

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 FR 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 intended 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 versus 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.

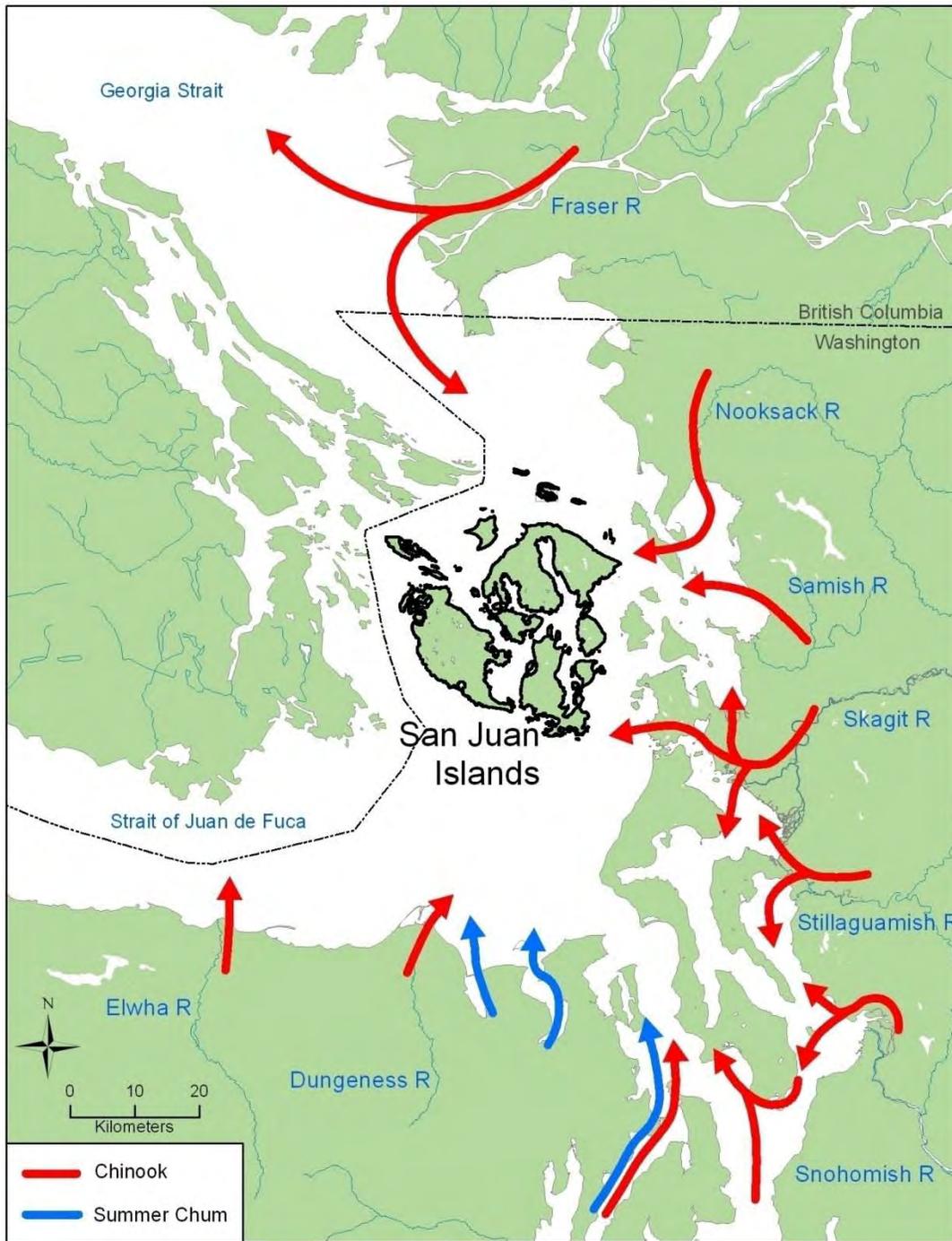


Figure 1. Location of San Juan Islands study area and conceptual varying migratory pathways for juvenile salmon coming from their source population rivers to mixed stock rearing areas within the southern Salish Sea.

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 differences 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.

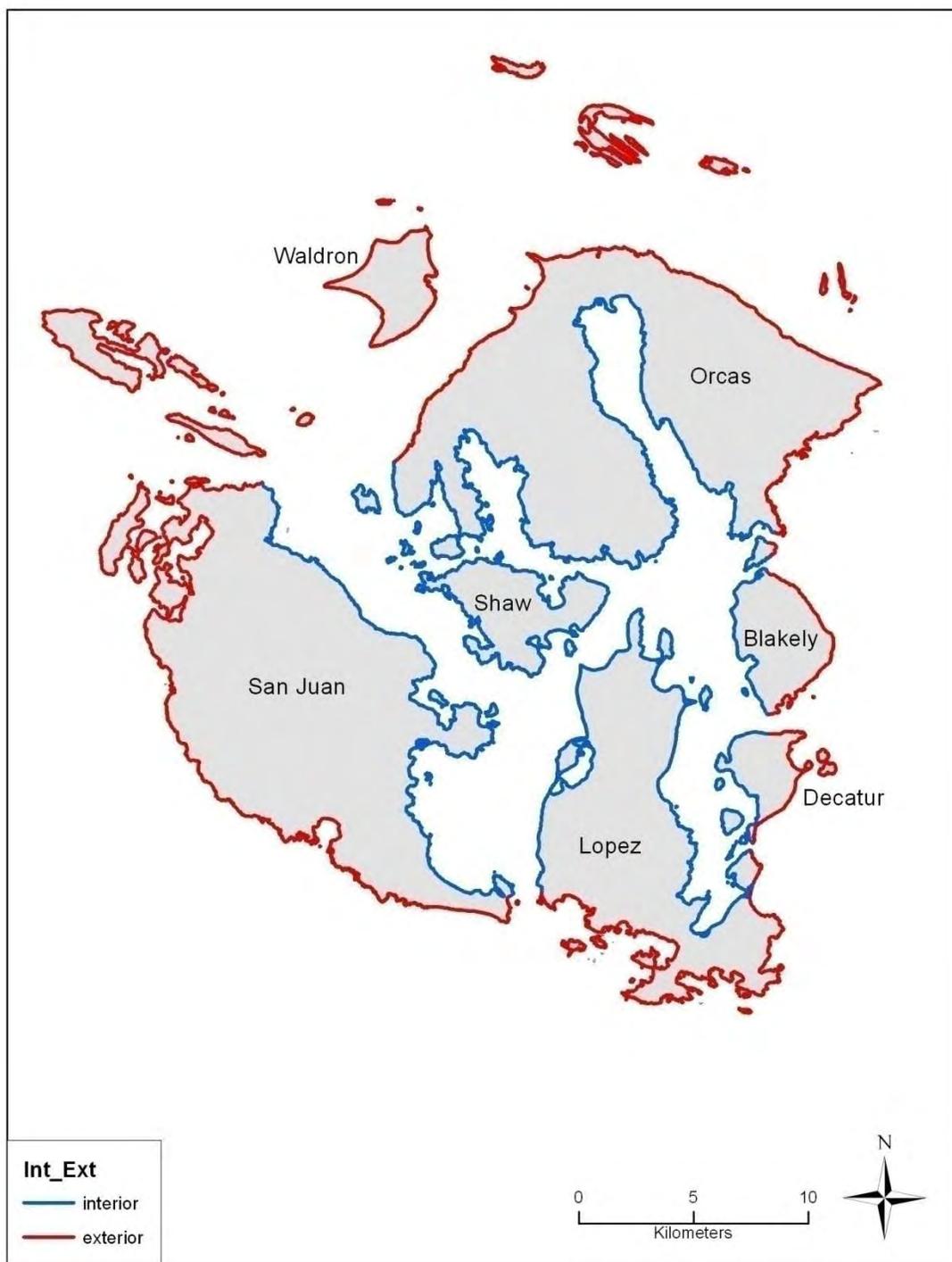


Figure 3. Interior and exterior areas within the San Juan Islands per our coarse space variable.

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 shoreline 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).

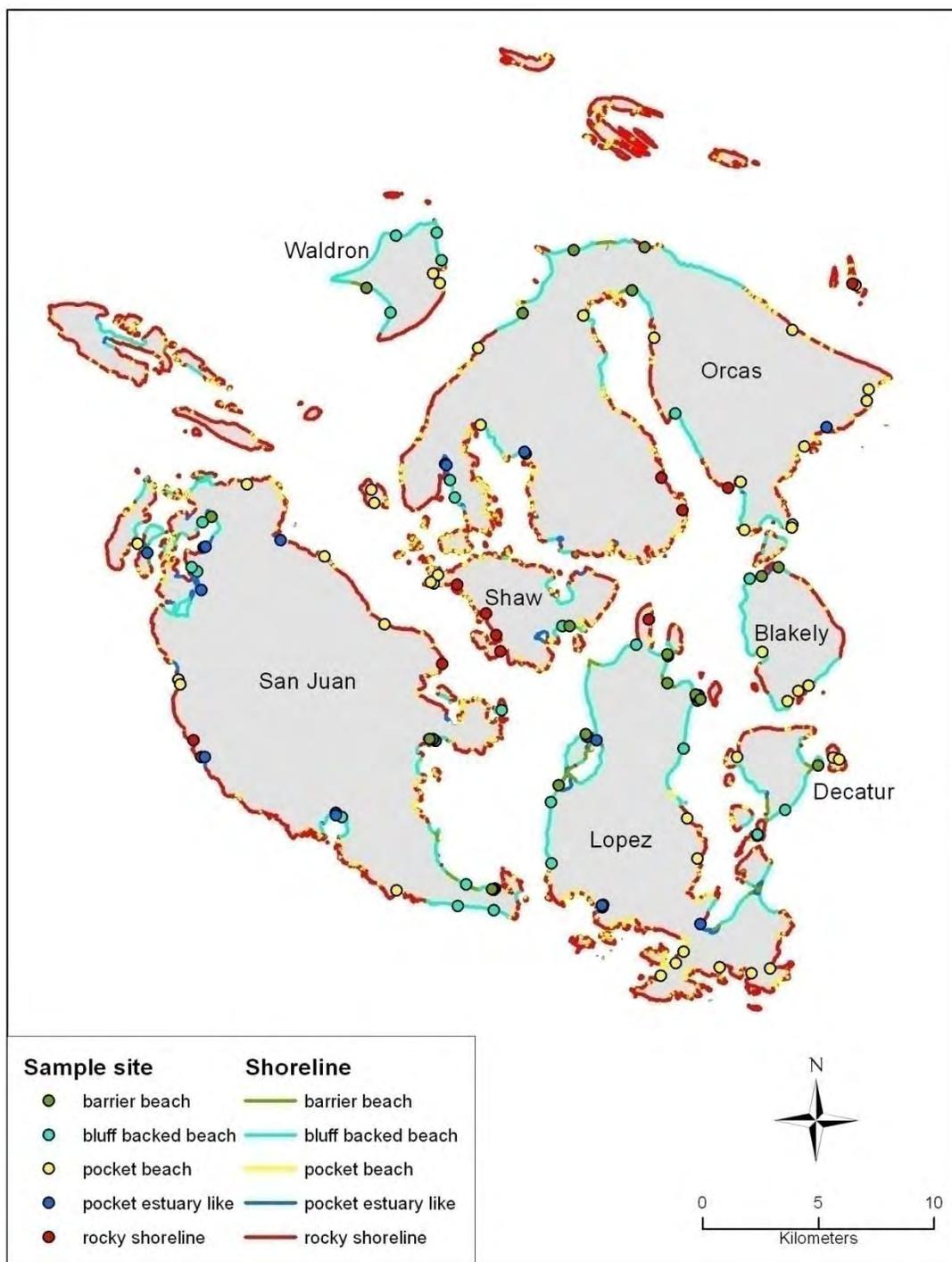


Figure 4. Location of 82 beach seine sites sampled in 2008 and 2009 in the San Juan Islands. Shown by shoreline type (SiteType3).

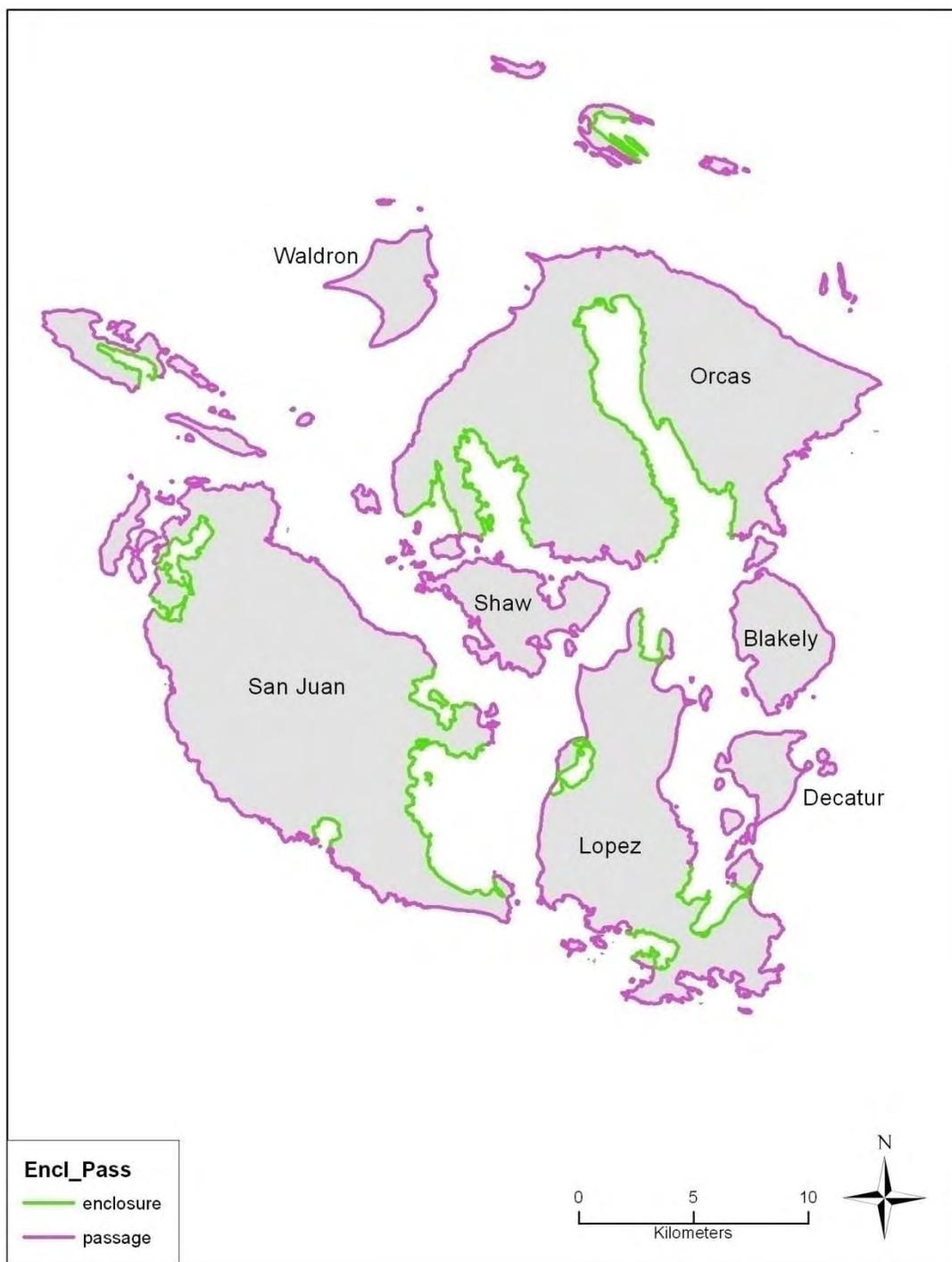


Figure 5. Enclosure and passage areas within the San Juan Islands per our intermediate-scale variable.

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

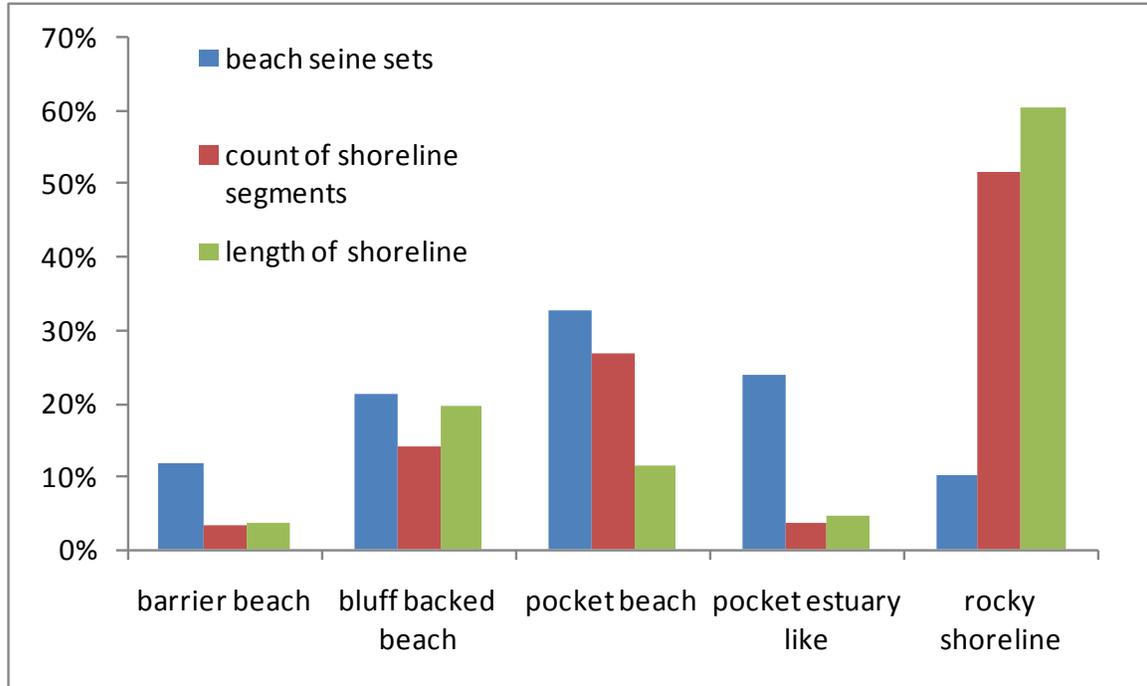


Figure 6. Relationship between beach seine effort by shoreline type and the amount of shoreline habitat by type.

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 was 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

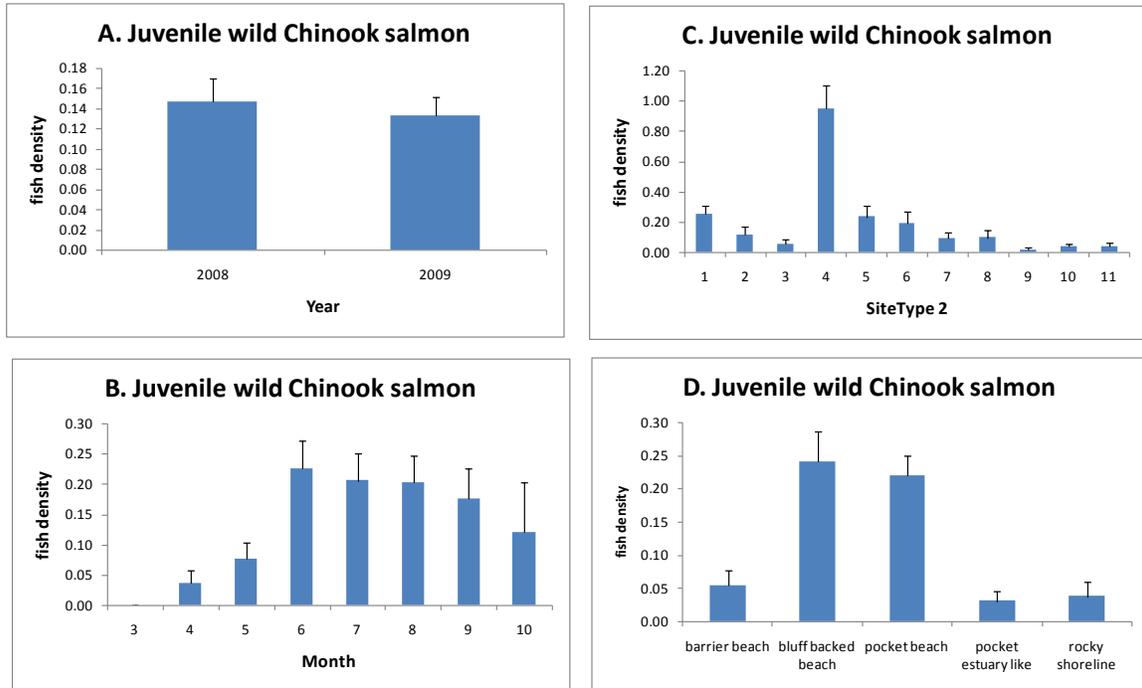


Figure 7. Relationship between average juvenile wild Chinook salmon densities (log-transformed fish per hectare) and year (Panel A), month (Panel B), SiteType2 (Panel C), and shoreline type (Panel D). Results are from 80 beach seine sites throughout the San Juan Islands in 2008 and 2009. Error bars are 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.

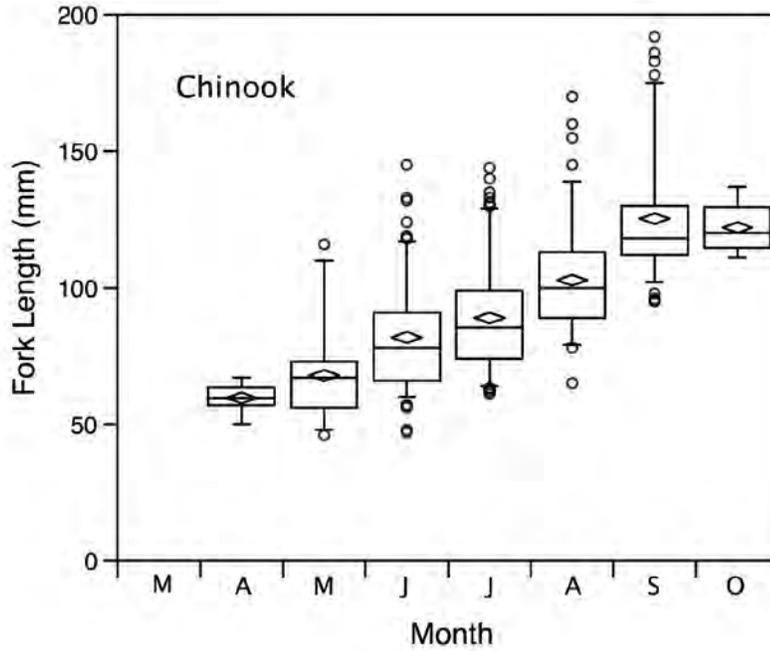


Figure 8. Fork lengths of wild juvenile Chinook salmon caught in shoreline habitats of the San Juan Islands, 2008-2009 combined. Diamonds are means, and boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Circles are outliers.

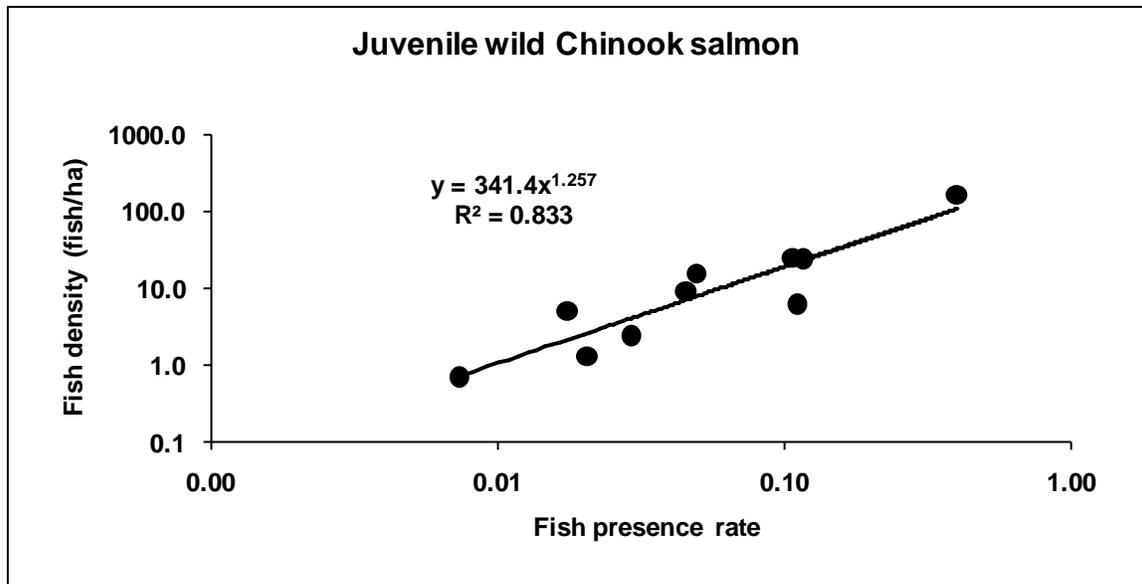


Figure 9. Correlation between presence and abundance of juvenile wild Chinook salmon in San Juan Islands shoreline habitats when beach seine sets are averaged by SiteType2.

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

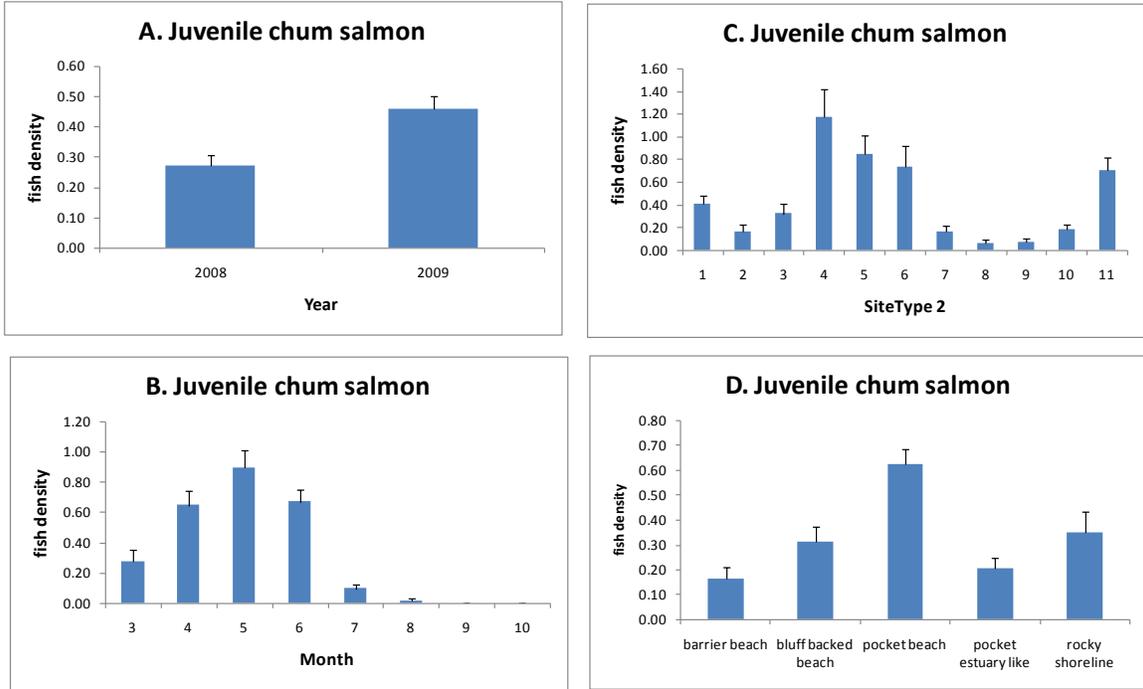


Figure 10. Relationship between average juvenile chum salmon densities (log-transformed fish per hectare) and year (Panel A), month (Panel B), SiteType2 (Panel C), and shoreline type (Panel D). Results are from 80 beach seine sites throughout the San Juan Islands in 2008 and 2009. Error bars are standard 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.

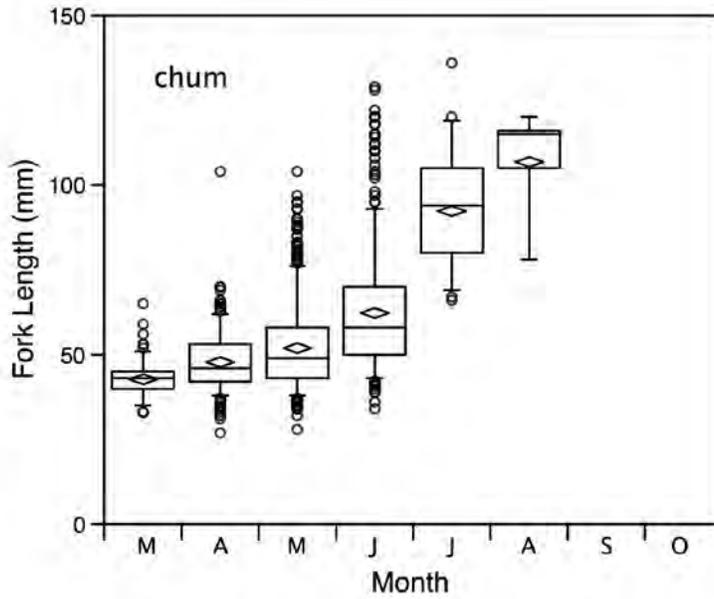


Figure 11. Box plot of fish size for juvenile chum salmon caught in shoreline habitats of the San Juan Islands, 2008-2009. Diamonds are means, and boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Circles are outliers.

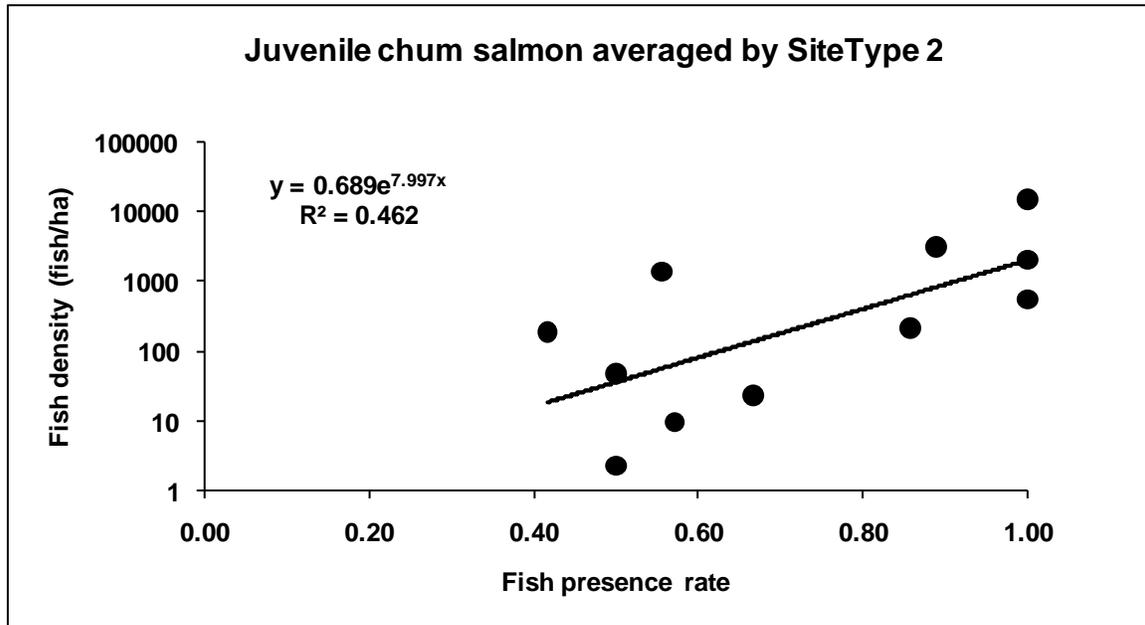


Figure 12. Correlation between presence and abundance of juvenile chum salmon in San Juan Islands shoreline habitats when beach seine sets are averaged by SiteType2.

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

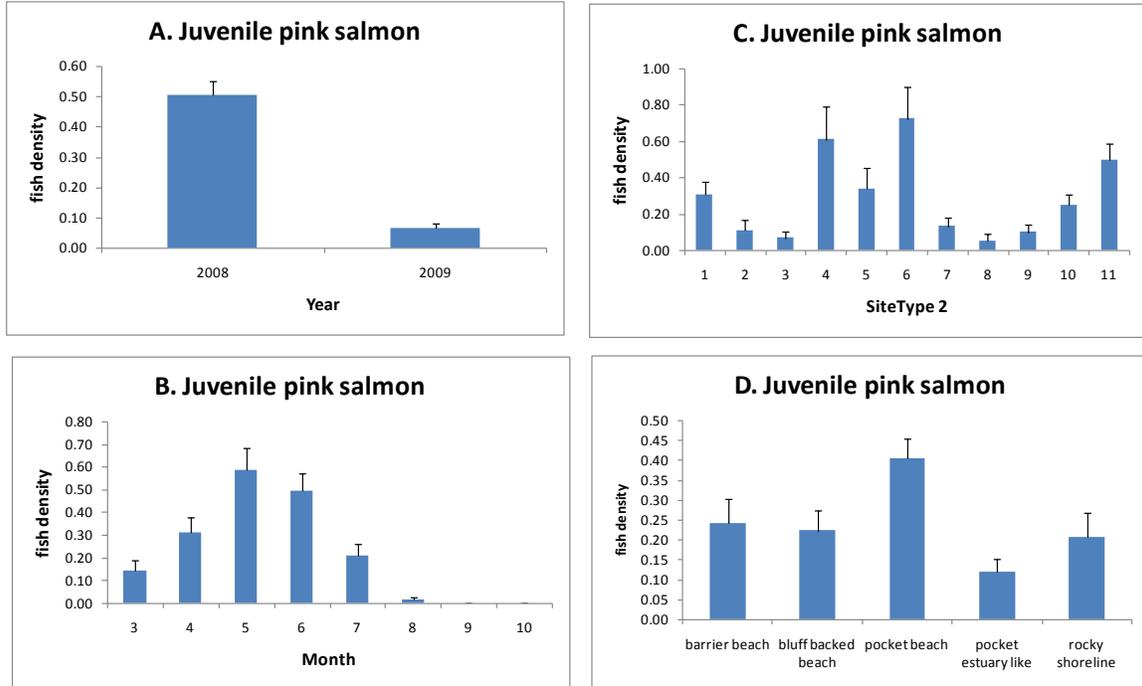


Figure 13. Relationship between average juvenile pink salmon densities (log-transformed fish per hectare) and year (Panel A), month (Panel B), SiteType2 (Panel C), and shoreline type (Panel D). Results are from 80 beach seine sites throughout the San Juan Islands in 2008 and 2009. Error bars are standard 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.

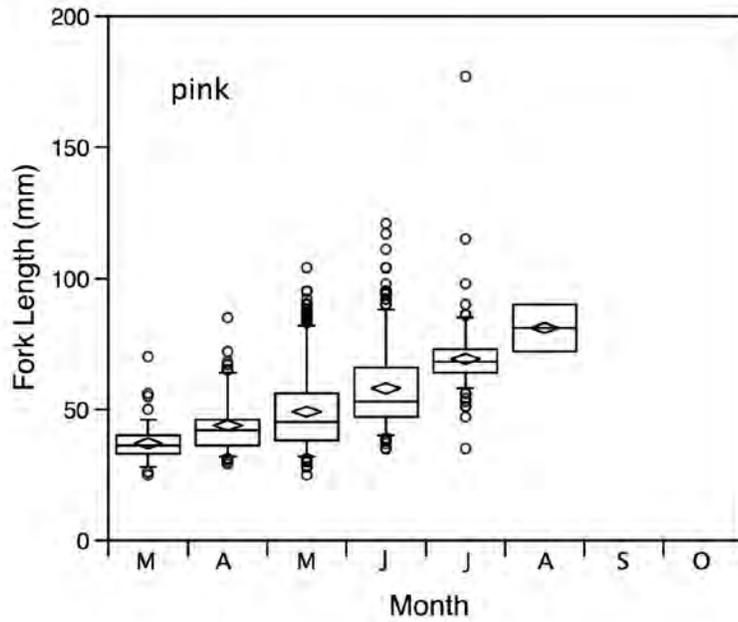


Figure 14. Box plot of fish size for juvenile pink salmon caught in shoreline habitats of the San Juan Islands, 2008-2009. Diamonds are means, and boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Circles are outliers.

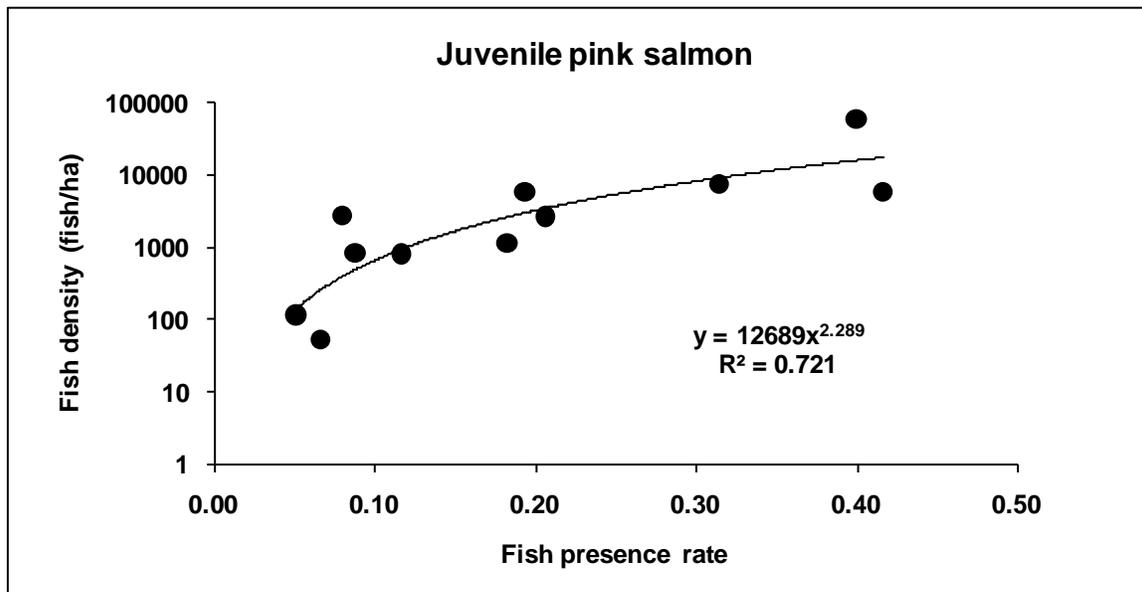


Figure 15. Correlation between presence and abundance of juvenile pink salmon in San Juan Islands shoreline habitats when beach seine sets are averaged by SiteType2.

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

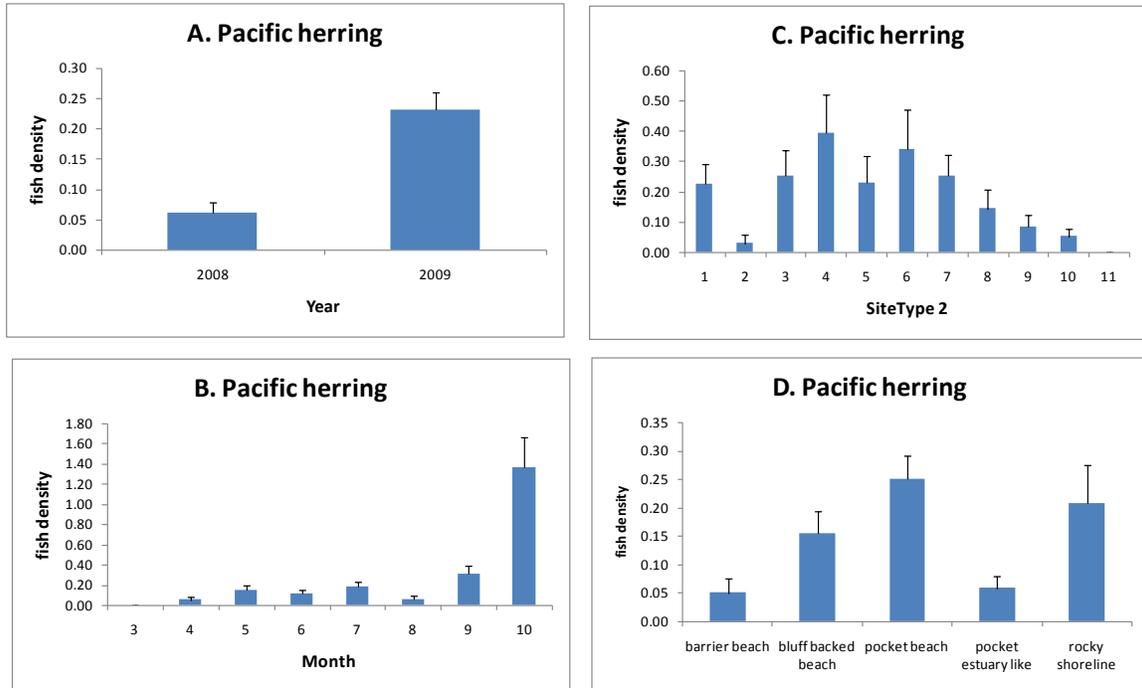


Figure 16. Relationship between average juvenile Pacific herring densities (log-transformed fish per hectare) and year (Panel A), month (Panel B), SiteType2 (Panel C), and shoreline type (Panel D). Results are from 80 beach seine sites throughout the San Juan Islands in 2008 and 2009. Error bars are 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.

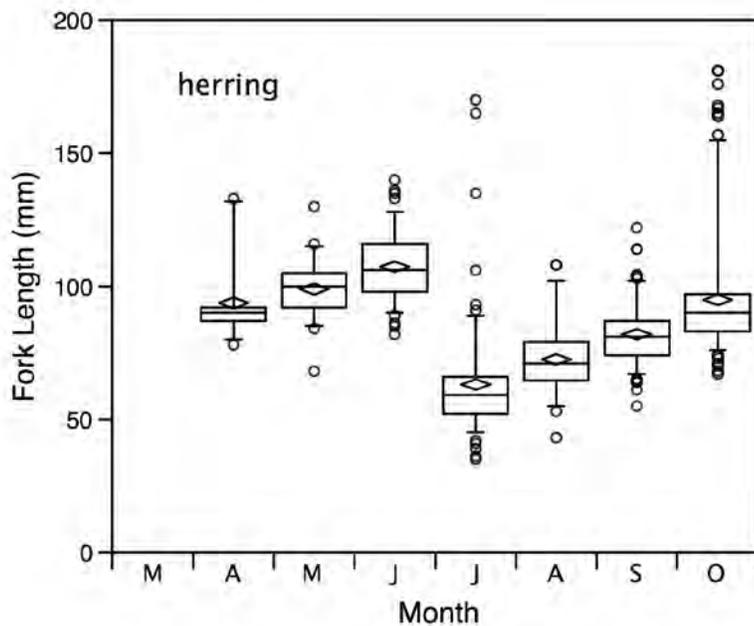


Figure 17. Box plot of fish size for Pacific herring caught in shoreline habitats of the San Juan Islands, 2008-2009. Diamonds are means, and boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Circles are outliers.

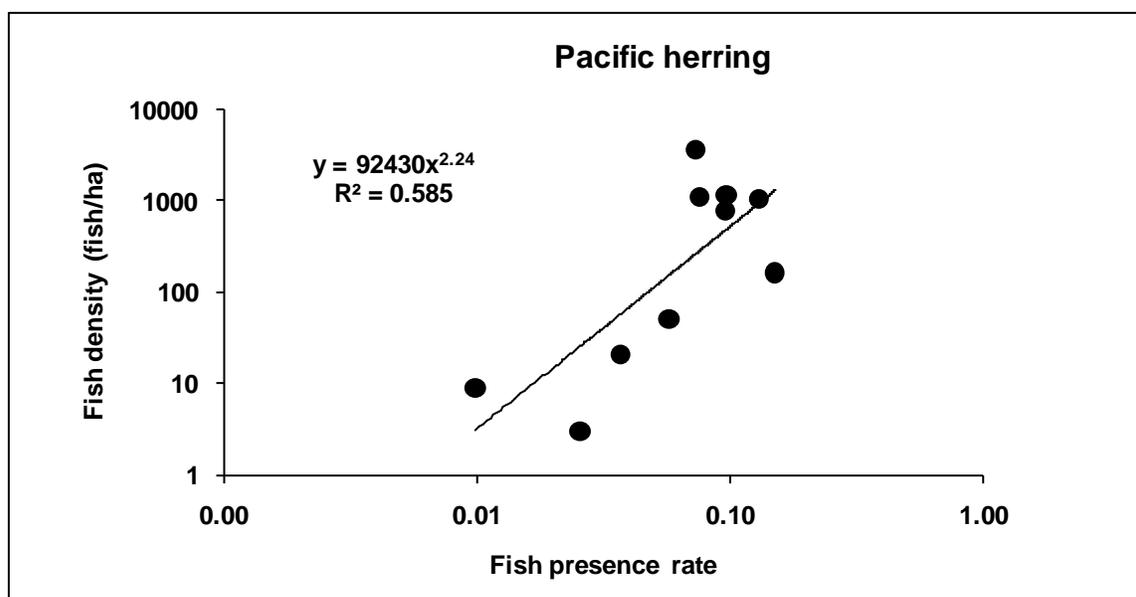


Figure 18. Correlation between presence and abundance of juvenile Pacific herring in San Juan Islands shoreline habitats when beach seine sets are averaged by SiteType2.

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

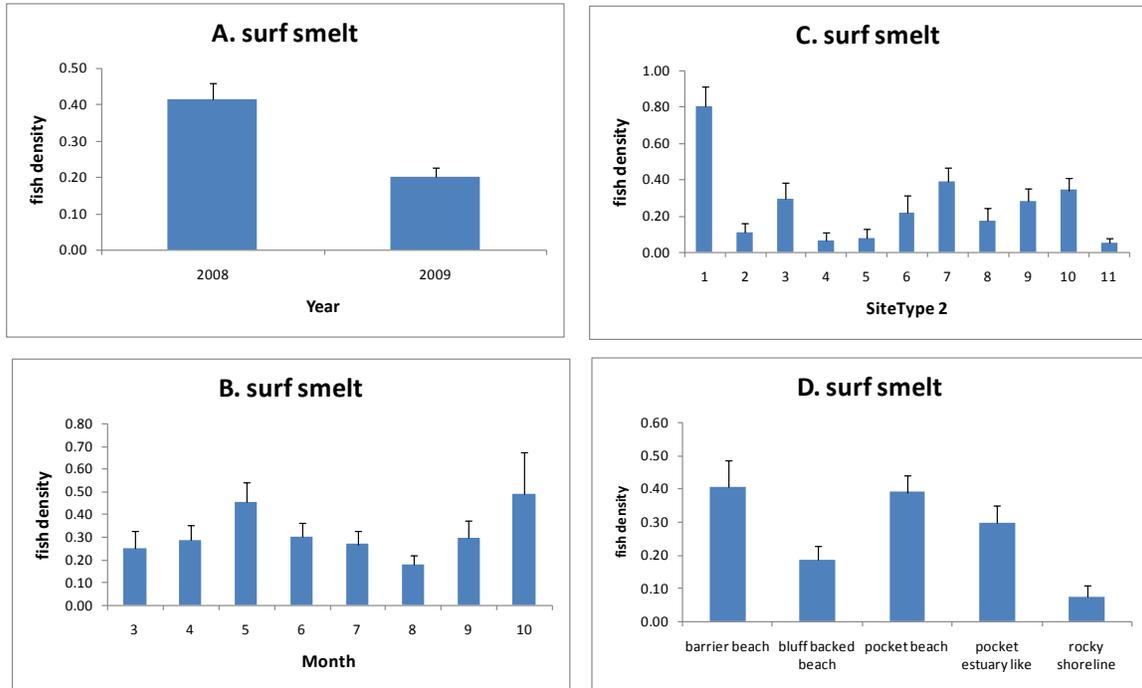


Figure 19. Relationship between average juvenile surf smelt densities (log-transformed fish per hectare) and year (Panel A), month (Panel B), SiteType2 (Panel C), and shoreline type (Panel D). Results are from 80 beach seine sites throughout the San Juan Islands in 2008 and 2009. Error bars are standard 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.

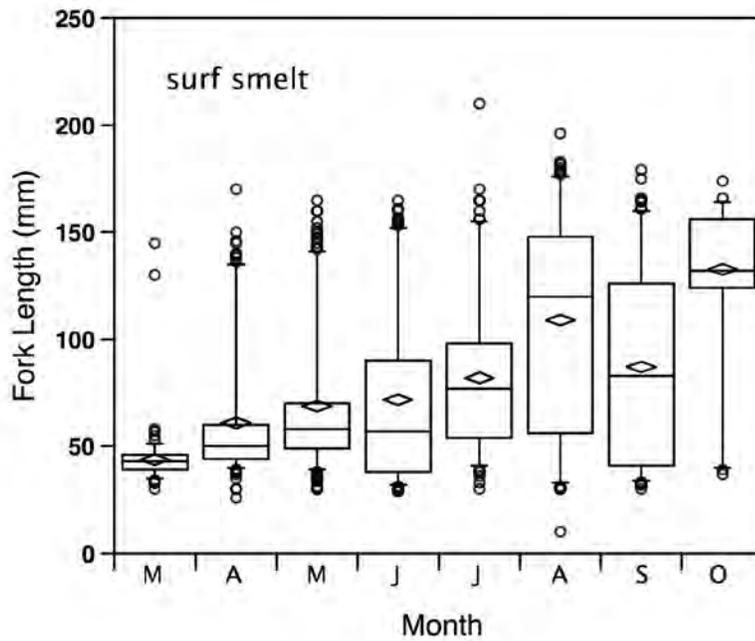


Figure 20. Box plot of fish size for juvenile surf smelt caught in shoreline habitats of the San Juan Islands, 2008-2009. Diamonds are means, and boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Circles are outliers.

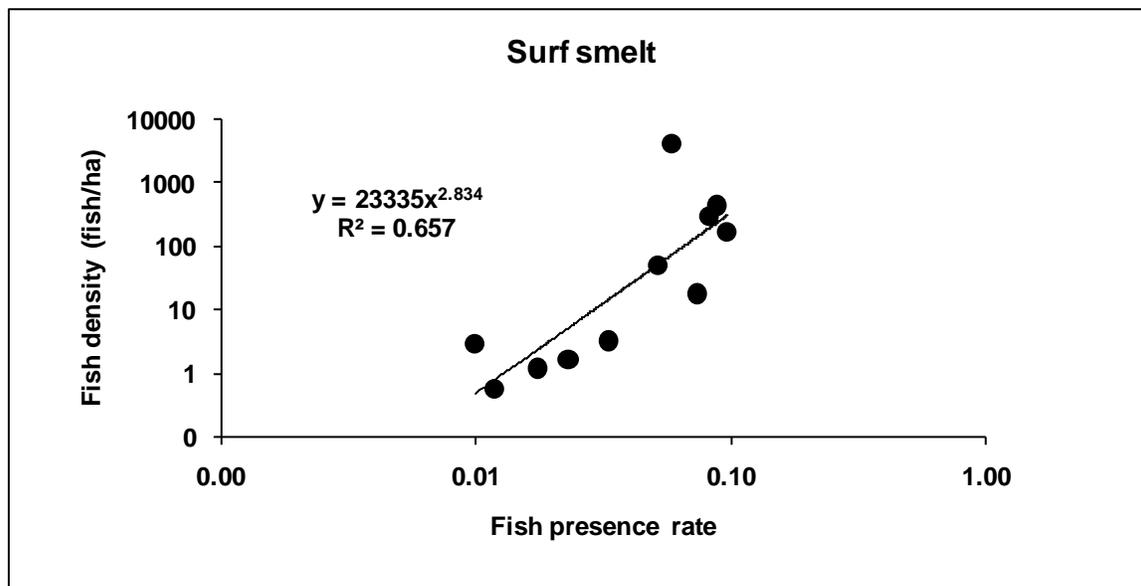


Figure 21. Correlation between presence and abundance of juvenile surf smelt in San Juan Islands shoreline habitats when beach seine sets are averaged by SiteType2.

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

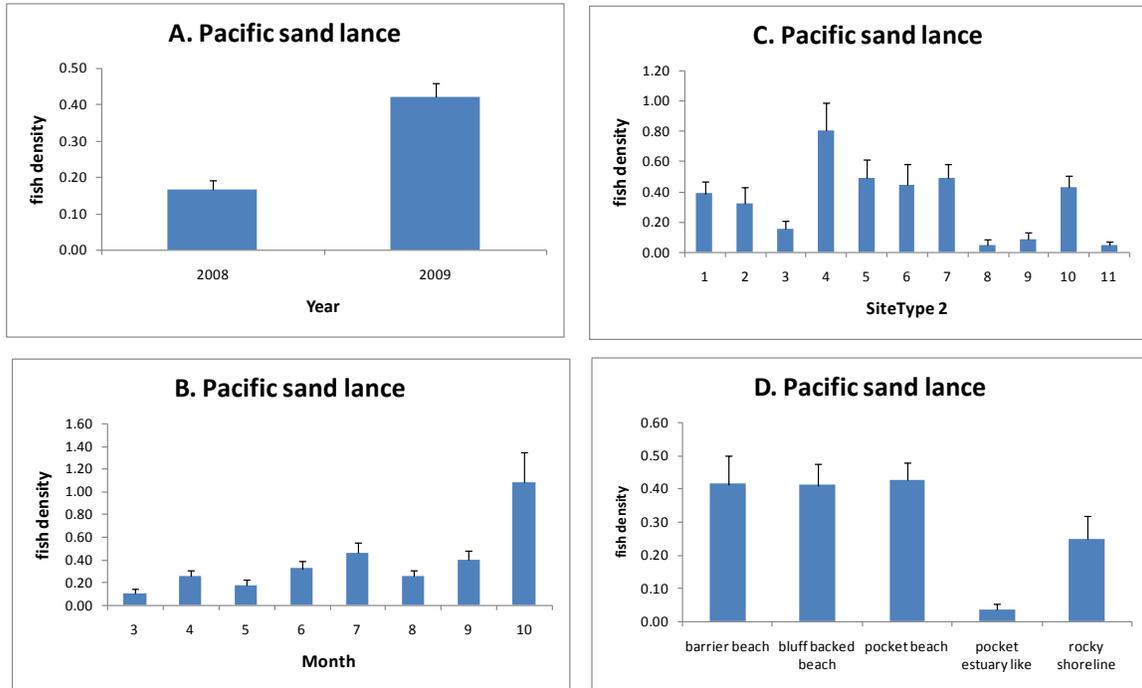


Figure 22. Relationship between average juvenile Pacific sand lance densities (log-transformed fish per hectare) and year (Panel A), month (Panel B), SiteType2 (Panel C), and shoreline type (Panel D). Results are from 80 beach seine sites throughout the San Juan Islands in 2008 and 2009. Error bars are 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.

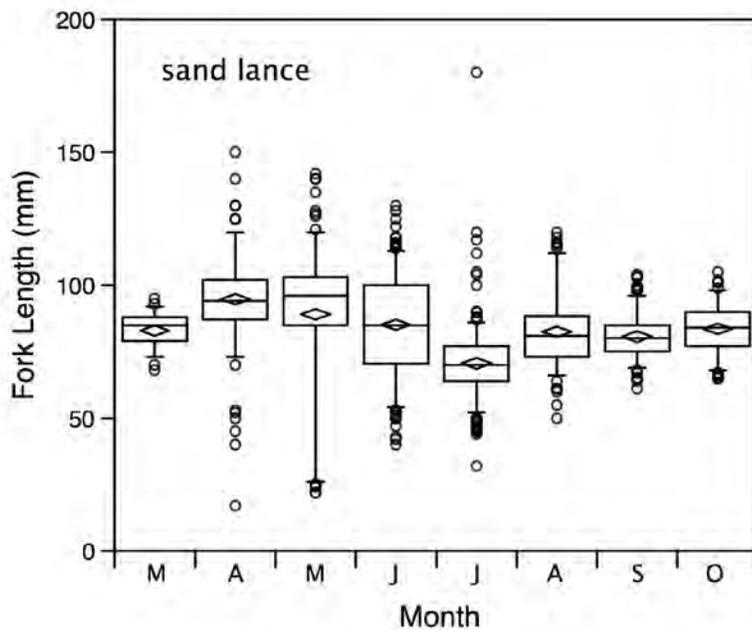


Figure 23. Box plot of fish size for Pacific sand lance caught in shoreline habitats of the San Juan Islands, 2008-2009. Diamonds are means, and boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Circles are outliers.

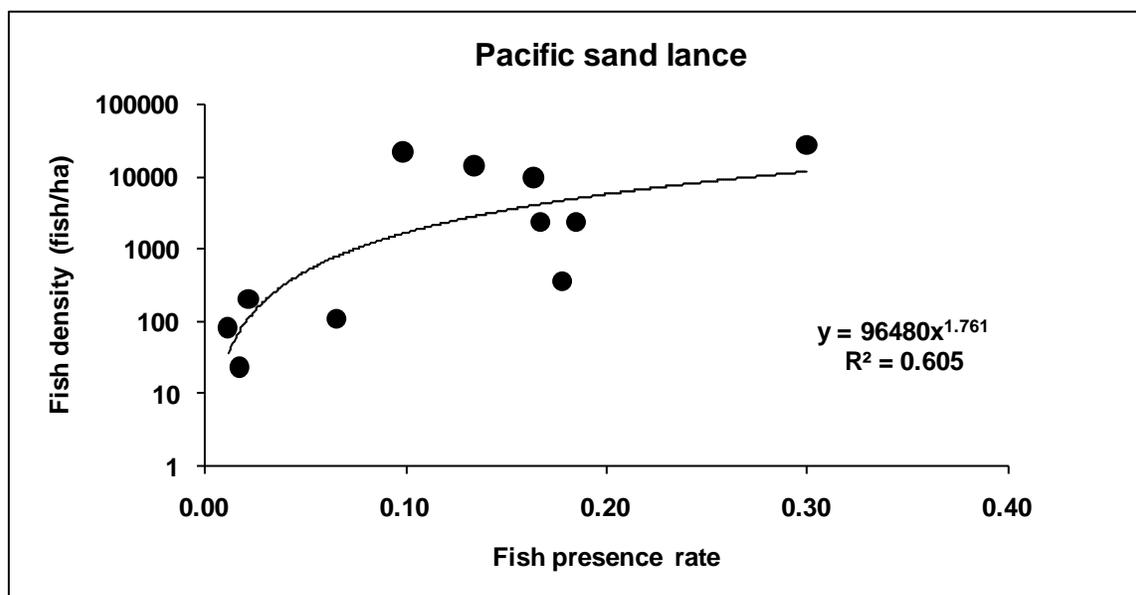


Figure 24. Correlation between presence and abundance of juvenile Pacific sand lance in San Juan Islands shoreline habitats when beach seine sets are averaged by SiteType2.

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 were 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

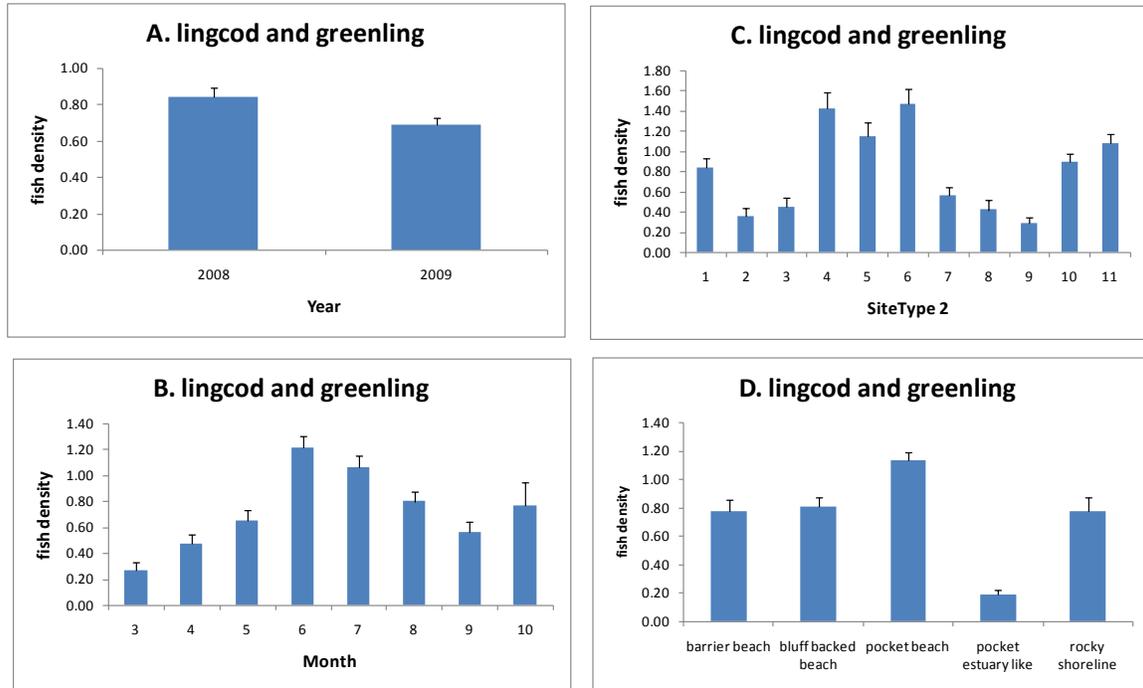


Figure 25. Relationship between average juvenile lingcod and greenling densities (log-transformed fish per hectare) and year (Panel A), month (Panel B), SiteType2 (Panel C), and shoreline type (Panel D). Results are from 80 beach seine sites throughout the San Juan Islands in 2008 and 2009. Error bars 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.

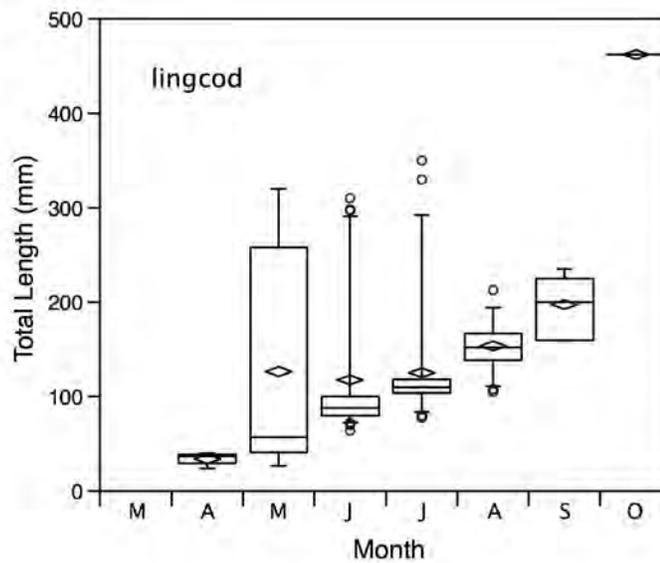
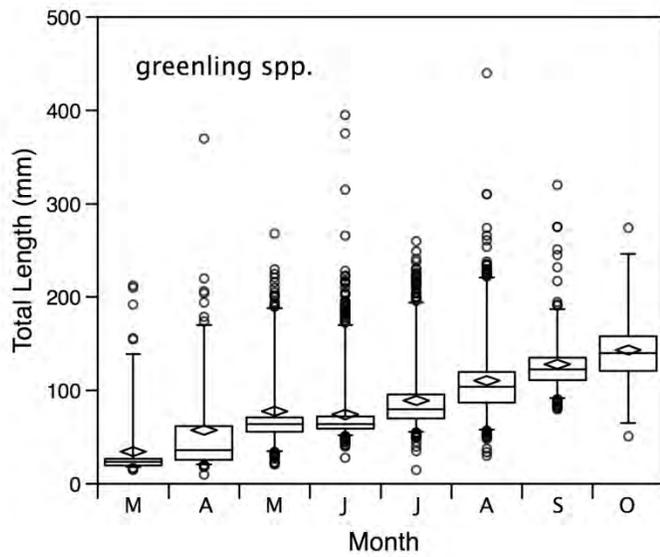


Figure 26. Box plot of fish size for greenling (top panel) and juvenile lingcod (bottom panel) in shoreline habitats of the San Juan Islands, 2008-2009. Diamonds are means, and boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Circles are outliers.

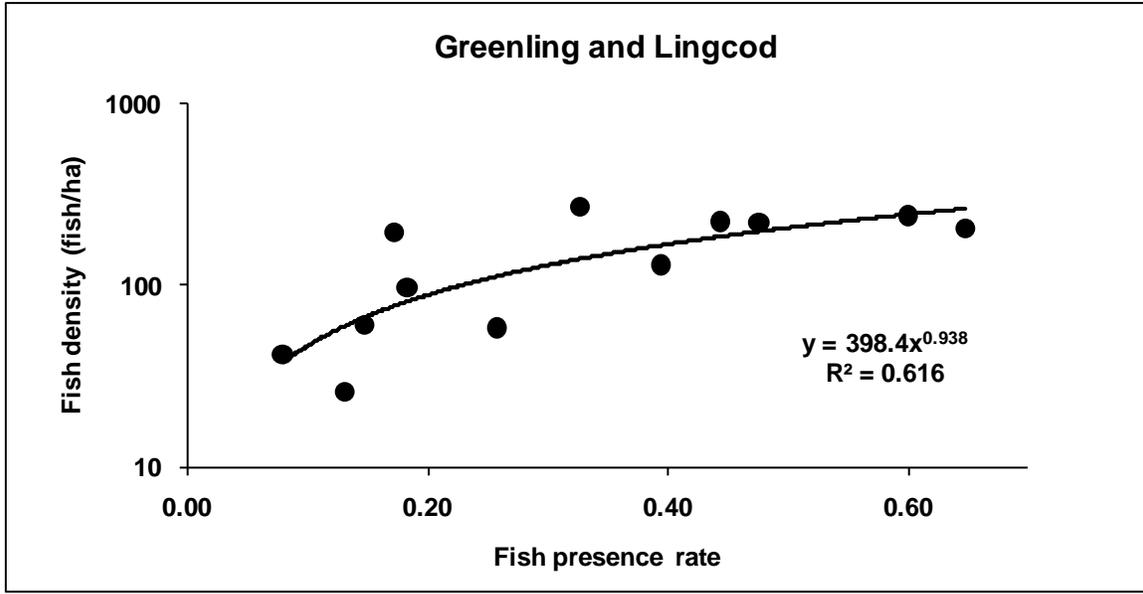


Figure 27. Correlation between presence and abundance of juvenile lingcod and greenling in San Juan Islands shoreline habitats when beach seine sets are averaged by SiteType2.

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	<i>0.625</i>	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	<i>0.625</i>	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	<i>0.027</i>	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:	
Interior	0.227	<i>0.059</i>	0.102
Exterior	0.553	0.143	<i>0.249</i>

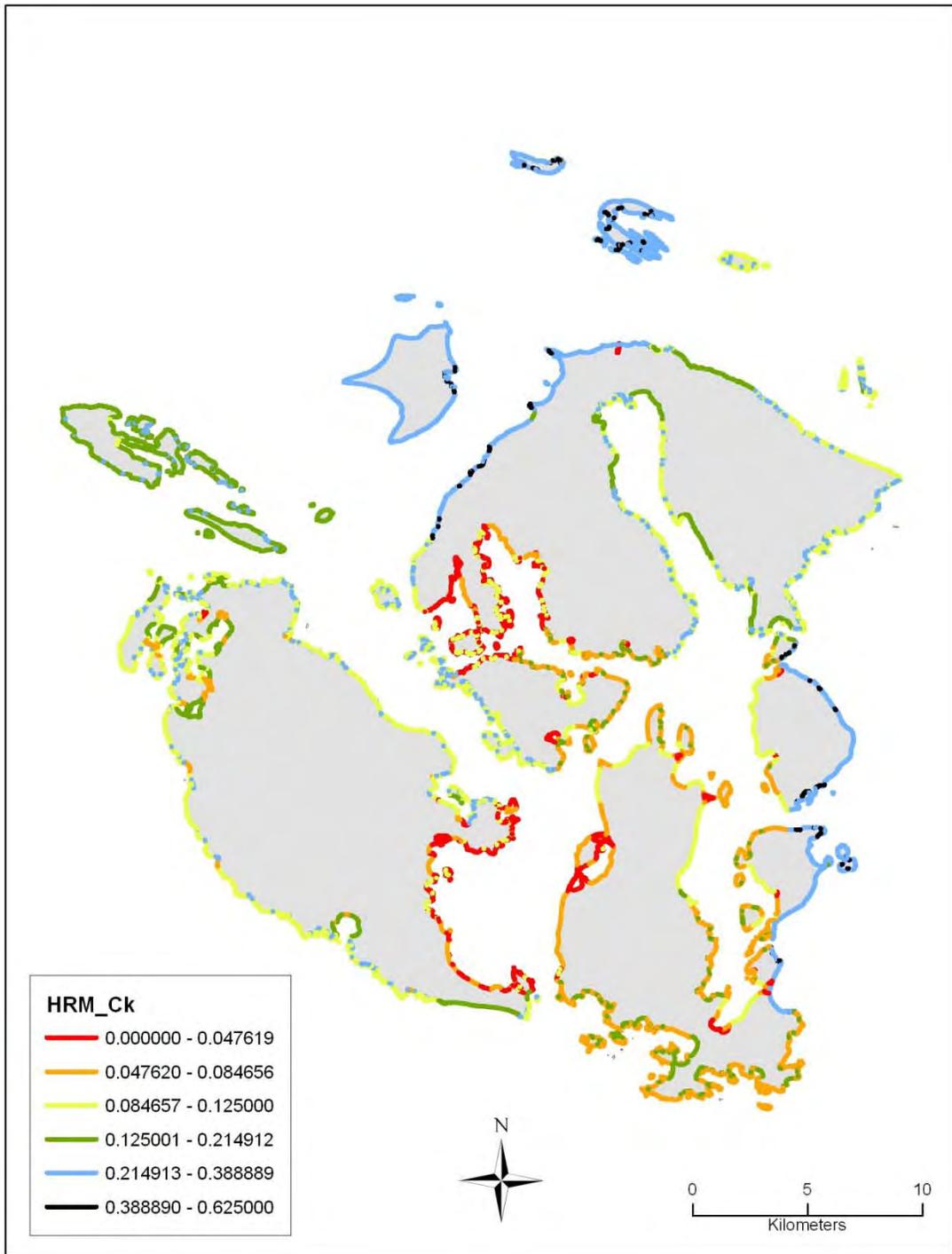


Figure 28. Fish presence probability for wild (unmarked) juvenile Chinook salmon for shoreline habitats (high resolution model).

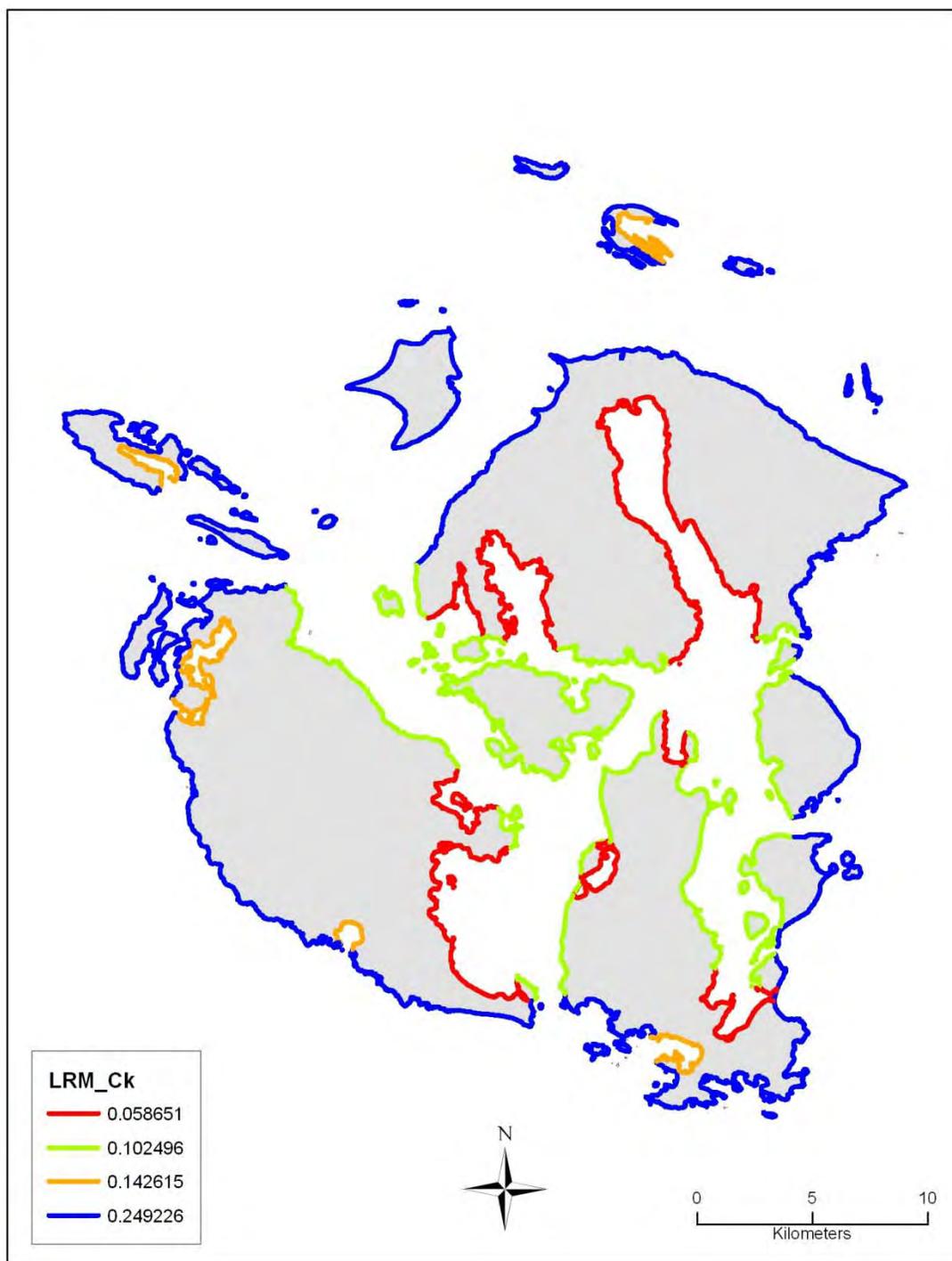


Figure 29. Fish presence probability for wild (unmarked) juvenile Chinook salmon for shoreline habitats (low resolution model).

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	<i>0.960</i>	0.450	0.750
	Rosario NW	1.000	0.364	0.722	<i>0.960</i>	0.450	0.750
	Rosario Strait SW	1.000	0.364	0.722	<i>0.960</i>	0.450	0.750
	Blakely Sound - Lopez Sound	0.417	<i>0.152</i>	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
Interior	0.568	<i>0.271</i>	0.523
Exterior	0.816	0.389	<i>0.751</i>

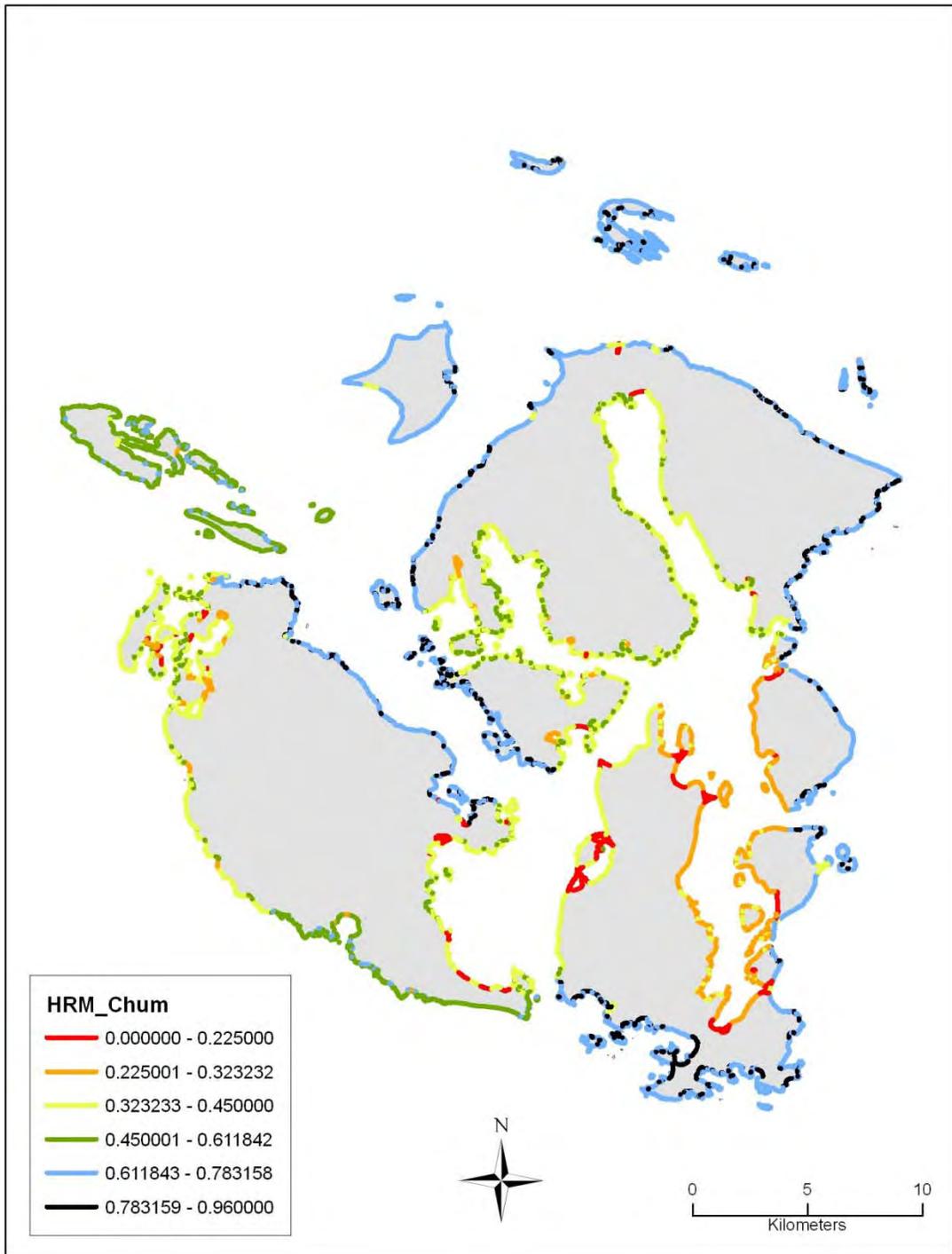


Figure 30. Fish presence probability for juvenile chum salmon for shoreline habitats (high resolution model).

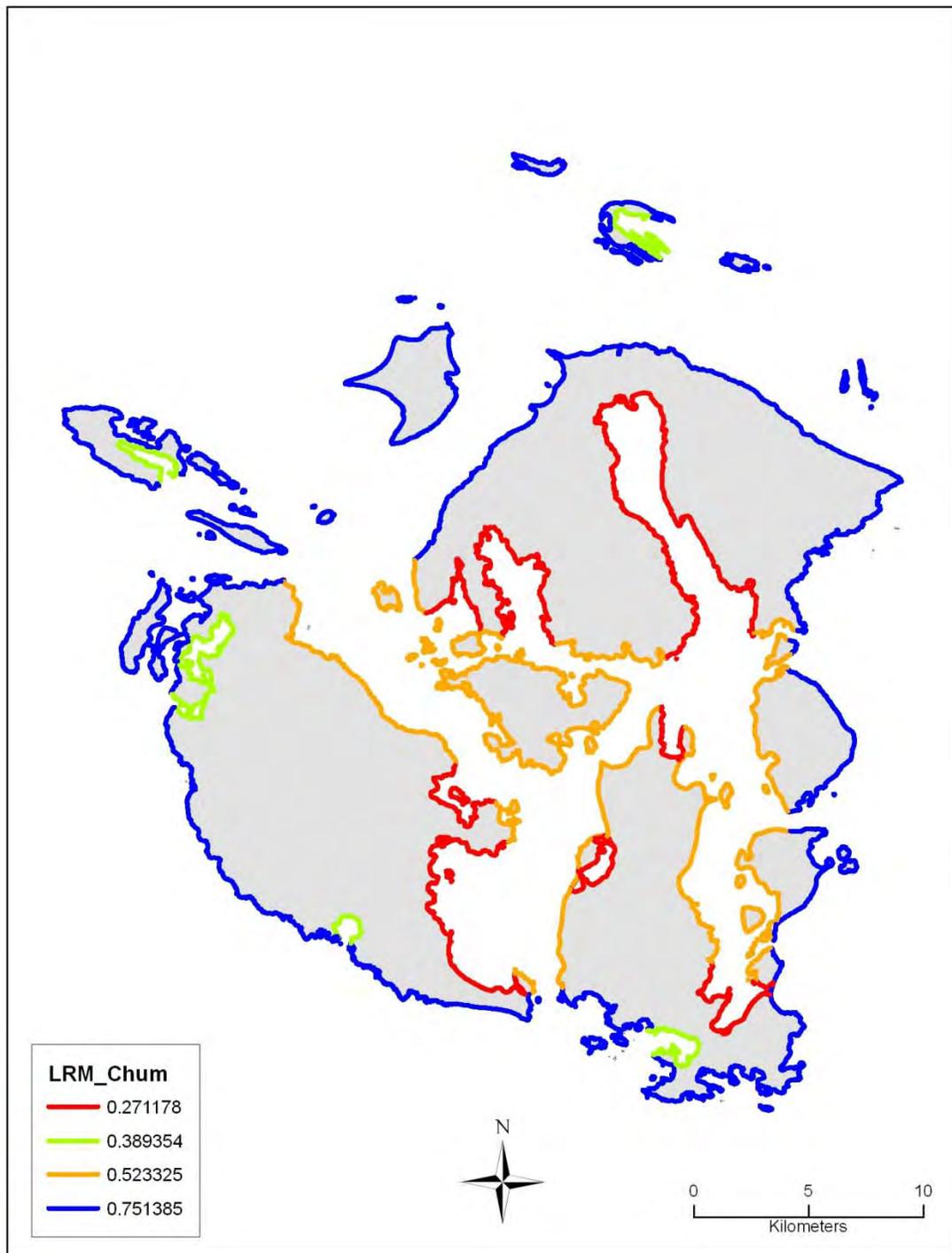


Figure 31. Fish presence probability for juvenile chum salmon for shoreline habitats (low resolution model).

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	<i>0.857</i>
	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	<i>0.070</i>	0.143
	Waldron Is - President Channel	1.000	0.545	0.800	0.818	0.421	<i>0.857</i>
	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:	
Interior	0.714	0.399	<i>0.599</i>
Exterior	0.641	<i>0.358</i>	0.538

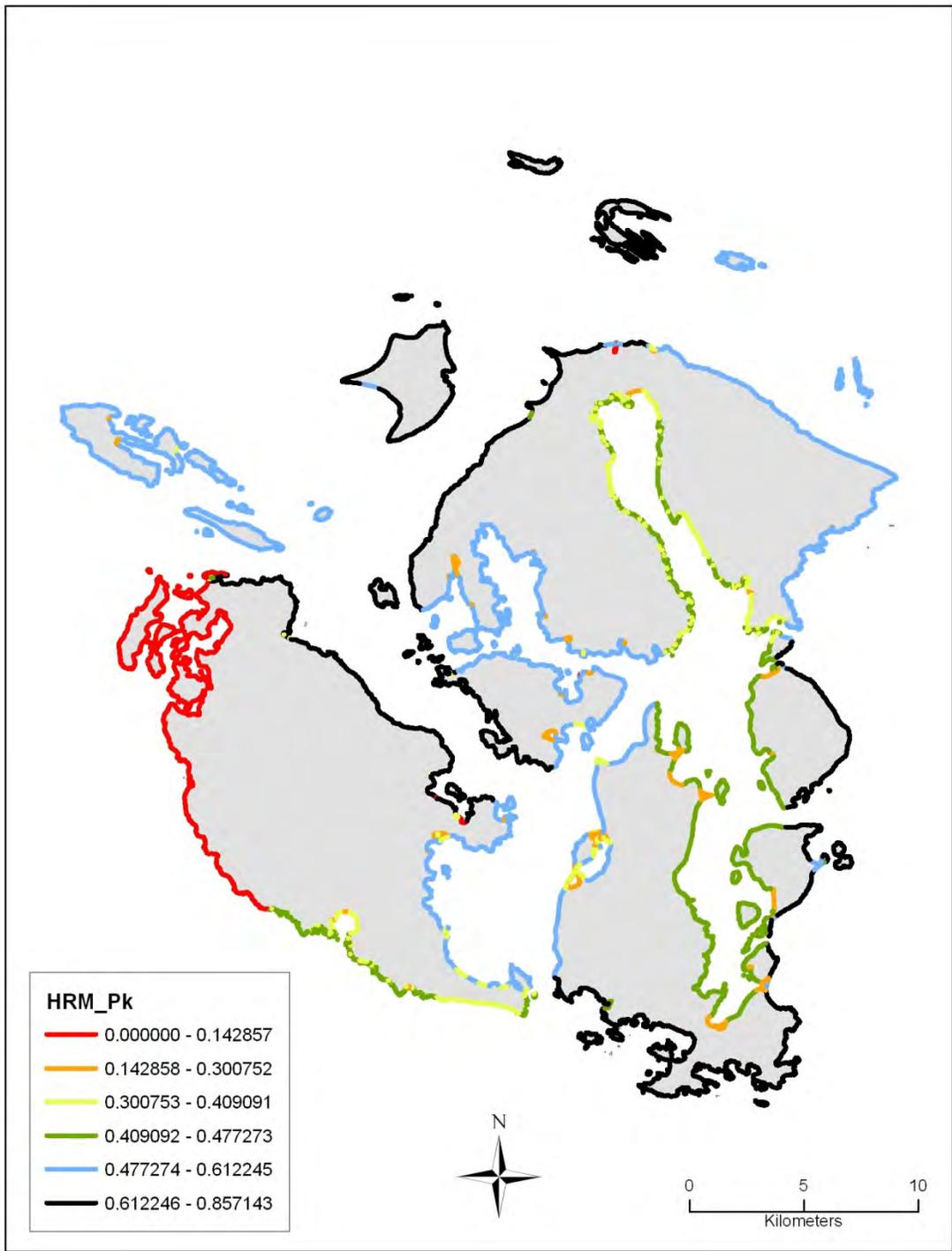


Figure 32. Fish presence probability for juvenile pink salmon for shoreline habitats (high resolution model).

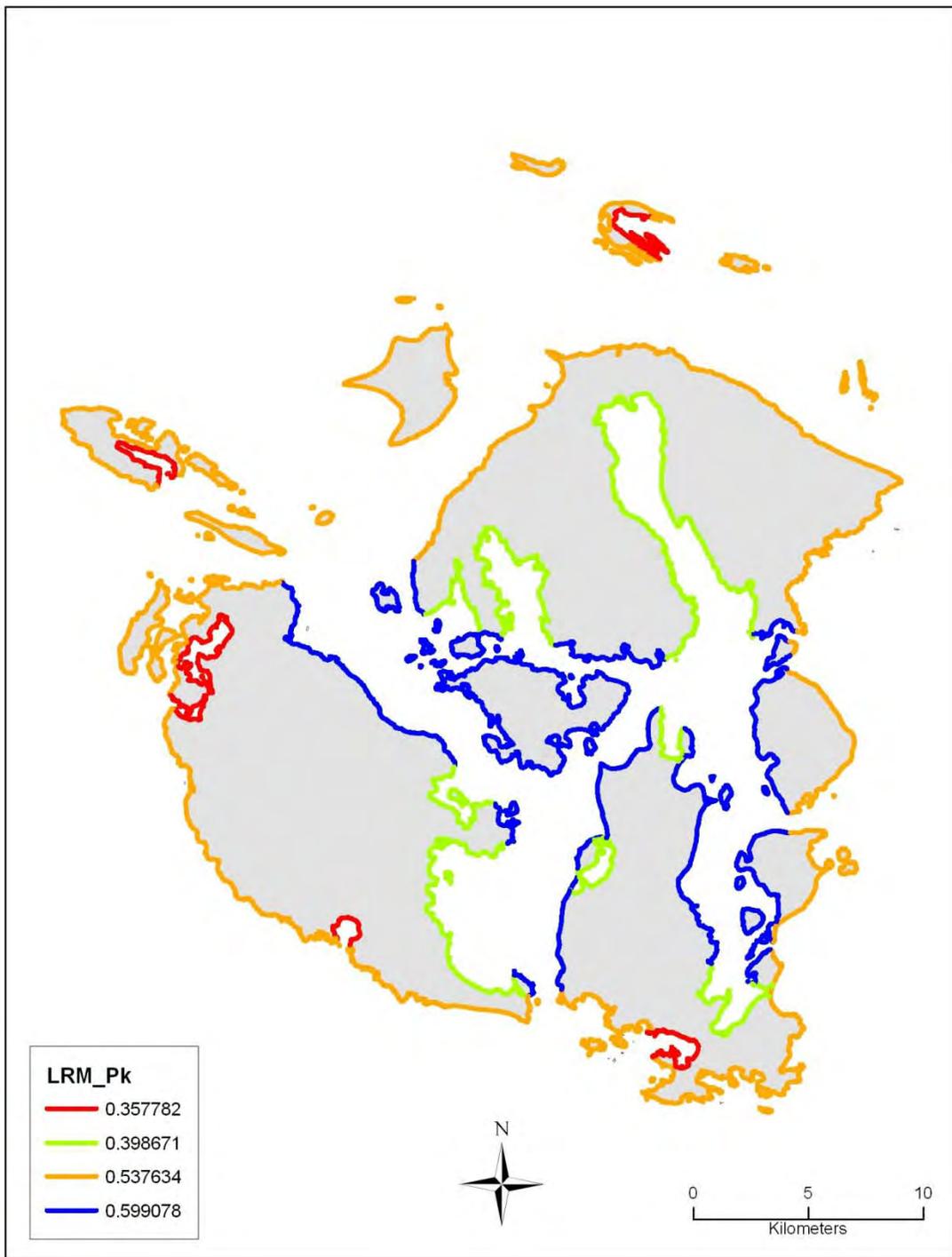


Figure 33. Fish presence probability for juvenile pink salmon for shoreline habitats (low resolution model).

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	<i>0.625</i>	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	<i>0.000</i>	<i>0.000</i>	<i>0.000</i>	<i>0.000</i>	<i>0.000</i>

		Enclosure	Passage
		LRM Fish presence rate:	
Interior	0.273	<i>0.095</i>	0.119
Exterior	0.526	0.184	<i>0.229</i>

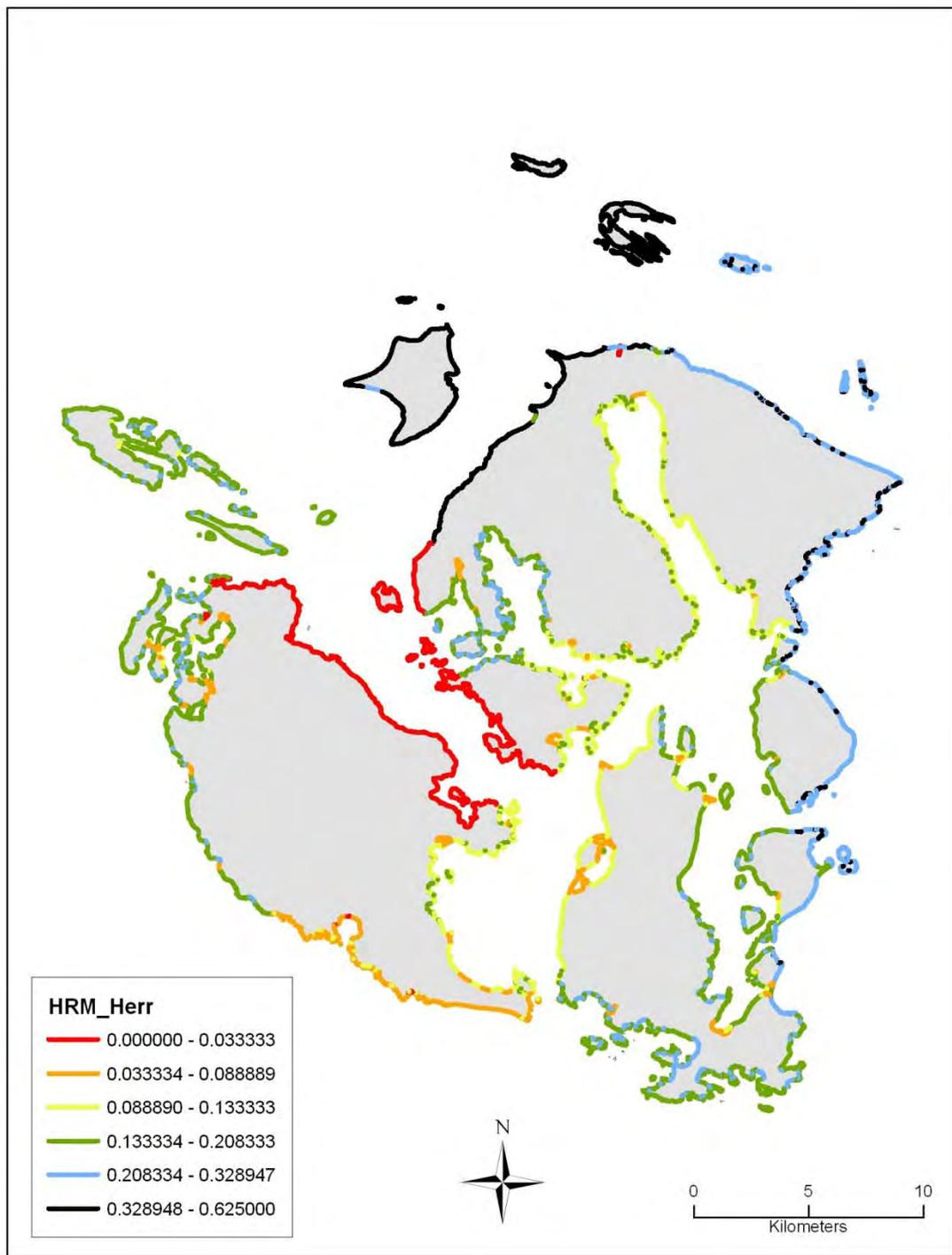


Figure 34. Fish presence probability for juvenile Pacific herring for shoreline habitats (high resolution model).

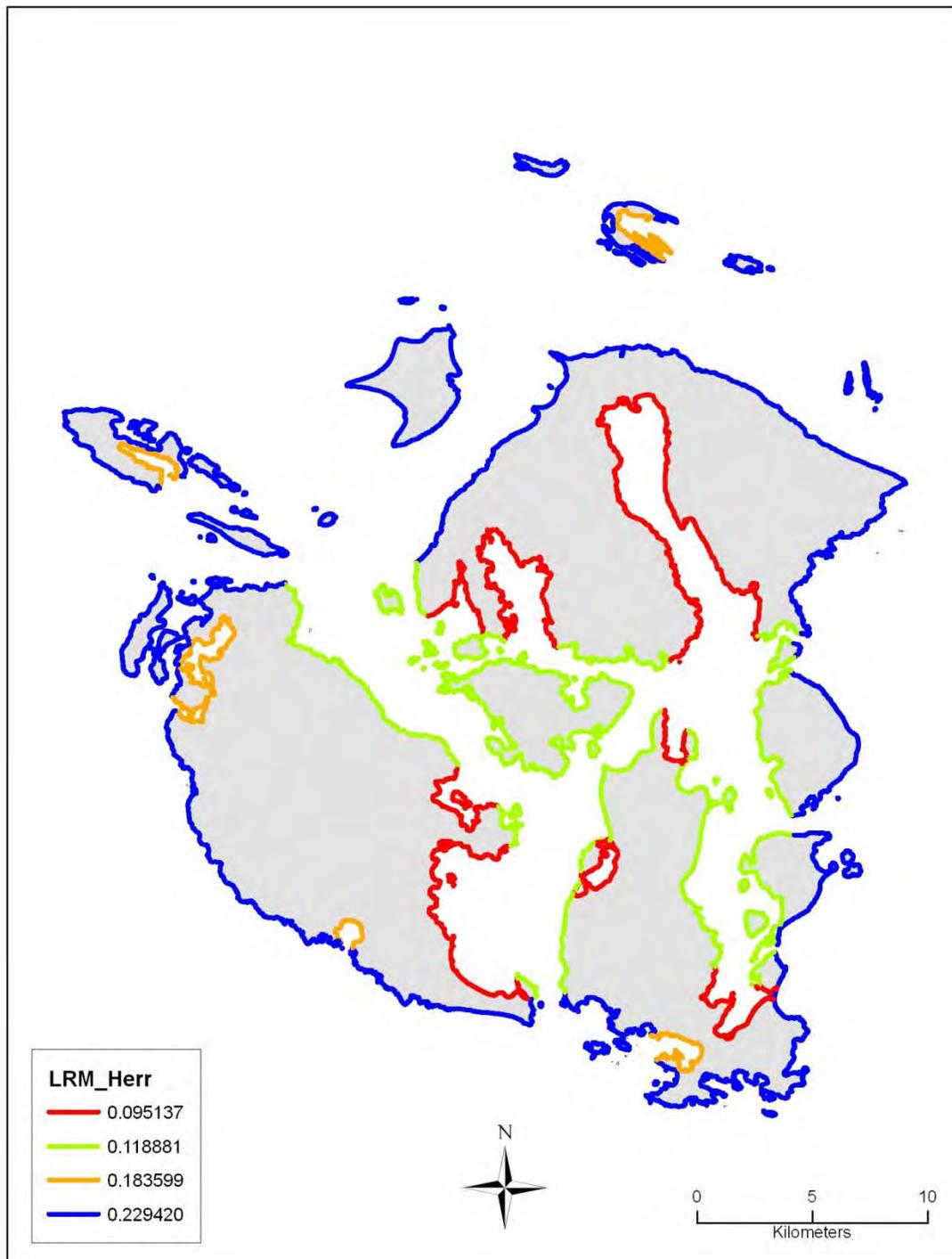


Figure 35. Fish presence probability for juvenile Pacific herring for shoreline habitats (low resolution model).

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	<i>0.021</i>
	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	<i>0.021</i>
	Rosario Strait SW	0.750	<i>0.545</i>	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:	
Interior	0.409	0.224	<i>0.144</i>
Exterior	0.447	<i>0.245</i>	0.158

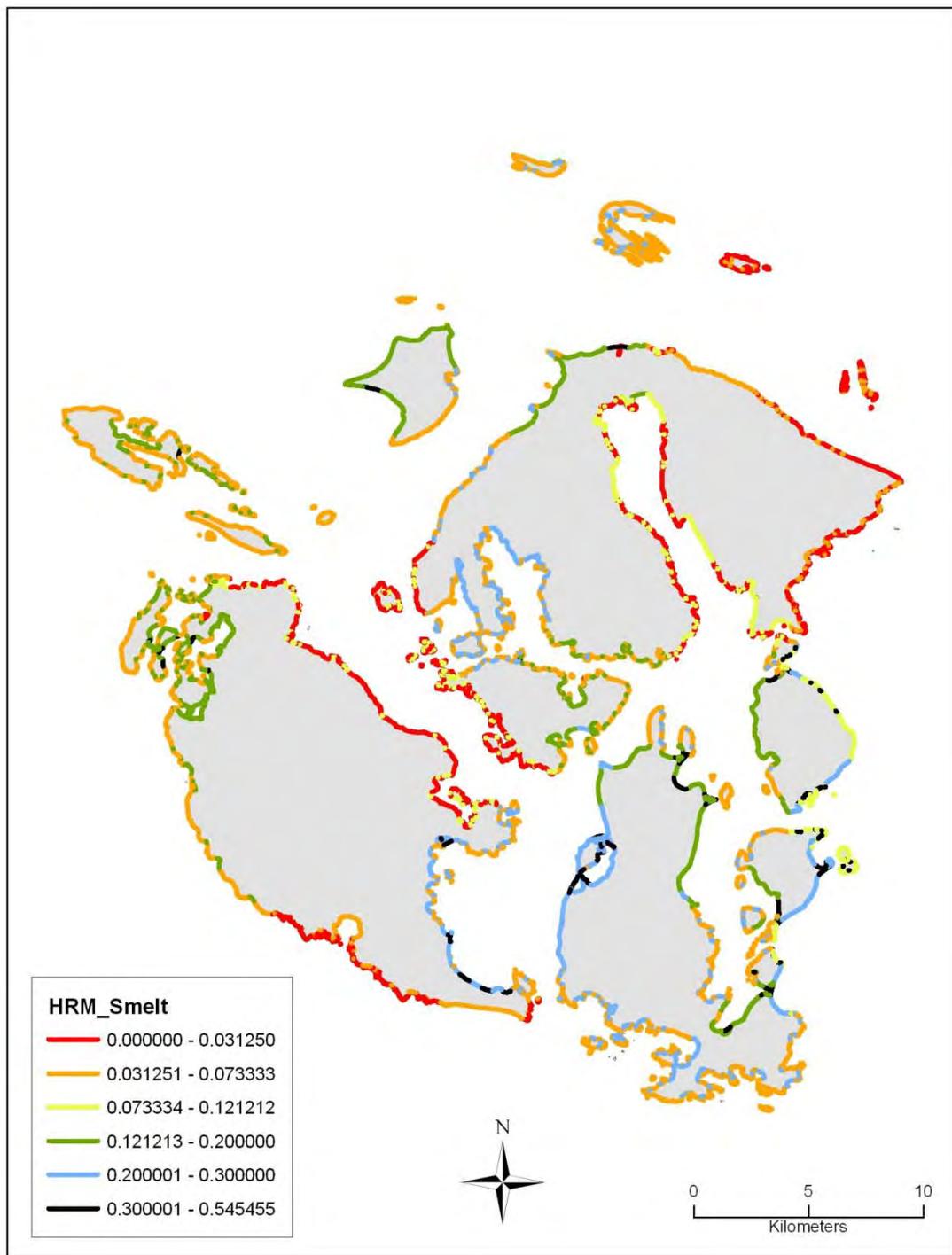


Figure 36. Fish presence probability for juvenile surf smelt for shoreline habitats (high resolution model).

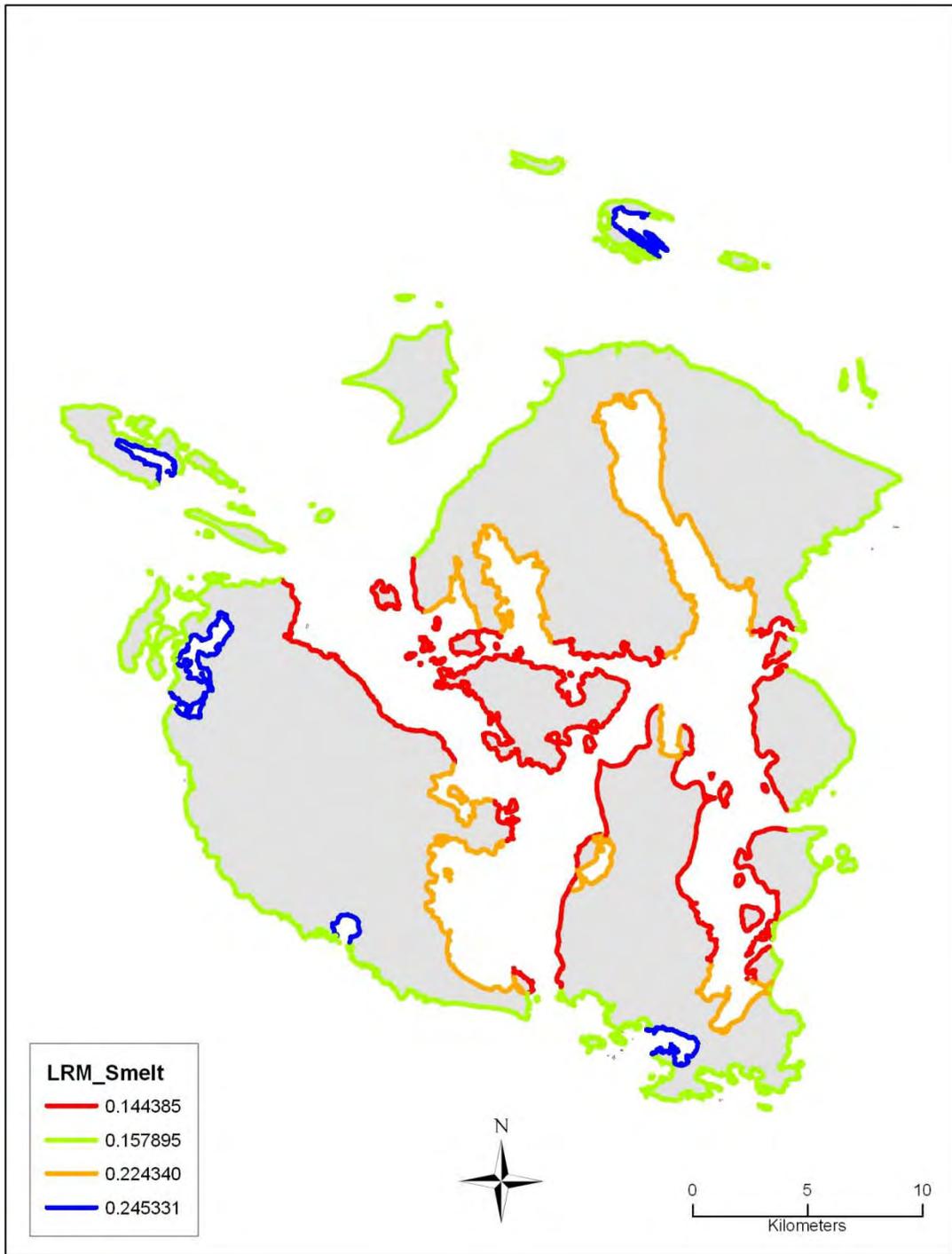


Figure 37. Fish presence probability for juvenile surf smelt for shoreline habitats (low resolution model).

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	<i>0.625</i>
	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	<i>0.625</i>
	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	<i>0.014</i>	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:	
Interior	0.364	<i>0.109</i>	0.196
Exterior	0.553	0.166	<i>0.298</i>

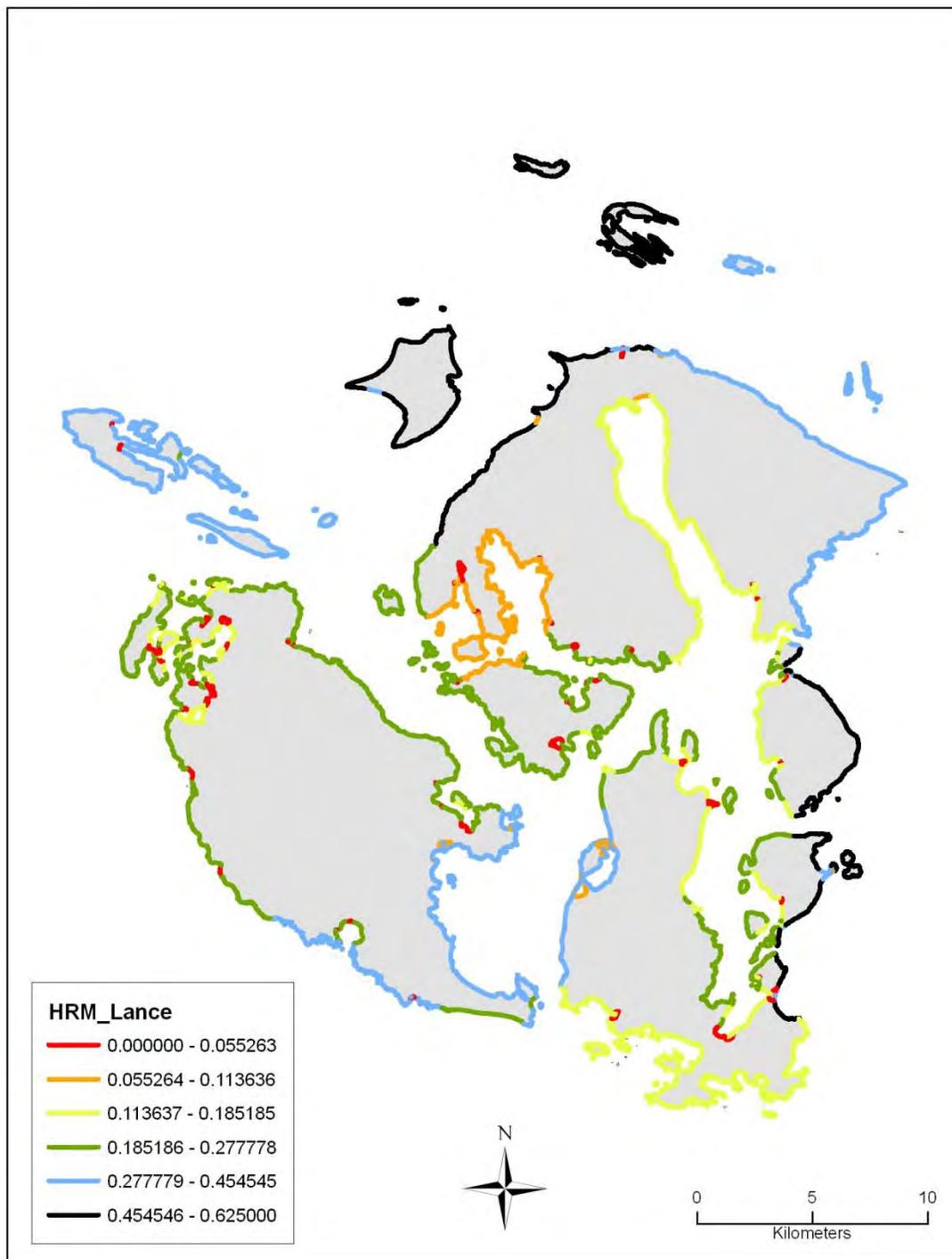


Figure 38. Fish presence probability for juvenile Pacific sand lance for shoreline habitats (high resolution model).

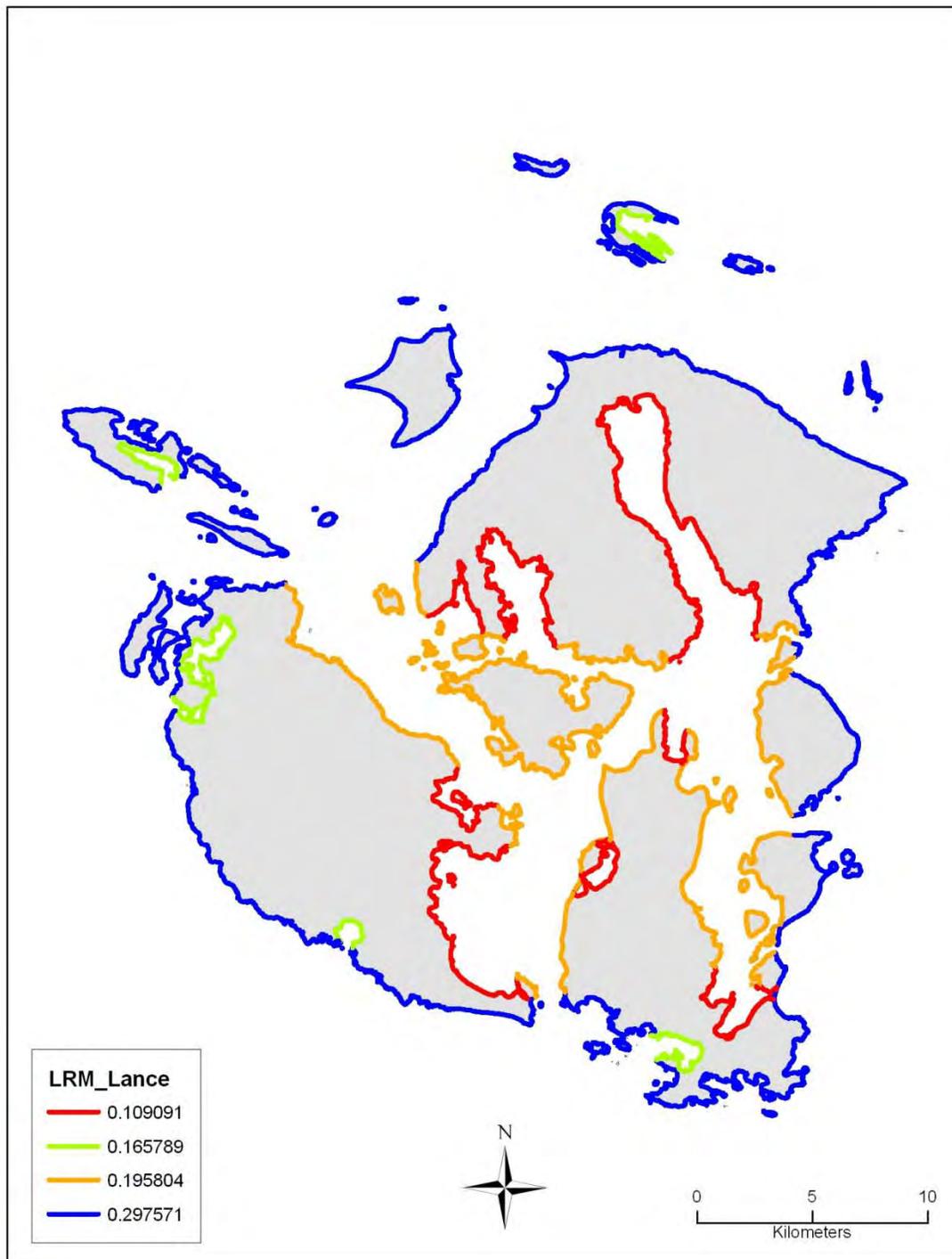


Figure 39. Fish presence probability for juvenile Pacific sand lance for shoreline habitats (low resolution model).

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	<i>0.150</i>	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	<i>0.960</i>	0.450	0.875
	Rosario NW	1.000	0.727	0.833	<i>0.960</i>	0.450	0.875
	Rosario Strait SW	1.000	0.727	0.833	<i>0.960</i>	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	<i>0.960</i>	0.450	0.875
San Juan Channel North	1.000	0.727	0.833	<i>0.960</i>	0.450	0.875	

		Enclosure	Passage
		LRM Fish presence rate:	
Interior	0.795	0.524	<i>0.712</i>
Exterior	0.737	<i>0.486</i>	0.659

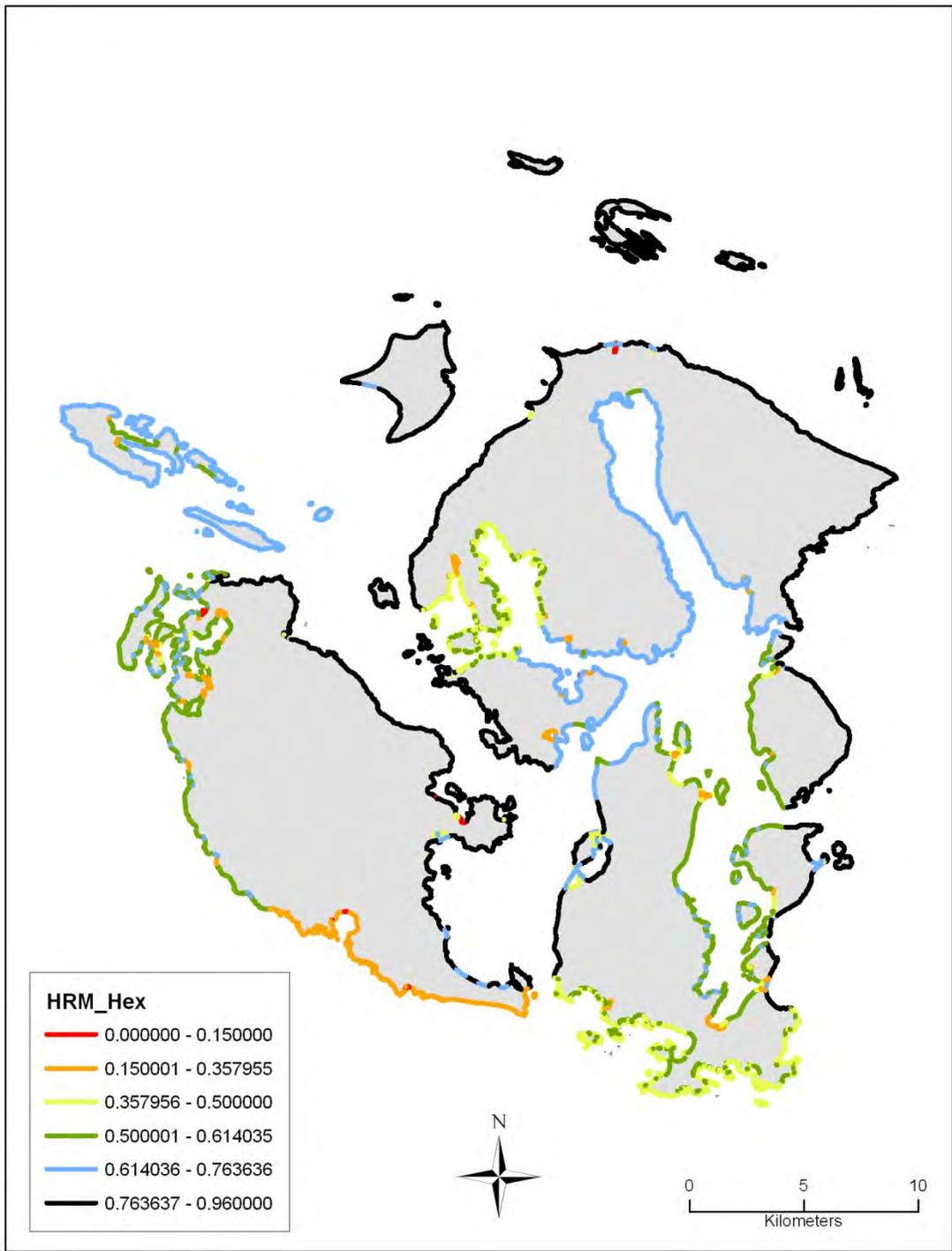


Figure 40. Fish presence probability for juvenile lingcod and greenling for shoreline habitats (high resolution model).

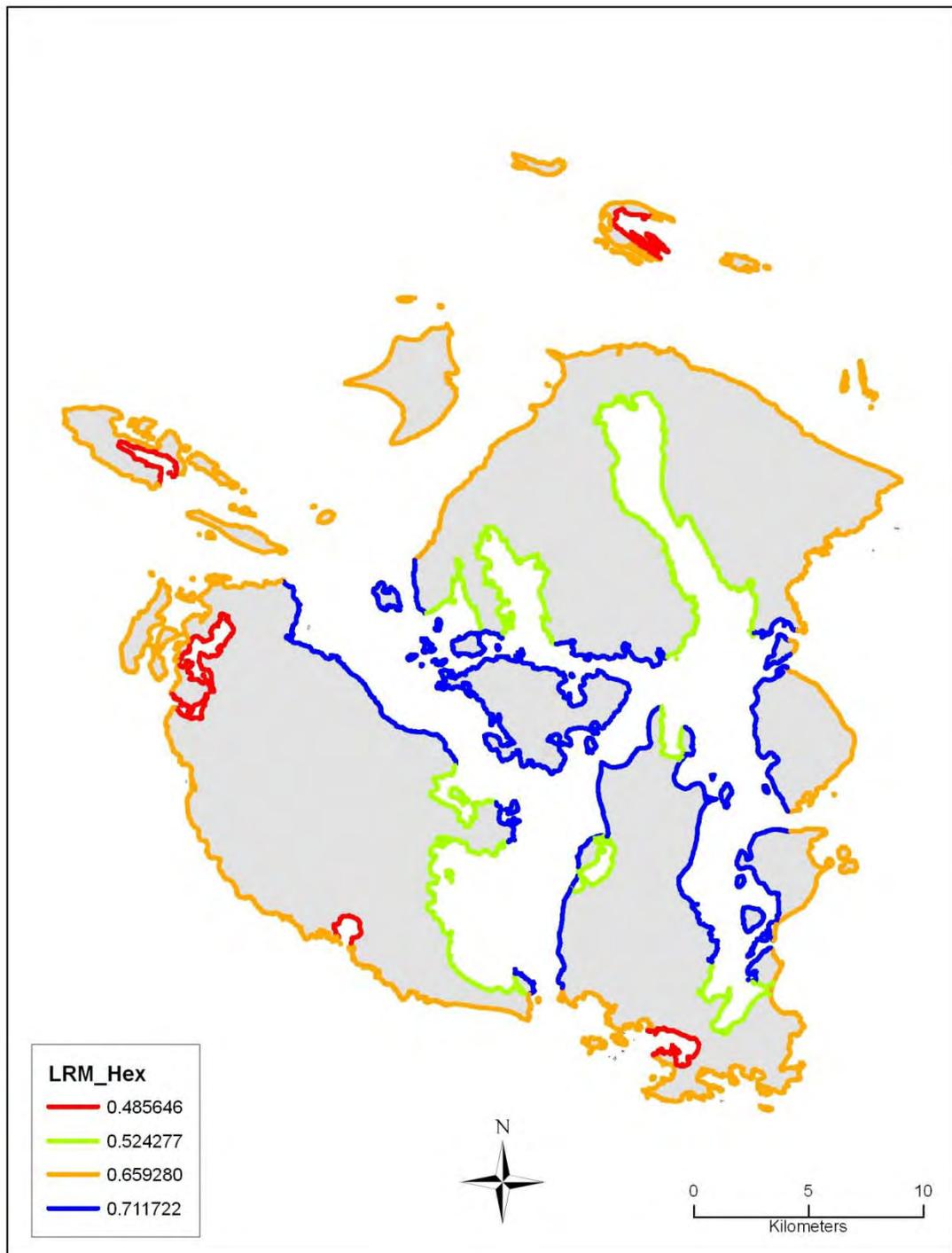


Figure 41. Fish presence probability for juvenile lingcod and greenling for shoreline habitats (low resolution model).

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 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 except 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, 2) 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 the 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.

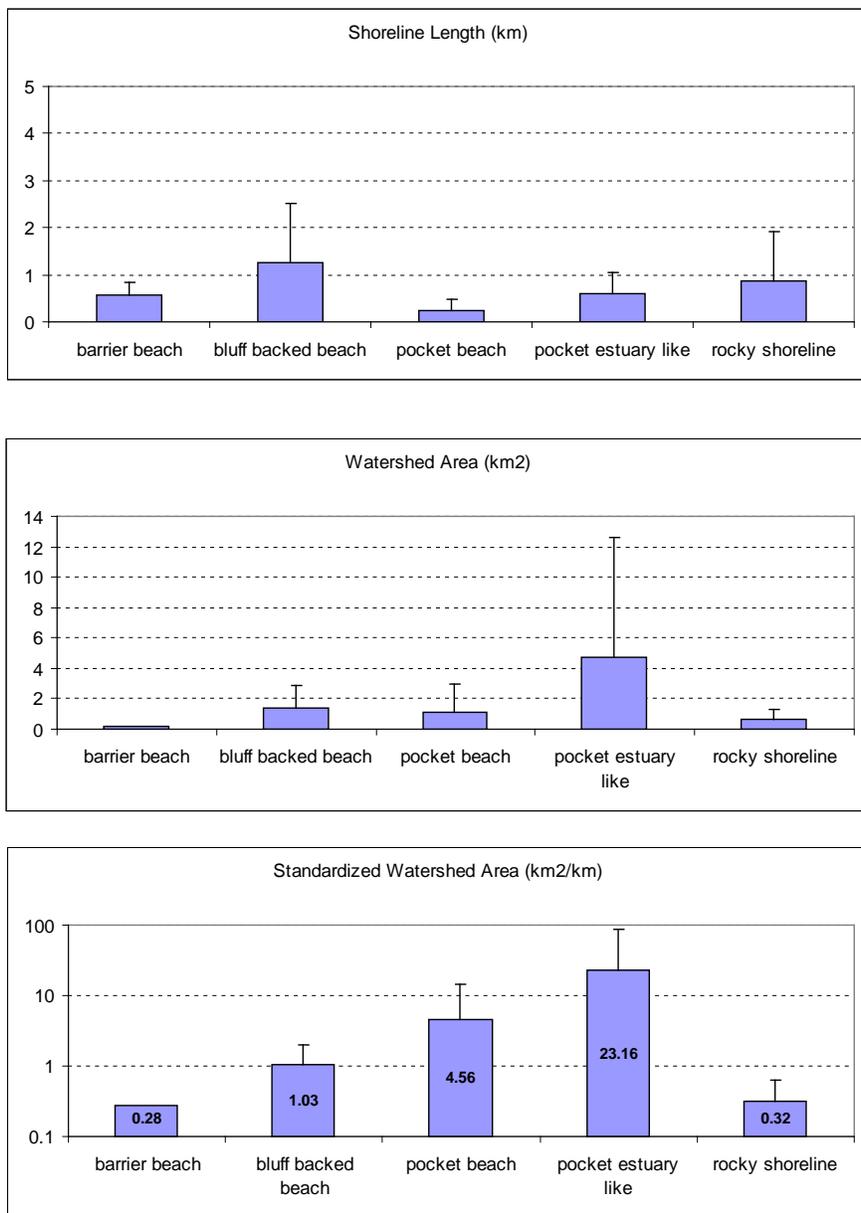


Figure 42. Summary of shoreline length and watershed area by shoreline types for 141 individual shoreline units in the San Juan Islands. Individual shoreline data are from McBride et al. (2009). Watershed areas are from Simenstad et al. (2011). The average value is shown for all three figure panels and 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.

References

- Bartz, K, E Beamer, K Currens, K Lakey, M Parton, K Rawson, M Rowse, NJ Sands, R Ponzio, and K Stiles. 2012. A Common Framework for Monitoring the Recovery of Puget Sound Chinook Salmon and Adapting Salmon Recovery Plans. Draft NOAA Technical Memorandum. National Marine Fisheries Service, NW Fisheries Science Center, Seattle.
- Beamer, E, R Henderson, and K Wolf. 2009. Lone Tree Creek and pocket estuary restoration: Progress report for 2004-2008 fish monitoring. Skagit River System Cooperative, LaConner, WA. Available at: www.skagitcoop.org.
- Beamer, E, A McBride, C Greene, R Henderson, G Hood, K Wolf, K Larsen, C Rice, and KL Fresh. 2005. Delta and nearshore restoration for the recovery of wild Skagit River Chinook salmon: Linking estuary restoration to wild Chinook salmon populations. Supplement to Skagit Chinook Recovery Plan, Skagit River System Cooperative, LaConner, WA. Available at: www.skagitcoop.org.
- Beamer, E, A McBride, R Henderson, J Griffith, K Fresh, T Zackey, R Barsh, T Wyllie-Echeverria, and K Wolf. 2006. Habitat and fish use of pocket estuaries in the Whidbey Basin and north Skagit County bays, 2004 and 2005. Skagit River System Cooperative, LaConner, WA. Available at: www.skagitcoop.org.
- Beamer, E, A McBride, R Henderson, and K Wolf. 2003. The importance of non-natal pocket estuaries in Skagit Bay to wild Chinook salmon: an emerging priority for restoration. Skagit River System Cooperative, LaConner, WA. Available at: www.skagitcoop.org.
- Beamish, RJ, C Mahnken, and CM Neville. 2004. Evidence that reduced early marine growth is associated with lower marine survival of coho salmon. *Transactions of the American Fisheries Society* 133:26-33.
- Beamish, RJ, DJ Noakes, GA McFarlane, W Pinnix, R Sweeting, and J King. 2000. Trends in coho marine survival in relation to the regime concept. *Fisheries Oceanography* 9:114-119.
- Bottom, DL, K Jones, TJ Cornwall, A Gray, and CA Simenstad. 2005a. Patterns of Chinook salmon migration and residency in the Salmon River estuary (Oregon). *Estuarine, Coastal, and Shelf Science* 64:79-93.
- Bottom, DL, CA Simenstad, AM Baptista, DA Jay, J Burke, KK Jones, E Casillas, and MH Schiewe. 2005b. Salmon at river's end: The role of the estuary in the decline and recovery of Columbia River salmon. Technical Memorandum-68, National Marine Fisheries Service, NWFSC, Seattle.
- Brennan, JS, KF Higgins, JR Cordell, and VA Stamatiou. 2005. Juvenile salmon composition, timing distribution, and diet in marine nearshore waters of central Puget Sound in 2001-2002. King County Department of Natural Resources and Parks, Seattle.
- Duffy, EJ. 2003. Early marine distribution and trophic interactions of juvenile salmon in Puget Sound. Master's thesis, University of Washington, Seattle.
- Fresh, KL., M. Dethier, C. A. Simenstad, M. Logsdon, H. Shipman, and others. 2011. Implications of observed anthropogenic changes to nearshore ecosystems in Puget Sound. Report prepared for PSNERP. PSNERP Technical Report 2011-03. Published by Washington Department of Fish and Wildlife and US Army Corps of Engineers. Available at <http://pugetsoundnearshore.org>

- Fresh, KL, DJ Small, H Kim, C Waldbillig, M Mizell, MI Carr, and L Stamatiou. 2006. Juvenile salmon use of Sinclair Inlet, Washington in 2001 and 2002. Report FRT-05-06, Washington Department of Fish and Wildlife, Olympia.
- Greene, CM, and TJ Beechie. 2004. Consequences of potential density-dependent mechanisms on recovery of ocean-type Chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 61:590-602.
- Greene, CM, D Jensen, GR Pess, EM Beamer, and EA Steel. 2005. Effects of environmental conditions during stream, estuary, and ocean residency on Chinook salmon return rates in the Skagit River, WA. Transactions of the American Fisheries Society 134:1562-1581.
- Greene CM, C Rice, L Rhodes, B Beckman, J Chamberlin, J Hall, A Baxter, J Cordell, and S Naman. 2012. Evaluating the ecological health of Puget Sound's nearshore pelagic foodweb. Final report: October 26, 2012. NOAA Fisheries. Northwest Fisheries Science Center, Seattle, Wa.
- Healey, MC. 1982. Juvenile Pacific salmon in estuaries: The life support system. Pages 315–341 in VS Kennedy, editor. Estuarine Comparisons. Academic Press, New York.
- Healey, MC. 1991. Life-history of Chinook salmon (*Oncorhynchus tshawytscha*). Pages 311–393 in C Groot and L Margolis, eds. Pacific salmon life histories. University of British Columbia Press, Vancouver.
- Magnusson, A, and R Hilborn. 2003. Estuarine survival rates of coho (*Oncorhynchus kisutch*) and Chinook salmon (*Oncorhynchus tshawytscha*) released from hatcheries on the U.S. Pacific coast. Estuaries 26(4B):1094–1103.
- McBride, A, S Todd, O Odum, M Koschak, and E Beamer. 2009. Developing a geomorphic model for nearshore habitat mapping and analysis. Skagit River System Cooperative, LaConner, WA.
- Miller, BS, CA Simenstad, JN Cross, KL Fresh, SN Steinfort. 1980. Nearshore fish and macroinvertebrate assemblages along the Strait of Juan de Fuca including food habits of common nearshore fish. Final report of three years sampling 1976-1979., MESA report EPA-600/7-80-027 EPA Seattle, Washington.
- Montgomery, D. R., E. M. Beamer, G. R. Pess, and T. P. Quinn. 1999. Channel type and salmonid spawning distribution and abundance. Canadian Journal of Fisheries and Aquatic Sciences 56:377-387.
- Mortensen, D, A Wertheimer, S Taylor, and J Landingham. 2000. The relationship between early marine growth of pink salmon, *Oncorhynchus gorbuscha*, and marine water temperature, secondary production, and survival to adulthood. Fishery Bulletin 98:319-335.
- Mouritsen KN. 1994. Day and night feeding of Dunlins (*Calidris alpina*): choice of habitat, foraging technique and prey. Journal of avian biology 25: 55-62.
- Penttila, D. 2007. Marine forage fishes in Puget Sound. Puget Sound Nearshore Partnership, Tech. Rep. No. 2007-03. U.S. Army Corps of Engineers, Seattle, WA.
- SandercocK, FK. 1991. Life history of coho salmon *Oncorhynchus kisutch*. Pages 395-445 in C. Groot and L. Margolis, editors. Pacific Salmon Life Histories. University of British Columbia Press, Vancouver.

- Shepherd, P. C F. and D. B. Lank. 2004. Marine and agricultural habitat preferences of Dunlin wintering in British Columbia. *Journal of Wildlife Management* 68:61–73.
- Simenstad, CA, KL Fresh, and EO Salo. 1982. The role of Puget Sound and Washington coastal estuaries in the life history of Pacific salmon: An unappreciated function. Pages 343–364 in VS Kennedy, editor. *Estuarine Comparisons*. Academic Press, New York.
- Simenstad, C. A., M. Ramirez, J. Burke, M. Logsdon, H. Shipman, C. Tanner, J. Toft, B. Craig, C. Davis, J. Fung, P. Bloch, K. Fresh, D. Myers, E. Iverson, A. Bailey, P. Schlenger, C., Kiblinger, P. Myre, W. Gerstel, and A. MacLennan. 2011. Historical change of Puget Sound shorelines: Puget Sound Nearshore Ecosystem Project change analysis. Puget Sound Nearshore Report No. 2011-01. Published by Washington Department of Fish and Wildlife, Olympia, WA, and U.S. Army Corps of Engineers, Seattle, WA.
- Warnock, N. 1996. Local and regional differences in habitat utilization by Dunlins (*Calidris alpina*) as revealed by radio-telemetry: conservation implications. *International Wader Studies* 8: 35-38.
- WRIA 2 Technical Advisory Committee. 2005. San Juan County Salmon Recovery Plan in Volume II (Local Watershed Chapters) of the Puget Sound Chinook Recovery Plan. Available at: <http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/PS-Recovery-Plan.cfm>.
- Zhang, Z, and RJ Beamish. 2000. Use of otolith microstructure to study life history of juvenile Chinook salmon in the Strait of Georgia in 1995 and 1996. *Fisheries Research* 46: 239-250.

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		
Major 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	Rocky Shoreline	
		Pocket Beach Estuary		
		Pocket Beach Closed Lagoon and Marsh		
	Rocky Beach	Veneered Rock Platform.		Rocky Shoreline
		Rocky Shoreline		
		Plunging Rocky Shoreline		
		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).

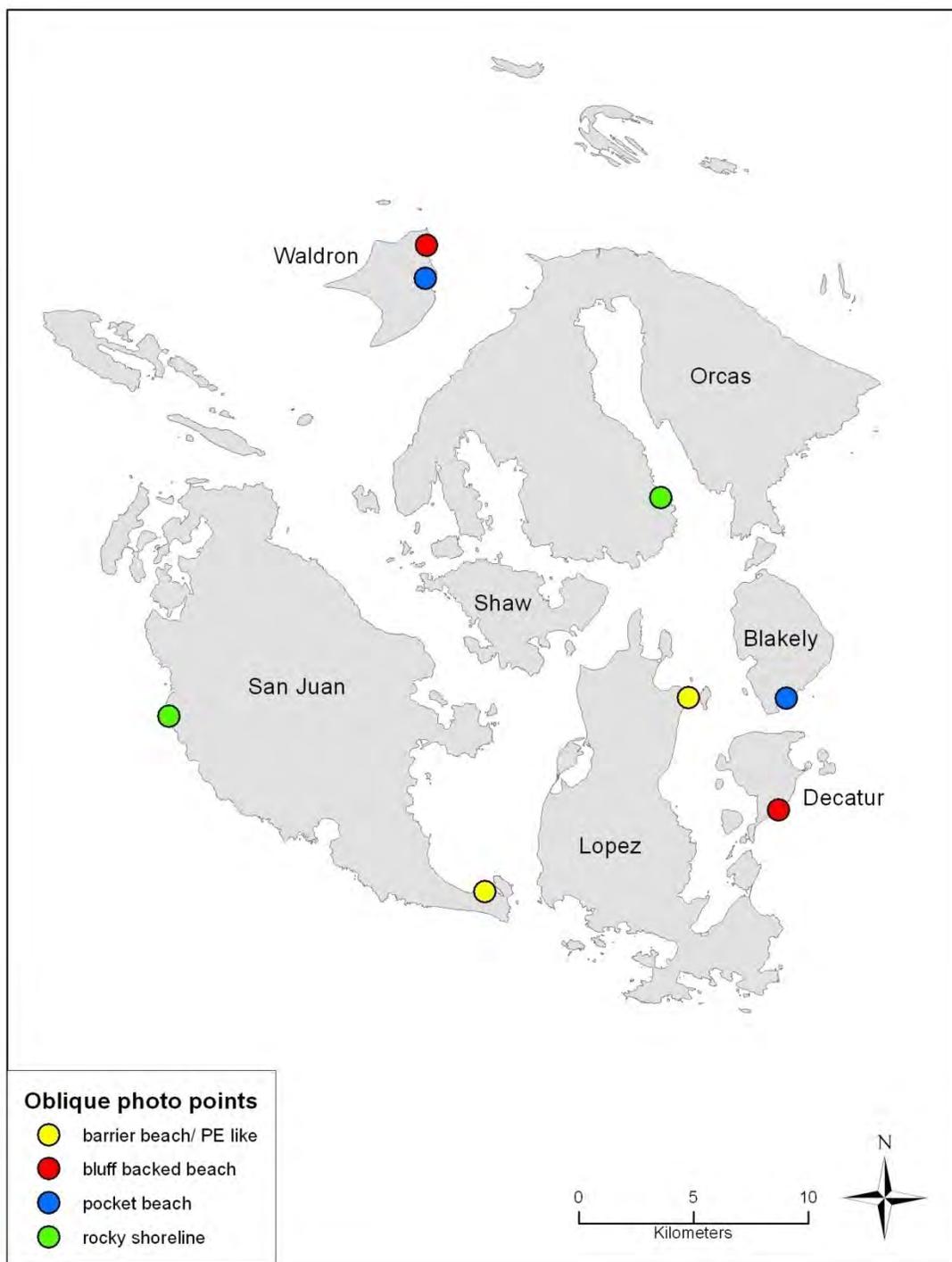


Figure A2. Location of oblique shoreline photos showing examples of different shoreforms. Photos downloaded from Washington State Department of Ecology website.



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

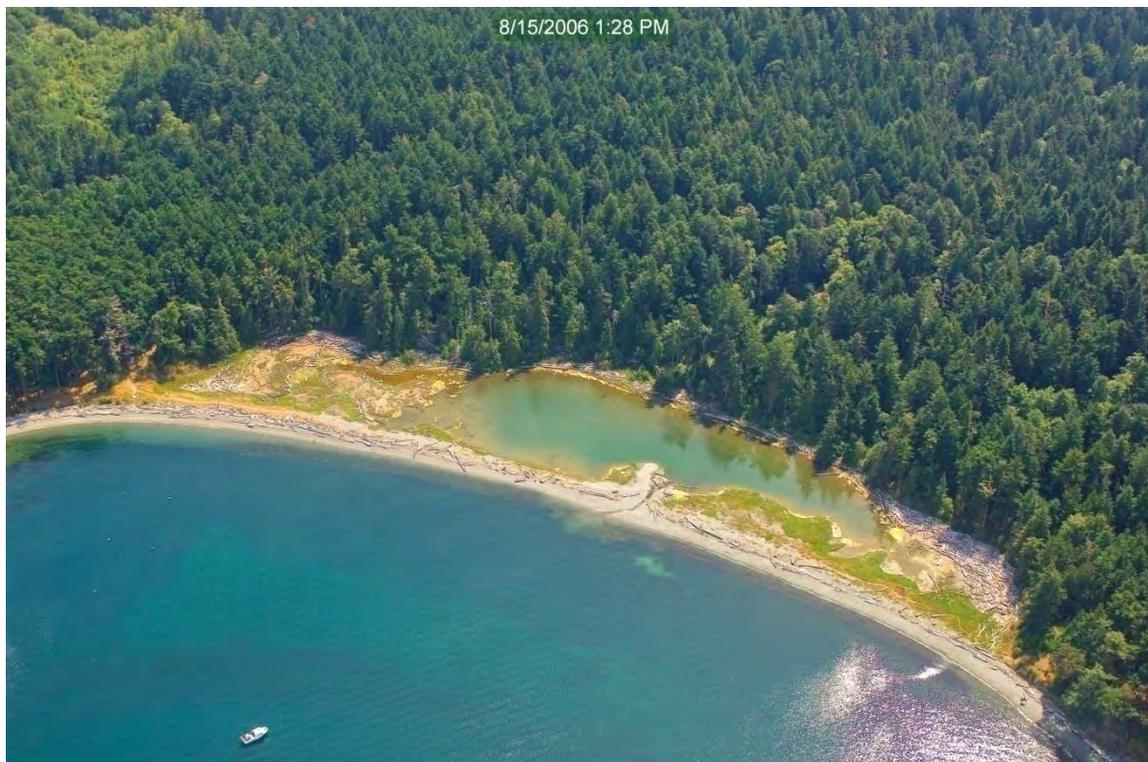


Figure A4. Photo of Third Lagoon on San Juan Island, showing both barrier beach and pocket estuary like shoreforms.

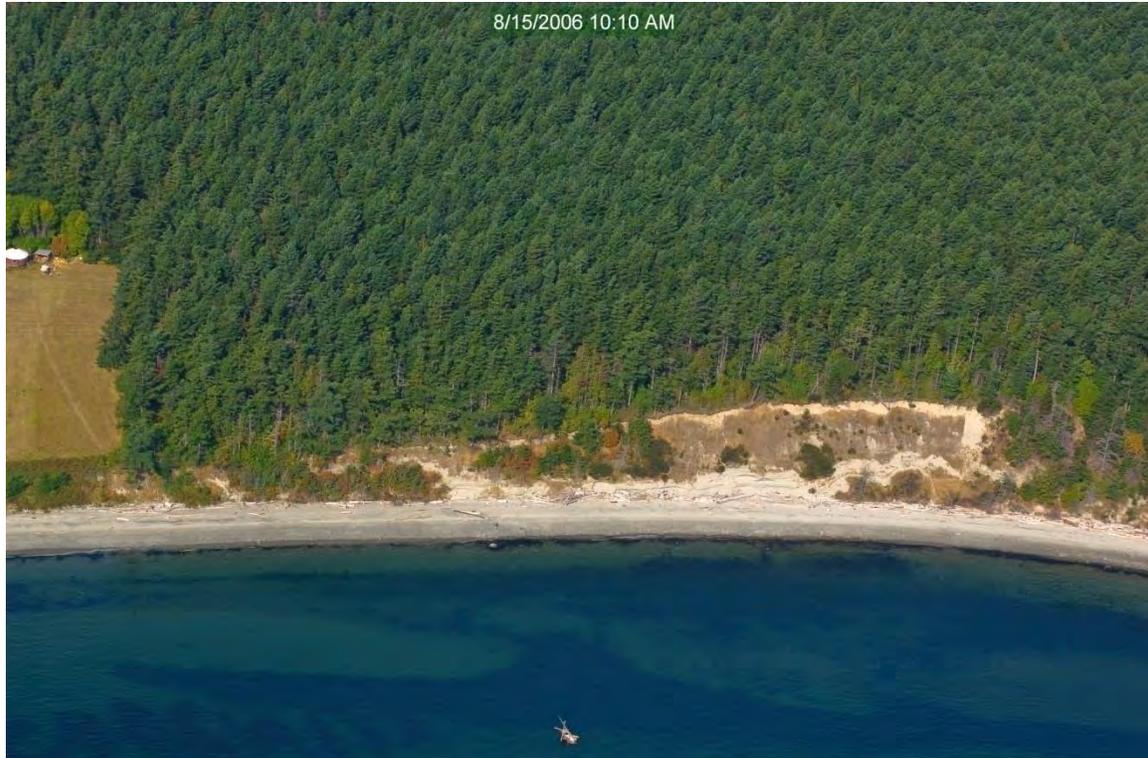


Figure A5. Photo of bluff backed beach on Waldron Island (Little Hammond).

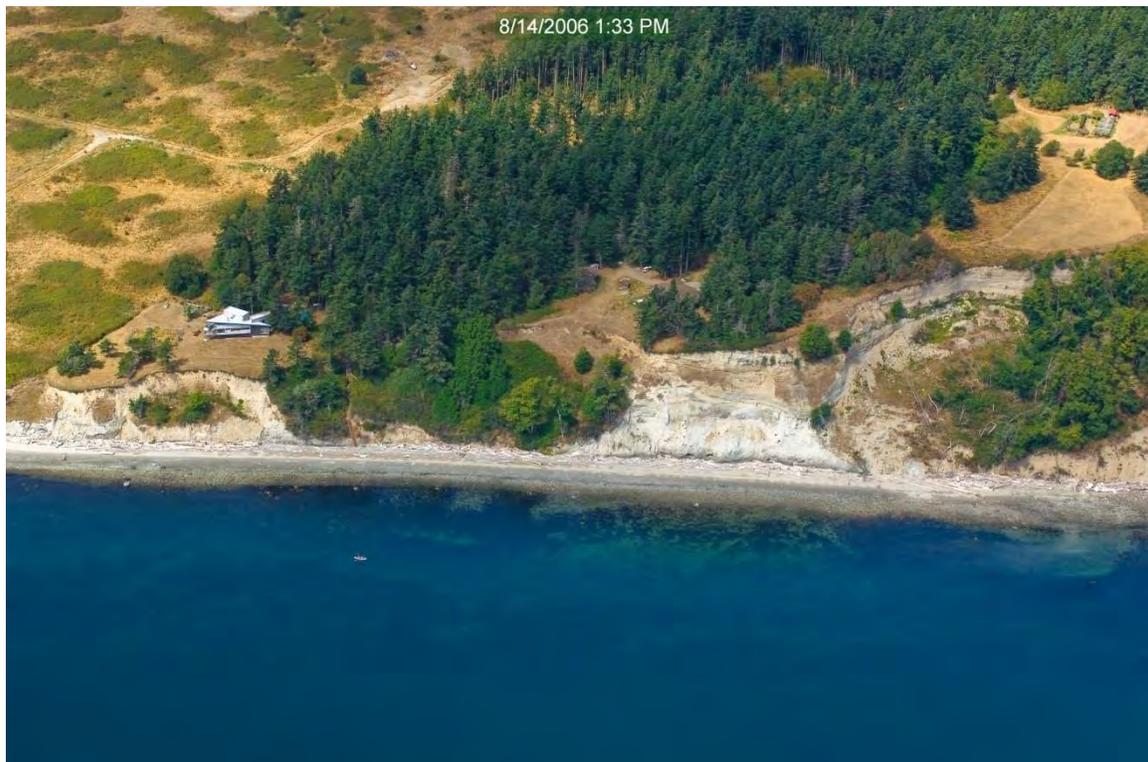


Figure A6. Photo of bluff backed beach on Decatur Island (White Cliff).



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



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

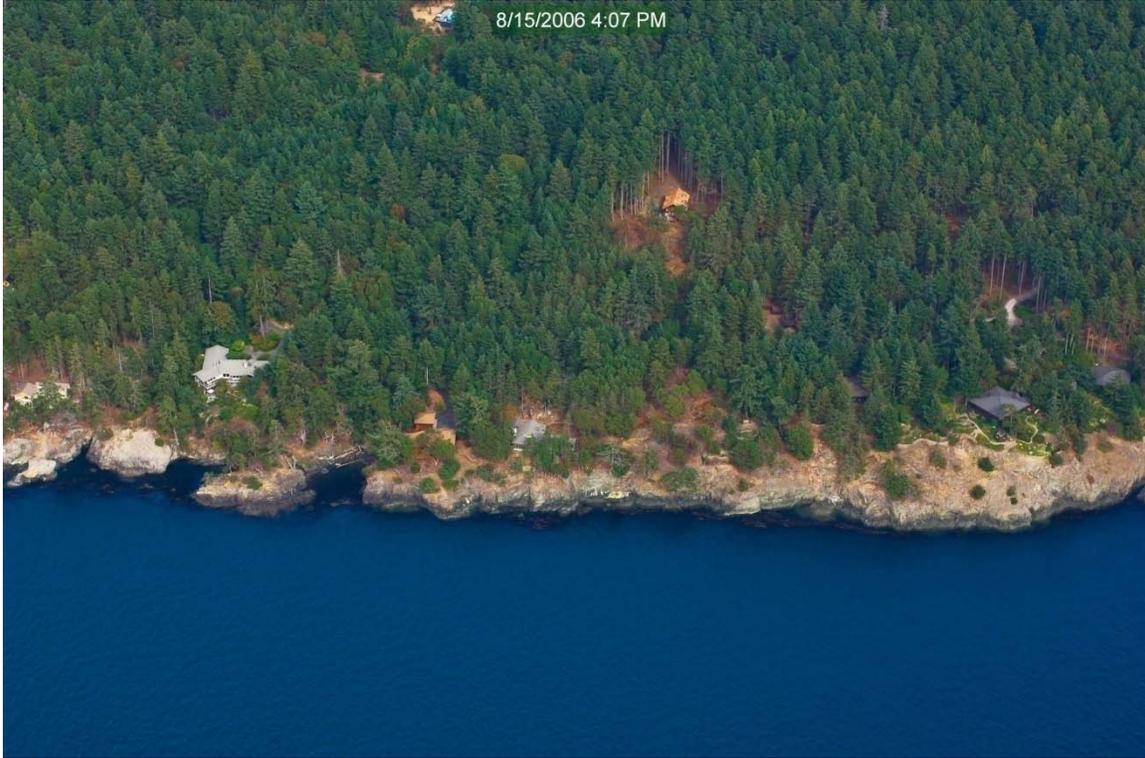


Figure A9. Photo of rocky shoreline on the west side of San Juan Island.

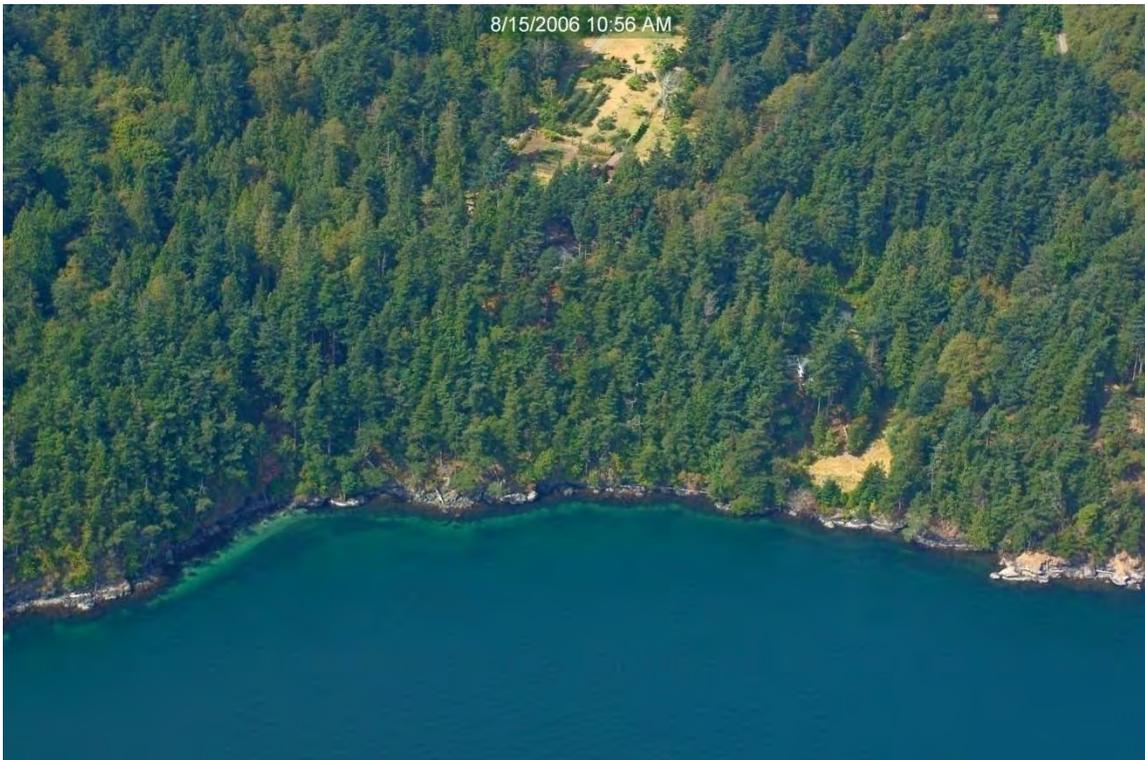


Figure A10. Photo of rocky shoreline on Orcas Island (within East Sound).

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.