GIS Census of Pocket Estuaries Accessible to Juvenile Salmon in the Whidbey Basin & Western Shore of Whidbey Island, 2014

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Race Lagoon on Whidbey Island. Photos courtesy WA Department of Ecology

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Contents

1.0 Introduction

Pocket estuaries are partially enclosed embayments found along the shoreline that are created by coastal landforms and/or antecedent geology and topography (stream valleys, coastal low lands), that often have depressed salinity compared to adjacent marine waters due to small streams, ground water, and surface runoff. Pocket estuaries are typically low energy groups of habitats including tidal channels, salt marshes, driftwood, and impoundments. The habitats within the pocket estuary are maintained by a variable combination of wave, tidal, and fluvial processes, from which specific pocket estuary types are delineated.

Pocket estuaries and small independent streams draining into nearshore areas within the Whidbey Basin are known to be an important rearing habitat for fry migrant Chinook salmon originating from the three Chinook salmon bearing rivers of the Whidbey Basin (Beamer et al 2003, Beamer et al 2006b, Beamer et al 2013). Within the Whidbey Basin juvenile Chinook salmon use of pocket estuaries is described as 'non-natal' use because juvenile Chinook salmon do not originate from the small streams often draining directly into the pocket estuaries. These small streams are too small support Chinook salmon spawning and are often not flowing at the time of Chinook salmon spawning. All Chinook salmon utilizing pocket estuaries must find them via migration pathways from their natal river and estuary, and then into pocket estuary habitats associated with the adjacent marine basin. Natal use of Whidbey Basin pocket estuaries and small streams is possible for chum and coho salmon, depending on stream size and other watershed characteristics (Beamer et al 2013). Because of the importance of pocket estuaries to Chinook salmon, restoration and protection of pocket estuaries has been a priority for Island County and other Whidbey Basin Chinook salmon recovery plans.

All salmon recovery plan areas in Puget Sound have active capital habitat restoration programs yet little is known about the status of all salmon habitat together. The status and trend of habitat critical to Puget Sound Chinook salmon populations is not known, yet many local Puget Sound Salmon Recovery Plans have stated goals of protecting existing habitat and/or achieving a net gain in habitat. Keeping track of restored habitat is only one part of the habitat equation for tracking salmon recovery. Without monitoring data, it is only an opinion as to whether existing salmon habitat is gaining or losing ground over time. As expected, opinions vary on the status and trend of salmon habitat. Several recent reports have attacked the tenet that existing salmon habitat is not currently being lost (Carman et al 2010; Judge 2011; NWIFC 2012). These reports have, in part, led the Puget Sound Region to more seriously track the status and trends of salmon habitat. Tracking the status and trends of salmon habitat has been included in the regional effort to develop and implement Monitoring and Adaptive Management Plans (MAMP) for all local chapters of the Puget Sound Chinook Recovery Plan. The MAMP process is being led by the Puget Sound Partnership (PSP) but implemented at the local (i.e., Lead Entity) level. A set of Common Indicators for monitoring Puget Sound Chinook salmon habitat (e.g., Fore 2015) has been generally accepted by Lead Entities in order to guide and make monitoring consistent across all of Puget Sound. Pocket estuary habitat extent, count, and connectivity are included in the Common Indicator set.

Knowledge of the extent and connectivity of pocket estuary habitat is one of the three highest priority data gaps for salmon habitat status and trends monitoring for WRIA 6 (Island County Lead Entity RFP, July 13, 2015). This monitoring project fills the knowledge gap with 2014 results. Combining the results from this project with the results from the Skagit Monitoring Pilot Project (Beamer et al. 2015), funded by PSP Interagency Agreement #2015-64, creates a trend result for Whidbey Basin pocket estuary habitat for the first decade of Puget Sound Chinook Recovery Plan implementation. This project also provides results for pocket estuaries along the western Whidbey Island shoreline (herein 'West Whidbey') in 2014. West Whidbey pocket estuaries presumably provide juvenile salmon rearing opportunity for a mixture of Puget Sound salmon populations (Wait et al 2007).

Indicators measured by this project are: 1) count of pocket estuaries accessible to juvenile salmon, 2) the extent of accessible pocket estuary habitat by type, and 3) their landscape position (i.e., connectivity), expressed as two separate metrics: distance between pocket estuaries and distance from nearest Chinook salmon natal river) (Table 1.1).

Table 1.1. Crosswalk of indicators for pocket estuaries from the 2005 Skagit Recovery Plan and PSP Common Indicator list.

Skagit Chinook Plan Indicator	**PSP Common Indicator**	**Method/Data Type**
Count of pocket estuaries accessible to juvenile salmon	Pocket estuary count	GIS census of pocket estuaries (points)
Pocket estuary area accessible to juvenile salmon	Pocket estuarine habitat area that is accessible	GIS census of pocket estuaries (polygon data)
	Extent of connected tidal wetlands	
	Extent of functional tidal channels	
Median distance between pocket estuaries	No common indicator identified	GIS census of pocket estuaries (points) integrated with GIS representation of fish migration pathways (lines)
Distance to nearest natal Chinook salmon river mouth	No common indicator identified	

2.1 Count of Pocket Estuaries Accessible to Juvenile Salmon

Methods

The count of pocket estuaries accessible to juvenile Chinook salmon rearing is monitored as point data in GIS. Remote sensed imagery shows whether pocket estuaries exist and whether there is a tidal hydrologic connection. When both characteristics are observed, i.e., pocket estuary habitat is present and tidal connection is present, then we infer juvenile salmon have access to the pocket estuary. If fish sampling has been conducted at the site and the results verify juvenile salmon presence, then we attribute the pocket estuary point as a site where salmon presence is known and we cite the reference Table 2.1. Many pocket estuaries within the Whidbey Basin have been sampled for fish since 2001 (see skagitcoop.org/programs/research/research-documents-map/) and the Wild Fish Conservancy completed a nearshore fish assessment of several West Whidbey pocket estuaries during 2005 and 2006 (Wait et al 2007).

Accessible pocket estuaries were digitized heads-up on a Wacom DTU-2231 interactive pen display tablet in ArcGIS (v. 10x) where the point was placed at the mouth of the pocket estuary outlet channel. Digitizing scale of points varied based on the actual size of the pocket estuary. Point data results can be compared to MAMP tracked goals in local recovery plans and the regional target for the number of pocket estuaries that are accessible to juvenile salmon.

We used four different image datasets to digitize pocket estuary habitat depending on the geographic coverage of each. The images are: Island County 2014 4-band orthophotos for true color and color infra-red (CIR) images (0.15m pixel size); Skagit County 2013 and 2015 pictometry images (0.15m and 0.1 m pixel size, respectively); Snohomish County 2012 orthophotos for true color (0.3m pixel size), and 2015 National Agriculture Imagery Program (NAIP) orthophotos (1m pixel size) for color infra-red (CIR) images outside of Island County. The time period represented by this polygon data layer of Whidbey Basin and west Whidbey pocket estuaries represents approximately ten years of Puget Sound Chinook recovery plan implementation (circa 2014).

Results and Discussion

We found 35 pocket estuaries accessible to juvenile salmon in the Whidbey Basin and west Whidbey shoreline in 2014 (Figure 2.1). Twenty-five pocket estuaries were within the Whidbey Basin and ten were in West Whidbey. The 25 accessible pocket estuaries within the Whidbey Basin is one more than was identified in 2005 (Beamer et al 2015) and is due to restoring connectivity to Crescent Harbor Saltmarsh. Of the 35 accessible pocket estuaries, 17 in the Whidbey Basin and 4 in West Whidbey have known juvenile salmon presence (Table 2.1).

In addition, fish sampling occurred at or nearby to six other pocket estuary sites. One occurrence of beach seining within Priest Point marsh and its adjacent nearshore did not detect any juvenile salmon (Beamer et al 2006b). Beach seining nearshore habitat adjacent to Camano Country Club, Double Bluff, Lagoon Point, and Maxwelton South all detected juvenile salmon (Beamer et al 2006b, Wait et al 2007).

To our knowledge, no fish sampling has occurred at the six remaining Whidbey Basin sites (Ika Lagoon, Gedney Island NorthEast, Mariners Cove, Mueller Park Lagoon N, Mueller Park Lagoon S, North Bluff Cr Lagoon) or three West Whidbey sites (Bayview Rd, Rocky Point, and Sills Rd).

Table 2.1. Summary of pocket estuaries accessible to juvenile salmon with known juvenile Chinook salmon use. Names of pocket estuaries coincide with names on Figure 2.1.

Basin	Pocket Estuary	Reference
Whidbey	Ala Lagoon	Beamer 2007a
	Arrowhead Lagoon	Beamer et al 2006b
	Crescent Harbor	Beamer et al 2016
	Elger Bay	Heatwole 2004; Kagley et al 2007b
	English Boom Lagoon	Beamer et al 2009a
	Grassers Lagoon	Beamer et al 2006b
	Harrington Lagoon	Beamer et al 2006a; Kagley et al 2007a
	Iverson Marsh	Beamer et al 2006b
	Kiket Lagoon	Beamer et al 2014
	Lone Tree Lagoon	Beamer et al 2003; Beamer et al 2006b; Beamer et al 2009b
	Maylor Marsh	Heatwole 2004
	Race Lagoon	Heatwole 2004; Henderson et al 2007
	Strawberry Point Lagoon	2016 SRSC unpublished data
	Sunnyshore Acres	Beamer et al 2006b
	Triangle Cove	Beamer et al 2006b
	Tulalip Bay	Beamer et al 2006b
	Turners Bay	Beamer et al 2006b; Beamer et al 2007b
West Whidbey	Cultus Bay	Wait et al 2007
	Deer Lagoon	Wait et al 2007
	Keystone Harbort	Wait et al 2007
	Lake Hancock	Wait et al 2007

Figure 2.1. West Whidbey Island and Whidbey Basin pocket estuaries that were accessible to juvenile Chinook salmon in 2014. Red lines are fish migration pathways used for landscape position analysis and blue stars represent river mouths (see section 2.3 of this report).

2.2 Accessible Pocket Estuary Area and Extent of Functional Tidal Channels

Methods

Mapping habitat extent

The extent of pocket estuary habitat by type is measured as polygon data. Only pocket estuaries that are determined to be accessible to juvenile salmon are measured. We digitized pocket estuary features heads-up on a Wacom DTU-2231 interactive pen display tablet in ArcGIS (v 10x) at a scale ranging from 1:150 to 1:1,500. We digitized pocket estuary feature types as polygons according to the nested scale classification developed by the RITT Common Framework (i.e. Bartz et al 2013) which has been adopted by the PSP for tracking implementation of Chinook recovery plans. Possible pocket estuary attributes for polygons are shown in Table 2.2. Habitat areas can be summarized by any polygon type, but generally the pocket estuary habitat area accessible to juvenile Chinook salmon would only include intertidal and subtidal polygons. Polygon results can be compared to MAMP tracked goals in local recovery plans and the regional target for the amount of pocket estuary habitat that is to be accessible to juvenile salmon.

We used four different image datasets to digitize pocket estuary habitat depending on the geographic coverage of each. The images are: Island County 2014 4-band orthophotos for true color and color infra-red (CIR) images (0.15m pixel size); Skagit County 2013 and 2015 pictometry images (0.15m and 0.1 m pixel size, respectively); Snohomish County 2012 orthophotos for true color (0.3m pixel size), and 2015 National Agriculture Imagery Program (NAIP) orthophotos (1m pixel size) for color infra-red (CIR) images outside of Island County. The time period represented by this polygon data layer of Whidbey Basin and west Whidbey pocket estuaries represents approximately ten years of Puget Sound Chinook recovery plan implementation (circa 2014).

The basic on-screen habitat mapping of individual pocket estuaries was done at a scale between 1:300 and 1:800 and followed a series of 4 steps to improve accuracy over what is apparent from orthophoto images alone. The steps are:

1. We used high resolution LiDAR (1m pixels) displayed at 1/3-meter intervals to identify unclear boundaries between intertidal vs backshore, backshore vs upland. We generally mapped areas below 3m NAVD88 as intertidal and above 3m as backshore; above 4m was considered upland and not mapped unless it was a known modification within the historic pocket estuary. In such cases, the polygon type may be: 'intertidal fill', 'created', or 'built' depending on the circumstance.
2. We used pictometry's oblique view to better interpret boundaries between habitat types that may be obscured in the normal aerial view. Specific examples include overhead tree canopy or houses on docks which can give a false sense of habitat boundaries.
3. We used Google Earth to aid in mapping boundaries between impoundment vs low tide terrace or tidal marsh vs floating vegetation by examining different air photos taken over the past several years at different tide levels. Having consistency in tidal stage between photo series used to map tidally influenced habitat is important. Specifically, for pocket estuary mapping having photos taken at a tidal stage approaching Mean Low Water (MLW)

allows the surveyor to clearly see channel/impoundment, tidal wetlands, and unvegetated tidal flats. Having photos taken at Mean Lower Low Water (MLLW) or extreme low water (ELW) was not necessary for our purposes.

4. We used 2015 NAIP 4-band orthos displayed as CIR (color-infrared) to aid mapping of vegetated areas vs non-vegetated.

We mapped to the seaward side of barrier beaches to the boundary between beach face and low tide terrace and within pocket estuaries to the upland or human developed boundary.

For the indictor 'pocket estuary area accessible to juvenile salmon' we summed the Table 2.2 habitat types: beach face, channel, impoundment, intertidal wood, low tide terrace, tidal forest, tidal marsh, and tidal scrub shrub for all pocket estuary shore types. These are the habitat types that are tidally inundated and where juvenile fish could directly live when flooded and access prey resources. For this indicator, we only count intertidal and subtidal habitats within the leeward side of the barrier beach. We do not count habitats at elevations higher than MHHW or habitats seaward of barrier beaches as 'pocket estuary area accessible to juvenile salmon.'

Table 2.2. Classification of pocket estuaries based on RITT Common Framework (See Table 11 of Bartz et al 2013) used to attribute GIS polygons of accessible pocket estuaries in the Whidbey Basin (see definitions in Appendix 2).

<table>
<tr><th>Broad habitat</th><th>System type</th><th>System subtype</th><th>Shoreline type</th><th>Habitat type</th></tr>
<tr><td rowspan="3">Nearshore marine</td><td rowspan="2">Drift cell</td><td>Coastal landform</td><td>• Barrier beach</td><td rowspan="3">• Backshore berm
• Backshore colluvium
• Backshore dune
• Backshore wood
• Built
• Channel (intertidal or subtidal)
• Fill (intertidal or subtidal)
• Impoundment (intertidal or subtidal)
• Intertidal wood
• Intertidal fill wood
• Low tide terrace
• Rocky beach
• Rocky platform
• Tidal marsh
• Tidal scrub shrub
• Tidal forest</td></tr>
<tr><td>Pocket estuary</td><td>• Created
• Drowned channel lagoon
• Longshore lagoon
• Stream delta lagoon
• Tidal channel lagoon
• Tidal channel marsh
• Tidal delta lagoon
• Modified</td></tr>
<tr><td>Rocky shoreline</td><td>Rocky pocket estuary</td><td>• Created
• Pocket beach estuary
• Pocket beach lagoon
• Pocket beach tidal marsh
• Modified</td></tr>
</table>

Classification of habitat function

Pocket estuary habitat extent results include areas that may be tidally muted, dredged, filled, armored, and/or covered with overwater structures – each of which is inconsistent with the idea of fully functional habitat for salmon. Moreover, many Whidbey Basin and West Whidbey pocket estuaries bear a human disturbance signal compared to their historic condition. Often this is in the form of truncating the system to some remnant of its historic extent. We utilized findings from an allometric analysis of tidal channel characteristics to address the question whether reducing the size of a pocket estuary from its historic extent is reason to classify the site functionally impaired for salmon. Hood (2007) found no difference in relationships of physical tidal channel metrics with tidal marsh area for tidal marshes adjacent to levees compared to reference marsh sites. The sites adjacent to levees in the Hood study are equivalent to our truncated sites. Thus, under our definition of 'functional' tidal wetland systems, including pocket estuaries, can be considered 'functional' habitat even though they may be reduced from their historic extent, i.e., are truncated.

To infer habitat functionality, we documented the presence or absence of four habitat disturbances: tidal muting structures, dredging, armoring, and over water structures. According to our classification, functional habitat for salmon in pocket estuaries:

- is not hydrologically muted,
- does not have significant wetted areas dredged or tidal wetlands filled, and
- is without extensive coverage of overwater structures or armoring.

We did not quantify the four disturbances for the 35 pocket estuaries monitored, but we did document which sites had tidal muting and extensive modification to their tidal footprint and/or outlet/inlet channel.

Results and Discussion

Pocket estuary extent

Total habitat area accessible to juvenile salmon for the 35 Whidbey Basin and West Whidbey pocket estuaries during 2014 was 626.348 hectares.

Total habitat area accessible to juvenile salmon for the 25 Whidbey Basin pocket estuaries was 409.299 hectares with the smallest site (Strawberry Point Lagoon) having only 0.363 hectares and the largest site (Triangle Cove) having 94.556 hectares (Table 2.3). Since the 2005 inventory, the one new pocket estuary accessible to juvenile salmon – Crescent Harbor Saltmarsh – added another 94.133 hectares of habitat while two other systems (Lone Tree Lagoon, Turners Bay) increased in size due to restoration activities occurring after 2005.

Total habitat area accessible to juvenile salmon for the 10 West Whidbey pocket estuaries was 216.954 hectares with the smallest site (Sills Rd) having only 0.618 hectares and the largest site (Lake Hancock) having 88.065 hectares (Table 2.4).

Appendix 1 shows each of the Whidbey Basin and West Whidbey pocket estuary mapped at the habitat and shore type levels. Text in Appendix 1 associated with each map figure describes trends and disturbances at each site.

Pocket estuary functionality

Overall impairment: Five of the 35 pocket estuaries accessible to juvenile salmon were impaired in 2014 based on extensive dredging, filling, armoring, and overwater structures (Table 2.5). Two of the five impaired sites had tidal muting present (Camano Country Club, Lagoon Point). Three of the five impaired site are in the Whidbey Basin (Camano Country Club, Gedney Island Northeast, Mariners Cove) while the remaining two sites are in West Whidbey (Keystone Harbor, Lagoon Point). The Cultus Bay pocket estuary's southern lobe (aka Sandy Hook) also has extensive dredging, filling, armoring, and overwater structures.

Outlet/inlet channel condition: Twenty-five of the 35 pocket estuaries accessible to juvenile salmon had natural outlet channels that were open to full tidal hydrology in 2014 (Table 2.5). Of the remaining 10 pocket estuaries, one had its outlet channel closed off to tidal hydrology by natural longshore sediment processes (Rocky Point), one had a completely created outlet (Strawberry Point Lagoon), and eight sites had modified outlets. Six of the eight sites with modified outlets had extremely modified conditions where the channel's width was narrower (and usually deeper) than natural channels, and its position was fixed in place with armoring or rock groins. These sites are Camano Country Club, Gedney Island Northeast, Mariners Cove, Keystone Harbor, Lagoon Point, and the Sandy Hook side of Cultus Bay. The two remaining sites were not as modified to the degree of the previous six sites. Crescent Harbor's outlet channel is modified with bridge abutments and likely narrower than a natural channel would be for a 90+ hectare tidal system. Mueller Park Lagoon N appears to be artificially impounded at its mouth with a small built or intertidal fill area.

Tidal footprint condition: Sixteen of the 35 pocket estuaries accessible to juvenile salmon had a natural tidal footprint in 2014, meaning the area exposed to tidal hydrology was not reduced significantly by human causes such as diking or filling (Table 2.5). Of the remaining 19 pocket estuaries, thirteen had tidal footprints significantly reduced in size by human causes (i.e., truncated), one site was created (Strawberry Point Lagoon), and five sites (Camano Country Club, Gedney Island Northeast, Mariners Cove, Keystone Harbor, Lagoon Point) were extensively dredged, filled, and armored.

It was outside our scope of work to estimate how much the tidal footprint was reduced from historic condition for the thirteen truncated sites. Our task was to measure the amount of habitat present in 2014. Also, for our method of classifying pocket estuary functionality, sites can be considered 'functional' habitat even though they may be reduced in size from their historic extent.

Transient pocket estuaries

We found and mapped four pocket estuaries that transiently formed lagoon and open outlet/inlet channel conditions over the Google Earth photo record (1990-2017). These sites are: Double Bluff, Maxwelton South, Rocky Point, and Sills Rd. All four sites are West Whidbey sites and are small in their intertidal extent. They may serve as examples of pocket estuary systems that are not big enough to persist given their drift cell position/condition, sediment grain sizes available, and wave energy dynamics.

We also excluded mapping several other ‘closed outlet/inlet lagoon’ sites also located in West Whidbey (e.g., several systems near Fort Ebey) because there was no evidence in the Google Earth photo record that they ever had open outlet channels.

Whidbey Basin trend 2005 – 2014

Between 2005 and 2014 Whidbey Basin pocket estuary tidal footprint changed from 304.523 hectares in 2005 to 409.299 hectares in 2014, an increase of 104.776 hectares (Table 2.6). Three completed restoration projects are the primary reason for a net increase in pocket estuary habitat. A total of 97.61 hectares was restored over the nine-year period primarily from three projects (Crescent Harbor, Turners Bay, and Lone Tree Lagoon) with Crescent Harbor restoring 94 hectares of historic saltmarsh alone. Gedney Island NorthEast increased pocket estuary tidal footprint, but its 0.4-hectare expansion was of its boat harbor through dredging. Restoration at Ala Spit appears to have reduced the tidal footprint of Ala Lagoon. The removal of rock groins at the south end of the spit may have contributed to increased overwash sediment and thus helped to build the barrier beach thereby reducing the lagoon’s size slightly. A natural change at North Bluff Cr Lagoon was detected where the barrier beach spit lengthened approximately 60 meters northward between 2005 and 2014 creating new pocket estuary channel area. Lastly, it is noteworthy that additional intertidal filling was not detected between the 2005 and 2014 time period.

Differences in methods between years are likely contributing to the 2005 – 2014 trend result in addition to the observed ‘true’ reasons (i.e., restoration, dredging, natural change in spit length) for pocket estuary habitat change. The issue of a methods-based explanation for habitat change can be explored with nineteen sites where only mapping methods changed and there was no obvious natural or human caused change at the site between 2005 and 2014 (Table 2.6). For these sites we observed a median percent change value of 5.74% (±2.99 95% CI) (Figure 2.2) and a decline in percent change by site size (Figure 2.3). Also, most (15 of 19) of the percent change values were in the positive direction, meaning the 2014 mapping effort generally found more habitat than the 2005 mapping effort at each site.

The differences between 2005 and 2014 results for these 19 sites are likely caused by: 1) mapping methods, 2) orthophoto image resolution, and 3) surveyor differences. Obviously, using higher resolution images in 2014 (0.15m pixel size compared to 1.0m) improves accuracy in habitat delineation. The four additional methods steps developed for the 2014 survey also improves accuracy and consistency of mapping. These two improvements alone (methods, images) leads us to believe the 2014 results are more accurate than the 2005 results.

We can’t unravel the effect of surveyor differences in this study. Separate experiments using the exact same methods and images but different surveyors would reveal possible surveyor influence on results. We suspect surveyor variability adds a small amount of noise in results that may hinder small scale (i.e. at the individual habitat polygon level) and small magnitude (e.g., < 0.1 hectares) interpretation of results but would likely not be a factor in detecting effects of restoration projects or habitat loss signals at the full site or basin level. We have this opinion based on our experience of detecting six sites that were either restored, dredged, or changed naturally (Table 2.6).

Table 2.3. Summary of pocket estuary habitat area accessible to juvenile salmon in hectares by habitat type and site within the Whidbey Basin 2014.

Basin	Site	beach face	intertidal wood	low tide terrace	tidal forest	tidal marsh	tidal scrub shrub	channel	impound-ment	Total
Whidbey Basin	Ala Lagoon	0.608	0.149	5.869		0.337		0.073	0.013	7.048
	Arrowhead Lagoon		0.185	0.177		1.741		0.115	0.133	2.350
	Camano Country Club			1.534		0.044			3.734	5.312
	Crescent Harbor		2.677	55.798		9.168	12.326	2.180	11.985	94.133
	Elger Bay	0.032	15.069	1.764	0.256	8.437	1.322	0.699	0.071	27.650
	English Boom Lagoon		0.552	0.022		0.660		0.042	0.076	1.353
	Gedney Island NorthEast								1.843	1.843
	Grassers Lagoon	0.190	0.109	5.318		0.715		0.066	1.347	7.745
	Harrington Lagoon		0.074	0.374		0.375		0.043	2.594	3.460
	Ika Lagoon		0.519			5.798	0.471	0.072	0.003	6.862
	Iverson Marsh	0.012	0.490	1.198		7.508		0.402		9.609
	Kiket Lagoon			0.114		0.310		0.005	0.746	1.174
	Lone Tree Lagoon			0.200		0.726		0.199	1.313	2.438
	Mariners Cove			2.250				0.015	2.205	4.470
	Maylor Marsh		0.708	1.170		20.396		0.683	0.830	23.787
	Mueller Park Lagoon N			0.093		0.052		0.016	0.845	1.006
	Mueller Park Lagoon S		0.018	0.045		0.209		0.058	1.131	1.461
	North Bluff Cr Lag	0.039	0.469	0.397		2.103		0.085	1.009	4.102
	Priest Point		0.154	0.501		0.340		0.053		1.048
	Race Lagoon	0.070	1.630	2.223		4.096		0.917	6.276	15.212
	Strawberry Point Lagoon	0.201	0.022	0.032		0.002		0.002	0.103	0.363
	Sunnyshore Acres		2.508	0.547		1.693		0.181	0.015	4.944
	Triangle Cove		1.877	79.351		5.779		7.476	0.072	94.556
	Tulalip Bay	0.075	0.484	52.386		0.755		0.248	10.933	64.881
	Turners Bay	0.078	0.873	15.192		4.978	0.012	0.509	0.850	22.492

Table 2.4. Summary of pocket estuary habitat area accessible to juvenile salmon in hectares by habitat type and site along the western Whidbey Island shore 2014.

Basin	Site	beach face	intertidal wood	low tide terrace	tidal forest	tidal marsh	tidal scrub shrub	channel	impound-ment	Total
West Whidbey	Bayview Rd	0.158	0.353	4.551		1.805		0.818	0.130	7.814
	Cultus Bay		0.297	39.417		7.950		2.069	2.886	52.619
	Deer Lagoon		0.431	26.523		5.654		5.419	4.396	42.423
	Double Bluff	0.007	0.008	0.322				0.074	0.338	0.749
	Keystone Harbor	0.829	0.092	0.968					3.942	5.831
	Lagoon Point	0.105		3.321		0.688		0.195	7.555	11.863
	Lake Hancock		7.256	8.649		39.981	10.787	3.169	18.224	88.065
	Maxwelton South	0.164	0.188	0.435		0.056		0.220	0.176	1.240
	Rocky Point		0.870	4.075					0.787	5.732
	Sills Rd			0.378				0.034	0.207	0.618

Table 2.5. Summary of pocket estuary outlet/inlet and tidal footprint conditions in 2014. Pocket estuaries shown in **bold** font are significantly impaired for juvenile salmon habitat function.

Basin	Site	2014 condition	
		Outlet/inlet channel condition	Tidal footprint compared to historic
Whidbey Basin	Ala Lagoon	natural	natural
	Arrowhead Lagoon	natural	truncated
	Camano Country Club	**modified**	**extensively dredged, armored, &filled**
	Crescent Harbor	modified	truncated (partially filled)
	Elger Bay	natural	natural
	English Boom Lagoon	natural	truncated
	Gedney Island NorthEast	**modified**	**extensively dredged, armored, &filled**
	Grassers Lagoon	natural	truncated
	Harrington Lagoon	natural	truncated
	Ika Lagoon	natural	natural
	Iverson Marsh	natural	truncated
	Kiket Lagoon	natural	truncated
	Lone Tree Lagoon	natural	natural
	Mariners Cove	**modified**	**extensively dredged, armored, &filled**
	Maylor Marsh	natural	truncated
	Mueller Park Lagoon N	modified	natural
	Mueller Park Lagoon S	natural	natural
	North Bluff Cr Lag	natural	truncated
	Priest Point	natural	truncated
	Race Lagoon	natural	natural
	Strawberry Point Lagoon	created	artificial
	Sunnyshore Acres	natural	natural
	Triangle Cove	natural	natural
	Tulalip Bay	natural	natural
	Turners Bay	natural	truncated
West Whidbey	Bayview Rd	natural	natural
	Cultus Bay	modified (south side)	truncated (north side) & dredge/filled south side)
	Deer Lagoon	natural	truncated
	Double Bluff	transient system, natural outlet in 2014	natural
	Keystone Harbor	**modified**	**extensively dredged, armored, &filled**
	Lagoon Point	**modified**	**extensively dredged, armored, &filled**
	Lake Hancock	natural	natural
	Maxwelton South	transient system, natural outlet in 2014	natural
	Rocky Point	transient system, closed outlet in 2014	natural
	Sills Rd	transient system, natural outlet in 2014	natural

Table 2.6. Whidbey Basin pocket estuary trend for habitat area accessible to juvenile salmon 2005 – 2014.

Change type	Site	Hectares of habitat			% change	Comments
		Year 2005	Year 2014	Change		
Mapping methods	Harrington Lagoon	3.457	3.46	0.003	0.1%	
	Mariners Cove	4.461	4.47	0.009	0.2%	
	Tulalip Bay	64.725	64.881	0.156	0.2%	
	Priest Point	1.061	1.048	-0.013	1.2%	
	Triangle Cove	93.212	94.556	1.344	1.4%	
	Grassers Lagoon	7.540	7.745	0.205	2.7%	
	Elger Bay	26.823	27.65	0.827	3.1%	
	Ika Lagoon	6.619	6.862	0.243	3.7%	
	Iverson Marsh	9.194	9.609	0.415	4.5%	
	Mueller Park Lagoon S	1.382	1.461	0.079	5.7%	
	Camano Country Club	5.706	5.312	-0.394	6.9%	
	Maylor Marsh	22.197	23.787	1.590	7.2%	Between 2011 and 2014 pilings were removed but the action had no detectable influence on tidal footprint extent
	Strawberry Point Lagoon	0.337	0.363	0.026	7.6%	
	Arrowhead Lagoon	2.162	2.35	0.188	8.7%	
	Kiket Lagoon	1.289	1.174	-0.115	8.9%	
	Sunnyshore Acres	4.503	4.944	0.441	9.8%	
	Race Lagoon	13.714	15.212	1.498	10.9%	
	Mueller Park Lagoon N	1.138	1.006	-0.132	11.6%	
	English Boom Lagoon	1.067	1.353	0.286	26.8%	Some restoration of connectivity was completed at the site circa 2006/7 but it had no detectable influence on tidal footprint extent
Mapping methods and real changes	Ala Lagoon	8.206	7.048	-1.158	14.1%	**Restoration:** removed rock groins which may have contributed to overwash sediment building the barrier beach in places thus reducing pocket estuary extent
	Crescent Harbor	0.000	94.133	94.133	Not applicable	**Restoration**: tide gate replaced with bridge in 2009
	Gedney Island NorthEast	1.439	1.843	0.404	28.1%	**Dredging**: boat harbor area expanded by 0.4333 hectares between 2011 and 2012
	Lone Tree Lagoon	2.216	2.438	0.222	10.0%	**Restoration**: restored 0.125 ha in 2006 (blocking culvert replaced with bridge)
	North Bluff Cr Lag	3.330	4.102	0.772	23.2%	**Natural change**: spit lengthened ~ 60 meters north creating new channel area; backshore was better mapped as intertidal wood in the 2014 survey
	Turners Bay	18.745	22.492	3.747	20.0%	**Restoration**: road removal circa 2008 restored 3.352 hectares to tidal inundation
	Total	**304.523**	**409.299**	**104.776**	**34.4%**	

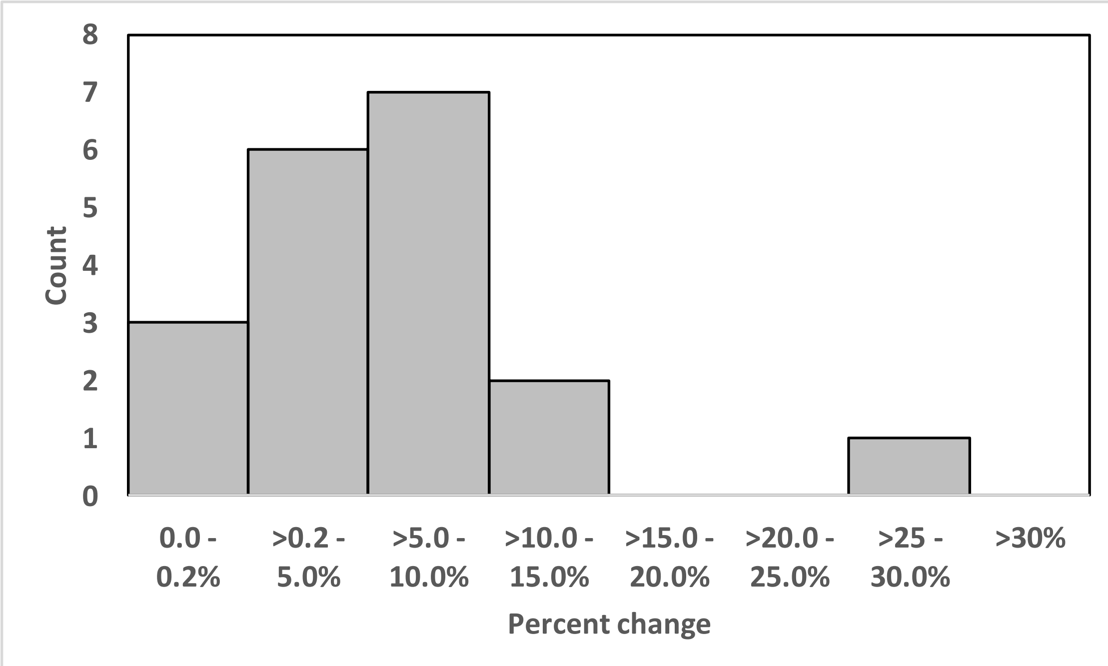

Figure 2.2. Frequency distribution of 'percent change' values for 19 pocket estuaries where only mapping methods changed and there was no obvious natural or human caused change at the site between 2005 and 2014.

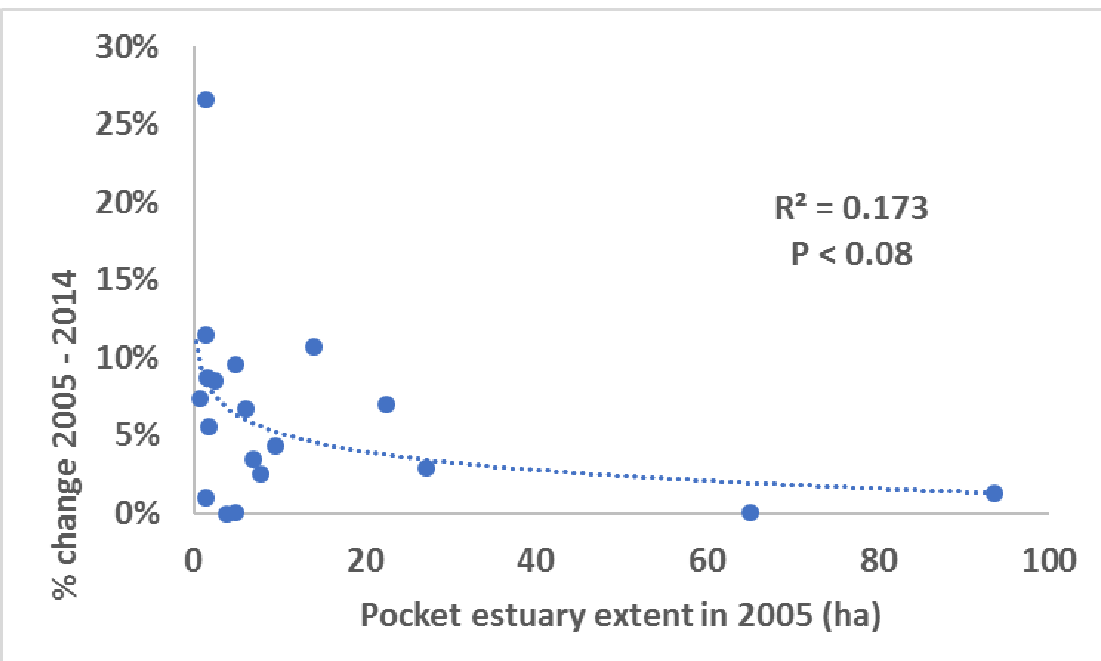

Figure 2.3. Relationship of 'percent change' and pocket estuary extent for 19 pocket estuaries where only mapping methods changed and there was no obvious natural or human caused change at the site between 2005 and 2014.

2.3 Landscape Position of Pocket Estuaries Accessible to Juvenile Salmon

Methods

We measured two indicators under the topic of landscape position of pocket estuaries: 1) *distance of pocket estuaries from natal Chinook salmon estuaries*, and 2) *distance between pocket estuaries*. All indicators are measured only for pocket estuaries that are accessible to juvenile salmon as identified in section 2.1 of this report. Both metrics are measurements of juvenile salmon habitat connectivity.

Pocket estuary distance indicators account for the pathway distance a fish must travel between pocket estuaries or from its natal river estuary to a pocket estuary. These distance indicators do not account for the complexity (i.e., branching, alternative pathways) of said pathway. We only report the shortest and most direct pathway for distance metrics.

To quantify pocket estuary distance indicators, we use GIS line data to depict the pathways fish must take to go from one place to another (e.g., a river mouth to a pocket estuary; one pocket estuary to another pocket estuary). Line data are digitized based on prevailing tidal current direction within the landscape according to a PNNL hydrodynamic model (Yang & Khangaonkar 2007) and assumptions that fry-sized juvenile salmon follow shoreline areas once in the nearshore. Chinook salmon fry movement assumptions are discussed in section 6.1 of Beamer et al (2005). The fish migration pathways used to quantify pocket estuary distance for Whidbey Basin and West Whidbey pocket estuaries in year 2014 are shown as lines in Figure 2.1

Results and discussion

All results are for pocket estuaries accessible to juvenile salmon in 2014.

Nearest natal Chinook salmon river: For the Whidbey Basin, the distance individual pocket estuaries are from the nearest natal Chinook salmon river ranges from 0.9 to 54.4 km (Figure 2.4, top panel). Ika Marsh is the closest to a natal river while Race Lagoon is the furthest. North Bluff Cr Lagoon, Harrington Lagoon, and Race Lagoon are all more than 50 km from the nearest Chinook salmon river within the Whidbey Basin. The median distance of pocket estuaries to the nearest natal Chinook salmon river is 13.9 km for the Whidbey Basin. For West Whidbey, the distance individual pocket estuaries are from the nearest natal Chinook salmon river ranges from 29.2 to 56.6 km (Figure 2.5, bottom panel). Rocky Point is the closest to a natal river while Lake Hancock is the furthest. The median distance of pocket estuaries to the nearest natal Chinook salmon river is 31.6 km for West Whidbey. Fifteen of the 25 Whidbey Basin pocket estuaries are nearest to the Skagit River whereas only six and four pocket estuaries are nearest to the Snohomish and Stillaguamish Rivers, respectively (Table 2.7). Eight of the ten West Whidbey pocket estuaries are nearest to the Snohomish River whereas only two and zero pocket estuaries are nearest to the Skagit and Stillaguamish Rivers, respectively.

Nearest neighboring pocket estuary: For the Whidbey Basin, the distance between nearest individual pocket estuaries ranges from 0.2 to 22.3 km (Figure 2.4, bottom panel). Mueller Park Lagoons North and South are the closest together at 0.2 km. Elger Bay is furthest from any other pocket estuary, with Sunnyshore Acres its closest neighbor at 22.3 km away. The median distance between pocket estuaries is 3.96 km. For West Whidbey, the distance between nearest individual pocket estuaries ranges from 1.9 to 16.9 km (Figure 2.5, top panel). Deer Lagoon and Bayview are the closest together at 1.9 km. Rocky Point is furthest from any other pocket estuary, with Ala Lagoon its closest neighbor at 16,9 km away. The median distance between pocket estuaries is 4.1 km.

Table 2.7. Count of pocket estuary by basin to their nearest natal Chinook salmon river.

River	West Whidbey	Whidbey Basin
Skagit	2	15
Snohomish	8	6
Stillaguamish	0	4

Connectivity of habitat is important to Chinook salmon recovery because the ease with which fish can find available habitat influences their survival. Juvenile Chinook salmon have been shown to move from one pocket estuary system to another (adjacent) pocket estuary system (Beamer et al 2013), suggesting connectivity of pocket estuaries within a larger landscape is important ecologically. Also, the location of pocket estuaries in proximity to the source of outmigrating Chinook salmon fry (i.e. their natal river) explains much of the variability in juvenile Chinook salmon abundance and presence in pocket estuaries (Beamer et al 2006b) and small streams draining into the nearshore system (Beamer et al 2013). Sites closer to the source of fish have more fish and higher presence rates. These connectivity concepts have been incorporated in local salmon recovery plans for habitat restoration and protection. Tracking connectivity of pocket estuaries is an important habitat status and trend metric. Landscape position results can be compared to MAMP tracked goals in local recovery plans and a regional target for connectivity of pocket estuaries with each other and the source of the fish that rear in them (e.g., the natal Chinook rivers).

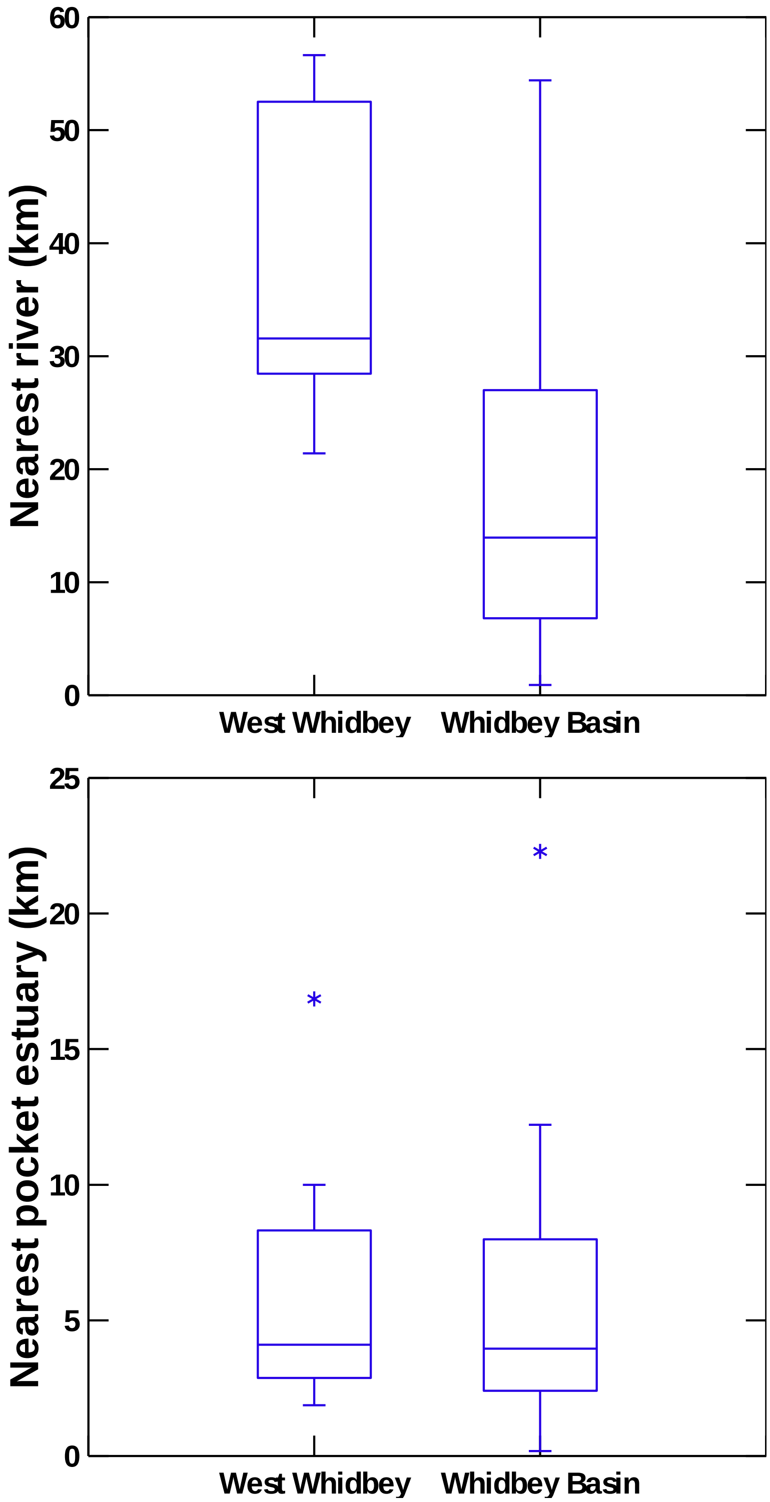

Figure 2.4. Boxplot results for pocket estuaries accessible to juvenile salmon in 2014: distance from nearest natal river (top panel) and distance between pocket estuaries (bottom panel). Boxes show the median, 25th and 75th percentiles within the 'box.' Whiskers show the 5th and 95th percentiles. Stars are observations that are still within the full distribution.

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Appendix 1. Pocket estuary figures and site notes

Map figures, along with any text, are presented by basin (Whidbey Basin, West Whidbey Island shore) and then alphabetically by site name. Text often provides a temporal context for each site based on viewing the Puget Sound historical survey ‘T-sheets’ and Google Earth photo records which offer photos over the 1990 to 2017 time period.

Whidbey Basin Sites

Ala Lagoon

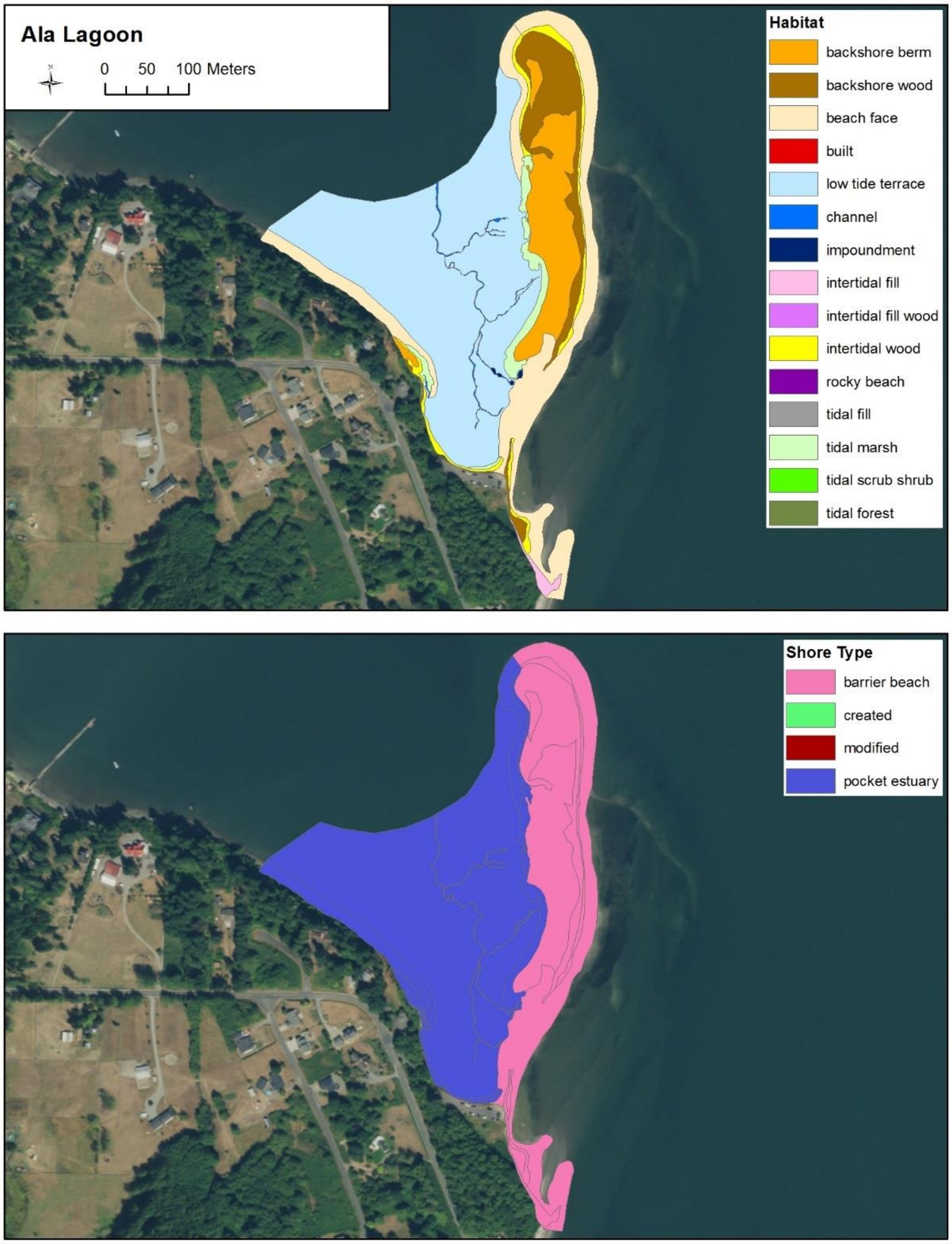


Figure A1. Nearshore habitat within the pocket estuary at Ala Lagoon, 2014.

Ala Lagoon shows significant over wash sediment transport and deposition near its south end just down drift of the rock groin. There is also evidence of spit formation offshore of the existing spit in this area.

Arrowhead Lagoon

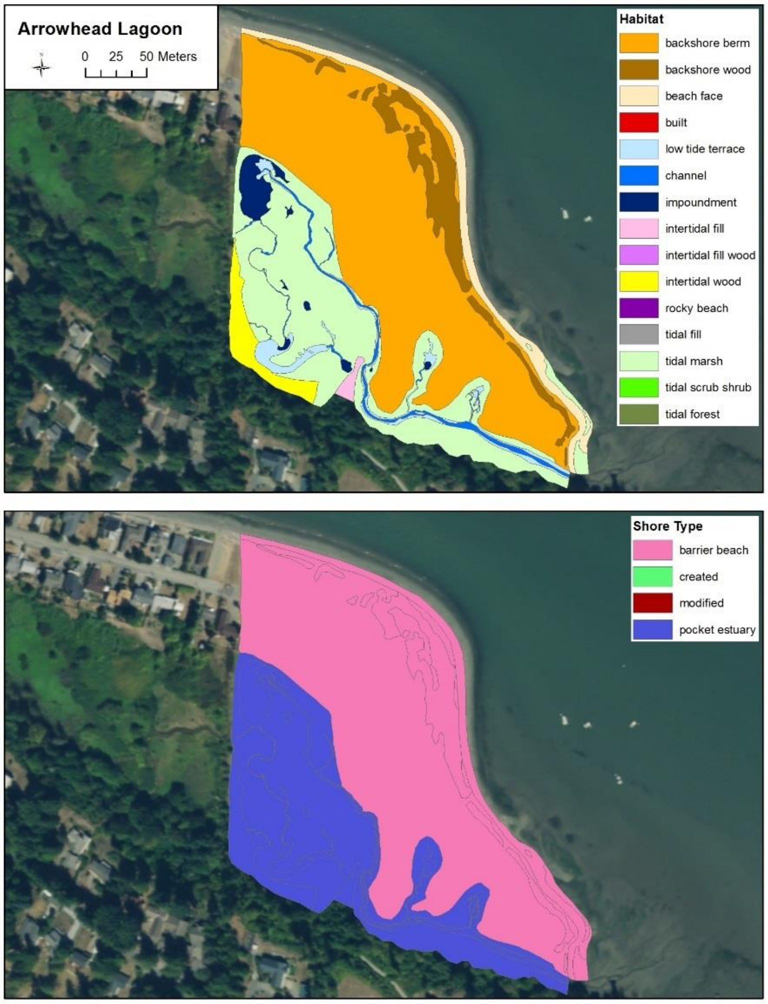


Figure A2. Nearshore habitat within the pocket estuary at Arrowhead Lagoon, 2014.

In 1990 there was no evidence of driving on the spit and the bridge over the channel was not present. By 2005 the access road to the area had been built and the bridge was present with evidence that vehicles had extensively driven on the spit. The size of impoundments at low tide appears to vary over the photo record possibly due to the amount of freshwater influencing the system. In September 2006 the impoundments are quite large while in 2014 the impounded areas are much smaller and forming marsh vegetation on previously unvegetated flats (mapped as low tide terrace). Also, on the SE edge of the barrier beach a small corridor of tidal marsh has formed at a lower elevation (outside) of the beach face. This feature was present in 2005 but had eroded significantly by 2009 and is now well formed in 2014. Lastly, backshore wood on the spit varies in position but has been reduced over time. The earliest photos (1990 and others) are too poor of resolution to observe wood well. However, it is obvious the density of backshore wood has been reduced (insert figure of 2007-2017) probably due to human causes (fire wood collection?). The exact locations of wood accumulations seem to vary, likely due to storm events.

Camano Country Club

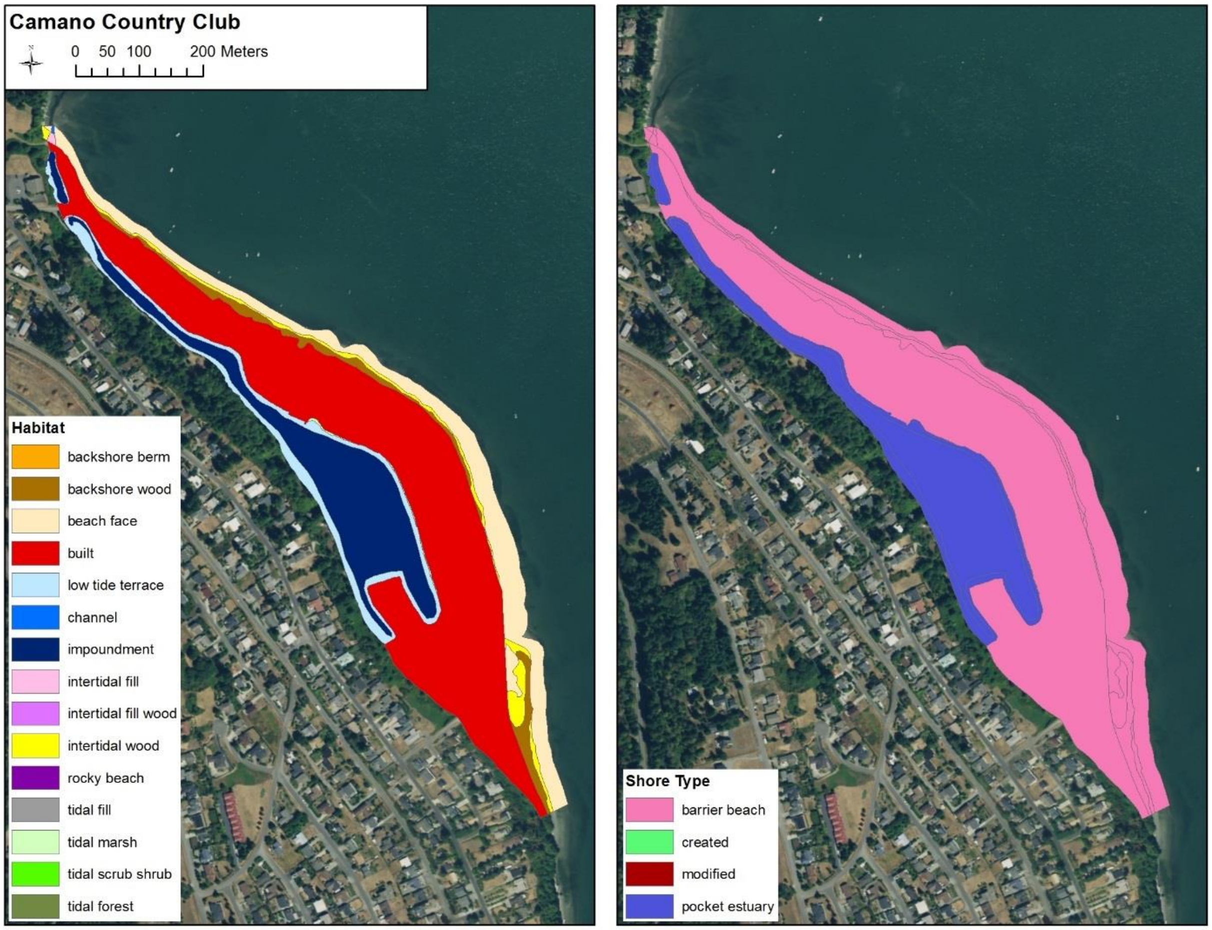


Figure A3. Nearshore habitat within the pocket estuary at Camano Country Club, 2014.

This site is present on the T-sheet. It is currently heavily build inside and out with two culverts impounding water within the lagoon. The Google Earth photo record shows a small transient spit forms near the SE corner of the barrier beach with a small backwater habitat occasionally present. This feature was present in 2011-2014, but not 2015-2017, 2005-2009, or 1990.

Crescent Harbor

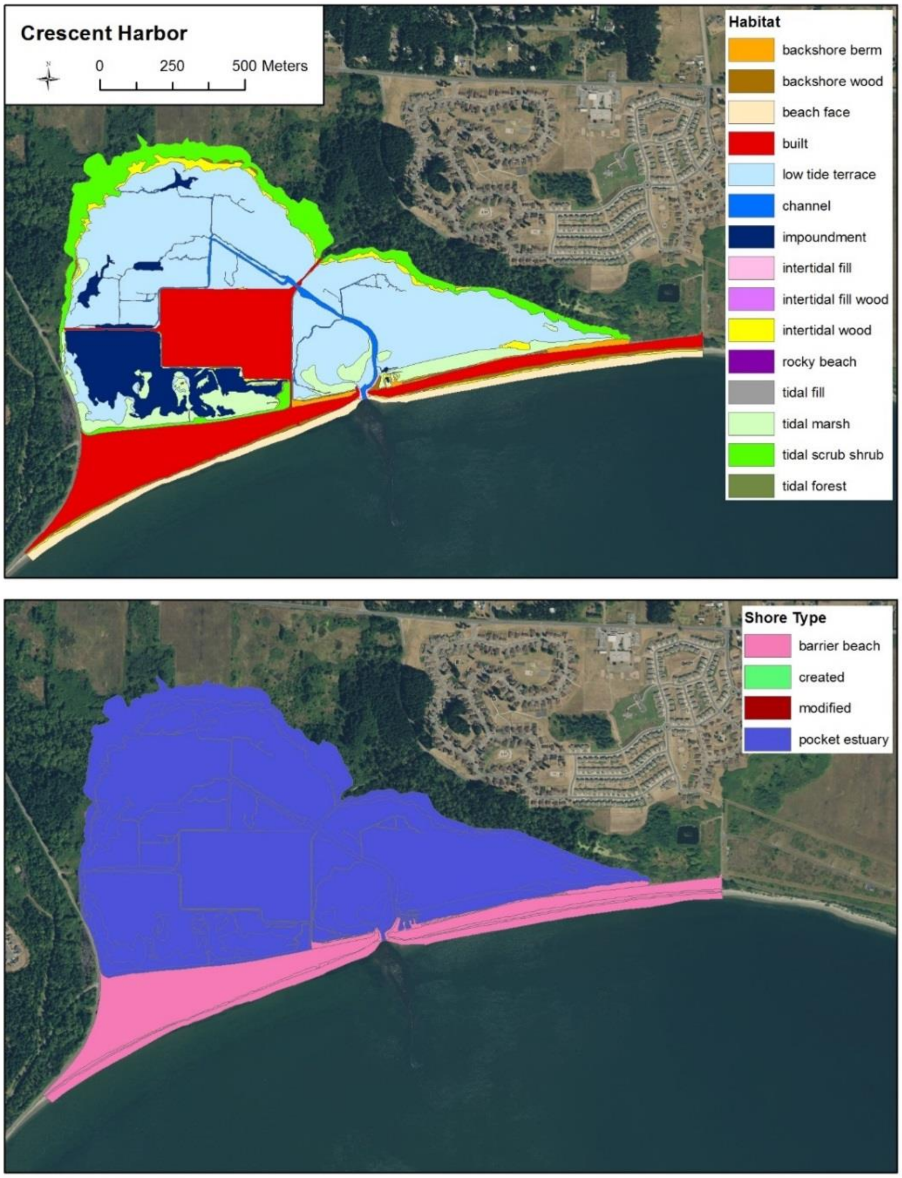


Figure A4. Nearshore habitat within the pocket estuary at Crescent Harbor, 2014.

Crescent Harbor Saltmarsh was restored in 2009 when the outlet/inlet channel tide gate was replaced by a bridge and improvements to connectivity within the site also occurred. The extensive low tide terrace area is transitioning due to restoration. Previous shrub or freshwater marsh areas are in the process of shifting to salt tolerant vegetation. Thus, in 2014 we observed dead marsh and dead scrub shrub vegetation. There are also many shallow channels and impoundments that we did not map due to their poorly formed nature. In future years, we expect these areas will have increased channel length and area as the unvegetated tidal flats fills in with vegetation and channel head cutting occurs. The restored tidal wetland also currently surrounds a sewer treatment plant and hosts a road on its barrier beach.

Elger Bay

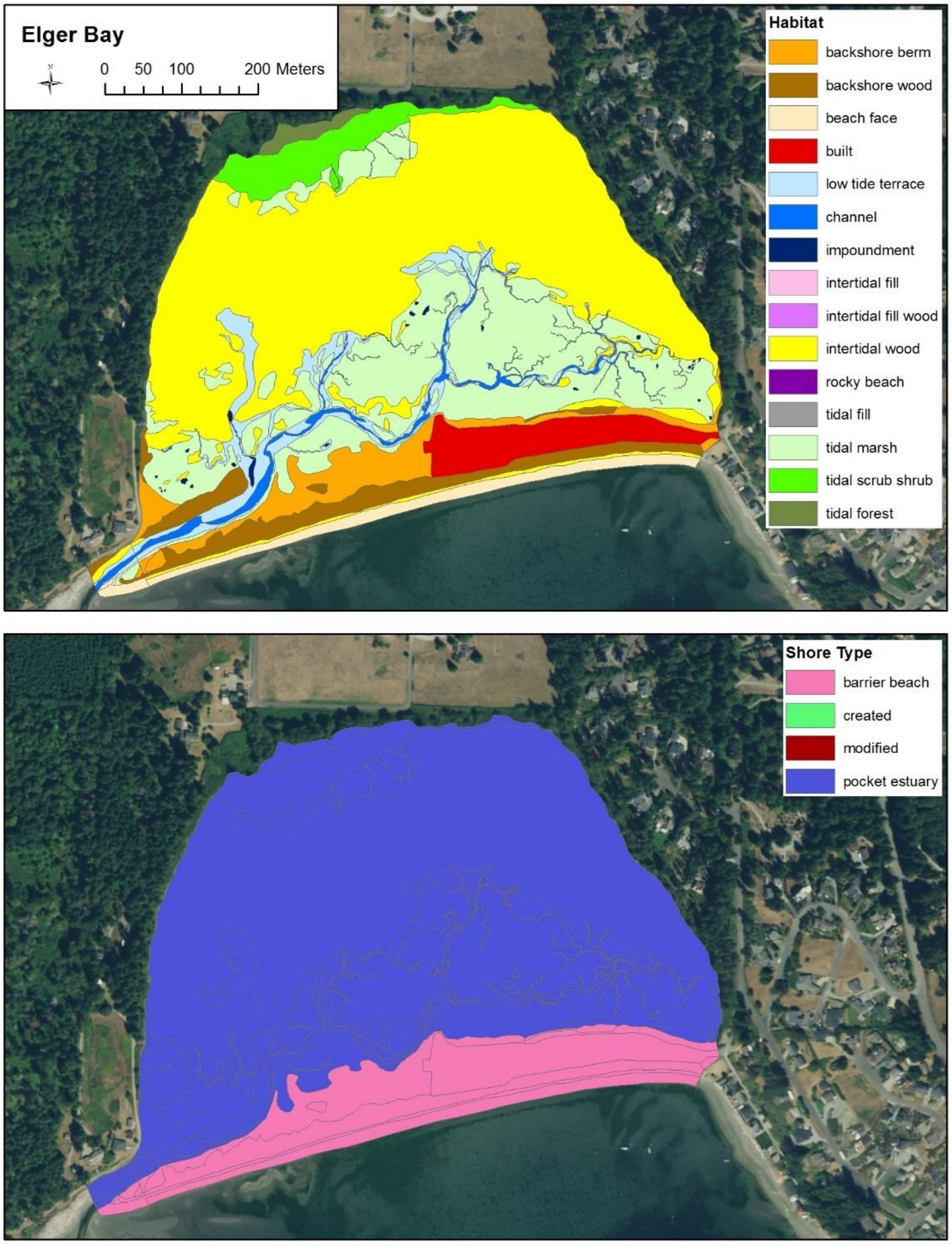
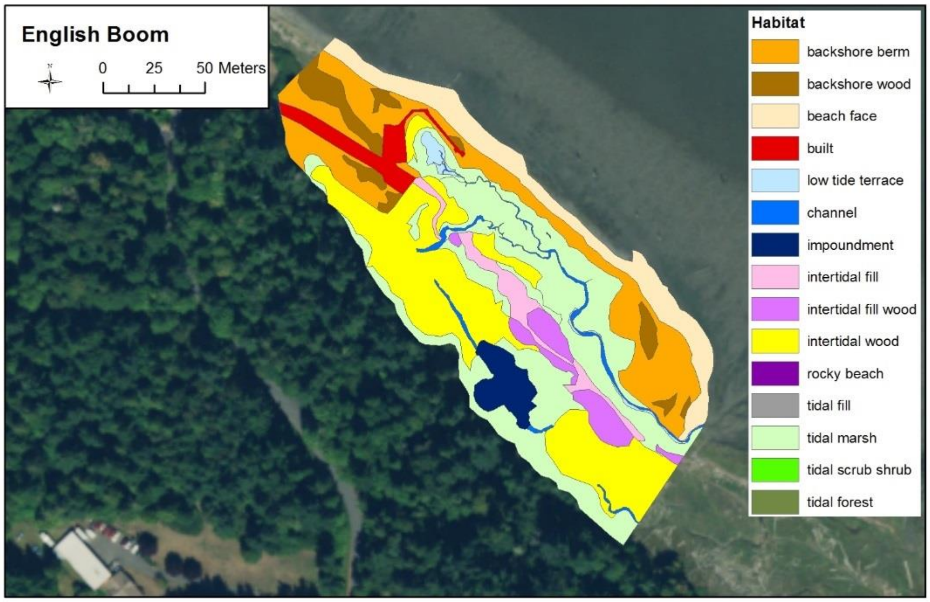


Figure A5. Nearshore habitat within the pocket estuary at Elger Bay, 2014.

The eastern side (350+ m of 790 m = 44%) of the Elger Bay spit had two or three residences in 1990. By 2006, there were seven houses and the spit was fully built. In 2014 there were still seven houses and all residences share a continuous bulkhead. Over the Google Earth photo record the inlet/outlet channel has remained roughly in the same alignment with some fluctuation below the beach face elevation. Over the photo record, much of the lagoon/marsh area is filled with driftwood.

English Boom Lagoon



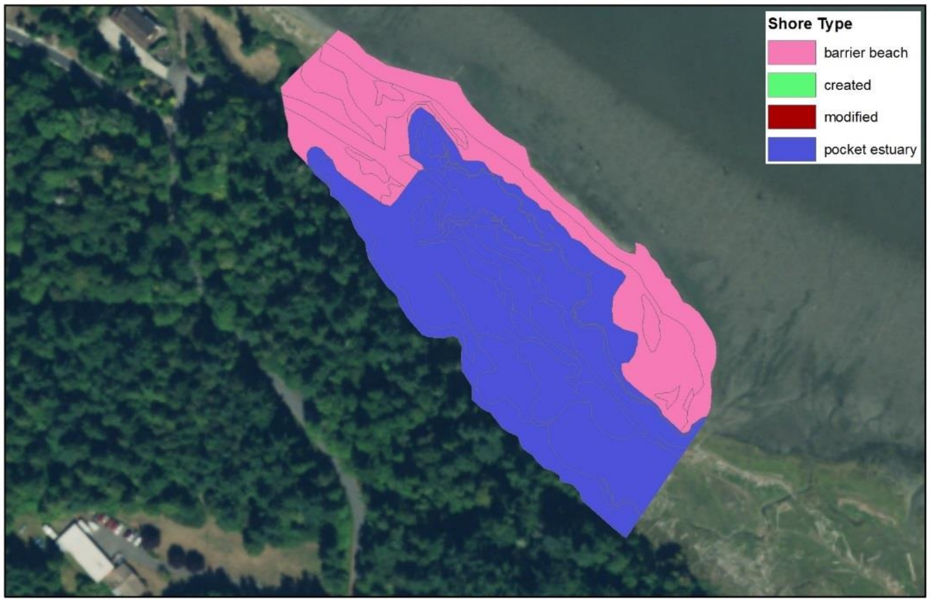


Figure A6. Nearshore habitat within the pocket estuary at English Boom Lagoon, 2014.

English Boom lagoon is located at the intersection of longshore drift cell processes and riverine delta processes. Also, early land use of the area appears to include a low-tech dike bisecting the marsh from the northwest to the southeast. We mapped the apparent high area within the marsh as intertidal fill. The T-sheet shows the area as tidal wetland but gives no resolution between longshore and riverine processes. The current barrier beach spit does not appear very active, growing only 16.5 meters in length (toward the SE) from 1990 to 2017 (0.6m/year).

Gedney Island NE

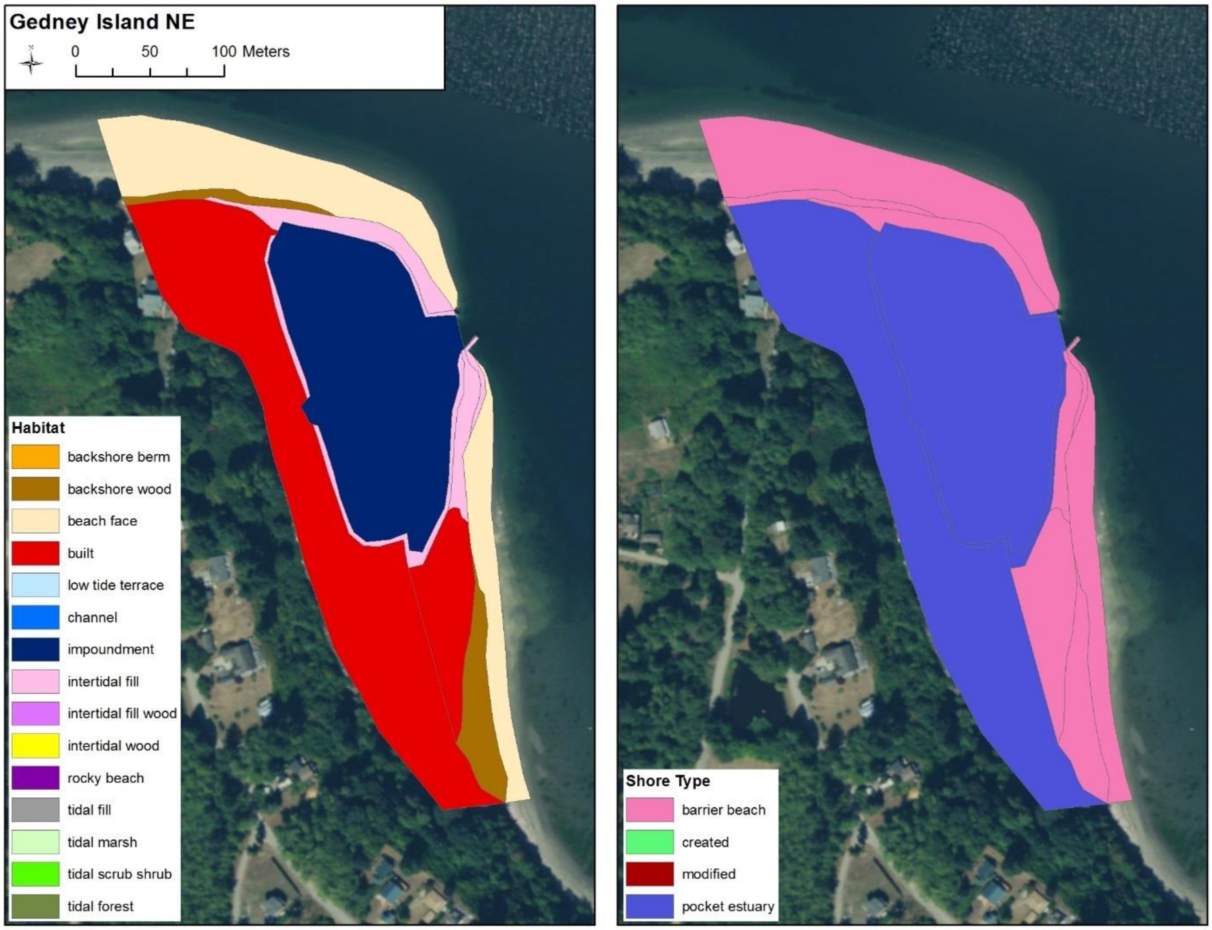


Figure A7. Nearshore habitat within the pocket estuary at Gedney Island NE, 2014.

This site is highly modified with dredging, rock jetties, and overwater structures. The T-sheet for this area did not map Gedney Island. We would need to look at photos earlier than 1990 to determine what natural shoreline conditions were at this site. Between 2011 and 2012, the harbor was expanded by 0.4333 hectares of intertidal/subtidal area.

Grassers Lagoon

Figure A8. Nearshore habitat within the pocket estuary at Grassers Lagoon, 2014.

The outlet location is stable over the Google Earth photo record (1990-2017) and drains from the NW to SE along the eastern spit.

Harrington Lagoon

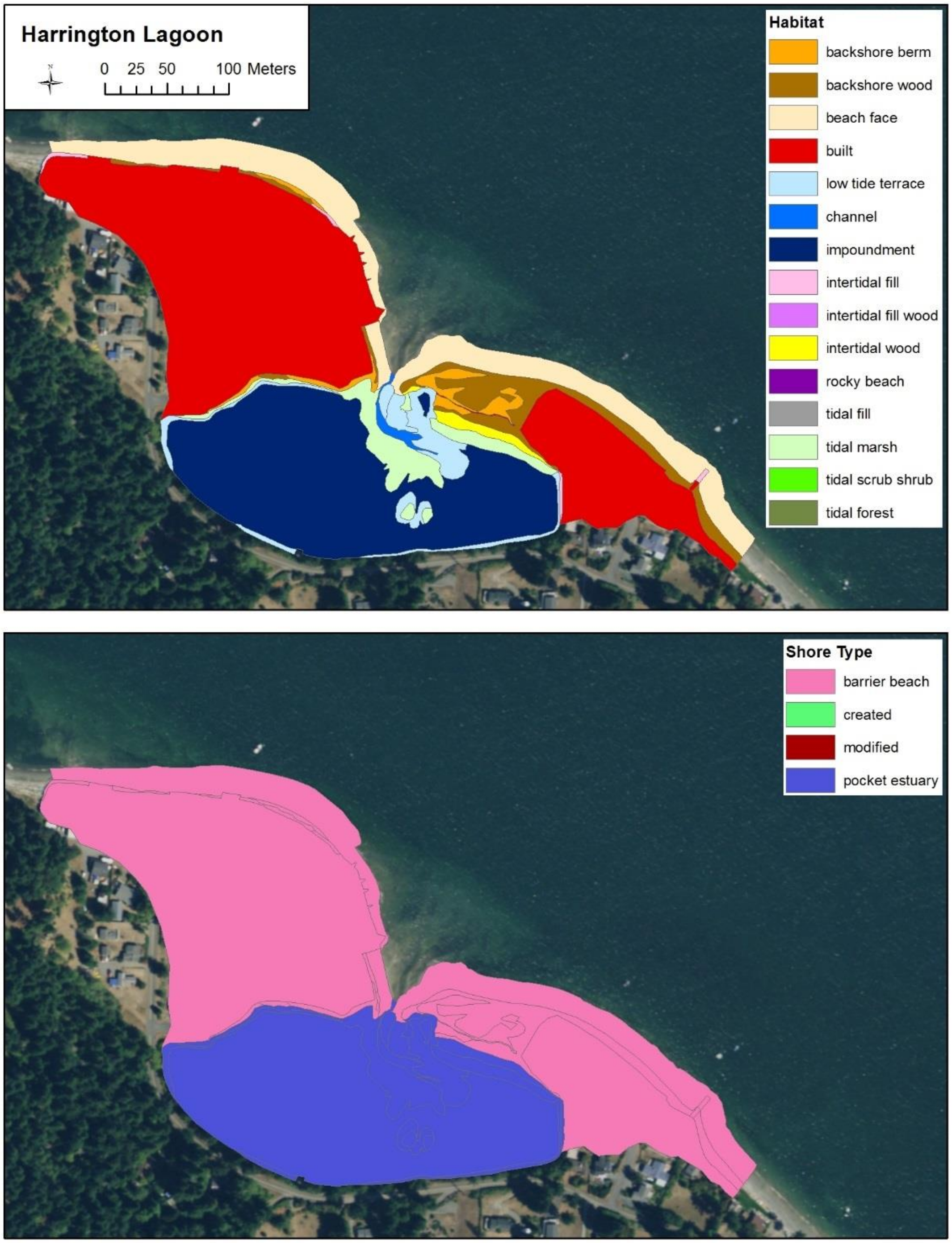


Figure A9. Nearshore habitat within the pocket estuary at Harrington Lagoon, 2014.

On the T-sheet, the outlet/inlet channel is oriented to drain northward and is located on the northwest side of the lagoon. The northwestern spit and historic outlet alignment have been developed with houses. Much of the southeast spit is now developed and the outlet now drains from the center of the lagoon.

Ika Lagoon

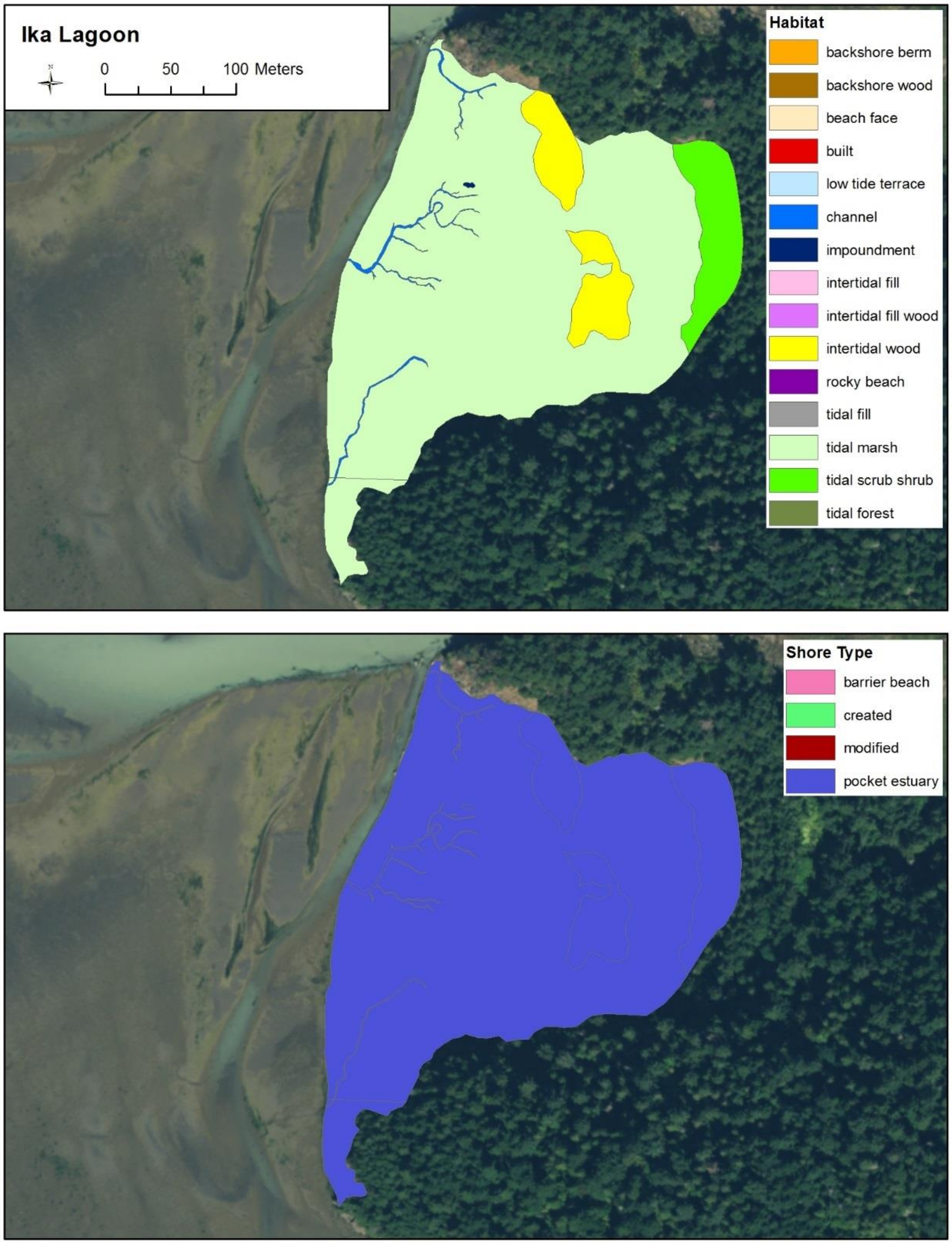


Figure A10. Nearshore habitat within the pocket estuary at Ika Lagoon, 2014.

Ika Lagoon, or more correctly Ika Marsh, is being absorbed into the Skagit tidal delta as the Skagit's North Fork marshes prograde westward completely encircling Ika Island.

Iverson Marsh

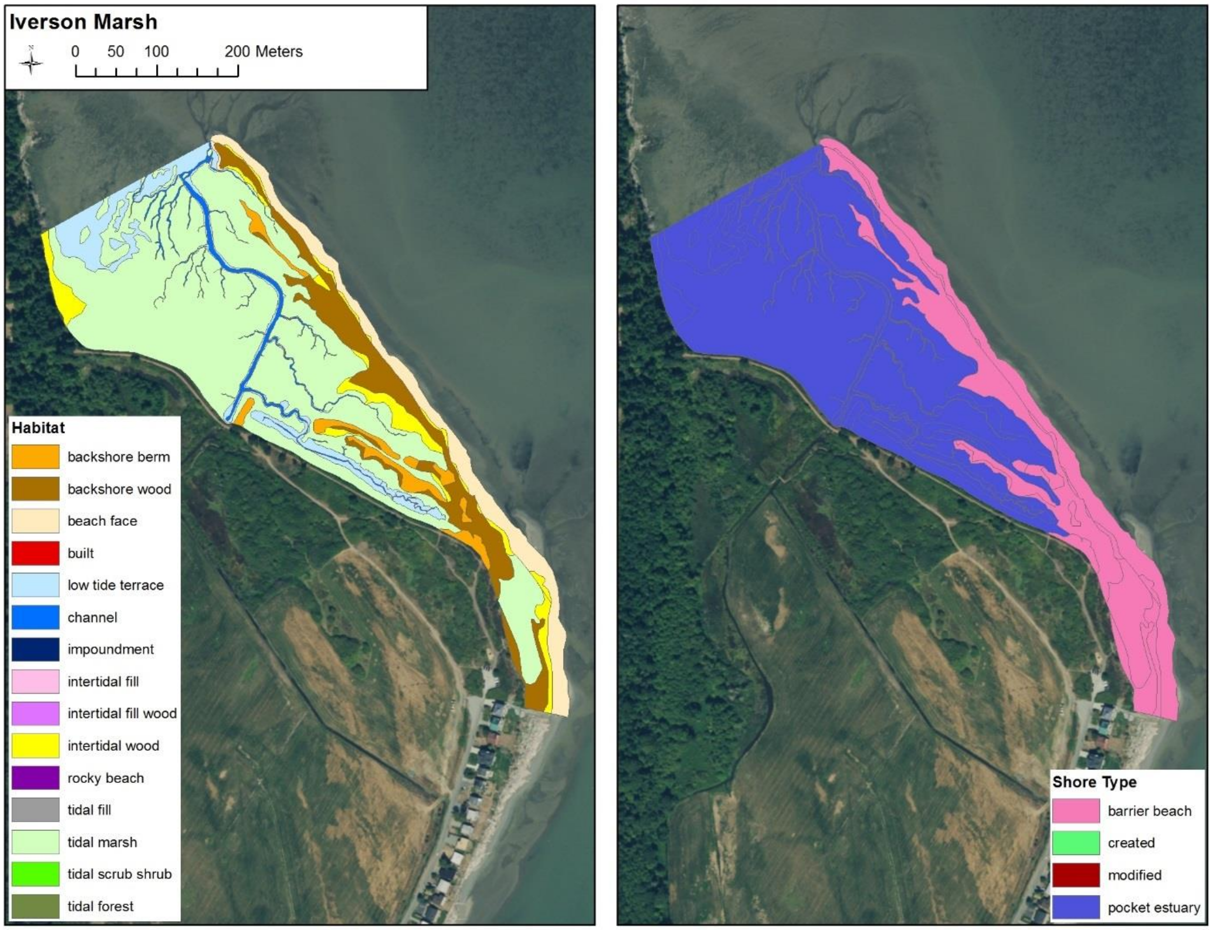
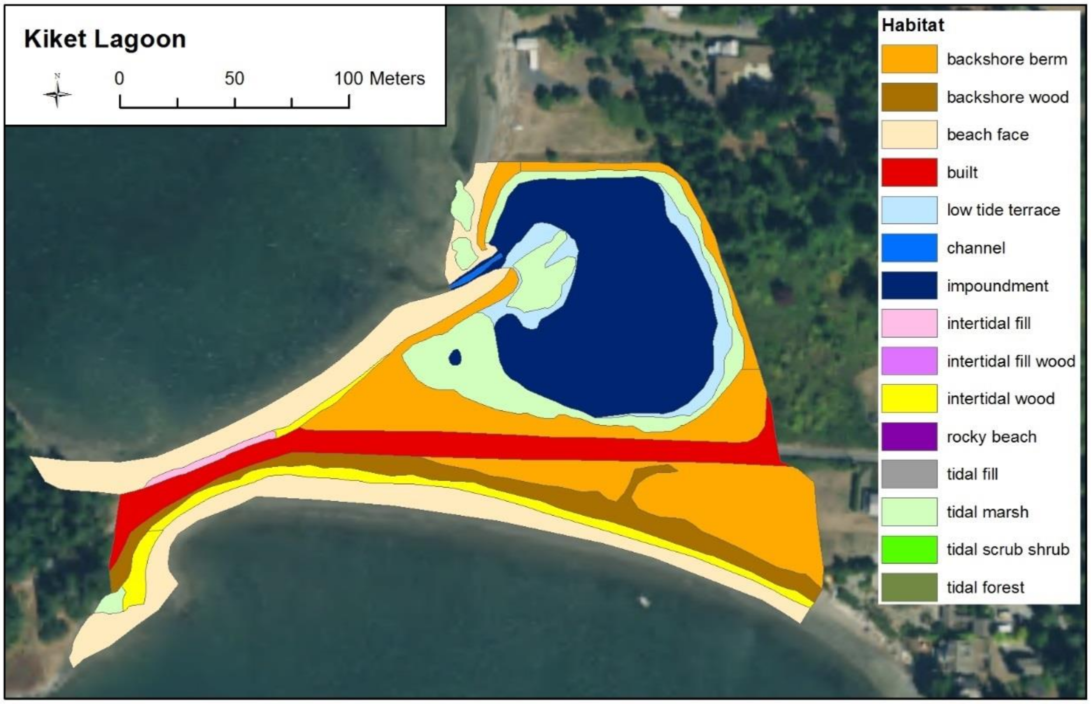


Figure A11. Nearshore habitat within the pocket estuary at Iverson Marsh, 2014.

Iverson Marsh is shown on the T-sheet as a large system located just north of Triangle Cove within Port Susan. Approximately 20% of the historic system remains or has reformed during its current condition. This site is located near the end of a drift cell where it merges into fluvial sediment processes of the Stillaguamish River delta. The spit has grown approximately 50 meters northward over the 27-year period of the Google Earth photo record (1990-2017). Also, a completely separate pocket estuary system may be forming on the south end, just north of the beach houses.

Kiket Lagoon



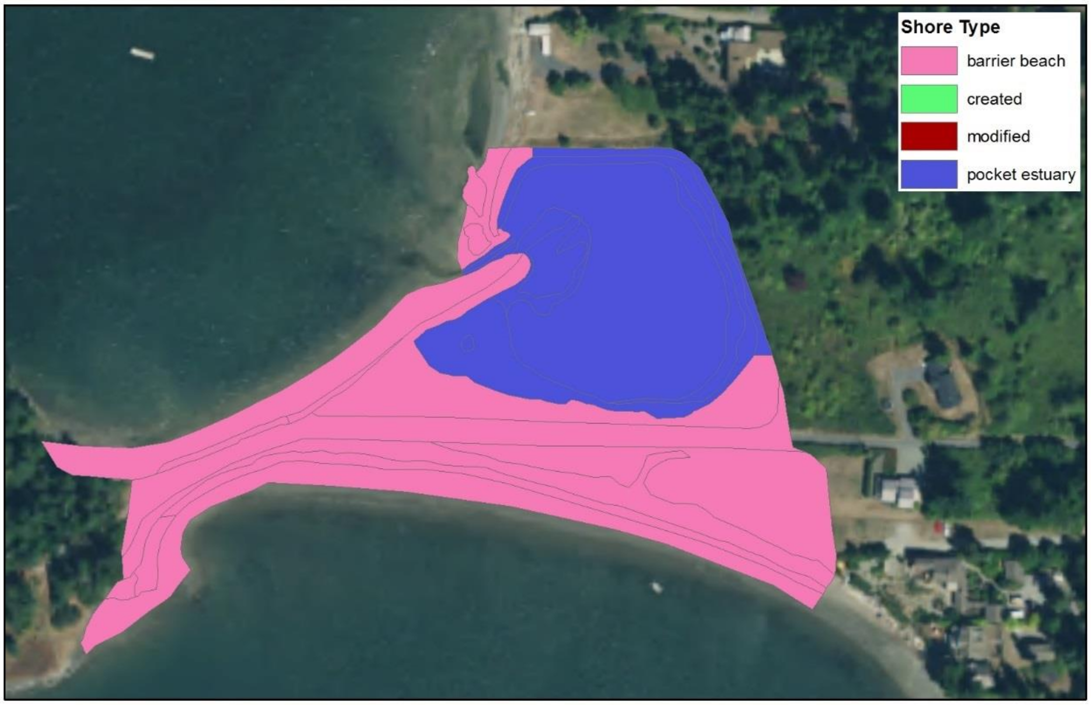


Figure A12. Nearshore habitat within the pocket estuary at Kiket Lagoon, 2014.

Kiket lagoon is shown on the T-sheet. The site has been filled on its northern side and disturbed with a road on its south side. Restoration plans are underway to improve landscape connectivity to the site as part of Kukitali Preserve's management plan

Lone Tree Lagoon

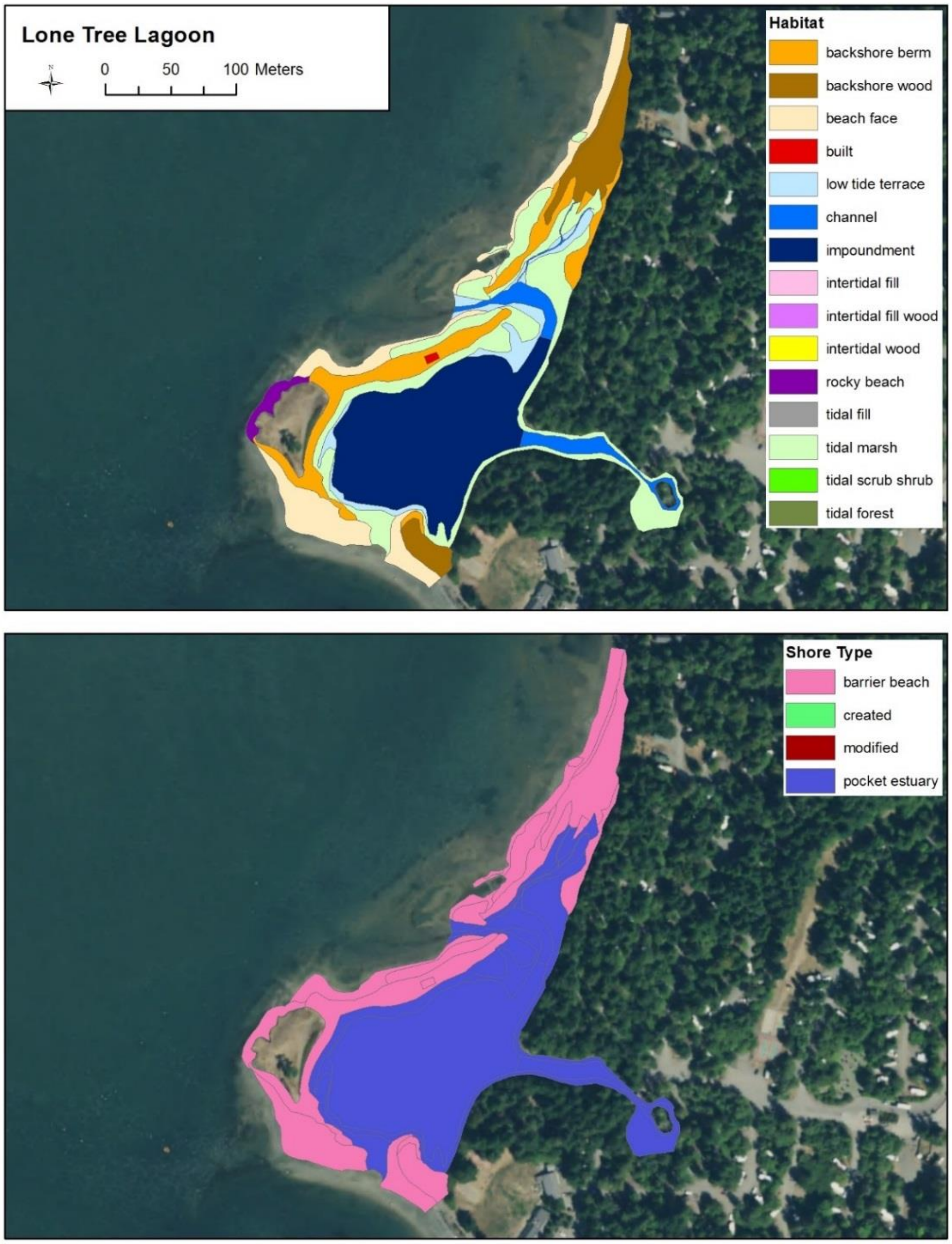


Figure A13. Nearshore habitat within the pocket estuary at Lone Tree Lagoon, 2014.

This site restored access to 0.125 hectares of drowned channel habitat in 2006 by removing a blocking culvert and replacing it with a bridge. Over the Google Earth photo record, the outlet/inlet channel location has remained stable. However, a shoal appears to be developing seaward of the northern spit. The first good photo showing this is 2006. It creates a complex parallel bar system for the northern spit. Also, the southern spit is growing very slowly (< 1 m/yr) into the lagoon.

Mariner's Cove

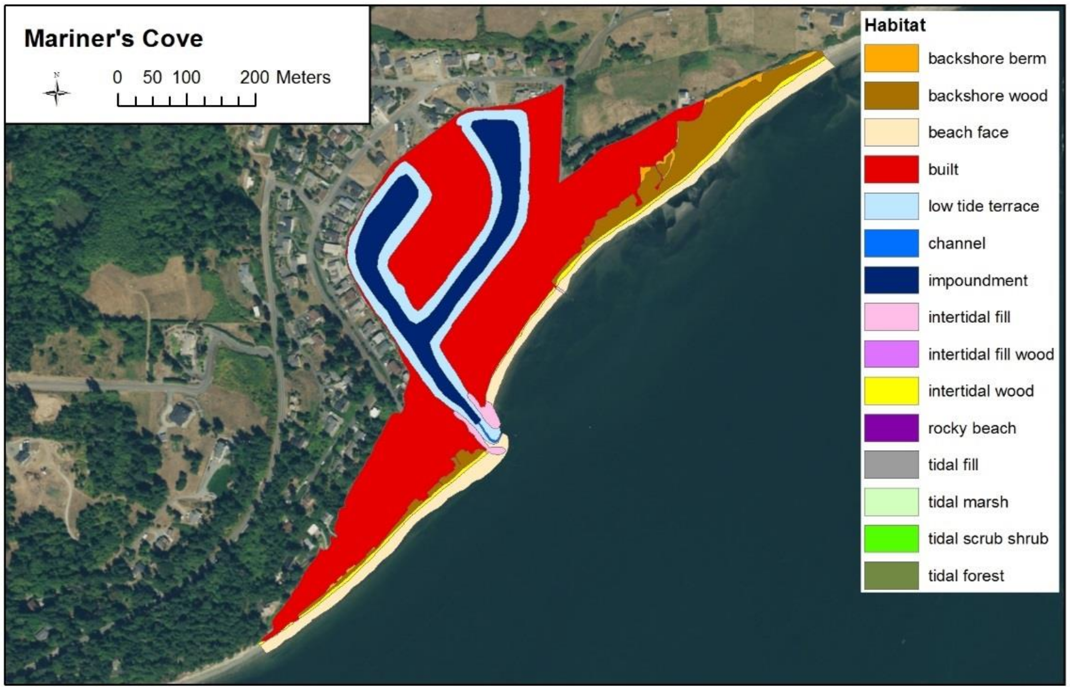


Figure A14. Nearshore habitat within the pocket estuary at Mariner's Cove, 2014.

This site is highly modified with dredging, rock jetties, and overwater structures. The area is shown on the T-sheet as settled in the late 1800s. Currently the site is developed as a residential harbor where the former lagoon or marsh has been entirely dredged or filled.

Maylor Marsh

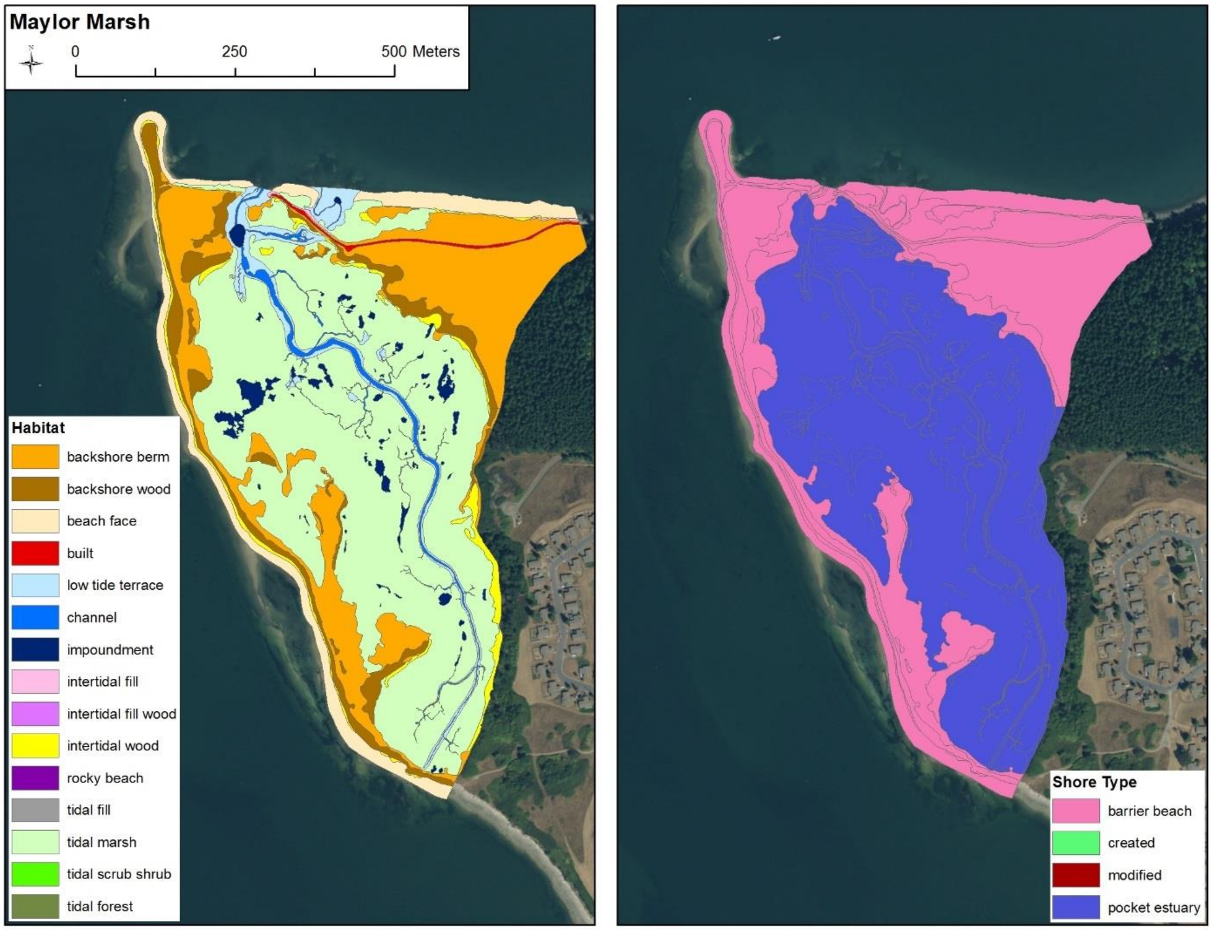


Figure A15. Nearshore habitat within the pocket estuary at Maylor Marsh, 2014.

Maylor Marsh is a tidal marsh system with intact drift cell sediment sources, but the site has a road crossing most of its north barrier beach and the historic outlet has likely been rerouted over 100 meters west from its original location. Sometime between 2011 and 2014 a row of pilings spanning the over 600 meter wide northern barrier was removed. The pilings may have been adjacent to a low-lying dike.

Mueller Park Lagoons (N and S)

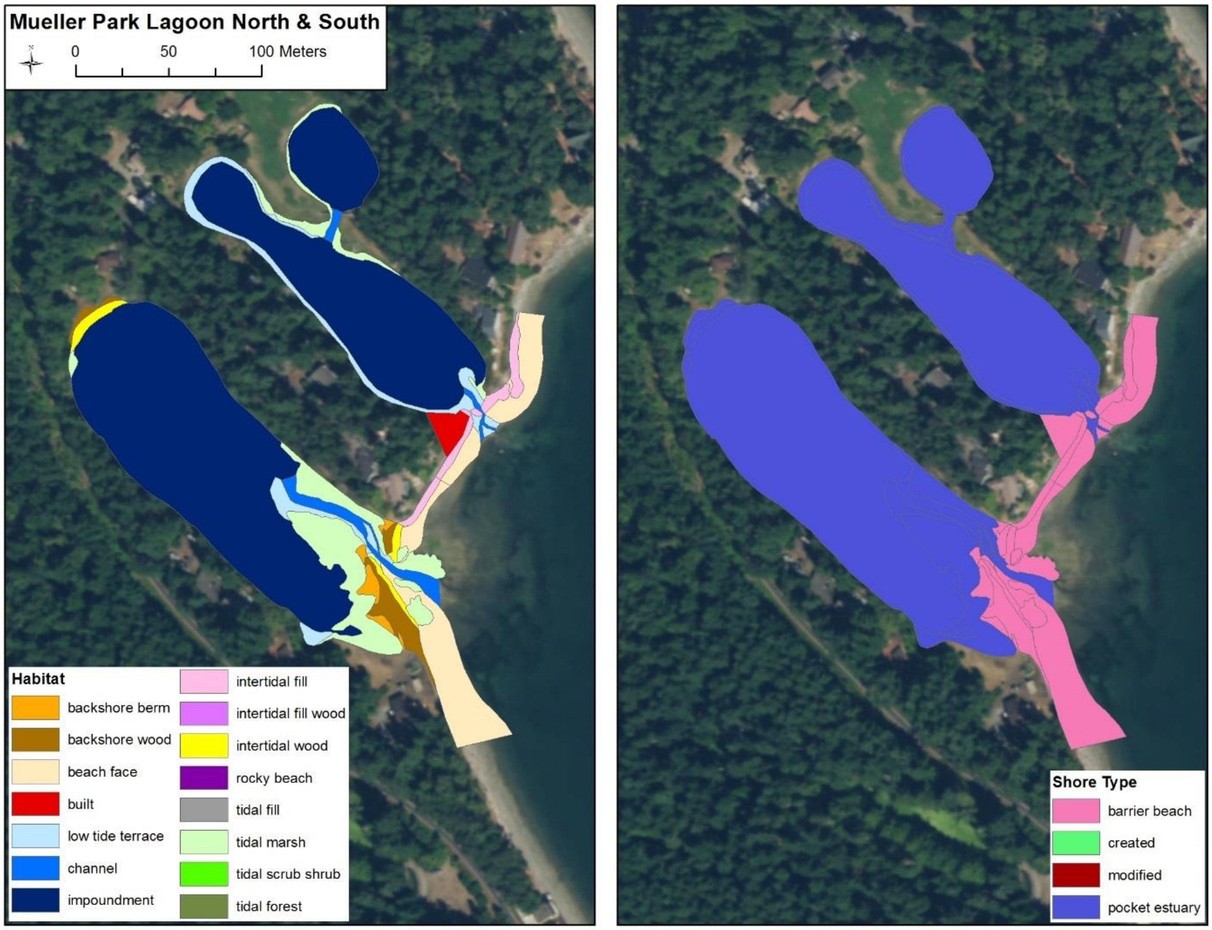


Figure A16. Nearshore habitat within the pocket estuary at Mueller Park Lagoons (N and S), 2014.

The north and south lagoons are separate pocket estuary system but they are in very close proximity to each other due to their unique geologic setting. Both systems are geologically different than the typical longshore lagoons of the Whidbey Basin. They are more like a pocket beach lagoons without any exposed bedrock. There appears to be two small valleys at the correct elevation relative to sea level to form these lagoons. The T-sheet only shows the southern system. The northern system appears to be artificially impounded at its mouth which is first apparent in the 2005 photo. The 1990 photo has too poor of resolution to determine whether the impounding feature was present then.

North Bluff Creek Lagoon

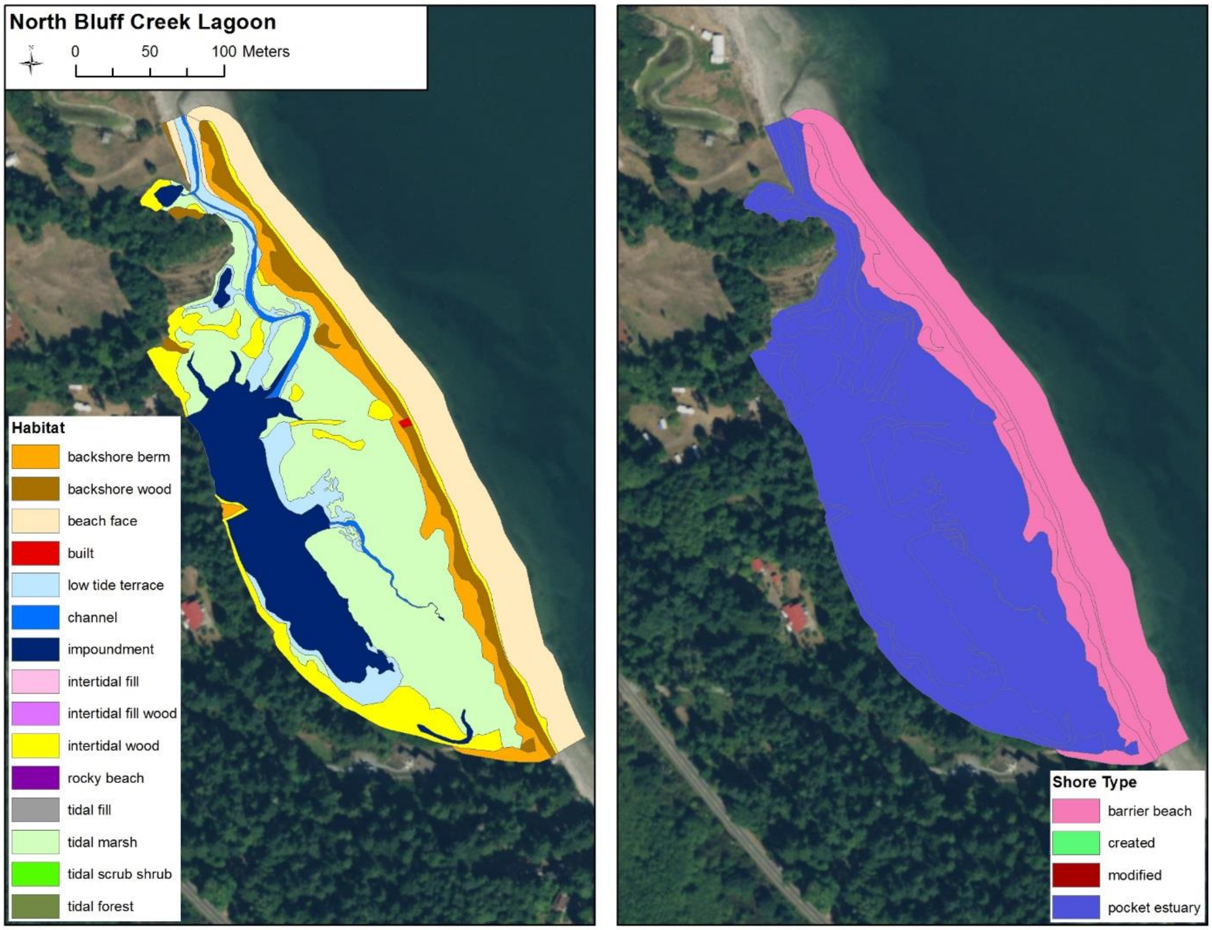


Figure A17. Nearshore habitat within the pocket estuary at North Bluff Creek Lagoon, 2014.

Based on the T-sheet and existing relic wetlands, the system was larger historically extending further to the north than the present system. A creek enters the system near the lagoon's outlet. The barrier beach spit end and outlet/inlet channel mouth location episodically moves by approximately 130 meters over the Google Earth photo record.

Priest Point

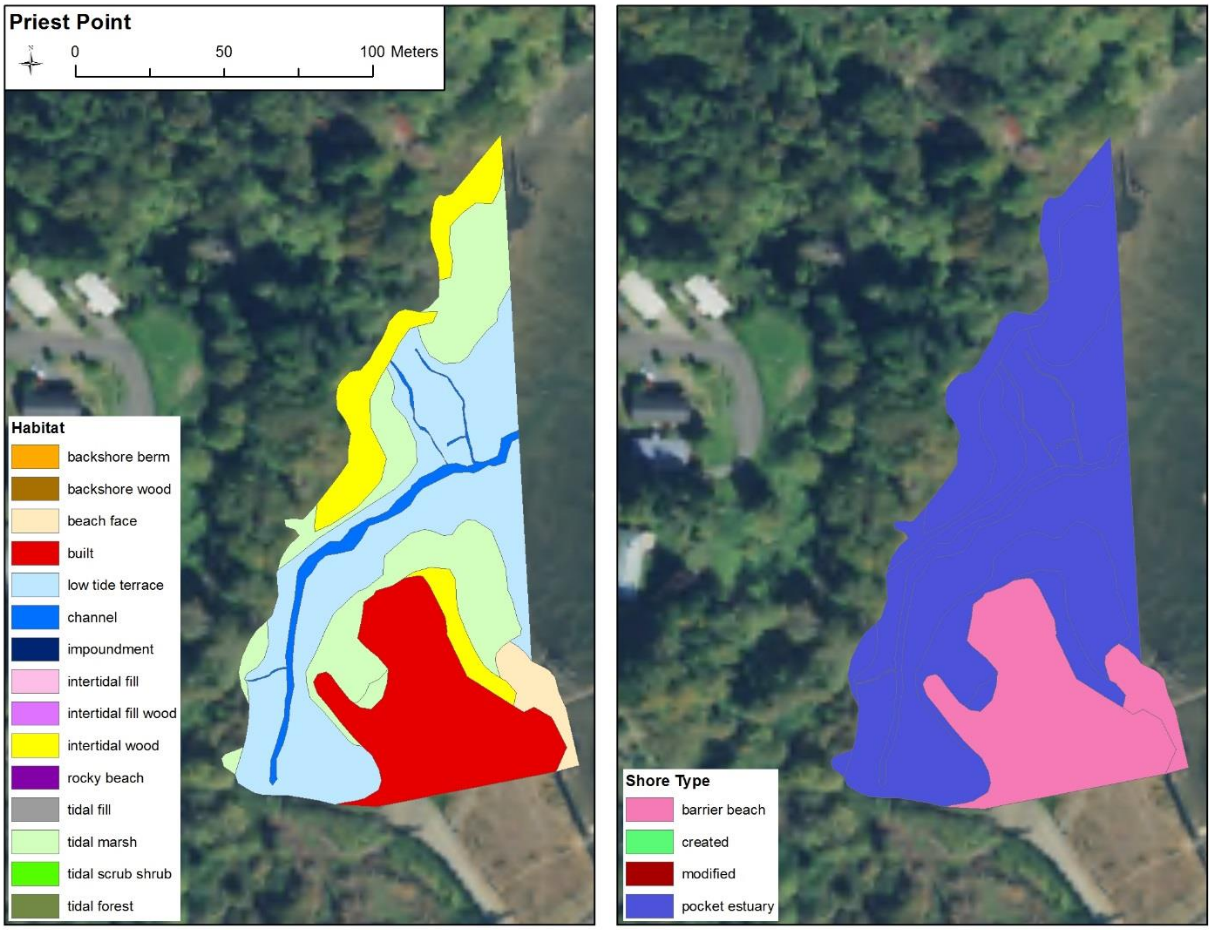


Figure A18. Nearshore habitat within the pocket estuary at Priest Point, 2014.

Priest Point is visible on the T-sheet. Its current condition is only a small relic of historic. The site is located where longshore and Snohomish River delta sediment processes interact. The shoreform appears to be originally formed by longshore processes, but in its truncated state very little evidence of the longshore sediment processes are present. Most of the historic spit is developed and armored. The relic pocket estuary habitat looks more like truncated tidal delta habitat. There is a large isolated wetland that drains into the relic pocket estuary.

Race Lagoon

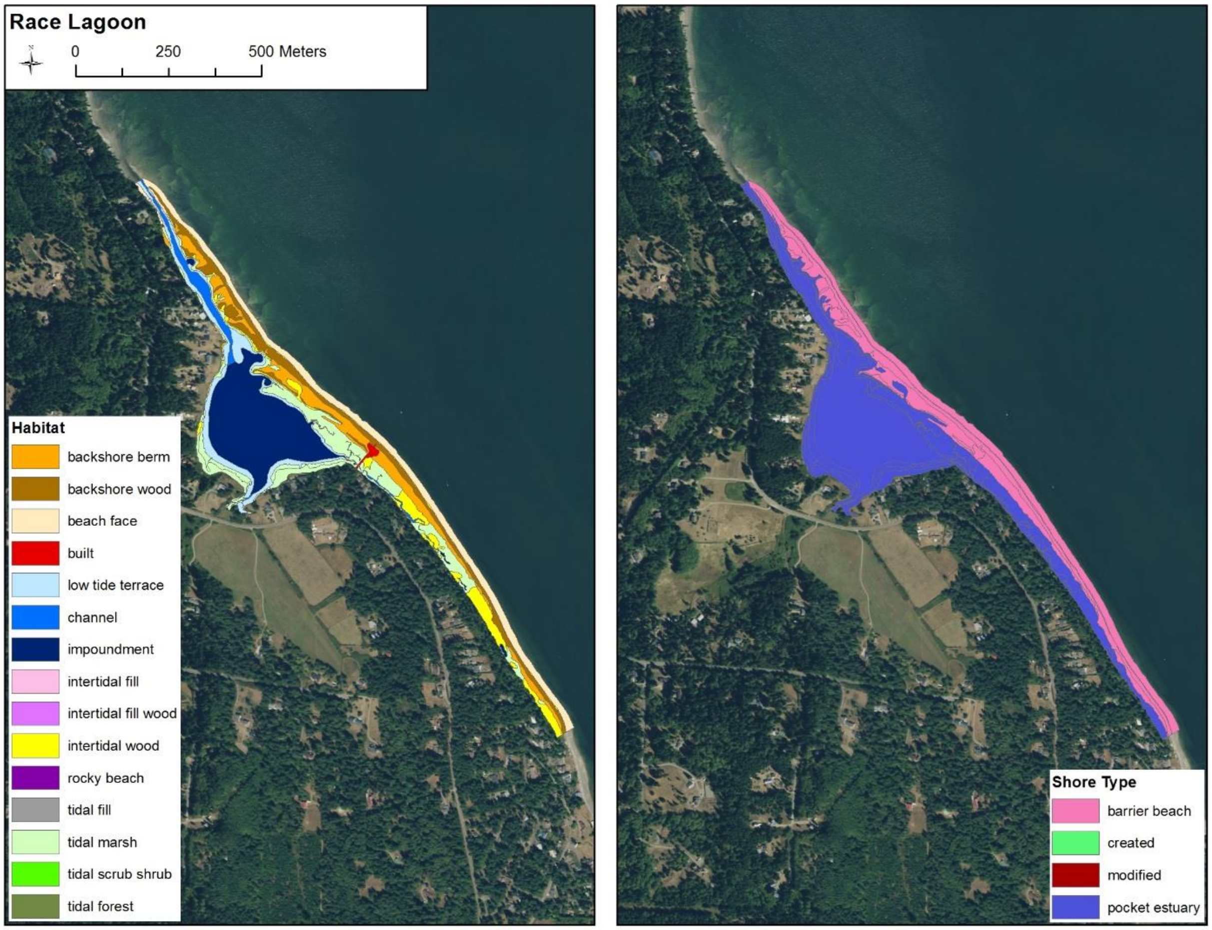


Figure A19. Nearshore habitat within the pocket estuary at Race Lagoon, 2014.

Race Lagoon is visible on the T-sheet. The site has a long narrow tidal channel marsh on its south side connecting to the lagoon proper. The outlet/inlet channel mouth has remained stable over the Google Earth photo record, draining the lagoon toward the north.

Strawberry Point Lagoon

Figure A20. Nearshore habitat within the pocket estuary at Strawberry Point Lagoon, 2014.

This site is not on the T-sheet. It was created by two rock groins. Since the site is artificial there is still a remnant bluff back beach, including some backshore habitat, within the artificial pocket estuary.

Sunnyshore Acres

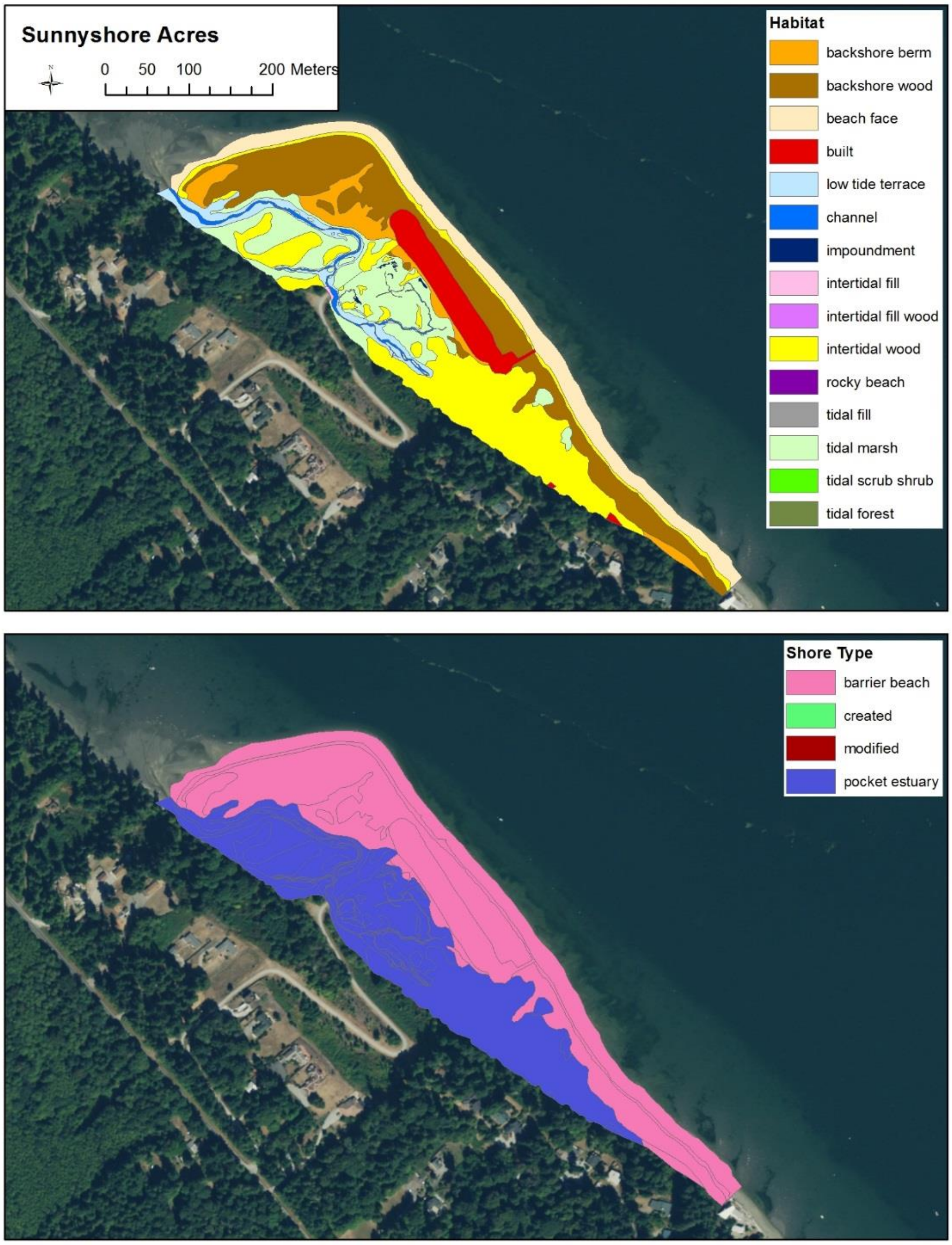


Figure A21. Nearshore habitat within the pocket estuary at Sunnyshore Acres, 2014.

This site is mapped on the T-sheet. The spit is shown as developed in the 1990 photo with a bridge crossing the lagoon/marsh to access the spit on its northern end. Several buildings and trailers are located on the spit which is cleared of vegetation and drift wood. Multiple overwater walkways cross the marsh on its south end so that home owners located on the bluff can access the spit beach. The outlet/inlet channel mouth has remained in the same location over the Google Earth photo record. Waves of longshore sediment deposits are visible in many photos north and west of the spit's recurve but no new lagoon or outlet appears to be forming.

Triangle Cove

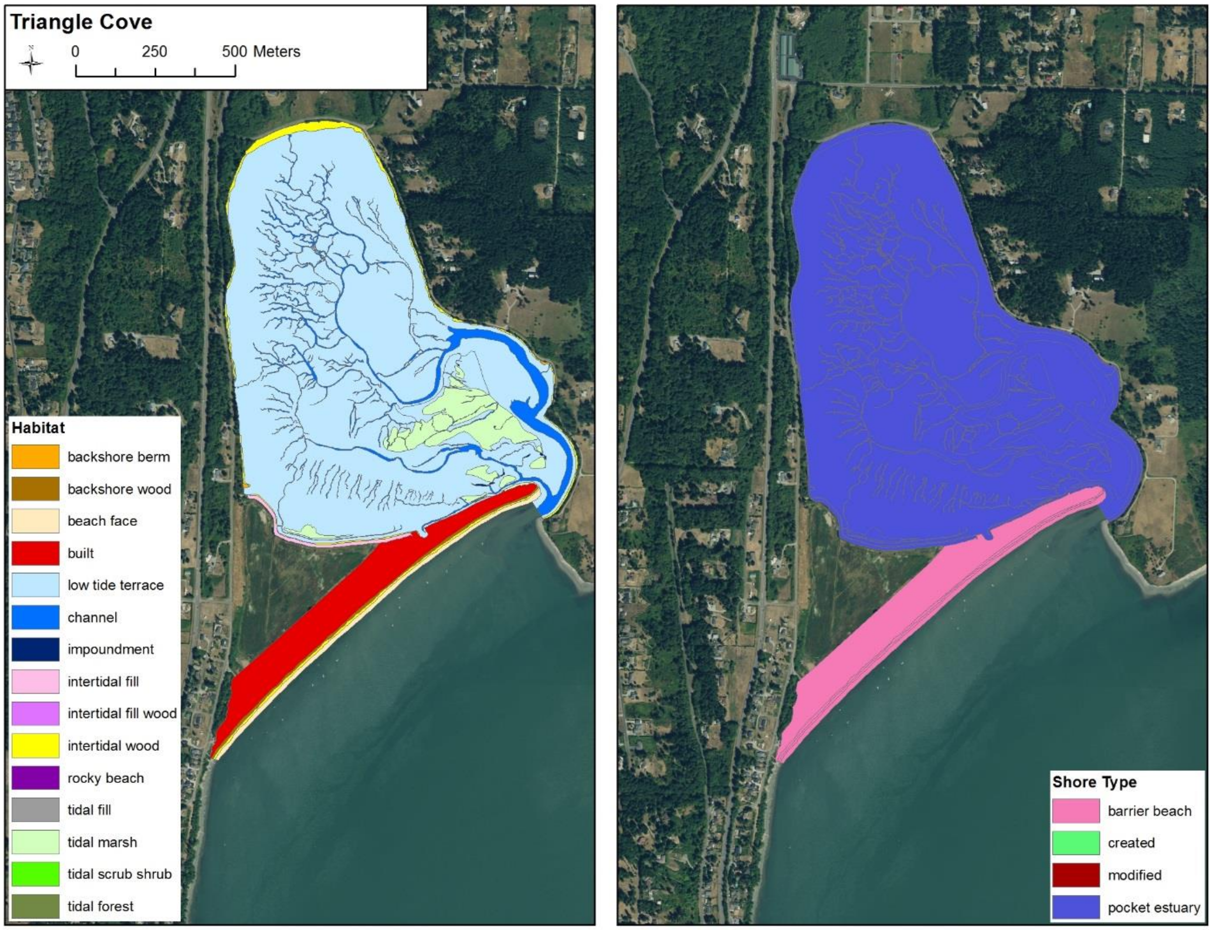


Figure A22. Nearshore habitat within the pocket estuary at Triangle Cove, 2014.

This site is mapped on the T-sheet. The spit is shown as fully developed with a road and houses in the 1990 photo. The marsh/lagoon area was infested by spartina and has been an active removal area for the Washington State Department of Agriculture's (WSDA) Spartina Eradication Program. In 2002, there were approximately 160 solid acres of *Spartina anglica* in the cove; by 2007 only 29 solid areas were left (Phillips et al. 2008). Only 4.56 solid acres of spartina remain in 2014 for all of Island County (WSDA 2017). In 2014, we mapped limited areas as marsh and make no distinction whether it is native or spartina marsh.

Tulalip Bay

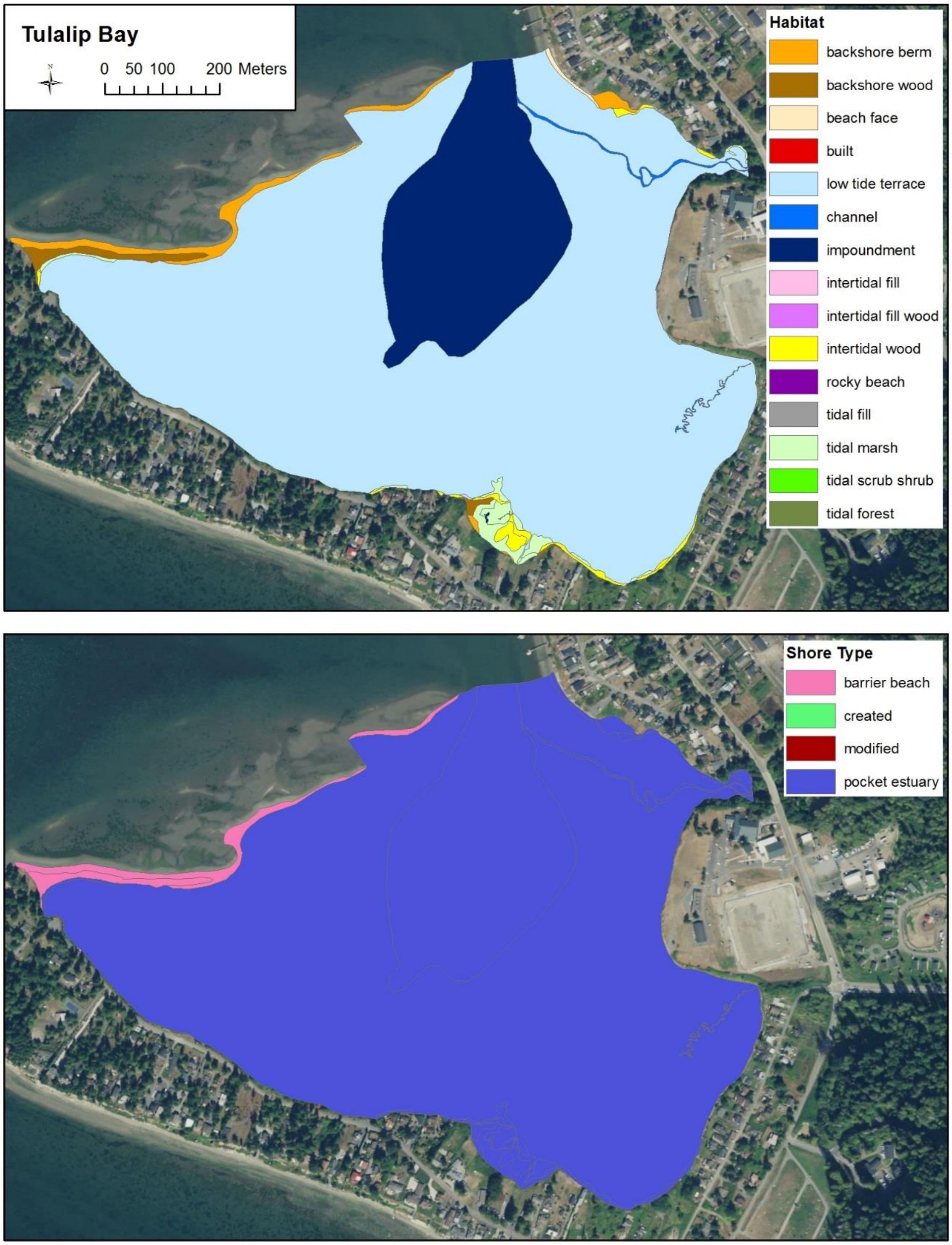


Figure A23. Nearshore habitat within the pocket estuary at Tulalip Bay, 2014.

Turners Bay

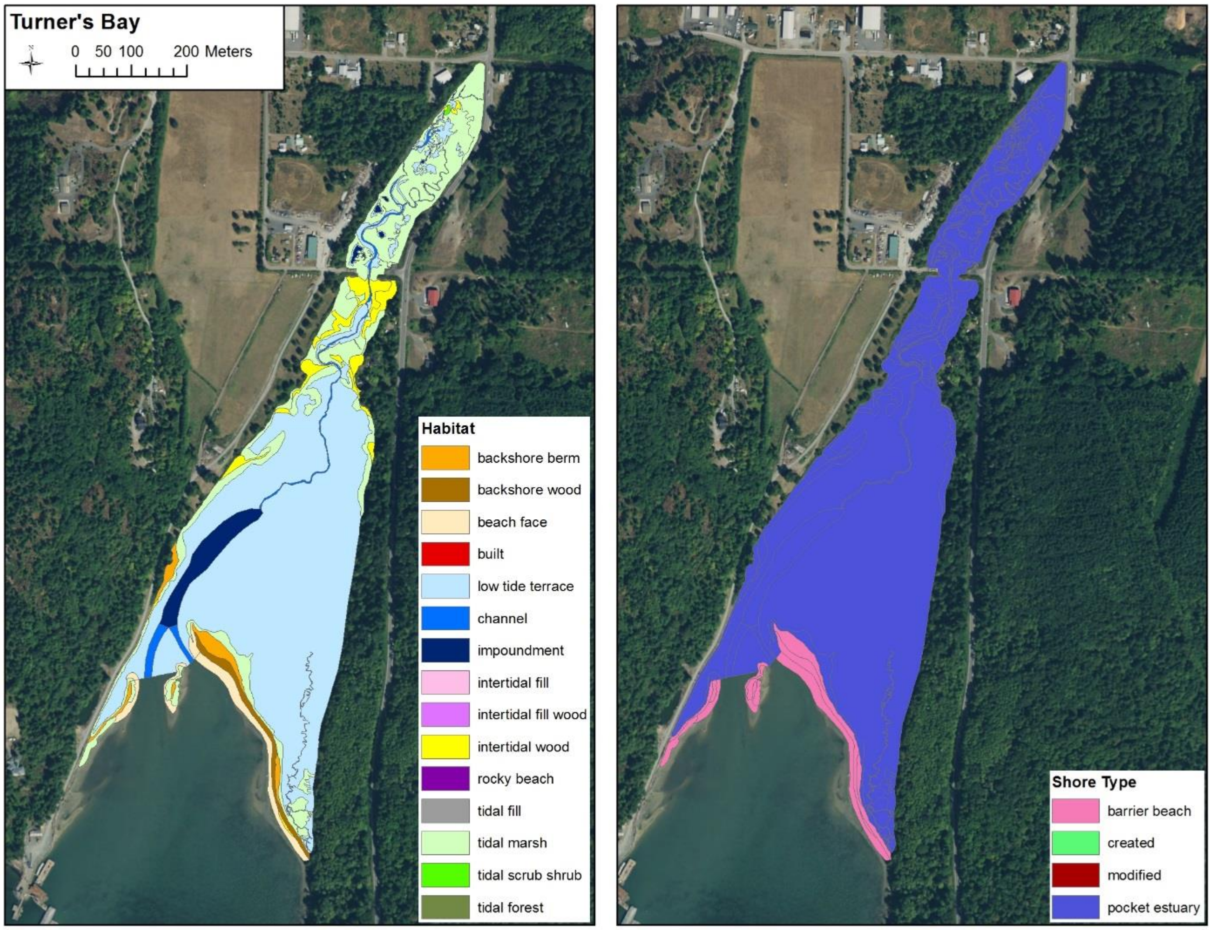


Figure A24. Nearshore habitat within the pocket estuary at Turners Bay, 2014.

This site is mapped on the T-sheet. The spit and shoreline on the western side is shown as fully developed with a road and parking with water access in the 1990 photo. Two isolated wetlands appear to be cutoff by the road. The wetlands are within the upper intertidal elevation range and culverts appear to drain them. In circa 2008, road removal at the north end restored 3.352 hectares to tidal inundation.

West Whidbey Island Sites

Bayview Rd

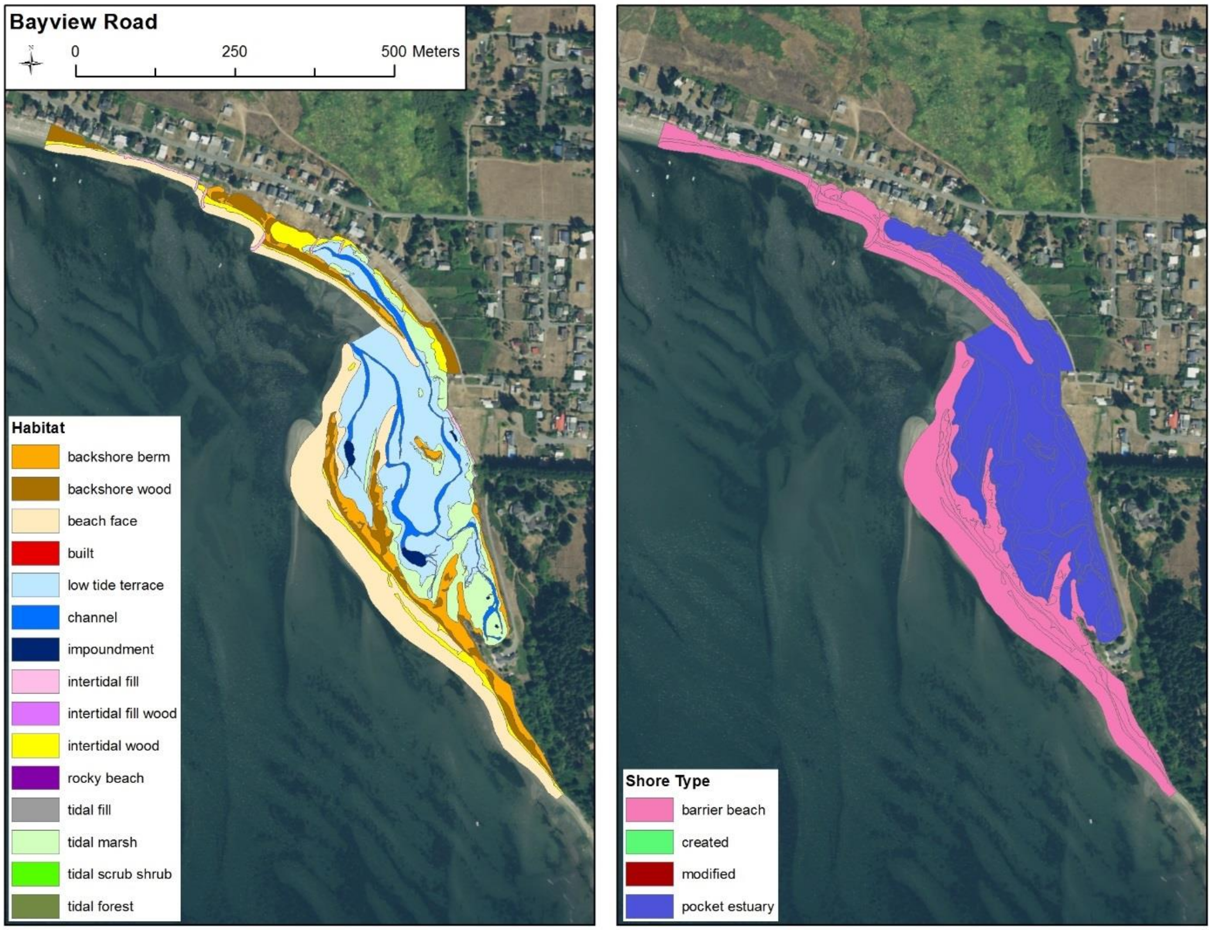


Figure A25. Nearshore habitat within the pocket estuary at Bayview Rd, 2014.

This site is a separate system located south of the historically massive Deer Lagoon system. The site is shown on the T-sheet. In the 1990 photo the site has a narrower and more northerly located outlet/inlet channel than mapped in 2014. The recent outlet/inlet location change occurred between 1990 and 2005. The change likely occurred naturally due to varying sediment and wave energy dynamics where the spit was breached further south forming a lagoon system with two distinct north and south lobes. Rock groins located in the north lobe might be influencing the lagoon system by reducing the northern spit's width and length over time. Over the Google Earth photo record, the outlet/inlet width has sequentially narrowed and widened due to the continual formation and movement of southern spit recurves and a general reduction in the northern spit. The outlet/inlet location has steadily moved north over the last decade, moving 300 meters from 2005 to 2017. It is now approximately 125 meters from its 1990 location.

Cultus Bay

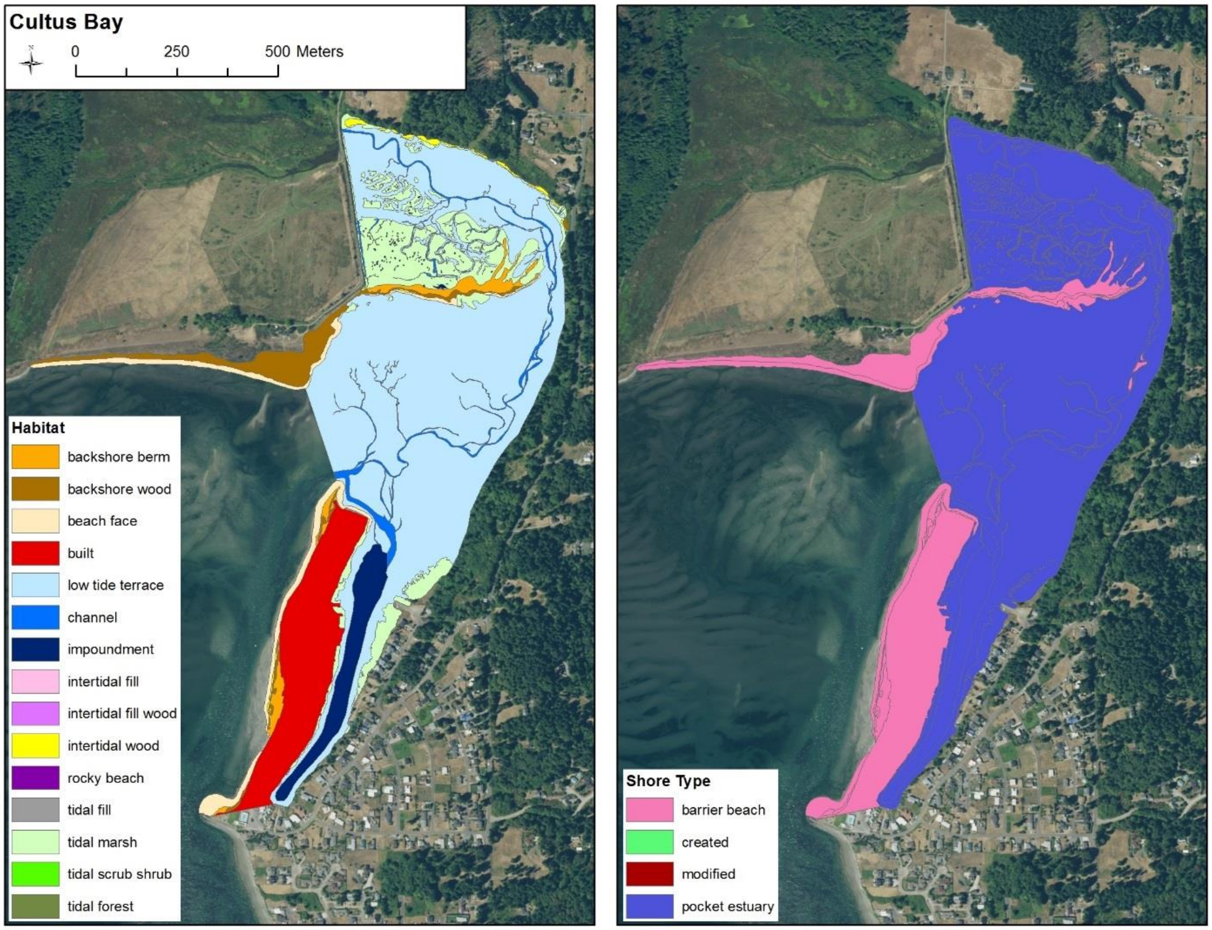


Figure A26. Nearshore habitat within the pocket estuary at Cultus Bay, 2014.

This site has two main fragments of a historically very large lagoon and tidal marsh system. The northern fragment is mostly tide flats with well-formed channel and marsh. It is connected to a freshwater source which drains into the marsh through a dike. The southern lobe (i.e., Sandy Hook) consists of habitat sheltered by a recurving spit. Both sides of the south spit have been developed for residential use with the seaward side protected by armoring and the lagoon side having many docks. The tidal channel has been dredged to accommodate the numerous docks and boat houses. In between the two lobes is a large area of tidal flat and channel. The entire area mostly drains at MLLW, with the exception of a narrow tidal channel and the dredged impoundment in the south lobe.

Deer Lagoon

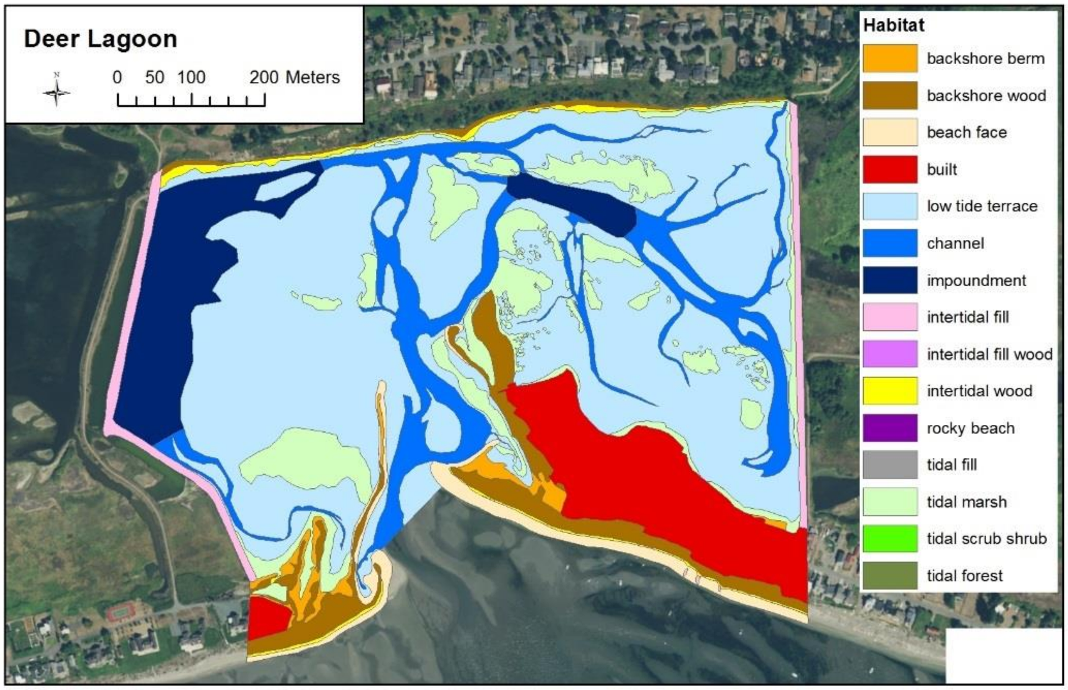


Figure A27. Nearshore habitat within the pocket estuary at Deer Lagoon, 2014.

This system is shown on the T-sheet. In 2014, approximately one third of its tidally influenced extent remains. The outlet/inlet channel is quite dynamic, varying in width from 40 to over 100 meters wide from 1990 to 2017. This is primarily due to continual formation and breaching of recurving spits at the lagoon's entrance.

Double Bluff

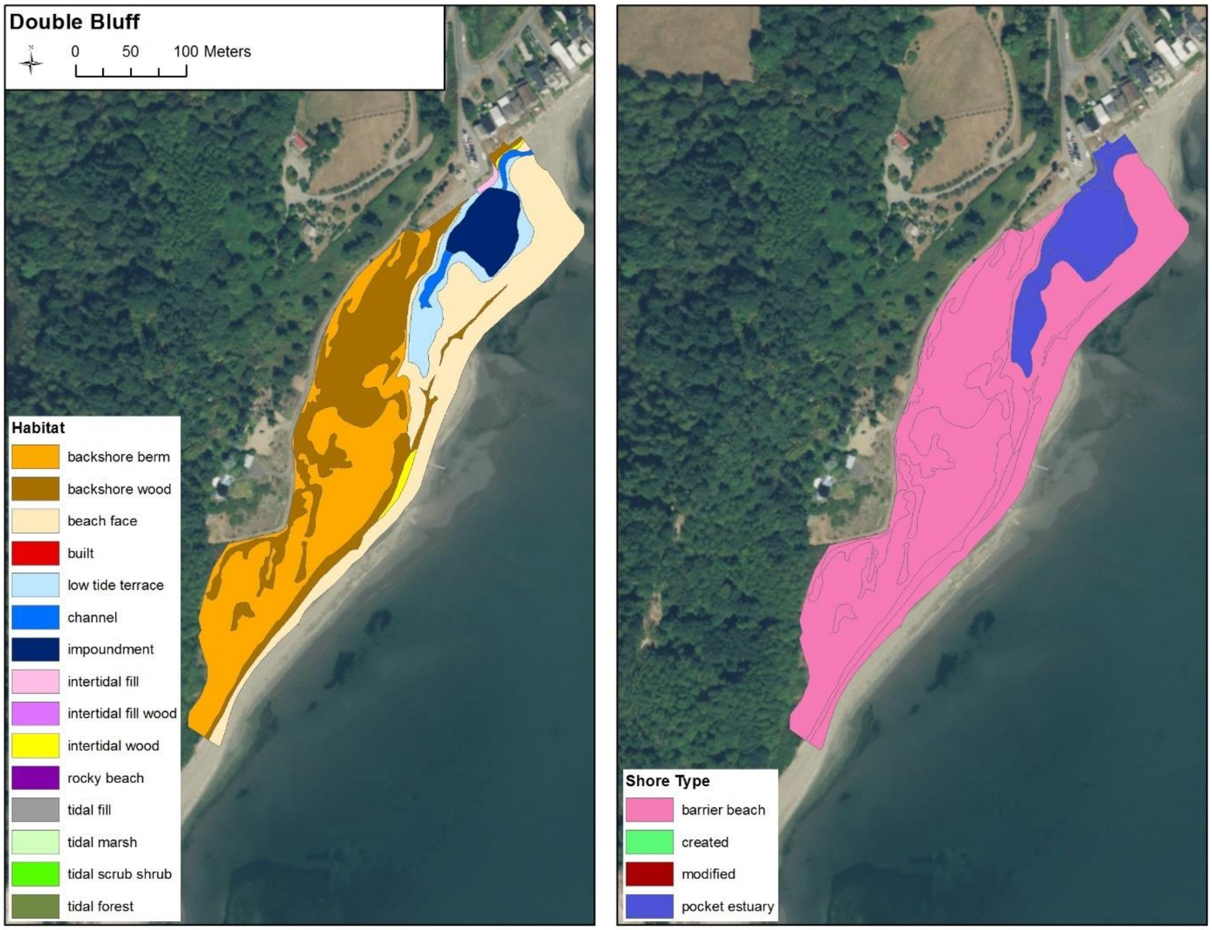


Figure A28. Nearshore habitat within the pocket estuary at Double Bluff, 2014.

The Double Bluff Lagoon site is located at Double Bluff County Park. The site is small and transient. It was not mapped on the T-sheet. Over the Google Earth photo record, lagoon or backwater habitat is visible on the 1990 photo but absent in 2006. In 2007 a recurving spit began to form and by 2009 lagoon or backwater habitat was again present. Open lagoon habitat persisted through 2016 but in 2017 the outlet and lagoon appear to be filling with longshore transported sediment. The site is located immediately downdrift of a major active sediment bluff.

Keystone Harbor

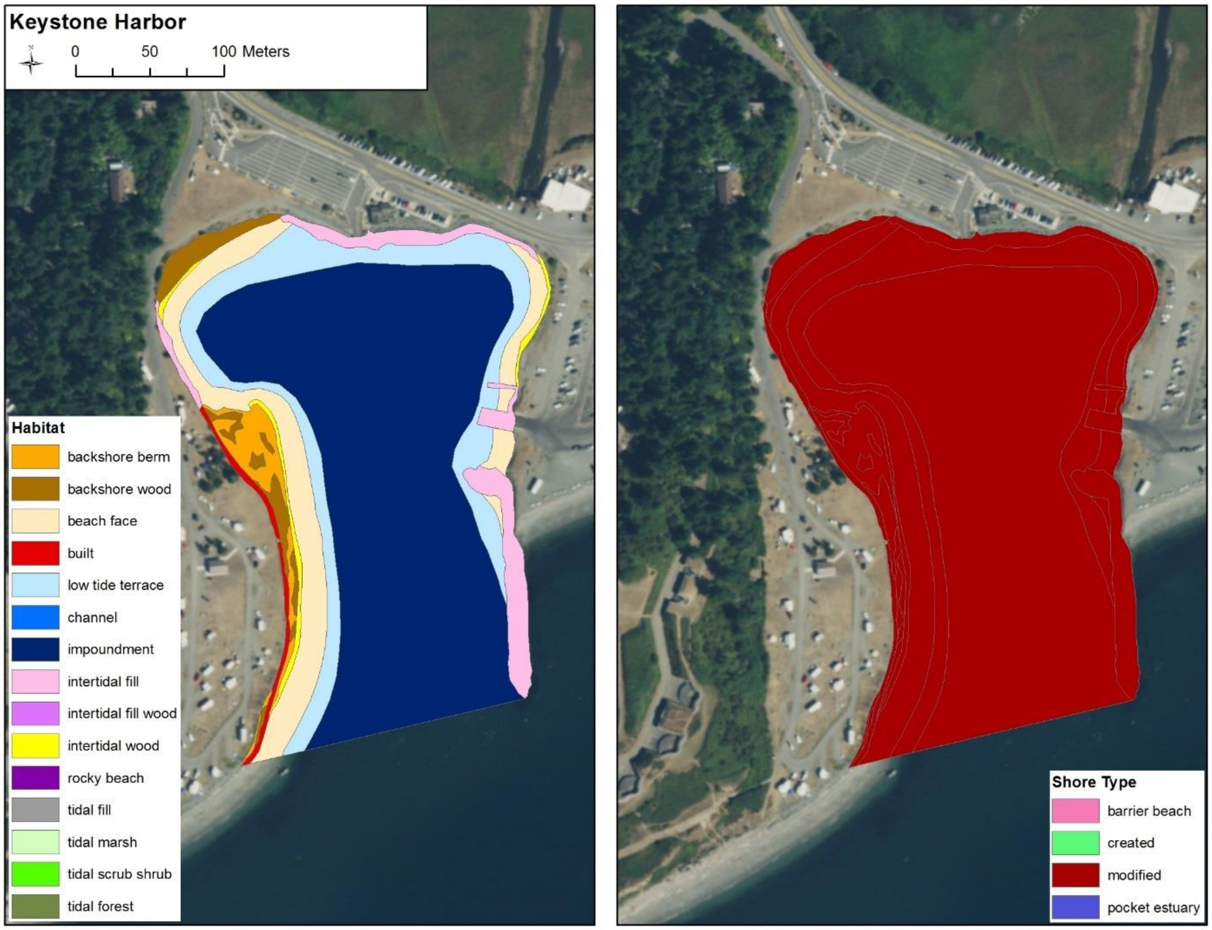


Figure A29. Nearshore habitat within the pocket estuary at Keystone Harbor, 2014.

Keystone Harbor is an artificial embayment associated with Crockett Lake. Historically, Crockett Lake is thought to have been a closed lagoon system (Herrera Environmental Consultants Inc. 2007; Park 2014). The T-Sheet shows Crockett Lake with a dredged channel flowing into Admiralty Inlet at the site of Keystone Harbor. This channel persists in its present condition. However, the channel is controlled by a tide gate which prevents unobstructed tidal flow and fish passage into the lake (Wait et al 2007).

Lagoon Point

Figure A30. Nearshore habitat within the pocket estuary at Lagoon Point, 2014.

This system is shown on the T-sheet. This large system has been extensively modified. The lagoon has been filled and dredged. The outlet/inlet channel relocated and protected with rock groins. Historically, the outlet/inlet channel drained southward indicating that net drift of sediment was from north to south along the shoreline. The lagoon system has two lobes oriented north of the outlet/inlet channel. The larger north lobe is culverted or tidegated while the smaller north lobe has full tidal exchange because a bridge spans its channel.

Lake Hancock

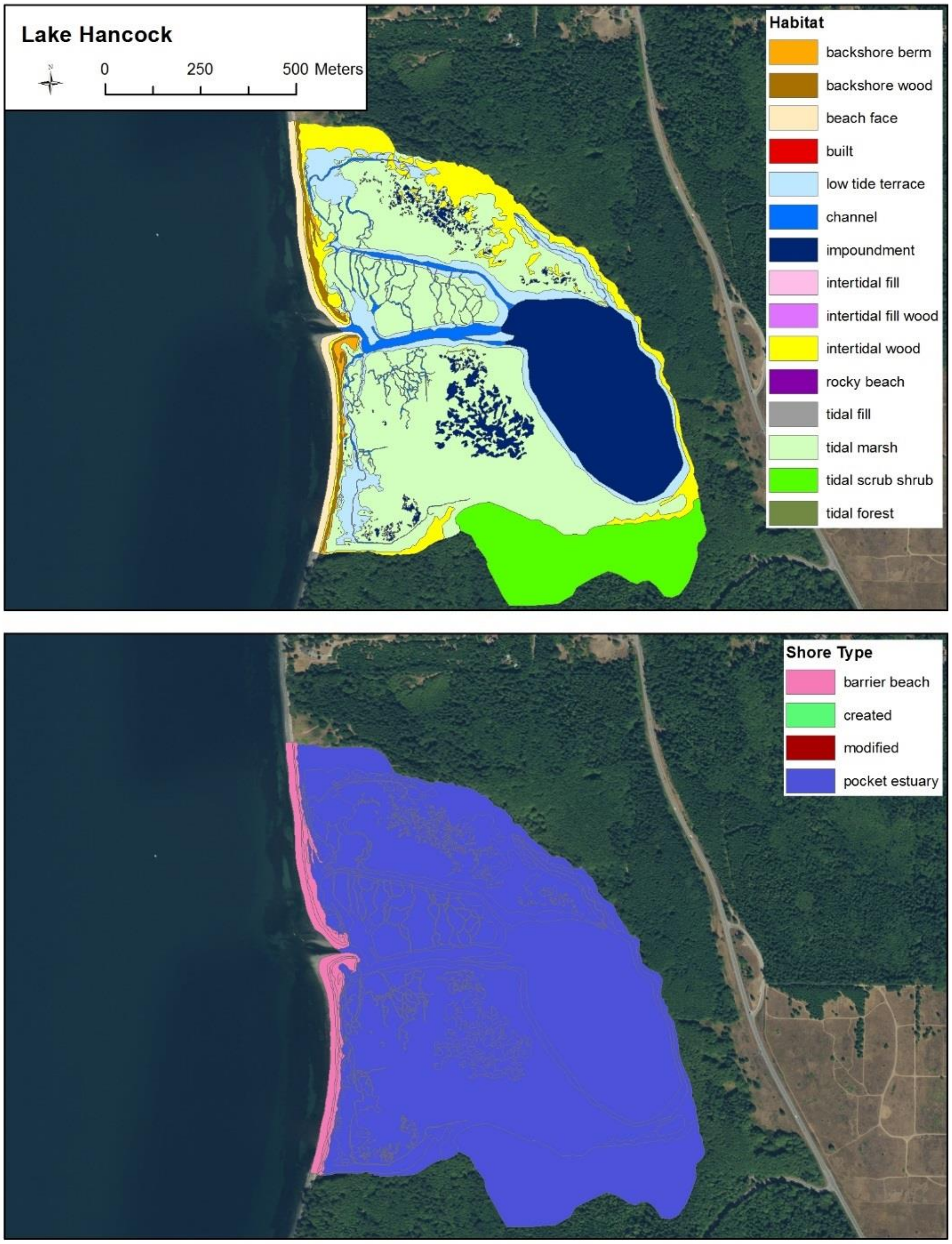


Figure A31. Nearshore habitat within the pocket estuary at Lake Hancock, 2014.

Lake Hancock is a large site without residential development. However, the site has been disturbed by dredging of a northern outlet/inlet channel. The T-sheet only shows one outlet – the main one. The site has remained relatively unchanged over the Google Earth photo record (1990-2017) other than possible incremental filling of the north outlet channel due to longshore sediment processes. The site also has a significant area on its south side at the correct elevation to support tidal scrub shrub vegetation.

Maxwelton South

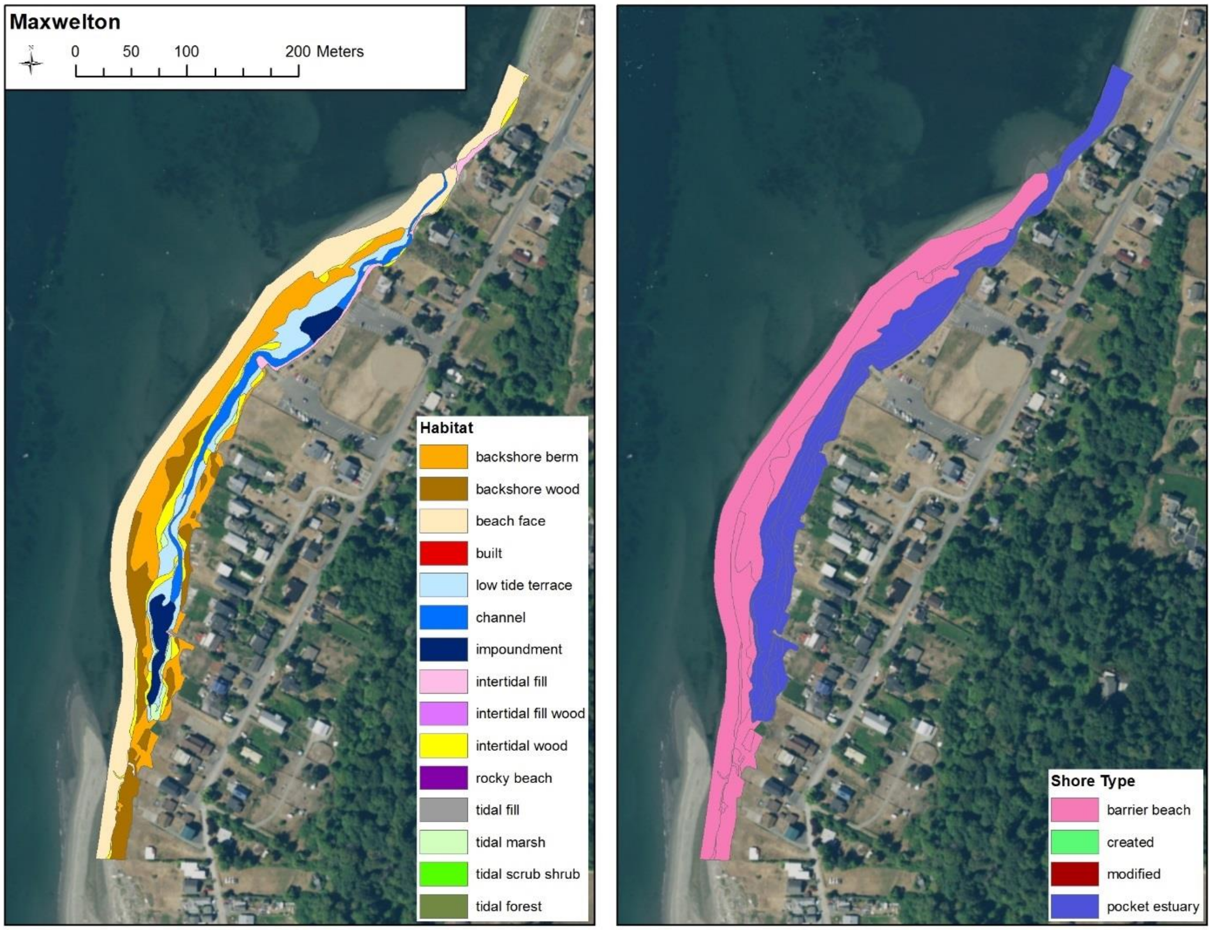


Figure A32. Nearshore habitat within the pocket estuary at Maxwelton South, 2014.

This small system is located on Maxwelton Beach and includes Dave Mackie Park. It is south of the Maxwelton Creek mouth which historically had a large estuary but is now tide gated. This system rapidly changes. In 1990, there was no lagoon present, but a shoreline paralleling bar was located 40-100m offshore. By 2006 the bar had connected to the shore creating a very small lagoon. Over the next decade the spit lengthened northward an average of 57 meters per year and the lagoon length and area increased.

Rocky Point

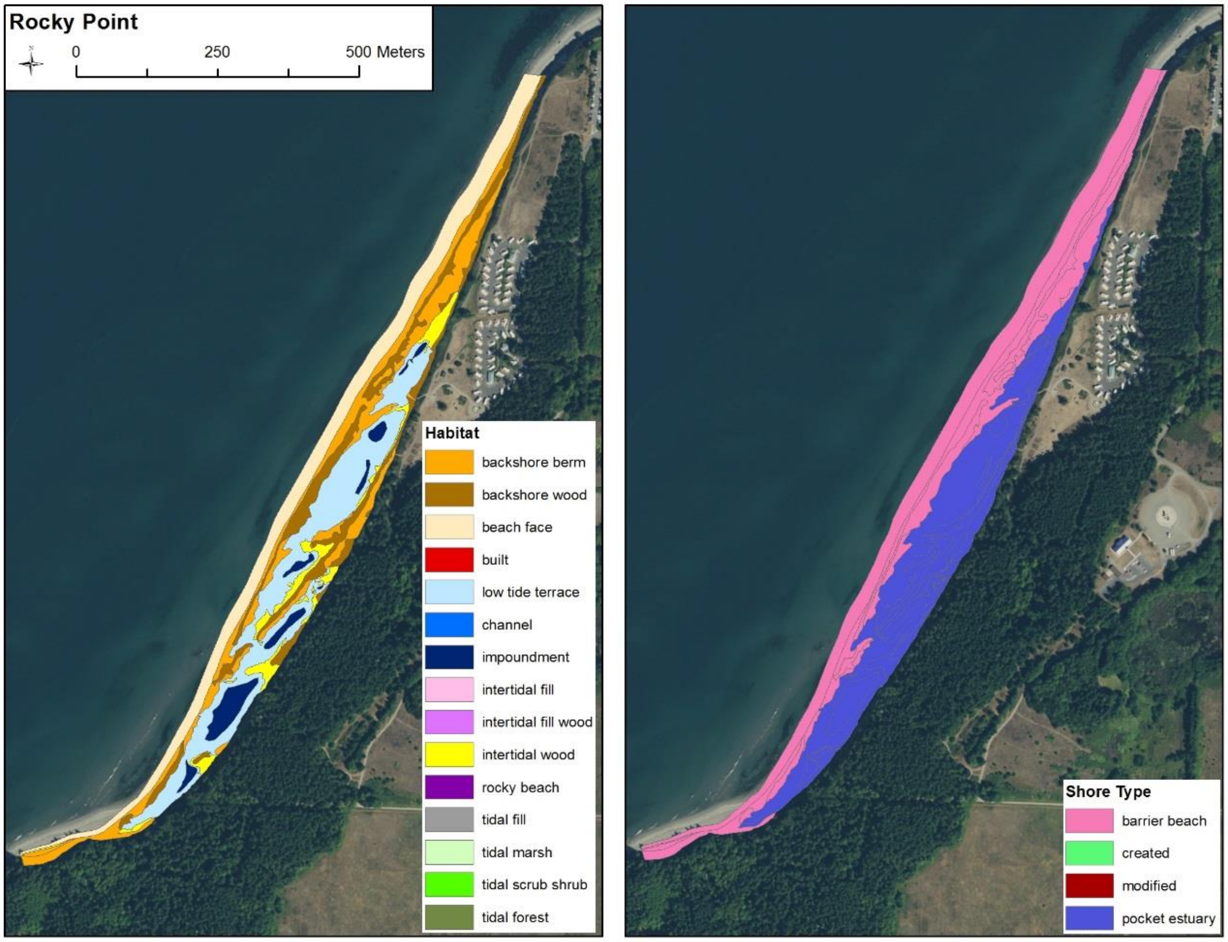


Figure A33. Nearshore habitat within the pocket estuary at Rocky Point, 2014.

The system is transient over the Google Earth photo record, 1990-2017. There is no evidence of a lagoon in 1990 but the area appears to be shallow on the photo. Between 2005 and 2009 the site had an open lagoon condition. For the 12 years of continuous photos on GoogleEarth (2005-2017) the site had an open lagoon outlet condition in five years, or 42% of the continual photo record. However, in 2014 (our habitat mapping year), the site was a closed lagoon system where we identified 7 impoundments which are relics of various open and closed lagoon conditions that started in 2005.

Sills Rd

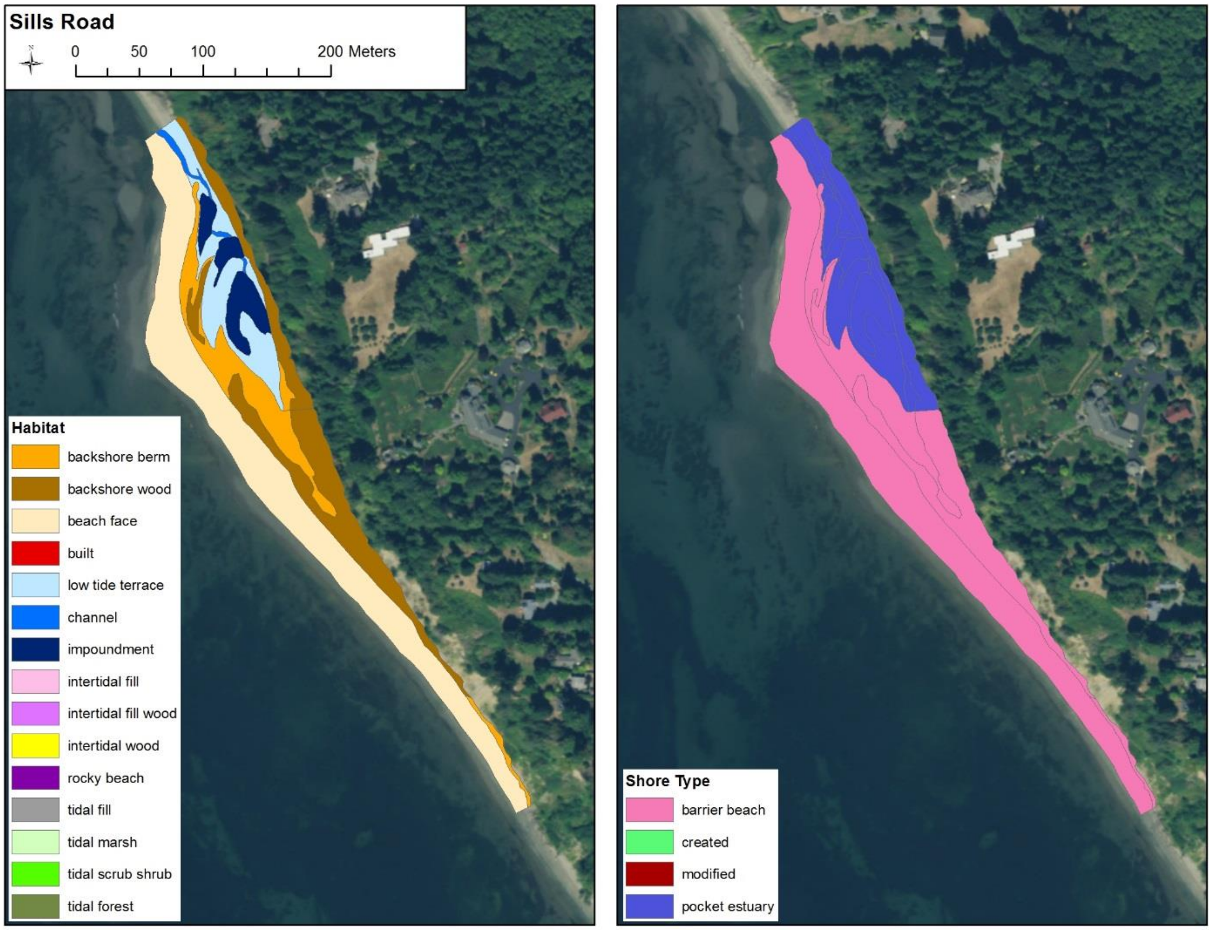


Figure A34. Nearshore habitat within the pocket estuary at Sills Rd, 2014.

The Sills Rd lagoon is a transient nearshore feature. The lagoon was not present in June 2010, was partially formed August 2011, and persisted through at least April 2015. In 2014 open lagoon habitat was present but by the June 2016 photo essentially no lagoon habitat is visible – the area was mostly high intertidal or backshore habitat.

Appendix 2. GIS Pocket Estuary Habitat Definitions

Nearshore Marine Environments

Drift Cells: a system within the nearshore marine environment. Drift cells are shore segments measured from one area of net sediment loss (eroding bluff) to a connected down-drift area of net sediment accumulation, where beach sediments are eroded, transported and deposited by waves dominantly in one direction over time.

Coastal landform - a geographic feature in the landscape that is formed by coastal energy and processes such as waves, tides, and coastal winds. Barrier beaches are a sub-set of these formed by wave deposition and longshore transport (waves moving sediments parallel to the shoreline). Coastal landforms are a subsystem of drift cells.

> Barrier beach - an elongate, narrow coastal landform created by sediment transport and deposition that forms a low lying, salt influenced, semi-permeable barrier to normal tides within the nearshore (e.g. spits, tombolos, and cuspate forelands). These beaches may be inundated by storm surge or exceptionally high tides. Barrier beaches are mobile within the nearshore due to wave and wind action at a time scale of years to decades.

Pocket estuary – a partially enclosed embayment found along the shoreline that is created by coastal landforms and/or antecedent geology and topography (stream valleys, coastal low lands) that often has depressed salinity compared to adjacent marine waters due to small streams, ground water, and surface runoff. Pocket estuaries are typically low-energy groups of habitats including tidal channels, salt marshes, driftwood, and impoundments. The habitats within the pocket estuary are maintained by a variable combination of wave, tidal, and fluvial processes, from which specific pocket estuary types (shoreline types) are delineated. Pocket estuaries are a subsystem of drift cells.

> Drowned channel lagoon - a tidal or subtidal impoundment or coastal backwater formed landward of a barrier beach and into which a tidally inundated stream flows. Coastal longshore transport as well as small-scale fluvial processes and tides construct this geomorphology and associated habitats. A type of pocket estuary.

> Longshore lagoon - a tidal or subtidal impoundment or coastal backwater formed landward of a barrier beach. Longshore drift is the principal coastal process driving the formation of longshore lagoons. A type of pocket estuary.

Tidal channel lagoon - low lying shoreline eroded by encroaching tides into tidal channels and tidal wetlands, across which a spit has formed seaward of the marsh to create a partially enclosed pocket estuary. A type of pocket estuary.

Tidal channel marsh - tidal channel and marsh habitat complex formed by tides inundating low, broad valley floors along the shoreline. A type of pocket estuary.

Stream delta lagoon - a tidal or subtidal impoundment or coastal backwater formed landward of a barrier beach and into which a stream delta and distributary channels flow. Coastal longshore transport as well as small-scale fluvial processes construct this geomorphology. A type of pocket estuary.

Created - a coastal feature that resembles and functions ecologically as one of the previously listed geomorphic types, but which is known to be created by built structures or fill introduced into the nearshore. A type of pocket estuary.

Modified - known to be a naturally formed pocket estuary historically, but its current condition has been so modified by human causes (e.g., dredging, intertidal filling, and armoring) that it does not resemble any of the natural geomorphic pocket estuary types. A type of pocket estuary.

Rocky Shorelines:

Pocket beach - an embayment along a rocky shoreline where a sediment beach forms in situ due to differential onshore erosion or antecedent upland topography and/or geology. These beaches are not connected to other sediment sources besides those derived from the adjacent rocky shoreline or upland geology. A subtype of rocky shoreline systems.

Rocky pocket estuary – a pocket estuary formed along rocky shorelines within pocket beaches where a barrier beach or tidal marsh has developed. It may or may not include a stream. These types of pocket estuaries include these shoreline types: pocket beach lagoon, pocket beach tidal marsh, pocket beach estuary, and pocket beach closed lagoon and marsh. A subtype of rocky shoreline systems.

Pocket beach estuary - a tidal or subtidal impoundment or coastal backwater formed landward of a barrier beach within a pocket beach into which a stream flows. In the case of rocky shorelines on-shore erosion forms the barrier beach rather than longshore drift. For pocket beach estuaries tides and fluvial processes maintain a breach in the barrier beach and the resultant impoundment in low areas landward of the beach. A type of rocky pocket estuary.

Pocket beach lagoon - a tidal or subtidal impoundment or coastal backwater formed landward of a barrier beach within a pocket beach along a rocky shoreline. In the case of rocky shorelines on-shore erosion forms the barrier beach rather than longshore drift, and tides maintain a breach in the barrier beach and the resultant impoundment in low areas landward of the beach. A type of rocky pocket estuary.

Pocket beach tidal marsh - tidal channel and marsh habitat complex formed by tides inundating a pocket beach and eroding sediments deposited within the pocket beach by onshore erosion of the rocky shoreline. A type of rocky pocket estuary.

Created - a coastal feature that resembles and functions ecologically as one of the previously listed geomorphic types, but which is known to be created by built structures or fill introduced into the nearshore. A type of pocket estuary.

Modified - known to be a naturally formed pocket estuary historically, but its current condition has been so modified by human causes (e.g., dredging, intertidal filling, and armoring) that it does not resemble any of the natural geomorphic pocket estuary types. A type of pocket estuary.

Habitat Types – unique habitat types that occur within one or many of the shoreline types—rocky pocket estuaries or drift cell pocket estuaries:

Backshore - the area above MHHW distinguishable in aerial photos as the area above the driftwood line and below the edge of upland vegetation. Also known as the supralittoral or supratidal zone.

Backshore berm - low lying sand, gravel, and driftwood comprising a barrier beach (wave deposited), partly or completely vegetated with salt- and drought-tolerant grasses and other vegetation.

Backshore colluvium - sediment deposits in the backshore derived from an adjacent bluff via slope failure. Slope failure can be caused by wave erosion at the toe of the bluff or by bluff and upland hydrology. Colluvium sediments are mixed grain, poorly sorted, unconsolidated sediments, depending on the composition of the bluff that failed.

Backshore dune - wind deposited, unconsolidated sand and silt derived from beaches and deposited in the backshore.

Backshore wood - wracks of driftwood that accumulate on backshore berms (at least three logs deep) such that vegetation is not visible amongst the wood.

Built - anthropogenic structures in the backshore zone.

Intertidal - the area between ELW and MHHW, distinguishable in aerial photos as the area between ELW and the driftwood, bluff base, or bulkhead line;

Subtidal - the area below ELW, distinguishable in aerial photos as the edge of water in photos flown during extreme low tides.

Beach face – the sloping surface of the beach extending from about MLW up to the highest extent of the wave swash zone. Sediment transport is most active in this zone for Salish Sea beaches.

Channel (intertidal or subtidal, natural or dredged) - tidally or fluvially carved channels in the form of stream distributaries, drowned stream channels, tidal blind channels in salt marsh, lagoon outlet channels, or channels on an intertidal alluvial fan.

Fill (intertidal or subtidal) - anthropogenic structures or fill material in the intertidal or subtidal zone. Intertidal fill may or may not exceed the elevation of high tide.

Impoundment (intertidal or subtidal, natural or dredged) - marine or brackish water pool accessible to fish via tidal channel, and connected to tidal flow during all or part of the tide cycle, that remains wet even when disconnected from open water by low tides.

Intertidal wood - wracks of driftwood that accumulate in the intertidal zone, usually on saltmarshes or behind (landward of) barrier beaches.

Intertidal fill wood – intertidal fill that has accumulations of wood over it.

Low tide terrace - a gently sloping to nearly flat platform below the beach face and extending below MLLW.

Rocky beach - the beach face of a bedrock shoreline comprised of bedrock and boulders with only minor amounts of smaller sediment.

Rocky platform - a wave-cut rocky platform, with or without sediment veneer.

Tidal marsh - flat or gently sloping tidally inundated wetland colonized by salt-tolerant herbaceous plants and often cut by tidal or fluvial channels.

Tidal scrub shrub - flat or gently sloping wetland colonized by salt-tolerant shrubs and small woody plants as well as herbaceous plants tolerant to brackish water and freshwater inundation from time to time.

Tidal forest - flat or gently sloping forested wetland with tidal influence. These are rarely found away from large river deltas.