Resilient and At Risk Priority Nearshore Habitats of San Juan County

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May 11, 2012

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INTRODUCTION

Coastal Geologic Services was contracted by Friends of the San Juans (FSJ) to assess the relative resilience and risk to valuable nearshore habitats in San Juan County (SJC) to implications of climate change and sea level rise (CC/SLR). Risk and resilience were measured using a suite of indicators to identify which habitats will be strained due to systemic and site-specific shoreline alterations, largely resulting from shoreline development. These results can be used to target areas for restoration and conservation in San Juan County, identify the greatest sources of risk that could be mitigated to prevent potential habitat loss, and inform resource managers of the spatial extent of the potential impact of CC/SLR in SJC and the necessity of conserving the most pristine, resilient habitats.

BACKGROUND

San Juan County encompasses 428 islands (those exposed at high tide), which represent the southern islands of the San Juan/Gulf Island archipelago. With a total of 408 miles of marine shoreline, San Juan County boasts more shoreline than any other county in the contiguous United States. These shorelines are diverse in character, and include a variety of geomorphic shoreline types (shoretypes). Each shoretype is associated with a suite of valuable nearshore habitat functions, structures and processes, upon which the larger marine ecosystem depends. Residential development is concentrated along the San Juan County shorelines in small subdivisions, villages, hamlets and resorts. Shoreline modifications commonly occur along the developed shorelines.

Shoreline modifications degrade nearshore ecosystem function and processes, which results in a less resilient nearshore ecosystem. Less resilient systems have a reduced capacity to naturally adapt to or overcome large-scale perturbations such as those predicted to occur as a result of global climate change and sea level rise. The relative resilience and risk to valuable nearshore habitats in San Juan County to implications of climate change and sea level rise will be explored in this study. San Juan County marine shorelines provide critical migratory and foraging habitats for juvenile salmonids out-migrating from the Puget Sound-Georgia Basin. Forage fish spawn in the upper intertidal and are a central component of the marine food web.

Physical characteristics and the greater context of each valuable nearshore habitat (identified in a previous study, described further below) will be assessed to identify which areas will be more resilient and those that are at the greatest risk of being lost as a result of climate change and sea level rise. The results will highlight where targeted restoration efforts that may increase resilience (thereby decreasing risk) and where to preserve resilient habitats for the long-term success of San Juan County nearshore ecosystems.

Implications of Climate Change and Sea Level Rise

The predicted increased rate of sea-level rise, as a result of global warming, will generally lead to higher coastal water levels, thereby altering geomorphologic configurations, displacing ecosystems and increasing the vulnerability of infrastructure (IPCC 2001, Pethick 2001). Recent research has also reported that non-bedrock shores, such as the glacially-derived material that makes up most of the region's bluffs, are likely to retreat more rapidly in the future due to an increase in toe erosion resulting from sea-level rise. Retreat rates may also be amplified in many areas due to increased precipitation, storminess (wave energy), storm frequency and higher ground water levels (Hosking and McInnes 2002, Pierre and Lahousse 2006). Inundation of estuarine beaches, tidal flats, inland and freshwater marshes and swamps, and brackish marsh is also likely to occur (Glick 2007).

Changes in sea level will also result in a spatial adjustment, landward and upwards, following a concept known as the Bruun Law (1962). This basic idea (though its accurate application to individual beaches is not well understood) appears to apply to all coastal landforms (Pethick 2001). The landward migration of the shoreline is a response to the changes in energy inputs brought about by sea-level rise. Knowing that this translation is to occur offers resource managers a tool, allowing decisions to be made to accommodate and, where possible, facilitate such migration (Pethick 2001). Knowing where shoreline translation will occur can inform planning and aid facilitating a proactive management approach. This is particularly relevant, where existing infrastructure and shore modifications occur that will eventually be inundated. Having early awareness of where these threatened structures occur, can allow for a strategic response to alter, move or remove the structure as a means of increasing overall ecosystem resilience and mitigating long term impacts to nearshore habitats.

Accommodating space to enable shoreline translation can allow salt marshes, sand dunes, and beaches to transgress (move landwards while maintaining their overall form). This concept is commonly referred to as "managed retreat" (Cooper 2003). Accommodating sea level rise prevents the diminishment and loss of natural features such as intertidal, upper beach and dune habitats, from being lost between a static backshore (such as a bulkhead or rock revetment) and rising sea level. The concept is commonly referred to "the coastal squeeze".

As a result of these processes related to global climate change, the shores of the San Juan Islands will undoubtedly incur considerable habitat loss along its modified shores, unless managers choose to take a proactive approach and start initiating programs focused on accommodating sea level rise and utilizing strategies such as managed retreat (e.g. removing shore armoring, relocating coastal roads, etc). There will also be further pressure to construct erosion control structures as a result of increased erosion rates, storminess and storm frequency. Permitting the building of additional bulkheads is not likely to provide a long-term solution, and will amplify habitat loss caused by the coastal squeeze. Relocating homes and infrastructure such as coastal roads out of inundation hazard areas provides multiple benefits of protecting infrastructure and nearshore habitats and processes, including shoreline translation.

Best Available Science Sea Level Rise Projection

Chapter 5 of the San Juan County Best Available Science Report provides a review of the most recent sea level rise projections throughout the Puget Sound region that are relevant to San Juan County. A range of projections was reiterated from Mote et al. 2008 and Clancy et al. 2008, which included a range of scenarios (very low-medium-very high) with the associated sea level rise projections (Table 1). These projections cite an upper limit (very high scenario) of 68.9 inches by the year 2100 (Herrera 2011).

Mean higher high water at the local NOAA tidal benchmark station located in Friday Harbor, is 2.4 meters or 7.8 feet above mean lower low water. The highest recorded water level (extreme high tide) at this station is 11.1 ft, resulting in an additional 3.4 ft rise in water level above mean higher high water currently occurring locally. High water events such as this are typically a result of the combined effect of El Nino conditions, which can raise local water levels from weeks at a time, a high spring tide and a storm surge. Although rare, the concurrence of these events happens periodically and extreme tidal elevations should be planned for in addition to the rise in mean sea level resulting from global climate change. Additionally, wave run-up particularly during storm events, also brings water higher on the supratidal beach.

Table 1. Comparison of “very high” local sea level rise estimates in Puget Sound by Mote et al (2008) and Cayan et al. (2008) from Clancy et al. (2008).

Component	Mote et al. (2008) “very high”	Cayan et al. (2008) “very high”
	2100	2100
Global sea level rise	93 cm (36.6 in)	140 cm (55.1 in)
Local atmospheric	15 cm (5.9 in)	15 cm (5.9 in)
Vertical land movement	20 cm (7.9 in)	20 cm (7.9 in)
Total local sea level rise	128 cm (50.3 in)	175 cm (68.9 in)

Priority Nearshore Habitats

Priority habitats identified and prioritized as part of an ongoing salmon recovery planning process in San Juan County (FSJ et al., 2012 *in prep*) are the fundamental unit of analysis for this study. Three data layers were used to define priority habitats in this salmon recovery context are: juvenile Chinook salmon nearshore habitat presence probability (Beamer and Fresh 2012), juvenile forage fish nearshore habitat presence probability and documented and potential forage fish spawning beaches (WDFW and FSJ 2004). Beamer and Fresh used probabilistic models based on extensive bi-weekly field sampling over 80 sites over 2-years in San Juan County (Beamer and Fresh 2012). The Friends and WDFW data represents forage fish spawning beaches documented to date in San Juan County (WDFW and Friends of the San Juans, 2004). Potential forage fish spawn beaches were mapped relying on air photo analysis and beach substrate composition (Moulton and Penttila 2001).

Priority nearshore regions applied to this assessment were developed for the WRIA 2 salmon recovery prioritization currently occurring as part of an adaptive management update of the San Juan County chapter of the Puget Sound Chinook Salmon Recovery Plan. Three datasets, weighted equally, were used to identify priority shoreforms, including juvenile Chinook salmon presence probability (Beamer and Fresh 2012), forage fish presence probability (Beamer and Fresh 2012), documented forage fish spawning beaches (FSJ/WDFW 2004) and potential forage fish spawning beaches FSJ/WDFW 2004). Documented forage fish spawning was considered high ranking, while potential forage fish spawning was a moderate ranking. Presence of juvenile Chinook salmon and juvenile forage fish, were binned into high, medium and low categories, respectively, based on the presence probability by shoreform. Highest priority ranking was applied to all shoreforms with two or more high priority criteria and moderate for the remaining third factor. High priority ranking was assigned to all shoreforms with one of the following three combinations: two moderate and one high, all moderate or two high and one low.

Table 2. Priority habitat rankings used for the WRIA 2 salmon recovery prioritization (FSJ et al. 2012 *in prep*).

Ranking Rules	Juvenile Chinook Presence Probability	Forage Fish Spawn	Juvenile Forage Fish Presence Probability	# Sites (shoreforms)	Shoreline Miles
HIGH	H	M	H		
HIGH	H	H	M		
HIGH	M	H	H		
			SUM HIGHEST	103 sites	8 miles
MODERATE	H	M	M		
MODERATE	M	H	M		
MODERATE	M	M	H		
MODERATE	M	M	M		
MODERATE	H	H	L		
MODERATE	H	L	H		
MODERATE	L	H	H		
			SUM HIGH	777 sites	59 miles

METHODS

The fundamental unit of analysis for this study is the priority habitat shoreform mapping developed for the WRIA 2 Nearshore Restoration Prioritization (FSJ et al. 2012 *in prep)*. For this analysis, the original priority habitat mapping GIS layers were merged into a single shapefile. The priority categories (high and moderate) were retained in the attribute table for later analysis.

A GIS project was created and populated with the necessary data sets to support the assessment criteria. The GIS data used in this analysis are described in Table 3. GIS metrics were then developed and applied to reflect the assessment criteria, which is described in detail below. Each of the nearshore characteristics contributing to the resilience or level of risk to priority nearshore habitats was scored for presence/absence (1/0). The overall resilience and level of risk score is simply the sum of the number of characteristics that are present within a given reach of priority habitat that contribute to resilience or risk.

The GIS metrics used to score and thus define resilient and at risk priority habitats are summarized briefly below and displayed in Tables 4 and 5, respectively. The physical characteristics associated with shorelines and their ability to translate landward, habitat needs for critical marine species, and available data sets, was considered when developing the metrics used to score resilient and risk in priority habitats. A normalized sum of the outputs to each metric conveyed the cumulative level of resilience or risk to priority nearshore habitats. The metrics developed to assess resilience and risk to projected sea level rise impacts were applied to all priority habitat shoreforms in the county. For example, all shoreforms that encompassed priority habitats were assessed for their ability to translate landward. For shoreforms that were located within drift cells, this was measured by assessing the sediment supply of the entire drift cell, however for pocket beaches it was assessed by assessing the degree of armoring within the individual shoreform.

Table 3. GIS data used to score resilience and risk to nearshore habitats in San Juan County.

Name	Source
Priority Nearshore Habitats for San Juan County salmon recovery	FSJ et al. 2012 *in prep*
Restoration Drift Cells	Coastal Geologic Services, Inc., MacLennan et al. 2010.
Simplified Shoreforms	FSJ et al. 2012 *in prep*
Conservation drift cells	Coastal Geologic Services, Inc., MacLennan et al. 2010.
Surface Geology, 1:100k	DNR Geology, 2008
Shoreline Armor	FSJ, 2008
Buildings	San Juan County, 2008
Roads	San Juan County, 2009

Sediment Supply and Shoreline Translation

Drift cells with more than 75% of their historic sediment supply intact were considered more resilient to sea level rise and likely to translate landward with relatively little habitat loss; therefore, these drift cells scored a point for resiliency. Shoreline translation in pocket beaches was assessed by how armored that shoreform was. If it was relatively unarmored (less than 25% of the shoreform) then it was considered relatively resilient and scored a point for resilience. Conversely, if the priority habitat was within a drift cell that had incurred a loss of 50% or more of the historic sediment supply or was within a pocket beach with 50% or more shoreline armor then it was scored for being at risk.

Natural Constraints

The presence of bedrock geology was used to indicate a natural constraint to shoreline translation. The metric addressed priority habitats that occurred waterward of a bedrock shoreline that would be squeezed or constrained as a result of the landward migration of the shoreline. For this metric, if bedrock was mapped on the shoreline then the shoreform was considered at risk (and scored for risk) and did not score for resilience. Even if it was partially overlapping bedrock, the presence of bedrock indicates a natural constraint to translation that would likely result in a decrease in priority habitats. For priority habitat shoreforms that were entirely free of bedrock geology (e.g. unconsolidated sand, gravel, and clay left behind by the glacial ice sheets) shoreline translation would be unconstrained and the shoreform would score for resilience and not being at risk to CC/SLR implications.

Shoreline Armor and the Coastal Squeeze

Shoreline armor was another metric used in the resilience and at risk scoring, as it represents a static shoreline, presenting a constraint to the landward migration of the shoreline. Priority nearshore habitats with shoreline armoring scored for being at risk and did not score for resilience.

The points for each of these 5 metrics were summed and then normalized to take into account the islands without inundation data. The maximum for the islands without the inundation data was 3 points.

Table 4. GIS metrics for scoring resilient habitats.

GIS metric	Data Source and Use	Rationale
Resilient Drift Cells	Drift cells were score as resilient if they had 75% or more of their historic sediment supply intact.	Sediment supply is critical to shoreline translation, and thus ecosystem resilience.
Resilient Pocket Beaches	Pocket beaches with 25% or less shoreline armor.	Pocket beaches that are relatively free of shore armor are better able to translate landward with habitats preserved.
No Inundated Infrastructure	No buildings or roads intersected inundation polygons.	Without infrastructure, translation is able to occur without the threat of engineered structures; therefore habitats are likely to persist.
No Bedrock	DNR surface geology, bedrock units displayed only.	Without the natural constraint of bedrock landward of habitats, shoreline and habitat translation is likely to occur.
No Armor	Friends shoreline armor	Intertidal habitats without landward armor are able to translate landward without narrowing/degradation.

Inundation Hazards

An inundation model was developed to assess risks associated with inundation hazards that could lead to habitat loss. The inundation model included the following sea level rise scenarios: a) 5.4 ft above current Mean Higher High Water (MHHW) and b) 9.1 ft above MHHW. The two elevations in this model represent a low and a very high sea level rise projection, respectively (as reported in Clancy et al 2009). Buildings and roads that were inundated in the 5.4 ft above MHHW sea level rise scenario, landward of priority habitat shoreforms scored as being at risk, as emergency erosion control structures such as dikes, armor and fill would likely be used to protect the subject infrastructure. Similarly, priority habitat shoreforms with landward infrastructure that would be inundated in the 9.1 ft above MHHW sea level rise scenario were also scored for risk. Priority habitat shoreforms with inundation hazards for both scenarios scored twice, as the likelihood that the shoreline would be further armored to preserve infrastructure is likely greater where there are multiple structures at risk. Due to a lack of LiDAR data, the inundation model was not run for the northern islands of San Juan County including: Stuart, Johns, Waldron, Patos, Sucia, Matia, Barnes, and Clark Islands. See the *SLR Shoreline and Inundation Model section* below for more details on the inundation model. Figures of the Inundation model results are shown in the Map Appendix.

Table 5. GIS metrics for scoring at risk habitats.

GIS metric	Data Source and Use	Rationale
At Risk Drift Cells	At Risk drift cells were defined as those cells that had incurred a loss of 50% or more of their historic sediment supply.	Sediment supply is required for shoreline translation. Habitats that occur within drift cells that have incurred considerable loss of sediment supply are less likely to successfully translate landward.
At Risk Pocket Beaches	Pocket beaches with 50% or more shoreline armor within the entire shoreform.	Sediment supply and the ability for the shoreline to migrate landward are both required for the beach profile to fully translate landward. If armoring occurs along more than half of the pocket beach, it is likely that the degradation to sediment supply and natural adaptive capacity of the entire shoreform will be reduced, resulting in beach habitat loss.
Inundated Infrastructure	Buildings and Roads that intersect inundation polygons	Habitats located landward of infrastructure (buildings and roads) are at risk of being lost due to the potential for new armoring or other protective structures designed to preserve the infrastructure.
Bedrock	DNR surface geology, bedrock units displayed only. Priority habitats were flagged as being waterward of bedrock where appropriate.	Bedrock represents a natural constraint to shoreline translation, as the beach profile does not migrate landward along bedrock, it simply adjusts vertically, and thus intertidal habitats will narrow as the shoreline recedes. It is likely that these shores will eventually transition to rocky shoretypes.
Armor	Friends shoreline armor, waterward of priority habitat	Armor represents a static shoreline, presenting a constraint to the landward migration of the shoreline. These shores will incur habitat loss via the coastal

		squeeze. Initially the uppermost beach habitats will degrade and narrow, followed by those habitats located lower on the beachface.

SLR Shoreline and Inundation Model

The first step to understanding inundation patterns in San Juan County was to create a MHHW shoreline. Developing a precise MHHW shoreline for all of San Juan County presents a number of challenges. For example, the elevation of MHHW differs throughout the County. The elevation of MHHW varies locally from +6.9 ft MLLW at southwestern San Juan Island to +8.8 ft MLLW in the northern extent of the county near Patos, Sucia, and Matia Islands. In addition, the elevation of MHHW is dependent on the location of MLLW (0) throughout the County.

Spargo et al. (2006) produced a numerical tidal elevation model of the San Juan Islands as part of NOAA's VDatum program. Nine tidal benchmarks within the County were used to develop a map of variation between tidal (MLLW) and fixed (NAVD88) datums as part of that study. The result was a tidal datum conversion grid for use in VDatum. In additional, MHHW was determined for the entire grid using the same network of tidal benchmarks. VDatum allows datum conversions for points within the grid, and was used to produce an ArcGIS raster representing the difference between NAVD88 and MHHW for all of San Juan County.

The best available elevation data for the San Juan County (uplands) is the 2009 LiDAR flights by Watershed Sciences for the Puget Sound Regional Council. Reported vertical accuracy for the data was reported as 0.12 ft with an average of 0.61 points per ft^2 (Water Sciences 2009). Data were provided in NAVD88 vertical datum, so a conversion to MLLW datum was required to determine MHHW.

A cell size of 10 ft was selected for this analysis as a balance between accuracy and processing time. Adjacent cells were found to have a difference of less than 0.01 ft, which was well within the level of error of both the LiDAR data and VDatum results. Values represented the amount to add to a given NAVD88 elevation to convert it to MHHW datum; in all cases here this was a negative value, as NAVD88 is always below MHHW in the Puget Sound and Straits (Figure 1).

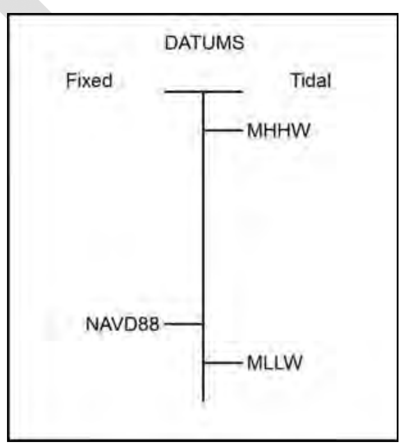

Figure 1. Representation of the relationship between fixed and tidal datums used in this study.

The two rasters, LiDAR and datum conversion, were then added to one another using the raster math toolset in ArcGIS Spatial Analyst. The output was set to the cell size of the LiDAR data and only performed math where both rasters overlapped. The result was a digital elevation model (DEM) of only the immediate vicinity of the shoreline of San Juan County in a vertical datum of MHHW. Mean higher high water + 5.4 and MMHW +9.1 ft contours were then created from the DEM to represent moderate and extreme sea level rise scenarios (Map 1, Map Appendix). The SLR shorelines used to create inundation polygons from MHHW – MMHHW + 5.4 ft and MHHW + 5.4ft to 9.1 ft. The co-location of buildings and other infrastructure (roads) were then analyzed to assess inundation threats throughout the County.

The above analysis includes several sources of error. The LiDAR data had a stated accuracy of 0.12 ft. Spargo et al. (2006) reported a modeling error of 0.36 (10.9 cm) vertical. Therefore, a maximum error of approximately 0.5 ft vertical could be found in the resulting DEM. In addition, the buildings and roads layers used to determine inundation hazards were county data sets, and may not have included all local, private roads and many structures/buildings were not included in the data set based on observation in vertical air photos.

RESULTS

As described in the *Methods* section high and moderate priority nearshore habitats were identified as being of high ecological value to salmon recovery efforts, for juvenile Chinook salmon and forage fish spawning and rearing. The relative resilience and risk to each priority habitat level (ranking) will be summarized below. The dominant drivers of risk and resilience throughout the county will also be discussed.

Resilient Habitats

Priority habitat shoreforms were scored to measure the relative resilience to implications of sea level rise and climate change. Scoring results showed that the large majority of all priority habitat shoreforms (65-82%) have at least a medium-high level of resilience to implications of SLR and CC (Figure 2, Table 6). High and moderate priority shoreforms had an equal ratio of shoreforms with a low level of resilience. Enhancing the resilience of these shoreforms should be a restoration priority for their role in supporting juvenile salmon and spawning and juvenile forage fish. Enhancing the resilience of shoreforms with a ranked as being moderately resilient should also be viewed as a priority, as the priority habitats associated with these shoreforms are vulnerable to several sources potential impacts. High priority habitat shoreforms appear to have reduced resilience largely due to natural constraints associated with bedrock geology. Three percent of the high and moderate priority habitat shoreforms scored as having low resilience. While exploring these results, it is important to keep in mind that any degradation in resilience can result in habitat loss, the magnitude of the loss and constraints associated with mitigating that loss will likely be greater among the lesser resilient shoreforms.

Priority habitats shoreforms that scored as highly resilient are found throughout the San Juan Islands within drift cells and in isolated pocket beaches (Map 2). The most resilient of the priority habitats are concentrated on the southeast side of San Juan County, including on Decatur, and Blakely Islands. Resilient priority habitats are also located in the vicinity of Waldron, Stewart, and along southeast Orcas Island. Moderately-highly resilient habitats are also found throughout the county, particularly around San Juan Island and along the southwest shore of Shaw and the north shore of Orcas Island. Shoreforms with low resilience were found along southeast Lopez Island, the north shore of San Juan and the north shore of Orcas Island. The habitats and shoreforms with the least resilience are located within the northern shores of the County, on Orcas, Shaw and San Juan Islands.

San Juan Island contains several of the most resilient habitats, which are sparsely distributed among the many pocket beaches throughout the island.

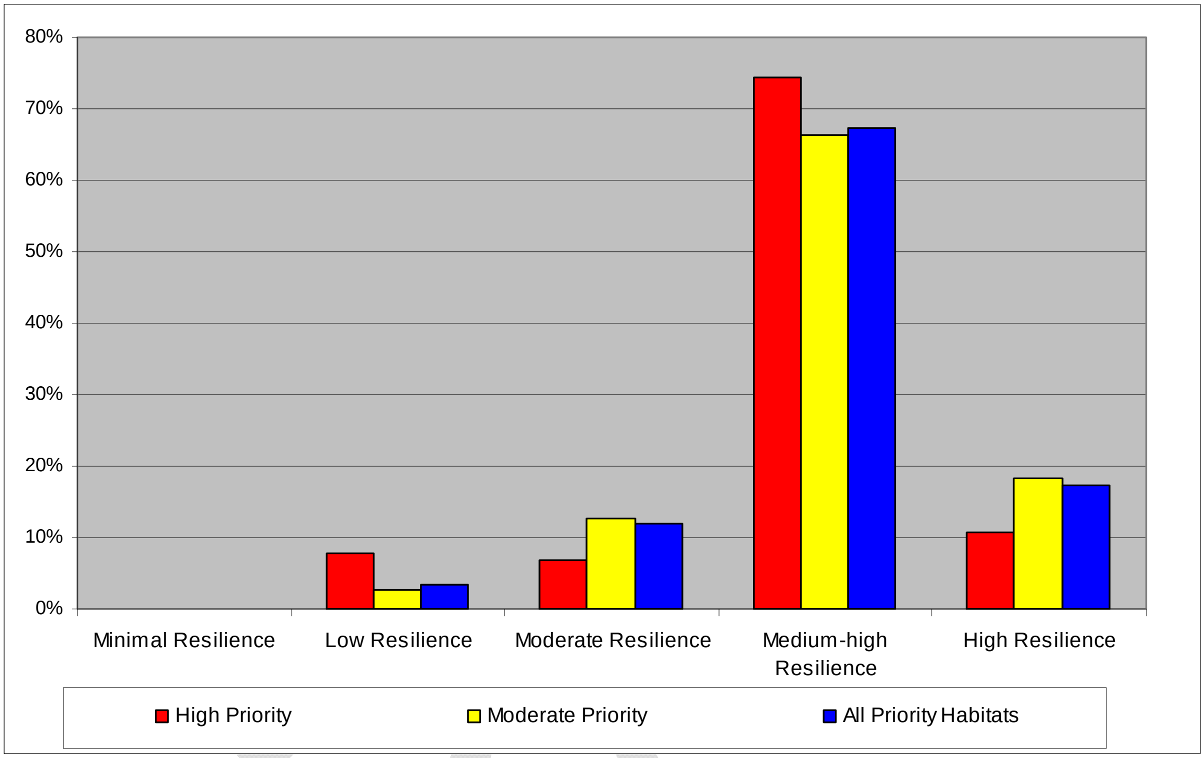

Figure 2. High and moderate priority nearshore marine habitats of San Juan County's relative resilience to implications of climate change and sea level rise.

Table 6. High and moderate priority nearshore marine habitats of San Juan County's relative resilience to implications of climate change and sea level rise.

	Minimal Resilience	Low Resilience	Moderate Resilience	Medium-high Resilience	High Resilience
High Priority	0%	8%	7%	75%	11%
Moderate Priority	0%	3%	13%	66%	18%
All Priority Habitats	0%	3%	12%	67%	17%

At Risk Habitats

Risk associated with implications of sea level rise and climate change was assessed for each of the priority habitat shoreforms in San Juan County. It is important to keep in mind when interpreting these results that because this is an additive model, and any source of risk receives a single point, those priority habitat shoreforms that appear to have only a low degree of risk, are still subject to a single threat that may ultimately result in habitat degradation or loss. Priority habitat shoreforms that have scored moderately or have the highest risk scores are far more likely to incur habitat loss as they represent shoreforms with several stressors known to impact nearshore processes and habitats in the face of CC/SLR.

Analysis of results revealed that most priority habitats will be subject to a low degree of risk (45%), and 34% will be subject to a moderate degree of risk (Table 7, Figure 3). Greater ratios of high priority habitat shoreforms are associated low and moderate levels of risk, as compared to moderate priority habitat shoreforms (Table 7). Moderate priority habitats had the greatest ratio shoreforms with a high level of risk. Though, neither high nor moderate priority habitat shoreforms was associated with a large portion of medium-high or high risk. However, because this is an additive model it is important to keep in mind that shoreforms with even a low or moderate degree of risk as still subject to one or more impact that is likely to contribute to habitat degradation or loss.

Table 7. Degrees of risk associated with climate change and sea level rise implications to high and moderate priority habitats in San Juan County, Washington.

	Minimal Risk	Low Risk	Moderate Risk	Medium-high Risk	High Risk
High Priority	11%	72%	8%	7%	3%
Moderate Priority	18%	57%	13%	8%	4%
All Priority Habitats	17%	59%	13%	7%	4%

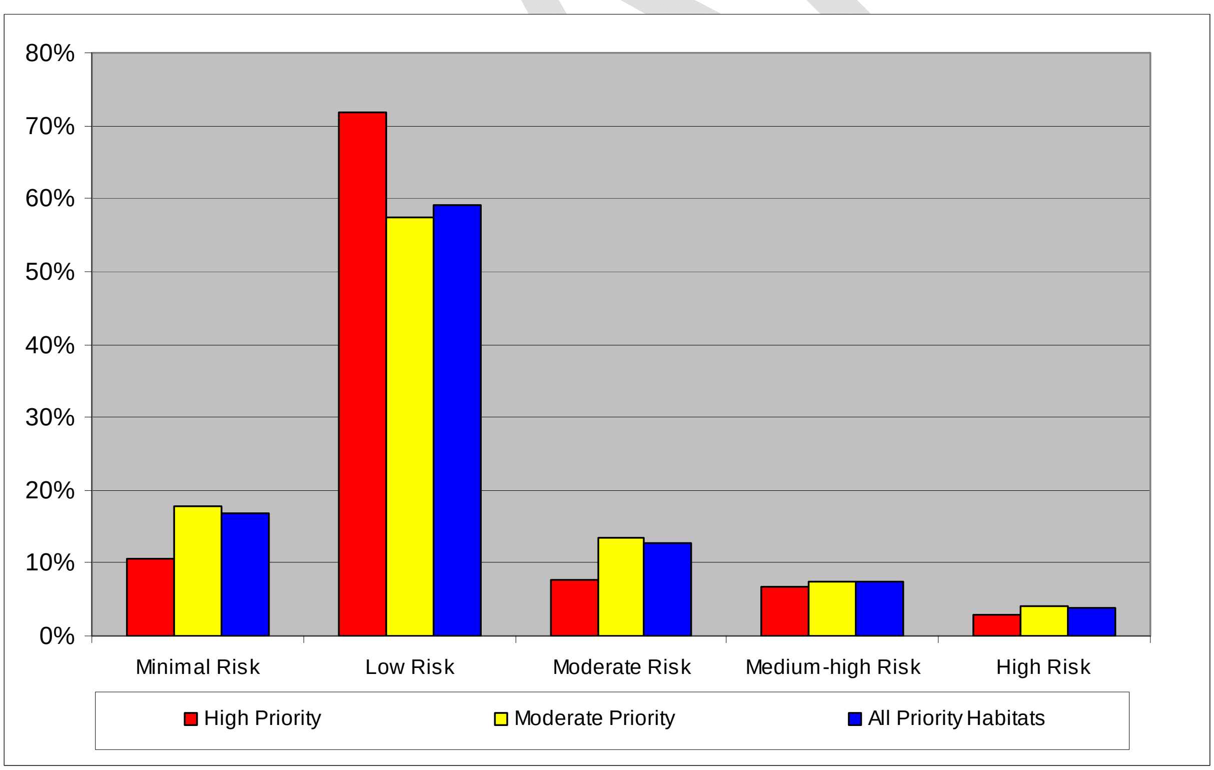

Figure 3. High and moderate priority habitat shoreforms relative risk to implications of sea level rise and climate change.

The different sources of risk to priority nearshore habitats associated with sea level rise and climate change varied throughout the county. Bedrock was by far the most frequently observed source of risk, occurring in 73% of the priority habitat shoreforms (Figure 4). Upland bedrock geology presents a natural constraint to shoreline translation, which can result in habitat narrowing and loss. However, the coarse resolution of the geology mapping in San Juan County could be artificially inflating this number. For all shoreforms in which bedrock was not a source of risk, the most prevalent remaining risks included: shoreline armor, followed by inundation hazards, and sediment supply issues (Figure 5). When planning restoration, actions should be focused on addressing these sources of risks.

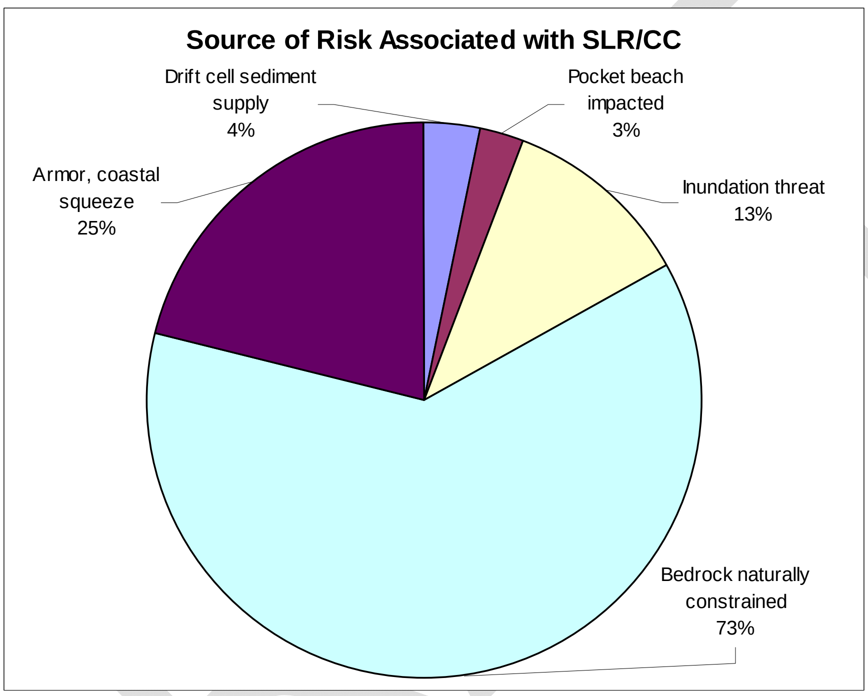

Figure 4. Occurrence of different sources of risk to priority nearshore habitats associated with climate change and sea level rise in San Juan County.

At risk priority habitat shoreforms are distributed exclusively throughout the ferry services islands of San Juan County (including Lopez, Shaw, San Juan and Orcas Islands, Map 3). More at risk habitat shoreforms were documented on San Juan Island than any other island. High risk habitat shoreforms on San Juan Island were located near Roche Harbor and Davidson Head along the north shore of the island, as well as near Friday Harbor and at the southern end of Griffin Bay. On Shaw Island the most at risk priority habitat shoreforms were located along the east shore of Broken Point and near Neck Point. The priority habitat shoreforms with the highest risk on Orcas are located along the north shore of Obstruction Pass, and on Lopez along the east shore of Hunter Bay. Far more moderately high risk priority habitat shoreforms were documented in the County than high risk. On San Juan Island the moderately-high risk habitats were found near Davidson Head, Friday Harbor, and a southern Griffin Bay. Shaw Island moderately-high risk habitats were located along the northwest shore of the island, at Broken Point and near Blind Bay and Hunter Point. On Orcas Island, several beaches along the northern shore of the island, the ferry landing, and a couple of short beaches in Pole Pass and Obstruction Pass were mapped as moderately high risk habitat shoreforms. Priority habitat shoreforms of moderate risk to SLR and CC implications occurred throughout the County, with the greatest abundance along the ferry-services islands. Broad reaches of priority habitat shores of the least risk were located along the northwest shore of Henry Island, Waldron and Decatur Islands, and northwest Blakely Island.

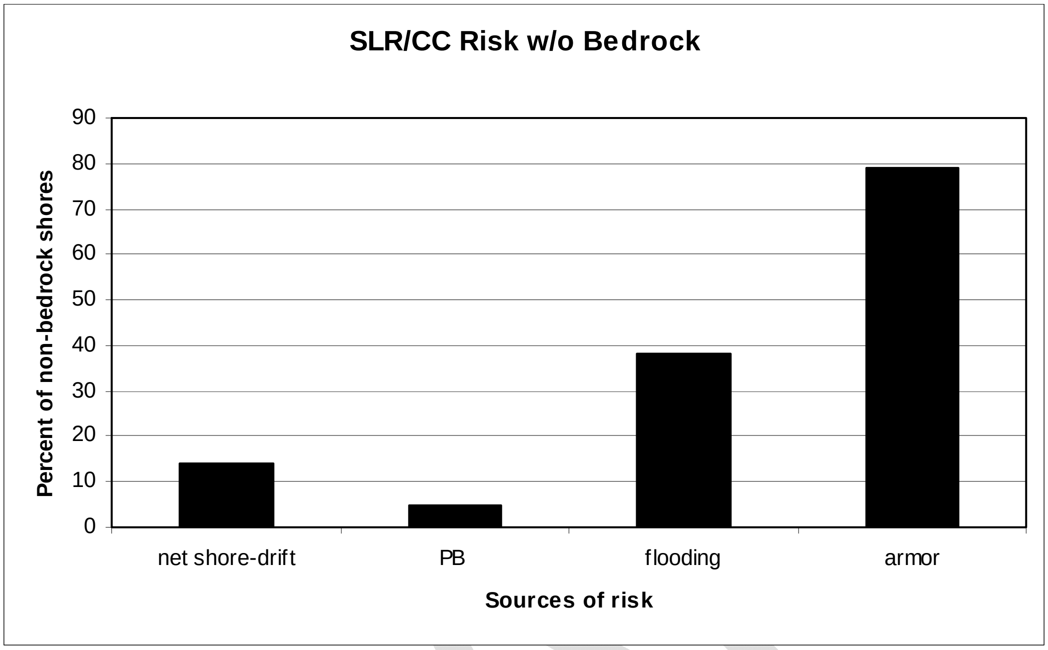

Figure 5. Occurrence of anthropogenic sources of risk to priority habitat shoreforms in San Juan County.

CONCLUSION

The purpose of this study was to assess and identify valuable nearshore habitats in San Juan County that were relatively resilient and at risk to implications of sea level rise and climate change. These results show that the majority of the shores of San Juan County are relatively resilient and are subject to one to two sources of risk in their current condition, which has the potential to be mitigated or off-set. Building resilience or reducing risks associated with climate change and sea level rise should address non-natural constraints such as shore armor and flooding hazards, rather than challenging the uncertainty of shoreforms with natural constraints. Preserving nearshore processes, particularly those that aid in the process of shoreline translation, including sediment supply and transport, avoiding the use of shore armor, and not building in inundation hazard areas will ensure that these conditions persists as sea levels rise and our climate slowly changes. Targeting restoration in at-risk areas to increase resilience will prevent future habitat loss. Removing the source of risk in priority habitat shoreforms with low levels of risk will increase resilience of San Juan County habitats as well as decrease the magnitude of habitat degradation that is incurred to habitats with multiple sources of risk. Many habitat restoration projects exist that entail relocating infrastructure such as roads, which could result in additional restoration opportunities with far reaching benefits to nearshore processes and habitats, both temporally and spatially. In priority habitats where few to no sources of risk were identified, it would be prudent to preserve or maintain those conditions to assure that some nearshore habitats are in the best condition possible to potentially outlast the widespread perturbation of sea level rise and climate change.

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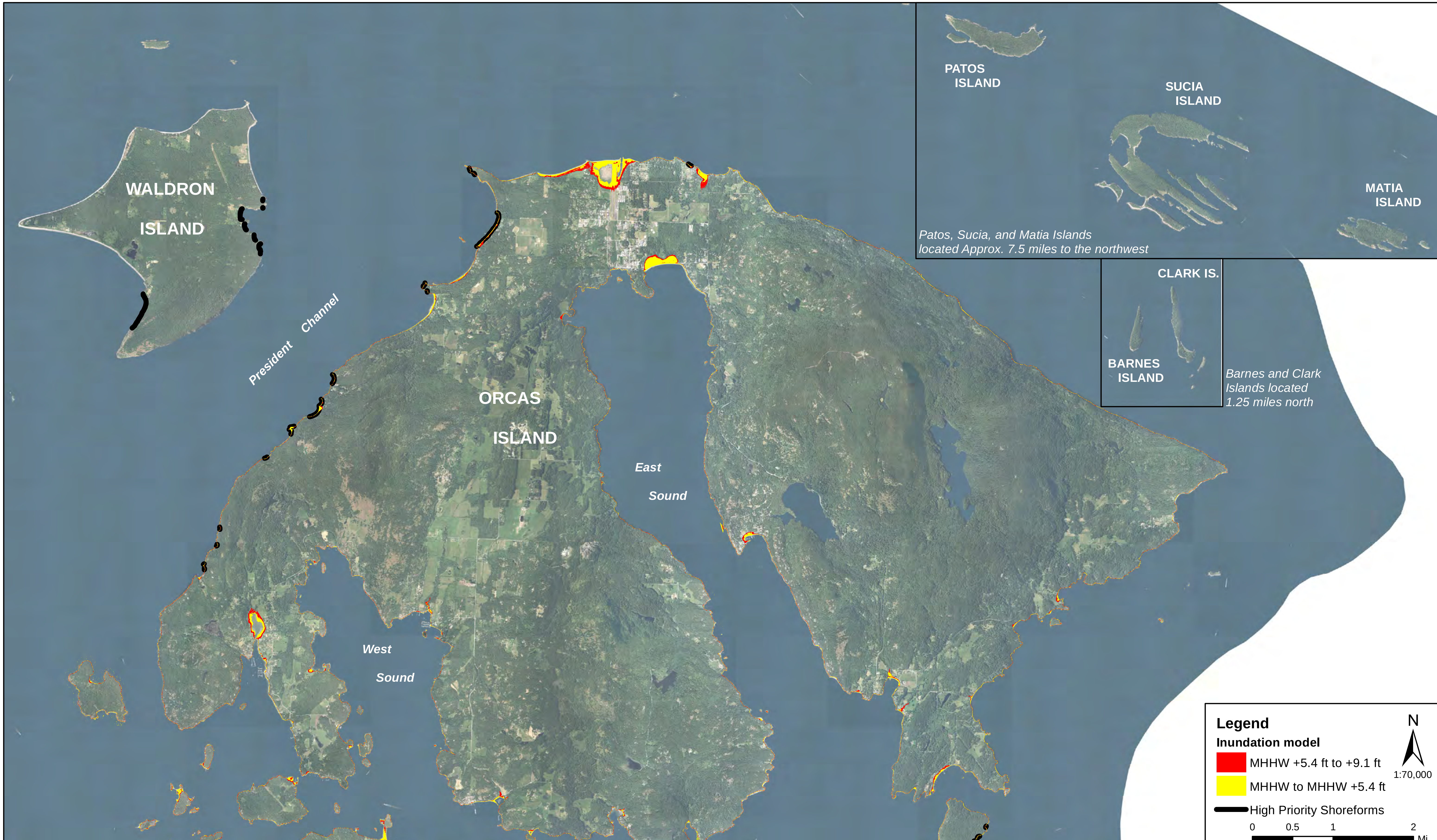
MAP

APPENDIX



Map 1A. Inundation model with Priority Nearshore Habitats* for Orcas Island. Note: inundation model not run for Waldron, Sucia, or Clark Islands due to lack of LiDAR.

Resilient and At Risk Priority Nearshore Habitats of San Juan County.

*San Juan County Aerial Photographs 2008. *Priority Nearshore Habitats for juvenile Chinook and juvenile and rearing forage fish (FSJ et al. in prep).*

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Map 1B. Inundation model with Priority Nearshore Habitats* for Blakely, Decatur, Center, Lopez, and Shaw Islands.

Resilient and At Risk Priority Nearshore Habitats of San Juan County.

*San Juan County Aerial Photographs 2008. *Priority Nearshore Habitat for juvenile Chinook and juvenile and rearing forage fish (FSJ et al. in prep).*

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Map 1C. Inundation model with Priority Nearshore Habitats* for San Juan, Pearl, Henry Is. Inundation model not run for Stuart, Johns Is.

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*San Juan County Aerial Photographs 2008. *Priority Nearshore Habitats for juvenile Chinook and juvenile and rearing forage fish (FSJ et al. in prep).*

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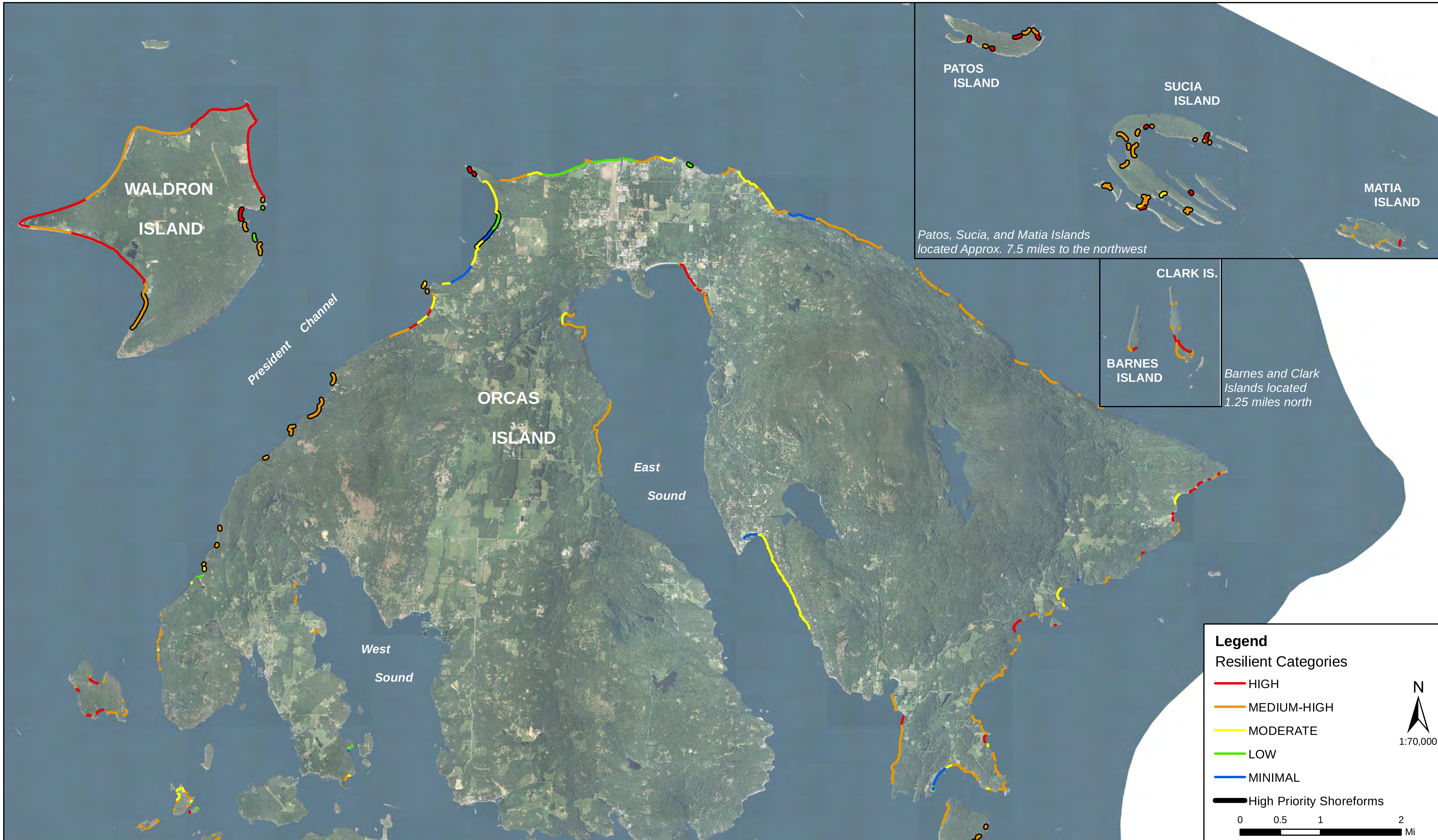

Map 2A. High and Moderate Priority Nearshore Habitat Shoreforms scoring as Resilient on Orcas, Waldron, Sucia, and Clark Islands.

Resilient and At Risk Priority Nearshore Habitats of San Juan County.

San Juan County Aerial Photographs 2008.

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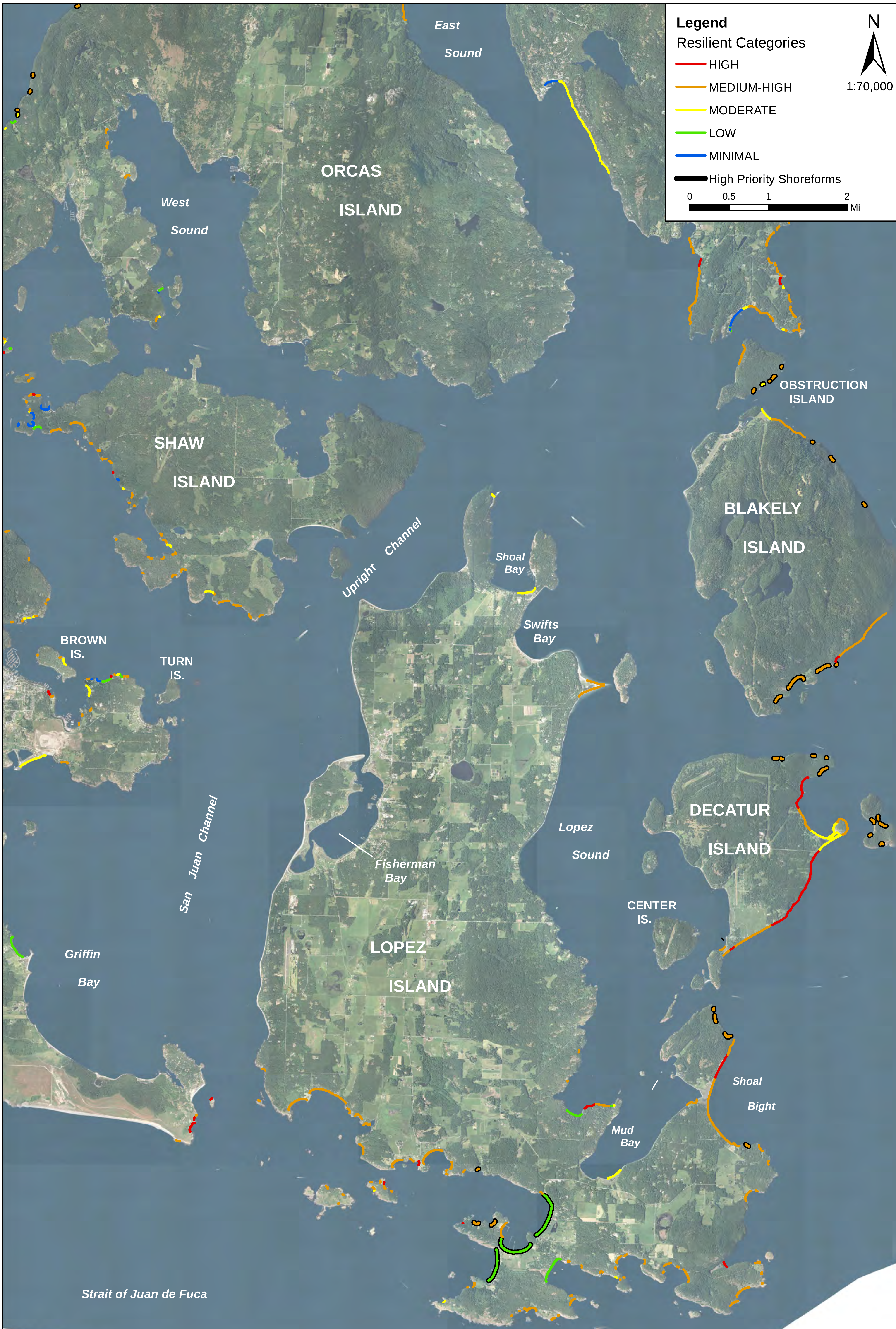

Map 2B. High and Moderate Priority Nearshore Habitat Shoreforms scoring as Resilient on Blakely, Decatur, Center, Lopez, Shaw Islands.

Resilient and At Risk Priority Nearshore Habitats of San Juan County.

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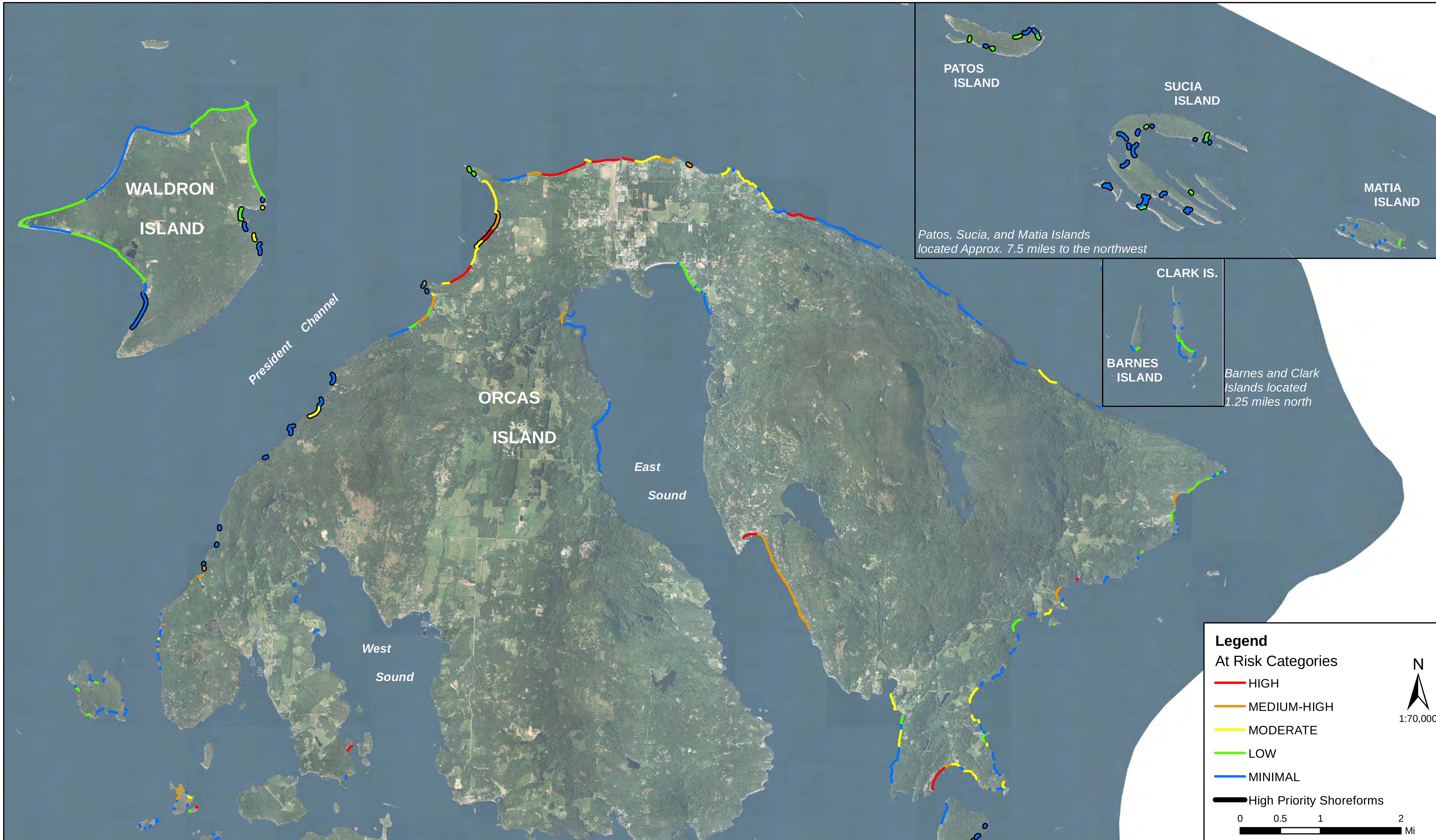
Map 2C. High and Moderate Priority Nearshore Habitat Shoreforms scoring as Resilient on San Juan, Pearl, Henry, Stuart, Johns Islands.

Resilient and At Risk Priority Nearshore Habitats of San Juan County.

San Juan County Aerial Photographs 2008.



Map 3A. High and Moderate Priority Nearshore Habitat Shoreforms scoring as At Risk on Orcas, Waldron, Sucia, and Clark Islands.

Resilient and At Risk Priority Nearshore Habitats of San Juan County.

San Juan County Aerial Photographs 2008.

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Map 3B. High and Moderate Priority Nearshore Habitat Shoreforms scoring as At Risk on Blakely, Decatur, Center, Lopez, and Shaw Is.

Resilient and At Risk Priority Nearshore Habitats of San Juan County.

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Map 3C. High and Moderate Priority Nearshore Habitat Shoreforms scoring as At Risk on San Juan, Pearl, Henry, Stuart, Johns Islands.

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