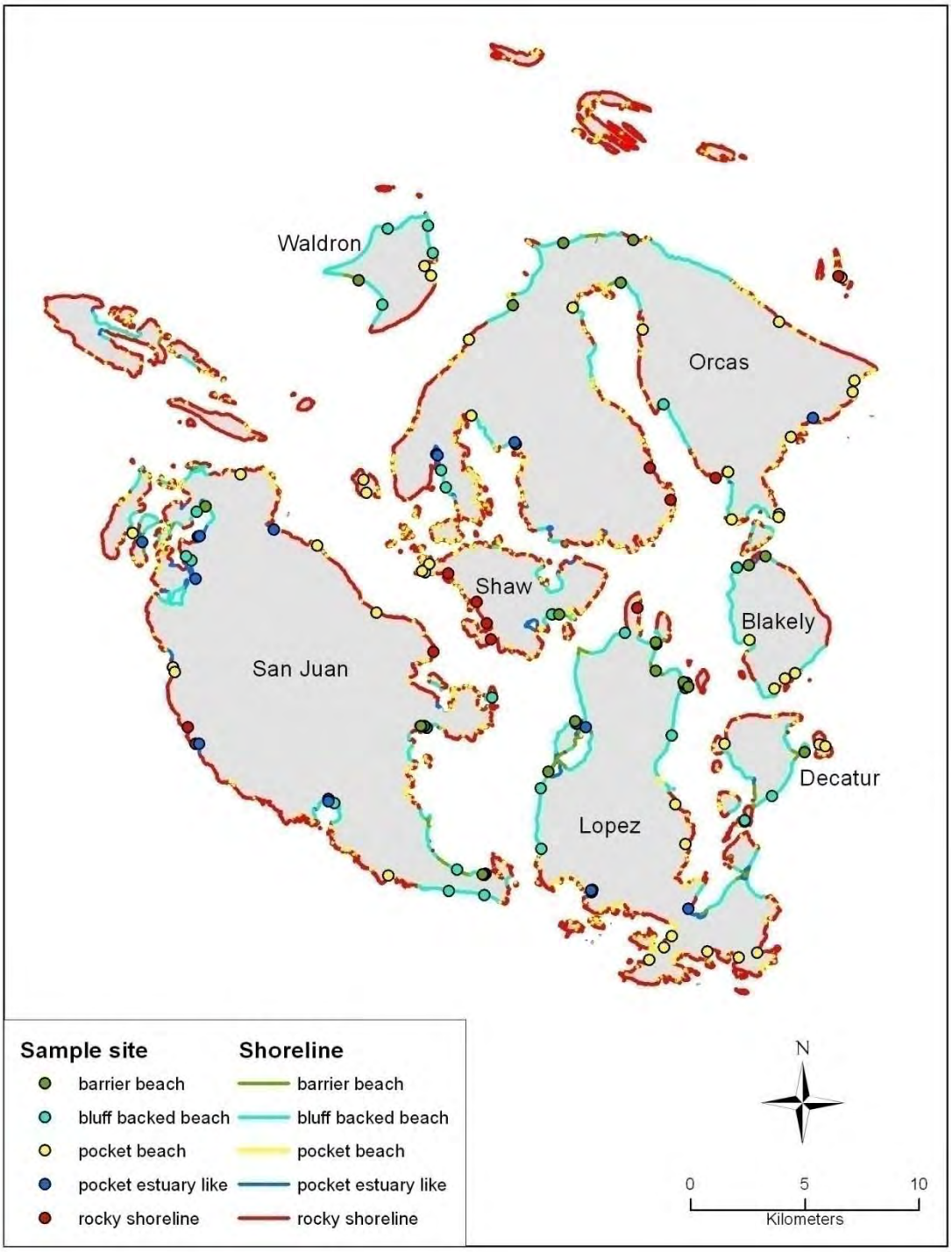

Figure 4. Location of 82 beach seine sites sampled in 2008 and 2009 in the San Juan Islands. Shown by shoreline type (SiteType3).

Figure 5. Enclosure and passage areas within the San Juan Islands per our intermediate-scale variable.

Site Selection and Sampling Effort

We selected beach seine sites from 12 of the 14 different areas (SiteType2) within the San Juan Islands. Within each of 11 of the 12 areas, we sampled a diversity of shoreline types (SiteType3). In SiteType2 #12 (Upright Channel) we only sampled bluff backed beaches. The number of sites and habitats within each of the 12 areas sampled varied based on factors such as logistics, access, and the shoreline types available for sampling (Table 1). A total of 1,375 beach seine sets were completed at 82 different sites over the two-year period (Table 2).

Our beach seine sampling effort under-sampled the amount of rocky shoreline present in the San Juan Islands when compared based on the count of shoreline segments or their total length (Figure 6). We also over-represented pocket estuaries and barrier beaches in our beach seine sampling.

Table 1. SiteType2 unique identifier numbers, and number of beach seine sets completed per area and shoreline type.

Area within San Juan Islands (SiteType2)	Site-Type2 ID#	Shoreline type (SiteType3)				
		Barrier beach	Bluff backed beach	Pocket beach	Pocket estuary like	Rocky shoreline
Str Juan de Fuca - S Lopez Is	1			133	38	
Str Juan de Fuca - San Juan Is	2		49	12	40	
Haro Strait NE	3	19	24	37	49	7
Waldron Is - President Channel	4		46	14		
Rosario NW	5			51	22	11
Rosario Strait SW	6	14		40		
Blakely Sound - Lopez Sound	7	38	46	37	34	
East Sound	8			48		39
Deer Harbor - West Sound	9		70	15	51	
San Juan Channel South	10	91	32		72	
San Juan Channel North	11			64	24	83
Upright Channel	12		25			

Table 2. Number of beach seine sets completed by year and month.

Month	Year		Total
	2008	2009	
March	62	72	134
April	91	114	205
May	87	109	196
June	101	120	221
July	93	121	214
August	101	114	215
September	62	95	157
October		33	33
Total	597	778	1375

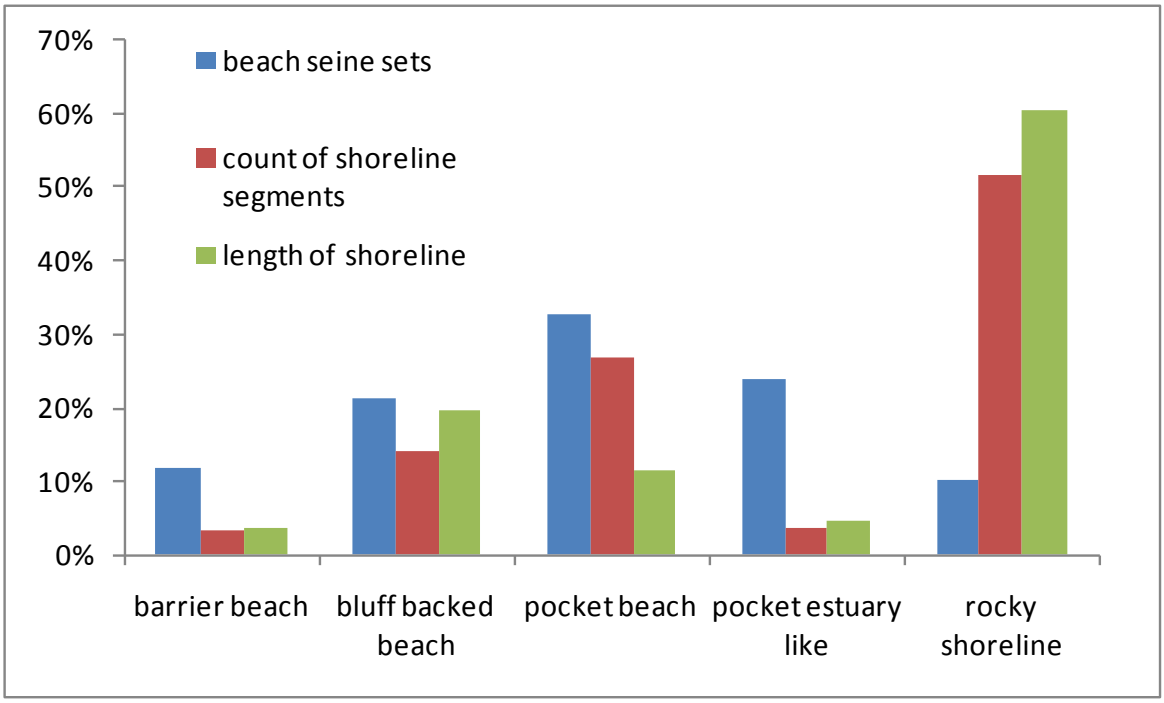

Figure 6. Relationship between beach seine effort by shoreline type and the amount of shoreline habitat by type.

Fish Sampling

Beach seine

We used beach seine methods to capture fish in shoreline habitats of the San Juan Islands (see cover photos). We used two different sized nets depending on the conditions at the site such as water depth, size of area, and substrate.

The small net beach seine methodology employed an 80-ft (24.4 m) by 6-ft (1.8 m) by 1/8-inch (0.3 cm) mesh knotless nylon net. The net was set in "round haul" fashion by fixing one end of the net on the beach, while the other end was deployed by setting the net "upstream" against the water current, if present, and then returning to the shoreline in a half circle. Both ends of the net were then retrieved, yielding a catch. The small net beach seine was usually deployed from a floating tub that was pulled while wading along the shoreline. Large net methods used a boat to set the net due to the nets larger size and deeper water at the site. The large net beach seine was 120-ft (36.6 m' by 12-ft (3.7 m) by 1/8-inch (0.3 cm) mesh knotless nylon net where one end of the net wass fixed on the beach while the other end was set by boat across the current (if present) at an approximate distance of 65-85% of the net's length depending on the site.

For each beach seine set, we identified and counted fish by species, and measured individual fish lengths by species. When one set contained 20 individuals or less of one species, we measured all individual fish at each site/date combination. For sets with fish catches larger than 20 individuals of one species, we randomly selected 20 individuals for length samples.

Fish density

For all fish sampled by beach seines, we calculated the density of fish by species for each set (the number of fish divided by set area). Set area is determined in the field for each beach seine set.

Analysis Methods

Statistical and graphical analysis of fish species

To accommodate our unbalanced sampling design (Table 1) we used generalized linear models (GLM) to evaluate the effects of temporal and habitat variables on fish density. Fish densities were log (x+1) transformed to reduce the effects of high skew and unequal variance across groups. Year, month, space, and shoreline type were evaluated for main effects as fixed factors for their influence on each species or species group. Statistical results from GLM for each effect are reported in tables for each species or species grouping along with graphical presentations. We excluded from the GLM analysis fish data from SiteType2 #12 (Upright Channel) to reduce effects of our unbalanced design. The 25 beach seine sets for Upright Channel (Table 1) were from one year (2009) and one shoreline type (bluff backed beach). We created box plots of fish size by month to characterize fish size and scatter plots of regressions between fish presence rate and fish density to determine whether results were correlated.

Fish probability of presence mapping

Based on results of GLM testing of effects for fixed variables (see results section below), we found strong support that both space and habitat type affected fish abundance but one variable did not appear more important than the other. Thus, we created two model versions to develop indices of fish presence probability based on fish presence rate results summarized by each of the 80 sites used in the GLM analysis. We ignored temporal effects (month and year) on fish species for these models because the purpose of each model is to map places in the San Juan Islands with varying levels of fish use, not to predict the when fish are present.

Models were created for each of the seven juvenile fish species or species groupings. A high resolution model (HRM) multiplied fish presence values for SiteType2 by SiteType3. A lower resolution model (LRM) multiplied fish presence rate values for the coarser-scaled space variable (interior/exterior) by the coarser scaled habitat type variable (enclosure/passage). For each model, the calculated fish presence probabilities could range between 0 and 1. The resulting fish probability of presence estimates relate to our beach seine sampling regime of twice per month from March through October. For example, a Chinook probability of presence value of 1 for a site means you are certain to find Chinook salmon present at the site if you beach seine twice per month from March through October.

Because we did not beach seine adequately in 3 of the 14 geographic regions (SiteType2s shown in Figure 2), we used fish presence rate results from the coarser-scaled spatial

variable ‘interior/exterior’ as a substitute for results from missing geographic areas (SiteType2 codes: 12, 13, and 14). We also lacked fish presence results for the shoreline type classified as ‘modified’ in GIS. There was no suitable fish presence rate result to use as a surrogate for modified shorelines so we did not make an estimate for modified shoreline areas in the HRM.

Because of the odd/even year abundance cycle of pink salmon, we used fish presence rate results from 2008 to create both HRM and LRM maps for juvenile pink salmon. We used both 2008 and 2009 fish presence rate results to create the map application models for all other fish species.

Results

Abundance, Timing, and Size

Chinook salmon

GLM testing for effects of fixed factors revealed log-transformed Chinook density was not influenced by years but was influenced by season (month), area within the San Juan Islands (SiteType2), and shoreline type as well as both coarse variables for space (int/ext) and habitat type (encl/pass) (Table 3).

Juvenile Chinook arrived in the San Juan Islands by April, peaked in the month of June, and remained relatively high in shoreline areas during summer months (Figure 7, Panel B). Juvenile Chinook salmon were most abundant in Region 4 (Waldron-President Channel) (Figure 7, Panel C) and bluff backed beach and pocket beach shoreline types (Figure 7, Panel D).

Fish size increased from April through October (Figure 8). Very few Chinook caught were fry sized fish (only 5 of the 491 fish measured were 50 mm or less in fork length) when they arrived in the San Juan Islands

Regression analysis revealed juvenile wild Chinook salmon presence and density was strongly and positively correlated in the San Juan Islands when beach seine sets are averaged by SiteType2 (Figure 9). Thus, shorelines in the San Juan Islands with higher juvenile wild Chinook presence rates also have greater abundance levels of wild juvenile Chinook The regression relation is a power function.

Table 3. ANOVA results from Generalized Linear Model effects testing for log-transformed juvenile Chinook salmon density.

Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
Year	0.150	1	0.150	0.539	0.463
Month	3.916	1	3.916	14.079	0.000
SiteType2	4.904	1	4.904	17.631	0.000
Shoreline type	7.641	4	1.910	6.869	0.000
Int_Ext	6.031	1	6.031	21.924	0.000
Encl_Pass	7.617	1	7.617	27.692	0.000

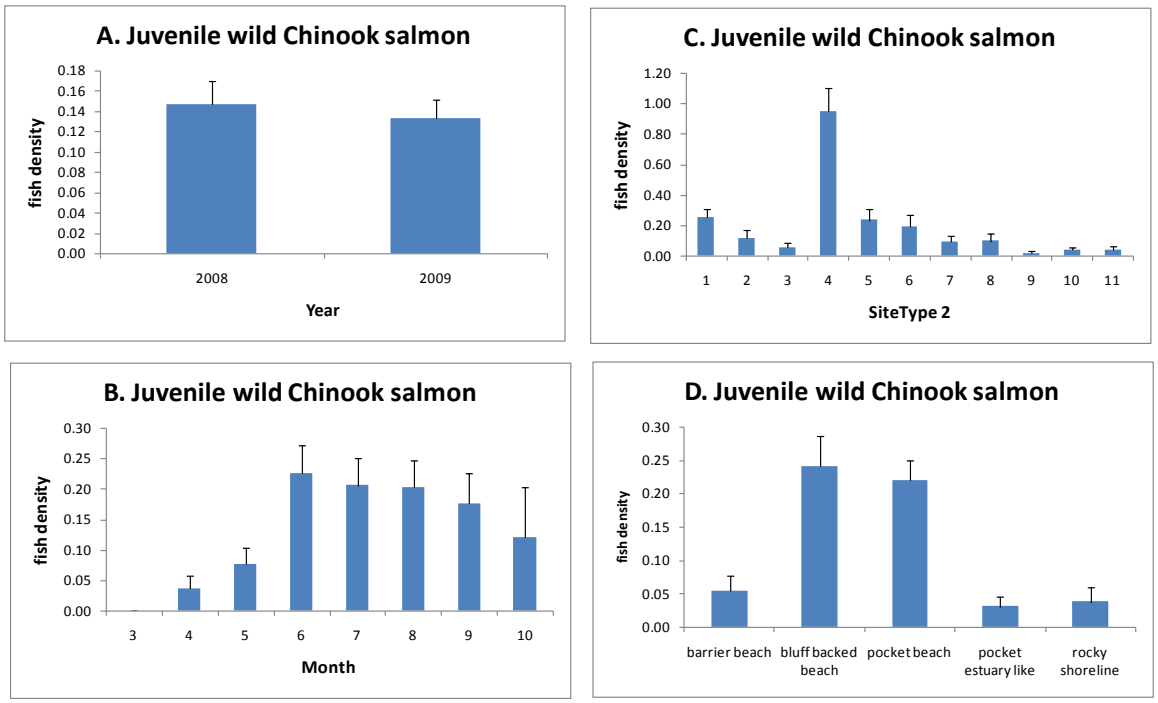

Figure 7. Relationship between average juvenile wild Chinook salmon densities (log-transformed fish per hectare) and year (Panel A), month (Panel B), SiteType2 (Panel C), and shoreline type (Panel D). Results are from 80 beach seine sites throughout the San Juan Islands in 2008 and 2009. Error bars are standard error. A description and location of the areas within the San Juan Islands coinciding to specific Sitetype2 codes (Panel C) are shown in Table 1 and Figure 2.

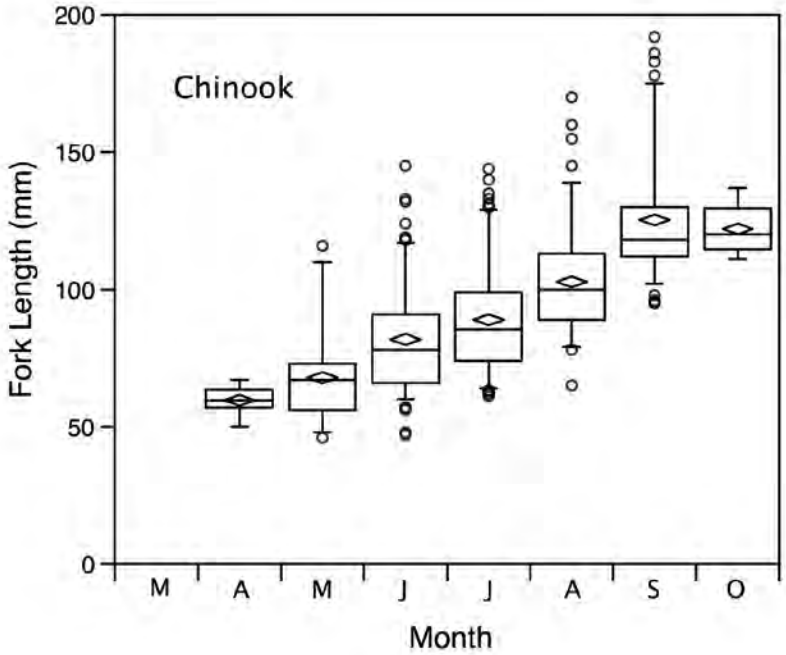

Figure 8. Fork lengths of wild juvenile Chinook salmon caught in shoreline habitats of the San Juan Islands, 2008-2009 combined. Diamonds are means, and boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Circles are outliers.

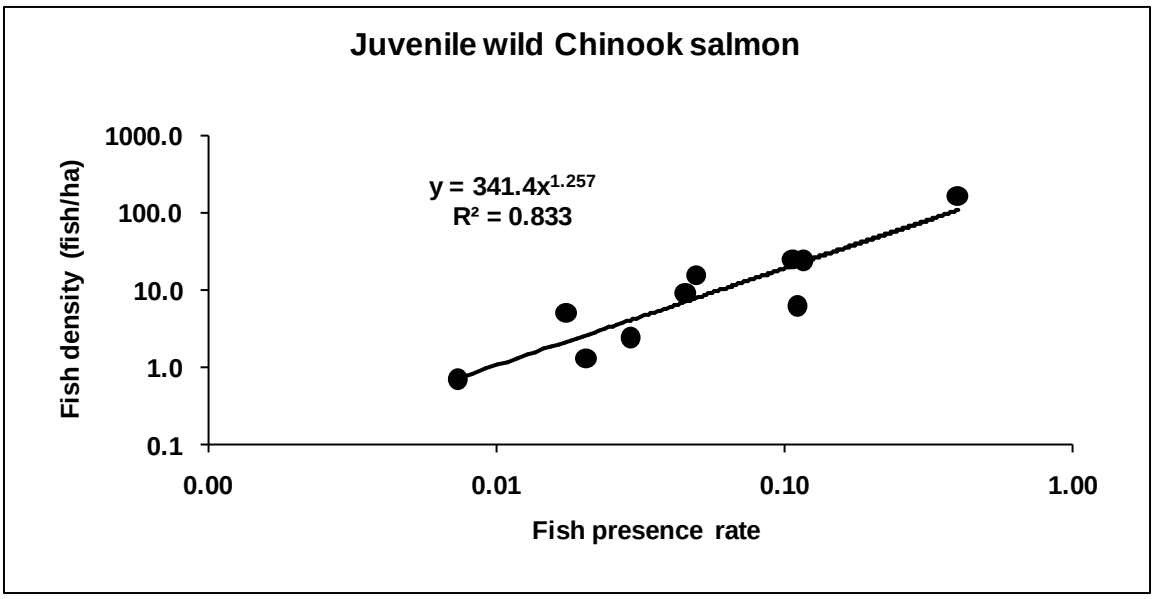

Figure 9. Correlation between presence and abundance of juvenile wild Chinook salmon in San Juan Islands shoreline habitats when beach seine sets are averaged by SiteType2.

Chum salmon

GLM testing for effects of fixed factors revealed log-transformed chum density was not influenced by area within the San Juan Islands (SiteType2), but was influenced by season (year and month), and shoreline type as well as both the coarse variables for space (int/ext) and habitat type (encl/pass) (Table 4).

Juvenile chum arrived in the San Juan Islands by March, peaked in the month of May, and disappeared from shoreline areas by August (Figure 10, Panel B). Juvenile chum salmon were most abundant at pocket beaches (Figure 10, Panel D).

Fish size increased more slowly from March through May than after May (Figure 11), possibly reflecting requirement of new fish each month. Most juvenile chum are fry-sized when they arrive in the San Juan Islands, but the length distribution does include some larger fish. Fish size increased steeply after May, possibly reflecting growth of individual fish residing in shoreline areas of the San Juan Islands and a lack of near recruitment of newly outmigrated fish from freshwater.

Regression analysis revealed juvenile chum salmon presence and density were positively correlated in the San Juan Islands when beach seine sets are averaged by SiteType2 (Figure 12). Thus, shorelines in the San Juan Islands with higher juvenile chum presence rates were also higher in juvenile chum abundance. The regression relation is an exponential function.

Table 4. ANOVA results from Generalized Linear Model effects testing for log-transformed juvenile chum salmon density.

Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
Year	14.202	1	14.202	14.333	0.000
Month	81.028	1	81.028	81.777	0.000
SiteType2	0.013	1	0.013	0.013	0.909
Shoreline type	49.403	4	12.351	12.465	0.000
Int_Ext	10.020	1	10.020	10.736	0.001
Encl_Pass	87.988	1	87.988	94.270	0.000

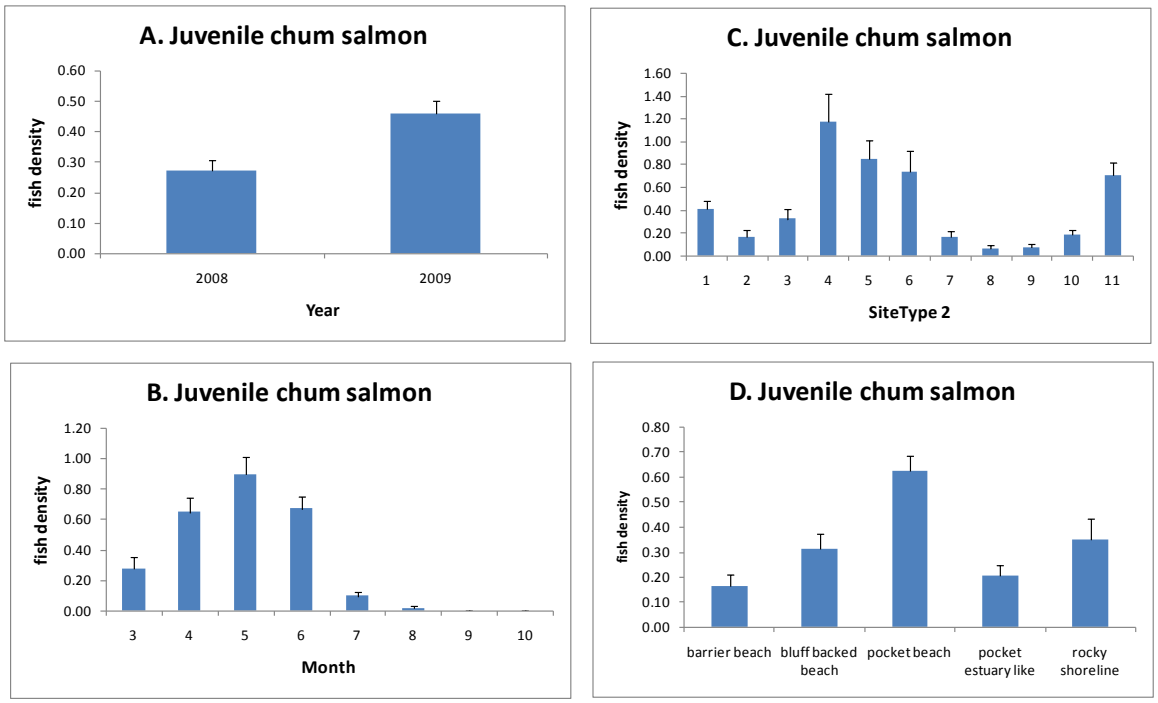

Figure 10. Relationship between average juvenile chum salmon densities (log-transformed fish per hectare) and year (Panel A), month (Panel B), SiteType2 (Panel C), and shoreline type (Panel D). Results are from 80 beach seine sites throughout the San Juan Islands in 2008 and 2009. Error bars are standard error. A description and location of the areas within the San Juan Islands coinciding to specific Sitetype2 codes (Panel C) are shown in Table 1 and Figure 2.

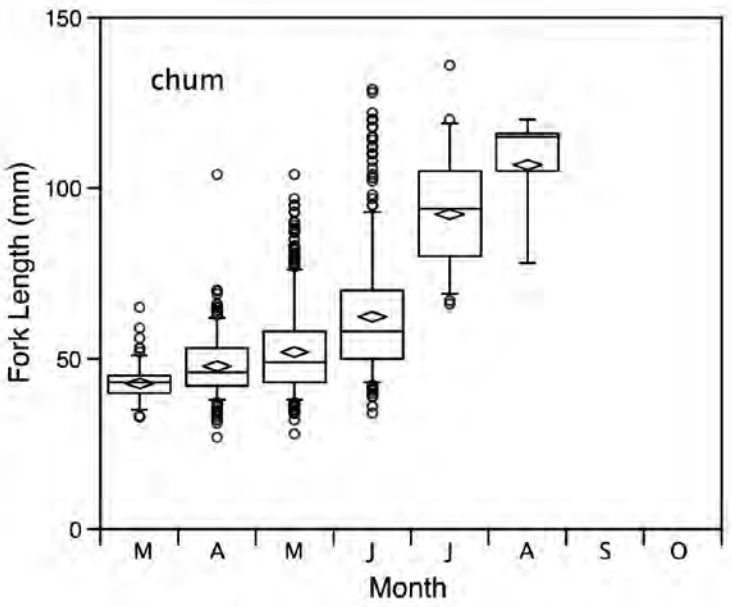

Figure 11. Box plot of fish size for juvenile chum salmon caught in shoreline habitats of the San Juan Islands, 2008-2009. Diamonds are means, and boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Circles are outliers.

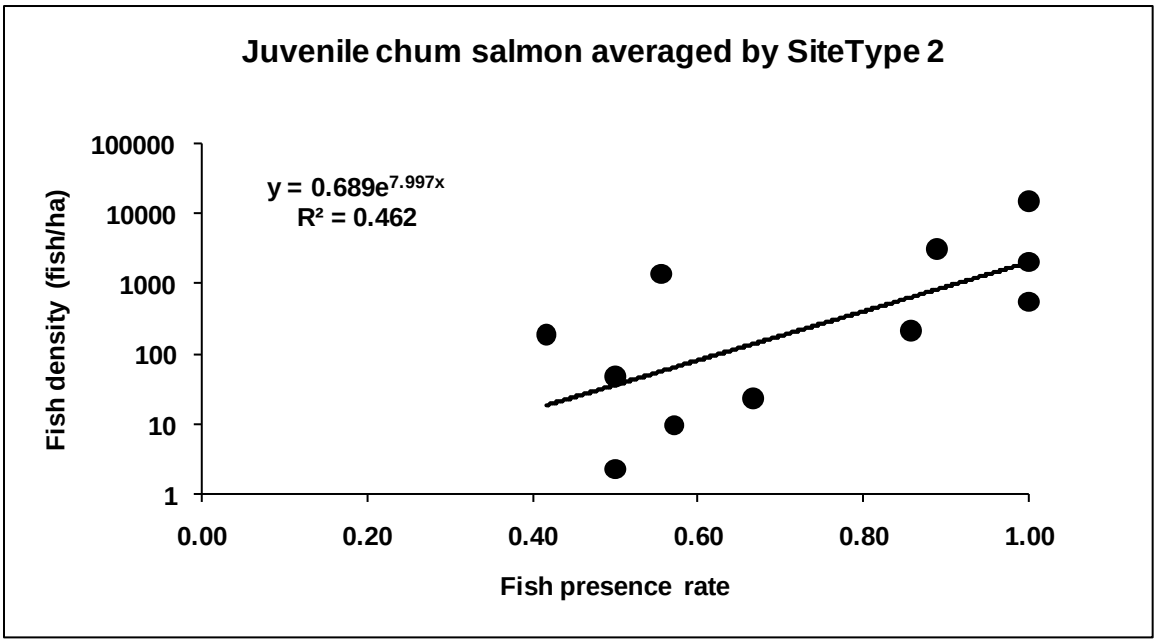

Figure 12. Correlation between presence and abundance of juvenile chum salmon in San Juan Islands shoreline habitats when beach seine sets are averaged by SiteType2.

Pink salmon

GLM testing for effects of fixed factors revealed log-transformed pink density was influenced by season (year and month), by area within the San Juan Islands (SiteType2) and by shoreline type (Table 5). For our coarser-scaled space and habitat type variables, pink salmon density was influenced by encl/pass but not by int/ext.

Juvenile pink salmon arrived in the San Juan Islands by March, peaked in the month of May, and disappeared from shoreline areas by August (Figure 13, Panel B). Juvenile pink salmon were most abundant pocket beaches (Figure 13, Panel D).

Fish size increased monthly (Figure 14). Most juvenile pink salmon are fry-sized when they arrive in the San Juan Islands, but the length distribution does include some larger fish.

Regression analysis revealed juvenile pink salmon presence and density was positively correlated in the San Juan Islands when beach seine sets were averaged by SiteType2 (Figure 15). Thus, shorelines in the San Juan Islands with higher juvenile pink presence rates also had greater abundance levels of juvenile pink abundance. The regression relation is a power function.

Table 5. ANOVA results from Generalized Linear Model effects testing for log-transformed juvenile pink salmon density.

Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
Year	61.828	1	61.828	95.661	0.000
Month	16.307	1	16.307	25.230	0.000
SiteType2	3.484	1	3.484	5.390	0.020
Shoreline type	23.273	4	5.818	9.002	0.000
Int_Ext	0.329	1	0.329	0.516	0.473
Encl_Pass	29.881	1	29.881	46.929	0.000

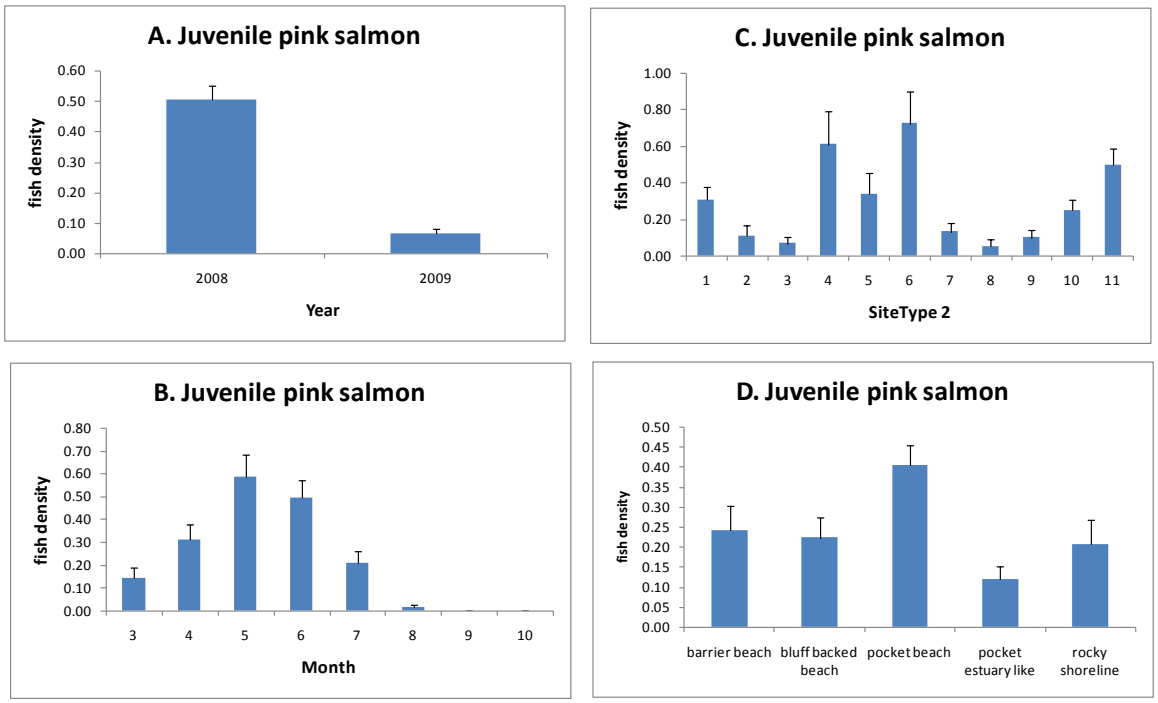

Figure 13. Relationship between average juvenile pink salmon densities (log-transformed fish per hectare) and year (Panel A), month (Panel B), SiteType2 (Panel C), and shoreline type (Panel D). Results are from 80 beach seine sites throughout the San Juan Islands in 2008 and 2009. Error bars are standard error. A description and location of the areas within the San Juan Islands coinciding to specific Sitetype2 codes (Panel C) are shown in Table 1 and Figure 2.

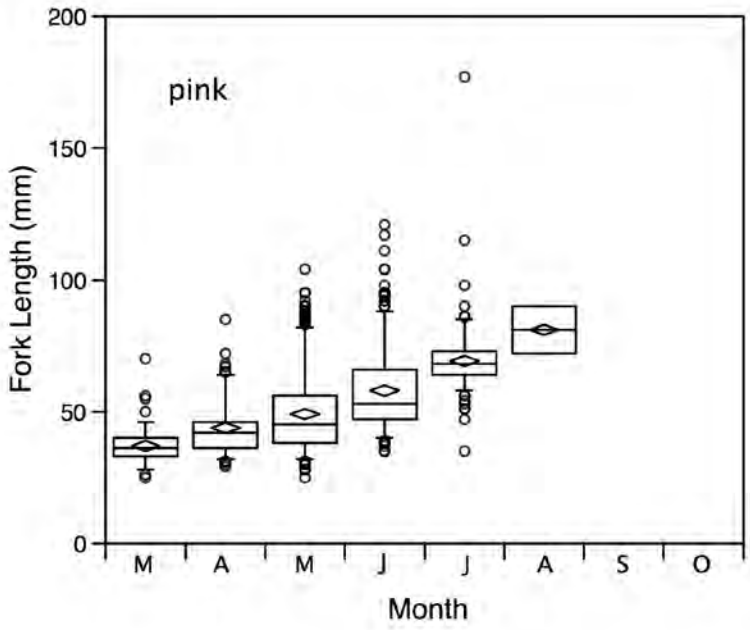

Figure 14. Box plot of fish size for juvenile pink salmon caught in shoreline habitats of the San Juan Islands, 2008-2009. Diamonds are means, and boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Circles are outliers.

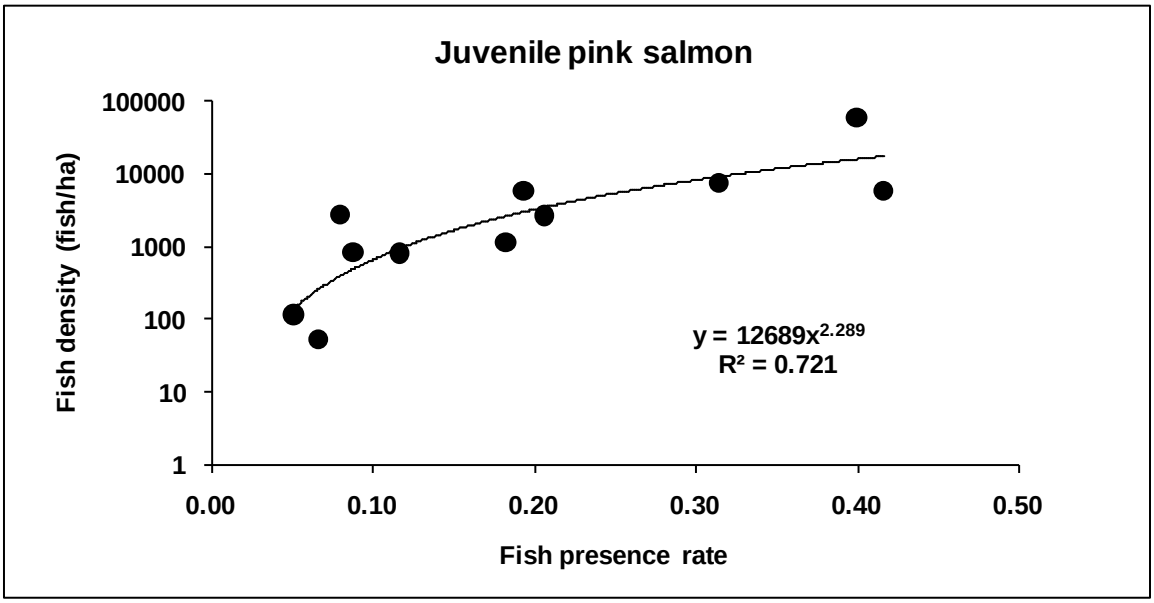

Figure 15. Correlation between presence and abundance of juvenile pink salmon in San Juan Islands shoreline habitats when beach seine sets are averaged by SiteType2.

Pacific herring

GLM testing for effects of fixed factors revealed log-transformed herring density was influenced by season (year and month), by area within the San Juan Islands (SiteType2) and by shoreline type (Table 6). For our coarser-scaled space and habitat type variables, herring density was influenced by int/ext but not by encl/pass.

Herring were present in shoreline habitats of the San Juan Islands throughout our study period, but abundance levels were substantially greater in October than any other month (Figure 16, Panel B). No herring were caught at any site within one SiteType2, number 11 (Figure 16, Panel C). Herring were most abundant associated with pocket beaches and rocky shorelines (Figure 16, Panel D).

Most herring measured were juvenile-sized (Figure 17). Overall, fish size increased monthly, but starting in July a new age class of young-of-the-year herring was found in shoreline habitats.

Regression analysis revealed herring presence and density to be positively correlated in the San Juan Islands when beach seine sets were averaged by SiteType2 (Figure 18). Thus, shorelines in the San Juan Islands with higher herring presence rates also have more herring. The regression relation is a power function.

Table 6. ANOVA results from Generalized Linear Model effects testing for log-transformed juvenile Pacific herring density.

Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
Year	7.896	1	7.896	18.388	0.000
Month	14.803	1	14.803	34.474	0.000
SiteType2	4.173	1	4.173	9.719	0.002
Shoreline type	6.710	4	1.678	3.907	0.004
Int_Ext	3.063	1	3.063	7.063	0.008
Encl_Pass	0.579	1	0.579	1.335	0.248

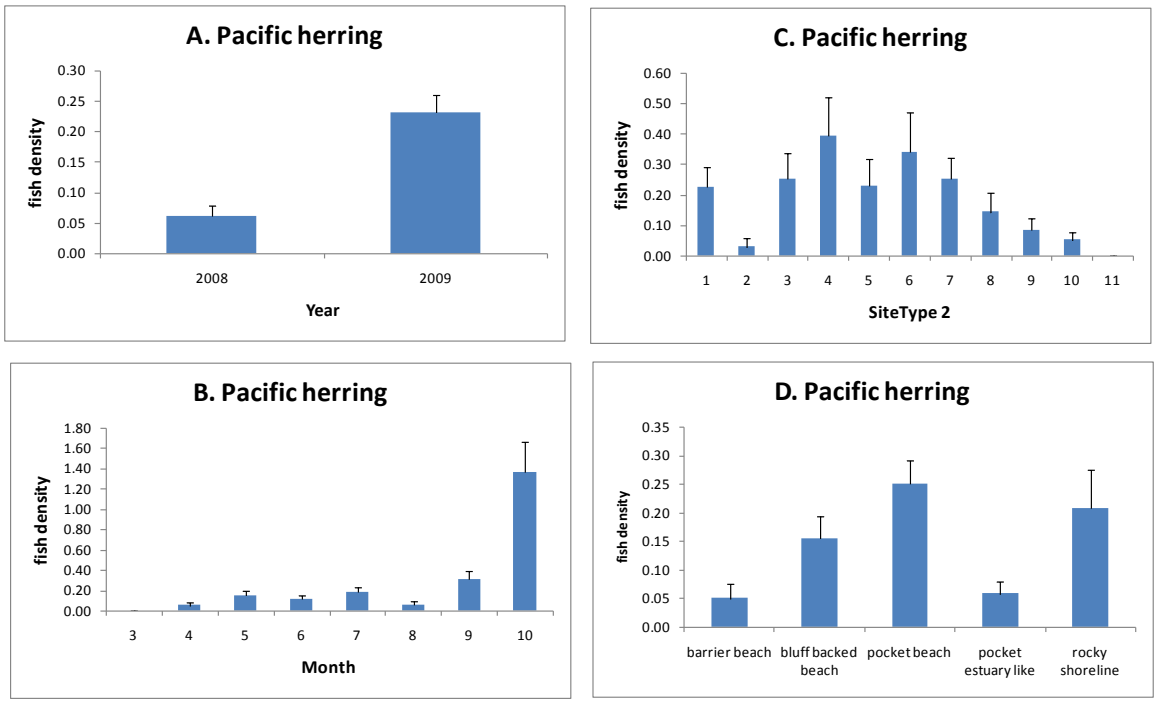

Figure 16. Relationship between average juvenile Pacific herring densities (log-transformed fish per hectare) and year (Panel A), month (Panel B), SiteType2 (Panel C), and shoreline type (Panel D). Results are from 80 beach seine sites throughout the San Juan Islands in 2008 and 2009. Error bars are standard error. A description and location of the areas within the San Juan Islands coinciding to specific SiteType2 codes (Panel C) are shown in Table 1 and Figure 2.

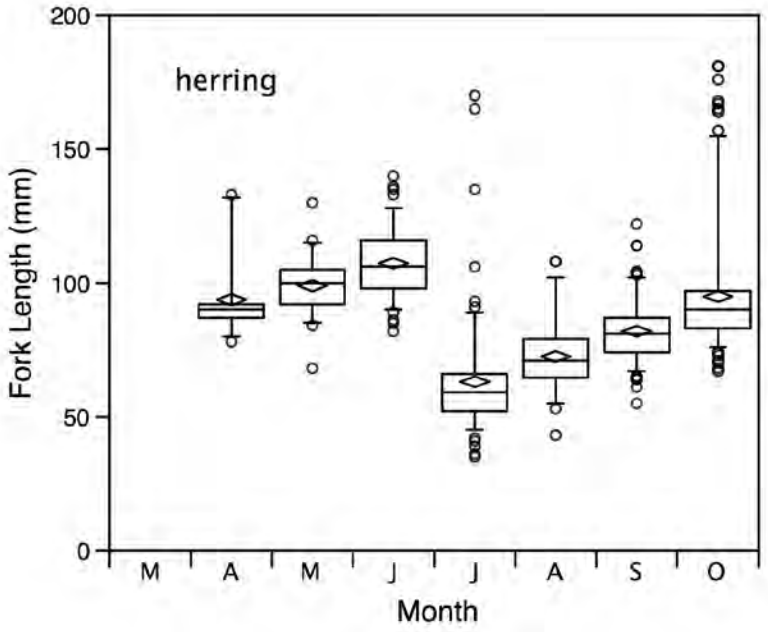

Figure 17. Box plot of fish size for Pacific herring caught in shoreline habitats of the San Juan Islands, 2008-2009. Diamonds are means, and boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Circles are outliers.

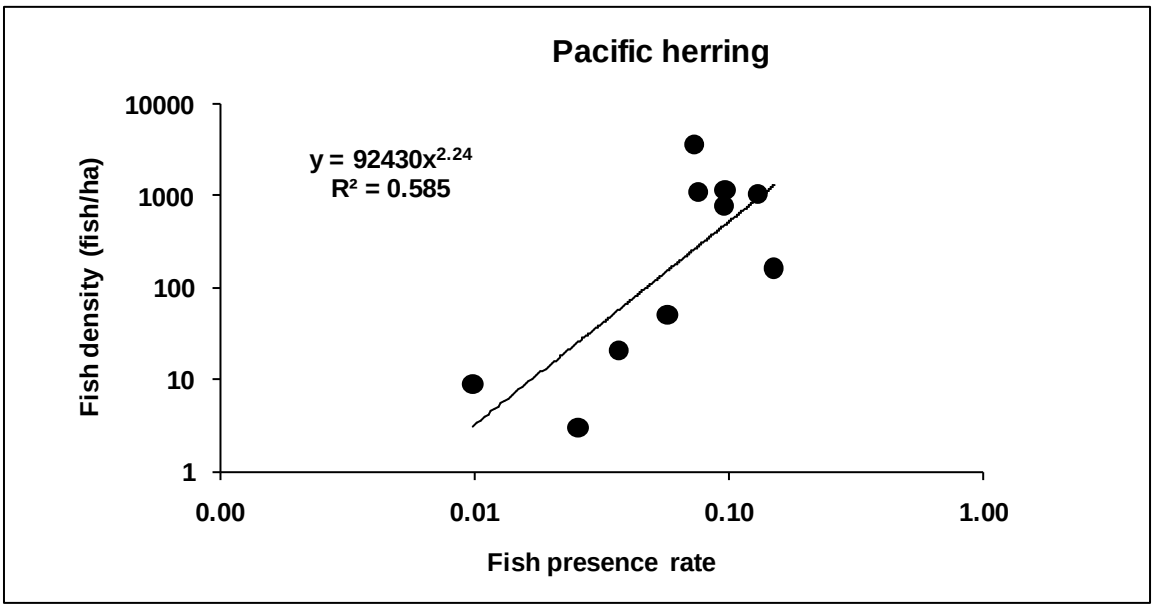

Figure 18. Correlation between presence and abundance of juvenile Pacific herring in San Juan Islands shoreline habitats when beach seine sets are averaged by SiteType2.

Surf smelt

GLM testing for effects of fixed factors revealed log-transformed smelt density was influenced by season (year but not month), by area within the San Juan Islands (SiteType2), and by shoreline type (Table 7). For our coarser-scaled space and habitat type variables, smelt density was influenced by both int/ext and encl/pass.

Surf smelt were present in shoreline habitats of the San Juan Islands throughout our study period (Figure 19, Panel B). Surf smelt were most abundant in barrier beaches and pocket beaches and least abundant in rocky shorelines (Figure 19, Panel D).

Most smelt measured were juvenile-sized through July, after which both juvenile- and adult-sized fish were present in shoreline habitats (Figure 20).

Regression analysis revealed that smelt presence and density were positively correlated in the San Juan Islands when beach seine sets were averaged by SiteType2 (Figure 21). Thus, shorelines in the San Juan Islands with higher smelt presence rates are also higher in smelt abundance. The regression relation is a power function.

Table 7. ANOVA results from Generalized Linear Model effects testing for log-transformed juvenile surf smelt density.

Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
Year	14.244	1	14.244	17.785	0.000
Month	0.388	1	0.388	0.485	0.486
SiteType2	10.871	1	10.871	13.573	0.000
Shoreline type	11.901	4	2.975	3.715	0.005
Int_Ext	8.757	1	8.757	10.908	0.001
Encl_Pass	18.565	1	18.565	23.124	0.000

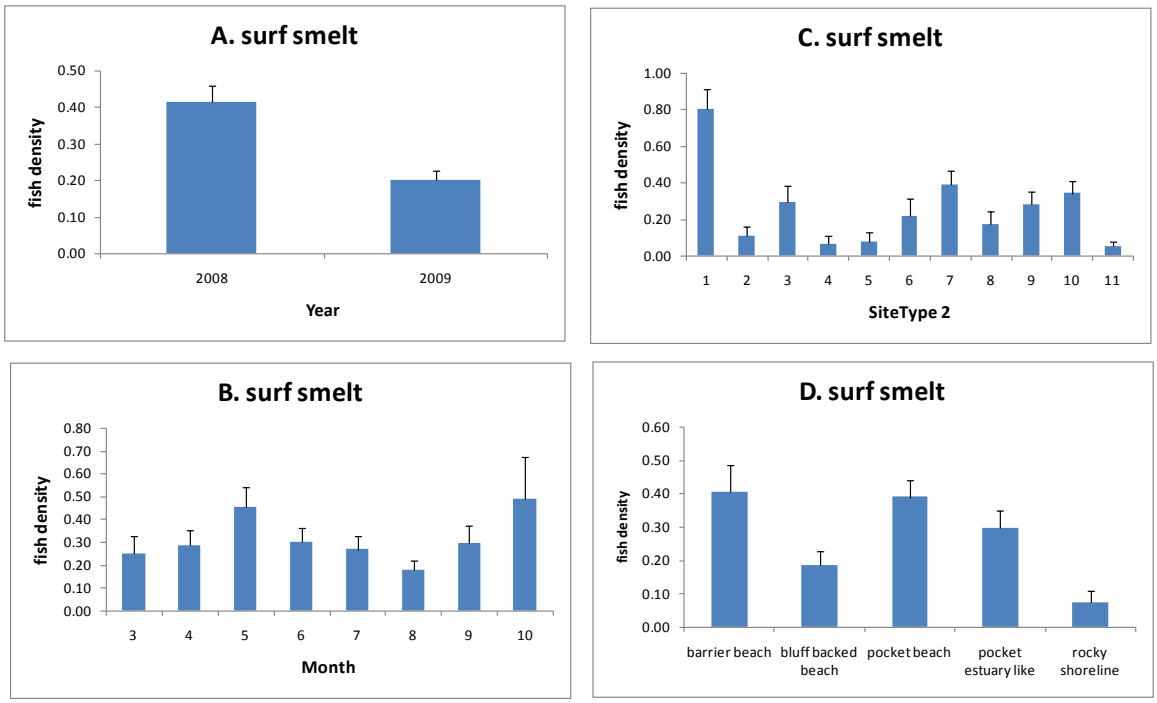

Figure 19. Relationship between average juvenile surf smelt densities (log-transformed fish per hectare) and year (Panel A), month (Panel B), SiteType2 (Panel C), and shoreline type (Panel D). Results are from 80 beach seine sites throughout the San Juan Islands in 2008 and 2009. Error bars are standard error. A description and location of the areas within the San Juan Islands coinciding to specific SiteType2 codes (Panel C) are shown in Table 1 and Figure 2.

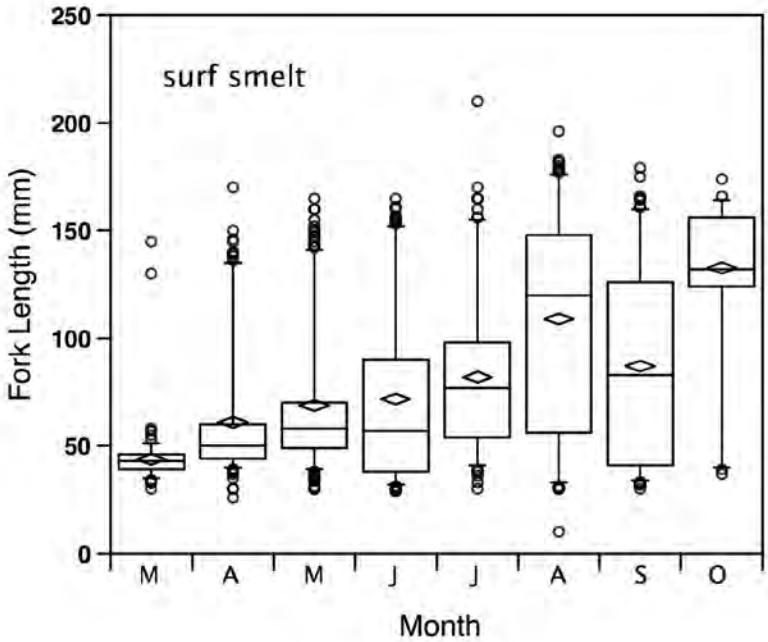

Figure 20. Box plot of fish size for juvenile surf smelt caught in shoreline habitats of the San Juan Islands, 2008-2009. Diamonds are means, and boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Circles are outliers.

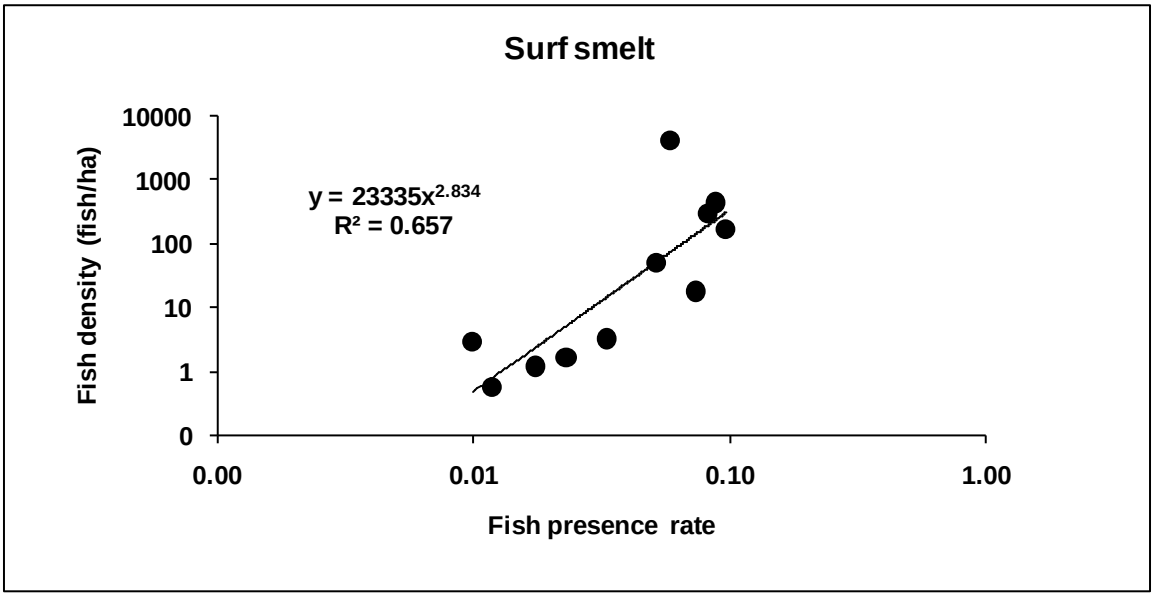

Figure 21. Correlation between presence and abundance of juvenile surf smelt in San Juan Islands shoreline habitats when beach seine sets are averaged by SiteType2.

Pacific sand lance

GLM testing for effects of fixed factors revealed log-transformed sand lance density was influenced by season (year and month), by area within the San Juan Islands (SiteType2), and by shoreline type (Table 8). For our coarser-scaled space and habitat type variables, sand lance density was influenced by encl/pass but not by int/ext.

Sand lance were present in shoreline habitats of the San Juan Islands throughout our study period (Figure 22, Panel B). Sand lance were most abundant in barrier beaches, bluff backed beaches, and pocket beaches (Figure 22, Panel D).

Juvenile- and adult-sized sand lance were found in shoreline habitats from March through June, but after June a new cohort of smaller (possibly young-of-the-year) sand lance dominated our catch (Figure 23).

Regression analysis revealed sand lance presence and density to be positively correlated in the San Juan Islands when beach seine sets were averaged by SiteType2 (Figure 24). Thus, shorelines in the San Juan Islands with higher sand lance presence rates also had higher numbers of sand lance. The regression relation is a power function.

Table 8. ANOVA results from Generalized Linear Model effects testing for log-transformed juvenile Pacific sand lance density.

Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
Year	19.193	1	19.193	22.645	0.000
Month	9.817	1	9.817	11.582	0.001
SiteType2	4.980	1	4.980	5.876	0.015
Shoreline type	30.989	4	7.747	9.140	0.000
Int_Ext	1.700	1	1.700	1.978	0.160
Encl_Pass	12.406	1	12.406	14.435	0.000

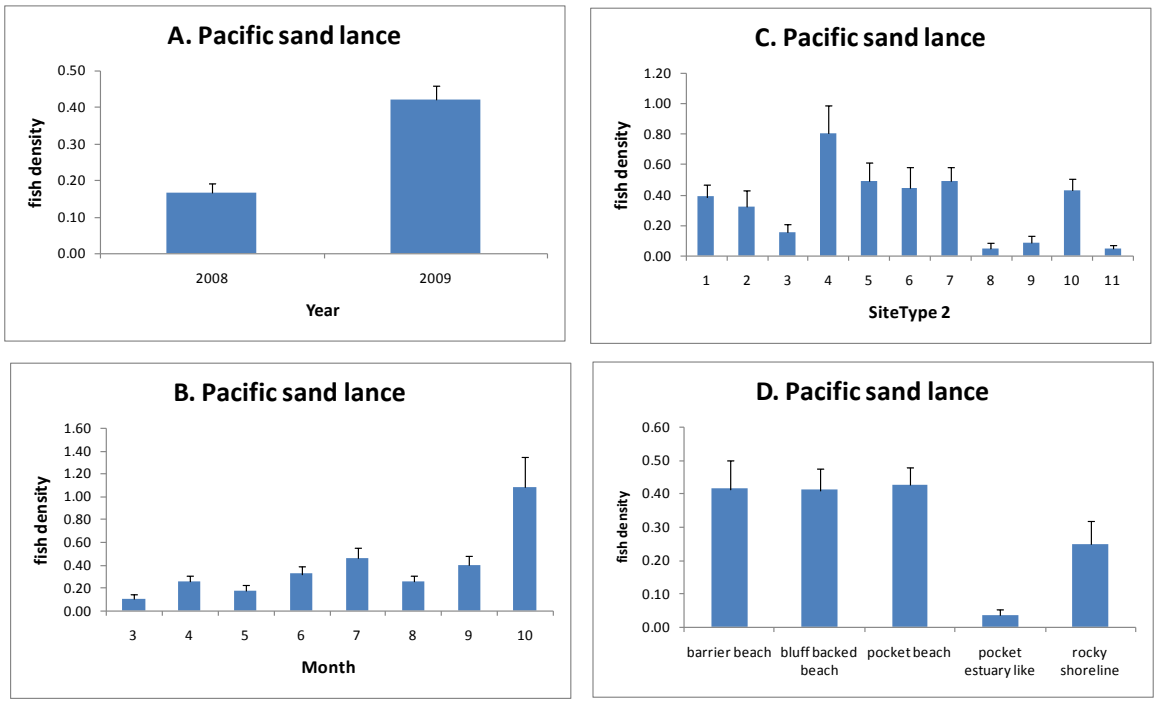

Figure 22. Relationship between average juvenile Pacific sand lance densities (log-transformed fish per hectare) and year (Panel A), month (Panel B), SiteType2 (Panel C), and shoreline type (Panel D). Results are from 80 beach seine sites throughout the San Juan Islands in 2008 and 2009. Error bars are standard error. A description and location of the areas within the San Juan Islands coinciding to specific SiteType2 codes (Panel C) are shown in Table 1 and Figure 2.

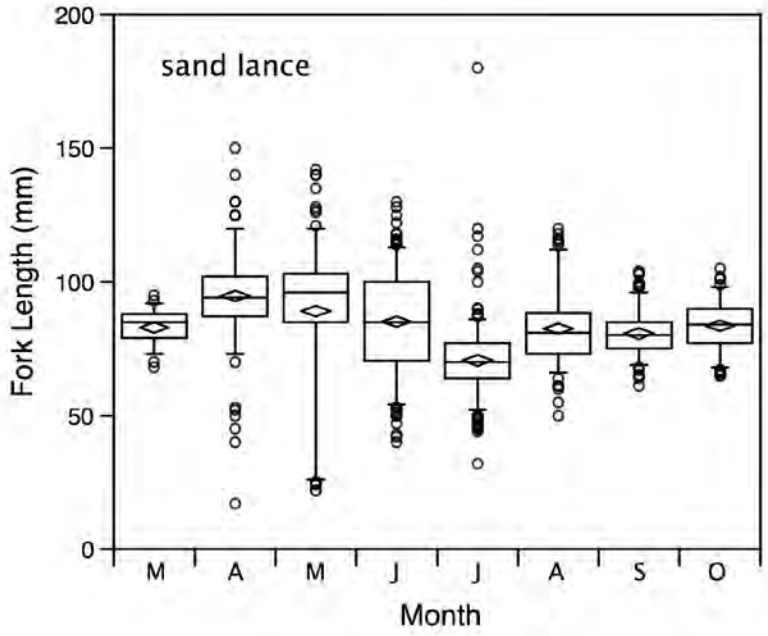

Figure 23. Box plot of fish size for Pacific sand lance caught in shoreline habitats of the San Juan Islands, 2008-2009. Diamonds are means, and boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Circles are outliers.

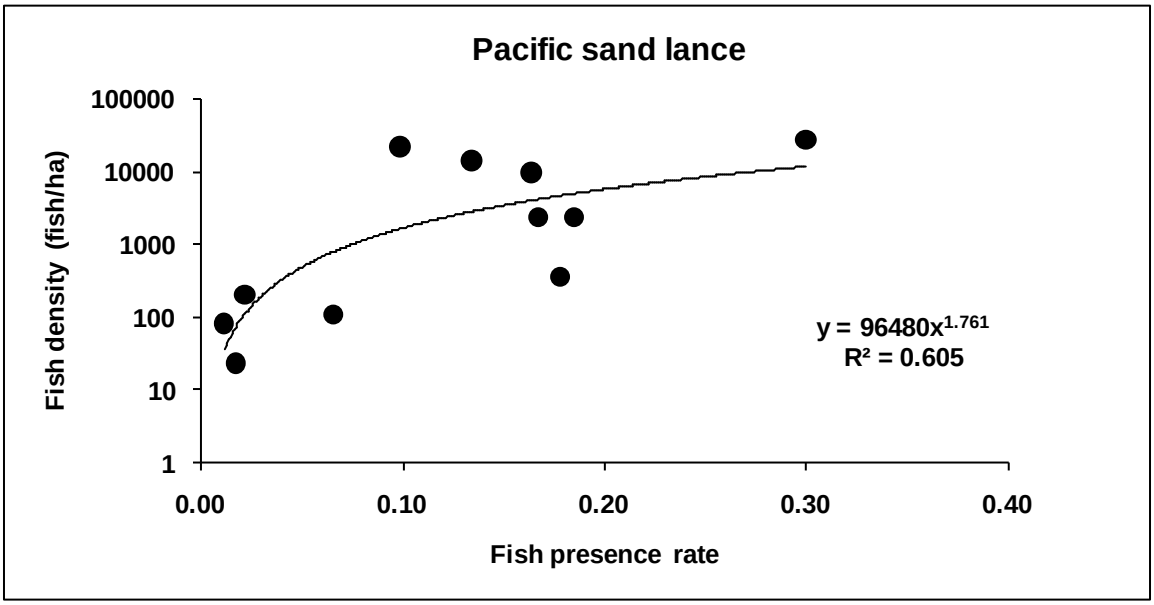

Figure 24. Correlation between presence and abundance of juvenile Pacific sand lance in San Juan Islands shoreline habitats when beach seine sets are averaged by SiteType2.

Lingcod and greenling

We combined lingcod and greenling catches as one group for abundance analyses because they are members of a single taxonomic family (Hexagrammidae). GLM testing for effects of fixed factors revealed log-transformed greenling/lingcod density was influenced by season (year and month), by area within the San Juan Islands (SiteType2), and by shoreline type (Table 9). For our coarser-scaled space and habitat type variables, greenling/lingcod density was influenced by encl/pass but not by int/ext.

Greenling/lingcod were present in shoreline habitats of the San Juan Islands throughout our study period, peaking in June and July (Figure 25, Panel B). Greenling/lingcod were most abundant in pocket beaches, but were relatively abundant in all shoreline types except pocket estuaries (Figure 25, Panel D).

Most greenling and lingcod caught were likely young-of-the-year juveniles from the previous winter (Figure 26). Greenling and lingcod each showed a steady seasonal increase in length.

Regression analysis revealed greenling/lingcod presence and density to be positively correlated in the San Juan Islands when beach seine sets werere averaged by SiteType2 (Figure 27). Thus, shorelines in the San Juan Islands with the greatest greenling/lingcod presence rates also had the greatest abundance of greenling/lingcod. The regression relation is a power function.

Table 9. ANOVA results from Generalized Linear Model effects testing for log-transformed juvenile lingcod and greenling density.

Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
Year	11.435	1	11.435	10.025	0.002
Month	14.658	1	14.658	12.850	0.000
SiteType2	12.254	1	12.254	10.742	0.001
Shoreline type	172.241	4	43.060	37.749	0.000
Int_Ext	0.290	1	0.290	0.256	0.613
Encl_Pass	162.233	1	162.233	143.124	0.000

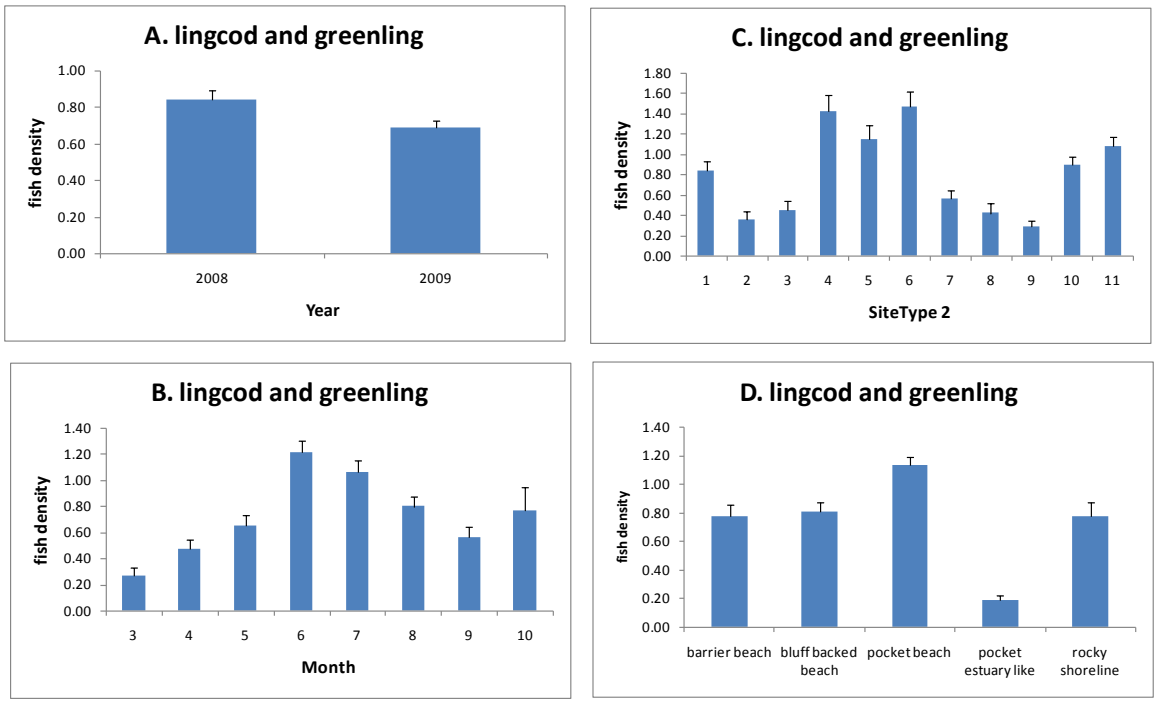

Figure 25. Relationship between average juvenile lingcod and greenling densities (log-transformed fish per hectare) and year (Panel A), month (Panel B), SiteType2 (Panel C), and shoreline type (Panel D). Results are from 80 beach seine sites throughout the San Juan Islands in 2008 and 2009. Error bars are standard error. A description and location of the areas within the San Juan Islands coinciding to specific Sitetype2 codes (Panel C) are shown in Table 1 and Figure 2.

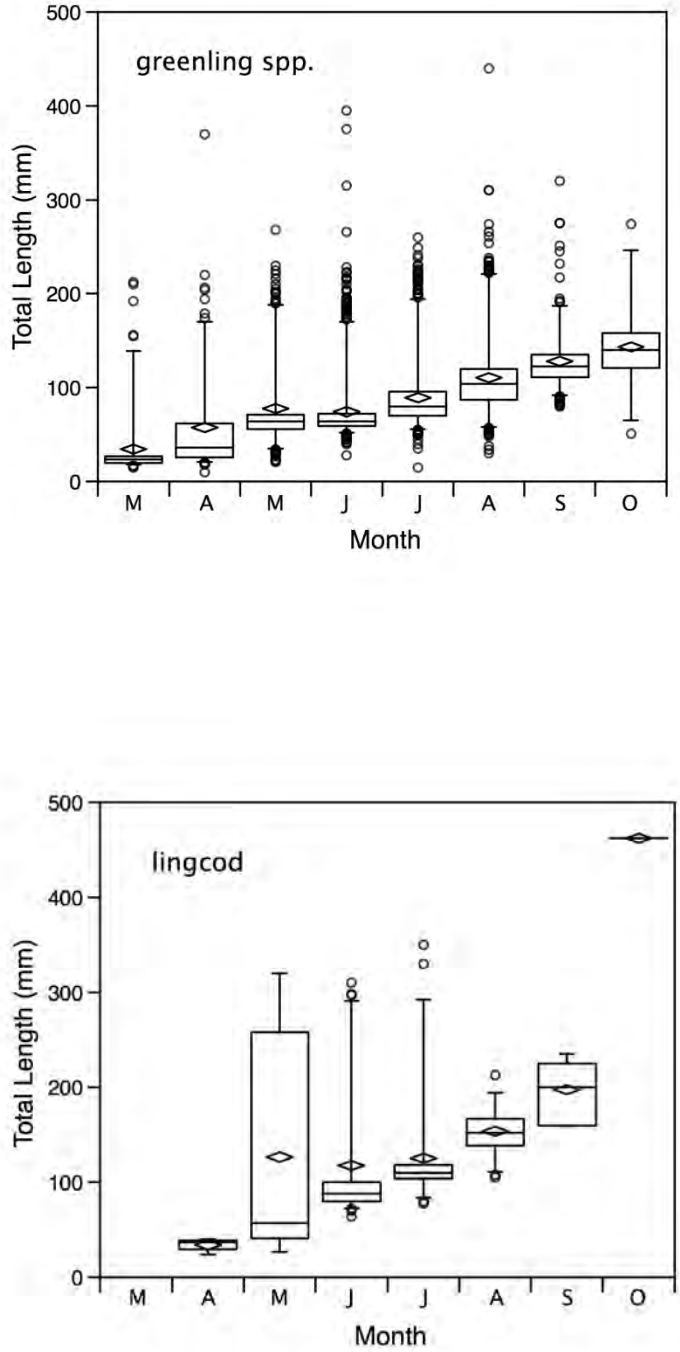

Figure 26. Box plot of fish size for greenling (top panel) and juvenile lingcod (bottom panel) in shoreline habitats of the San Juan Islands, 2008-2009. Diamonds are means, and boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Circles are outliers.

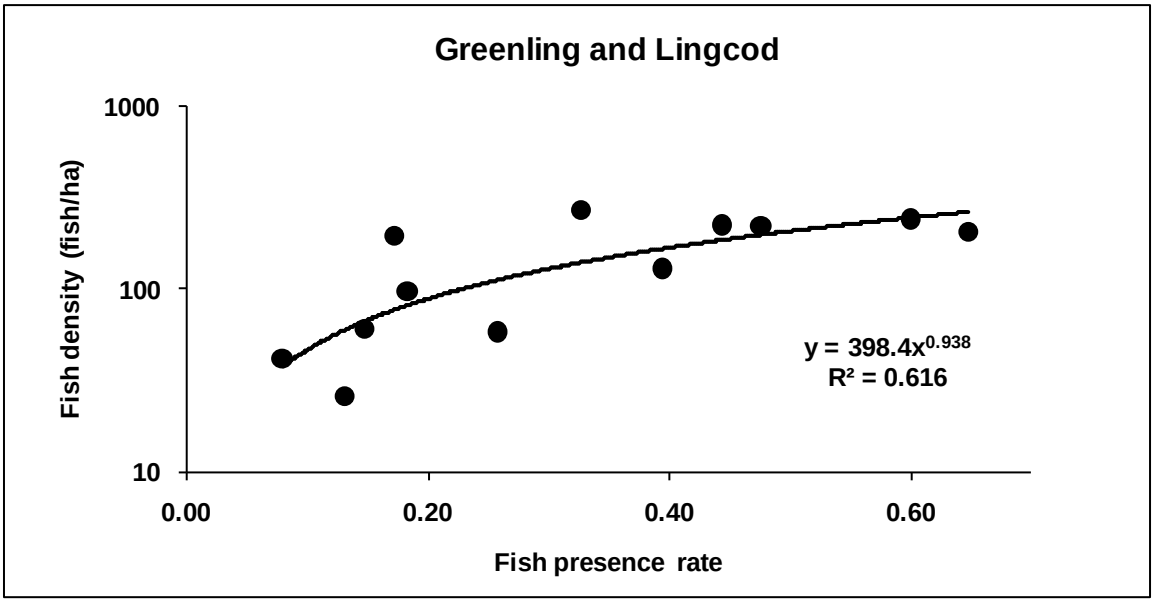

Figure 27. Correlation between presence and abundance of juvenile lingcod and greenling in San Juan Islands shoreline habitats when beach seine sets are averaged by SiteType2.

Fish Probability of Presence Mapping

Chinook salmon

The estimated values of wild juvenile Chinook salmon presence probability ranged from 0.027 to 0.625, a 23-fold difference (Table 10). Two of the eleven SiteType2s had juvenile Chinook salmon in caught at all sites. Pocket beaches had the highest juvenile Chinook salmon presence rate, while pocket estuaries had the lowest.

Table 10. Fish probability of presence matrices for high (top table) and low (bottom table) resolution models of wild (unmarked) juvenile Chinook salmon. Fish presence rate results are shown in bold. Indices of fish presence probability are not bolded. The maximum and minimum value for each model is in *italics*.

			SiteType3 (Shoreline Type)				
			barrier beach	**bluff backed beach**	**pocket beach**	**pocket estuary like**	**rocky shoreline**
		HRM Fish presence rate:	**0.273**	**0.389**	**0.625**	**0.190**	**0.250**
SiteType2	**Str Juan de Fuca - S Lopez Is**	**0.286**	0.078	0.111	0.179	0.054	0.071
	Str Juan de Fuca - San Juan Is	**0.429**	0.117	0.167	0.268	0.082	0.107
	Haro Strait NE	**0.444**	0.121	0.173	0.278	0.085	0.111
	Waldron Is - President Channel	**1.000**	0.273	0.389	*0.625*	0.190	0.250
	Rosario NW	**0.500**	0.136	0.194	0.313	0.095	0.125
	Rosario Strait SW	**1.000**	0.273	0.389	*0.625*	0.190	0.250
	Blakely Sound - Lopez Sound	**0.250**	0.068	0.097	0.156	0.048	0.063
	East Sound	**0.500**	0.136	0.194	0.313	0.095	0.125
	Deer Harbor - West Sound	**0.143**	0.039	0.056	0.089	*0.027*	0.036
	San Juan Channel South	**0.167**	0.045	0.065	0.104	0.032	0.042
	San Juan Channel North	**0.375**	0.102	0.146	0.234	0.071	0.094

		Enclosure	**Passage**
	LRM Fish presence rate:	**0.258**	**0.451**
Interior	**0.227**	*0.059*	0.102
Exterior	**0.553**	0.143	*0.249*

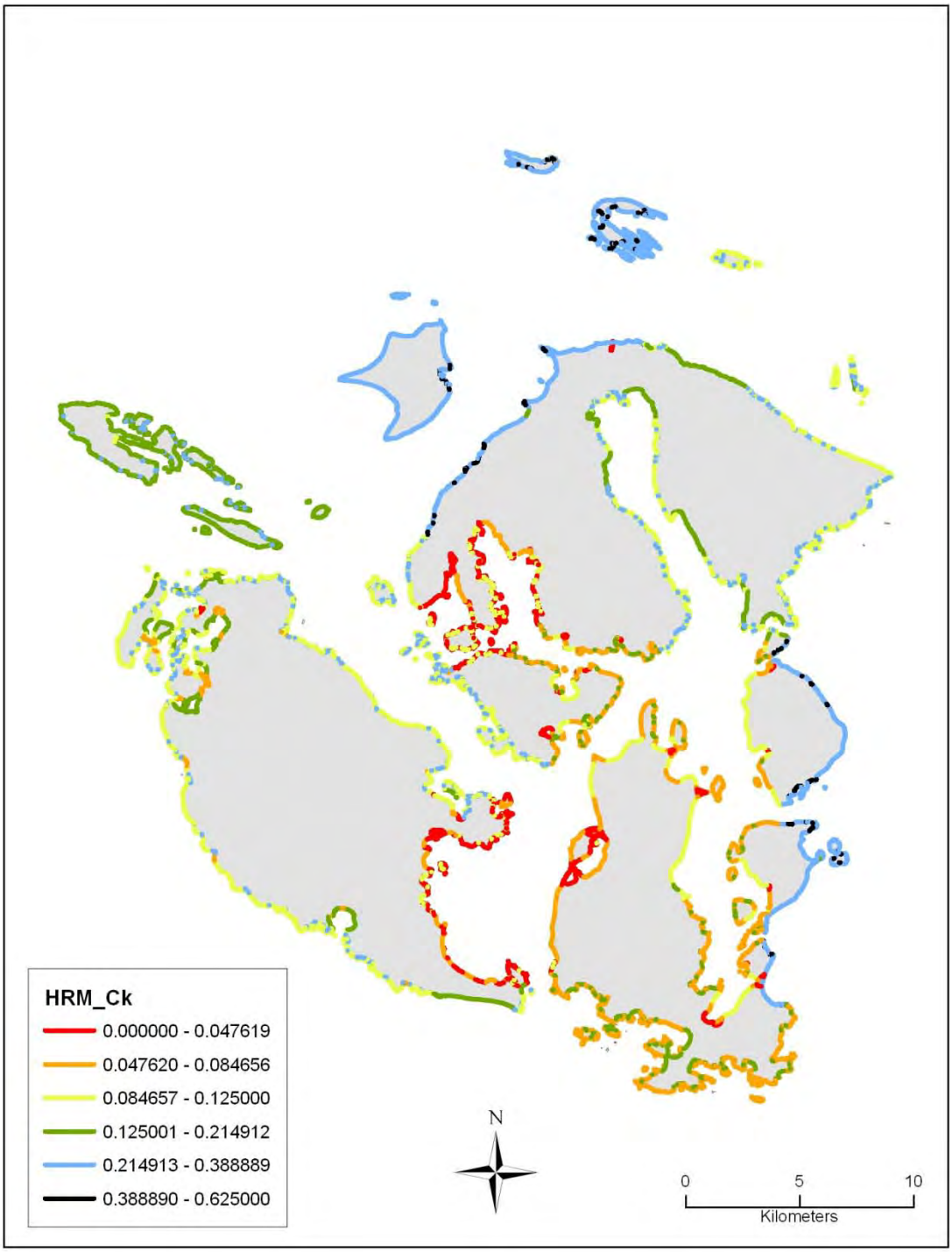

Figure 28. Fish presence probability for wild (unmarked) juvenile Chinook salmon for shoreline habitats (high resolution model).

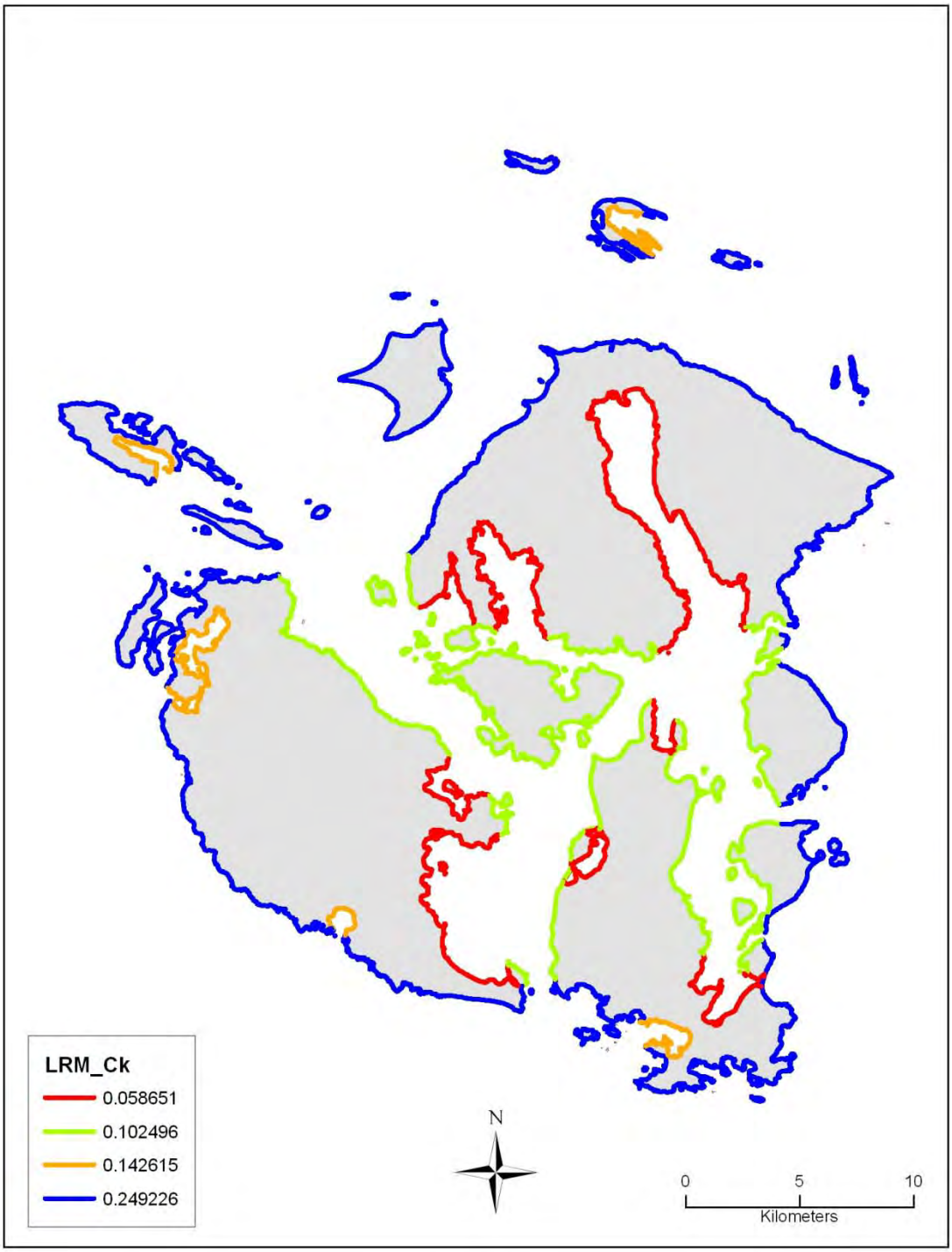

Figure 29. Fish presence probability for wild (unmarked) juvenile Chinook salmon for shoreline habitats (low resolution model).

Chum salmon

The estimated values of juvenile chum salmon presence probability ranged from 0.152 to 0.960, a 6-fold difference (Table 11). Three of the eleven SiteType2s had chum caught at all sites. All remaining SiteType2s – except Blakely Sound / Lopez Sound – had relatively high (0.500 or greater) fish presence rates. Pocket beaches had the highest juvenile chum salmon presence rate.

Table 11. Fish probability of presence matrices for high (top table) and low (bottom table) resolution models of juvenile chum salmon. Fish presence rate results are shown in bold. Indices of fish presence probability are not bolded. The maximum and minimum value for each model is in *italics*.

			SiteType3 (Shoreline Type)				
			barrier beach	**bluff backed beach**	**pocket beach**	**pocket estuary like**	**rocky shoreline**
		HRM Fish presence rate:	**0.364**	**0.722**	**0.960**	**0.450**	**0.750**
SiteType2	**Str Juan de Fuca - S Lopez Is**	**0.857**	0.312	0.619	0.823	0.386	0.643
	Str Juan de Fuca - San Juan Is	**0.667**	0.242	0.481	0.640	0.300	0.500
	Haro Strait NE	**0.556**	0.202	0.401	0.533	0.250	0.417
	Waldron Is - President Channel	**1.000**	0.364	0.722	*0.960*	0.450	0.750
	Rosario NW	**1.000**	0.364	0.722	*0.960*	0.450	0.750
	Rosario Strait SW	**1.000**	0.364	0.722	*0.960*	0.450	0.750
	Blakely Sound - Lopez Sound	**0.417**	*0.152*	0.301	0.400	0.188	0.313
	East Sound	**0.500**	0.182	0.361	0.480	0.225	0.375
	Deer Harbor - West Sound	**0.571**	0.208	0.413	0.549	0.257	0.429
	San Juan Channel South	**0.500**	0.182	0.361	0.480	0.225	0.375
	San Juan Channel North	**0.889**	0.323	0.642	0.853	0.400	0.667

		Enclosure	**Passage**
	LRM Fish presence rate:	**0.477**	**0.921**
Interior	**0.568**	*0.271*	0.523
Exterior	**0.816**	0.389	*0.751*

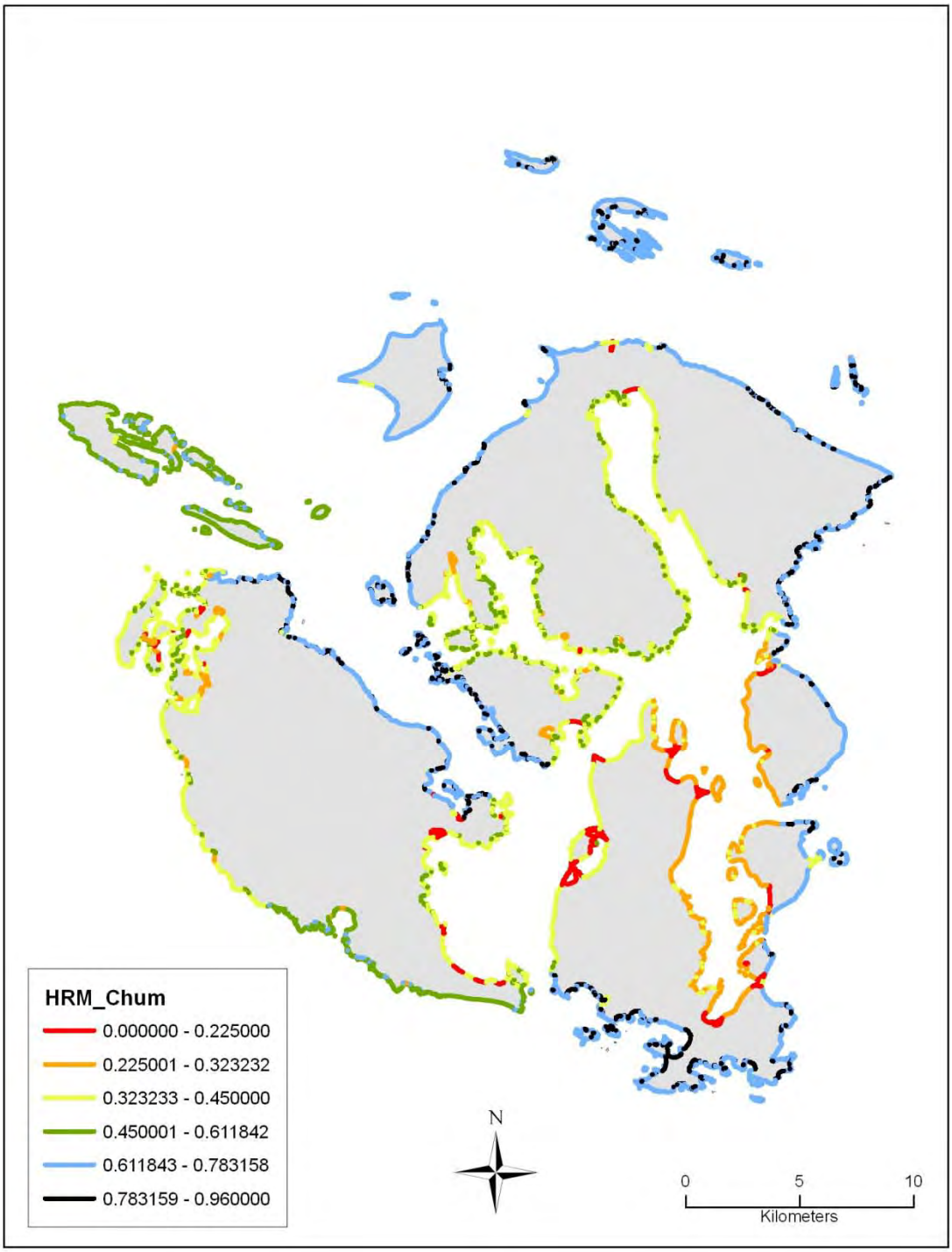

Figure 30. Fish presence probability for juvenile chum salmon for shoreline habitats (high resolution model).

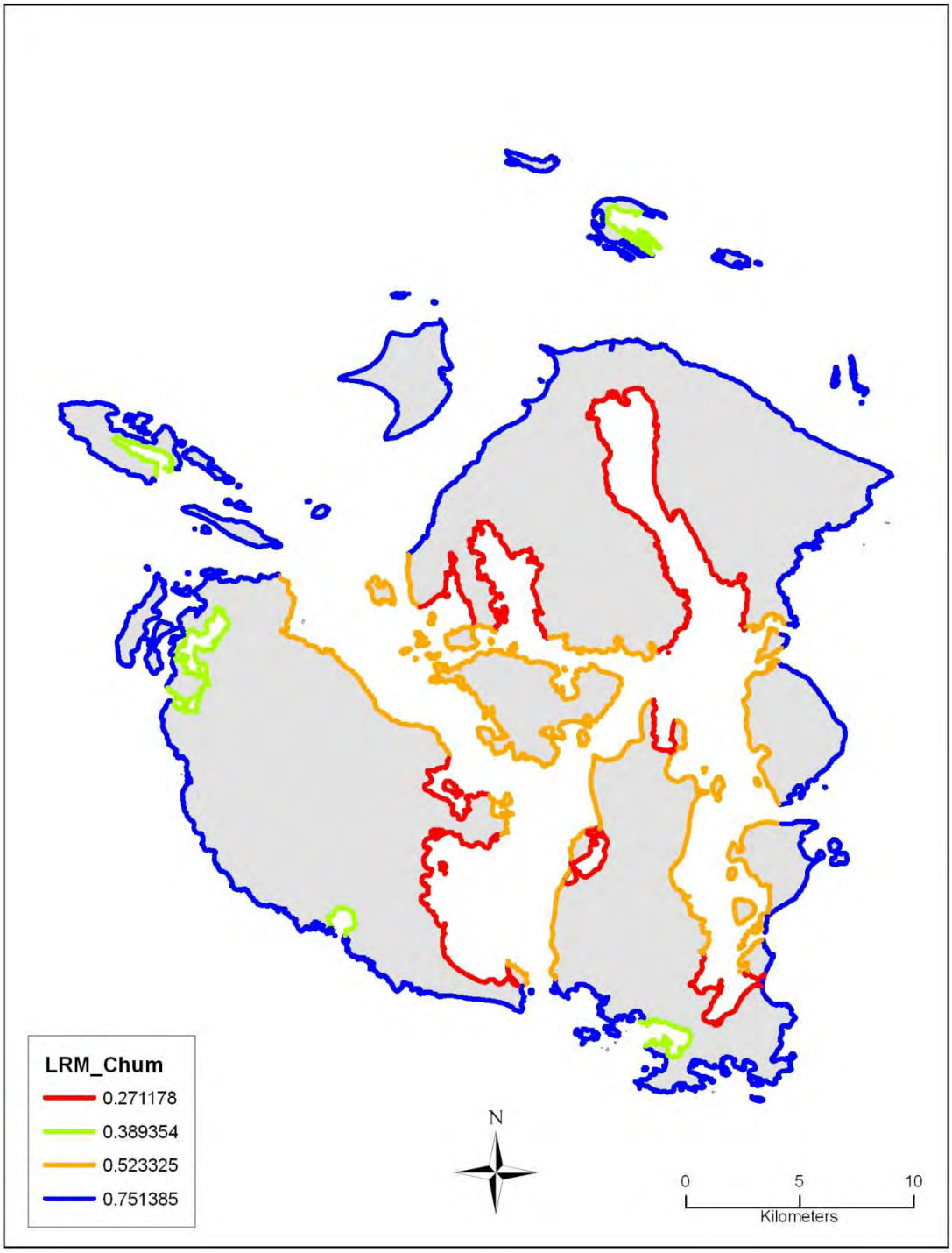

Figure 31. Fish presence probability for juvenile chum salmon for shoreline habitats (low resolution model).

Pink salmon

The estimated values of juvenile pink salmon presence probability ranged from 0.07 to 0.857, a 12-fold difference (Table 12). All but one SiteType2 (Haro Strait NE) had high (0.500 or greater) juvenile pink salmon presence rates. Pocket beaches, bluff backed beaches, and rocky shorelines had the highest juvenile pink salmon presence rates.

Table 12. Fish probability of presence matrices for high (top table) and low (bottom table) resolution models of juvenile pink salmon. Fish presence rate results are shown in bold. Indices of fish presence probability are not bolded. The maximum and minimum value for each model is in *italics*.

			SiteType3 (Shoreline Type)				
			barrier beach	**bluff backed beach**	**pocket beach**	**pocket estuary like**	**rocky shoreline**
		HRM Fish presence rate:	**0.545**	**0.800**	**0.818**	**0.421**	**0.857**
SiteType2	**Str Juan de Fuca - S Lopez Is**	**1.000**	0.545	0.800	0.818	0.421	*0.857*
	Str Juan de Fuca - San Juan Is	**0.500**	0.273	0.400	0.409	0.211	0.429
	Haro Strait NE	**0.167**	0.091	0.133	0.136	*0.070*	0.143
	Waldron Is - President Channel	**1.000**	0.545	0.800	0.818	0.421	*0.857*
	Rosario NW	**0.667**	0.364	0.533	0.545	0.281	0.571
	Rosario Strait SW	**1.000**	0.545	0.800	0.818	0.421	0.857
	Blakely Sound - Lopez Sound	**0.545**	0.298	0.436	0.446	0.230	0.468
	East Sound	**0.500**	0.273	0.400	0.409	0.211	0.429
	Deer Harbor - West Sound	**0.714**	0.390	0.571	0.584	0.301	0.612
	San Juan Channel South	**0.636**	0.347	0.509	0.521	0.268	0.545
	San Juan Channel North	**0.875**	0.477	0.700	0.716	0.368	0.750

		Enclosure	**Passage**
	LRM Fish presence rate:	**0.558**	**0.839**
Interior	**0.714**	0.399	*0.599*
Exterior	**0.641**	*0.358*	0.538

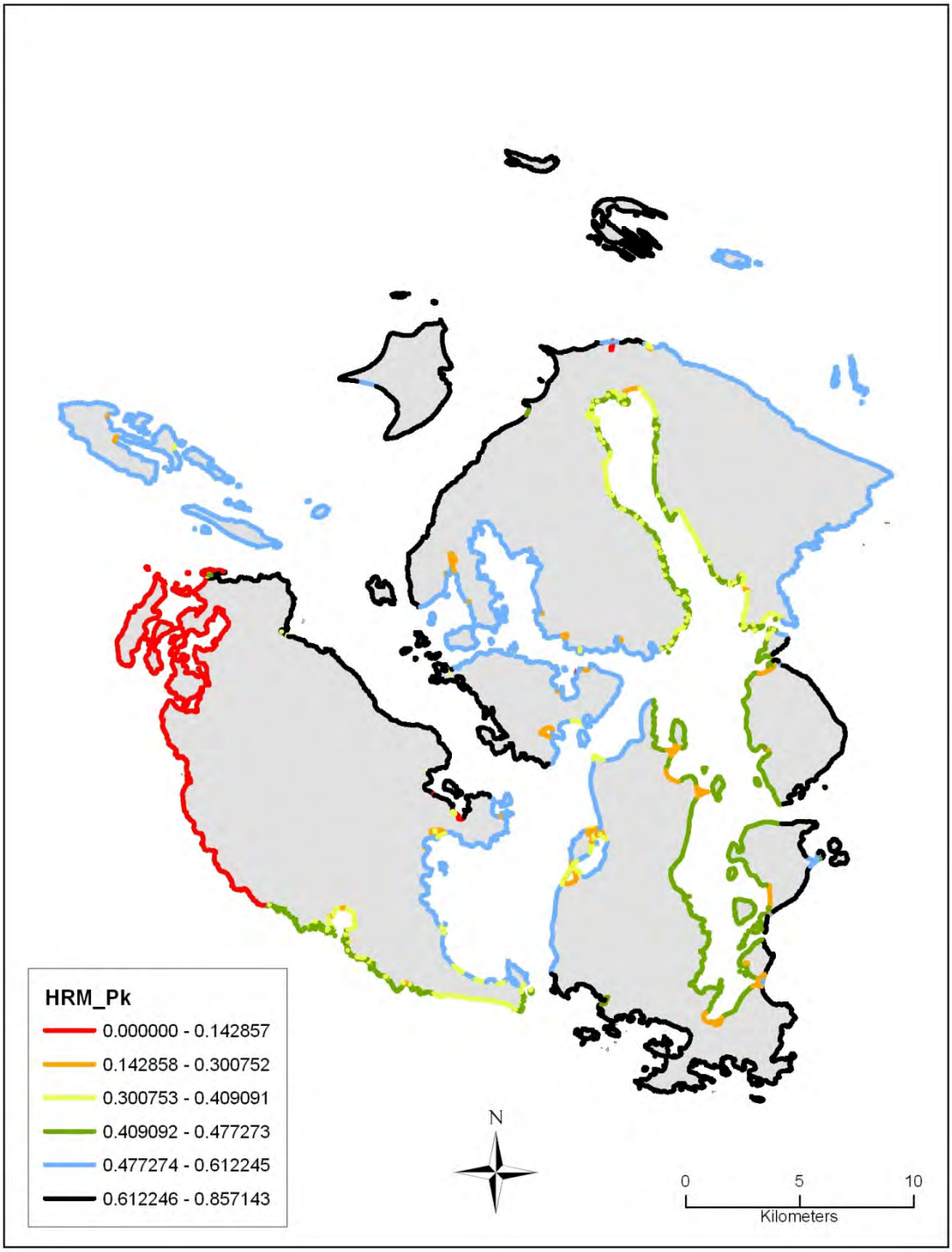

Figure 32. Fish presence probability for juvenile pink salmon for shoreline habitats (high resolution model).

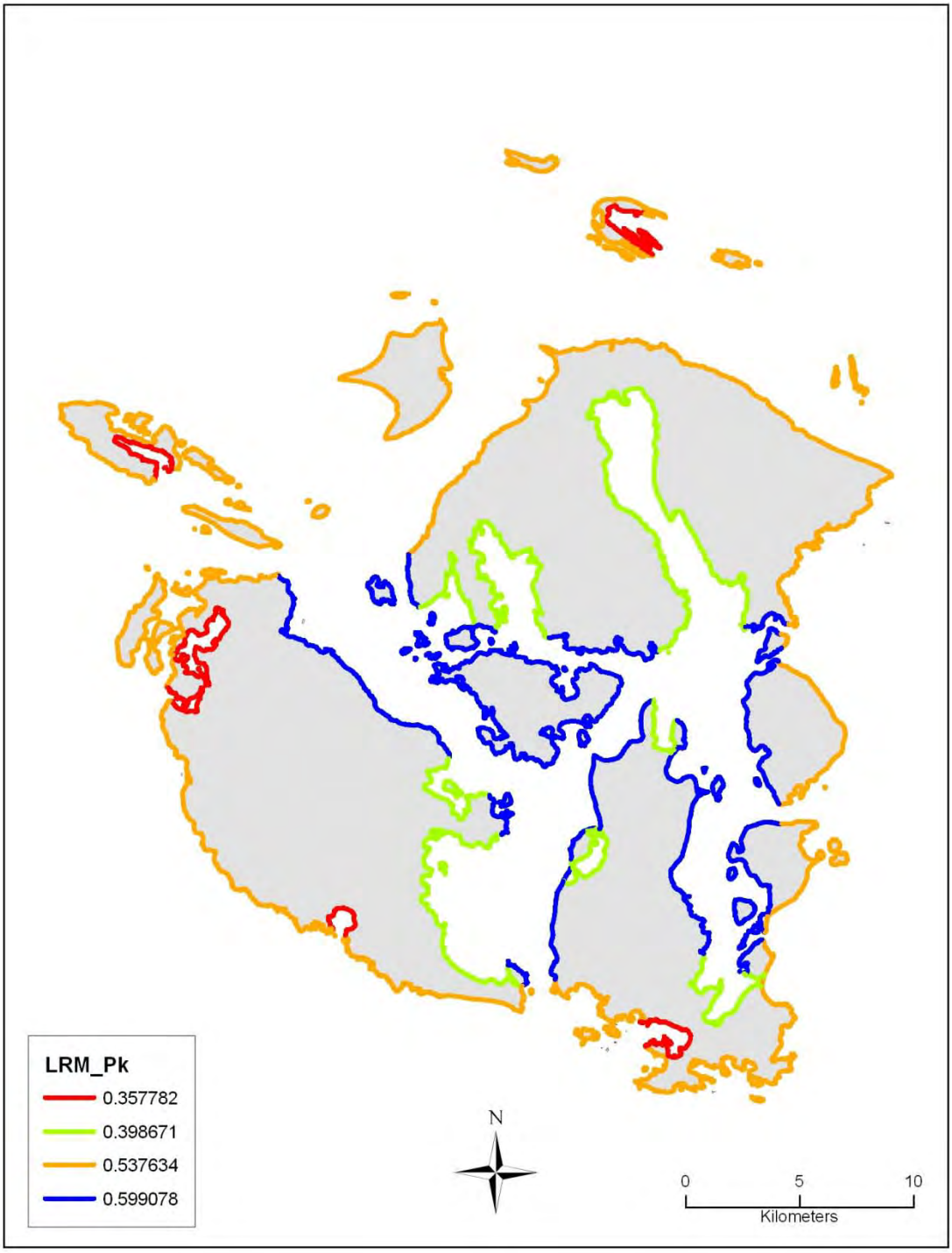

Figure 33. Fish presence probability for juvenile pink salmon for shoreline habitats (low resolution model).

Pacific herring

The estimated values of Pacific herring presence probability ranged from zero (0.000) to 0.625 (Table 13). One SiteType2 (Waldron-President Channel) had herring caught at all its sites, while no herring were caught in the San Juan Channel North area. Pocket estuaries had the lowest fish presence rate by shoreline type. The highest herring presence rate was in pocket beaches.

Table 13. Fish probability of presence matrices for high (top table) and low (bottom table) resolution models of juvenile Pacific herring. Fish presence rate results are shown in bold. Indices of fish presence probability are not bolded. The maximum and minimum value for each model is in *italics*.

			SiteType3 (Shoreline Type)				
			barrier beach	**bluff backed beach**	**pocket beach**	**pocket estuary like**	**rocky shoreline**
		HRM Fish presence rate:	**0.250**	**0.389**	**0.625**	**0.200**	**0.375**
SiteType2	**Str Juan de Fuca - S Lopez Is**	**0.429**	0.107	0.167	0.268	0.086	0.161
	Str Juan de Fuca - San Juan Is	**0.167**	0.042	0.065	0.104	0.033	0.063
	Haro Strait NE	**0.444**	0.111	0.173	0.278	0.089	0.167
	Waldron Is - President Channel	**1.000**	0.250	0.389	*0.625*	0.200	0.375
	Rosario NW	**0.667**	0.167	0.259	0.417	0.133	0.250
	Rosario Strait SW	**0.750**	0.188	0.292	0.469	0.150	0.281
	Blakely Sound - Lopez Sound	**0.417**	0.104	0.162	0.260	0.083	0.156
	East Sound	**0.333**	0.083	0.130	0.208	0.067	0.125
	Deer Harbor - West Sound	**0.429**	0.107	0.167	0.268	0.086	0.161
	San Juan Channel South	**0.308**	0.077	0.120	0.192	0.062	0.115
	San Juan Channel North	**0.000**	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*

		Enclosure	**Passage**
	LRM Fish presence rate:	**0.349**	**0.436**
Interior	**0.273**	*0.095*	0.119
Exterior	**0.526**	0.184	*0.229*

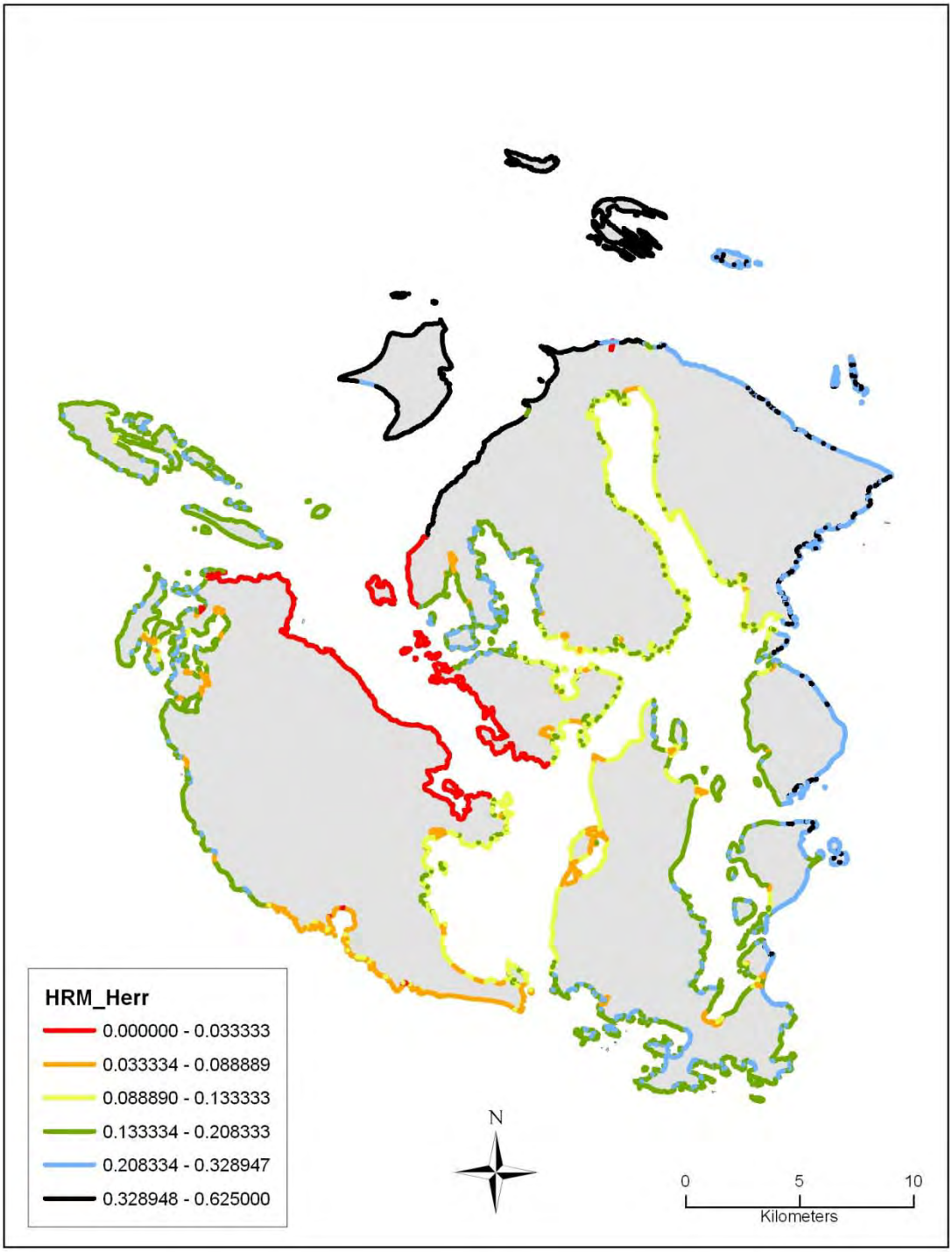

Figure 34. Fish presence probability for juvenile Pacific herring for shoreline habitats (high resolution model).

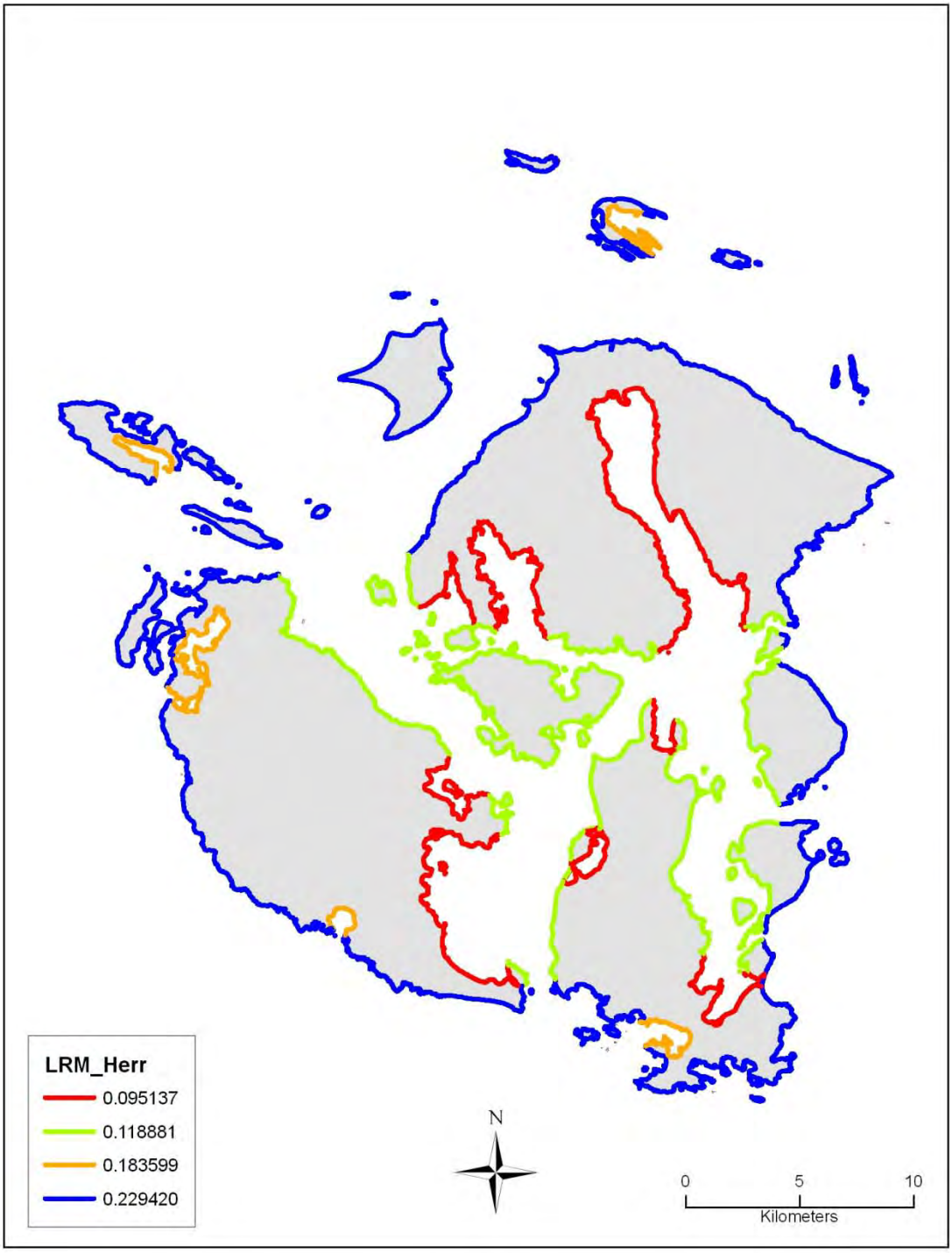

Figure 35. Fish presence probability for juvenile Pacific herring for shoreline habitats (low resolution model).

Surf smelt

The estimated values of surf smelt presence probability ranges from very low (0.021) to 0.545, more than a 26-fold difference (Table 14). The lowest surf smelt presence rates were in rocky shoreline while the highest rates were associated with barrier beaches. All other shoreline types had intermediate surf smelt presence rates.

Table 14. Fish probability of presence matrices for high (top table) and low (bottom table) resolution models of juvenile surf smelt. Fish presence rate results are shown in bold. Indices of fish presence probability are not bolded. The maximum and minimum value for each model is in *italics*.

			SiteType3 (Shoreline Type)				
			barrier beach	**bluff backed beach**	**pocket beach**	**pocket estuary like**	**rocky shoreline**
		HRM Fish presence rate:	**0.727**	**0.389**	**0.440**	**0.400**	**0.125**
SiteType2	**Str Juan de Fuca - S Lopez Is**	**0.571**	0.416	0.222	0.251	0.229	0.071
	Str Juan de Fuca - San Juan Is	**0.167**	0.121	0.065	0.073	0.067	*0.021*
	Haro Strait NE	**0.444**	0.323	0.173	0.196	0.178	0.056
	Waldron Is - President Channel	**0.500**	0.364	0.194	0.220	0.200	0.063
	Rosario NW	**0.167**	0.121	0.065	0.073	0.067	*0.021*
	Rosario Strait SW	**0.750**	*0.545*	0.292	0.330	0.300	0.094
	Blakely Sound - Lopez Sound	**0.500**	0.364	0.194	0.220	0.200	0.063
	East Sound	**0.250**	0.182	0.097	0.110	0.100	0.031
	Deer Harbor - West Sound	**0.571**	0.416	0.222	0.251	0.229	0.071
	San Juan Channel South	**0.583**	0.424	0.227	0.257	0.233	0.073
	San Juan Channel North	**0.222**	0.162	0.086	0.098	0.089	0.028

		Enclosure	**Passage**
	LRM Fish presence rate:	**0.548**	**0.353**
Interior	**0.409**	0.224	*0.144*
Exterior	**0.447**	*0.245*	0.158

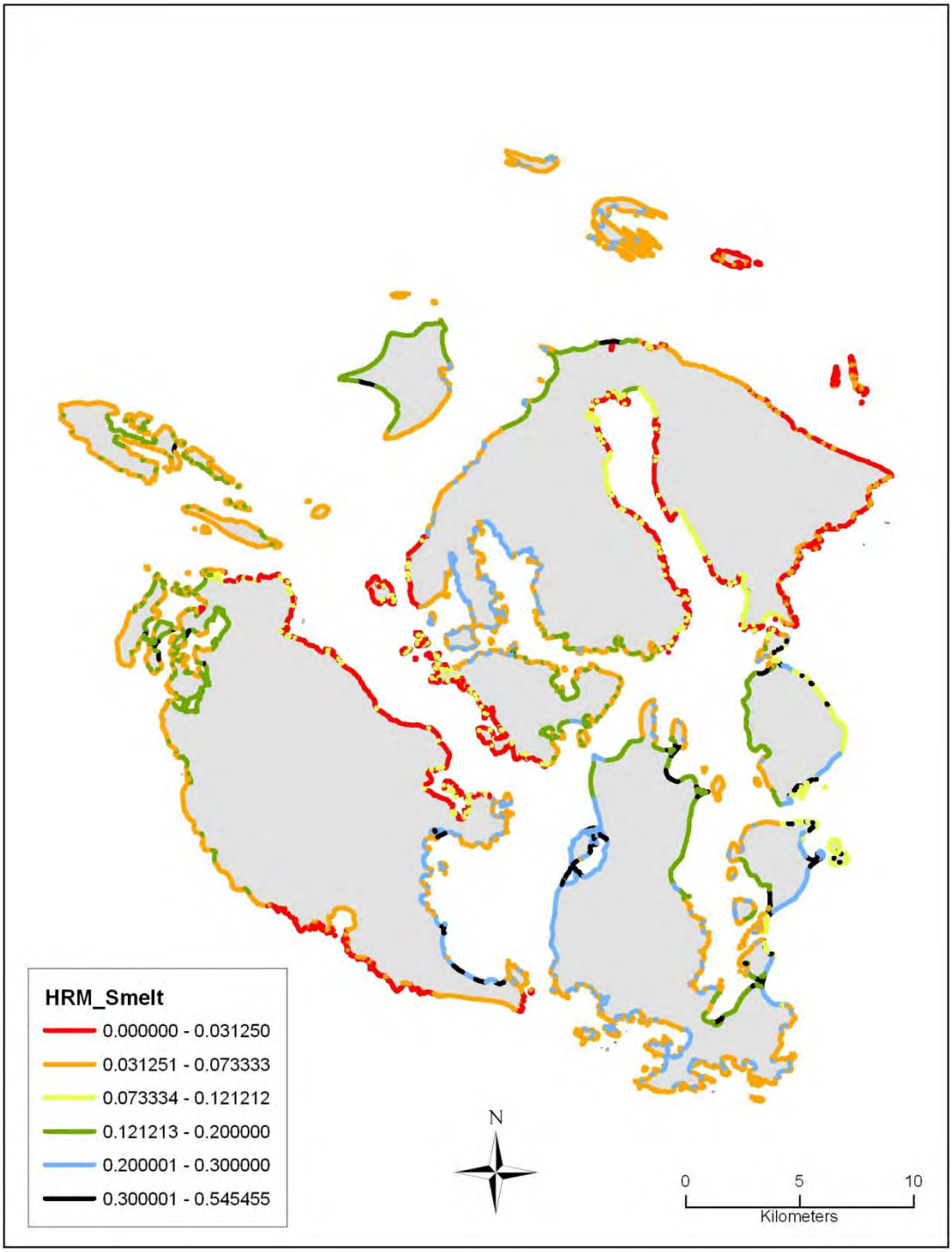

Figure 36. Fish presence probability for juvenile surf smelt for shoreline habitats (high resolution model).

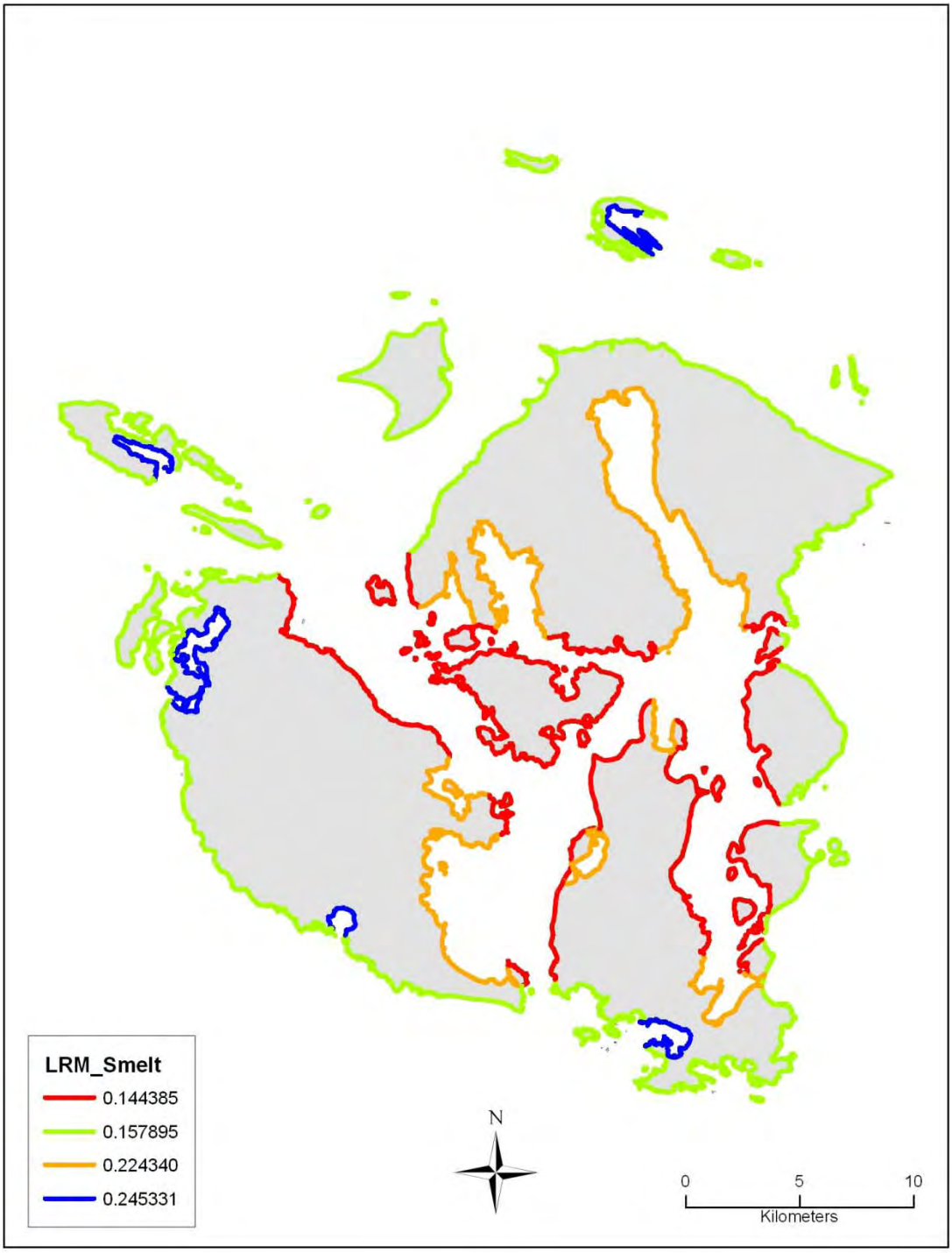

Figure 37. Fish presence probability for juvenile surf smelt for shoreline habitats (low resolution model).

Pacific sand lance

The estimated values of Pacific sand lance presence probability ranged from nearly zero (0.014) to 0.625, a 44-fold difference (Table 15). Two SiteType2s (Waldron-President Channel and Rosario NW) never caught sand lance. Pocket estuaries had the lowest fish presence rate.

Table 15. Fish probability of presence matrices for high (top table) and low (bottom table) resolution models of juvenile Pacific sand lance. Fish presence rate results are shown in bold. Indices of fish presence probability are not bolded. The maximum and minimum value for each model is in *italics*.

			SiteType3 (Shoreline Type)				
			barrier beach	**bluff backed beach**	**pocket beach**	**pocket estuary like**	**rocky shoreline**
		HRM Fish presence rate:	**0.455**	**0.556**	**0.600**	**0.100**	**0.625**
SiteType2	**Str Juan de Fuca - S Lopez Is**	**0.286**	0.130	0.159	0.171	0.029	0.179
	Str Juan de Fuca - San Juan Is	**0.500**	0.227	0.278	0.300	0.050	0.313
	Haro Strait NE	**0.333**	0.152	0.185	0.200	0.033	0.208
	Waldron Is - President Channel	**1.000**	0.455	0.556	0.600	0.100	*0.625*
	Rosario NW	**0.667**	0.303	0.370	0.400	0.067	0.417
	Rosario Strait SW	**1.000**	0.455	0.556	0.600	0.100	*0.625*
	Blakely Sound - Lopez Sound	**0.333**	0.152	0.185	0.200	0.033	0.208
	East Sound	**0.250**	0.114	0.139	0.150	0.025	0.156
	Deer Harbor - West Sound	**0.143**	0.065	0.079	0.086	*0.014*	0.089
	San Juan Channel South	**0.667**	0.303	0.370	0.400	0.067	0.417
	San Juan Channel North	**0.333**	0.152	0.185	0.200	0.033	0.208

		Enclosure	**Passage**
	LRM Fish presence rate:	**0.300**	**0.538**
Interior	**0.364**	*0.109*	0.196
Exterior	**0.553**	0.166	*0.298*

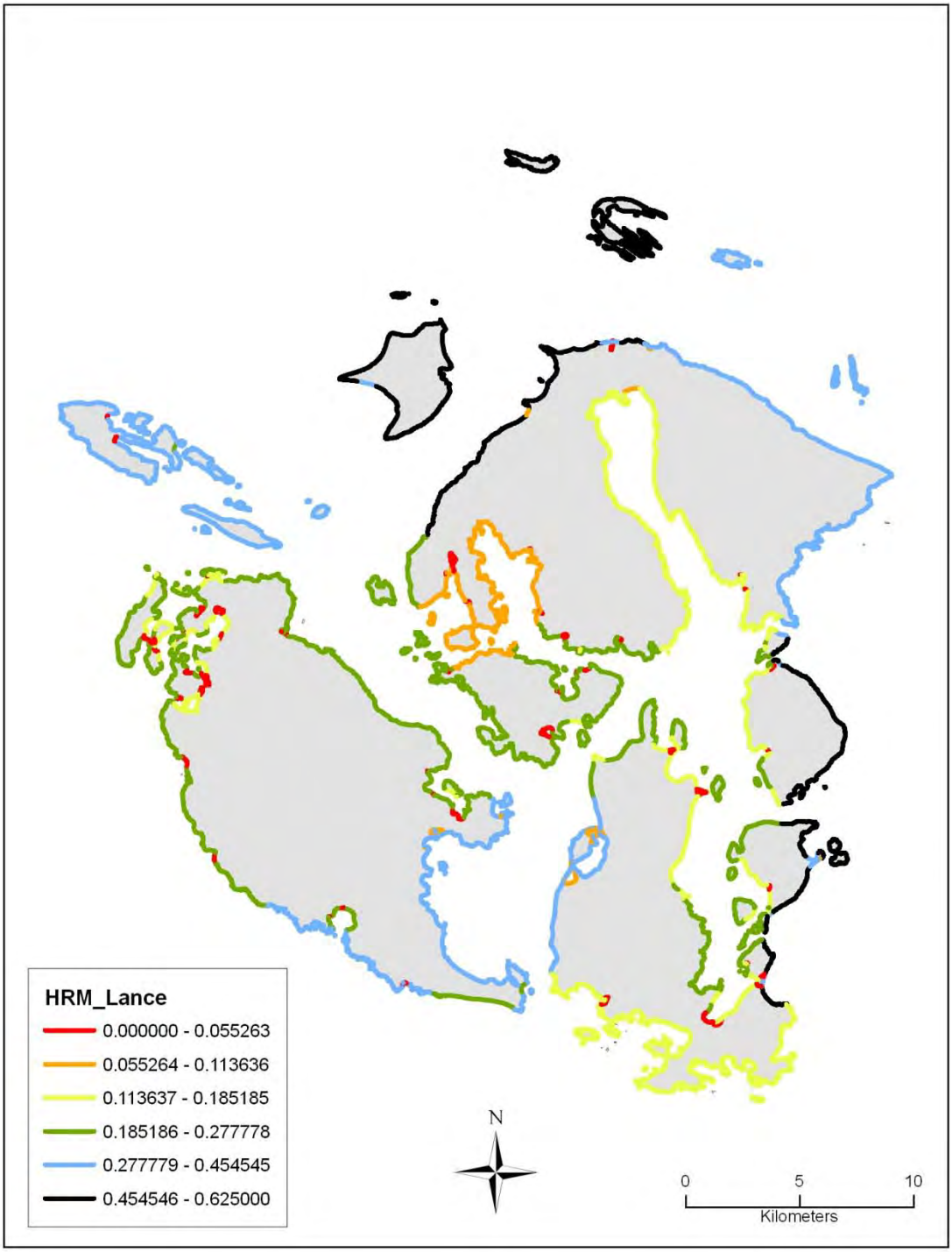

Figure 38. Fish presence probability for juvenile Pacific sand lance for shoreline habitats (high resolution model).

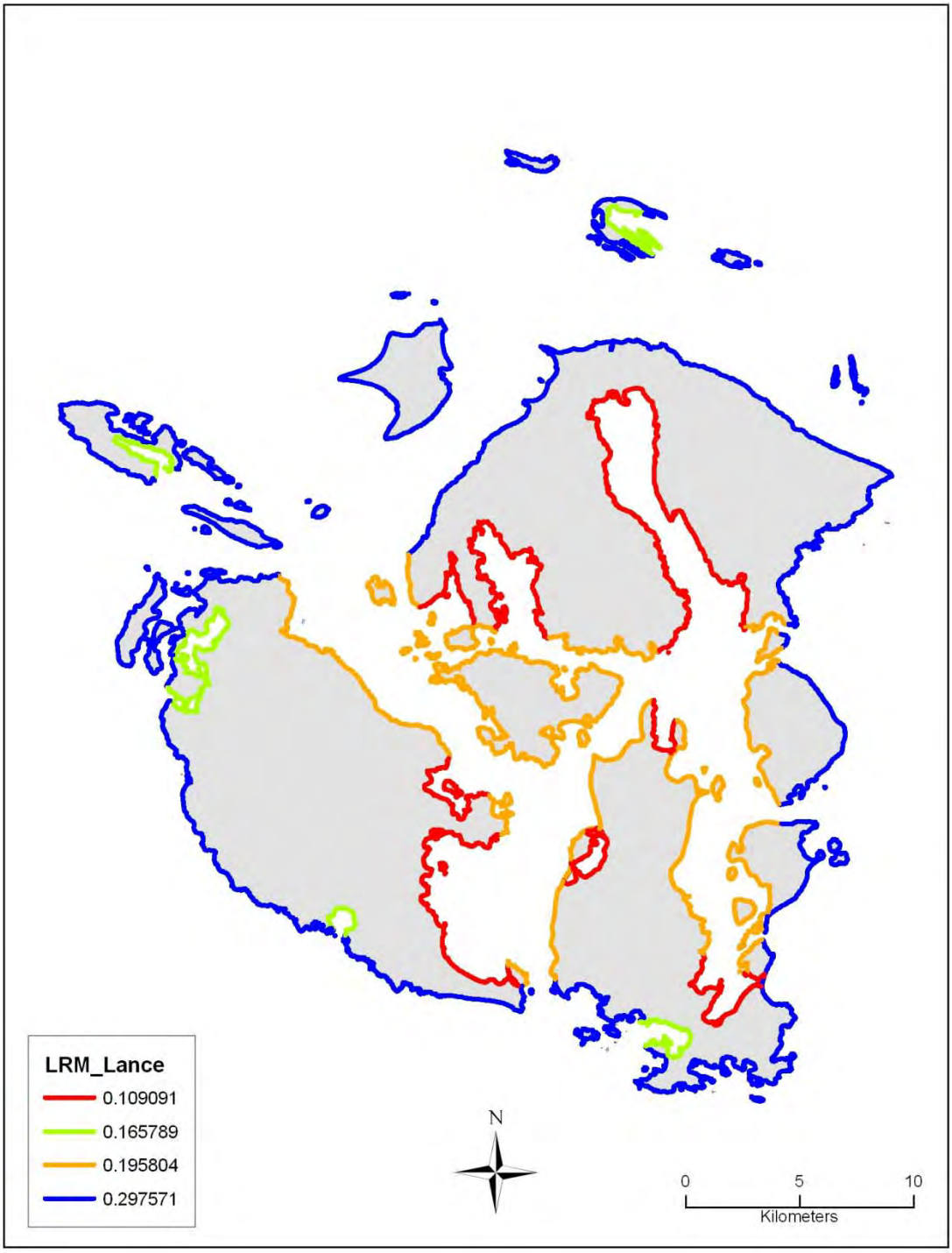

Figure 39. Fish presence probability for juvenile Pacific sand lance for shoreline habitats (low resolution model).

Lingcod and greenling

We combined lingcod and greenling as one group for fish presence results because they are members of a single taxonomic family (Hexagrammidae). The estimated values of lingcod/greenling presence probability ranged from 0.15 to 0.96, a 6-fold difference (Table 16). Nearly half of the SiteType2s had lingcod/greenling caught at all sites. Pocket beaches had the highest fish presence rate; all shoreline types - except pocket estuaries - had high (> 0.700) values.

Table 16. Fish probability of presence matrices for high (top table) and low (bottom table) resolution models of juvenile lingcod and greenling. Fish presence rate results are shown in bold. Indices of fish presence probability are not bolded. The maximum and minimum value for each model is in *italics*.

			SiteType3 (Shoreline Type)				
			barrier beach	**bluff backed beach**	**pocket beach**	**pocket estuary like**	**rocky shoreline**
		HRM Fish presence rate:	**0.727**	**0.833**	**0.960**	**0.450**	**0.875**
SiteType2	**Str Juan de Fuca - S Lopez Is**	**0.571**	0.416	0.476	0.549	0.257	0.500
	Str Juan de Fuca - San Juan Is	**0.333**	0.242	0.278	0.320	*0.150*	0.292
	Haro Strait NE	**0.667**	0.485	0.556	0.640	0.300	0.583
	Waldron Is - President Channel	**1.000**	0.727	0.833	*0.960*	0.450	0.875
	Rosario NW	**1.000**	0.727	0.833	*0.960*	0.450	0.875
	Rosario Strait SW	**1.000**	0.727	0.833	*0.960*	0.450	0.875
	Blakely Sound - Lopez Sound	**0.667**	0.485	0.556	0.640	0.300	0.583
	East Sound	**0.750**	0.545	0.625	0.720	0.338	0.656
	Deer Harbor - West Sound	**0.571**	0.416	0.476	0.549	0.257	0.500
	San Juan Channel South	**1.000**	0.727	0.833	*0.960*	0.450	0.875
	San Juan Channel North	**1.000**	0.727	0.833	*0.960*	0.450	0.875

		Enclosure	**Passage**
	LRM Fish presence rate:	**0.659**	**0.895**
Interior	**0.795**	0.524	*0.712*
Exterior	**0.737**	*0.486*	0.659

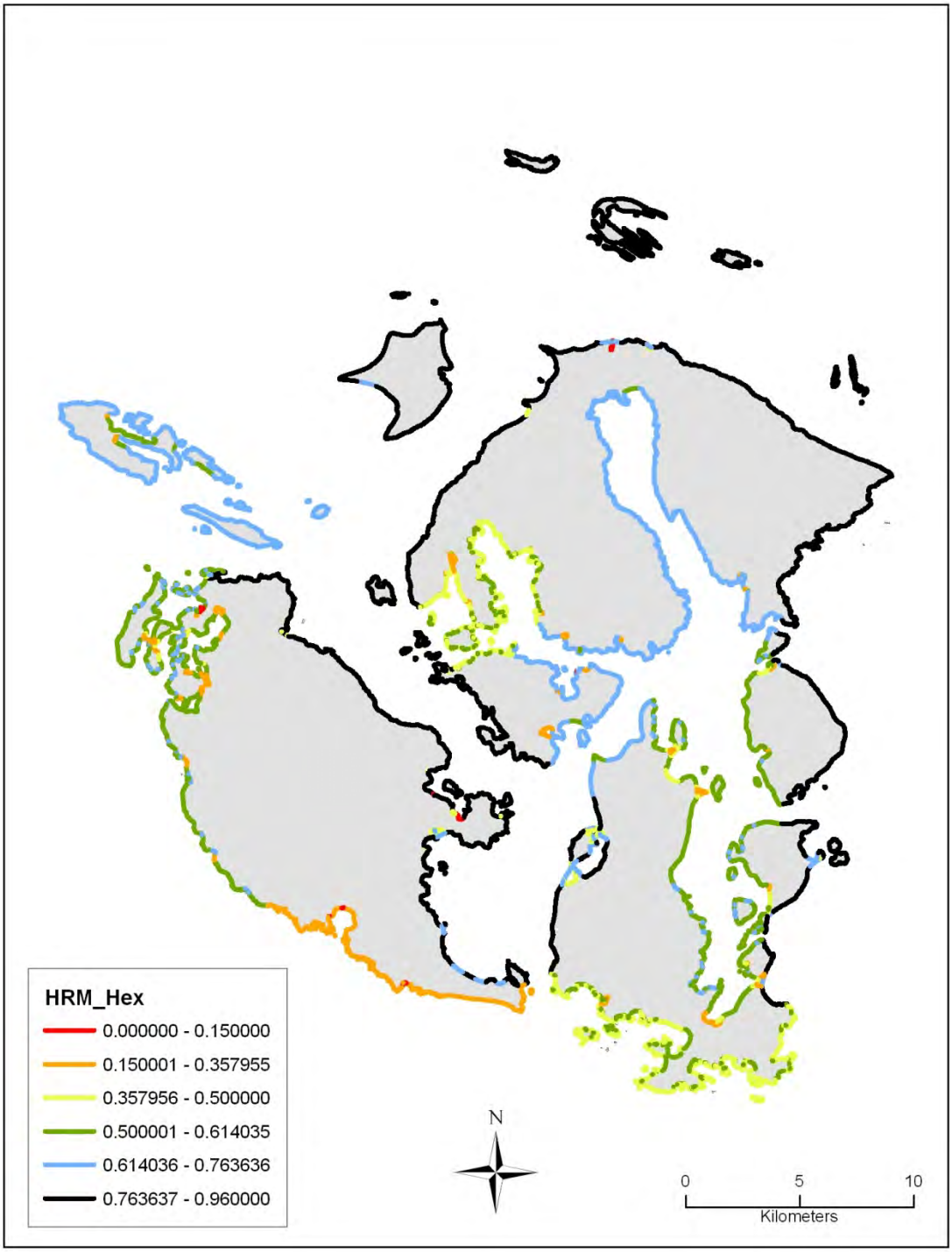

Figure 40. Fish presence probability for juvenile lingcod and greenling for shoreline habitats (high resolution model).

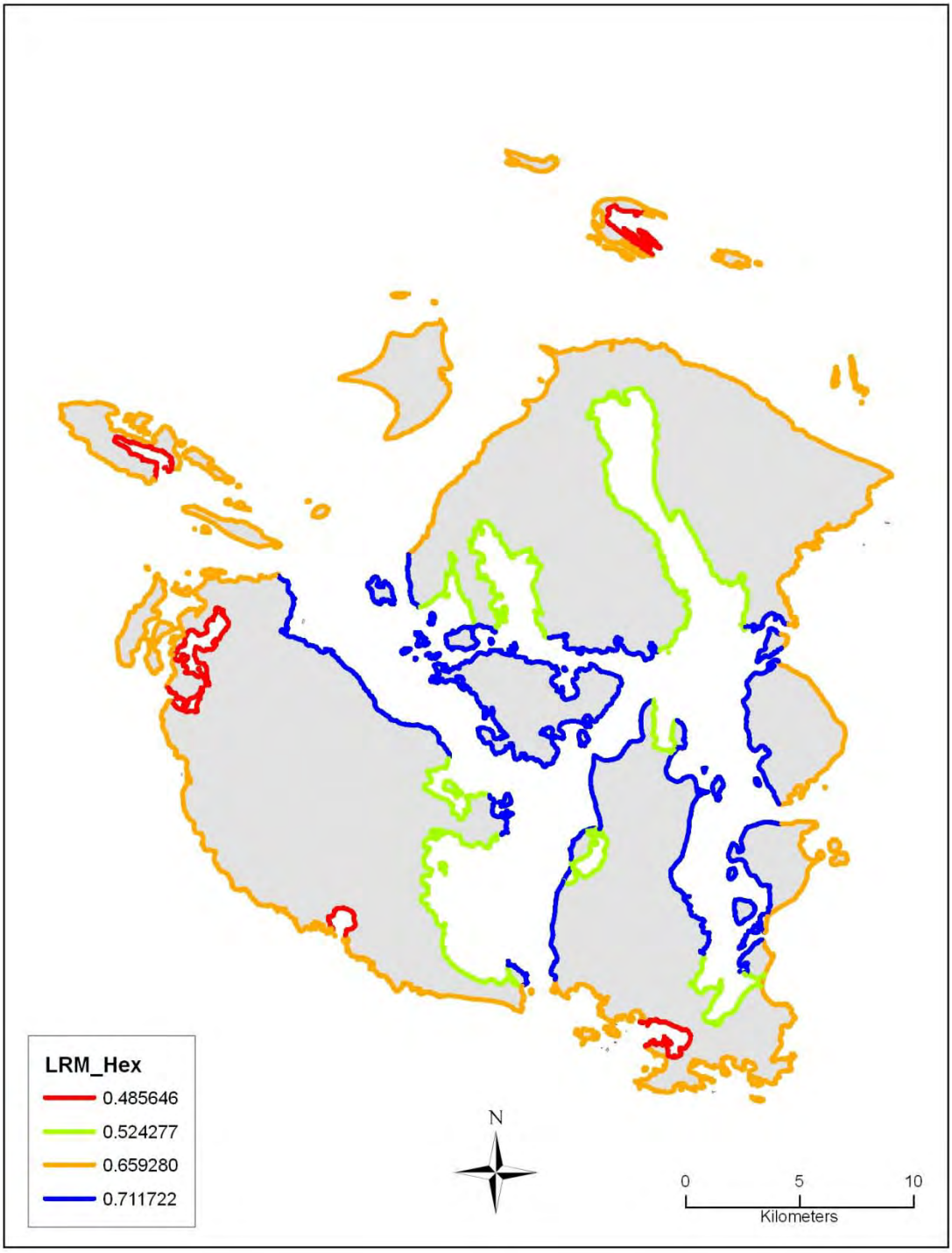

Figure 41. Fish presence probability for juvenile lingcod and greenling for shoreline habitats (low resolution model).

Discussion

Achieving study objectives

The primary objective of this research was to determine if we could define predictable relationships between habitat type and fish presence or abundance and, then convert these relationships into applications that could be used by shoreline planners to help identify places for fish species protection and restoration actions. Our hypothesis was that fish using shallow shoreline areas would vary in presence and abundance with habitat conditions as measured at different scales (shoreline type and place) and over time (month and year). We tested this for three species of juvenile salmon, three species of forage fish, and lingcod/greenling. We found, not unsurprisingly, that there were significant differences in fish density as a function of shoreline type and place (or both) for these seven species.Further, there were strong temporal signals for six of the seven species. For example, juvenile Chinook salmon were abundant from June to September while herring were primarily abundant in September-October. Surf smelt was the only species examined that did not exhibit statistically significant variation in monthly abundance. Smelt were abundant at similar levels throughout our sampling period. We found that fish density and fish presence were positively correlated but the strength of these relationships varied with species. This then allowed us to develop maps of fish presence based upon these factors. As we defined it, fish presence refers to the likelihood a particular species would be found in a particular shoreline type or place. Our maps (Figures 28 through 41) and accompanying tables (Tables 10 through 16) provide a relative sense of where a fish species is more likely to be found when viewed within the context of our sampling design.

Our maps of fish presence do not imply that if you sampled by beach seine one time between March and October at a barrier beach in East Sound that you would have a 13.6% chance of finding juvenile Chinook salmon (see Table 10). Rather, our results suggest that if you sampled according to our beach seine methods monthly from March to October in years like 2008 and 2009 that you would find juvenile Chinook salmon 13.6% of the time in East Sound barrier beaches. However, even though repeating our sampling years of 2008 and 2009 with their unique fish population sizes is not possible, relationships within years should be consistent regardless of the type of year. Thus, a better example use of our results in context would be:

- All shoreline types or areas in the San Juan Islands have a greater than zero probability of juvenile Chinook salmon presence (i.e., no values in Table 10 are zero), but some places in the San Juan Islands are up to 23 times higher in their fish presence value than the lowest value area in the San Juan Islands.
- The highest value places for juvenile Chinook presence are pocket beaches compared to other geomorphic shoreline types and the locations/landscape areas where you are least likely to find juvenile Chinook salmon are West Sound/Deer Harbor and San Juan Channel South (Table 10).
- If you sampled according to our beach seine methods monthly from March to October, the chance of finding juvenile Chinook at a barrier beach in East Sound would be twice that as at a barrier beach in Blakely Sound (Table 10).

Differences between high and low resolution fish presence models

Because of limitations in fish sampling effort, we created two model versions of fish presence probability to in order to provide indices of fish presence for all areas of the San Juan Islands. The high resolution model (HRM) is our best predictor of fish presence for areas with adequate fish sampling. The low resolution model (LRM) is a useful comparison to HRM results for areas without adequate fish sampling. The only estimate of fish presence for shorelines classified as "modified" in GIS is in the LRM. Each HRM has fish presence values for 55 different possibilities (11 SiteType2's by 5 SiteType3s) while each LRM has fish presence values for only four different possibilities (2 exterior/interior values by 2 enclosure/passage values) (see Tables 10 through 16). Thus, the LRM fish presence ranges are always smaller than the HRM fish presence ranges. Also, the low side of the LRM range is always higher than low side of the HRM range while the high side of the LRM range is always lower than high side of the HRM range.

The coarse spatial variable (interior/exterior), while a statistically significant for mean fish abundance, over simplifies fish spatial patterns within the San Juan Islands compared to our higher resolution spatial variable (SiteType2) and based on our fish migration pathway hypotheses (see later discussion on juvenile salmon and forage fish). The same appears true for shoreline habitat type. The five shoreline types (SiteType3) are better at explaining mean fish abundance than enclosure/passage. Thus, we do not recommend use of the LRM results <u>except</u> for: a) shorelines classified as "modified" and b) spatial areas where inadequate fish sampling occurred. The areas with inadequate fish sampling are:

- Blind Bay, and Stuart – Spieden Islands (SiteType2s with no fish sampling as a part of our study),
- Upright Channel (a SiteType2 with inadequate fish sampling during our study, see Table 1), and
- Matia, Sucia, and Patos Island area (an area classified within two different SiteType2s that were adequately sampled for fish during our study, but are very distant from the actual sampling sites, see Figure 4).

Study limitations

Nearshore habitats are considered to provide at least three general ecological functions for juvenile salmon: 1) refuge from predators, 3) a place for feeding and high growth rates, and 3) pathway for fish to move from their natal river to ocean rearing areas (after Simenstad et al. 1982). Shoreline habitats may provide similar functions for forage fish species. In addition, shoreline habitats provide a direct role in reproduction because of the intertidal (surf smelt and sand lance) or shallow subtidal (herring) spawning nature of forage fish. Shallow shoreline habitats may provide a nursery function to greenling and lingcod populations based on their seasonal abundance patterns observed in our study. Clearly, additional studies and analyses would be required more explicitly link fish abundance and occurrence levels to the functional uses described above.

We did not directly measure how fish "used" any particular habitat type or place in the San Juan Islands. For example, we did not measure diet, residence time, or growth rates of individual fish in a particular place or habitat type. Thus, we do not know solely based

on results from our study if changes in fish abundance or presence also infer a change in the functional value of shoreline habitats. For example, are places with higher fish presence or abundance also places with a higher level of a particular ecological function or places with more ecological functions?

Many studies, for a wide variety of species, suggest that abundance or occurrence of a species in a place can be correlated with use or value of that place. For example, Dunlin – a wading shorebird species – are more abundant on intertidal mudflats when they are foraging compared to other habitat types because these places provide abundant and high quality food but roosting Dunlin favor other habitat types (Mouritsen 1994; Warnock 1996; Shepherd and Lank 2004). An obvious salmon example is aggregations of fish in a spawning areas such as a particular channel type that provides optimal characteristics for reproductive success in the face of naturally occurring disturbances such as stream bed mobilizing flood events (Montgomery et al. 1999). Another example is juvenile coho salmon, which rear primarily in pools in streams and are rarely found in riffles or glides (Sandercock 1991).

Likewise, we hypothesize shoreline areas within the San Juan Islands with higher ecological function for a fish species are also areas where that particular fish species is more abundant (or more frequently occurring). Our study is a good first step in documenting the temporal and spatial variability of fish abundance and presence throughout the San Juan Islands and does support our ecological function hypothesis in several simplistic ways.

We found fish are directly living in shallow shoreline areas of the San Juan Islands. At the risk of stating the obvious – we caught many fish rather than the opposite (no fish). At the population level, fish are directly occupying shallow shoreline habitats for periods of months (or longer) and not days, suggesting that functions related to foraging and survival will be important to individuals. Our fish timing curve results (Figures 7D, 10D, 13D, 16D, 19D, 22D, 25D) demonstrate how long each species' population is present in shallow shoreline habitats of the San Juan Islands and thus exposed to beneficial resources (and threats) provided by shoreline habitats. We argue later in this report why certain shoreline types may (pocket beaches) or may not (pocket estuaries) exhibit high abundance or presence values for juvenile Chinook salmon. For juvenile salmon, we also show that shallow shorelines of the San Juan Islands are being used as a migratory pathway and that places with higher abundance or presences rates are likely along more heavily used pathways. As stated later in this report, proximity to salmon bearing rivers is consistent with our spatially explicit results for juvenile salmon.

Individual Fish Species

Chinook salmon

Because Chinook salmon are federally protected in Puget Sound, a major focus of our work was on Chinook salmon. Streams in the San Juan Islands are too small to be used by Chinook salmon for spawning and the proximity of the islands' shoreline are not

immediately adjacent to any major Chinook salmon bearing river (Figure 1). Thus, the San Juan Salmon Recovery Plan (WRIA 2 TAG 2005) hypothesized:

- Early outmigrant life history stages of Chinook salmon are not likely to be found in shoreline habitats of the San Juan Islands.
- Timing of juvenile Chinook salmon within the San Juan Islands is likely to be later than in mainland nearshore areas.

Both hypotheses were largely confirmed by our study. Very few fry sized (≤ 50 mm) Chinook salmon were caught in our sampling effort (Figure 8) and the arrival time of juvenile Chinook salmon in shallow shoreline habitats of the San Juan Islands was April (Figure 7B), several months later than in nearshore areas adjacent to Chinook bearing river systems (e.g., Beamer et al. 2005).

Juvenile wild Chinook salmon were most abundant in bluff backed and pocket beaches of the San Juan Islands, but not in pocket estuaries, with the pocket beaches in the Waldron and Rosario SW areas having the greatest occurrence and abundance of juvenile Chinook salmon. All combinations of shore types and place had a greater than zero probability that Chinook salmon would be present which suggests that juvenile Chinook salmon can potentially use any shallow shoreline in the San Juan Islands. The 23 fold difference in juvenile Chinook salmon presence probability based on t he different shoretype/place combinations suggests that certain places within the San Juan Islands are more likely to support juvenile Chinook salmon than others.

The low catches of juvenile Chinook salmon associated with pocket estuaries in the San Juan Islands were different than observations for juvenile Chinook salmon in shoreline habitat nearer to natal river systems where pocket estuaries are high abundance areas, especially late winter through early spring periods (Beamer et al 2006). In pocket estuaries located near Chinook salmon bearing river systems, fry sized juveniles colonize pocket estuary habitats where they are thought to have a growth/survival (Beamer et al 2003) and osmoregulatory (Beamer et al 2009) advantage compared to adjacent nearshore habitats.

The lack of juvenile Chinook in pocket estuary habitats of the San Juan Islands may be in response to the distance from Chinook salmon bearing river systems. Logically, salmon fry can only occur early in the year (late winter and early spring) before they outgrow that life stage. By the time juvenile Chinook arrived in the San Juan Islands they were typically larger than fry sized. Also, juvenile Chinook salmon arrived in the San Juan Islands on the late side of the pocket estuary use period known to exist in other nearshore areas (e.g., the Whidbey Basin: Jan/Feb through May/June).

Thus, we suggest that pocket estuary habitats in the San Juan Islands do not provide direct habitat use for fry migrant Chinook salmon because the fish that move into the San Juan Islands are too large and arrive too late in the year to need this type of habitat. In essence, juvenile Chinook have already outgrown their need for this type of habitat by the time they reach the San Juan Islands. This may be purely a geographic issue (distance to natal rivers with large numbers of migrant fry) or may be a geographic and current population status issue (e.g., the natal river systems nearest to the San Juan Islands are

currently producing low numbers of fry migrants). We point out the potential population status issue because population status can change while geographic position does not change. Certainly, Puget Sound Chinook populations are at less than desired levels. Actions to improve their status are being implemented which may increase migrant Chinook fry populations in the future.

Pink and Chum Salmon

The other two juvenile salmon species analyzed in this report, pink and chum salmon, were more abundant than Chinook salmon and were also present earlier in the year than juvenile Chinook salmon. Pink salmon do not spawn in streams within the San Juan Islands and only limited spawning by chum salmon is possible within the San Juan Islands, so most fish we captured are from other, more distant sources. We speculate that many of the pink and chum salmon are from Canadian sources such as the Fraser River and possibly Vancouver Island streams. Potential United States sources of juvenile Pink salmon in the San Juan Islands include two northern Puget Sound Rivers with abundant pink and chum salmon populations: the Skagit and Nooksack Rivers.

Both pink and chum salmon had similar fish presence rates in the geomorphic shoreline types with both species most likely to be found in pocket beaches, barrier beaches, and rocky shore areas. As was the case with juvenile Chinook salmon, presence of pink and chum salmon was highest in the Rosario SW and Waldron shorelines, compared to other areas. These shorelines are areas within the San Juan Islands expected to be encountered first by fish coming from the Fraser River, Nooksack, and Skagit rivers.

Forage Fish

We consistently caught three species of forage fish (Pacific herring, surf smelt and sand lance) in shoreline areas of the San Juan Islands. In most shoreline areas of Puget Sound, some combination of the three species is typically found (Fresh et al. 1979; Miller et al. 1980; Fresh et al. 2006; Greene et al. 2012). Spawning areas of the three species are widely distributed in northern Puget Sound and into Canada and include local spawning populations (Pentilla 2007). Although we did not age any of the forage fish we captured, length/age data from other studies (Pentilla 2007) suggested that at least two age classes of each species of forage fish were present based on our length results: herring (age 0 and age 1; Figure 17), smelt (age 0, age 1, and likely age 2+; Figure 20), and sand lance (age 0, age 1, and possibly age 2+; Figure 23). Juvenile life stages were the most abundant stage for all three species, suggesting shallow shoreline habitats in the San Juan Islands were functioning as a nursery area for forage fish.

All three forage fish species exhibited monthly variability in density in shoreline areas and there also was interannual variability in abundance. Pacific herring and sand lance exhibited similar monthly patterns in density with the largest catches of both species occurring in the fall. Surf smelt did not exhibit a consistent pattern in monthly density values. Pacific herring and sand lance were more distributed throughout the San Juan Islands, although both species tended to be more abundant along the northern perimeter of the San Juan Islands. Surf smelt on the other hand were primarily caught along the southern part of Lopez Island.

Factors that could account for variability in forage fish density between years, months and areas are complex but we propose that the timing of spawning and how water currents transport larvae and post larval fish are especially important. Because all three species spawn in the San Juan Islands, the temporal and spatial distribution of these species in shoreline areas is to some degree driven by when and where these species spawn in the San Juan Islands. For example, surf smelt are known to spawn along Lopez Island and so their high density in this area may be driven by local spawning populations. Conversely, although Pacific herring spawn in several parts of the San Juan Islands, much larger herring populations spawn to the north in Canada and to the east in the United States along the mainland between Birch Bay and Sandy Point. Prevailing ebb tide currents (from the north) would be expected to transport herring larvae and post larva fish from these spawning populations towards the San Juan Islands. Thus, many of the herring utilizing the nearshore habitats of the San Juan Islands, may come from more distant, non-local populations. The situation with sand lance is less clear because while local beach spawning populations have been identified, recent evidence suggests that there may be much larger groups of sand lance spawning subtidally. It is unclear where subtidal populations spawn, when they spawn and how they are distributed following spawning.

Similar to juvenile Chinook salmon, the presence of herring was greatest in pocket beaches. However, one difference between herring and juvenile Chinook salmon was the strong association of herring with rocky shore types; juvenile Chinook salmon did not have a strong association with this shore type. Sand lance and surf smelt were also strongly associated with pocket beaches but were also associated with drift cell systems, likely reflecting an association with their intertidal spawning locations which can only occur in erodible shoreline types.

Importance of pocket beaches

Pocket beaches were an important shoretype in the San Juan Islands for all seven species or species groupings with respect to fish density or presence. In Puget Sound, pocket beaches are relatively rare (Fresh et al. 2011) but because of the extensive rocky shoreline geology of the San Juan Islands, they are relatively common in this area (Figure 6).

Pocket beaches are typically semi enclosed so they are relatively protected from the strong tidal currents and wind driven waves that characterize straighter unprotected shorelines. As such, these “backwater” areas of the nearshore may provide a hydrodynamic refuge where small migratory fish (e.g., juvenile salmon) and other young fishes may be using tidal currents as highways and pulling off into these calm relatively enclosed areas for transitory rearing. The semi enclosed nature of pocket beaches and their smaller and unconsolidated substrate (compared to adjacent rocky shoreline beaches) may offer juvenile fish a higher quality environment for feeding on certain substrate associated food items such as amphipods and copepods.

Upland disturbance potential on nearshore habitat types

Pocket beaches and pocket estuaries have relatively short shoreline lengths but differentially large watershed areas associated with them. Pocket beaches and pocket estuaries have disproportionately more watershed area than other shoreline types (Figure 42). This fact has both potentially positive (pathways for upland derived nutrients, terrestrial prey items, etc.) and negative aspects (pathways for pollutants or other stressors to nearshore habitats).

Pocket beaches (and pocket estuaries) have several elements that distinguish them from other shoreline types that should be considered in any plans to protect and restore these habitats. Unlike drift cell systems (barrier and bluff backed beach systems), which dominate in the rest of Puget Sound (Fresh et al. 2011), the processes that maintain pocket beaches do not involve sediment dynamics over long stretches of shoreline. We propose that the processes and disturbances that affect these systems are more restricted to the pocket beach themselves and the surrounding watershed. Thus, protection of pocket beaches may involve more of a focus on local and watershed threats than would need to occur for a beaches within drift cell systems.

Applications of this study

As indicated, the main application of our work was targeted at developing models that would support developing conservation strategies for salmon in the San Juan Islands. Our work provides a method of developing strategies for different types of habitats and places. Because of the length of its shoreline (>650 kilometers), fish density or presence can only be directly measured for a small part of an area like the San Juan Islands. Thus, there is a need to predict what fish distribution and abundance is in places that are not sampled. Our approach which generated map applications was intended to provide a way to identify the conservation approach that should be adopted in places that had not been directly sampled.

Our results also can be used by planners to help manage the types of human activities that could influence different shoreline habitats. For example, the types of disturbances that would seem to most likely affect a pocket beach are local, along the shoreline and associated with the surrounding watershed connected to the pocket beach. Conversely, in drift cell shoreline types, disturbance may be both local or occur at considerable distances from a place, such as bluff back beaches supplying appropriate sediment grain sizes to barrier beaches where smelt spawn. Our study results can also be used to help define work windows for shoreline construction activities that minimize disturbance to key fish species.

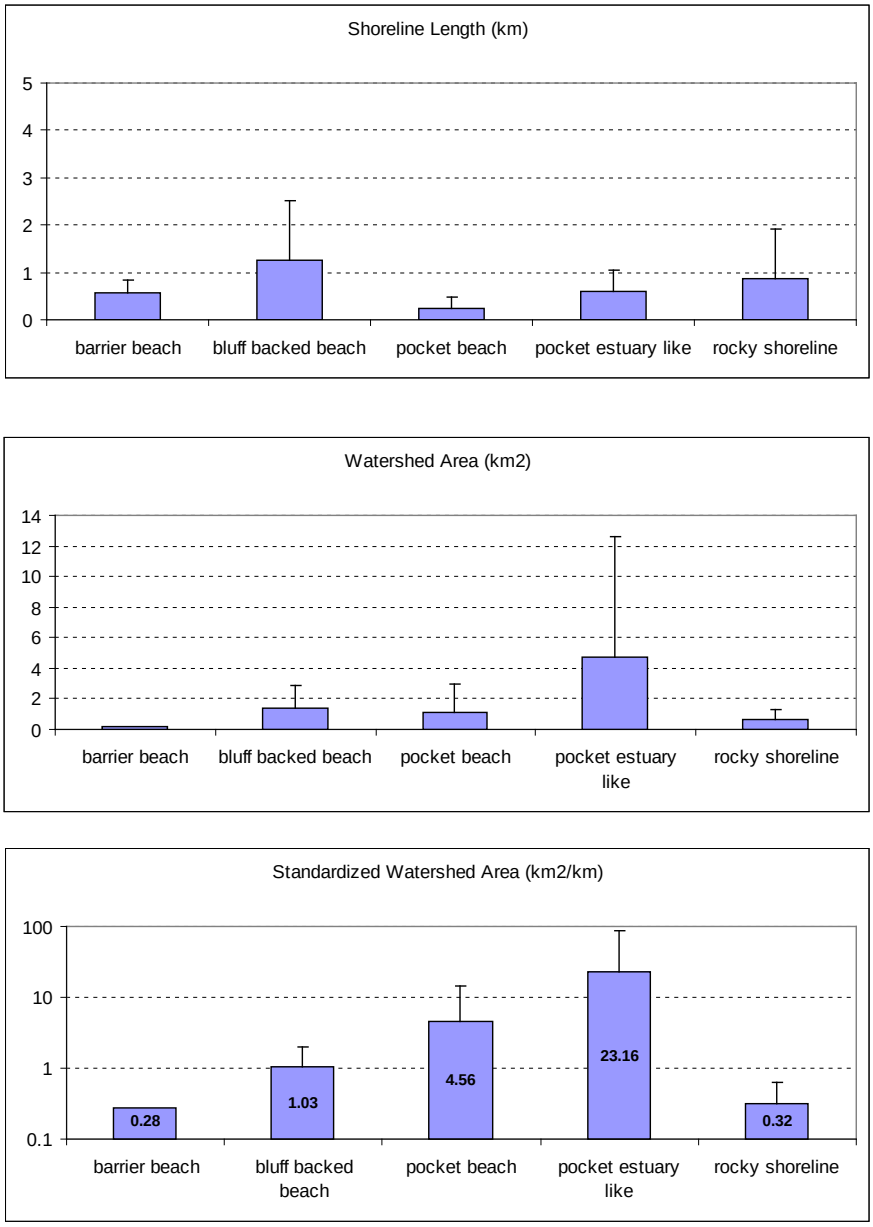

Figure 42. Summary of shoreline length and watershed area by shoreline types for 141 individual shoreline units in the San Juan Islands. Individual shoreline data are from McBride et al. (2009). Watershed areas are from Simenstad et al. (2011). The average value is shown for all three figure panels and error bars are one standard deviation. Top panel: Length (in kilometers) of individual shoreline units by type. Middle panel: Watershed area (in square kilometers) associated with individual shoreline units by type. Bottom panel: Standardized watershed area associated with individual shoreline units by type. Standardized watershed area is watershed area divided by shoreline length. The Y axis is logarithmic scale.

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Appendices

Appendix A: Shoreline Type Examples

RITT classification (Bartz et al. 2012)			**Shoreline type used in this study** (Beamer & Fresh 2012)
System Type	**System Sub-Type**	**Shoreline Type**	
Mayor River System	Natal Chinook Estuary	Drowned Channel	Not used. Major river systems do not exist in the San Juan Islands.
		Tidal Delta	
		Delta Lagoon	
Drift Cell System	Coastal Landform	Barrier Beach (including spits, cusps, tombolos)	Barrier Beach
	Bluff Backed Beach	Sediment Source Beach	Bluff Backed Beach
		Depositional Beach	
		Beach Seep	
		Plunging Sediment Bluff	
	Pocket Estuary (embayment)	Drowned Channel Lagoon	Pocket Estuary
		Tidal Delta Lagoon	
		Longshore Lagoon	
		Tidal Channel Lagoon (or Marsh)	
		Closed Lagoon and Marsh	
		Open Coastal Inlet	
Rocky Shoreline	Rocky Pocket Estuary	Pocket Beach Lagoon	
		Pocket Beach Estuary	
		Pocket Beach Closed Lagoon and Marsh	
	Rocky Beach	Veneered Rock Platform.	Rocky Shoreline
		Rocky Shoreline	
		Plunging Rocky Shoreline	
		Pocket Beach	Pocket Beach

Figure A1. Crosswalk of shoreline habitat types used in this study (Beamer and Fresh 2012) compared to the Puget Sound Recovery Implementation Technical Team (RITT) framework for monitoring recovery of Puget Sound Chinook salmon (Bartz et al. 2012).

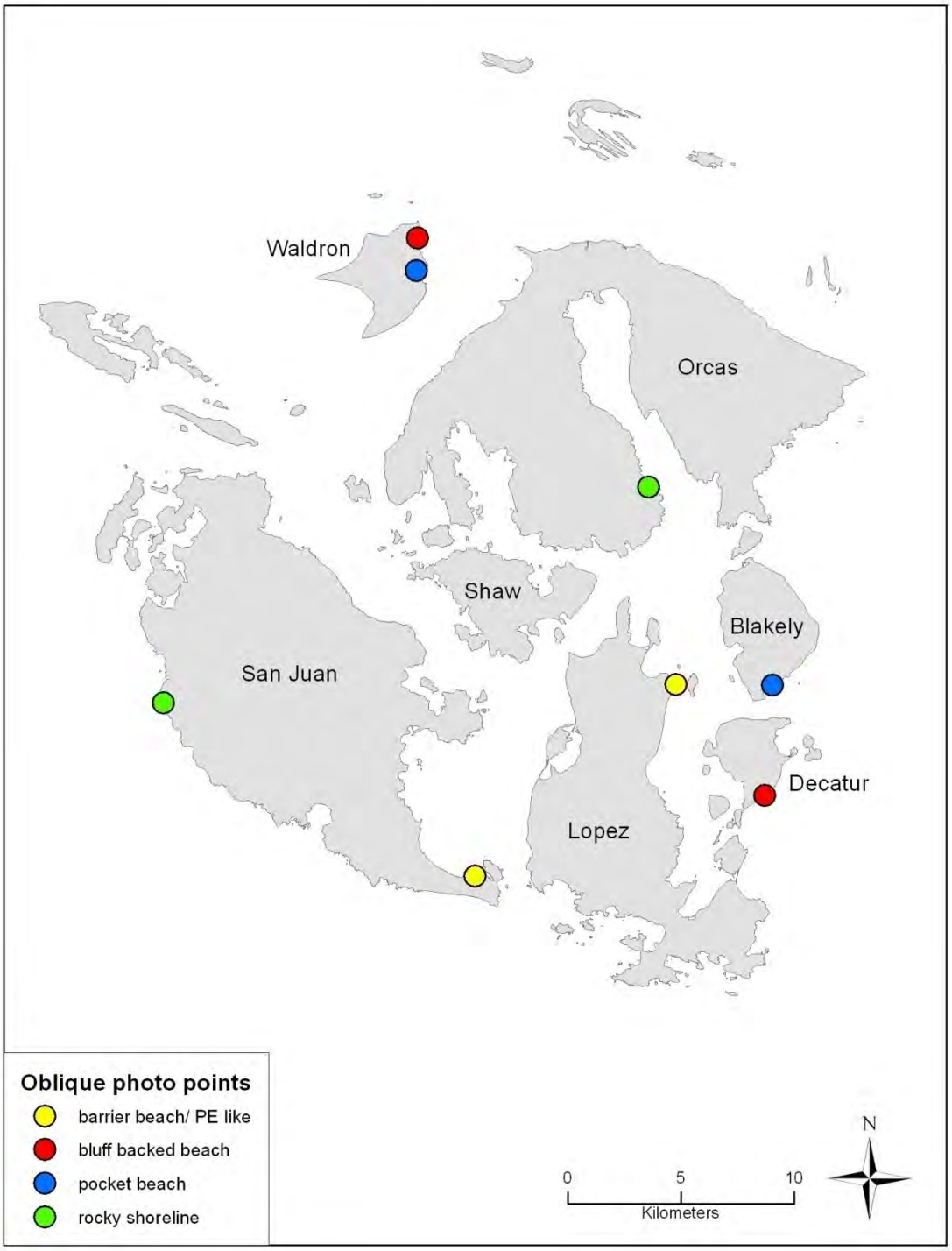

Figure A2. Location of oblique shoreline photos showing examples of different shoreforms. Photos downloaded from Washington State Department of Ecology website.

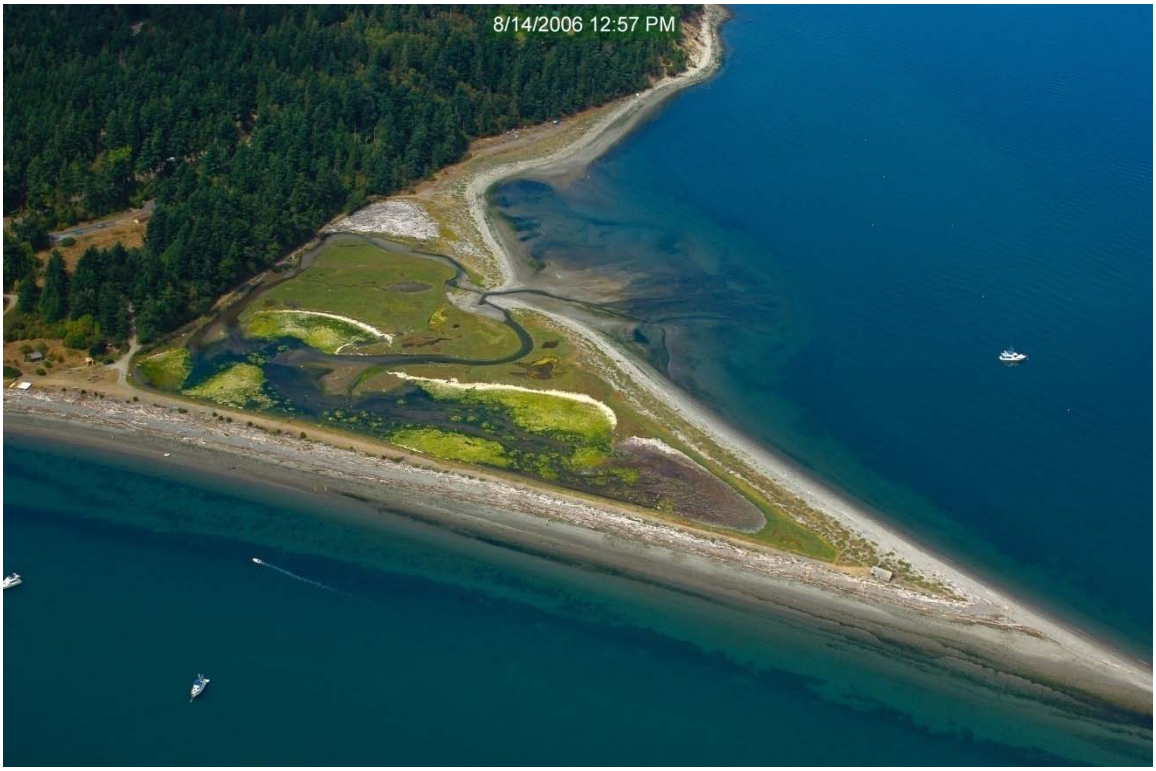

Figure A3. Photo of Spencer Spit on Lopez Island, showing both barrier beach and pocket estuary like shoreforms.

Figure A4. Photo of Third Lagoon on San Juan Island, showing both barrier beach and pocket estuary like shoreforms.

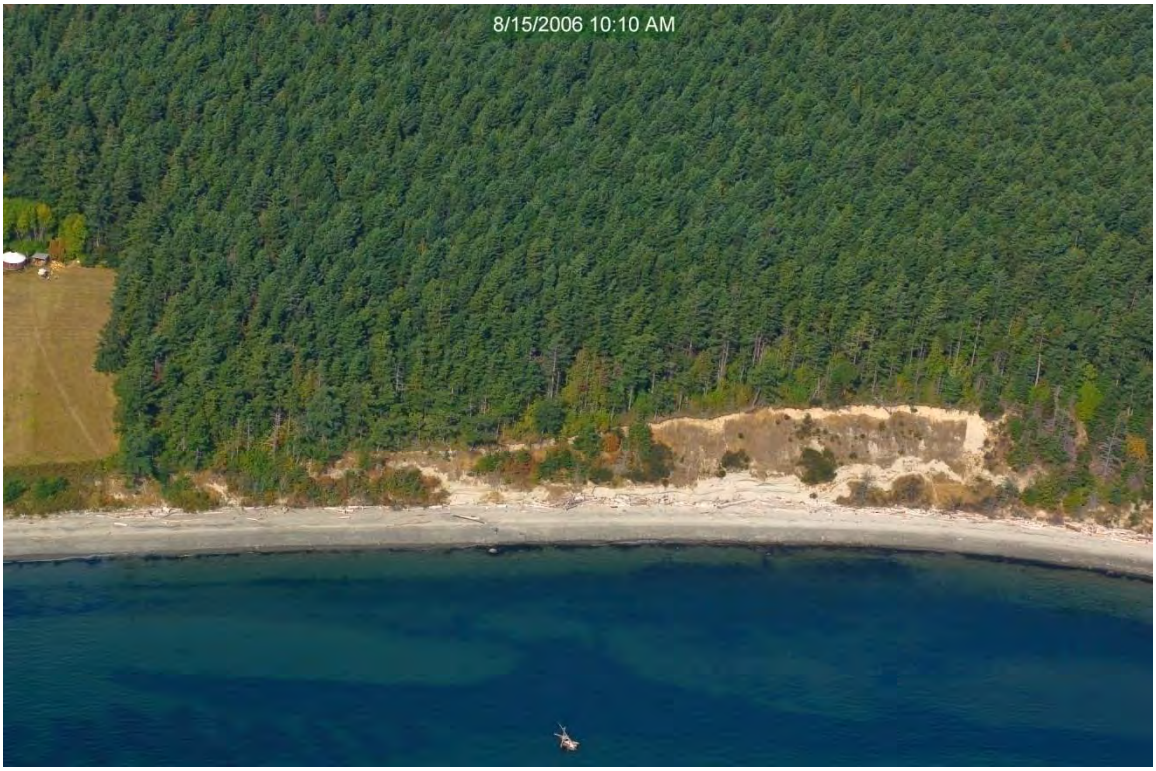

Figure A5. Photo of bluff backed beach on Waldron Island (Little Hammond).

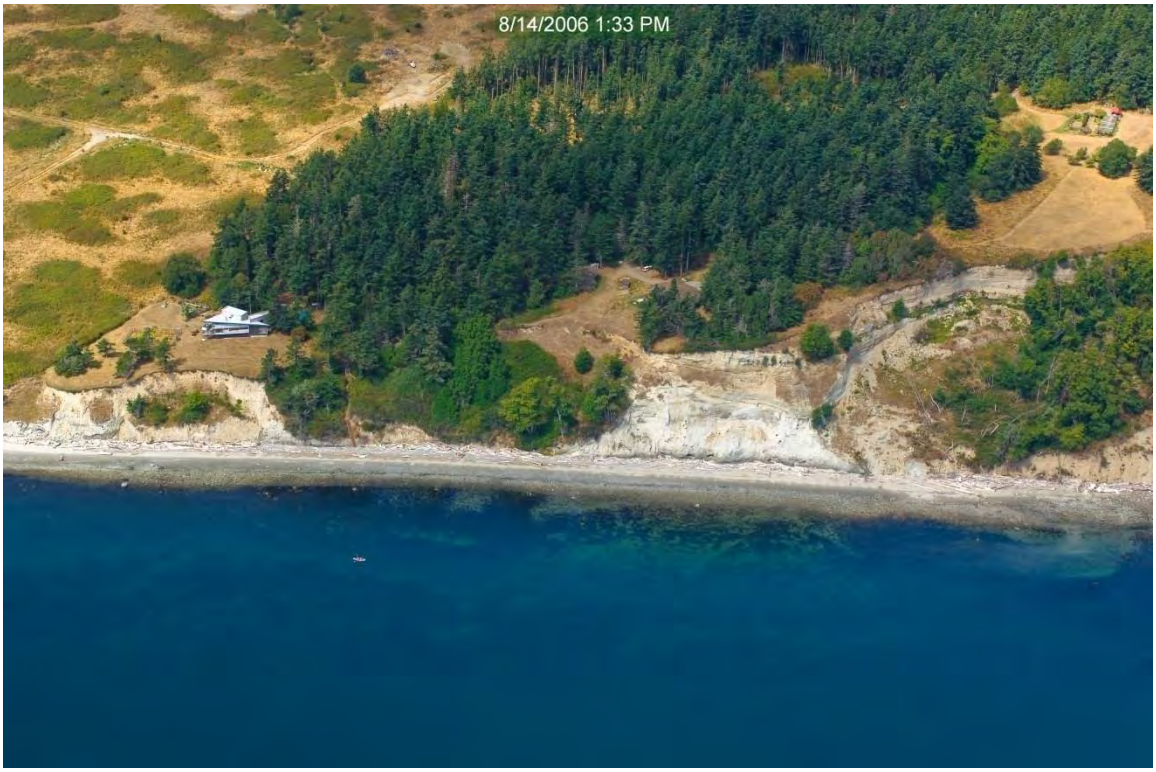

Figure A6. Photo of bluff backed beach on Decatur Island (White Cliff).

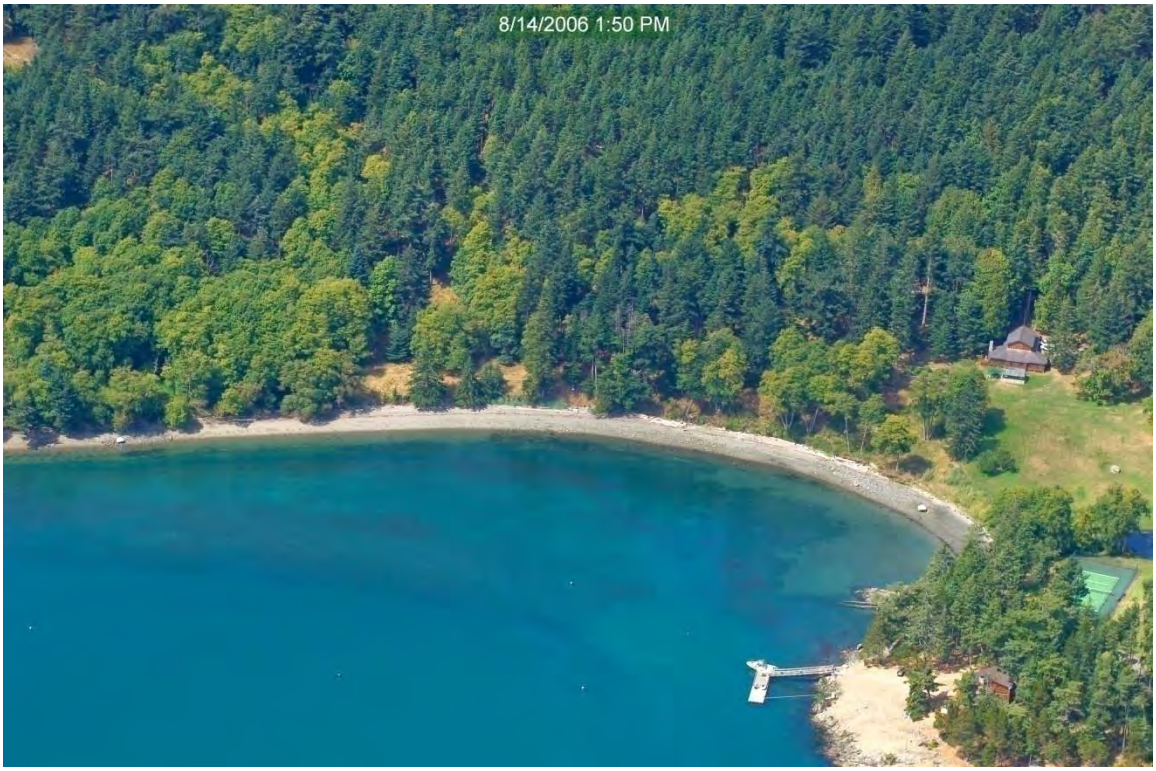

Figure A7. Photo of pocket beach on Blakely Island (Runstad Cove).

Figure A8. Photo of pocket beach on Waldron Island (Mail Bay).

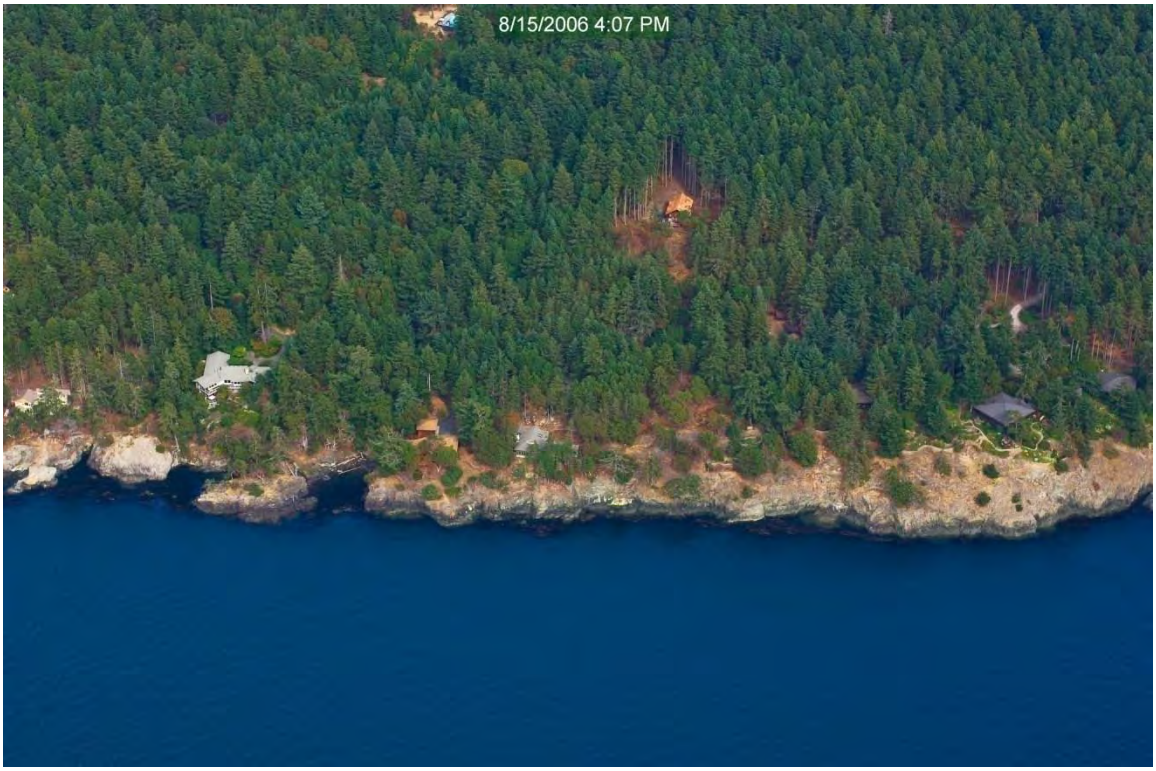

Figure A9. Photo of rocky shoreline on the west side of San Juan Island.

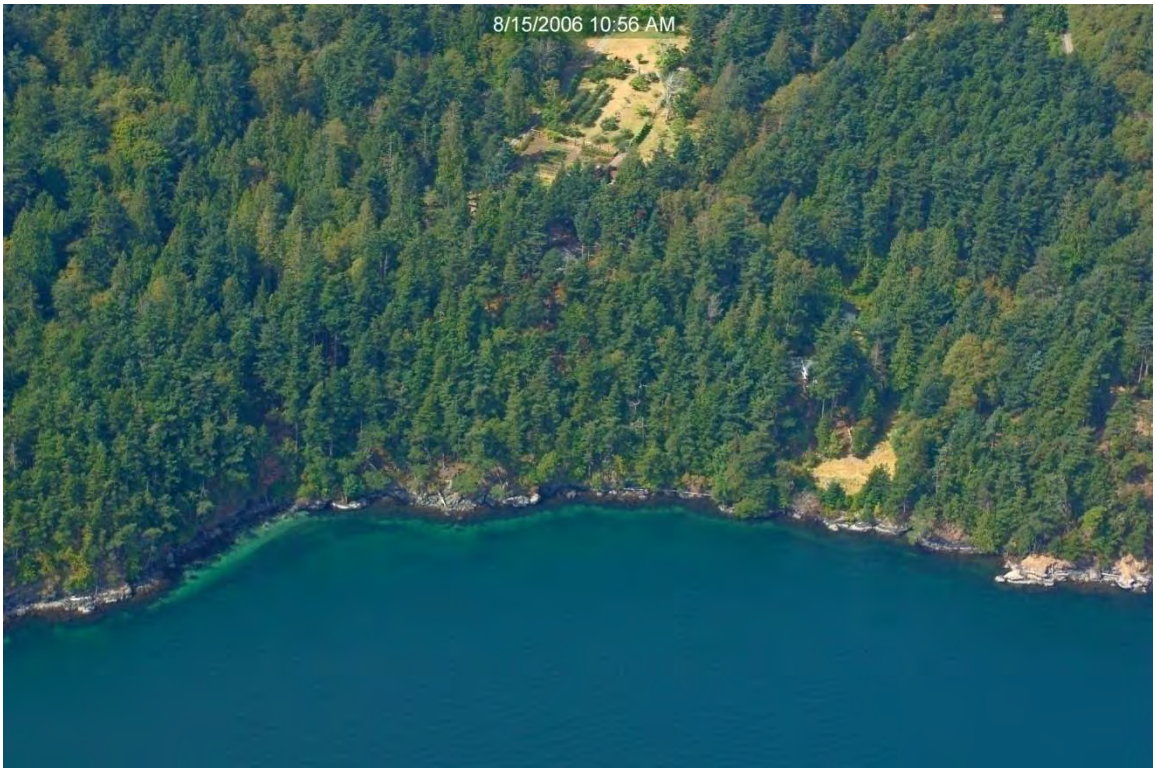

Figure A10. Photo of rocky shoreline on Orcas Island (within East Sound).

Appendix B: GIS Metadata

Metadata for: *SJ_geomorph_FishProb.shp*

DESCRIPTION:
Shoreline arcs for San Juan County (WRIA 2) showing geomorphic data and fish probability of presence by species.

PURPOSE:
To show shoreline habitat, geomorphology, and fish presence probabilities for the WRIA 2 Habitat-Based Assessment of Juvenile Salmon project.

SUPPLEMENTARY INFORMATION:
Arcs for this theme were pulled from SSHIAP's (Salmon & Steelhead Habitat Inventory & Assessment Program, under WDFW & Northwest Indian Fisheries Commission) geomorphic arcs for the WRIA 2 area only. All of SSHIAP's attribute fields were kept in the theme, including their shoretype designation 'GeoUnit'.

Arcs were attributed with Puget Sound RITT (Recovery Implementation Technical Team, appointed by NOAA) shoretype determinations. The RITT nested shoreline habitat classification was compiled from Shipman's 2008 (WDOE) and McBride et al.'s 2009 (SRSC) geomorphic classifications. It includes several scales, three of which we use because they are geomorphic and process-inferred: System Type (RITT_SysTy), System Sub-Type (RITT_SubTy), and Shoreline Type (SiteType3). The coarsest classification is System Type which includes: Major River Systems, Drift Cell Systems, and Rocky Shorelines. The next tier down is Sub-Type which includes: Source Population (natal) Chinook Estuaries (a Major River System); Coastal Landforms, Bluff Backed Beaches, and Pocket Estuaries (all Drift Cell Systems); and Rocky Pocket Estuaries and Rocky Beaches (both Rocky Shoreline systems).

Arcs were also attributed by region (SiteType2), whether they are interior or exterior (int/ext), enclosure or passage (encl/pass), and for fish probability of presence. Region and interior/exterior boundaries were determined by Eric Beamer of SRSC. Shoreline type determinations were taken from SSHIAP's 'GeoUnit', categorized by SRSC, and edited per Coastal Geologic Services (CGS, of Bellingham, WA) 2011 mapping of pocket beaches in the San Juan Islands. While many pocket beaches were mapped by CGS that weren't in SSHIAP's data, there were a few pocket beaches in SSHIAP's data that weren't mapped by CGS. Arcs in these places were re-typed by SRSC, usually to the dominant adjacent shoretype. These determinations are noted in the Comments field. Enclosure/pass determinations were done by SRSC at an intermediate scale only (i.e. larger than a SiteType3 [shoreform] size but smaller than a SiteType2 [region] size). Scale was determined for each watershed by shoreline length and watershed area, with special exceptions for small islands and headlands. Enclosure was determined by shoreline sinuosity (length of bay opening and average bay depth). Fish probability of presence was determined by both high and low resolution models per Beamer and Fresh (2011) for seven juvenile fish (wild Chinook salmon, chum salmon, pink salmon, lingcod

& greenling (family Hexagrammidae), surf smelt, Pacific herring, and Pacific sand lance).

ATTRIBUTES (created by SRSC):
SiteType2 = Intermediate geographic scale, descriptively named after waterbodies or islands.
SiteType3 = Dominant simplified geomorphic shoreform, categorized by SRSC per SSHIAP's 'GeoUnit' (and incorporating CGS' new determinations).
RITT_SysTy = Geomorphic, process-inferred system type, per RITT's nested shoreline habitat classification.
RITT_SubTy = Geomorphic, process-inferred sub-system type, per RITT's nested shoreline habitat classification.
Int_Ext = Classification of whether arc is within the interior or exterior of the San Juan landscape.
Encl_Pass = Classification of whether arc is within a tidal and wind-protected water body such as a bay or inlet (enclosure) or a less protected water body such as a strait, sound, or pass (passage).
Length_km = Length of arc in kilometers.
Watershed = Name of watershed.
HRM_Ck = Wild juvenile Chinook salmon presence determined by high resolution model.
LRM_Ck = Wild juvenile Chinook salmon presence determined by low resolution model.
HRM_Chum = Juvenile chum salmon presence determined by high resolution model.
LRM_Chum = Juvenile chum salmon presence determined by low resolution model.
HRM_Pk = Juvenile pink salmon presence determined by high resolution model.
LRM_Pk = Juvenile pink salmon presence determined by low resolution model.
HRM_Hex = Juvenile lingcod and greenling presence determined by high resolution model.
LRM_Hex = Juvenile lingcod and greenling presence determined by low resolution model.
HRM_Smelt = Juvenile surf smelt presence determined by high resolution model.
LRM_Smelt = Juvenile surf smelt presence determined by low resolution model.
HRM_Herr = Juvenile Pacific herring presence determined by high resolution model.
LRM_Herr = Juvenile Pacific herring presence determined by low resolution model.
HRM_Lance = Juvenile Pacific sand lance presence determined by high resolution model.
LRM_Lance = Juvenile Pacific sand lance presence determined by low resolution model.

Metadata from SSHIAP:
The Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP) has mapped the Washington State shoreline according to geomorphology. In 2008 SSHIAP completed a quality assurance (QA) on the initial draft dataset for the Puget Sound region. In 2009, SSHIAP completed a QA version for the outer Washington coast using similar methodologies. The mapping was based on a geomorphic classification model developed by McBride et al. (2005). The model uses existing information to determine dominant processes (i.e., tidal erosion, wave deposition, fluvial deposition), surface

geology/shoreline material (e.g. bedrock, cohesive sediments, loose sediments), and topography (i.e., steep, gentle, and flat) to map the shoreline into geomorphic units. The Washington Department of Natural Resources (WDNR) ShoreZone spatial dataset represents the shoreline, and WDNR aquatic boundary spatial dataset and National Wetlands Inventory spatial dataset represent the Extreme Low Water (ELW). In performing the quality assurance phase of the mapping for the Puget Sound region, SSHIAP used supplemental datasets that were not widely available during the initial mapping phase, including a revised drift cell dataset (unpublished from PSNERP 2008), 1:24000 scale geology maps in a few locations, historic and current tidal wetland datasets available through the University of Washington River History Project (UWRHP), and the Washington Department of Ecology oblique air photos from 2006, available via the world wide web at the Washington Digital Coastal Atlas. Data is available as ArcGIS geodatabase format.

This nearshore classification was developed for addressing specific applications regarding habitat protection, restoration, and land use policies and regulations that affect nearshore processes, including salmonid habitat structure and function.

Scoping Memorandum concerning the Pacific Gateway Terminal

Individual Comment on Species in the Salish Sea

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November 3, 2012

UNIVERSITY OF CALIFORNIA, DAVIS

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November 3, 2012

GPT/BNSF Custer Spur EIS Co-Lead Agencies
c/o CH_2M HILL
1100 112th Avenue NE, Suite 400
Bellevue, WA 98004

Dear U. S. Army Corps of Engineers, Whatcom County Planning Department and Washington Department of Ecology Representatives,

Thank you for the opportunity to comment on the scope of the Environmental Impact Statement (EIS) for the Proposed Gateway Pacific Terminal / Custer Spur. The proposed deepwater multimodal terminal in the Cherry Point area of Whatcom County will be designed to ship copious amounts of coal and other product and consequently, the building of this terminal and the associated BNSF Railway Custer Spur connection will greatly increase vessel traffic within the US and Canadian waters of the Salish Sea. While much of the EIS will focus on the terrestrial impacts of development as well as the nearshore impacts of developing the deepwater port, the EIS would be woefully incomplete if it did not also include examination of the probable impacts to the marine ecosystem in the regions where the vessels transiting to and from the port will travel, specifically, the marine waters of Whatcom, Skagit, San Juan, Jefferson, and Clallam Counties as well as the potentially impacted Canadian waters adjacent to and contiguous with the US waters mentioned.

The Salish Sea is approximately 17,000 square kilometers of marine water that is habitat to 37 species of mammals, 172 bird species, nearly 300 species of marine and anadramous fishes and over 3,000 macroinvertebrates.[1,2,3] As of January 1, 2011, one or more jurisdiction within the region (British Columbia, Washington State, the US Federal Government or the Canadian Federal Government) has listed 113 of these species as threatened, endangered, of concern, or candidates for listing.[1] The listing of nearly 33% of the mammal species, 33% of the bird species and 13% of the fish species suggests an ecosystem that is a non-resilient state of decay and is not in a good position to fare well from potential incremental stressors such as increased vessel noise or catastrophic events such as a major oil spill.

The marine waters of the Salish Sea are important culturally to the Tribes and First Nations of Washington and British Columbia and the areas non-native residents. These natural resources are also economically important to the people of the region. In addition to supporting the obvious subsistence, recreational and commercial fisheries, the watchable wildlife of the region support a $2 billion / year

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http://www.seadocsociety.org

industry.[4] This is money brought by residents of richer counties and cities into rural, less wealthy counties like San Juan, Jefferson and Clallam. The economic trade off of creating a few jobs in a more wealthy urban area like Bellingham needs to be weighted in light of the potential damage it could bring to both harvestable and watchable fish and wildlife resources of less economically well off rural counties.

I implore you to ensure that the scope of the EIS being developed for the proposed deepwater multimodal terminal in the Cherry Point area of Whatcom County also extend to the counties and regions where ships entering and leaving this proposed port would transit, including Clallam, Jefferson and San Juan County as well as to the waters and resources of neighboring British Columbia. The potential impact of increased vessel traffic needs to be evaluated in light of potential major stressors such as increased vessel-related noise, increased potential for a catastrophic oil spill, increased potential for vessel strike to marine birds and mammals, and increased pollution associated with the ship's marine diesel engines. These stressors should be evaluated for every species of concern, including candidate species that are not yet Federally listed by the U.S. or Canada.[1] Risks also need to be considered for their potential economic impact to the marine ecosystem and the businesses and livelihoods they support. I appreciate you including these factors in the draft EIS and look forward to reviewing it when it becomes available.

Sincerely,

Joseph K. Gaydos, VMD, PhD
Chief Scientist and Wildlife Veterinarian
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Scoping Memorandum concerning the Pacific Gateway Terminal

Impact of Fugitive Dust on Forage Fish, in particular the Pacific Sand Lance

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January 3, 2013

Individual comment detail

Name: Greene, Gary
Date: Jan. 3, 2013
City: Eastsound
Part: Multiple/not listed
Natural environment: Marine species, fish or fisheries, Water quality
Comment: Comment on Potential Fugitive Coal Distribution from the Proposed Cherry Point Coal Loading Facilities and Outward Transport of Product

H. Gary Greene, Professor Emeritus, Moss Landing Marine Labs/Tombolo

I am a marine geologist (PhD, Stanford University, 1977) involved in the past 18 years in mapping the seafloor of the Salish Sea for the purpose of evaluating geohazards and marine benthic habitats. I am a research faculty member at Friday Harbor Laboratories of the University of Washington and Emeritus Professor at Moss Landing Marine Labs, San Jose State University in California. One of my major research interests is the health of the forage fish Pacific sand land (PSL) and the subtidal benthic habitats they occupy. The scientific community is just starting to understand the habitat needs of this critical fish and the introduction of exotic components, such as coal to PSL benthic habitats will exacerbate our studies, a personal concern for me. I also live on Orcas Island and adverse impacts to the marine environment matters to me.

My specific concerns about the development of the coal loading facilities at Cherry Point are in regard to the potential impact that fugitive coal particles would have on the health and survival of a critical forage fish in the region, PSL (Ammodytes hexapterus). It appears to me that not much is known about the transport and toxicity of coal particles in the Salish Sea and what impacts to marine benthic habitats may occur if coal is introduced into the estuary of the San Juan Archipelago and southern Georgia Basin, including the Whatcom County shoreline and subtidal habitats. Whatcom County's seafloor, and most of Rosario Strait, is unmapped in high-resolution and critical PSL benthic habitats there are not fully identified. However, poor resolution and single trace echosounder data indicate that subtidal PSL benthic habitats may be present in close proximity to the proposed coal loading facilities.

The Pacific sand lance (PSL) is an important forage fish along the coastal North Pacific Ocean from northern California to northern Hokkaido, Japan, and is one of six species in the genus Ammodytes (Robards et al., 1999a,b). Although PSL is a key component in the Northwest Straits regional food web, very little is known of this species' biology. For example, only three peer-reviewed papers detail the biology of PSL in Puget Sound compared with 16 such manuscripts on Pacific herring (Clupea harengus pallasi). The burrowing behavior, recruitment rates and conditions, relative abundance and distribution, population structure, local spawning habits, and spawning and burial substrates remain largely unknown (Robards et al., 1999a, 2002; Tribble, 2000). The work that has been done on the biology and habitat of PSL has focused on the nearshore and shallow sub-tidal areas; little work has been done on the deep sub-tidal habitats, although recent initial studies have been completed (Greene et al. 2011). A disjunction occurs between the abundance of sand lance and the availability of known habitat and the hypothesis put forward by Greene et al. (2011) that predominant and important habitats exist in the deep

sub-tidal areas.

In the Northwest Straits region, PSL serve as the primary link between zooplankton and higher order predators, and are a vitally important food source for 29 species of birds, 10 species of marine mammals, and 30 species of commercial and sport fishes (Meyer et al., 1979; Auster and Stewart, 1986; Geiger, 1987; Robards et al., 1999a,b; Tribble, 2000). Specifically, this species is a crucial component in the diet of common murres, rhinoceros auklets, tufted puffins, harbor seals, minke whales, salmon, lingcod, rockfish and other groundfishes (Geiger, 1987). The condition of the Northwest Straits region's ecosystem depends in large part on the large biomass of forage fish, including PSL, that transfer phytoplankton production to higher trophic levels (Fresh, 1979; Fresh et al., 1981; Duffy, 2003; Zamon, 2001, 2003; Johnson et al., 2008)

The PSL is known to deposit its spawn on sandy upper intertidal beaches throughout the Puget Sound Basin (Penttila 1995a, 2007). Roughly 10% of the shoreline of the Puget Sound basin comprised of fine-grained beaches has been found being used by spawning sand lance. It has been hypothesized that PSL might also use sub-tidal sandy substrates for spawn deposition, although no conclusive physical evidence of this has ever been documented.

Much of what is known about PSL benthic habitat comes from shallow water studies. Sand lance are dependent upon benthic sediment habitats to burrow into and, therefore, this species is most often associated with fine- to coarse-grain sand- or gravel-oxygenated sediments (Meyer et al., 1979; Auster and Stewart, 1986) in nearshore inter-tidal (-0.3m MLLW) and shallow (to 100 m) habitats (Wright et al., 2000; Pinto, 1984; Ostrand et al., 2005; Quinn, 1999; Robards et al., 1999a,b; Auster and Stewart, 1986). In the inter-tidal, sand lance were found to be buried 5.0 cm deep and to be oriented horizontally in the oxygenated sediment layer at densities of 5 fish per square meter and can remain buried in inter-tidal sediments during low tide exposure (Quinn, 1999). Sediment size conducive for sand lance to penetrate and burrow into ranged in size from 0.36 to 1.0 mm in diameter (Quinn, 1999). Inter-tidal beaches have been documented as habitat for PSL and their eggs (Moulton and Penttila, 2000). Sediments provide habitat for overwintering (Healy, 1984), to rest and conserve energy (Quinn, 1999), to avoid predation (Reay, 1970) and as spawning substrate where their adhesive eggs attach while incubating. When the fish emerge from the substrate they form large schools and feed on zooplankton in the water column during the day (Dick and Warner, 1982; Robards et al., 1999a, b; Auster and Stewart, 1986; Geiger, 1987). They emerge from the sand at dawn and are vulnerable to predators as they enter the water column (Hobson, 1986).

Deposits of clean sand at the water depths where PSL reside in the sub-tidal environment (typically < 100 m) are common where relatively strong currents continuously sweep the seafloor. In order to maintain a deposit, a plentiful sand supply is necessary, although finer sediment might transit through the area and coarser sediment might be present as a lag. Sand-wave fields consisting of ripples, waves and dunes are common in such areas, and several fields have been mapped near the San Juan Islands (Barrie et al., 2009; Greene et al., 2011). One such sand-wave field was documented by Blaine (2006) in San Juan Channel of the San Juan Islands and was found to be a productive PSL habitat. The aerial extent of this sand-wave field is delimited by a distinct boundary where the sand waves are in sharp contact with a relatively featureless surrounding seafloor. Such abrupt transitions have been reported in other nearby sand-wave fields (Barrie et al., 2009). However, although it is suspected that such fields may be

present in and around the proposed coal loading facilities, no clear bathymetric images exists to confirm this.

The results of the Greene et al. (2011) study are far-reaching and multidisciplinary. Extensive sampling of the San Juan Channel sand wave field, a proto-typical PSL sub-tidal habitat type, on a regular basis through the summer, fall and winter seasons of 2010 and through the winter, fall and spring seasons of 2011 allowed for documentation of PSL occupancy and relative abundances. Comparative evaluation of the results from a tank experiment study and the in situ sampling confirmed the assumption of Greene et al. (2011) that PSL prefer grain sizes of 0.5-1.0 mm (medium- to coarse-grain sand) to any other grain sizes, although PSL were found to occupy all types of substrate from gravels to silt, and that dynamic bedforms can act as preferred habitats for the fish. All life stages of PSL after the larval stage were represented in the proto-typical habitat and one egg was recovered suggesting that recruitment may also occur in PSL sub-tidal habitats.

Tentative conclusions drawn from the work of Greene et al. (2011) that PSL prefer to burrow into medium- to coarse-grain (~0.5-1 mm) size sand in dynamic bedforms that have a wave amplitude of 3-5 m and wavelength of ~100 m, the seafloor conditions found at the proto-typical habitat type in San Juan Channel where the highest concentrations of PSL was found during the investigation. Mature fish found in the San Juan Channel sand wave field were primarily caught in the northern and southern part of the bedform where sediment is smaller in size. It was found that more fish burrow into the sediment during winter months than during summer months (Greene et al., 2011).

Although Greene et al. (2011) prepared a predictive potential PSL sub-tidal habitat model that would have a geomorphology similar to the San Juan Channel sand wave field, further investigation needs to be done to validate the most promising habitat types. Metrics for the predictive model include grain size (0.5-1.0 mm, ~1 phi), depth (30-80 m), wave amplitude (3-5 m), wavelength (50-100 m), and current strengths of ~0.06 m/sec. However, smaller concentrations of fish occur at different types of fields or sand flats and further study needs to be undertaken to place limits and threshold conditions for the habitat attraction for these smaller concentrations of fish within the Salish Sea. In addition, Greene et al. (2011) tentatively concluded that PSL can travel a fair distance from their egg laying sites to sub-tidal habitats, however this relationship also needs further investigation.

Stability of the dynamic bedforms that may be promising sub-tidal habitats in the Salish Sea appear to be near the threshold of stability. Any changes in current strength could upset this stability and such change could come about from continued tectonic uplift or eustatic rebound (possibly leading to increase in current strength) or sea level rise (possibly leading to decrease in current strength). More physical oceanographic measurements need to be made in order to better understand this process.

Based on the known habitat types of PSL and the tendency of the fish to occupy clean, well-aerated substrates, the possibility that fine- to medium-size coal particles could be swept onto beaches and into the subtidal habitats is of paramount concern as interstitial clogging of important habitats in close proximity to the facilities can be impacted. Nothing is known about how coal particles will transit through the San Juan Archipelago or wash up on beaches. Strong

tidal currents and winter storm waves all have the potential to sweep fugitive coal particles into the critical habitats of PSL. Concentration of these particles may be detrimental to the survival of PSL.

Questions that should be addressed and hopefully answered in the Environmental Impact Statement for the Gateway Pacific Terminal include:
1) how will fugitive coal particles be incorporated into natural sediments, if at all;
2) how concentrated will the particles become and what will be the toxicity to benthic organisms, especially Pacific sand lance; and
3) how far will the particles be distributed from their point of entry into the water.
All sub-tidal PSL habitats should therefore be located and mapped within close proximity to the coal-loading facilities and along the bulk carrier routes, where coal is likely to be introduced into the marine environment. Coal toxicity associated with dissolution or any other chemical processes that occur in marine and estuarine environments also need to be addressed. If potential impacts are found, how will they be mitigated?

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