Healthy Beaches for People and Fish:

Protecting shorelines from the impacts of armoring today and rising seas tomorrow

Tidal elevation of surf smelt spawn habitat study for San Juan County, Washington

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The goal of the *Healthy Beaches for People and Fish*: *Protecting shorelines from the impacts of armoring today and rising seas tomorrow* project is to improve the long-term protection of nearshore marine ecosystems by developing new technical tools and identifying management strategies that specifically address sea level rise and the cumulative impacts of shoreline armoring.

The *Healthy Beaches for People and Fish* project was completed by Friends of the San Juans in partnership with Coastal Geologic Services, Salish Sea Biological and the Washington Department of Fish and Wildlife in 2014. Project approach and work was guided by a technical advisory group, which included representatives from The University of Washington, United States Geological Survey, Puget Sound Partnership, Skagit River Systems Cooperative, Samish Indian Nation, San Juan County Public Works, San Juan County Salmon Recovery Lead Entity, The Tulalip Tribes, Padilla Bay National Estuarine Research Reserve and the Washington State Departments of Ecology, Natural Resources and Fish and Wildlife.

The project contained four distinct areas that informed management recommendations:

- A legal review of existing local, state and federal shoreline regulations and their ability to address sea level rise and cumulative impacts;
- Sea level rise vulnerability assessment for San Juan County;
- Forage fish spawning habitat research; and
- Surveys of coastal managers, regulators and researchers.

Reports and data products associated with this project can be found online at www.sanjuans.org/NearshoreStudies.htm and include:

Friends of the San Juans. 2014. Healthy Beaches for People and Fish: Protecting shorelines from the impacts of armoring today and rising seas tomorrow. Final Report to WDFW and the U.S. EPA. Friday Harbor, Washington.

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Whitman, T., D. Penttila, K. Krueger, P. Dionne, K. Pierce, Jr. and T. Quinn. 2014. Tidal elevation of surf smelt spawn habitat study for San Juan County Washington. Friends of the San Juans, Salish Sea Biological and Washington Department of Fish and Wildlife.

Whitman, T. and S. Hawkins. 2013. The impacts of shoreline armoring on beach spawning forage fish habitat in San Juan County, Washington. Friends of the San Juans. Friday Harbor, Washington.

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<u>Tidal Elevation of Surf Smelt Spawn Study for San Juan County, Washington</u>

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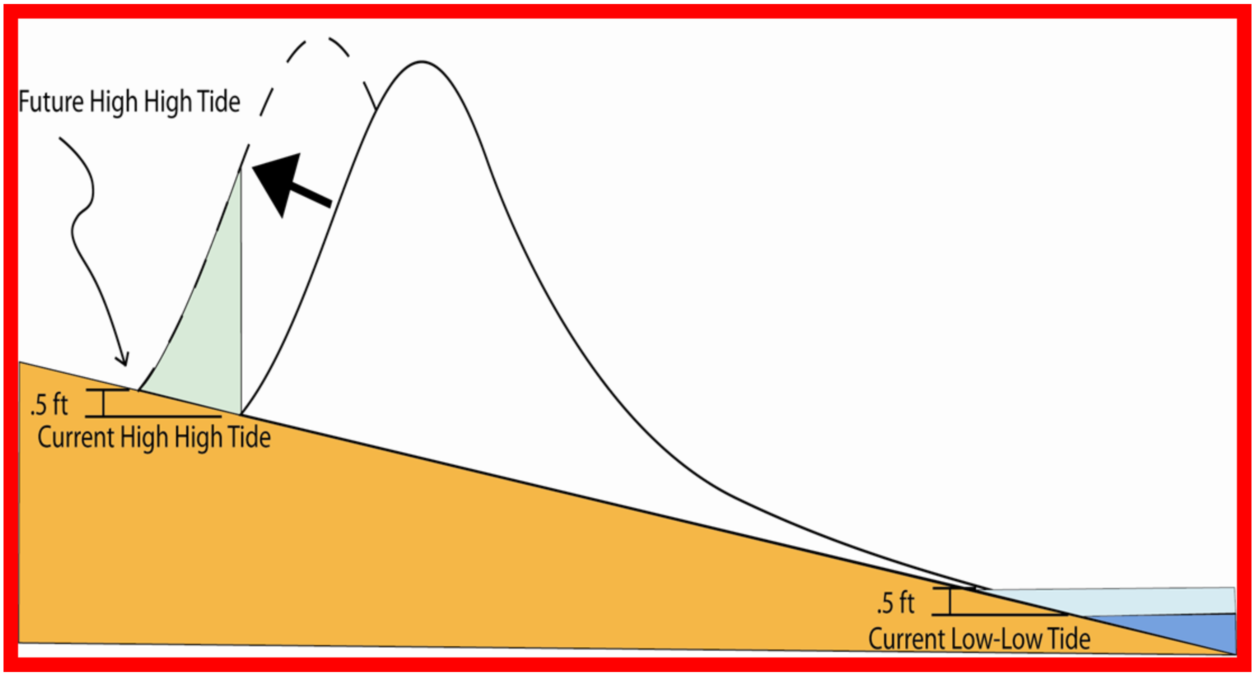
Background

The Surf Smelt, *Hypomesus pretiosus,* is an important "forage fish" link in the marine food webs of the Puget Sound/Salish Sea basin (Penttila 2007). Forage fish play a key role in marine food webs, with a small number of species providing the trophic connection between zooplankton and larger fishes, squids, seabirds and marine mammals, including Endangered Species Act (ESA) listed species such as Chinook salmon and the marbled murrelet (Simenstad et al. 1979, Bargmann 1998). Surf Smelt are obligate upper intertidal spawners on mixed sand-gravel beaches, and are presently estimated to use about 10% of the Puget Sound shoreline for spawning (Penttila 2007).

Beach spawning forage fish, such as Surf Smelt (*Hypomesus pretiosus*) and Pacific sand lance (*Ammodytes hexapterus*), are threatened by land use activities along shorelines, where development is also concentrated (Bargmann 1998, Penttila 2007). Conservation of marine forage fish spawning habitat has been a focus of conservation efforts along shorelines in Washington State for many years. Several Washington laws including Washington State's Growth Management Act, Shoreline Management Act, and Hydraulic Code require the protection of surf smelt and pacific sand lance spawning habitat (Penttila 2007).

Because of their dependence on upper intertidal area with fine grained sand and gravel substrates, forage fish spawning habitat is especially vulnerable to the impacts of shoreline armoring and rising sea levels (Krueger et al. 2010). Shoreline armoring can directly bury spawning habitat and also affects beach conditions for spawning forage fish waterward of the modification (Penttila 2007, Rice 2006). Hardened shorelines can increase wave energy at both the toe and the ends of armoring structures, resulting in a lowering of the beach profile and loss of finer grained sediments required for spawning (Johannessen and MacLennan 2007, Penttila 2007, Griggs 2005). Armoring is often associated with the removal of shoreline vegetation, reducing a source of large woody debris and organic material to the beach, altering microclimate and increasing egg mortality (Penttila 2002, Penttila 2007 and Rice 2006). Sea level rise is expected to exacerbate the impacts of shoreline armoring on forage fish spawning habitat by preventing the upper portion of the habitat from migrating inland with the rising tides (Krueger et al. 2010, Griggs 2005)(Figure 1). In addition, sea level rise and other effects of climate change, such as increased frequency and strength of storms, may increase demand for new shoreline armoring, further compounding forage fish spawning habitat loss.

Figure 1: Conceptual model of shift of forage fish egg distribution with sea level rise on an unarmored beach. (from Krueger et al. 2010)



Introduction

Surf Smelt spawning habitat was first documented within San Juan County by in the Washington Department of Fish and Wildlife (WDFW) in 1989, although local residents and fisherman likely knew of its spawning activity many years prior to that time. Subsequent Surf Smelt spawning habitat surveys conducted in the 1990s by the Washington Department of Fish and Wildlife (Penttila 1999) and early 2000's by Friends of the San Juans (FSJ 2004) mapped approximately 10 miles of Surf Smelt spawning habitat within San Juan County, located within 76 individual beaches. A map of known distribution of Surf Smelt spawning locations for San Juan County, Washington, is provided below in Figure 2. Forage fish spawning data is also available on WDFW's website at: http://wdfw.wa.gov/conservation/research/projects/marine_beach_spawning/

While year-around data do not exist for most sites in the county, Blind Bay, Shaw Island (as identified by WDFW and Westcott Bay, San Juan Island, (as identified by FSJ)) were documented as year-around spawning locations . Multiple additional sites in the county, including Hunter and Mud Bays on Lopez Island, also had Surf Smelt spawn activity spread throughout the year (Penttila 1999, FSJ 2004).

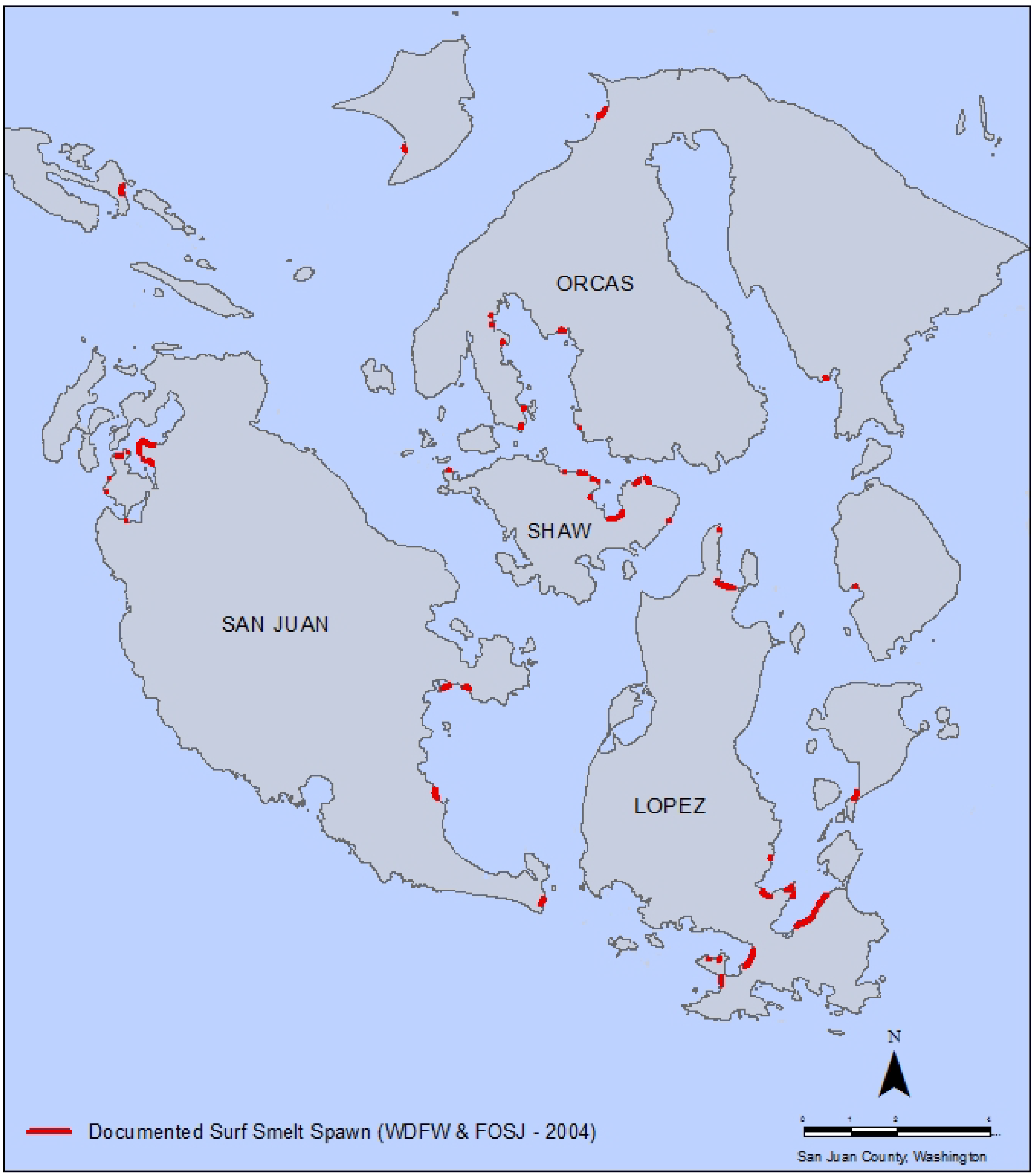
Most assessment of Surf Smelt spawning habitat in Puget Sound has been limited to presence/absence surveys to document site use and spawning habitat distribution, with substrate collected from one elevation along a transect oriented parallel to the waterline. This study investigated the vertical distribution of incubating Surf Smelt eggs at known spawning sites in San Juan County.

Project results were used to assess likely impacts of rising sea levels on surf smelt spawning habitat assuming shoreline armoring limited landward migration of habitat, commonly referred to as the "coastal squeeze" (Huppert et al. 2009, Griggs 2005). Improved understanding of the vertical extent of intertidal habitat utilized by Surf Smelt has direct application to forage fish habitat management decisions such as shoreline development project review, quantification of cumulative effects and the potential impacts to spawning beaches of rising sea levels, as well as restoration and protection project design and effectiveness monitoring.

Related research on intertidal egg distribution was recently conducted in central Puget Sound by the Washington Department of Fish and Wildlife, with results also showing a high proportion of eggs at higher beach elevations (Krueger et al. 2010).

The goal of this study was to improve understanding of the distribution of incubating Surf Smelt eggs as a function of intertidal elevation at known spawning beaches in San Juan County across subregions, sites and seasons. The study also explored potential impacts of rising sea levels on surf smelt spawning habitat. Data generated by this project within San Juan County may be applicable to other marine shorelines in the Puget Sound basin, after adjusting for differences in local tidal elevation ranges.

Figure 2. Documented Surf Smelt Spawning Sites in San Juan County



Methods

Pilot Study

In the summer of 2011, a small pilot project was undertaken in San Juan County to improve understanding of the tidal range of habitat occupied by incubating Surf Smelt eggs and inform the feasibility and research design of a larger study. In May and June of 2011, experimental sample sets were collected from Surf Smelt spawn deposits visible upon inspections at eleven sites in two regions of San Juan County. Substrate samples were collected from multiple tidal elevations from the lower intertidal-across the vertical beach profile- to the toe of the bank, along transects oriented perpendicular to the waterline. Results documented Surf Smelt spawn as high as 9.0 feet above Mean Lower Low Water (MLLW) , with nearly one third of incubating eggs located above Mean Higher High Water (MHHW), a location often considered by managers and regulators to be the upper extent of spawn (Penttila 2011). A small percentage of live eggs (5%), were documented at the uppermost beach extent, at the bank toe (Penttila 2011).

Site Selection:

We focused our effort on Surf Smelt known to be spawning within the San Juan County study area. Surf Smelt spawning has been documented at 72 individual beaches in San Juan County (See Figure 2). The project attempted to collect samples of egg deposition on beach-surface material from at least 30 separate spawning sites from August 2012 through September 2013 with the goal of maximizing geographic extent as well as capturing spawn events from multiple times of the year.

40 random sampling locations in San Juan County were selected using an ARC GIS query of known Surf Smelt spawning sites from the San Juan County forage fish project database (FSJ 2004) and the WDFW database (http://wdfw.wa.gov/conservation/research/projects/marine_beach_spawning/). We defined the population of sites as those that had at least some shoreline with no armoring below 11 feet MLLW. Spawning season data from WDFW and FSJ databases was used to set the sampling schedule, in an effort to improve efficiency of field efforts. Access (landowner permission/remoteness/weather conditions etc.) also influenced the final field survey effort.

Field Surveys:

Visual field inspection for egg presence was conducted by pre-sampling either during the time of the site visit or during site reconnaissance visits ahead of time to increase success of full sampling efforts. Sampling sites were selected for collection of full data transects where field visible surf smelt spawn deposit was present somewhere on a beach surface, regardless of its position relative to the backshore. For sites with visible eggs present, vertical transect surveys were conducted perpendicular to the waterline and egg deposition/substrate samples were collected from multiple elevations across the beach between the waterline and the toe of the bank (See Figure 3.). At each sample site, a measuring tape was laid across the beach face from the waterline (“0’ foot mark) perpendicularly to the upland toe. Depending on the width of the band of suitable spawning substrate, tidal conditions and the steepness of the beach, an average of 6 substrate samples were collected (one each from vertical foot increments across the beach face) from approximately +4 to +9 MLLW. In cases where the heaviest visible spawn occurred within the one foot vertical increments (substrate sample stations) along the beach transect, an additional substrate sample was collect at a 0.5 foot increment, between the two samples. In some cases the waterline at the time of the sample or upland beach constraints such as protruding bedrock, limited the overall number of samples collected along the transect to less than the target of six. Each sample was composed of approximately 500 grams of sediment from the surface-inch of the beach material, filling a 400ml jar.

Figure 3. Field Methods: for each spawning beach with visible eggs present 1 transect (white tape) was established from the waterline to the bank toe, and 6 substrate samples were collected at one vertical foot intervals (locations marked by red stakes/cups).

The tidal elevation of the waterline at the time of the site visit was known from tables of predicted elevations at short time-intervals for the synoptic Friday Harbor, WA, tide gauge station, NOAA ID No. 9449880, which also provides observed tidal elevations over time, thus taking into account real-time barometric effects (see: www.tidesandcurrentsnoaa.gov). Sediment-sample positions were located along the tape starting with sample #1, intentionally positioned down-beach of the estimated lower edge of potential surf smelt spawning/incubation substrate at the site, usually in silty sand/gravel. Sediment samples 2-6 were then positioned at one-vertical- foot intervals along the tape up-beach from sample 1, with sample 6 usually positioned in the transition zone between marine sediments and terrestrial vegetation, vertically above the estimated surf smelt spawning habitat. The one-vertical-foot sample elevation increments were determined with a LM30 CST Berger vertical laser level and reflector-equipped telescoping stadia rod. Once in position, all sediment sample locations were visually marked, and the sample site photo-documented with digital photographs up-beach on the tape from the waterline and laterally through the site from both sides.

Field records included: the estimated (predicted) tidal elevations of the waterline and all sample locations, distances from the waterline up-beach on the tape of all sample locations, qualitative notes on the character of the beach surface sediments at each sample location, and qualitative notes on the occurrence of field- visible smelt eggs amongst the sample locations. A GPS lat-long was recorded for each sampling site with a Garmin 74H held-held device at the approximate MHHW line. The operating manual for the Garmin 74H GPS unit states that estimated accuracy will be 10-16 feet, unless the GPS system is being manipulated by the US Department of Defense, at which time the accuracy would be purposely degraded to 49 feet. Immediately upon the completion of each field sampling day, the each elevation sample was separately preserved in Stockard Solution, the 5% aqueous mix of formaldehyde, glycerol, and glacial acetic acid routinely used forage fish egg sample preservation by WDFW.

<u>Lab Analysis:</u>

Samples were processed to determine eggs density, embryological-stage distribution, and in-situ egg mortality percentages, using standard WDFW protocols (Moulton and Penttila 2001). The substrate samples were lab-processed following WDFW forage fish survey protocols for “scoop-samples” of field-visible spawn deposits (Moulton and Penttila 2001, rev. 2006). Generally 100-150 grams of sediment from each preserved sample was arranged around the inside edge of a large petri dish in a sufficiently narrow band width to be entirely visible in the field of a stereo-microscope. After immersion in water, this material was carefully inspected with forceps at 10X from one end of the deposit to the other. Any encountered Surf Smelt eggs were counted as they were aged into a set of 8 embryological-stage categories, plus dead eggs, on a multi-place mechanical counter. After the visual inspection, the inspected portion of the sediment (usually the entire sub-sample within the dish) was removed from the dish, blotted for a few minutes on absorbent paper towels, transferred to a tared dish, and damp-weighed on a digital lab-scale to the nearest 0.1 gram.

<u>Database:</u>

Results were compiled into an ARC 10.1 Geographic Information Systems geodatabase which included data fields for each transect and its associated egg/substrate samples across the vertical beach profile, as well as linked site photos and scanned copies of field and lab records.

<u>Analysis of Results:</u>

Elevation data collected in the field were corrected for the difference between the predicted and observed water level recorded at the Friday Harbor tide gage by adding or subtracting the difference between the predicted and observed water level at the time of the survey.

Egg densities were estimated for each sample by dividing the total number of eggs in each sample by the weight of the sample. Gamma distributions were fit to the egg density data collected from each of the beaches where eggs were found to describe the spatial distribution of Surf Smelt eggs relative to beach elevation (Figure 6). The gamma distribution was selected empirically, because its flexibility allowed a good fit to the egg densities observed in this study and in a previous study (Krueger et al 2010). We plotted a cumulative gamma distribution of smelt eggs as a function of intertidal elevation (Figure 7). This figure illustrates how we estimated the proportion of eggs that would be lost under different sea-level rise scenarios assuming that shoreline armoring is located at MHHW +1.5 feet and that beach morphology does not change though time. The MHHW +1.5 elevation in the San Juan Islands is about 9.3 feet above MLLW; this elevation was used as a proxy for the elevation of OHW and the toe of shoreline armoring because the highest elevation that eggs were collected at during this study was 9.2 feet, and previous studies have used a similar estimate for the OHWM when the OHWM was not identified in the field (Krueger et al. 2010 and Quinn et al. 2012). Shoreline armoring has been placed waterward of MHHW +1.5 feet, especially in the past, but because the intent of this study was to model potential impacts resulting from sea-level rise, rather than direct impacts of shoreline armoring, we chose an elevation above where eggs were observed. We considered five sea-level rise scenarios, about +0.2 feet, +0.5 feet, + 1.1 feet, 2.0 feet, and +3.0 feet above current sea-level. These estimates of sea-level rise correspond with the 2030, 2050, 2100, and 2100 ± standard deviation sea-level rise projections for Seattle made by the National Research Council (NRC 2012).

Results

<u>Field surveys</u>

Exploratory field surveys for incubating Surf Smelt (including standard WDFW protocol bulk samples as well as visual field investigation) were conducted at a total of 39 beaches with previously documented spawning in San Juan County (54% of known sites in the county) on 49 dates between September 2012 and September 2013. This represented a substantially larger field effort than was originally scoped for the project as eggs were not located on many visits, requiring multiple return field days. Incubating eggs were discovered on just 11 of those site date combinations with just 9 dates yielding egg densities high enough to support collection of 26 vertical egg distribution data transects. The 26 tidal elevation of spawn transect data were collected on 15 individual beaches, representing 21% of the known Surf Smelt spawning sites in the county.

Table. 1 Field Survey Summary

Smelt Spawning Beach in Study	Number Transects Collected	Collection Date (s)
#1	2	September 10, 2012 and July 7, 2013
#2	2	September 10, 2013 and November 12, 2013
#3	2	September 10, 2013 and November 12, 2013
#4	1	July 7, 2013
#5	1	July 7, 2013
#6	1	July 7, 2013
#7	2	June 20, 2013
#8	2	June 20, 2013
#9	1	September 19, 2013
#10	3	July 10, 2013 and September 19, 2013 (2)
#11	2	March 14, 2013, June 27, 2013
#12	2	July 10, 2013 and September 19, 2013
#13	2	July 10, 2013 and September 19, 2013
#14	1	June 27, 2013
#15	2	June 27, 2013 and August 16, 2013

Note: at beaches where transects were conducted on the same day, transects were a minimum of 1,000 feet apart. Transects conducted at the same beach on different dates were not all collected from the same locations, but distances between samples varied, depending on visible egg presence.

While exploratory (versus formal) field surveys were conducted within numerous regions of six islands (Blakely, Lopez, Orcas, San Juan, Shaw and Waldron) with known Surf Smelt spawning beaches (Figure 4), eggs were noted in just five regions on three islands of San Juan County: Blind Bay (Shaw Island), Westcott Bay (San Juan Island) and Mud, Hunter and Shoal Bays (Lopez Island). All formal sampling occurred during September and November of 2012, as well as March and June through September 2013. Although we attempted to do formal surveys in October, December, January, February and May, we found no eggs present. See Figures 5 and Appendix B for maps of known spawn sites where eggs were present and full transect surveys were completed and field photos of survey sites, respectively.

Figure 4. Surveys of Previously Known Surf Smelt Spawning Sites where no eggs were detected

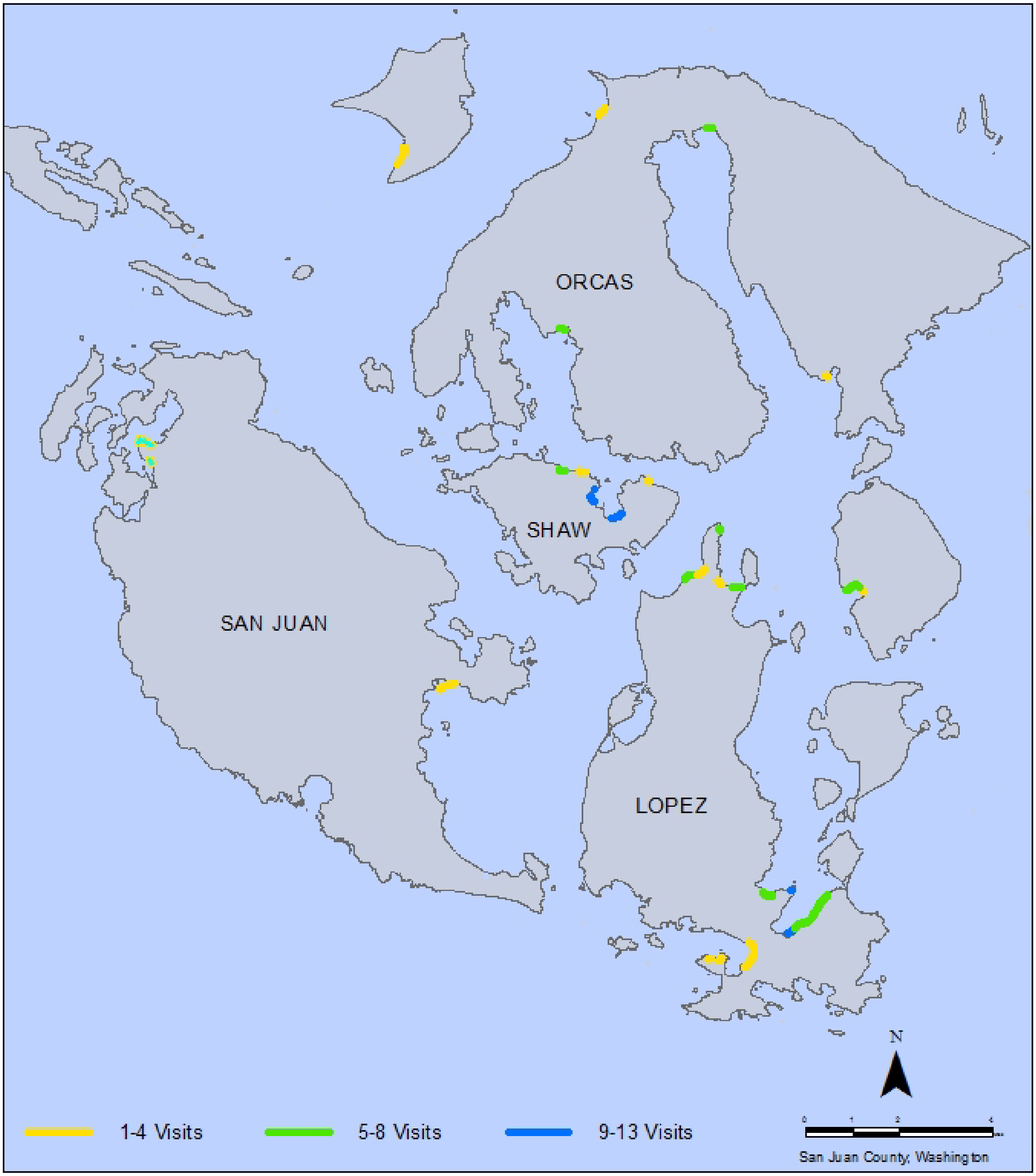
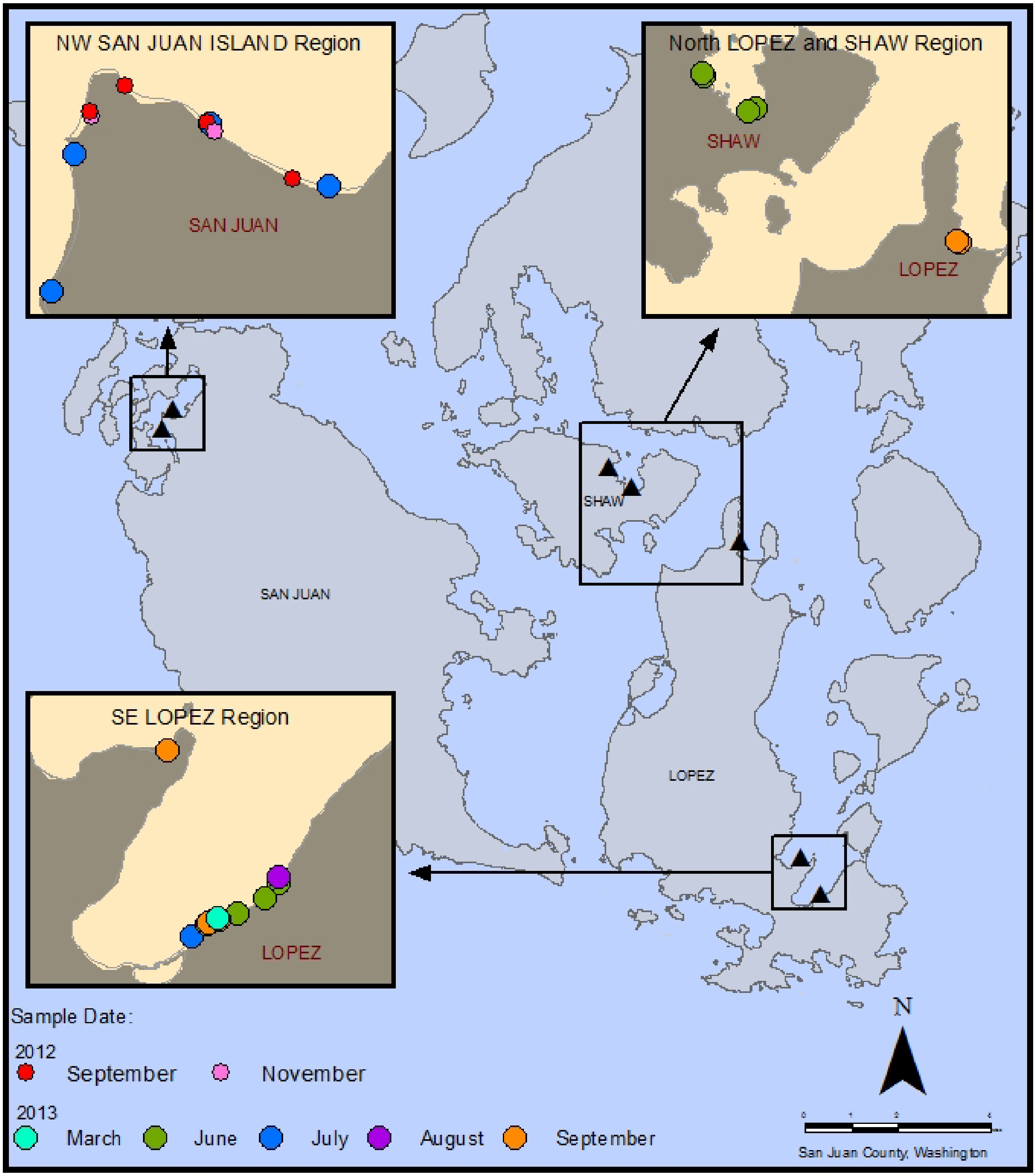


Figure 5. Known Surf Smelt Spawning Sites with Eggs Present and Transect Surveys Completed.



Lab Analysis

Of 165 substrate samples collected along 26 individual transects at 15 spawning beaches between September 2012 and September 2013, 73 contained eggs, and egg densities ranged from 0.0 to 53.9 eggs per gram (mean density of egg bearing samples, 3.4 eggs/gram beach sediment). A total of 6,115 Surf Smelt eggs were collected across surveys and sites. Eggs were observed in samples from elevations ranging from as low as 3.7 feet to as high as 9.2 feet MLLW. As seen in previous studies of vertical egg distribution of Surf Smelt (Krueger et al. 2010, Penttila 2011) the majority of eggs occurred in the upper intertidal zone. Over 80% of eggs were located in the upper third of the local tide range, at or above 6.2 feet MLLW, and over 30% occurred at or above MHHW (7.6 MLLW for Friday Harbor) (Figure 6).

Examination of the cumulative gamma distribution suggests that on the beaches sampled for this study, a rise in sea-level of 0.2, 0.5, 1.1, 2.0, and 3.0 feet would inundate about 10%, 19%, 35%, 80% and 99% respectively of Surf Smelt eggs (Figure 8).

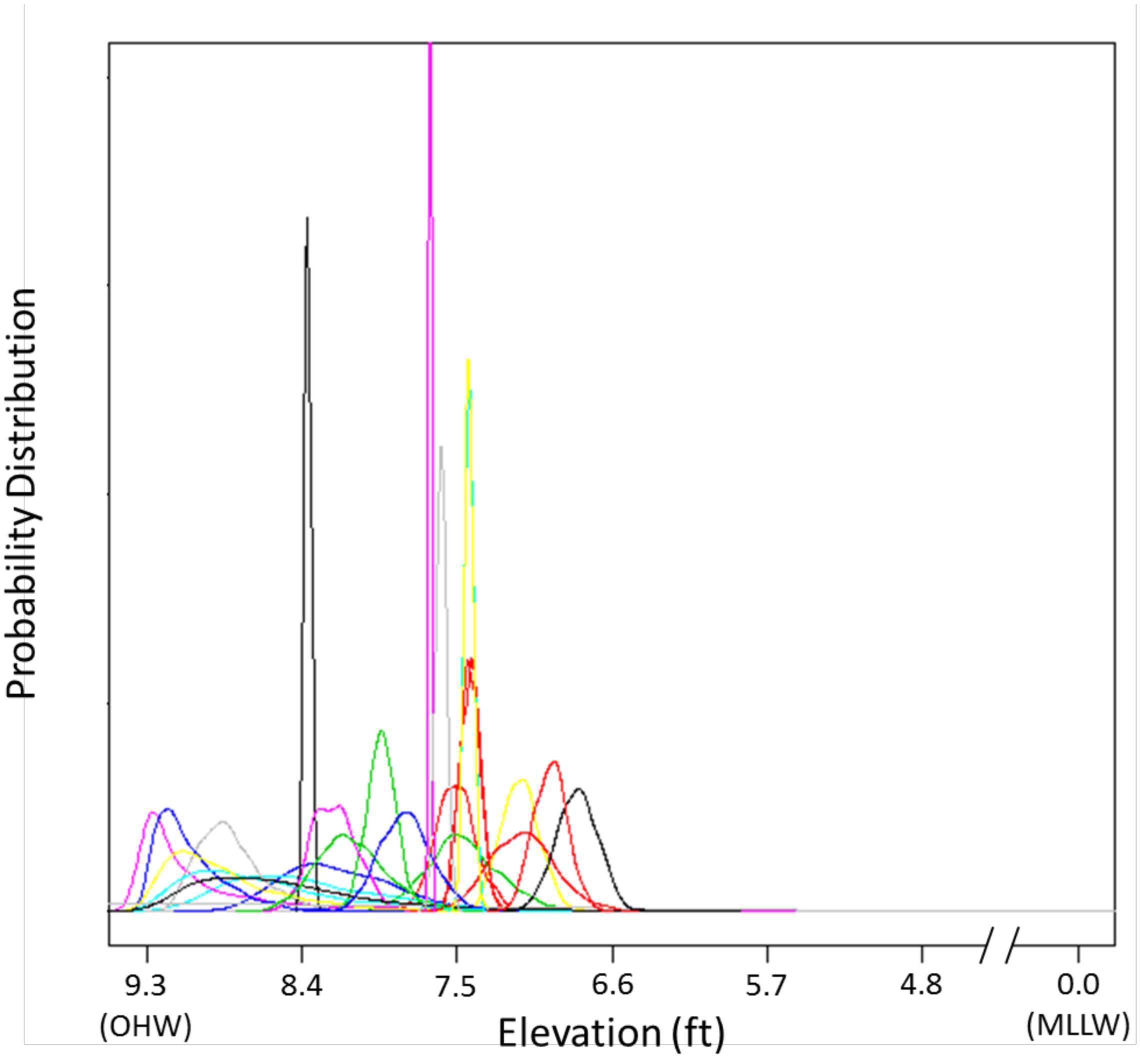
Table 2. Surf Smelt Egg Distribution by Tidal Elevation

Elevation (feet MLLW)	Total Smelt Egg (count)	Percent of total Smelt Eggs (percent)	Number of Samples with eggs (count)
Below 3 (n=1)	0	0%	0
3.0-3.9 (n=11)	1	< 1%	1
4.0-4.9 (n=24)	2	< 1%	1
5.0-5.9 (n=27)	187	3%	9
6.0-6.9 (n=29)	2116	35%	24
7.0-7.9 (n=31)	2458	40%	22
8.0-8.9 (n=25)	1241	20%	15
9.0-9.9* (n=15)	110	2%	1
Above 9.9 (n=2)	0	0%	0

Note: Data summarized across all sites and dates. Sample size n refers to the number of substrate samples at that elevation range across 165 samples from 26 transects at 15 beaches.

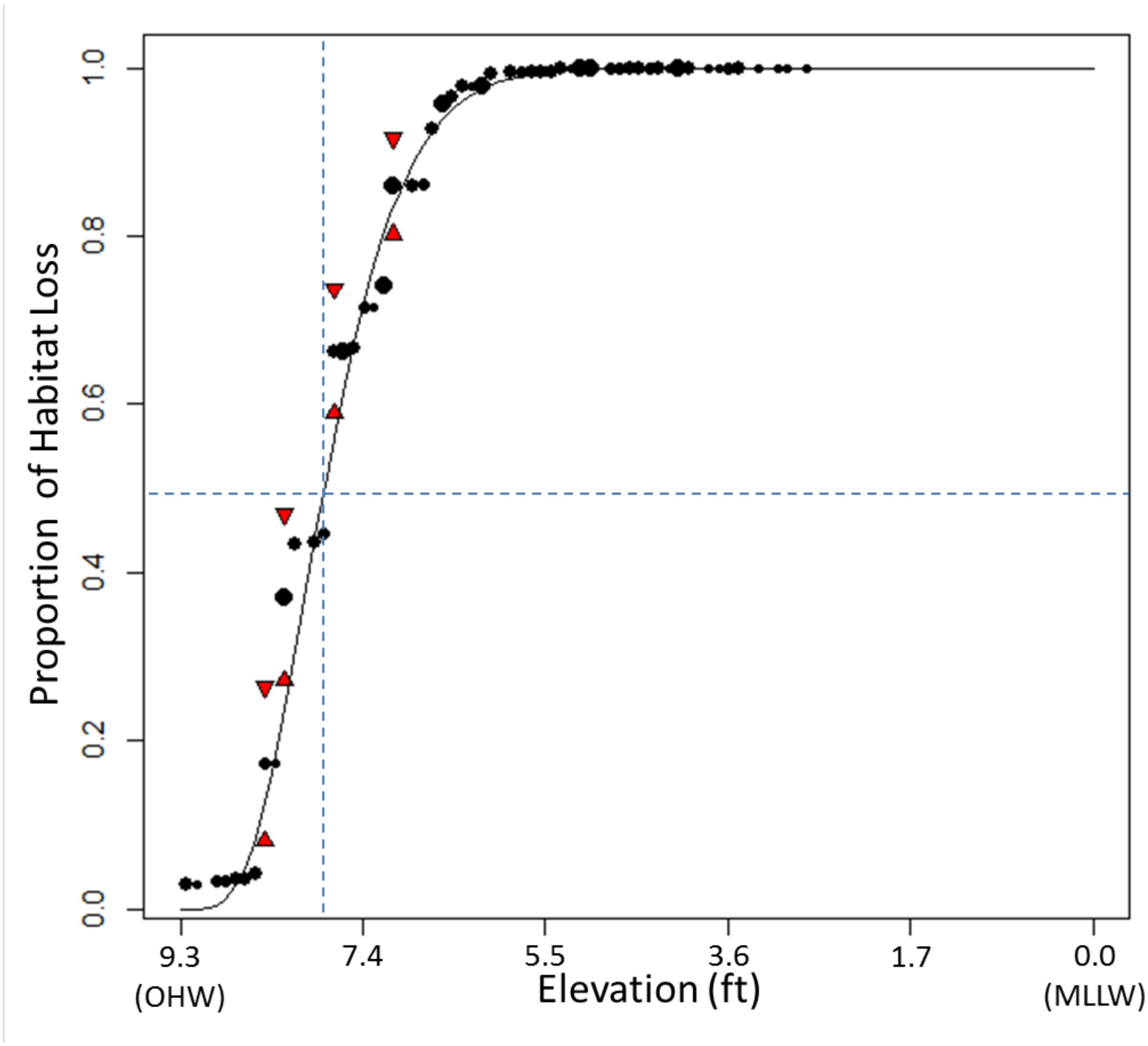
**Note: the highest elevation of eggs in this elevation range was 9.2 MLLW*

Figure 6: Gamma probability density functions fit to egg density data from 26 San Juan County Surf Smelt spawning beaches that describe the spatial distribution of Surf Smelt eggs in relation to beach elevation.



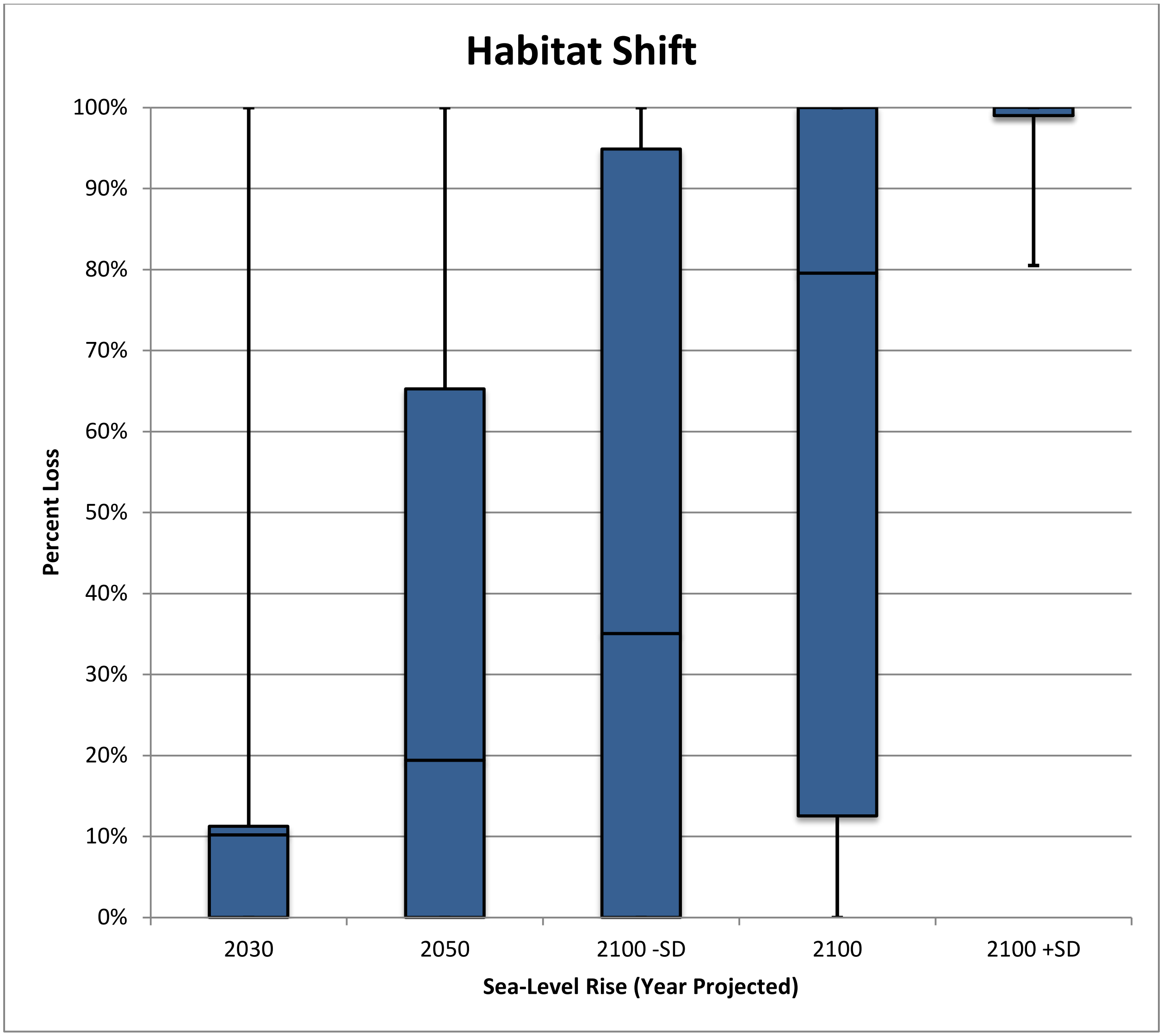
The area under each curve is equal to 1, and the width of the curve describes the elevation range from which eggs were found at that beach. The x-axis is the approximate elevation in feet (+/-0.2 feet) relative to the MLLW. Note that elevation intervals are not exact due to rounding error. The y-axis is the probability distribution of the likelihood of encountering eggs at a given elevation.

Figure 7: Cumulative gamma distribution describing the proportion of Surf Smelt eggs in relation to beach elevation.



The x-axis is the approximate elevation in feet relative to the MLLW. Note that elevation intervals are not exact due to rounding error. The y-axis is the projected proportion of habitat lost. Points are samples; large points are several samples at an elevation. Triangles mark standard deviations that are greater than 5% of the mean. The dashed lines intersect where approximately 50% of eggs are inundated due to a sea-level rise.

Figure 8: Box and whisker plot describing Surf Smelt eggs lost at four sea level rise scenarios (n = 26 beaches).



The sea-level rise scenarios for the years 2030, 2050, 2100 minus 1 Standard Deviation, 2100, and 2100 plus 1 Standard Deviation correspond to about +0.2 feet, +0.5 feet, + 1.1 feet, +2.0 feet, and +3.0 feet above current sea-level respectively (NRC 2012). Lines within boxes identify the means, boxes include the middle 70% of the data points, and whiskers describe the range.

Discussion

Incubating Surf Smelt eggs can be found across a range of intertidal elevations, with the majority of eggs located around mean higher high water (MHHW). Distribution of eggs was variable, possibly reflecting localized differences in spawning substrate character with tidal elevation, variable timing of individual spawning events in relation to high-tide waterline positions on the beach during daily, monthly and seasonal tidal cycles, and variable redistribution of incubating eggs by wave action after spawning events. Extensive field reconnaissance surveys of known spawning sites in San Juan County for the purposes of this research found less spawn than in the past, suggesting that that smelt spawning activity at previously documented, year-round sites within San Juan County was depressed in both time and space, most notably throughout the winter months.

Difficulty finding eggs on known spawning beaches meant that samples were not collected from randomly selected beaches as originally planned, and only three samples containing eggs were collected during the winter season. Samples were collected in San Juan County from beaches where spawning had been previously documented and which had relatively abundant spawn at the time of sampling, i.e. spawn visible on the beach. As such, we cannot extrapolate the relation between egg abundance and elevation beyond other similarly documented Surf Smelt spawning beaches in the region. However, there is no reason to believe that the site selection process used here would introduce bias. We included all sites with an abundance of eggs, and the distribution of eggs as a function of intertidal elevation was consistent with our field studies on many other beaches in Puget Sound(D., Penttila pers com) and with Krueger et al. (unpublished study).

As obligate upper intertidal spawners, Surf Smelt would be among the earliest and most directly impacted species by rising sea levels. Results demonstrate that the narrowing and loss of Surf Smelt spawning habitat as a result of the coastal squeeze as armored shorelines block the landward retreat of a beach in the face of rising sea levels is likely to be significant. As continued shoreline development and climate change impacts (storminess and rising sea levels) are both expected to increase demand for shoreline armoring in the region, improved protection and restoration efforts will be needed to ensure Surf Smelt spawning habitat exists into the future.

With 26 surveys completed at 15 known Surf Smelt spawning beaches across 7 different months between September 2012 and September 2013 and 5 regions (3 islands) of San Juan County, the study marks the most detailed sampling completed in the region for tidal elevation distribution data for surf smelt spawn over such a wide geographical area. The results should stimulate parallel studies in other parts of the Salish Sea Basin with different tidal-amplitude regimes.

Management Implications

Project findings should inform management of shoreline modifications in San Juan County and beyond. With 80% of incubating eggs located in the upper third of the beach, and 30% of the eggs located above MHHW, natural beach substrates at elevations significantly higher than local MHHW play a valuable role for spawning habitat.

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