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Port Susan Marine Stewardship Area
Armor Removal Assessment Report
for Snohomish County Marine Resources Committee

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COASTAL GEOLOGIC SERVICES

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Introduction

Coastal Geologic Services Inc. (CGS) was contacted by Snohomish County to conduct a shore armor removal assessment for the Snohomish County portion of the Port Susan Marine Stewardship Area (PS MSA; Map 1). Armor is defined herein as bulkheads, revetments, seawalls, and other similar erosion control structures. The main objective of the project was to build a prioritized list of shoreline parcels where armor removal projects are feasible, in terms of not jeopardizing existing infrastructure, and where armor removal would best restore physical processes to benefit the greater nearshore ecosystem. A secondary objective was to identify unarmored parcels where shore armor is unnecessary to protect existing infrastructure.

To achieve these objectives, the feasibility and potential benefit of armor removal were assessed within each parcel in the study area. Feasibility was assessed remotely to identify parcels where armor removal is considered infeasible because it protects major structures built close to the shoreline. Any subsequent armor removal planning at parcel(s) level will require a more thorough assessment of feasibility through site visits and higher resolution site-specific analysis. As part of this contract, field assessments to inform feasibility will be performed on three sites in which there is both high ecological benefit and landowner interest. Additional site assessments in the Port Susan Marine Stewardship Area may be conducted as part of another study contracted by the Northwest Straits Foundation. The final results of this assessment will provide a foundation for later integration with local planning frameworks and shoreline regulations.

The study area encompasses 382 shoreline parcels along 8.3 miles within one net shore-drift cell (SNO-1[1]), which exhibits northward drift from Hermosa Point (northwest Tulalip Bay) to the Stillaguamish River delta (Map 2). The study area includes parcels that are within areas where littoral drift occurs. The northern extent of the study area is marked by the terminus of the littoral drift cell, where nearshore sediment transport is dominated by fluvial processes associated with the Stillaguamish River delta. The study area shores are comprised of the following shoretypes: 47% modified (armored) shore; 36% feeder bluffs[2]; 7.6% accretion shoreforms[3]; 4.8% feeder bluff exceptional[4]; and 3.6% transport zone[5]

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[1] Drift Cell: also referred to as net shore-drift cell, a littoral drift cell is a coastal compartment that contains a complete cycle of sedimentation, including sources, transport paths, and sinks. The cell boundaries delineate the geographic area within which the budget of sediment is balanced, providing the framework for the quantitative analysis of coastal erosion and accretion. See Johannessen and MacLennan (2007) for further description of drift cells.

[2] Feeder bluff: A coastal bluff with active erosion and/or mass wasting which periodically supplies moderate volumes of sediment to the nearshore, with a longer recurrence interval than feeder bluff exceptional segments. The bluff face typically has vegetation indicative of disturbance, with evidence of landslides and toe erosion (MacLennan et al 2013).

[3] Accretion shoreform: Sediment sink or depositional shores, areas of the marine shoreline where sediment is deposited, either currently or in the past.

[4] Feeder bluff exceptional: Coastal bluffs with active erosion and/or mass wasting (episodic erosion) which periodically supplies substantial volumes of sediment to the nearshore in greater quantities with a shorter recurrence interval than feeder bluffs. The bluff face typically has little to no vegetation, active landslides and toe erosion, and may include colluvium and toppled large woody debris (MacLennan et al 2013).

[5] Transport zone: A bluff or bank which supplies sediment input to the nearshore from erosion/mass wasting and does not have an accretion shoreform present. Littoral sediment is typically transported alongshore. The bluff face typically has considerable coniferous vegetation with few signs of disturbance from landslide activity or is of low relief such that sediment input is very limited.

(Map 2, MacLennan et al. 2013). Forage fish spawning has been observed on 172 of parcels' adjacent shore (Map 3, WDFW, 2014).

Methods

The approach to reach the objectives of this assessment consists of three separate analyses discussed in further detail below (Figure 1). In addition, parcels were also identified that meet coarse-scale criteria for beach nourishment and hard armor, as outlined in the WDFW *Marine Shorelines Design Guidelines* (Johannessen et al. 2014). These methods and analyses build on a current project for the Northwest Straits Foundation, studying the Island County portion of PS MSA and east Jefferson County:

- Background shore change rates
- Armor (bulkhead) removal feasibility
- Benefit assessment criteria

The combined results of these analyses were used to identify and rank the highest priority sites for restoration (i.e., armor removal) and protection (i.e., preventing new armor) that can serve as a basis for outreach efforts and project development.

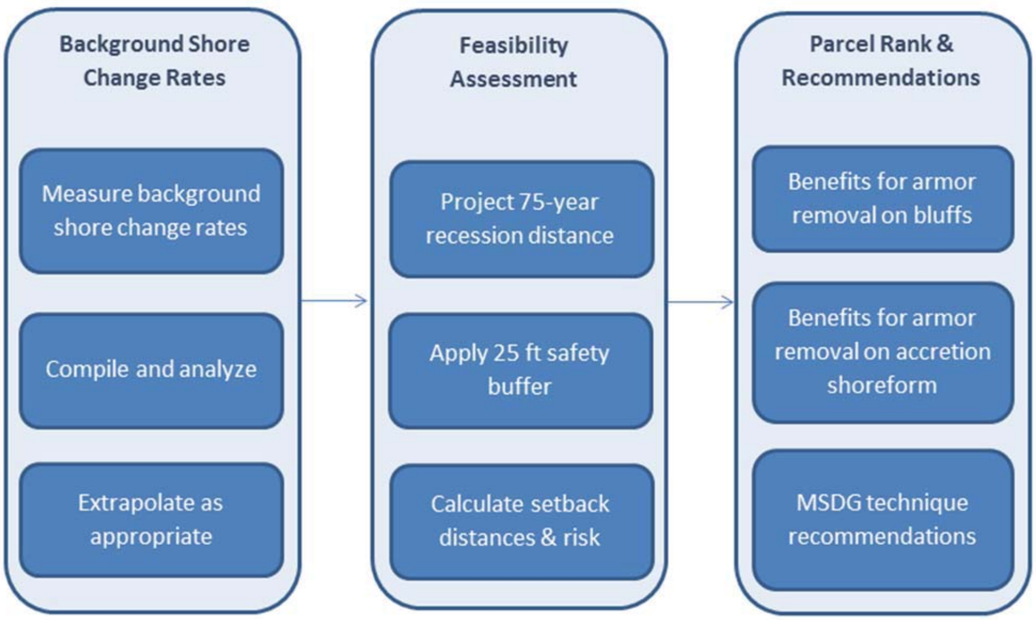


Figure 1. Three separate analyses used to identify and rank parcels for armor removal

Background Shore Change Rates

The objective of this analysis was to better understand the range of historical shore change, referred to as background shore change, within the study area. Shore change data provides a measure of how dynamic a given reach of shore is (the rate it is eroding [-] or accreting [+]), and can be used to project the future position of the shoreline or bluff crest. Background shore change rates are a critical element of assessing the feasibility of armor removal.

Change rates were measured using current and historical georectified vertical aerial photo analysis in Geographic Information Systems (GIS; ArcMap 10.3.1). The historical position of various shoreline proxies (bluff crest, log line, vegetation line, etc.) were examined and compared with their current position. The bluff crest was the shoreline proxy selected for shore change analysis of bluff shores. For accretion shoreforms, either the vegetation line or the log line was selected for analysis based on which proxy could be interpreted with the greatest certainty. Different historical aerial photos sets were used for different areas based on availability and the ability to clearly view the subject feature with a high level of confidence. Photos were typically 1:12,000 scale and ranged from 1947–1965. Current features were digitized from the most recent (2012) vertical aerial photographs of high resolution or more commonly from Light Detection and Ranging (LIDAR) imagery.

The techniques applied in the shore change analysis are widely published in the field of coastal geomorphology (Moore 2000, Ruggerio and List 2009, Fletcher et al. 2003, Ruggerio et al. 2003, Morton et al. 2004). Several efforts were made to reduce unnecessary error and uncertainty. These efforts included:

- Having a single geomorphologist interpret the position of the various shoreline proxies to reduce inconsistency
- Change rates were measured from unarmored shores within the study area
- Digitizing was conducted outside of large, deep-seated landslide complexes
- If the feature was shaded or its position was difficult to interpret leading to decreased uncertainty, breaks in the line were placed to assure change was measured only in areas where there was adequate certainty
- Digitizing shore change only within the central portion of the air photo (away from edges) to reduce potential error resulting from the georectification process and
- Interpreting the most landward shoreline proxy, which are known to have less error than waterward proxy

Aerial photos were interpreted and shoreline features that could be interpreted with the greatest certainty and positional accuracy were digitized by coastal geomorphologist Andrea MacLennan and then reviewed by coastal geologist Jim Johannessen. Figure 2 provides an example of the digitizing process from both historical imagery and LIDAR data. Change rates were measured from tightly spaced transects (spaced 25 ft apart) and analyzed using an ArcGIS extension called Digital Shoreline Analysis Systems (DSAS, Thieler et al. 2013).

The average change rates were then calculated and analyzed within and across the different shoreform types within the study area. Shore change rates are reported as the average measured change per year (ft/year) of accretion (deposition, displayed as a positive number) or recession (erosion, displayed as a negative number). In total, change rates were measured and compiled from 28 sites in the Port Susan and nearby Camano Island shores, consisting of five accretion shoreforms and 24 bluff sites (Map 4).

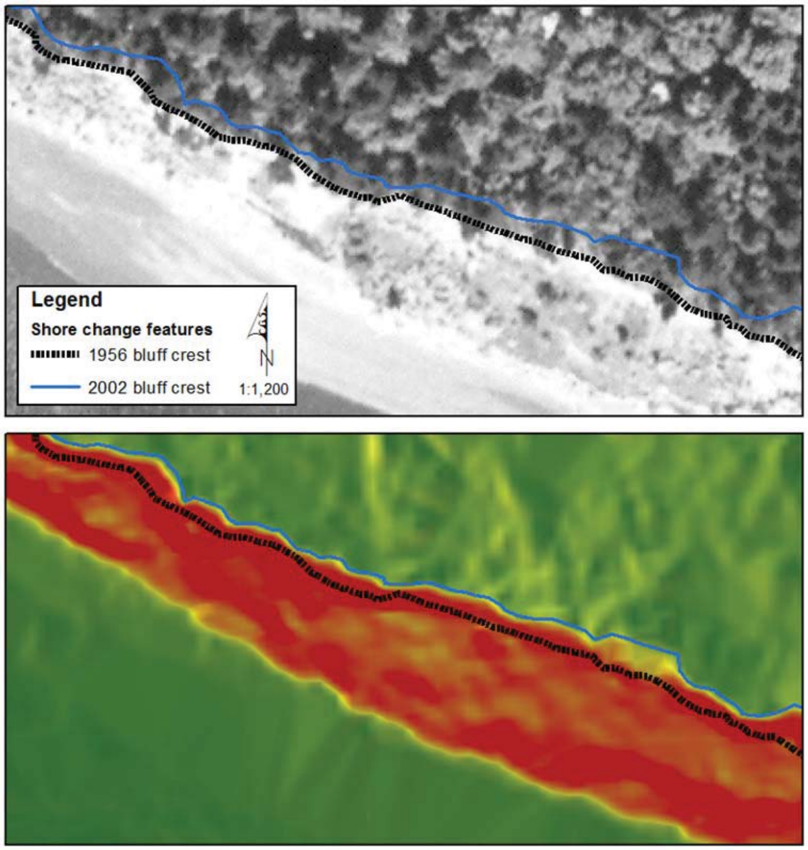


Figure 2. Bluff crest digitizing example from 1956 historical vertical image (top) and 2002 LIDAR slope change imagery of a bluff on southwest Camano Island. The distance between the two bluff crest lines represents the measured bluff crest recession across the period of analysis.

Despite efforts to reduce uncertainty and unnecessary error, the erosion rates measured in this effort are likely skewed toward the higher end of the actual range of erosion rates observed within the study area. This is because the conditions required to interpret and digitize bluff features (with a high degree of certainty) are more often found on bluffs that are eroding at a moderate rate. Therefore the upper end of the range of erosion rates is typically oversampled. For example, bluffs that are exposed to the south are typically less shaded by overhanging vegetation, and are also exposed to the predominant (strongest) and prevailing (most commonly occurring) southerly winds leading to more toe erosion and mass wasting (Johannessen and MacLennan 2007). The crest of a bluff can be interpreted with much greater accuracy on a bluff face devoid of vegetation. Bluffs that are free of vegetation on the bluff face are often some of the most rapidly eroding in the region. Similarly, bluffs that are heavily vegetated are also commonly shaded, which can preclude visibility of the bluff crest and are therefore not often selected to measure bluff recession using these methods. Under sampling the more slowly eroding bluffs results in an over-estimate of bluff erosion rates for the study area. However, within the context of recommending armor removal, over-estimating the potential risk to infrastructure provides an added measure of safety.

Shore Change Data

Change rate data were measured and compiled from 28 sites in the Port Susan and nearby Camano Island shores, consisting of five accretion shoreforms and 23 bluff sites (Table 1, Map 4). New change rates were measured from a total of 15 different shoreforms, between the years of 1947/1965 and 2003/2012 in the Port Susan Marine Stewardship Area (Table 1). To supplement this information, previously calculated change rates were compiled from 13 additional bluffs on Camano Island to augment the data set and produce more robust results (CGS 2015). The bluffs on Camano Island and within the PS MSA are appropriate for comparison due to their similar tidal range, bluff height, stratigraphy, and wave exposure. These existing change rates were measured by CGS (for the NWSF project; CGS 2015) and USGS (Keuler 1988). Keuler (1988) applied several different approaches to measuring shore change, one of which required field-based physical measurement of the length between a documented survey monument and the bluff crest. This method is very accurate and can be applied on more slowly eroding bluffs. New measured change rates from within the Port Susan study area included the following sites:

- 2 Feeder Bluff Exceptional shores
- 8 Feeder bluffs
- 5 Accretion Shoreforms

Most bluffs in the Snohomish PS MSA study area have over 6 miles of fetch and are exposed to the predominant (strongest) southerly wind conditions. Maximum fetch measures ranged up to 17.5 miles of exposure to the south. Despite most shores being oriented to the south, the angle at which waves hit the shore varied considerably. Some west-facing shores were exposed to waves from both the northwest and southwest. Analysis of the new shore change data showed that there was no apparent difference between change rates based on shore orientation, except for on accretion shoreforms. For example bluffs oriented to the south had similar erosion rates to other bluffs oriented to the north (with equal wave exposure). Similar to other regional studies of accretion shoreforms (CGS 2013), these landforms typically exhibit erosion along the south-facing shores and accretion along the north facing shores. This pattern has been documented elsewhere (CGS 2013, Johannessen 1993) and is a result of the larger process of the entire landform migrating northward in response to the predominant (strongest) and prevailing (most common) southerly wind conditions.

Measuring bluff recession from historical air photos produces a certain amount of error. Although several efforts were made to reduce the error associated with shore change measures, some degree of error remains. The remaining sources of error include both positional error and measured uncertainty. Positional error relates to the accuracy of defining the true shoreline position in a given year. Positional error was reduced as much as possible by using the most landward shoreline proxy. Measurement error relates to the operator-based manipulation of the map and photo products (Fletcher et al. 2003) such as the georectification process, root mean square error (measure of the accuracy of the georectification process) values, pixel size, and digitizing shoreline features. Measurement error was far more prevalent in this analysis. The combined cumulative error for the measured erosion rates ranged from ± 0.1 to 0.2 ft/year. It should be noted that in some cases the measured erosion rate is smaller than the combined cumulative error. This error is only relevant to the measures performed from historical aerial photos, and not the (Keuler) field-based measures (shown in the Source column of Table 1).

Table 1. Compiled and measured change rates for the Port Susan MSA. Positive rates indicate accretion; negative rates indicate erosion. Orientation is to the northern or southern quadrant. FB = Feeder Bluff, FBE = Feeder Bluff Exceptional, AS = Accretion Shoreform.

Shoretype	Shoreform ID	Length (ft)	Change Rate (ft/yr)	Source	Fetch (mi)	Orientation
FBE	6	1221.4	-0.9	CGS PS MSA	17.5	S
FB	8	703.6	-0.7	CGS PS MSA	14.4	S
FB	475	1045.8	-0.6	CGS NWSF	5	S
FB	7	495.8	-0.5	CGS PS MSA	15.6	S
FBE	3	814.9	-0.5	CGS PS MSA	8.5	S
FB	7440	917.9	-0.4	CGS PS MSA	6.5	S
AS	17	621.5	-0.4	CGS PS MSA	5.6	N
FBE	2754	1343.5	-0.4	CGS NWSF	11	S
FB	7438	577.0	-0.4	CGS PS MSA	7.3	N
FB	473	1553.6	-0.4	CGS NWSF	7.0	S
FB	2468	902.8	-0.4	CGS PS MSA	6.5	S
FBE	2755	1097.2	-0.3	CGS NWSF	12.0	S
FBE	2759	713.0	-0.3	CGS NWSF	18.0	S
FB	779	1053.2	-0.3	CGS NWSF	7.0	N
FB	2309	2587.7	-0.3	CGS NWSF	7.0	S
AS	1430	292.7	-0.3	CGS PS MSA	15.7	N
FB	4	634.6	-0.3	CGS PS MSA	8.3	S
FB	2310	1519.2	-0.3	CGS NWSF	11	S
FB	776	466.7	-0.2	CGS NWSF	19	S
FB	23	378.5	-0.2	Keuler, USGS	8.1	S
FB	7440	871.8	-0.2	CGS PS MSA	7.1	N
FB	1970	1522.8	-0.2	CGS NWSF	4.0	S
FB	5	313.1	-0.2	CGS PS MSA	8.3	S
AS	6	522.1	-0.2	CGS PS MSA	5.4	N
FB	24	549.4	-0.1	Keuler, USGS	9.0	S
FB	10	641.3	0.0	Keuler, USGS	9.1	S
AS	1432	719.9	0.1	CGS PS MSA	8.2	S
AS	12	977.0	0.4	CGS PS MSA	7.5	N

Armor Removal Feasibility

Armor removal feasibility was assessed by applying a series of GIS queries to screen-out parcels infeasible for armor removal. Different armor removal feasibility criteria were developed for bluff shores versus accretion shoreform shores, as the different shoretypes are subject to different hazards. Both criteria addressed structure setback distances (from either the bluff crest or the high water shoreline), measured shore change rates resulting from shore change analysis, existing hazard mapping, and the presence of adjacent armor.

In 2014, CGS delineated the position of the bluff crest and digitized the most waterward extent of all shoreline buildings/structures in Snohomish County shores of the PS MSA. These data were then used in GIS to calculate building setback distances by measuring the shortest distances between these two features (bluff crest and building/structures). Setback distance is relevant to armor removal feasibility on bluffs as it provides a direct measure of the proximity to the primary structure to the erosion hazard of the bluff crest. Building setback distances along accretion shoreforms were measured from the mean higher high water (MHHW) line as mapped using a digital elevation model created with LIDAR data. MHHW was identified as 11.1 ft above mean lower low water (MLLW) from a tidal station at Tulare Beach (NOAA Station # 9448043), near the center of the study area.

Shore change data was paired with fetch categories to identify parcels with safe setback distances for the next 75 or more years (Table 2). A 25-ft safety buffer was added to the 75-year bluff recession distance to provide an added measure of safety. Parcels that encompassed deep-seated landslide areas (as mapped by USGS and WDNR) and structures that were located within the 100-year flood hazard area were considered infeasible for armor removal. For parcels with no identified buildings at risk, armor removal was considered feasible.

Table 2. Seventy-five year bluff recession distances with 25-ft safety buffer added for different fetch categories. As described in the Shore Change Data section above, cumulative error for these values ranges from ± 0.1–0.2 ft/yr.

Fetch (miles)	Average Recession Rate (ft/yr)	Recession Projected Over 75 yrs (ft)	+ 25 ft Safety Buffer (ft)
0-5	-0.2	14	39
<5 -10	-0.3	19	44
>10	-0.4	32	57

Armor removal can be problematic along shores with adjacent armor. Shore armor can cause waves to diffract around the ends of the armor structure, and reflect from return walls[6], both resulting in localized adjacent erosion. This type of localized erosion can be particularly problematic along parcels with very limited shoreline length, especially when occurring from both sides of the parcel. If erosion caused by adjacent armor were to cumulatively account for a large portion of a parcel's shoreline length, then the armor removal could have less benefit. Therefore, parcels with armor on both adjacent shores, and that measure less than 60 ft in length, were considered infeasible for armor removal.

Benefits Assessment Criteria

The ecological benefit of armor removal was assessed for all parcels regardless of feasibility or the presence of shore armor (Tables 3 and 4). Benefit scores for unarmored parcels were used to identify priority bluffs for protection. The metrics shown in Tables 3 and 4 are described for armored shores and address the potentially restored condition, however, when applied to unarmored bluffs the condition is translated as currently intact. For example it is assumed that the intact bluff shoreline length will supply sediment that will be transported to considerable miles of down-drift shore.

[6] Return wall: A short wall placed perpendicular to the end of a wall to increase its stability.

Because of the inherent differences in ecological processes and functions that occur at bluffs and accretion shoreforms, different criteria were developed to assess the relative benefit of armor removal (Tables 3 and 4). Bluff parcels could score a maximum of 105 points, with 43% of the score potentially coming from beach sediment sustenance, another 43% from direct habitat benefits, and 14% from indirect habitat benefits (Table 3, Figure 3).The scoring bins (high, medium, low, 0/none) were established by analyzing the distribution of the metric results separately for accretion shoreforms and bluffs. In general the break points were delineated at 33 and 67% but in some cases there were minor adjustments to reflect the distribution of the data.

Table 3. Metrics applied to rank the potential benefit of armor removal on bluff parcels and protection priorities among unarmored bluffs. Higher scores equal higher potential ecological benefit. H = High, M = Medium, L = Low, 0 = None

Category	Metric Name	Metric Rationale	Score Type	Max Score	Explanation of Calculation
Beach Sediment Sustenance (45 pt)	Length of down-drift shore	Sediment supplied from the subject bluff will support (supports) considerable lengths of down-drift shores.	H/M/L/0	15	The total length of shore from the subject parcel to the drift cell terminus. High (15 points) is >3 miles; medium (10 points) is >1 mile, low (5 points) is >0 miles, and zero points are given for parcels with zero miles of down-drift shore.
	Percent of cell down-drift	Sediment supplied from the subject bluff sustains X% of the down-drift shore (calculated in GIS for each parcel), normalized out of 15 available points. This metric provides a measure of regional influence.	0–15	15	The linear extent of down-drift shore that the bluff supplies sediment to was measured in GIS and expressed as a percent (of the total length of the drift cell), multiplied by 15, and rounded to the nearest integer.
	Potential volume of sediment input (total parcel)	Compare the potentially restored volume of sediment supply or intact sediment supply for protection (cubic yards/year)	H/M/L/0	15	[Erosion rate in ft/yr] times the [armor length in the parcel in feet, or shoreline length for protection] times the [mean bluff height in feet]. High (15 points, >146 cy/yr), medium (10 points, 24–146 cy/yr), low (5 points <24 cy/yr), or 0 points for 0 cy/yr.
Direct Habitat Benefits (45 pts)	Forage fish spawn	Armor removal would immediately recover this buried/constrained habitat. Protecting this sediment supply would help sustain this valued habitat.	Present/ Near/ Absent	15	15 points if forage fish spawning has been documented within 300 feet of the parcel. 10 points if forage fish spawning is within 1000 ft of the parcel. Otherwise, 0 points.
	Restorable length (ft)	Measured length of potential armor removal area. Measured length of shore for protection.	H/M/L/0	15	Length of armor on parcel. High (15 points) is >100 ft, moderate (10 points) is >60 ft, low (5 points) is >20 ft, with 0 points for ≤20 ft.
	Adjacent opportunity	References results of feasibility screening in adjacent parcels. If there was no house on the property it is often feasible.	2 shores, 1 shore, or partial	15	Potential to increase (cumulative) length of armor removal along adjacent shores. Armor removal feasible on both adjacent parcels = 15 pts, one adjacent shore = 10 pts
Indirect Habitat Benefits (15 pts)	Down-drift forage fish spawning habitat	Measured length of documented spawning area to potentially benefit from the sediment supply restoration/protection.	H/M/L/0	15	Sum of length of forage fish spawning habitat located down-drift (dissolved by species). High (15 points) is >1.5 miles, moderate (10 points) is >0.5 miles, low (5 points) is >0 miles, with 0 points given for 0 miles.

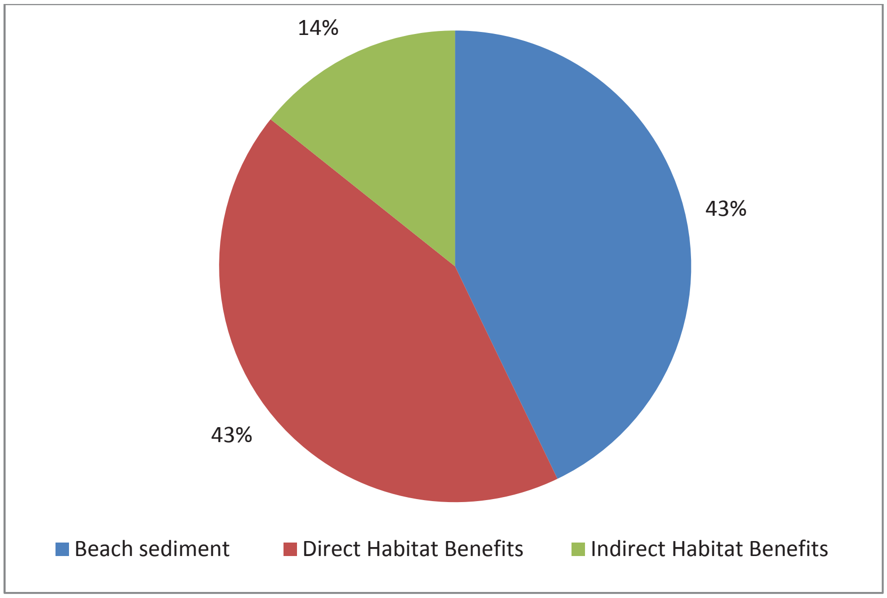


Figure 3. Scoring categories for the benefits of armor removal for bluffs

Armor removal on accretion shoreforms results in different ecological responses which are captured in Table 4. Accretion shoreform parcels could score a maximum of 60 points with equal portions of the score addressing benefits associated with restored cross-shore connectivity, forage fish spawning area, shoreline length, and the presence of adjacent opportunities (Figure 3). Restored cross-shore connectivity refers to the degree of recovered marine riparian area potentially resulting from armor removal. The relative benefit of cross-shore restoration that can be achieved was associated with how far the existing armor infringes on the upper beach and intertidal areas. For bluffs, the benefit of restored cross-shore connectivity is represented in the sediment supply restoration and indirect habitat benefit metrics. Parcels in which armor was located above MHHW (abbreviated as modified backshore or MB) would have the least potential restored cross-shore connectivity. Shores with armor at approximately MHHW would have moderately restored cross shore connectivity. And shores where armor extends lower into the intertidal, waterward of MHHW (referred to as modified intertidal or MI) would result in the most restored cross-shore connectivity.

The resulting benefit assessment scores for each shoreform type (bluff and accretion shoreforms) were then used to separately identify armor removal priorities. Benefit assessment scores were also applied to all unarmored bluffs (using the same approach as outlined in Table 5), which were then analyzed to determine bluff protection priorities. This benefit scoring approach was based on existing observations of coastal processes.

Armor removal and bluff protection priorities were identified based on a parcel's combined feasibility and the highest benefit assessment scores. The top scoring armored bluffs that were also feasible for armor removal (i.e., top 33%) were identified as the "top" priority parcels for feeder bluff restoration (via armor removal). Similarly, the top scoring (i.e., top 33%) accretion shoreforms were selected and identified (separately) as the "top" priority parcels for beach restoration (via armor removal). Parcels that scored below the "top" ranking parcels but in the highest 67% of all parcels for bluffs and accretion shoreforms, respectively, were identified as "high" priority parcels for armor removal.

Table 4. The metrics below will be applied to all armored accretion shoreforms. MB = Modified backshore, MHHW = Modified at Mean Higher High Water, MI = Modified Intertidal.

Category	Metric Name	Metric Rationale	Score Type	Max Score	Explanation of Calculation
Marine Riparian Restoration (15 pts)	Cross-shore connectivity	The more the shore armor infringes on the intertidal the more it affects cross-shore connectivity.	MB (5) MHHW (10) MI (15)	15	15 points when armor would be removed that extends into the intertidal (below +10.3 ft MLLW). 10 points awarded for armor removed between MHW and MHHW. 5 points for armor removed from the backshore above MHHW (above +11 ft MLLW).
Direct Habitat Benefits (45 pts)	Forage fish spawn	Armor removal would immediately recover this buried/constrained habitat.	Present/Absent	15	15 points if forage fish spawning has been documented on the parcel. Otherwise, 0 points.
	Restorable length (ft)	Measured length of potential armor removal area.	H/M/L/0	15	Length of armor on parcel. High (15 points) is >100 ft, moderate (10 points) is >60 ft, low (5 points) is >20 ft, with 0 points for ≤20 ft.
	Adjacent opportunity	This would be results of the feasibility screening. If there is no house on the adjacent property it is generally feasible.	2 shores, 1 shore, or partial	15	Potential to increase the cumulative length of armor removal along adjacent shores. Armor removal feasible on both adjacent parcels = 15 pts, one adjacent parcel = 10 pts,

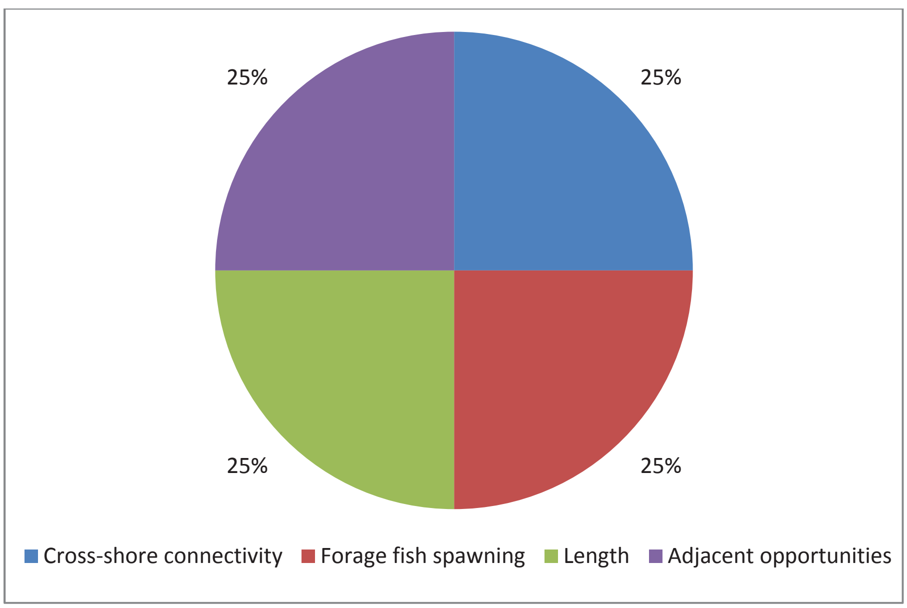


Figure 4. Scoring categories for the benefits of armor removal for accretion shoreforms

Identification of Appropriate Restoration Techniques

Conditions within each parcel found in the study area were also assessed to determine which of the Washington State Department of Fish and Wildlife's *Marine Shoreline Design Guidelines* techniques would be appropriate. *Marine Shoreline Design Guidelines* recommendations include armor removal, large wood installations, beach nourishment, reslope/revegetation, and armor (Johannessen et al. 2014). As a preliminary step to this determination, cumulative risk was calculated for each parcel, using an approach outlined in the *Marine Shoreline Design Guidelines* (Table 5; Map 5). Cumulative risk takes into account shoretype, fetch, setback distance, and infrastructure type.

Table 5. Excerpt from: *Marine Shorelines Design Guidelines* (Table 4-3) Cumulative risk model. Low risk: scores 0–15, Moderate risk: scores 16–36, High risk: scores >36.

CUMULATIVE RISK MODEL			
EROSION POTENTIAL			
Shoretype	**Score**	**Fetch[7]**	**Score**
No Appreciable Drift (NAD)-Bedrock/Low Energy	0	0–1 mile	1
Modified, Accretion Shoreform, NAD-Delta	1		
NAD-Artificial , Transport Zone, Pocket Beach	2	1–5 miles	2
Feeder Bluff	3	5–15 miles	3
Feeder Bluff Exceptional	4	15+ miles	4
Erosion Potential Score =		**Shoretype Score + Fetch Score**	
INFRASTRUCTURE THREAT			
Setback	**Score**	**Infrastructure Type**	**Score**
>60 ft	1	Property without structures	1
36–60 ft	2	Septic drainfield or unattached residential infrastructure, not lived in	2
21–35 ft	3	Home or residential building	3
0–20 ft	4	Major infrastructure	4
Infrastructure Threat Score =		**Setback Score + Infrastructure Type Score**	
CUMULATIVE RISK TOTAL (product):		**Erosion Potential x Infrastructure Threat**	

After calculating risk, the appropriate erosion control techniques were determined (remotely, using GIS) by applying the criteria shown in Table 6. These recommendations, along with all other parcel characteristics, are included in the project geodatabase (geographic database). The employment of BMPs or best management practices, such as planting native vegetation, reducing run-off, and removing invasive species, are appropriate for all waterfront properties. Similarly, "relocation" or moving houses landward, away from the shoreline is also applicable to every site and the feasibility is largely dependent on the foundation and other structural elements of the building. The recommended techniques identified for each parcel reflect only the results of this initial remote assessment and site visits should be performed to confirm feasibility, affirm on-the-ground site conditions, and gain insight into design parameters (as outlined in Chapter 4 of the *Marine Shorelines Design Guidelines*). Because a more detailed analysis of armor removal was applied as part of this assessment (when compared to the MSDG criteria for bulkhead removal shown in Table 6), the bulkhead removal recommendation included in the project geodatabase represent the results of the larger armor removal assessment, the methods of

[7] The frequency of occurrence of high wind and waves from each defined fetch was not considered.

which have been described in the Armor Removal and Benefits Assessment Criteria sections of this report.

Table 6. Excerpt from: *Marine Shoreline Design Guidelines* (Table 5-8) approach for identifying appropriate design techniques based on key variables. Risk categories reference cumulative risk model scores and associated categories as shown above. Fetch categories: Low = 0–1 miles, Moderate = 1–5 miles, High = 5–15 miles.

Risk	Fetch or Wave Energy	Shoretype	Backshore Width	Appropriate Technique
All	All	All	NA	RELOCATION & BMPs
Low	Low to Very high	All	NA	NO ACTION
Low	Low to Very high	All	Low to High	BULKHEAD REMOVAL*
Low to Moderate	Low to Moderate	All	Moderate to High	LARGE WOOD
Low to Moderate	Low to Moderate (drift aligned)	All**	Low to High	BEACH NOURISHMENT
	Low to Very high (swash aligned)	All**	Moderate to High	
Low to Moderate	Low to Moderate	Bluff	Moderate to High	RESLOPE AND REVEG
High	High or Very high	All	Moderate to High	HARD ARMOR REVETMENT
High	Moderate to Very high	All	Low	HARD ARMOR VERTICAL

*If not armored then NO ACTION.

**Beach nourishment is only appropriately applied at bluff sites when integrated with other measures including backshore vegetation and an evaluation of littoral drift OR on shores with low wave energy (0–1 miles).

Results & Discussion

The Snohomish County portion of the Port Susan Marine Stewardship Area consists of 382 parcels (excluding the Stillaguamish River Delta), 283 (74%) of which have 20 ft or more of shore armor. There are more bluff parcels (251) than accretion shoreforms (131 parcels; Table 7). All results are found in the project geodatabase and are displayed in Maps 6 through 9. Parcel shoreline length varied considerably across the study area, and ranged from just a few feet of right-of-way shore to over half a mile. The average parcel shoreline length measured 116 ft and the most frequently occurring parcel shoreline length was 50 ft. Much of the study area is exposed to high (301 parcels, greater than 5 miles of fetch) to very high (81 parcels, greater than 15 miles of fetch) wave energy for the Puget Sound region. The wave energy corresponds to maximum fetch measures reported in the ShoreZone Inventory (WDNR 2001). Wave energy categories were adopted from a regional engineering and geotechnical guidance document for managing shoreline erosion in Puget Sound (Cox et al. 1994). The maximum measured fetch for each parcel ranged from 5.6 to 18 miles, and was 9.3 miles on average. This level of fetch is a driving factor in the erosion rates observed within the study area, as well as the types of erosion control that are appropriate for these shores (Johannessen and MacLennan 2007, Johannessen et al. 2014). In addition, the prevailing (most common) winds in the region originate from the same orientation as the greatest fetch (to the south) in the Port Susan Marine Stewardship Area (Johannessen and MacLennan 2007).

Table 7. Summary of parcel conditions resulting from assessment.

Shoretype	Total Parcels	Armored	Not Armored	Structures	No Structures	Infeasible	Feasible	Protection
Bluffs	251 (66%)	186 (74%)	65 (26%)	212 (84%)	39 (16%)	222 (88%)	29 (12%)	29 (12%)
Accretion Shoreforms	131 (34%)	97 (74%)	34 (26%)	119 (91%)	12 (9%)	68 (52%)	63 (48%)	NA
Total	**382**	**283 (74%)**	**99 (26%)**	**331 (87%)**	**51 (13%)**	**290 (76%)**	**92 (24%)**	**29 (8%)**

Eighty-seven percent of the parcels (331) in the study area have a house or building (structure) on them, leaving 13% (51 parcels) without structures. Structures mapped in 2014 were defined as a primary residence on the property, which could include park structures, but did not include storage shacks on the beach, gazebos, or other ancillary structures. Armor was mapped along half of the parcels without structures (24 parcels). All of these parcels were initially considered feasible for armor removal and were later manually reviewed to confirm initial feasibility. There were more armored bluff parcels without structures than armored accretion shoreform parcels without structures.

Structures were set back on average 48 ft from the bluff crest. Structures on accretion shoreforms had a lower average setback distance of 40 ft from the high water shoreline. Thirty-five structures were located within the 100-year flood hazard area, which does not appear to be directly related to setback distance (Map 3).

Structures that were mapped waterward of the bluff crest were identified as having negative setback distance. Forty-eight parcels were identified as having negative setback distances. All but one of these parcels is currently armored.

Cumulative risk scores calculated per WDFW Guidelines were calculated for each parcel. Most (85%) of all parcels had only moderate cumulative risk, and only seven parcels were considered to have high cumulative risk (Map 5). Low risk parcels were typically larger and distributed throughout the study area (Map 5). The parcels with the highest risk were located in the northern half of the study area, where parcel density is highest.

Despite the greater number of bluff parcels, far fewer bluff sites were feasible for armor removal than accretion shoreform sites (Table 7). Even among armored bluff parcels without structures, QA/QC review revealed that several parcels that initially appeared to be feasible for armor removal were in fact not feasible, as armor removal could potentially threaten a coastal road or structure on an adjacent parcel.

Armor Removal Priorities

Results of these analyses identified a total of 92 parcels feasible for armor removal in the PS MSA study area (Table 7, Map 6). Roughly one-third (29) of the parcels in which armor removal was feasible were bluff shores (feeder bluff exceptional, feeder bluffs, or transport zones), which prior to being armored provided variable volumes of sediment to the nearshore via mass wasting and coastal erosion. Far more accretion shoreform (63) parcels were identified as feasible for armor removal. Initial assessment of parcel conditions also identified that all of the accretion shoreform parcels feasible for armor removal could also be appropriate site for beach nourishment; though additional site assessment would be required to confirm if beach nourishment would be both needed and beneficial.

Bluffs

The top ranking bluffs for armor removal included 5 parcels that were primarily found in the central and southern portions of the study area (Table 8, Map 7). High benefit bluffs for armor removal included 14 parcels, largely located in the central and northern reaches of the study area. There are several adjacent high priority armor removal bluffs, where targeted outreach to the local community could help to gain landowner willingness from multiple property owners. Moderate scoring armor removal priorities included 10 additional parcels, which are feasible for armor removal but would provide fewer benefits than top and high ranking sites.

Table 8. The number of feasible parcels for armor removal by shoretype and benefits ranking.

Feasible Parcels for Armor Removal	Total	Top	High	Moderate
Bluffs	29	5	14	10
Accretion Shoreform	63	6	27	30
Total	92	11	41	40

Benefit scores for feasible bluff parcels ranged from 48–88 points out of a total of 105. Top ranking parcels scored 77–88 points, with an average score of 79 points. High priority sites scored 68–73 points, with an average score of 72 points. Moderate priorities scored 48–67 points, with an average of 63 points. The uneven distribution of the number of parcels per prioritization bin (top, high, and moderate) was due to tied benefit scores among the feasible armor removal parcels in the study area. Because the prioritization bins are calculated by percentile, there are gaps between them.

None of the bluffs in the Port Susan Marine Stewardship Area supply sediment to a down-drift barrier estuaries or lagoons, so that metric was removed from the scoring criteria (Table 3). Most of the feasible armor removal bluffs had adjacent properties in which armor removal was also feasible and would benefit many miles of down-drift shore. Two-thirds of the bluffs that were identified as feasible for armor removal (21 out of 29 parcels) would have direct benefit to forage fish spawning habitat and all would result in (indirect) benefit to down-drift forage fish spawning areas. Armor removal would result in an average of 127 cubic yards per year of restored sediment supply (Tables 9 and 10; average of the results of the restored sediment supply metric).

The average length of armor feasible for removal from a bluff parcel measured 120 ft and the median was 61 ft. The parcel with the greatest length of armor that was identified as feasible to remove measured 1,705 ft and the minimum recommended armor removal bluff site measured 25 in length.

Table 9. Summary of restoration benefit scores for all bluff parcels in which armor removed was feasible. High, Medium and Low represent scoring bins. *Maybe = 0 parcels had a maybe feasible parcel adjacent to the subject site.

Restoration Benefit Scoring Criteria	Feasible Armor Removal Parcels	High		Med		Low	
		Break	# Parcels	Break	# Parcels	Break	# Parcels
Length of down-drift shore	29	>3 mi	10	>1 mi	19	>0 mi	0
Percent of cell down-drift	29	Scored as %					
Potential vol. sediment input cy per year	29	>146 cy	9	23–146 cy	19	>23 cy	0
Restorable length (ft)	29	>100 ft	3	>60 ft	12	>20 ft	14
Adjacent opportunity	28	2 sides	19	1 side	9	Maybe*	1
Down-drift forage fish spawning	29	>1.5 mi	11	>0.5 mi	13	>0 mi	5

Table 10. Summary of restoration benefit data for all bluff parcels in which armor removal was feasible.

Restoration Benefit Scoring Criteria	Average value	Min	Max
Length of down-drift shore (mi)	3.2	1.3	8.2
Percent of cell down-drift (%)	33%	1%	83%
Potential volume of sediment input (cy/yr)	127	0	320
Down-drift forage fish spawning (mi)	2.1	0.2	5.2

Accretion shoreforms

Sixty-three accretion shoreforms were identified as feasible for armor removal (Table 7, Map 7). Six of these sites were top priorities and another 27 were ranked as high priorities for armor removal (Table 8). Top priority accretion shoreform parcels scored from 45–50, with an average of 47 points. High priority parcels scored from 30–40 points, with an average of 38 points. Moderate priority parcels scored between 20 and 25 points, and averaged 24 points. The uneven distribution of the number of parcels per prioritization bin (top, high, and moderate) was due to tied benefit scores among the feasible armor removal parcels in the study area. Because the prioritization bins are calculated by percentile, there are gaps between them.

The average accretion shoreform parcel (shoreline) length that is feasible for armor removal was 55 ft, (with a median of 51 ft), therefore considerable additional benefit would be achieved through finding adjacent neighbors willing to form partnerships for larger removal projects. There exist several examples throughout the region (Samish Island, Blakely Island, Dungeness Bay; Zelo et al. 2000, Johannessen et al. 2014) where multiple adjacent properties owners successfully coordinated bulkhead removal and beach nourishment together. However, beach nourishment would not be required at all sites that are feasible for armor removal. In many cases the armor at accretion shoreforms is landward of a prograding beach in this typically depositional environment. The maximum length of armor feasible for removal measured 162 ft and the minimum unit was 20 ft in length.

Of the accretion shoreforms where armor removal is recommend, several parcels have armor in the intertidal zone, thereby interrupting cross-shore connectivity and burying upper intertidal habitats.

Most armor removal opportunities on accretion shoreforms are relatively short in shoreline length, but as previously mentioned, there are many opportunities for collaboration among landowners.

Table 11. Summary of restoration benefit data for all accretion shoreform parcels in which armor removal was feasible.

Restoration Benefit Scoring Criteria	Total Parcels	High		Med		Low	
		Break	# Parcels	Break	# Parcels	Break	# Parcels
Cross-shore connectivity	63	Mod intertidal	3	Modified MHHW	59	Modified backshore	1
Forage fish spawning habitat	32	P/A					
Adjacent opportunity	61	2 sides	44	1 side	17	Maybe*	0
Restorable length		>100 ft	3	>60 ft	8	>20 ft	52
Total	63						

*Maybe was only used where mapped landslides (by USGS or WDNR) occur within the parcel, however no parcels met this criteria in the PS MSA.

Marine Shorelines Design Guidelines Techniques

The appropriate *Marine Shorelines Design Guidelines* techniques for each parcel were compiled in the project geodatabase. The main drivers of what techniques are appropriate for which sites included: cumulative risk, wave energy, and shoretype. Due to the relatively high wave energy in the study area, large wood installations and reslope and revegetation were not appropriate for any parcels.

Beach nourishment was identified as appropriate for 131 properties (Map 8), 97 of which are currently armored and 63 of which encompass forage fish spawning areas. Currently armored parcels that were not identified as armor removal priorities but were identified as appropriate for beach nourishment would require additional assessment to determine if armor removal and beach nourishment (conducted in concert) are feasible at the site. Sites that have been identified as armor removal priorities, are feasible for armor removal alone, and do not necessarily also require beach nourishment. Similar to armor removal recommendations, site visits would be required to confirm the feasibility of beach nourishment recommendations.

Twenty-six currently unarmored parcels were identified as requiring “no action”, meaning that the wave energy and cumulative risk at the site did not require erosion control of any kind. In contrast, 5 currently unarmored parcels were identified as places in which the conditions may necessitate armor one day, though relocation of threatened structures could be much less impacting on the nearshore if the request for armor on these properties arises.

Protection Priorities

Benefit scores for unarmored bluffs were used to prioritize bluffs for protection. In total, 66 unarmored bluffs were prioritized with 22 top ranking parcels for preservation (Map 8). Twenty-two high priority parcels were identified for protection. Twenty-two moderate protection priorities were identified, which represent the lower scoring unarmored bluff parcels in the study area. Several of the top ranking priority bluffs for protection are larger parcels, which are distributed throughout the PS MSA.

Conclusion

All armor removal recommendations were manually reviewed to ensure that armor removal would not pose a threat to existing infrastructure. Remote assessments are very effective but have some limitations in that not all constraints to armor removal may be visible via air photo analysis. For example, several parcels that the GIS analysis had identified as feasible for armor removal were in fact not feasible, due to potential threat to nearby roads. Other hazards difficult to identify via air photo include large landslide complexes or the presence of considerable nearshore fill. Final feasibility for armor removal should be assessed by visiting the properties and confirming the lack of additional hazards and other constraints that could impact feasibility.

The outputs of this analysis can function as a prioritized menu of armor removal opportunities for which outreach strategies and long-term planning could be developed. Parcel ownership information has been incorporated into the project geodatabase to facilitate land owner outreach including educational workshops and site assessments. The outreach element can be a long-term process that can change considerably over time as properties change hands. Working at the neighborhood scale has been effective for other local groups facilitating education and outreach efforts to shoreline property owners in the region (such as Friends of the San Juans). Working at the local scale could also help to develop landowner willingness across multiple property owners, which can prove to be very efficient, enhance project success, and add benefit to the nearshore ecosystem. Direct outreach could occur in efforts to educate and start a dialogue with owners regarding potential armor removal. In addition, this project geodatabase can continue to be built upon with the integration of social and demographic data that can help to refine educational and outreach materials that will meet the needs of Snohomish County and the Port Susan community.

References

Coastal Geologic Services, 2015. Feeder bluff restoration assessment for Island and East Jefferson Counties. Prepared for the Northwest Straits Foundation. Preparers: Andrea MacLennan, Jim Johannessen and Branden Rishell.

Coastal Geologic Services, 2013. Sea Level Rise Vulnerability of San Juan County. Prepared by A. MacLennan, J. Waggoner, J. Johannessen and S. Williams. Prepared for Friends of the San Juans.

Cox, J. K. MacDonald, T. Tigert, 1994. Engineering and Geotechnical Techniques for Shoreline Erosion Management in Puget Sound. Coastal Erosion Management Studies Volume 4. Shorelands and Environmental Assistance Program, Washington Department of Ecology, Olympia, Washington.

Fletcher, C., J. Rooney, M. Barbee, S.C. Lim, and B. Richmond, 2003. Mapping shoreline change using digital orthophotogrammetry on Maui, Hawaii. Journal of Coastal Research, SI (38), 106-124. West Palm Beach (Florida), ISSN 0749-0208.

Johannessen, J. W. 1993. Net shore-drift in San Juan County and parts of Jefferson, Island, and Snohomish Counties, Washington. Western Washington University Masters Thesis.

Johannessen, J., A. MacLennan, A. Blue, J. Waggoner, S. Williams, W. Gerstel, R. Barnard, R. Carman, and H. Shipman, 2014. Marine Shoreline Design Guidelines. Prepared for Washington Department of Fish and Wildlife, Olympia, WA by Coastal Geologic Services Inc. http://wdfw.wa.gov/publications/01583/

Johannessen, J. and A. MacLennan, 2007. Beaches and Bluffs of Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-04. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington. Available at http://pugetsoundnearshore.org/technical_papers/beaches_bluffs.pdf.

MacLennan, A., J. Johannessen, S. Williams, W. Gerstel, J. Waggoner, A. Bailey, 2013. Feeder Bluff Mapping of Puget Sound. Prepared for the Washington Department of Ecology and Washington Department Fish and Wildlife, Bellingham, Washington. 121 p., 20 maps.

Moore, L.J. 2000. Shoreline Mapping Techniques. Journal of Coastal Research. Vole 16 (1), p. 111-124.

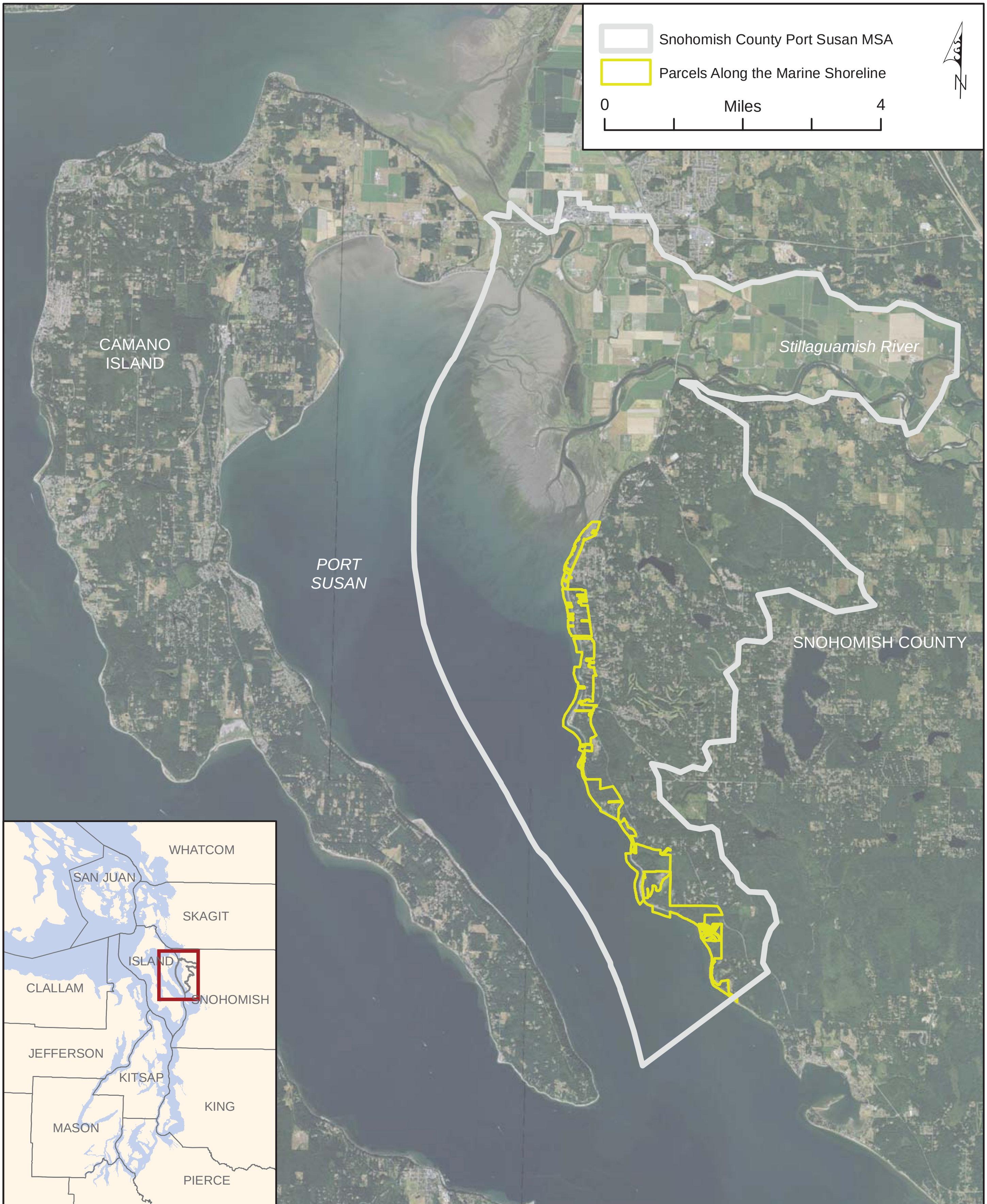
Morton, R.A., T. Miller, and L. Moore, 2004. National assessment of shoreline change: Part 1: Historical shoreline changes and associated coastal land loss along the U.S. Gulf of Mexico: U.S. Geological Survey Open-file Report 2004-1043.

Ruggiero, P., G.M. Kaminsky, and G. Gelfenbaum, 2003. Linking proxy-based and datum based shorelines on a high-energy coastline: Implications for shoreline change analysis. Journal of Coastal Research, SI (38), 57-82. West Palm Beach (Florida), ISSN 0749-0208.

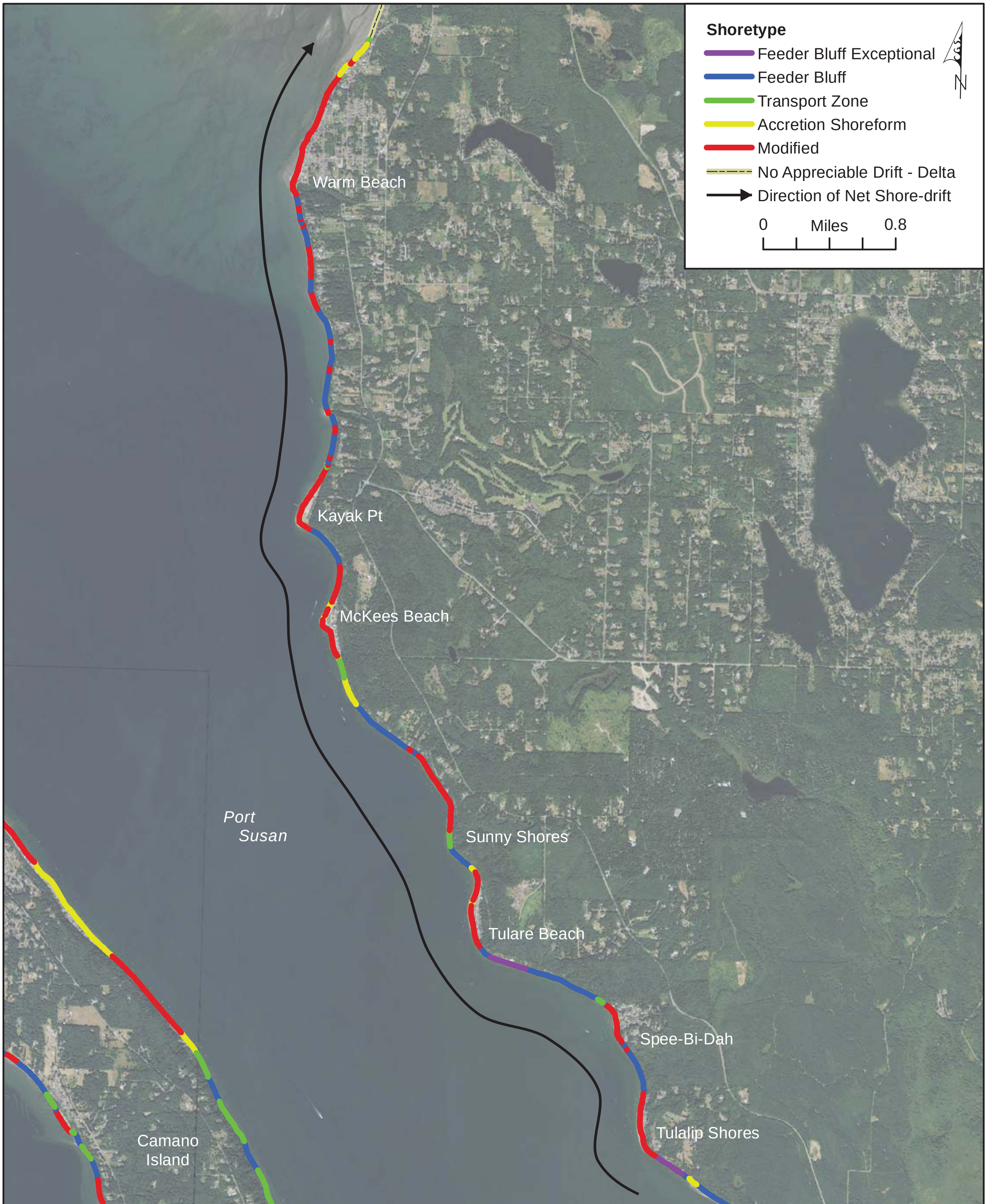
Ruggerio, P. and J.H. List. 2009. Shoreline position and change rate accuracy. Journal of Coastal Research. V. 25, No. 5. p. 1069-1081.

Thieler, E.R., E.A. Himmelstoss, J.L. Zichichi, and A. Ergul , 2013. Digital Shoreline Analysis System (DSAS) version 4.0—An ArcGIS extension for calculating shoreline change: U.S. Geological Survey Open-File Report 2008-1278. http://pubs.usgs.gov/of/2008/1278/.

Zelo, I., H. Shipman, and J. Brennan, 2000. Alternative Bank Protection Methods for Puget Sound Shorelines. Prepared for the Shorelands and Environmental Assistance Program, Washington Department of Ecology, Olympia, Washington. Publication # 00-06-012.



Map 1. Location of the Port Susan Marine Stewardship Area.
Aerial background courtesy USDA NAIP (2011).
Parcel boundaries are approximate and based on GIS layers
Port Susan Marine Stewardship Area Armor Removal Assessment



Map 2. Geomorphic shoretypes within the Port Susan MSA (MacLennan et al. 2013). *Aerial background courtesy USDA NAIP program (2011)*
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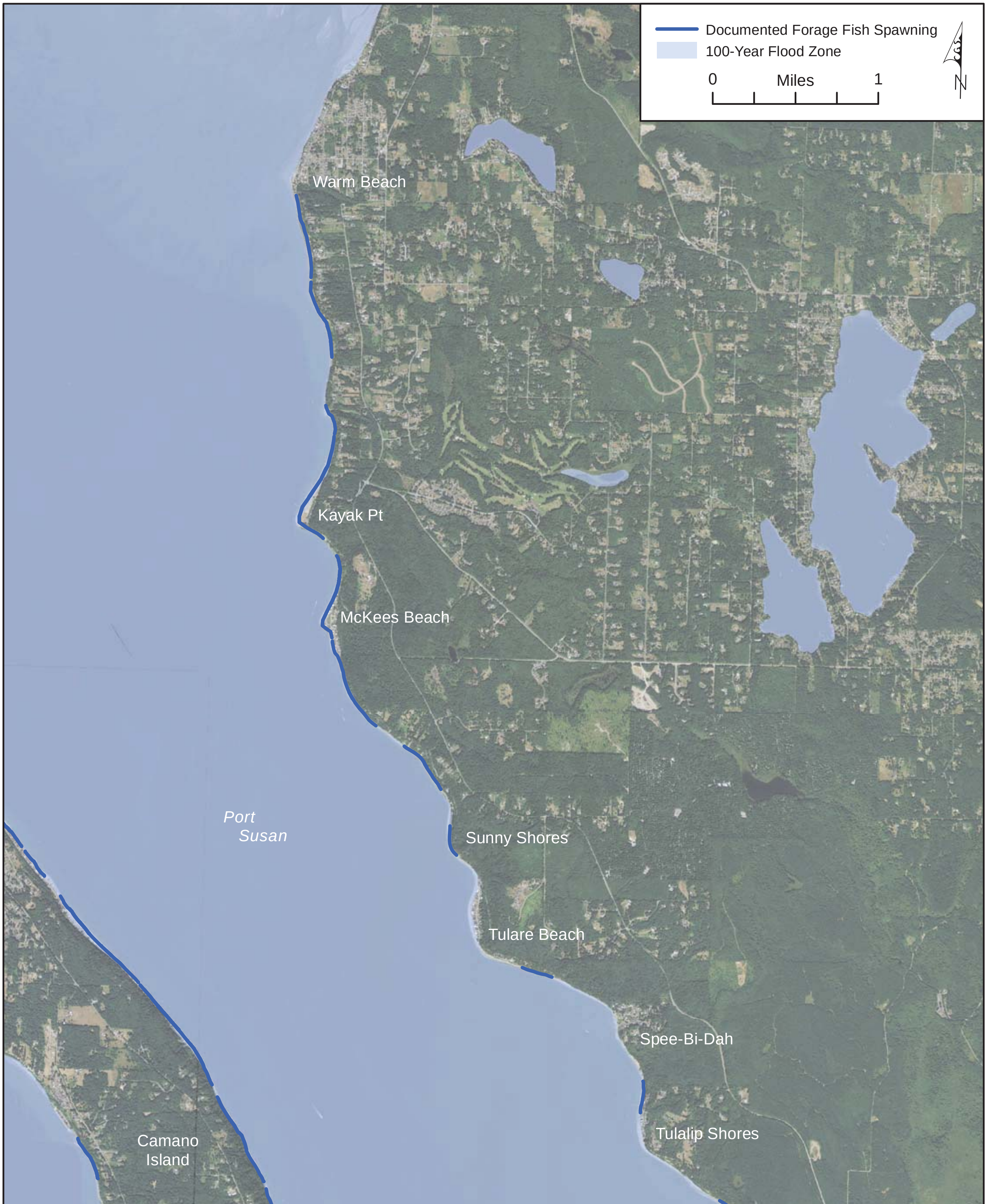
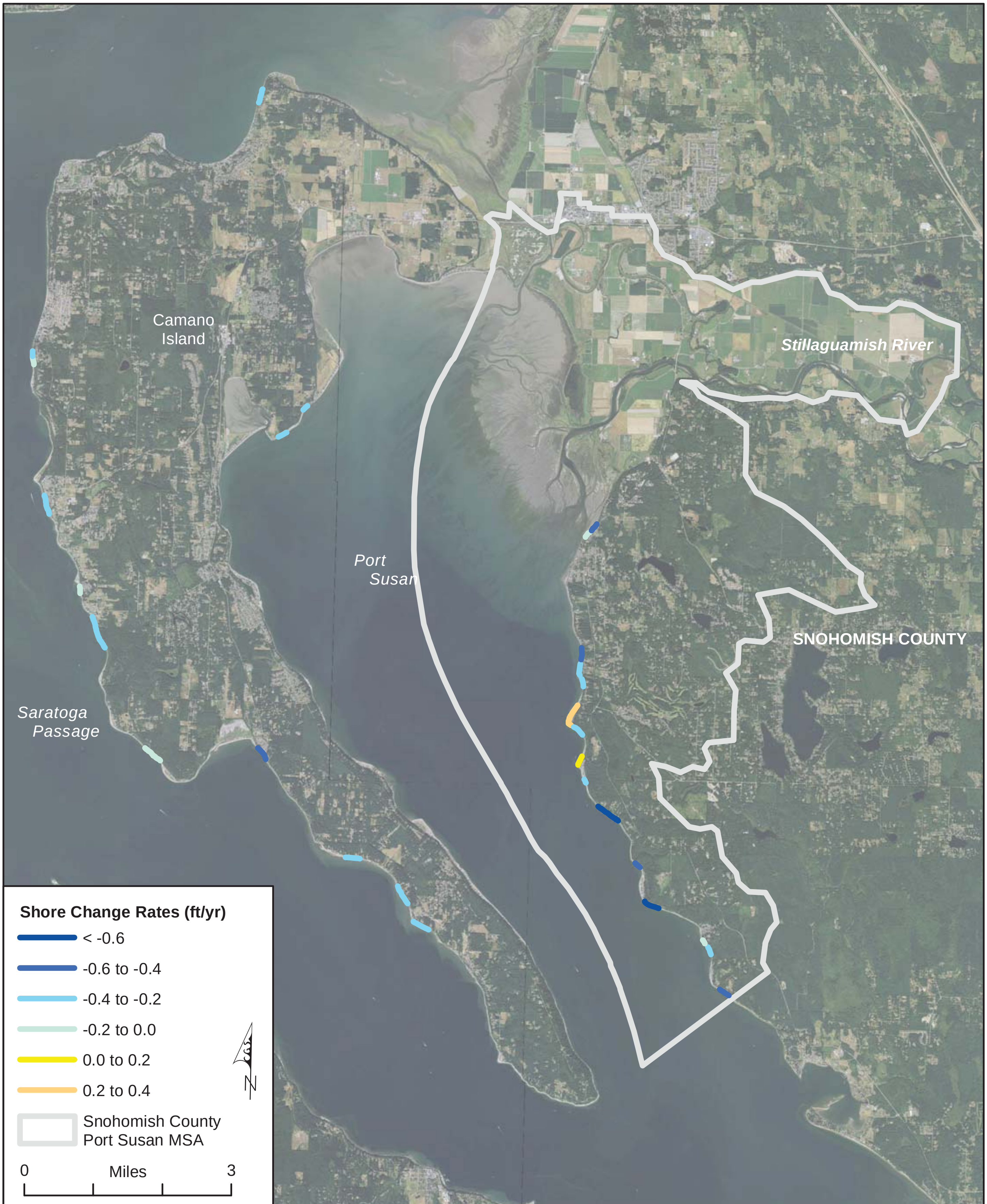


Map 3. Documented forage fish spawning and 100-year flood plain. *Fish data from WDFW (2014). Aerial background courtesy USDA NAIP program (2011)*
Port Susan Marine Stewardship Area Armor Removal Assessment



Map 4. Measured and compiled shore change rates surrounding the Port Susan MSA. *Aerial background courtesy USDA NAIP program (2011)*

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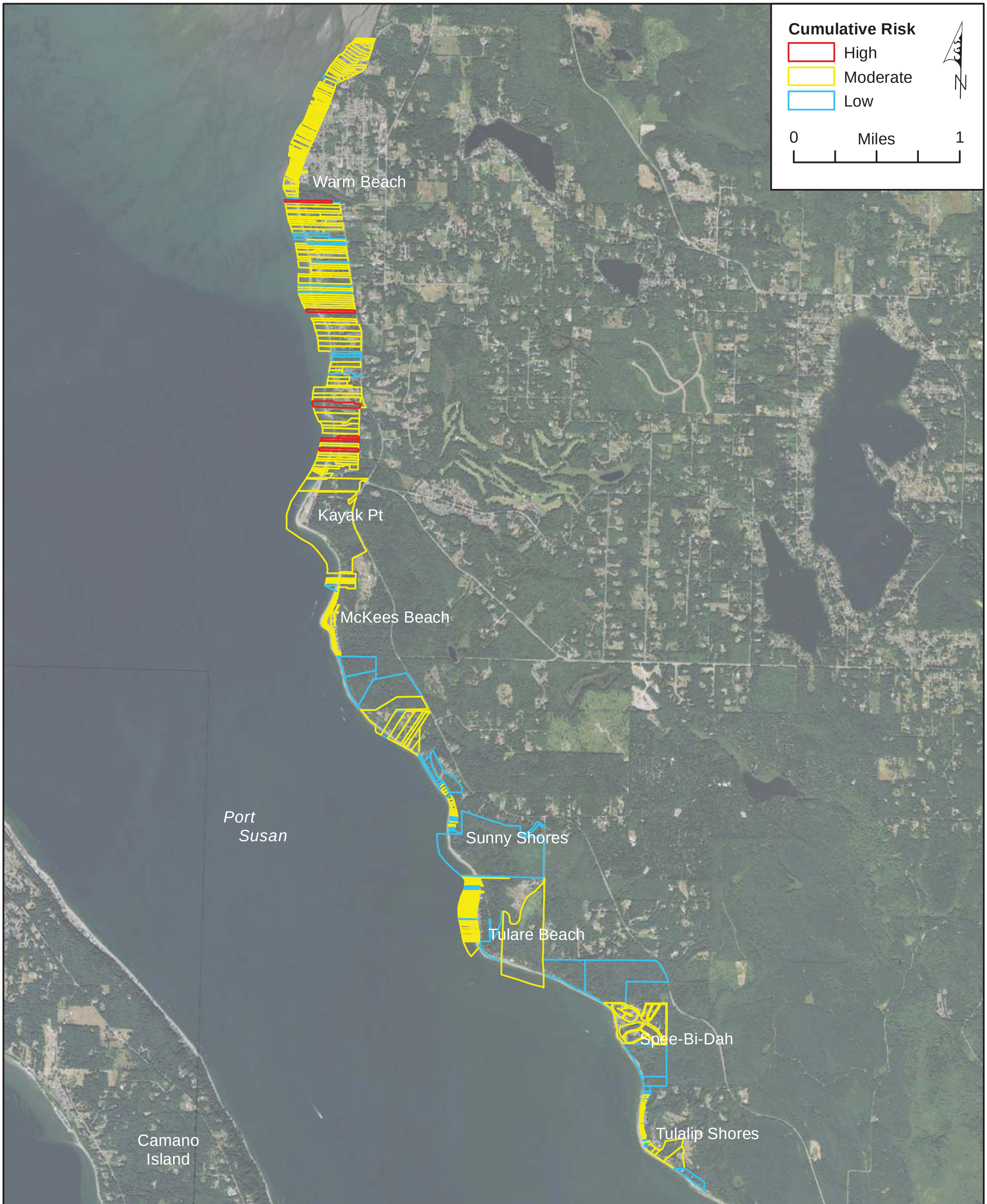
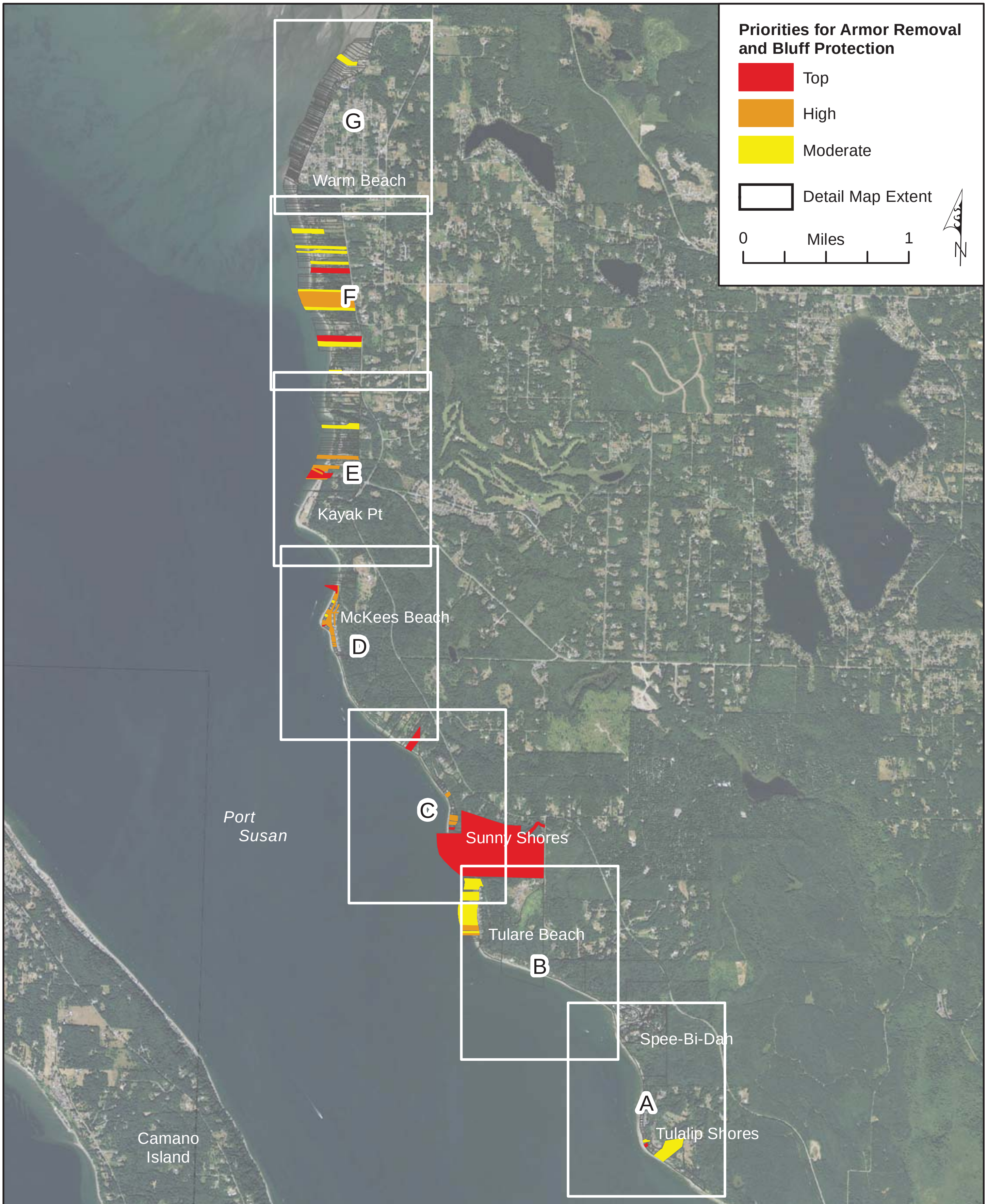


Map 5. Cumulative Risk for Erosion in the Port Susan MSA (discontinuous inland parcels removed). *Aerial background courtesy USDA NAIP program (2011) Parcel boundaries are approximate and based on GIS layers*
Port Susan Marine Stewardship Area Armor Removal Assessment



Map 6. Index to detail maps 7-9 within the Port Susan MSA, with an overview of parcel priorities. *Aerial background courtesy USDA NAIP program (2011) Parcel boundaries are approximate and based on GIS layers*
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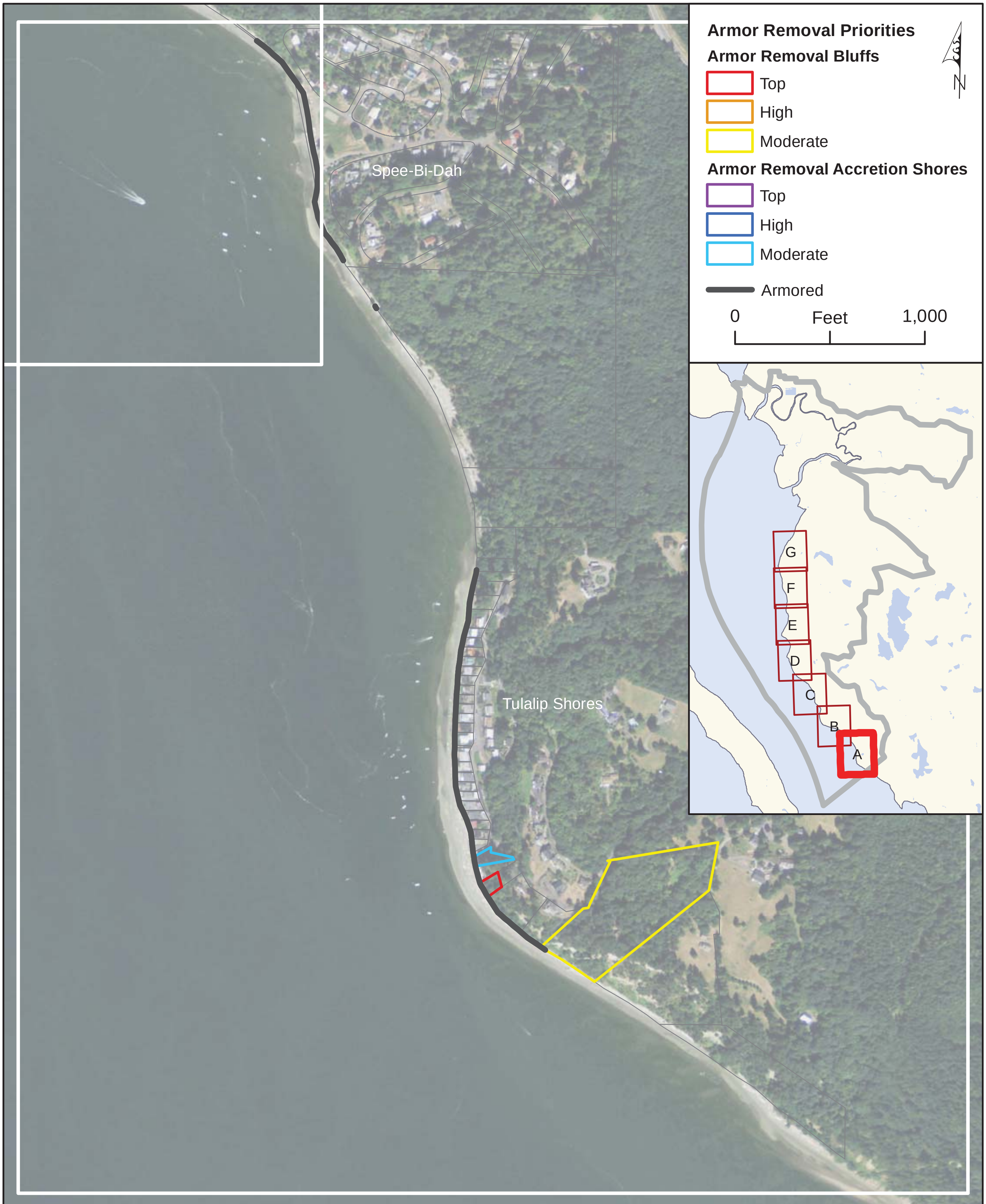

Map 7A. Armor removal priority parcels within the Port Susan MSA.
Aerial background courtesy USDA NAIP program (2011)
Parcel boundaries are approximate and based on GIS layers
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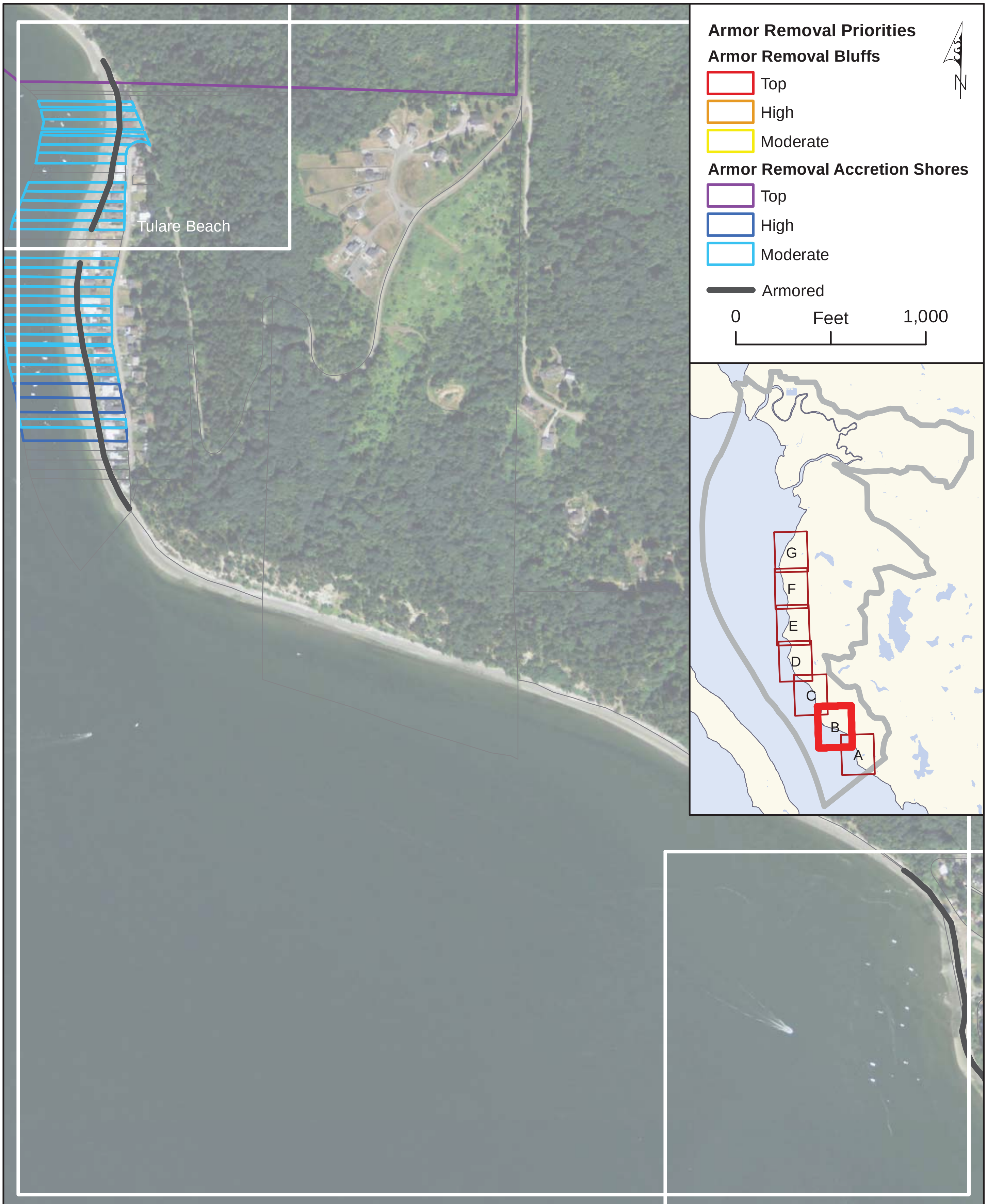
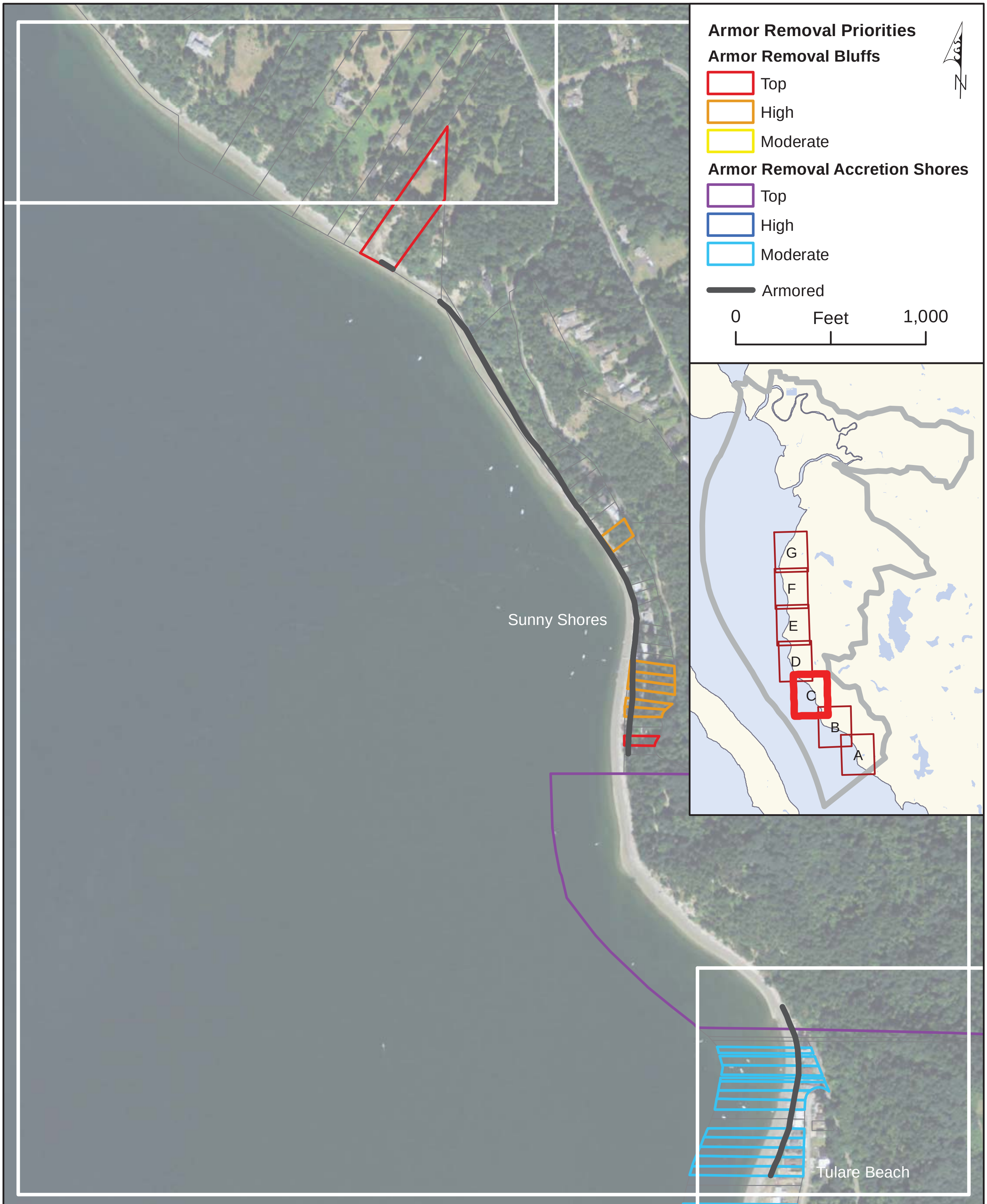


Map 7B. Armor removal priority parcels within the Port Susan MSA.
Aerial background courtesy USDA NAIP program (2011)
Parcel boundaries are approximate and based on GIS layers
Port Susan Marine Stewardship Area Armor Removal Assessment



Map 7C. Armor removal priority parcels within the Port Susan MSA.
Aerial background courtesy USDA NAIP program (2011)
Parcel boundaries are approximate and based on GIS layers
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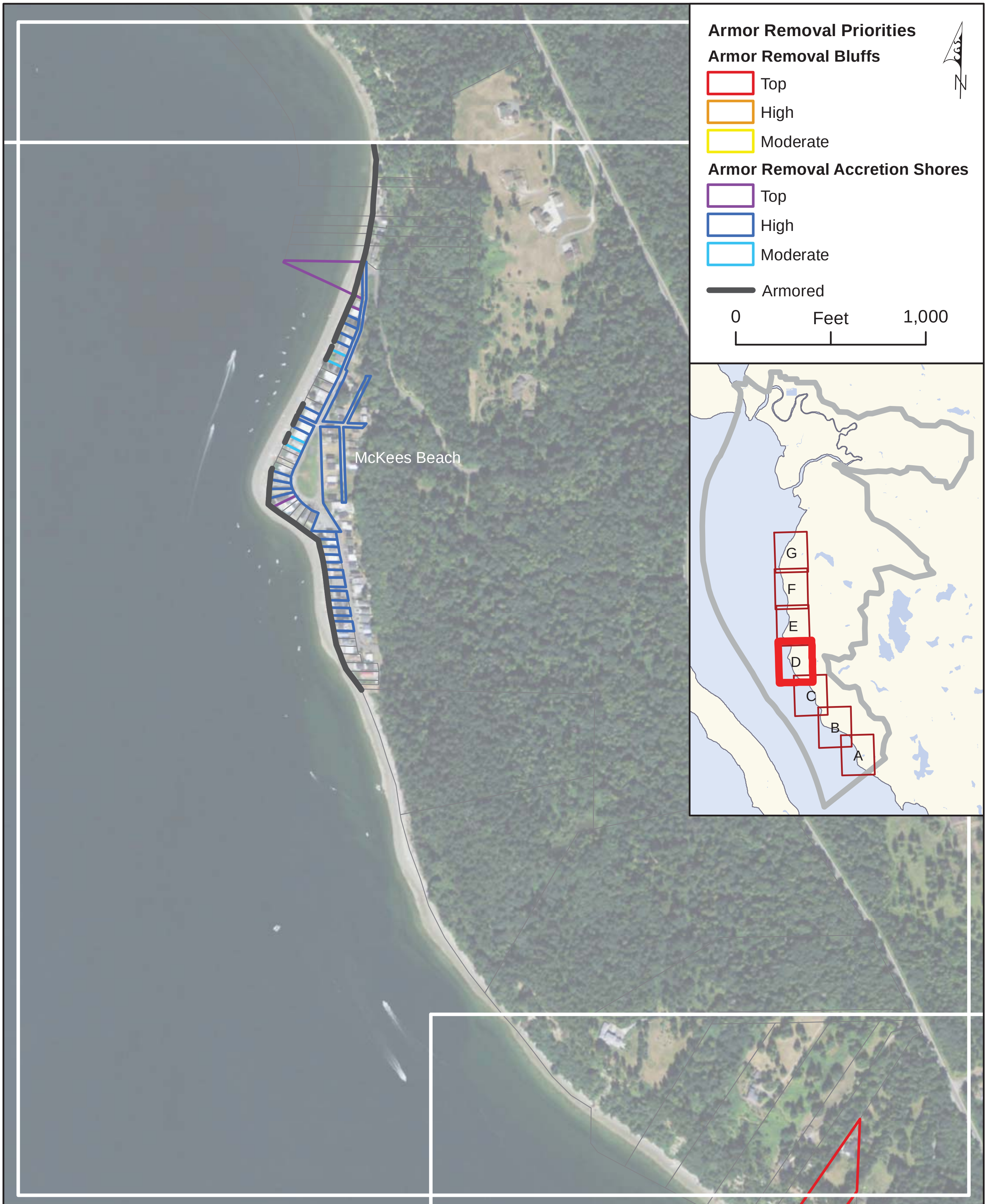

Map 7D. Armor removal priority parcels within the Port Susan MSA.
Aerial background courtesy USDA NAIP program (2011)
Parcel boundaries are approximate and based on GIS layers
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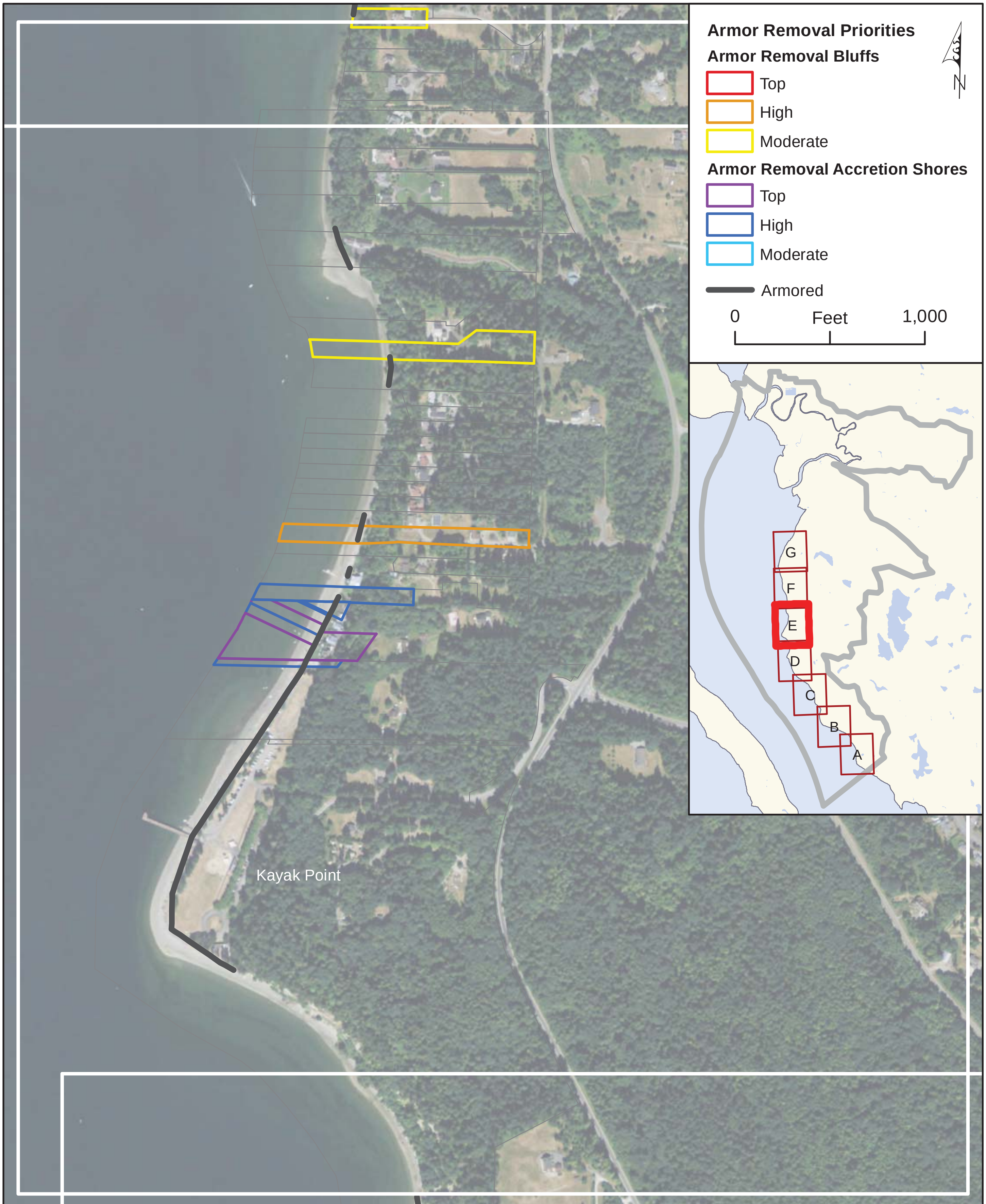

Map 7E. Armor removal priority parcels within the Port Susan MSA.
Aerial background courtesy USDA NAIP program (2011)
Parcel boundaries are approximate and based on GIS layers
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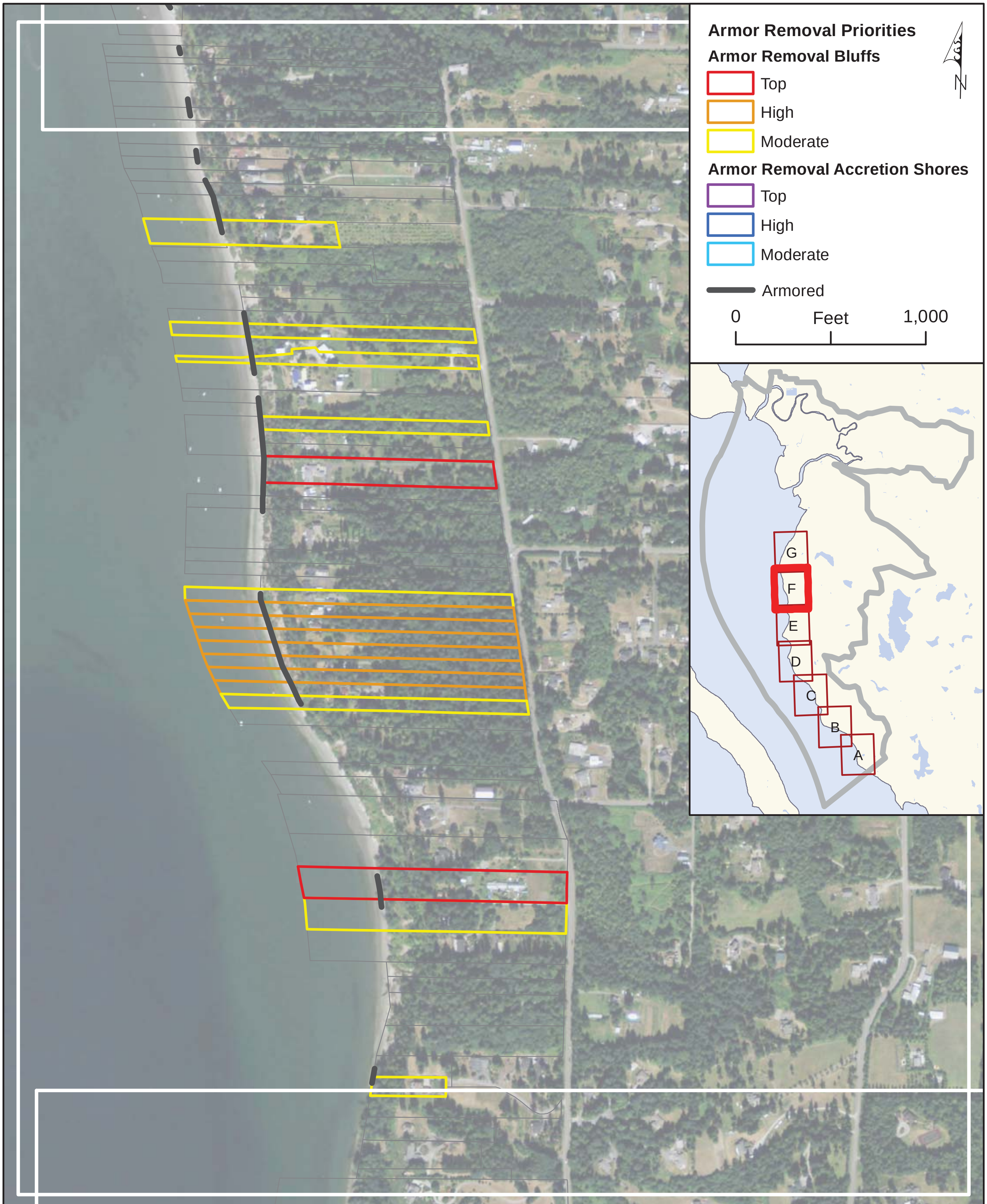

Map 7F. Armor removal priority parcels within the Port Susan MSA.
Aerial background courtesy USDA NAIP program (2011)
Parcel boundaries are approximate and based on GIS layers
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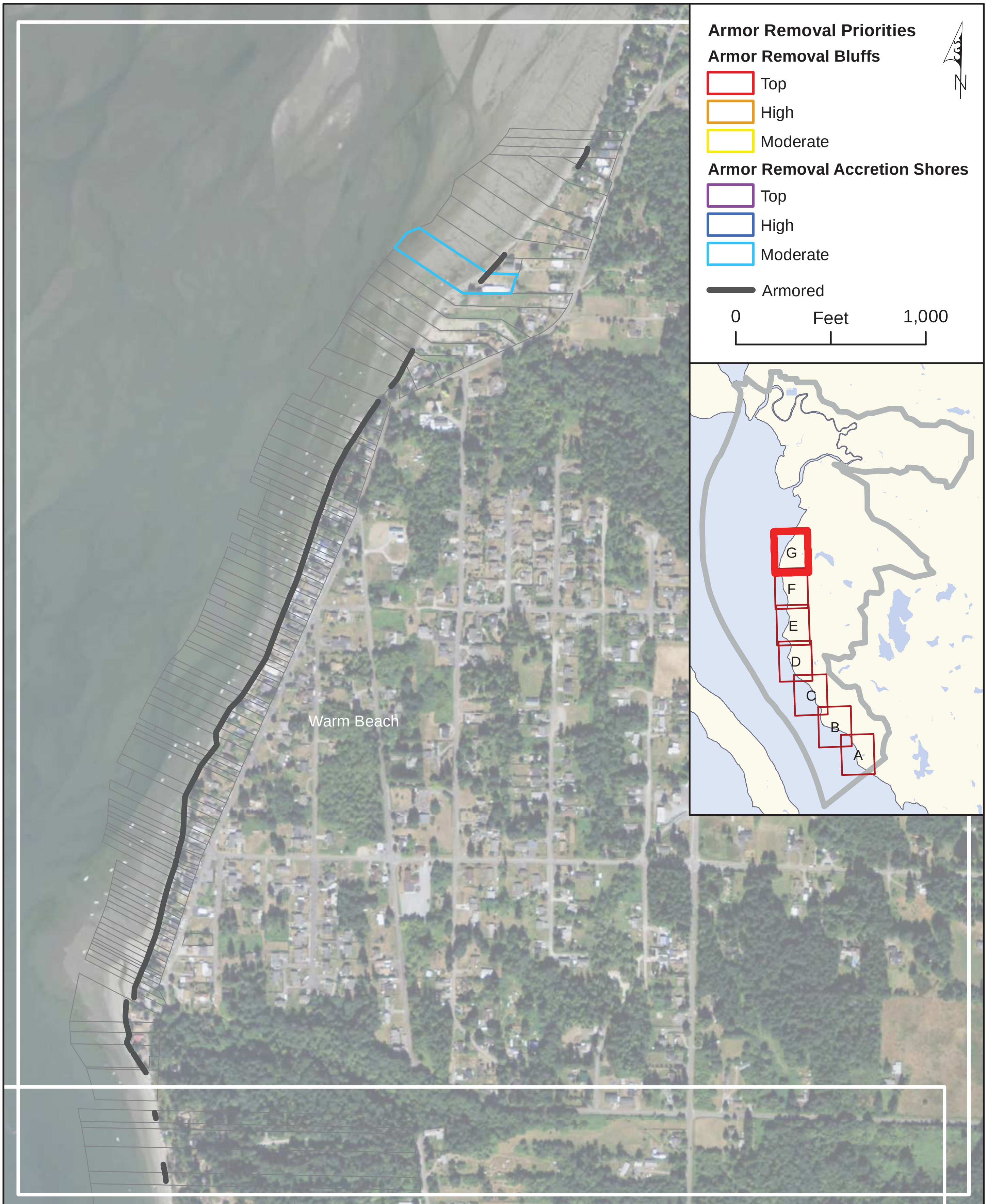

Map 7G. Armor removal priority parcels within the Port Susan MSA.
Aerial background courtesy USDA NAIP program (2011)
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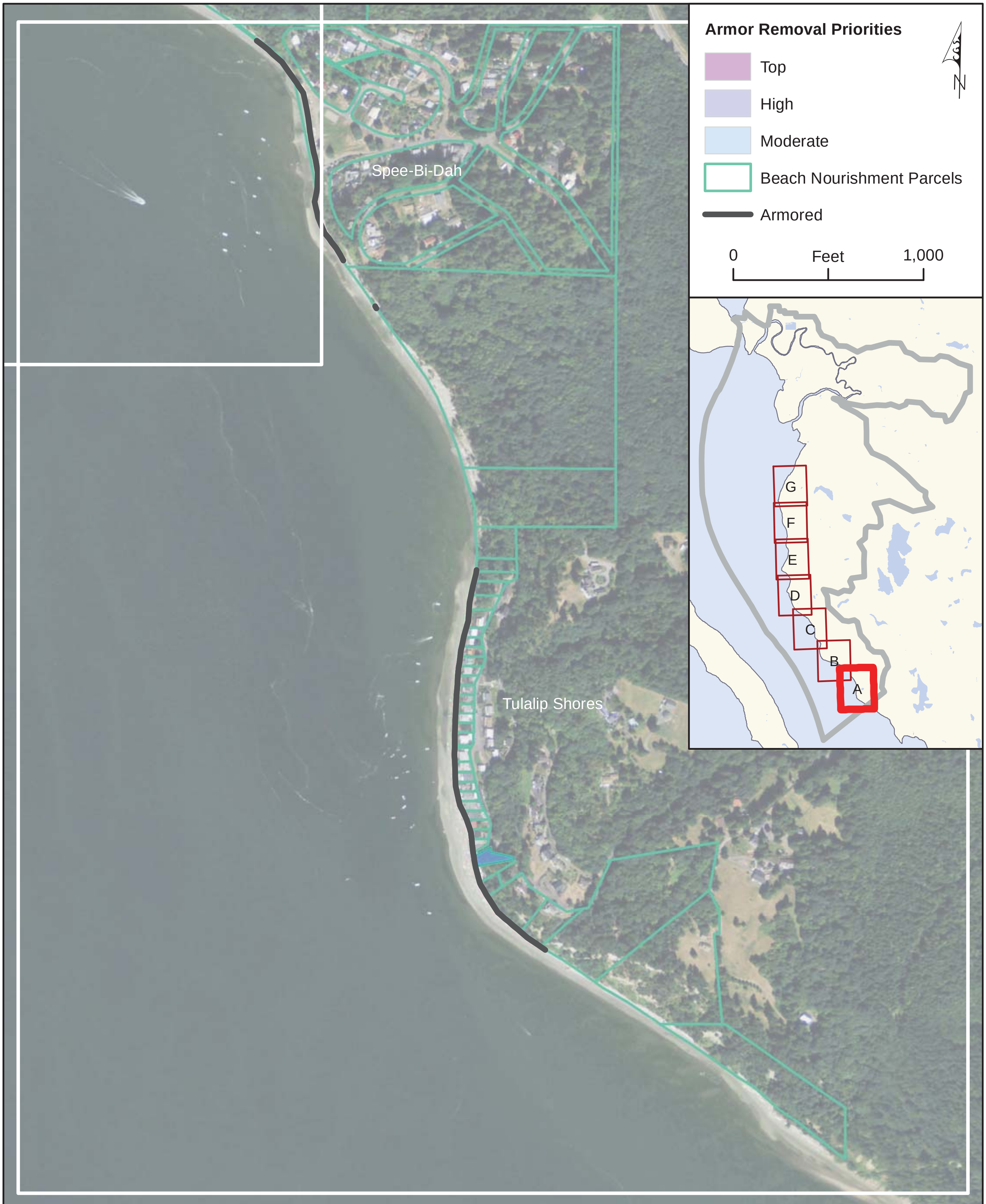

Map 8A. Beach nourishment opportunities within the Port Susan MSA.
Aerial background courtesy USDA NAIP program (2011)
Parcel boundaries are approximate and based on GIS layers
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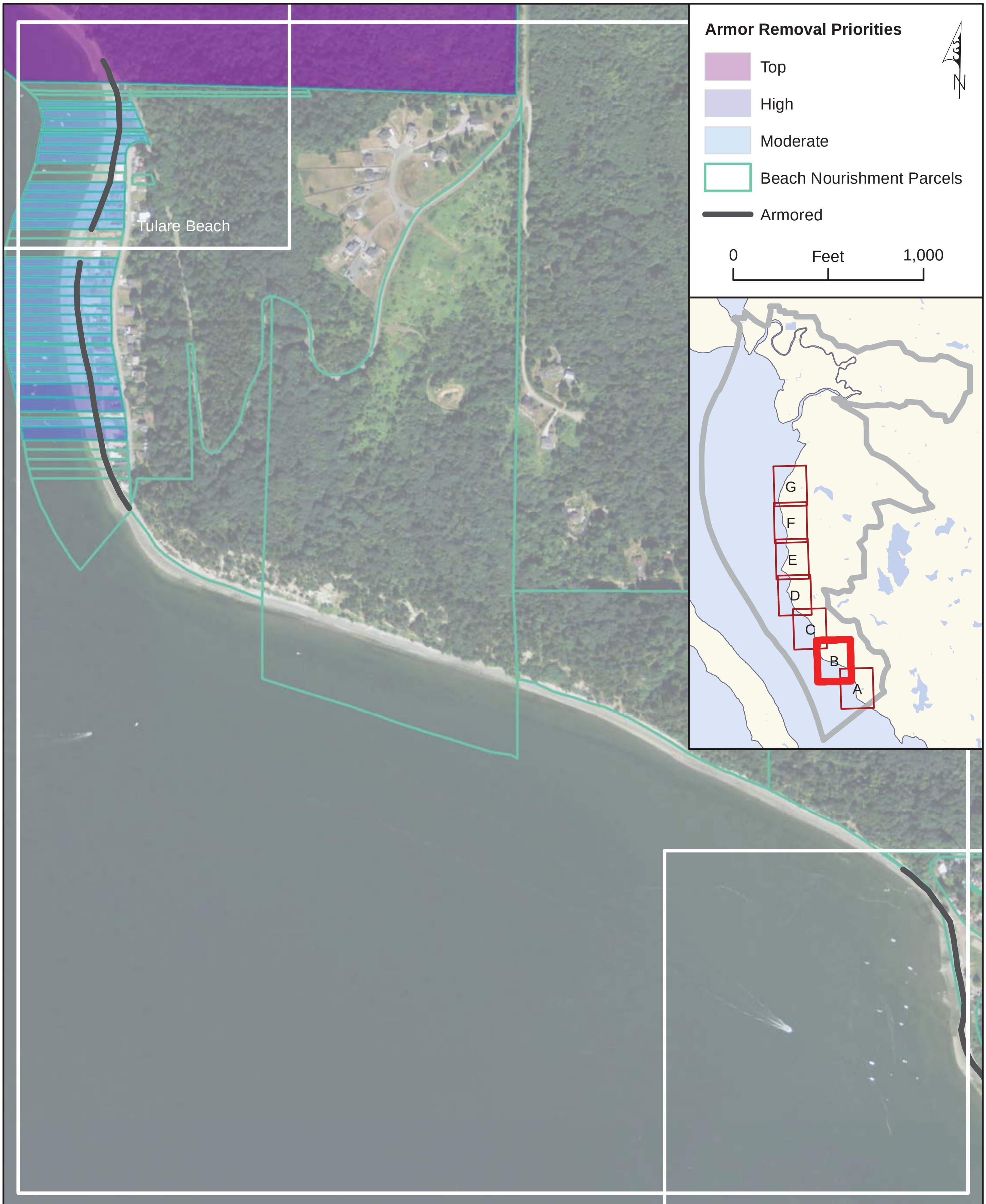

Map 8B. Beach nourishment opportunities within the Port Susan MSA.
Aerial background courtesy USDA NAIP program (2011)
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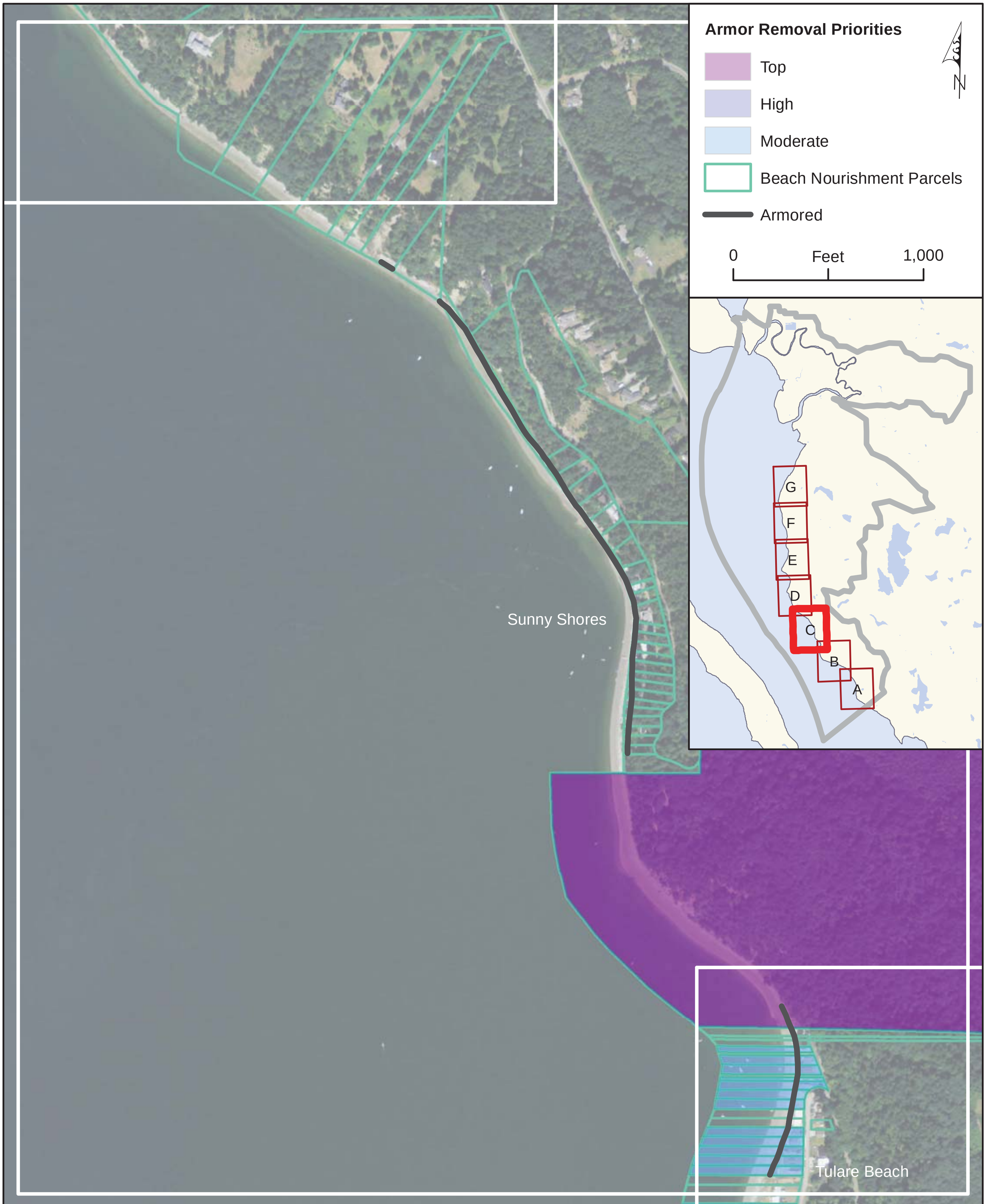
Port Susan Marine Stewardship Area Armor Removal Assessment



Map 8C. Beach nourishment opportunities within the Port Susan MSA.
Aerial background courtesy USDA NAIP program (2011)
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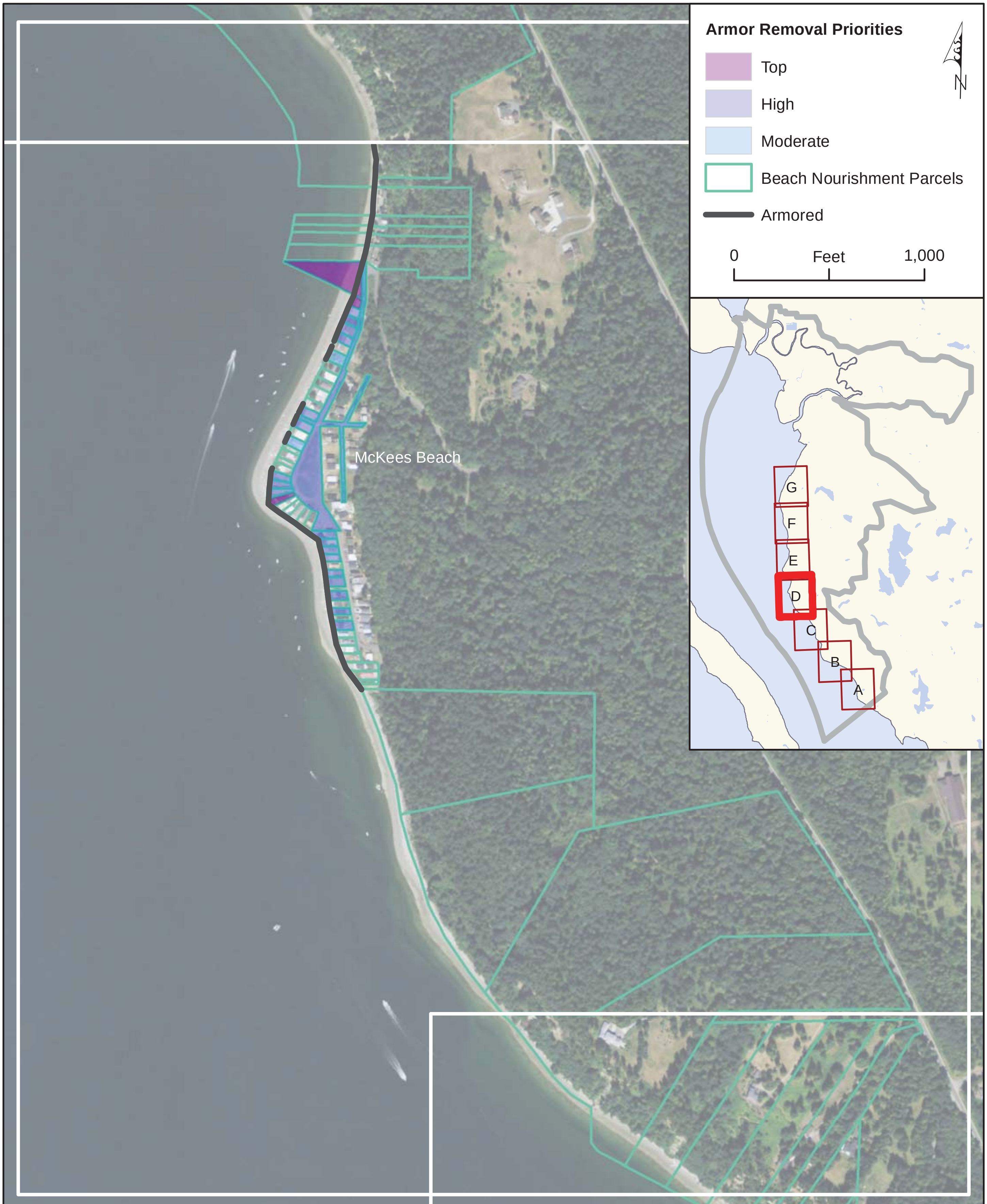

Map 8D. Beach nourishment opportunities within the Port Susan MSA.
Aerial background courtesy USDA NAIP program (2011)
Parcel boundaries are approximate and based on GIS layers
Port Susan Marine Stewardship Area Armor Removal Assessment

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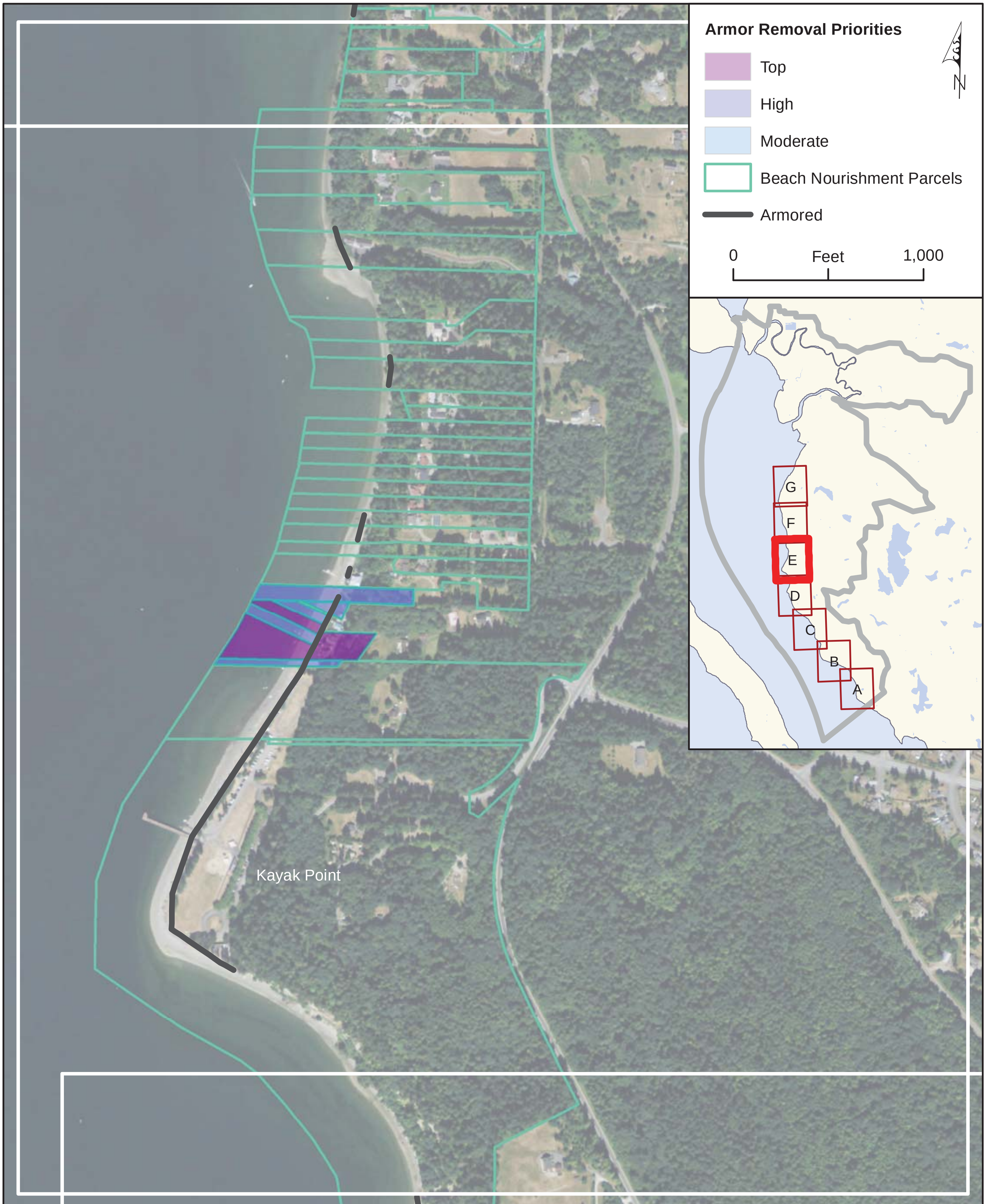

Map 8E. Beach nourishment opportunities within the Port Susan MSA.
Aerial background courtesy USDA NAIP program (2011)
Parcel boundaries are approximate and based on GIS layers
Port Susan Marine Stewardship Area Armor Removal Assessment

Map 8F. Beach nourishment opportunities within the Port Susan MSA.
Aerial background courtesy USDA NAIP program (2011)
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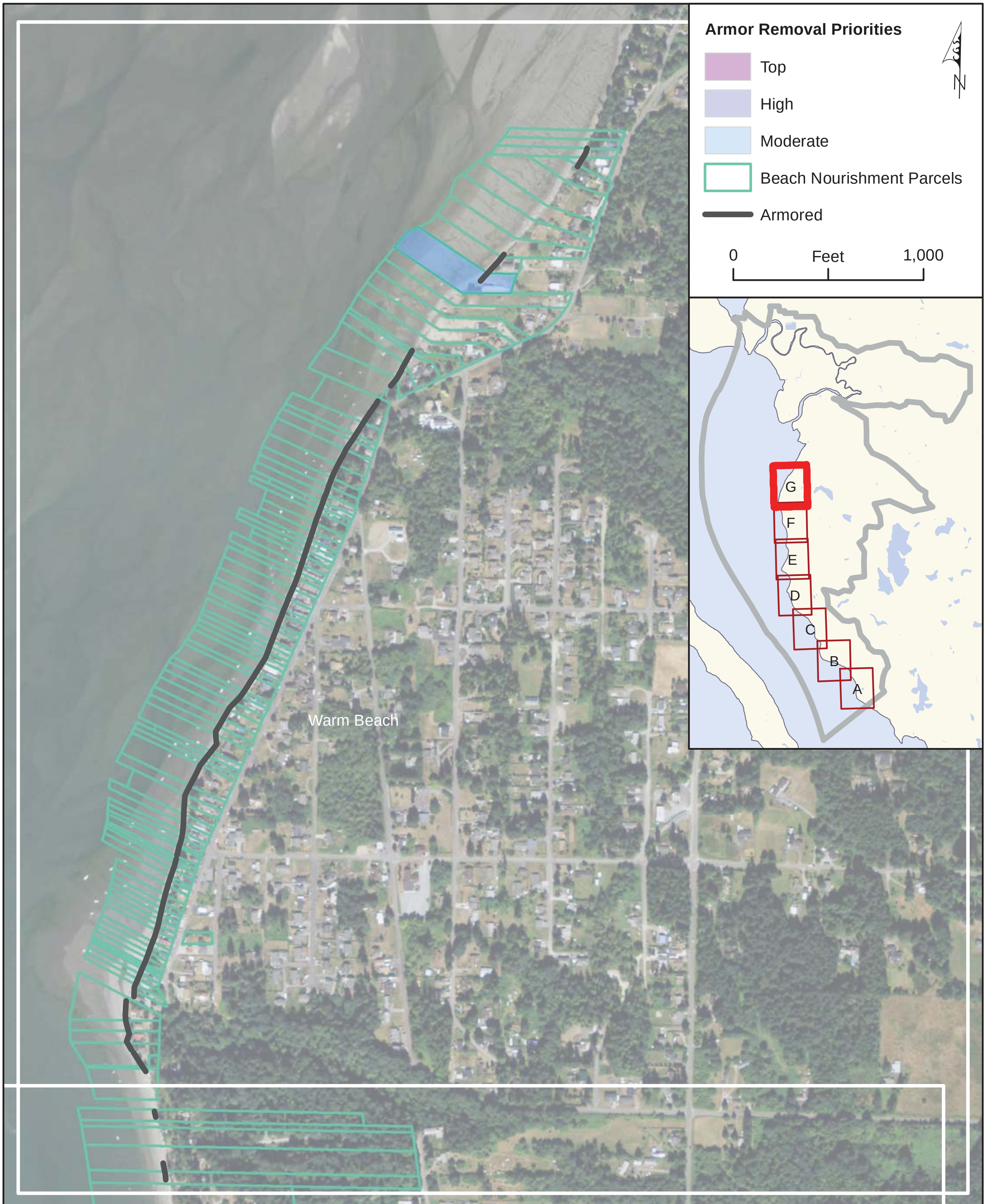
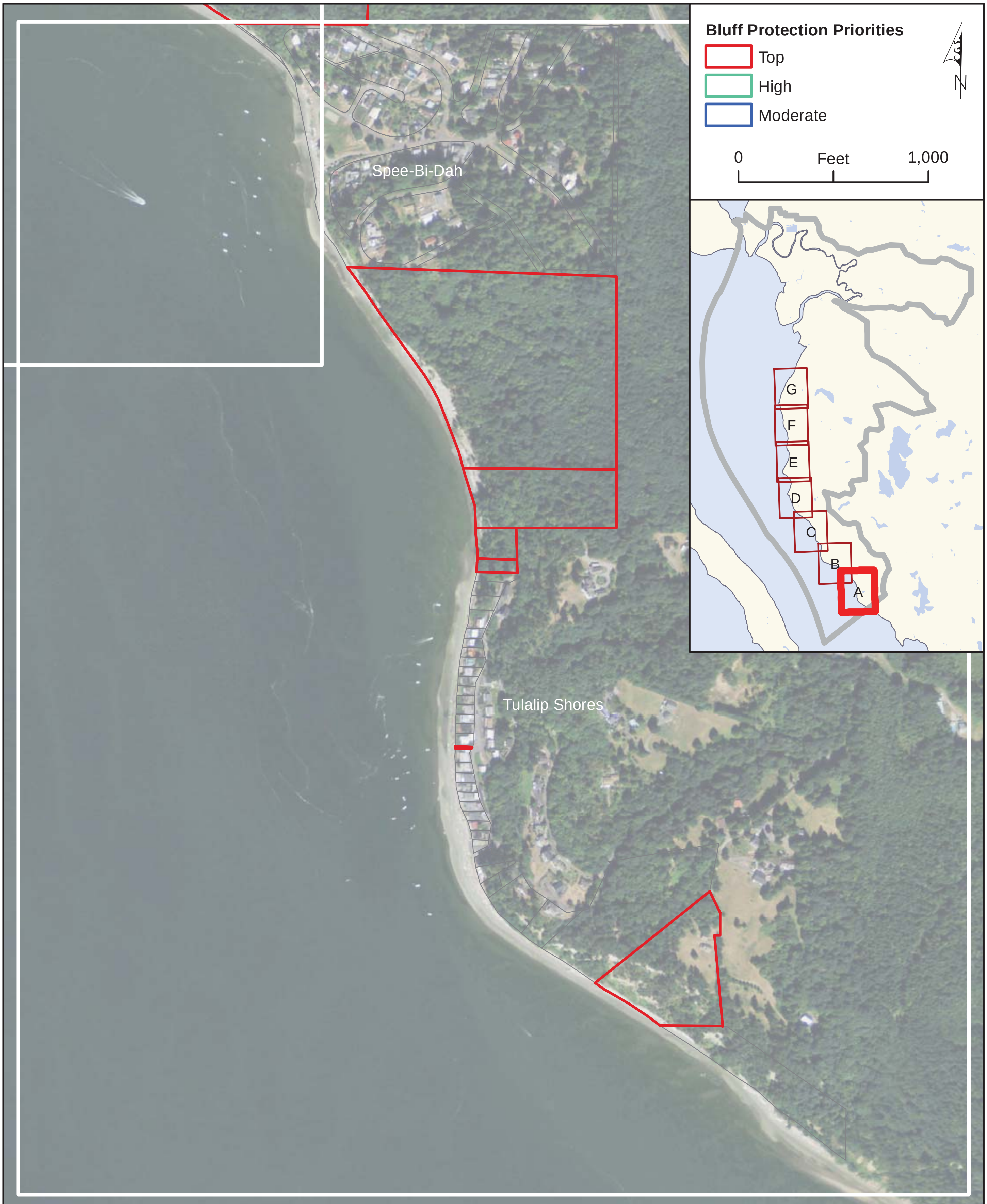
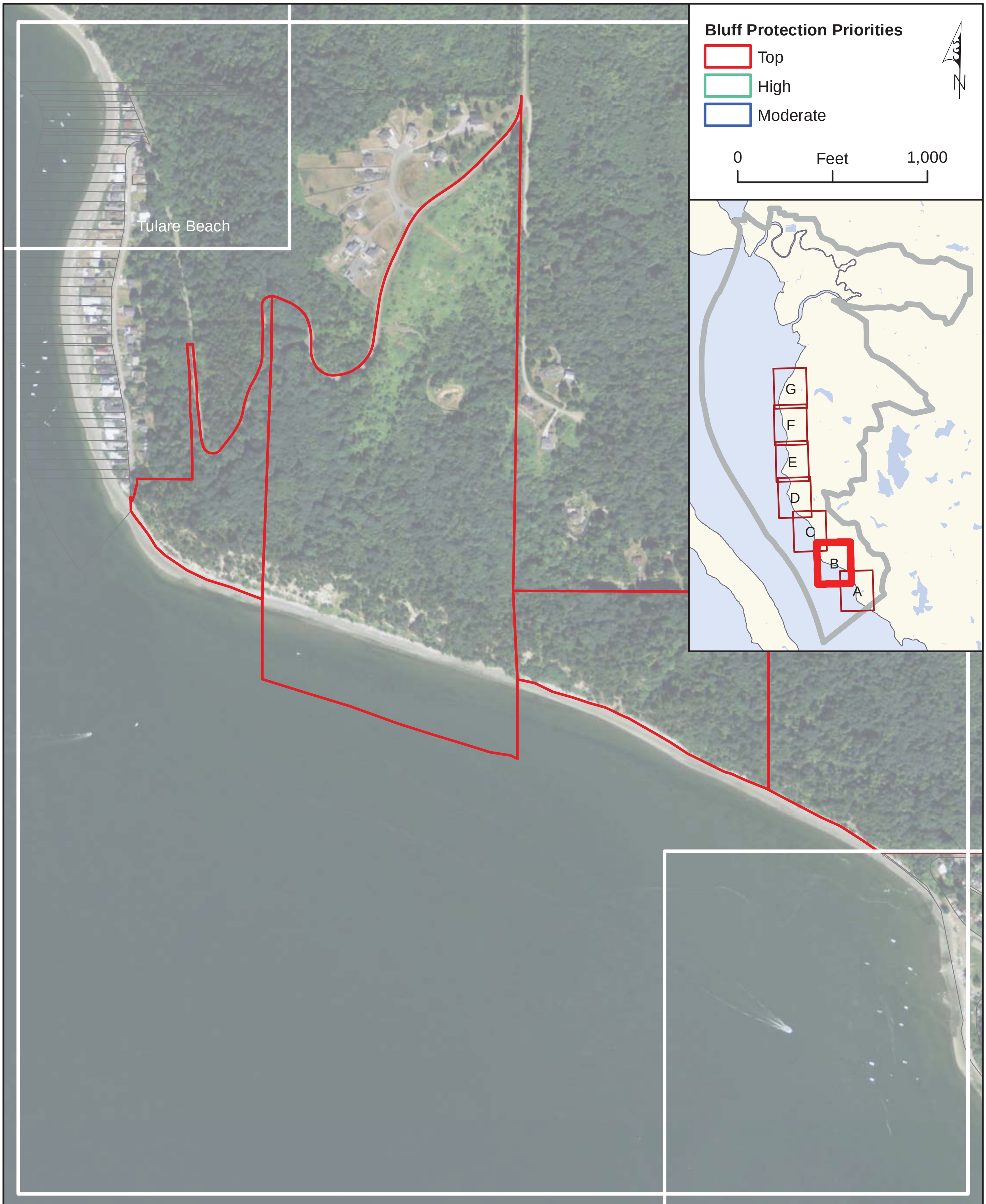


Map 8G. Beach nourishment opportunities within the Port Susan MSA.
Aerial background courtesy USDA NAIP program (2011)
Parcel boundaries are approximate and based on GIS layers
Port Susan Marine Stewardship Area Armor Removal Assessment

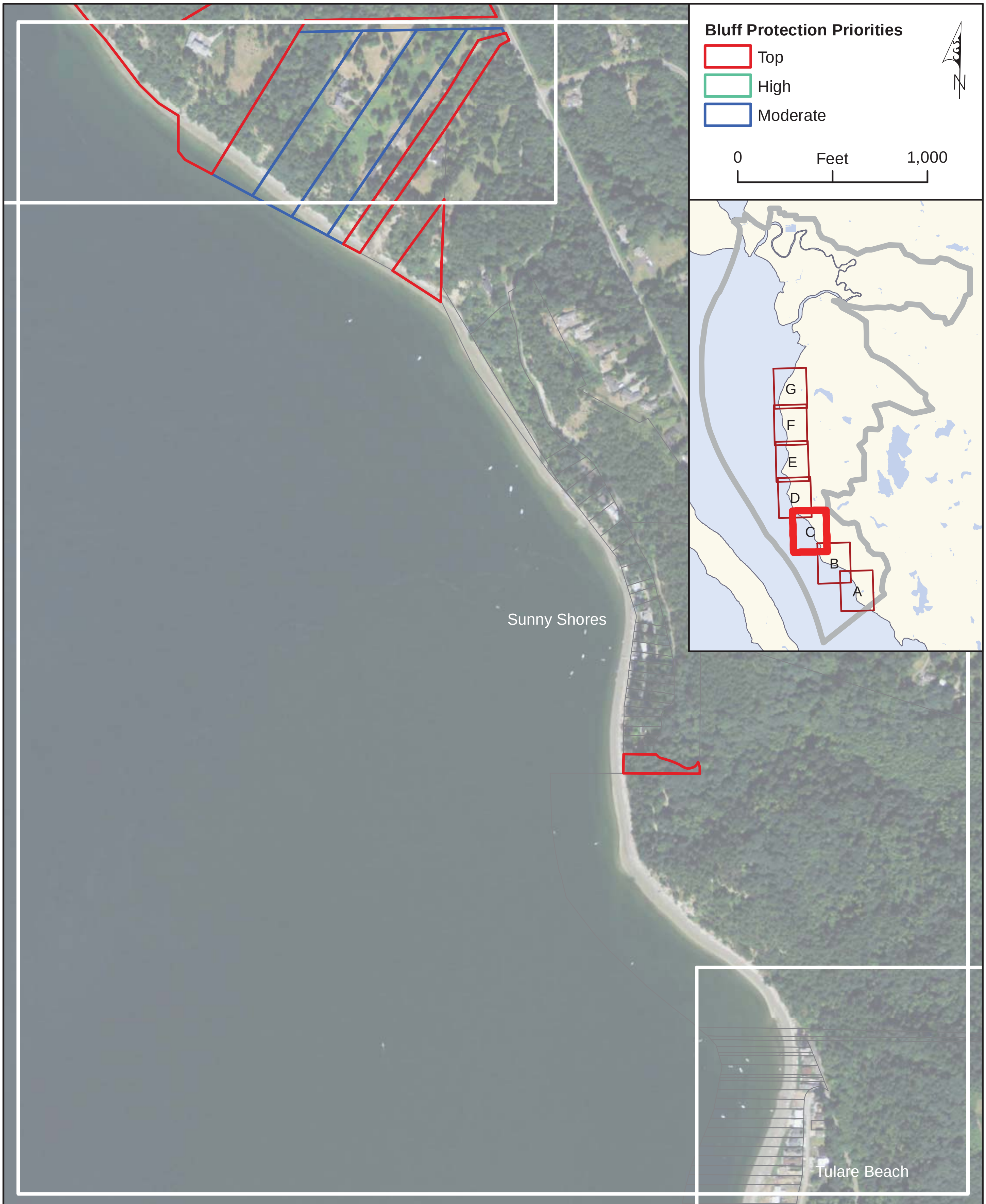


Map 9A. Bluff protection priorities within the Port Susan MSA.
Aerial background courtesy USDA NAIP program (2011)
Parcel boundaries are approximate and based on GIS layers
Port Susan Marine Stewardship Area Armor Removal Assessment



Map 9B. Bluff protection priorities within the Port Susan MSA.
Aerial background courtesy USDA NAIP program (2011)
Parcel boundaries are approximate and based on GIS layers
Port Susan Marine Stewardship Area Armor Removal Assessment

SNOHOMISH COUNTY MARINE RESOURCES COMMITTEE
COASTAL GEOLOGIC SERVICES



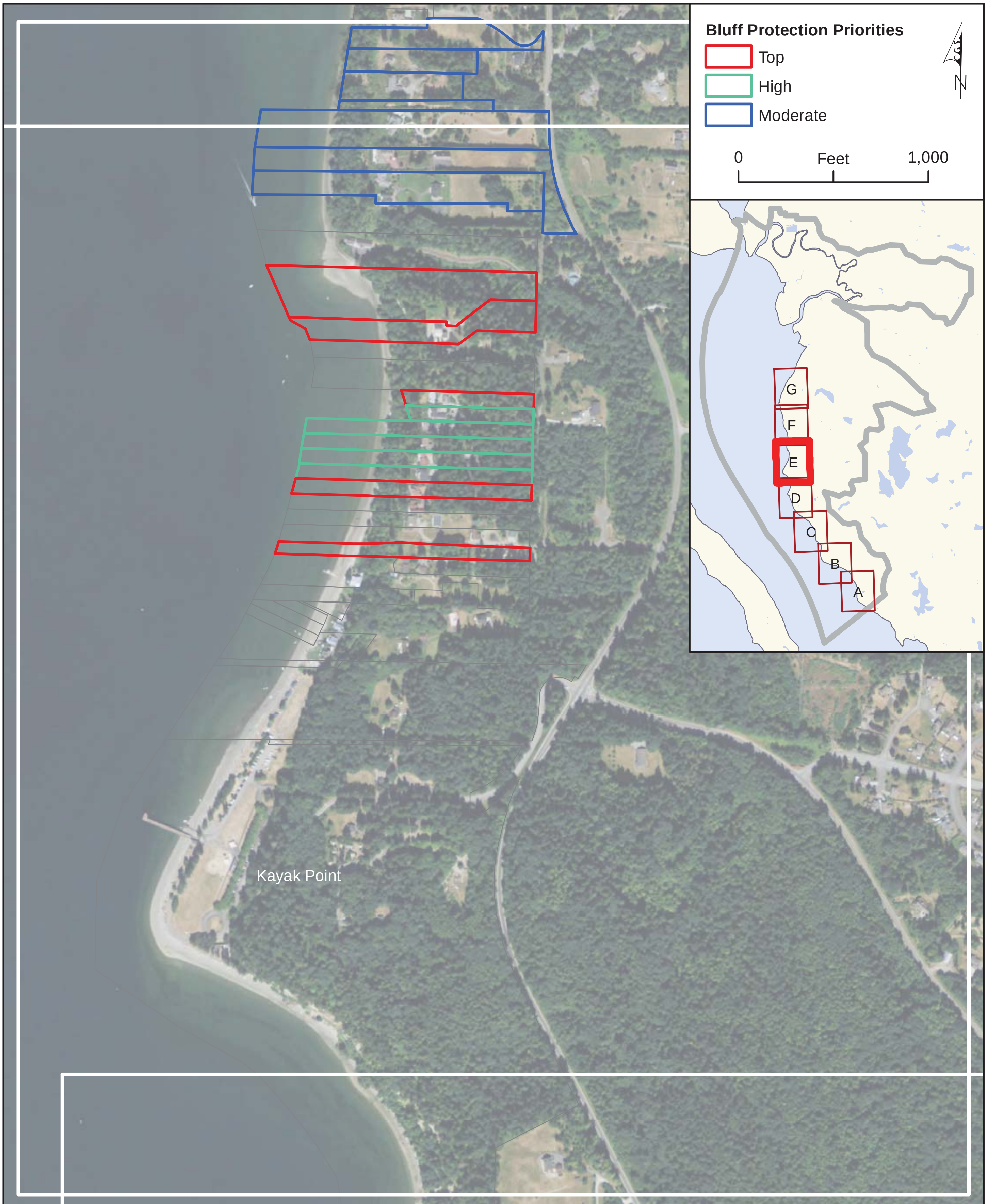
Map 9C. Bluff protection priorities within the Port Susan MSA.
Aerial background courtesy USDA NAIP program (2011)
Parcel boundaries are approximate and based on GIS layers
Port Susan Marine Stewardship Area Armor Removal Assessment

SNOHOMISH COUNTY MARINE RESOURCES COMMITTEE

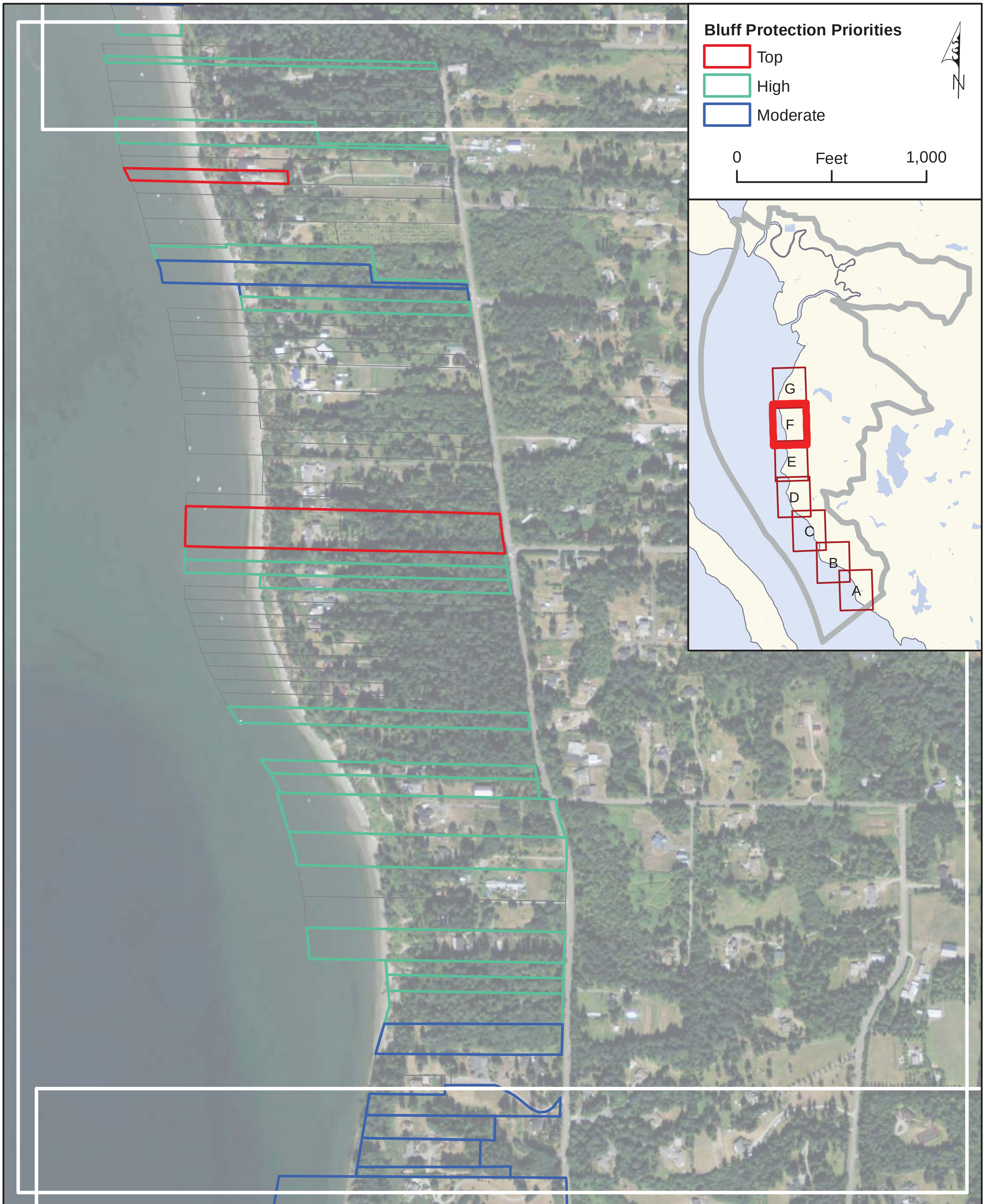
COASTAL GEOLOGIC SERVICES

Map 9D. Bluff protection priorities within the Port Susan MSA.
Aerial background courtesy USDA NAIP program (2011)
Parcel boundaries are approximate and based on GIS layers
Port Susan Marine Stewardship Area Armor Removal Assessment

SNOHOMISH COUNTY MARINE RESOURCES COMMITTEE
COASTAL GEOLOGIC SERVICES



Map 9E. Bluff protection priorities within the Port Susan MSA.
Aerial background courtesy USDA NAIP program (2011)
Parcel boundaries are approximate and based on GIS layers
Port Susan Marine Stewardship Area Armor Removal Assessment



Map 9F. Bluff protection priorities within the Port Susan MSA.
Aerial background courtesy USDA NAIP program (2011)
Parcel boundaries are approximate and based on GIS layers
Port Susan Marine Stewardship Area Armor Removal Assessment

SNOHOMISH COUNTY MARINE RESOURCES COMMITTEE

COASTAL GEOLOGIC SERVICES

Map 9G. Bluff protection priorities within the Port Susan MSA.
Aerial background courtesy USDA NAIP program (2011)
Parcel boundaries are approximate and based on GIS layers
Port Susan Marine Stewardship Area Armor Removal Assessment

Snohomish County Marine Resources Committee

Coastal Geologic Services

Each of the attributes or column names represent spatial data that CGS has compiled to conduct the PS MSA Armor Removal Assessment.
The columns below provide more easy to understand names, attribute descriptions, and data sources for each of these data.
All data included here is attributed to the marine shoreline parcels that are encompassed within the Snohomish County shores of the PS MSA.
Additional interim data was developed to conduct the analysis but most data products were maintained in the spreadsheet.
These data will be analzed and summarized in the draft report, which will be delivered to the MRC in early July.

Attribute Name / Column Header	Full Name	Description	Source
OBJECTID			
PIDText	Parcel ID	Unique identifier from original parcel database	Washington State Parcel database and Puget Sound shoreline parcel database (CGS 2014)
BluffOrAS	Bluff parcel or AS-type parcel	Identifies dominant shoretype within the parcel	Puget Sound shoreline parcel database, with new updates (CGS 2014)
ArmOver20ft	Armor within the parcel	Presence/absence of armor in the parcel (20 ft minimum)	Puget Sound shoreline parcel database (CGS 2014)
HasStr	Has Structure	Whether a structure was digitized within the parcel	CGS. Digititzed from aerial photos
ArmNoStr	Armor, no structure	Armor over 20 feet long, but no digitized structure	Calculated
ShoreLen	Shorelength	Shoreline length in the parcel.	Calculated
ShoreTypeCount	No of shoretypes	Number of shoretypes found within the parcel.	CGS. Intersect parcel data with CGS shoretype mapping (MacLennan et al. 2013)
ST1	Shoretype 1	Shoretyp 1 shoretype	CGS. Intersect parcel data with CGS shoretype mapping (MacLennan et al. 2013)
ST1Len	Shoretype 1 legnth	Length of shoretype	CGS. Intersect parcel data with CGS shoretype mapping (MacLennan et al. 2013)
ST1Pct	Shoretype 1 %	Shoretype 1 percent of parcel length	CGS. Intersect parcel data with CGS shoretype mapping (MacLennan et al. 2013)
ST2	Shoretype 2	Shoretyp 1 shoretype	CGS. Intersect parcel data with CGS shoretype mapping (MacLennan et al. 2013)
ST2Len	Shoretype 2 legnth	Length of shoretype	CGS. Intersect parcel data with CGS shoretype mapping (MacLennan et al. 2013)
ST2Pct	Shoretype 2 %	Shoretype 1 percent of parcel length	CGS. Intersect parcel data with CGS shoretype mapping (MacLennan et al. 2013)
ST3	Shoretype 3	Shoretyp 1 shoretype	CGS. Intersect parcel data with CGS shoretype mapping (MacLennan et al. 2013)
ST3Len	Shoretype 3 legnth	Length of shoretype	CGS. Intersect parcel data with CGS shoretype mapping (MacLennan et al. 2013)
ST3Pct	Shoretype 3 %	Shoretype 1 percent of parcel length	CGS. Intersect parcel data with CGS shoretype mapping (MacLennan et al. 2013)
ST4	Shoretype 4	Shoretyp 1 shoretype	CGS. Intersect parcel data with CGS shoretype mapping (MacLennan et al. 2013)
ST4Len	Shoretype 4 legnth	Length of shoretype	CGS. Intersect parcel data with CGS shoretype mapping (MacLennan et al. 2013)
ST4Pct	Shoretype 4 %	Shoretype 1 percent of parcel length	CGS. Intersect parcel data with CGS shoretype mapping (MacLennan et al. 2013)
FetchMi	Fetch in miles	Fetch is the open water distance over which waves can form.	Shorezone Database (WDNR 2001).
WaveNRGBin	Wave Energy bins	Bins for Wave energy (Low/Mod/High/Very High) used in calculating cumulative risk and identifying appropriate design techniques.	Referenced measured fetch (miles) and Marine Shore Design Guidelines document (Johannessen et al. 2014)
CumlRisk	Cumulative Risk Score	Cumulative Risk calculation described in methods section of the report.	CGS measured, using method referenced in WDFW Marine Shorelines Design Guidelines (Johannessen
RiskBin	Cumulative Risk Bins	Cumulative Risk calculation described in methods section of the report.	CGS measured, using method referenced in WDFW Marine Shorelines Design Guidelines (Johannessen
NoAct	No Action	Parcels in which no action should be applied.	CGS. Identified parcels for no action based on site conditions using methods referenced in WDFW Marine Shorelines Design Guidelines (Johannessen
ReloBMP	Relocation or BMPs	Parcels in which structure relocation and/or implementation of BMPs are appropriate and beneficial.	
RE	Relocation	Parcels in which structure relocation could be considered. Project data did not include sufficient details to adequately assess this.	
BR	Bulkhead removal	Parcels in which bulkhead removal could be considered, if a bulkhead is present (MSDG calculation, not screened for feasibility!)	CGS. Using methods outlined in WDFW Marine Shorelines Design Guidelines (Johannessen et al. 2014).
LW	Large wood	Parcels in which large wood placement could be considered. Project data did not include sufficient details to adequately assess this.	
BN	Beach Nourishment	Parcels in which beach nourishment is likely feasible. Site visist required to confirm.	CGS. Using methods outlined in WDFW Marine Shorelines Design Guidelines (Johannessen et al.
Hard	Hard Armor	Parcels in which hard armor is an appropriate design technique.	CGS. Conditions within the parcel referenced to meet the criteria outlined in WDFW Marine
HasBlufStr	Has bluff structure	Digitized bluff and structure in parcel	CGS. From the two component fields.
BluffFeasArmRm	Bluffs Feasible for Armor Removal	Bluffs with adequate setback distances for feasible armor removal.	CGS. Conditions within the parcel referenced to meet the criteria outlined in WDFW Marine
DdBELPts	Down-drift barrier estuary or lagoon points	Benefit score which does not apply to any parcels in the study area, so was omitted.	

LenDdPts	Length of down-drift score points	Benefit score, per table 3	CGS. Conditions within the parcel referenced the benefits ranking criteria developed for this project
PctDdPts	Percent of down-drift score points	Benefit score, per table 3	CGS. Conditions within the parcel referenced the benefits ranking criteria developed for this project
SedVolPts	Sediment volume points	Benefit score, per table 3	CGS. Conditions within the parcel referenced the benefits ranking criteria developed for this project
FfHerePts	Forage fish presence points	Benefit score, per table 3	CGS. Conditions within the parcel referenced the benefits ranking criteria developed for this project
ArmLenPts	Armor length points	Benefit score, per table 3	CGS. Conditions within the parcel referenced the benefits ranking criteria developed for this project
AdjArmPts	Adjacent armor points	Benefit score, per table 3	CGS. Conditions within the parcel referenced the benefits ranking criteria developed for this project
DdFfLenPts	Down-drift forage fish length points	Benefit score, per table 3	CGS. Conditions within the parcel referenced the benefits ranking criteria developed for this project
AllBluffBnftPts	All bluff benefit points	Cumulative results of potential benefits for all bluff parcels, including infesible and unarmored parcels.	CGS. Conditions within the parcel referenced the benefits ranking criteria developed for this project and described in the methods document.
FeasBluffBnftPts	Feasible (for armor removal) bluff benefit points	Benefit score, as above, for feasible parcels	CGS. Conditions within the parcel referenced the benefits ranking criteria developed for this project
FeasBluffPrio	Feasible (for armor removal) bluff restoration priority	Bluff armor removal parcels that are likely to result in the greatest benefit to the nearshore ecosystem.	CGS prioritized bluff restoration using the distribution of benefit scores for parcels that were identified as feasible for armor removal. Top = highest scoring 33%, High = highest scoring 66%,
BluffNoArm	Bluff, no armor	Bluff parcels with <20 feet of armor	CGS. From the two component fields.
BluffProtBnftPts	Bluff protection (unarmored) benefit points	Benefit score, as above, for unarmored bluff parcels	CGS. Conditions within the parcel referenced the benefits ranking criteria developed for this project
BluffProtPrio	Bluff protection (unarmored) priority	Unarmored bluffs that provide multiple benefits to the nearshore ecosystem.	CGS prioritized bluffs for protection using the distribution of benefit scores for all unarmored bluffs. Top = highest scoring 33%, High = highest
HasASStr	AS , has structure	AS parcel with a digitized structure	CGS. From the two component fields.
ASFeasArmRm	Accretion Shoreforms Feeasible for Armor Removal	Cumulative results of potential benefits resulting from armor removal on accretion shoreforms.	CGS. Conditions within the parcel referenced to meet the criteria outlined in WDFW Marine Shorelines Design Guidelines (Johannessen et al.
ASArmElevPts	AS, armor elevation points	Benefit score, per table 4	CGS. Conditions within the parcel referenced the benefits ranking criteria developed for this project
ASFfHerePts	AS, forage fish presence points	Benefit score, per table 4	CGS. Conditions within the parcel referenced the benefits ranking criteria developed for this project
ASArmLenPts	AS, armor length points	Benefit score, per table 4	CGS. Conditions within the parcel referenced the benefits ranking criteria developed for this project
ASAdjArmPts	AS, adjacent armor points	Benefit score, per table 4	CGS. Conditions within the parcel referenced the benefits ranking criteria developed for this project
AllASBnftPts	All AS benefit points	Potential benefit resulting from armor removal on accretion shoreforms, including infesible and unarmored parcels.	CGS. Conditions wihtin the parcel referenced the benefits ranking criteria developed for this project and described in the methods document.
FeasASBnftPts	Feasible AS benefit points	Benefit score, as above, for feasible parcels	CGS. Conditions within the parcel referenced the benefits ranking criteria developed for this project
FeasASPrio	Armor Removal Priorities for Accretion Shoreforms	Accretion shoreform armor removal parcels that are likely to result in the greatest benefit to the nearshore ecosystem.	CGS prioritized accretion shoreforms using the distribution of benefit scores for all parcels identified as feasible for armor removal. Top = highest scoring 33%, High = highest scoring 66%,

PS_MSA_Structures

Personal GeoDatabase Feature Class

Thumbnail Not Available

Tags

Port Susan Marine Stewardship Area, Snohomish County

Summary

Coastal Geologic Services, Inc. (CGS) conducted a LiDAR/GIS analysis of the marine shoreline located within the Port Susan Marine Stewardship Area (MSA) of Snohomish County. The position of the crest of all shoreline bluffs and the most waterward point of primary structure (residential house or other large building) located on waterfront parcels will be digitized to inform future restoration and shoreline management planning. These data can be used together to measure structure setback distances which can inform the feasibility of alternatives to hard shore armoring, such as soft shore protection and bulkhead removal.

Description

The position of the crest of all shoreline bluffs and the most waterward point of primary structure (residential house or other large building) located on waterfront parcels will be digitized to inform future restoration and shoreline management planning.

Shoreline bluff crest was delineated from LiDAR slope in GIS by digitizing the bluff crest at a scale of 1:500. Structure points were digitized in GIS based on visual identification of the most waterward location of the primary structure along individual shoreline parcels. The points were placed based on visual identification using the 2012 vertical air photo imagery provided by Snohomish County.

QAQC was conducted incrementally panning the view frame from north to south at 1:1,200 in GIS. Both datasets were reviewed at the same time using this method, checking the bluff crest polyline with the LiDAR slope background and then the structure points with the 2012 vertical air photo. Question areas were flagged and discussed with the mapper. Agreement of changes by the mapper and reviewer resulted in a completion of QAQC.

Credits

Coastal Geologic Services, Inc.

Use limitations

There are no access and use limitations for this item.

Extent

West	-122.370075	**East**	-122.314481
North	48.178655	**South**	48.078619

Scale Range

Maximum (zoomed in)	1:5,000
Minimum (zoomed out)	1:500,000

You are currently using the Item Description metadata style. Change your metadata style in the Options dialog box to see additional metadata content.

PSMSAARA_Results_20150805

File Geodatabase Feature Class

Thumbnail Not Available

Tags

Snohomish County, Port Susan MSA

Summary

The main objective of the project is to build a prioritized list of parcels where armor removal projects are feasible, in terms of not jeopardizing existing improvements, and where armor removal will restore physical processes to benefit the greater nearshore ecosystem. A secondary objective is to identify unarmored parcels where shore armor is unnecessary to protect existing improvements.

Description

To achieve the project objectives, the feasibility and potential benefit of armor removal are currently being assessed within each parcel in the study area. Feasibility screening performed in this assessment is a remote exercise, and is meant to filter out clearly infeasible projects, such as where the removal of armoring would threaten property improvements. Final feasibility would need to be affirmed with site-visits and higher resolution site-specific analysis conducted by an expert in Puget Sound coastal and bluff processes. Field assessments will be performed on 3 sites (as part of this contract), in which there is both high ecological benefit and landowner interest. Additional site assessments in the Port Susan MSA may be conducted as part of another study contracted by the Northwest Straits Foundation. The final results of this assessment will provide a foundation for later integration with local planning frameworks, the Washington Department of Fish and Wildlife's Marine Shoreline Design Guidelines, and local shoreline regulations.

Results version from 2015-08-05. Please see associated spreadsheet for field definitions. Parcel boundaries are modified from GIS layers and are not cannonical; they are only suited to displaying the results of this study.

Credits

Coastal Geologic Services, Inc.

Use limitations

There are no access and use limitations for this item.

Extent

West	-122.371376	**East**	-122.313456
North	48.178005	**South**	48.076593

Scale Range

Maximum (zoomed in)	1:5,000
Minimum (zoomed out)	1:625,000

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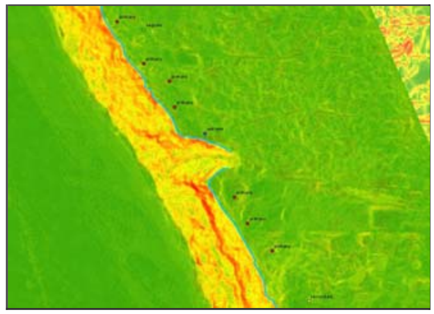
PSMSAARA_BluffCrest

File Geodatabase Feature Class



Tags

Port Susan Marine Stewardship Area, Snohomish County

Summary

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QAQC was conducted incrementally panning the view frame from north to south at 1:1,200 in GIS. Both datasets were reviewed at the same time using this method, checking the bluff crest polyline with the LiDAR slope background and then the structure points with the 2012 vertical air photo. Question areas were flagged and discussed with the mapper. Agreement of changes by the mapper and reviewer resulted in a completion of QAQC.

Credits

Coastal Geologic Services, Inc.

Use limitations

There are no access and use limitations for this item.

Extent

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North	48.178315	**South**	48.061031

Scale Range

Maximum (zoomed in) 1:5,000
Minimum (zoomed out) 1:500,000

You are currently using the Item Description metadata style. Change your metadata style in the Options dialog box to see additional metadata content.