Improving Wetland Conservation and Management through Updated Wetland Mapping in the Chenega Region, Alaska

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Executive Summary

Introduction:

Alaska Center for Conservation Science (ACCS) in partnership with the Chugach Regional Resources Commission (CRRC) and the U.S. Fish & Wildlife Service (USFWS) presents an updated wetland and deepwater digital map for Alutiiq tribal lands in the western Prince William Sound region of Southcentral Alaska. We improved 1980s-era wetland mapping through segmentation analysis informed by satellite imagery, remotely-sensed data, and ground verification of habitat types. Our methodology represents one of the first semi-automated mapping effort to successfully predict the wetland status of lands in Alaska at a target mapping unit (TMU) of 0.5 acres. The final geodatabase was developed in accordance with national wetland mapping standards, reviewed according to national mapping quality assurance/quality control protocols, and submitted to the USFWS National Wetlands Inventory (NWI) national dataset (FGDC 2009, 2013). Wetland and deepwater polygons are further attributed by hydrogeomorphic descriptors of landscape position, landform, water flow path, and waterbody type (LLWW, Brinson 1993).These descriptors capture the geomorphic setting of a wetland, its proximity to other wetlands and waterbodies, and the dominant water source and flow path, which all influence the functions a wetland can perform (Brinson 1993; Tiner 2014).This high-resolution and accurate wetland and deepwater map will enable local land owners and managers to better evaluate the wetland functions and conserve and responsibly develop their natural resources.

Study Area:

Our updated wetland and deepwater mapping covers the Evans Island – Latouche Island watershed, located in western Prince William Sound between the communities of Seward and Whittier (Figure 1). In addition to a peninsular portion of the mainland, the study area includes the Latouche, Elrington, Evans, and Bainbridge Islands. This pristine landscape is one of rocky coastal headlands, temperate rainforests, blanketing wetlands, and rugged alpine peaks. The region is characterized by a temperate climate with maritime influence, resulting in high precipitation and mild temperatures with moderate seasonal range. Chenega, an Alutiiq village of approximately 55 residents located on Evans Island is the only permanent community within the study area (US Census Bureau 2023).

Table 1. Identifiers and metrics for the Evans Island – Latouche Island watershed.

Hydrologic Unit Code	Name	Community	Year of Current NWI	Area (acres)
1902020303	Evans Island – Latouche Island	Chenega	1982	131,049

Map of Study Area:

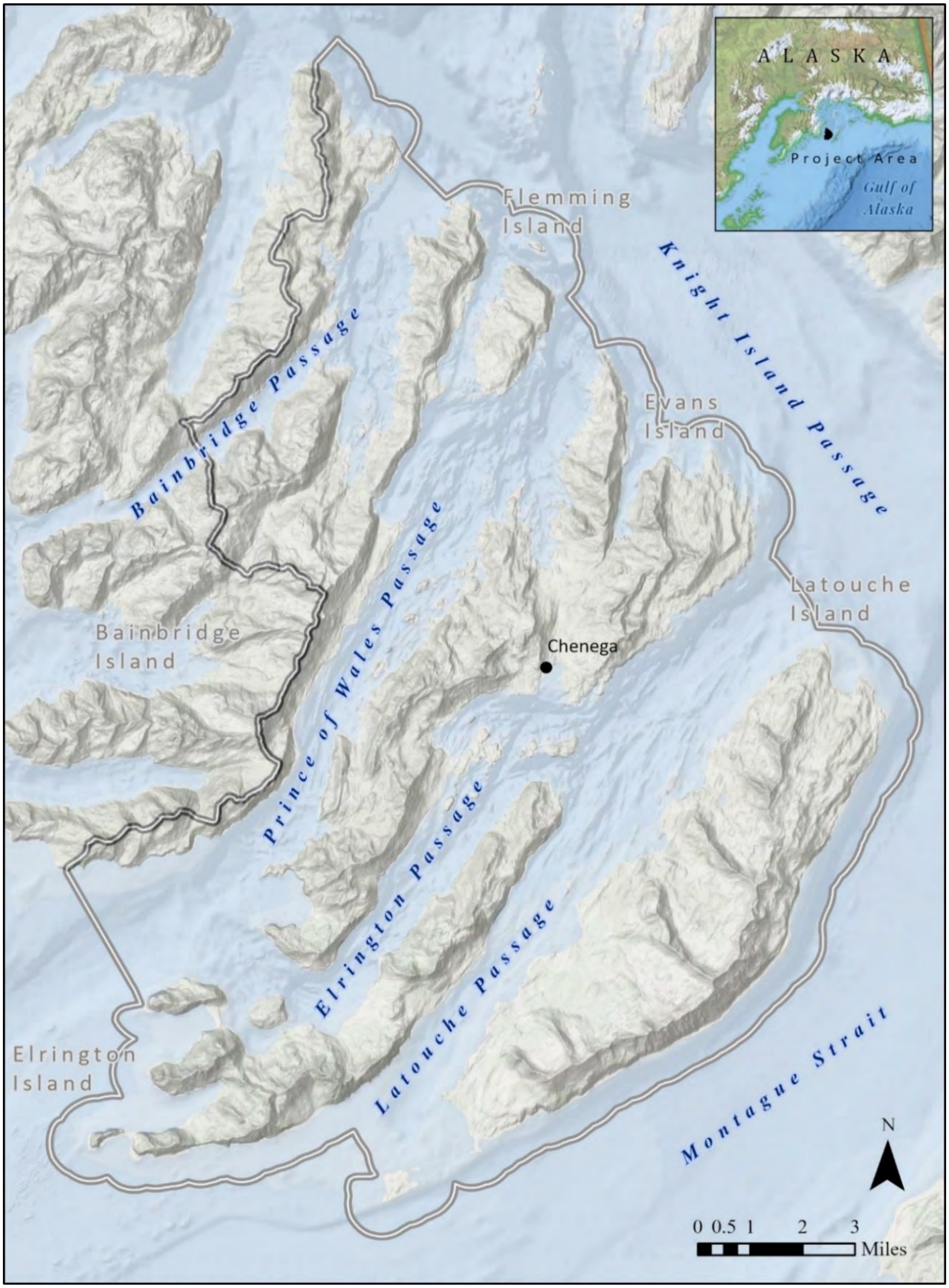

Figure 1. Project area showing the Evans Island – Latouche Island watershed in the Chenega Region of Western Prince William Sound.

Classification Results:

The elevational gradient of the study area is broad, which supports a diversity of types, including: ocean waters, protected estuaries, salt and freshwater marshes, fens, bogs, woody wetlands, riparian and alpine floodplains, lakes, ponds, and streams. Shallow bedrock, which inhibits drainage, and abundant precipitation combine to promote extensive wetland development. The resulting map delineates 23 wetland and deepwater classes (nine wetland and 14 deepwater) with wetlands and freshwater bodies occupying 31 and 1 percent of the terrestrial area[1], respectively (Figure 2, Table 2). When estuarine and marine deepwater are excluded, freshwater forested and shrub wetlands occupy the greatest percent of the terrestrial area (Table 3).

Table 2. Summary of wetland and deepwater generalized categories by area for the Chenega region; estuarine and marine deepwater are excluded from the calculation of terrestrial area.

Status	Generalized Types	Acres	Percent of Terrestrial Area
Wetland	Estuarine and Marine Wetland	2,282	3
	Freshwater Forested/Shrub Wetland	14,462	22
	Freshwater Emergent Wetland	3,678	5
Deepwater	Estuarine and Marine Deepwater	65,465	not applicable
	Riverine	91	<1
	Freshwater Pond	329	<1
	Other (PRB1H)	7	<1
	Lake	193	<1
Upland	not applicable	44,543	68
	Study Area	131,049	100

[1] Terrestrial area is defined as lands not permanently flooded by marine or estuarine waters.

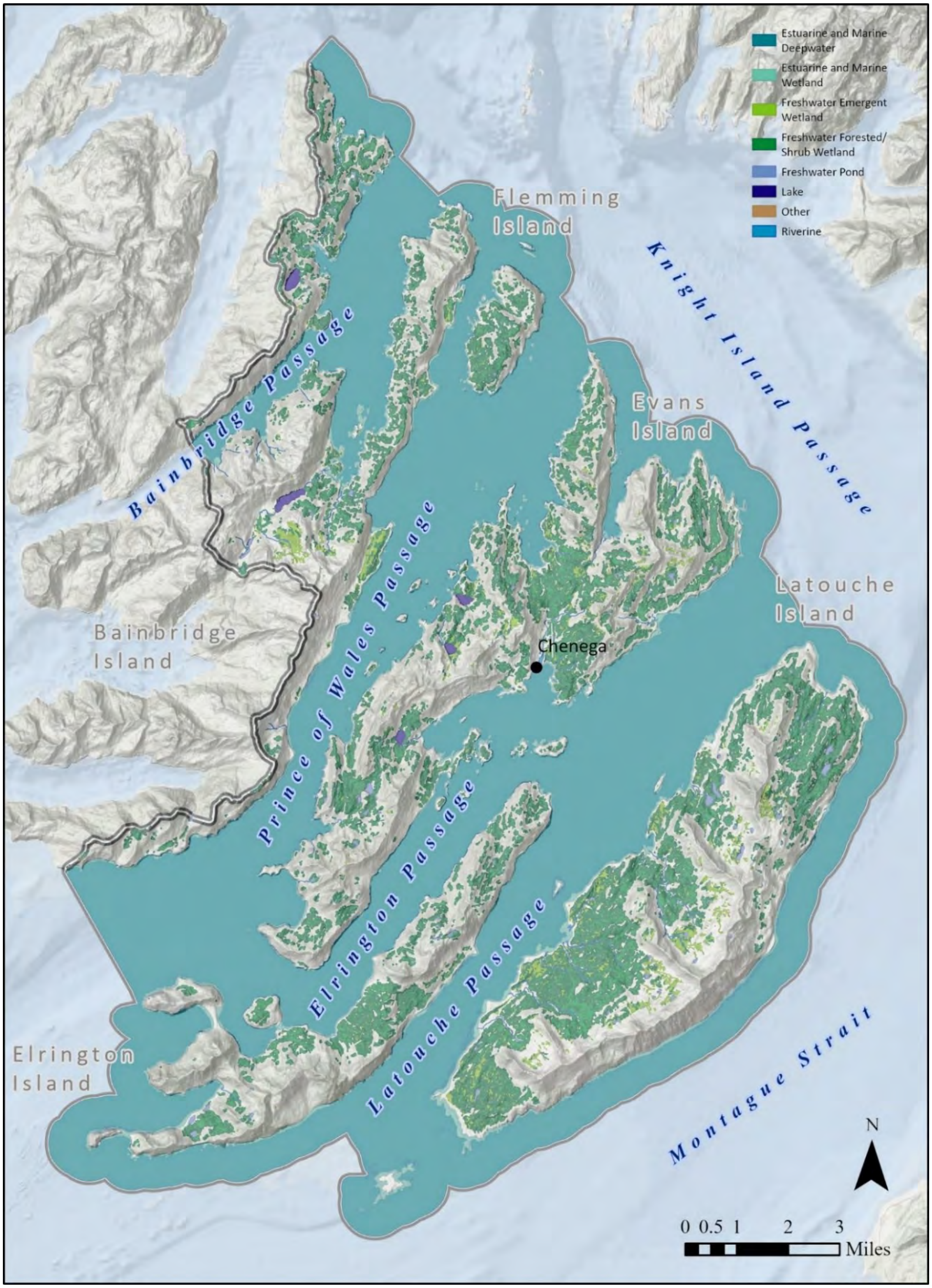

Figure 2. Updated distribution of generalized wetland and deepwater types for the Evans Island – Latouche Island watershed in the Chenega region of Western Prince William Sound. Note: for this project, 'Other' is equivalent to PRB1H.

Table 3. Summary of wetland and deepwater classes by area for the Chenega region; estuarine and marine deepwaters are excluded from the calculation of percent area.

Generalized Wetland Type, Code, and Description		Acres	Percent Terrestrial Area
Estuarine and Marine Deepwater		**65,465**	not applicable
M1AB1L	Marine subtidal with algal aquatic bed	181	0.28
M1UBL	Marine subtidal with unconsolidated bottom	65,284	99.54
Estuarine and Marine Wetland		**2,282**	**3.48**
E2EM1P	Intertidal estuarine emergent, persistent vegetation with irregular flooding	29	0.04
M2AB1M	Lower intertidal marine algal aquatic bed with irregular exposure	1,531	2.33
M2AB1N	Upper intertidal marine aquatic bed with regular flooding	150	0.23
M2RS1N	Intertidal bedrock shore with regular flooding	229	0.35
M2US1N	Intertidal unconsolidated cobble or gravel shore with regular flooding	343	0.52
Freshwater Emergent Wetland		**3,678**	**5.61**
PEM1C	Palustrine emergent wetland with seasonal flooding	109	0.17
PEM1D	Palustrine emergent wetland with continuous saturation	1,767	2.69
PEM1E	Palustrine emergent wetland with seasonal flooding or saturation	1,803	2.75
Freshwater Forested/Shrub Wetland		**14,462**	**22.05**
PFO4B	Palustrine needleleaf forested wetland with seasonal saturation	9,564	14.58
PSS1C	Palustrine deciduous shrub wetland with seasonal flooding	53	0.08
PSS4B	Palustrine needleleaf shrub wetland with seasonal saturation	4,845	7.39
Freshwater Pond		**329**	**0.50**
PAB3H	Freshwater pond with aquatic vascular bed	86	0.13
PUB3H	Freshwater pond with unconsolidated mud bottom	240	0.37
PUS2C	Seasonally flooded, unconsolidated sand shore of freshwater pond	3	0.01
Lake		**193**	**0.29**
L1UB3H	Freshwater lake with unconsolidated mud bottom	193	0.29
L2RS1C	Seasonally flooded, rocky bedrock shore of freshwater lake	1	0.00
Other		**7**	**0.01**
PRB1H	Freshwater pond with rock bottom	7	0.01
Riverine		**91**	**0.14**
R1UB1V	Riverine, unconsolidated cobble or gravel bed, permanently flooded with fresh water yet experiences tidal influence	19	0.03
R2UB1H	Riverine, lower perennial unconsolidated cobble or gravel bed, permanently flooded with fresh water	56	0.09
R3UB1H	Riverine, upper perennial unconsolidated cobble or gravel bed, permanently flooded with fresh water	11	0.02
R4SB3J	Riverine, streambed of unconsolidated cobble or gravel, intermittently flooded with fresh water	4	0.01
	Total Wetland and Deepwater Area	**86,506**	not applicable

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Source Satellite Imagery:

The Alaska High Resolution Imagery 2020 (AHRI; © Maxar 2021) composite provided the basis for both image segmentation and manual delineation of types. The AHRI 2020 composite has a 0.5 m resolution and four bands: blue, green, red, and near-infrared. For manual delineation, the multi-band raster was used in false color mode to accentuate differences in the reflectance of vegetation and moisture of the ground surface. All bands were used in segmentation after being resampled to a 1 m resolution. Acquisition dates in the project area were either September 2014, June 2018, or July 2020.

- AHRI composite, 2020: a 4-band, 0.5-meter image mosaic; image captured by MAXAR, product licensed through the State of Alaska.

Collateral Data:

Collateral data were used to represent temporal dynamism in the project area and to confirm or refute the initial prediction of wetland or deepwater types. Incorporation of collateral data into the automated portion of the workflow greatly improved model performance and compensated for differences in acquisition dates in the AHRI 2020 composite (see methods). Unfortunately, we were not able to locate existing georeferenced vegetation plot data from the project area that could inform the classification. Instead, we relied on professional judgement and vegetation plot data collected in conjunction with our field effort. The types of data, date of production, source and notes on our use of the products follow.

- Sentinel-1 2021: synthetic-aperture radar product with 10-meter resolution, provided by the Copernicus Data Space Ecosystem. We compiled median pixels for VV (vertical-vertical) and VH (vertical-horizontal) polarizations along ascending paths collected from 2015 through 2021 for the months of June-August (summer), September-October (fall), and January-March (winter).
- Sentinel-2, Level 2A Surface Reflectance 2021: 13-band, 10-/20-meter resolution, multispectral satellite imagery provided by the Copernicus Data Space Ecosystem. We compiled median pixels for a subset of bands and derived metrics from 2019 through 2021 for the months of June, July, August, and September (as separate monthly composites).
- IfSAR-derived slope, 2014: 5-meter hypsography provided by the State of Alaska.
- IfSAR-derived topography, 2014: 5-meter topographic metrics derived from the State of Alaska Digital Terrain Model. We included aspect, elevation, heat load index, position, radiation index, roughness, slope, surface area, surface relief, and surface relief. We additionally included distance to coast derived from a manually delineated coastline.
- National Hydrography Dataset (NHD), 2020: a vector-based geodatabase provided by the US Geological Survey.
- NWI wetland map for the Evans – Latouche Island HUC 8 level watershed, 1982. a vector-based geodatabase of manually delineated wetlands and deepwater for the study area, provided by the USFWS in support of this project.
- Georeferenced air and ground photographs collected during summer 2022 field work.

Inventory Method:

Historically, wetlands and waters mapped according to the National Wetland Classification (FGDC 2009, 2013) have been delineated manually. Despite increasingly-available remotely sensed data and access to large amounts of computational resources, automated approaches to mapping wetlands have been ecologically-coarse. One challenge to automating the mapping of wetland and deepwaters in accordance with the national standard is that the classification integrates contextual information, such as tidal regime, water salinity, deepwater substrate characteristics, and vegetation persistence; information that is often not directly represented in, or interpretable from, point-in-time captures of remotely sensed data. We have implemented a semi-automated strategy for wetland mapping that retains advantages of automation while enabling a wetland ecologist to focus on providing the contextual information necessary to assign wetland and deepwater classes.

Classification:

For the assessment of wetland or deepwater condition, we employed a semi-automated workflow that integrates the automated recognition and labeling of segments with the manual delineation of training and ancillary data. We used ArcGIS Pro version 3.1.0 for field planning, creation of training data, manual delineation of wetland and deepwater types, and model assessment. We used the following software for the automated portion of the workflow: spectral and textural data processing in Google Earth Engine (GEE; Gorelick et al. 2017); spatial processing using ArcGIS Pro 3.2.0 with Python 3.11.8; data extraction using R 4.3.2 and RStudio 2023.09.1 with fasterize 1.0.5 (Sumner 2018), raster 3.6–26 (Hijmans et al. 2023), sf 1.0–14 (Pebesma et al. 2023), and tidyverse 2.0.0 (Wickham et al. 2019); and predictive statistical modeling in the Anaconda 2023.09 distribution of Python 3.11 with Scikit-learn 1.3.2 (Pedregosa et al. 2011). All scripts used to conduct automated portions of our workflow are publicly available on GitHub.

For the assignment of Landscape Position, Landform, Water Flow Path, Waterbody Type (LLWW) attributes to wetland and deepwater polygons, we followed an adaptation of a key developed for the western states (Lemly et al. 2018). The final map is produced at a level of detail consistent with a 1:24,000 scale map product or finer. Please see step 11 below and Appendix 9 for details.

Our work was performed in the following sequence:

1. Image segmentation: We resampled the AHRI 2020 composite to 1 m resolution, loaded the data into GEE, and calculated a modified enhanced vegetation index-2 (EVI-2), normalized difference vegetation index (NDVI), and normalized difference water index (NDWI). We calculated segments on the blue, red, green, near infrared, modified EVI-2, NDVI, and NDWI bands using simple non-iterative clustering (Achanta and Susstrunk 2017) as implemented in GEE. To create covariates for model training and prediction, we calculated the per segment mean, standard deviation, and range of all original and derived AHRI bands. To represent dynamic temporal characteristics of each segment, we calculated the per segment mean of original and derived Sentinel-1 polarizations and Sentinel-2 bands for all seasonal composites. Finally, we calculated the zonal mean of our topographic covariates to represent surface characteristics and the topographic capacity for water accumulation. Appendix 1 provides the full set of covariates summarized per segment.

2. Creation of training data: Image segmentation delineates clusters of pixels that have statistically similar data signatures. Importantly, the segmentation process does not predict the type of wetland or deepwater represented by that segment. Instead, we manually delineated a subset of representative wetland or deepwater polygons throughout the project area to serve as a training

dataset. To create training data, we first reviewed the imagery to develop a working set of wetland, deepwater, and upland types that could be identified from remotely-sensed imagery. We then created polygons representative of each type and evenly distributed throughout the project area. In its final form the training data included over 8,000 polygons and covered approximately 15% of the terrestrial project area. While not required by FGDC data standards for wetland mapping, coarse upland types were characterized to improve model performance.

3. Assignment of labels to segments: A random forest classifier statistically associated labeled segments from the training dataset with the suite of textural, spectral, and topographic covariates summarized to each segment. Because the number of labeled samples depended on the rarity of the class within the project area, we applied a class balance weighting equal to the inverse proportion of samples out of the total. The trained classifier then predicted a label to each segment. In this way, our model assigned all segments to wetland, deepwater, or upland classes based on the statistical relationships between training data and covariates following a schema developed by the wetland analyst.

4. Intermediate assessment of accuracy: To evaluate the predictive accuracy of our model, we divided the study area into a regular 10 km grid and split our training data by those grids. We validated the model through multiple cross validation iterations. During each cross-validation iteration, we retained the labeled samples within a single grid as independent test data (i.e., data not used to train the classifier). We predicted labels to the withheld test data using a model trained on the training data from all other grids such that labeled samples from each grid were predicted once. We merged the predictions from the independent test data merged across all iterations. The merged predictions enabled us to calculate a confusion matrix with user's and producer's accuracy while avoiding optimistic bias from spatial autocorrelation. To the extent possible, we targeted types with low accuracy and difficult to interpret imagery in field sampling. Intermediate accuracy assessment allowed us to identify:

    a. analyst error, inconsistency, or omission – corrected by the revision or addition of training data
    b. ecological ambiguity related to the application of wetland categories to continuous ecological gradients that vary in space (e.g., soil moisture, salinity) or time (e.g. seasonal and tidal inundation) – corrected by the incorporation of ancillary data such as the manual delineation of maximum extent of mean high tidal water
    c. model error – corrected through the enforcement of labeling rules, incorporation of ancillary datasets, creation of conformational and correctional polygons

    Thus, the intermediate accuracy assessment helped the wetland analyst identify the classes that required the highest amount of corrective effort.

5. Field verification: Helicopter-assisted field work was conducted from July 11 to 14, 2022 during which we completed 65 air plots and 18 ground plots (Appendices 3 and 4, respectively). Within the restrictions of approved landing zones, we attempted to sample the full variation of wetland, deepwater, and upland types within each 10 km verification grid. Air plots were completed opportunistically by hovering over the area of interest to document the type of wetland, deepwater, or upland habitat. For these plots we collected basic information on dominant plant species based on top foliar cover, took a pair of photos capturing the ground cover and landscape position. For wetland and deepwater habitat, we assigned a wetland code in accordance with the NWI classification (FGDC 2013); for upland plots we assigned a land cover class from a set of types we developed for the study area (Appendix 4). Ground plots were accessed by foot from approved helicopter landing zones. For each ground plot we collected data to satisfy the minimum standards for field data collection at the

vegetation classification tier (VTWG 2022). In addition to plot metadata such as geographic location, terrain slope and aspect, physiography, geomorphology, topography and disturbance, we estimated absolute foliar cover for all non-trace (cover >1%) vascular species and high-cover (cover >5%) non-vascular species; covers were also estimated for each stratum of vegetation and predefined classes of abiotic ground cover such as rock, soil, litter, and downed wood (Appendices 3, 5-7). For plots along the coast, we sampled the salinity of ocean waters, we did not collect soils information at any ground plot. In addition to the plot data collected during a field effort, first-hand experience of the system imparted a better understanding of the range of types and their relation to each other on the landscape. Using the combination of quantitative data and our qualitative comprehension of the system, we revised the training polygons that we believed to be incorrect and delineated additional training polygons.

6. Creation of additional training and ancillary data: The intertidal zone was defined in part, by a manually-delineated coastline corresponding to our interpretation of the average of high tidal water heights, also referred to as mean high water. Manual delineation of a coastline was deemed necessary because coastlines available for the project area lack the horizonal accuracy necessary to define the intertidal range. The coastline was chiefly used to restrict the occurrence of tidally-influenced habitats at elevations above this limit.

7. Model rerun: The prediction of wetland and deepwater types from remotely sensed data was an iterative process. The model was rerun with new training data and rule sets. See steps 3 and 4.

8. Manual delineation of uncommon types: Because the model relied on training data to predict occurrence, it did not perform well for wetland and deepwater types that have a geographically limited expression within the project area, are of small or narrow extent, or are defined by traits not interpretable from remotely sensed data. For example, riverine types were hand delineated because they are not common on the Chenega landscape and typically manifest as narrow, linear features that segmentation analysis fails to identify. Similarly, the status of deepwater types as marine or estuarine was also determined manually because the salinity of water and exposure of a coastline is not easily quantified from remotely-sensed data. We manually delineated the following types:

Table 4. Wetland codes of manually delineated wetland types and their descriptions.

Wetland Code	Description
E2EM1P	Intertidal estuarine, persistent emergent vegetation with irregular flooding
R1UB1V	Riverine, unconsolidated cobble or gravel bed, permanently flooded with fresh water yet experiences tidal influence
R2UB1H	Riverine, lower perennial with unconsolidated cobble or gravel bed, permanently flooded with fresh water
R3UB1H	Riverine, upper perennial unconsolidated cobble or gravel bed, permanently flooded with fresh water
R4SB3J	Riverine, streambed of unconsolidated cobble or gravel, intermittently flooded with fresh water
PRB1H	Freshwater pond with rock bottom, permanently flooded
PEM1C	Palustrine emergent wetland with seasonal flooding
PSS1C	Palustrine deciduous scrub-shrub wetland with seasonal flooding

9. Aggregation of polygons: We dissolved polygon boundaries by attribute to merge adjacent polygons representing the same type. To preserve ecologically meaningful delineations of wetland and deepwater habitat, we employed a target mapping unit (TMU) that was a smaller scale than the minimum mapping unit (MMU) suggested by FGDC guidance. Specifically, we enforced an MMU of 0.5 ac and a TMU of 1 ac for marine waters, an MMU of 0.125 ac and a TMU of 0.5 ac for terrestrial wetlands, and an MMU of 0.125 ac and TMU of 0.5 ac for terrestrial waters. Where our automated process predicted wetland types smaller than the MMU, we removed the polygon and reassigned the omission based on geographic distance to aggregated neighboring polygons with area greater than the MMU. The distance-based reassignment generalized the new boundaries between adjacent aggregated polygons. We separated lakes from ponds based on an area threshold of greater than or equal to 20 acres. Finally, we removed all upland types from the dataset as these are not a required deliverable**.**

10. Polygon smoothing: We applied smoothing algorithms at two points in the map generation process. First as a raster-based smoothing algorithm, which added and subtracted pixels to create a more generalized edge. Second, as a vector-based smoothing algorithm, which generalizes polygon edges based on a 10 m tolerance of edge length between vertices.

11. Assignment of Landscape Position, Wetland Landform, Water Flow Path, Waterbody Type (LLWW) to wetland and deepwater polygons: LLWW refers to the hydrogeomorphic descriptors of landscape position, landform, water flow path, and waterbody type, a classification system originally developed by the USFWS (Tiner 2014). We developed a semi-automated process for the assignment of LLWW type that builds on ArcGIS models built for the western United States (Lemly et al. 2018) and modified for use in coastal environments (Geist and Steer 2019). The basic structure of the LLWW code is two letters for Landscape Position, two letters for Wetland Landform or Waterbody Type, and two letters for Water Flow Path (Table 4, Figure 3). We elected to assign either Wetland Landform (left panel) or Waterbody Type (right panel), as the two fields are mutually exclusive. Data preparation and model steps for the assignment of the LLWW attributes are outlined in Appendices 8 and 9, respectively.

Table 5. Definitions of two-letter codes used to describe the landscape position, landform, flow path and waterbody type of wetland and deepwater habitats.

Category of Code	Code	Name
Waterbody and Wetland Type	PD	pond
	LK	lake
	ST	stream
	ES	estuary
	OB	ocean
	TE	terrene
Landscape Position	MA	marine
	ES	estuarine
	LE	lentic
	LO	lotic
	TE	terrene
Flow Path	BT	bidirectional-tidal
	OU	outflow
	TH	throughflow
	VR	vertical flow
Landform	BA	basin
	FL	flat
	FR	fringe
	IL	island
	SL	slope

Table 6. Example LLWW codes for wetland (left panel) and waterbody features (right panel); modified from Lemly et al. 2018.

Wetland Feature Example:

PEM1C	System = P (palustrine) Class = EM (emergent) Subclass = 1 (persistent) Water Regime = C (seasonally flooded)
LOBATH	Landscape Position = LO (lotic) Wetland Landform = BA (basin) Flow Path = TH (through flow)

Waterbody Feature Example:

PAB3H	System = P (palustrine) Class = AB (aquatic bed) Subclass = 3 (rooted vascular) Water Regime = H (permanently flooded)
LOPDTH	Landscape Position = LO (lotic) Waterbody Type = PD (pond) Flow Path = TH (through flow)

Data Limitations:

The map presented here uses ground and remotely sensed data to predict wetland and deepwater type. Initial predictions are refined by reattribution of type or manual adjustment of extent in a GIS environment. As such, not all types and extents have been confirmed in the field. Further, the map does not include terrestrial wetlands and waters that are less than 0.125 ac in area or less than 15 feet in width, which excludes the delineation of small pools of water, upland inclusions in wetland complexes, wetland inclusions in upland complexes, and narrow streams.

General Description of Project Area:

Climate:

The climate in Western Prince William Sound is temperate maritime with relatively low annual variation in temperature and precipitation. Summers (June - September) are warm and rainy, with an average temperature of 11.5°C (53°F) and average precipitation of 13.2 cm (5.2 in) per month. Winters (October – May) are mild and snowy, with an average temperature of 1°C (34°F) and precipitation of 17 cm (6.6 in) per month, with an average annual total of 1.6 m (5.3 ft) of snow (NOAA 2023).

Geography:

The Chenega region is characterized by steep, rugged mountains extending from sea level to over 600 m. The outer coast is rocky and exposed, with high energy shorelines punctuated by protected beaches and estuaries. Streams are short and swift, with headwaters originating in alpine valleys. Ponds perch on shallow bedrock and lakes lie in ice-carved basins. While glaciers are not found within the study area, the higher elevations of the Prince William Sound region are capped by ice fields from which valley and piedmont glaciers drain (Gallant et al. 1995).

Geology:

The geology of Prince William Sound is principally structured by the subduction of the Pacific plate beneath the North American plate along the Aleutian Trench. The Chenega region is located on the leading edge of the North American Plate, which has been deformed by the varied forces active at a consumptive plate margin. Compression has thrust the geologic backbone of the region approximately 1,800 m skyward while down warping has produced the region's characteristic sunken coastline replete with drowned cirques and deep fjords (Hamilton and Nelson 1989). Subduction-induced down warping has dropped the landscape an estimated 100 m since the Wisconsin glaciation (Wiles and Calkin 1990).

Tectonic releases along the Aleutian Trench produce earthquakes at moderate frequency and occasionally high intensity (Haeusser and Plafker 1995). The 9.2-magnitude 1964 Good Friday Earthquake raised the Chenega region between 1.3 and 3.5 m with displacement increasing from west to east across the study area (Plafker 1969). The village of Chenega, formerly located on the southern end of Chenega Island, was destroyed by an earthquake-induced tsunami that hit minutes after the Good Friday quake with a 22 m runup height. The tsunami killed 23 of 75 residents, resulting in the highest relative loss of life of any community affected by the earthquake (Brothers et al. 2016). Post-seismic tectonic uplift has raised the coast between 20 and 40 cm between 1964 and 1995 (Cohen and Freymueller 2001). The rate of tectonic uplift far out paces global sea-level rise (eustatic rate of rise: 1.8 mm/yr; Pendelton et al. 2006) and results in a net positive rate of rise for the region.

Glacial History:

Prince William Sound is a landscape sculpted by ice. The region was extensively glaciated during the Pleistocene epoch and experienced three major intervals of glacial expansion in the late Holocene with advances occurring 3600 ybp, in 600 A.D., and during the Little Ice Age from 1300 to 1850 A.D. Features typical of glaciated terrain, such as aretes, horns, cirques, U-shaped valleys, and morainal deposits in valleys and on lower hillslopes, are abundant (Gallant et al. 1995).

Vegetation:

Coniferous forests, codominated by Sitka spruce (*Picea sitchensis*) and hemlock (*Tsuga* sp.) are the dominant vegetation type within the project area. Sitka spruce tends to occupy the coastal rim and riparian corridors, with the abundance of hemlock increasing with elevation and distance from the ocean. Within the project area, spruce show moderate levels of mortality from infestation by the native spruce beetle, *Dendroctonus rufipennis*. While mountain hemlock (*Tsuga mertensiana*) is the most common hemlock species, a stand of western hemlock (*Tsuga heterophylla*) was observed on the outer coast of Latouche Island; we believe this may represent the western limit of this species' range. Upland forest understories are typically shrub rich with copperbush (*Elliottia pyroliflora*), rusty menziesia (*Menzisia ferruginea*), devilsclub (*Oplopanax horridus*), and oval-leaf blueberry (*Vaccinium ovalifolium*). Small wetland pockets within continuous coniferous forest are characterized by American skunkcabbage (*Lysichiton americanus*) and a greater contribution of feather (e.g., *Pleurozium schreberi, Rhytidiadelphus loreus*) and sphagnum mosses in the understory.

Many mountain sideslopes within the project area experience active mass wasting and are too unstable to support vegetation. Those that have stabilized are characterized by extensive thickets of Sitka alder (*Alnus viridis* ssp. *sinuata*) and salmonberry (*Rubus spectabilis*) shrubs. Treeline communities are largely Krummholz mountain hemlock and Sitka alder interspersed with herbaceous meadows.

Above elevational tree line, alpine tundra characterized by variable contributions of dwarf shrubs, lichens, graminoids, ferns, and forbs. The abundance of dwarf shrub and lichens tends to increase with exposure, while the abundance of grasses, sedges, ferns and forbs tends to increase with protection and moisture. Thus, dwarf shrub communities are more common on alpine ridges and other convex landforms, while herbaceous meadows are more common in topographic depressions, areas of late-lying snow, and along the shores of lakes, ponds, and streams.

At lower elevations, extensive wetland complexes of sedge-rich fens and sphagnum-rich bogs blanket areas of gentle topography where shallow bedrock or other densic layers retard the infiltration of surface and ground water. In the nearshore environment, vegetation transitions from coastal meadows comprised of salt-tolerant species such as beach rye grass (*Leymus mollis*) and large umbels such as Scottish licorice-root (*Ligusticum scoticum*), sea coast angelica (*Angelica lucida*), and common cowparsnip (*Heracleum maximum*), to beach communities comprised of halophytic species such as beach pea (*Lathyrus japonicus*), seaside sandplant (*Honckenya peploides*), and seaside ragwort (*Senecio psuedoarnica*). Coastal herbaceous communities transition to algal beds, comprised of rockweed (*Fucus*) species and mixed red macroalgae in the intertidal zone. In the subtidal, eelgrass (*Zostera marina*) is common in protected estuaries; bull kelp (*Nerocystis luetkeana*) beds are common where wave energy is high.

Soils:

Due to recent deglaciation and steep topography, soils within the project area are young, and form over gravelly till and colluvium underlain by bedrock. The mineral soils developing from these parent materials are typically silt loams with moderate to excessive drainage, particularly where sediments are deep and the terrain is sloped. Hydric soils form where shallow, cohesive bedrock retards the infiltration of precipitation. Here, organic matter accumulates as peat and wetland conditions develop.

Land Use:

Permanent settlements are rare in this ecoregion, occurring exclusively at lower elevations along the coast.

Following the Good Friday Earthquake, the village of Chenega was relocated to Evans Island in 1984. The community is comprised of 50-70 residents and is accessible only by air or water. In 1989, the Exxon Valdez tanker ran aground on the Bligh Reef in Eastern Prince William Sound discharging millions of gallons of oil to the water. The environmental damage that ensued destroyed the subsistence resources on which native peoples rely for decades to come.

Natural History, Important Features:

Western Prince William Sound has been used by the Chugach and Eyak peoples since pre-history. Moose, mountain goats, and smaller mammals are hunted in the mountains. Streams yield salmon and freshwater fish. Coastal areas provide marine resources as well as coastal birds and their eggs. Edible greens, roots, and berries are also harvested. In addition to subsistence and recreational use, the region has been mined for its mineral resources. The Beatson Mine, located on Latouche Island, produced copper from 1907-1930 and at its peak supported 4,000 residents. The ongoing remediation of the site now supports an unspecified number of seasonal workers (State of Alaska 2023).

Description of Wetland Habitats:

Classification Standard:

The National Wetland Classification Standard provides a national system for the description and mapping of wetland and deepwater habitat in the United States (FGDC 2013). The system is hierarchical; wetland and deepwater habitats are separated into five major systems (marine, estuarine, riverine, lacustrine, and palustrine) represented by similar hydrological, geomorphological, chemical, and biological influences. These systems are further divided into finer-scale subsystems and classes related to frequency of inundation and substrate and vegetation characteristics (Figure 3). Water regimes are appended to describe the type, frequency, and duration of flooding or saturation (FGDC 2013).

- The **marine** system consists of the open ocean overlying the continental shelf and its associated coastline.
- The **estuarine** system consists of deepwater tidal habitats and adjacent tidal wetlands that are usually semi-enclosed by land with some access to the open ocean, and in which ocean water is at least occasionally diluted by freshwater runoff from the land.
- The **riverine** system includes all wetlands and deepwater habitats contained within a channel.
- The **lacustrine** system includes wetland and deepwater habitats that are situated in a topographic depression or a dammed river channel, lacking trees, shrubs, persistent emergents, emergent mosses or lichens with 30 percent or greater areal coverage; and total area of at least 8 ha (20 ac).
- The **palustrine** system includes all non-tidal deepwater habitats with total area less than 8 ha (20 ac) acres and non-tidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens and waterbodies.

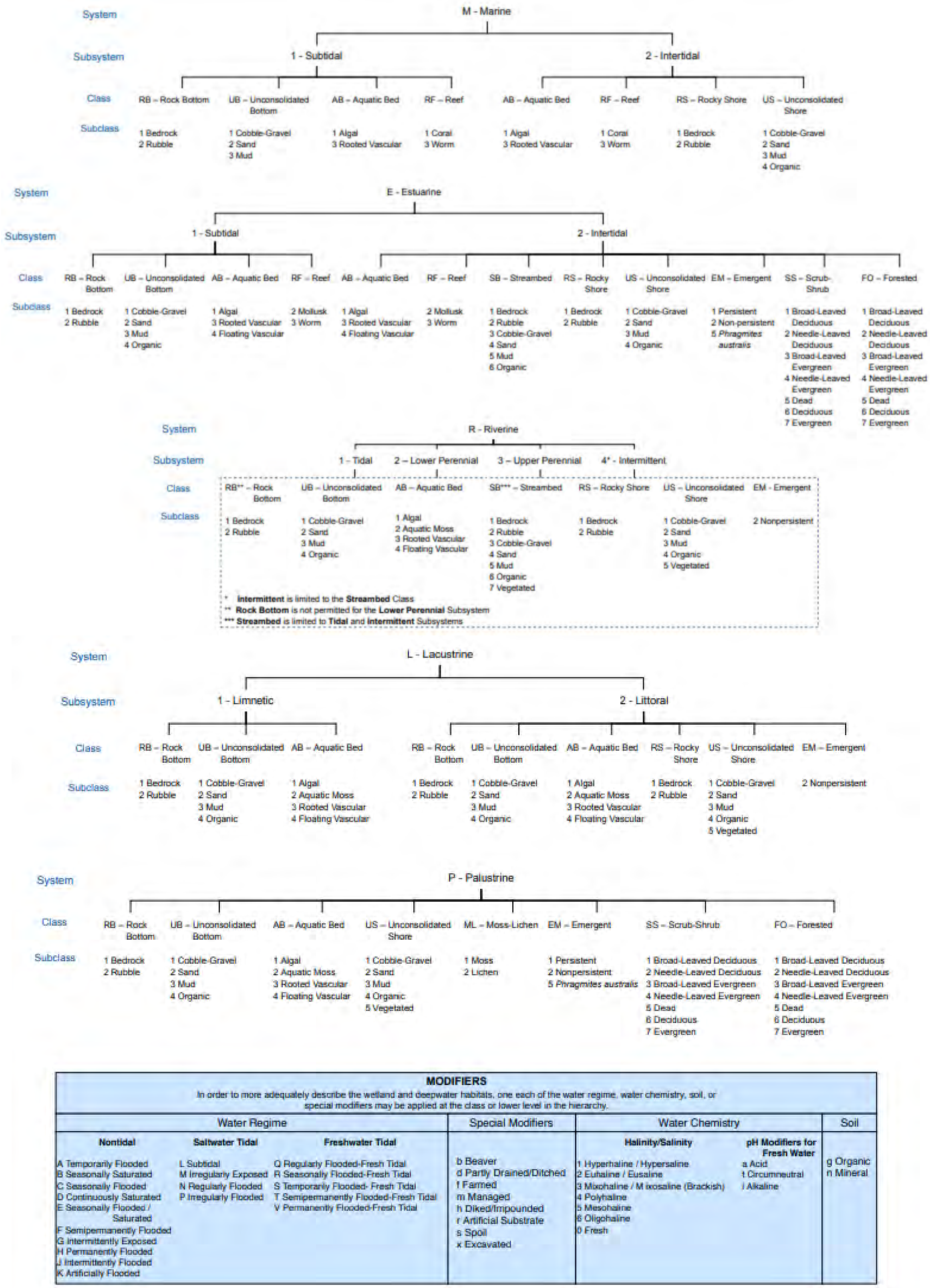

Figure 3. Classification hierarchy of wetlands and deepwater habitats of the United States (FGDC 2013).

Wetland codes can be collapsed into generalized wetland categories to both provide a class-level representation of types and to give greater resolution to the palustrine system, which is the most common type in Alaska. Using the generalized categories, all subclasses of palustrine emergent wetlands (PEM, PML) are collectively referred to as 'Freshwater Emergent Wetlands'. Similarly, all subclasses of palustrine forested wetlands (PFO) or shrub (PSS) wetland are referred to as 'Freshwater Forested/Shrub Wetlands'. Palustrine wetlands with unconsolidated bottoms, (PUB), shores (PUS) or algal beds (PAB) are collectively referred to as 'Freshwater Pond'. Palustrine wetlands with rock bottoms (PRB) are categorized as 'Other', External to the palustrine system, all lacustrine (L) and riverine (R) types are referred to as 'Lake', and 'Riverine' respectively. All classes of intertidal estuarine (E2) and intertidal marine (M2) wetlands are collectively referred to as 'Estuarine and Marine Wetland' whereas all classes of subtidal estuarine (E1) and subtidal marine (M1) are referred to as 'Estuarine and Marine Deepwater'. Non-wetland, terrestrial habitats are collectively referred to as 'Upland'.

Wetland Classification Codes:

Table 7. The unique wetland and deepwater codes identified for the Evans – Latouche Island study area along a hypothetical gradient from ocean to alpine.

Wetland Codes	Descriptions
M1UBL	Marine subtidal with unconsolidated bottom
M1AB1L	Marine subtidal with algal aquatic bed
M2AB1M	Lower intertidal marine algal aquatic bed with irregular exposure
M2AB1N	Upper intertidal marine aquatic bed with regular flooding
M2RS1N	Intertidal bedrock shore with regular flooding
M2US1N	Intertidal unconsolidated cobble or gravel shore with regular flooding
E2EM1P	Intertidal estuarine emergent, persistent vegetation with irregular flooding
PEM1C	Palustrine emergent wetland with seasonal flooding
PEM1D	Palustrine emergent wetland with continuous saturation
PEM1E	Palustrine emergent wetland with seasonal flooding or saturation
PFO4B	Palustrine needleleaf forested wetland with seasonal saturation
PSS1C	Palustrine deciduous shrub wetland with seasonal flooding
PSS4B	Palustrine needleleaf shrub wetland with seasonal saturation
L1UB3H	Freshwater lake with unconsolidated mud bottom
L2RS1C	Seasonally flooded, rocky bedrock shore of freshwater lake
PAB3H	Freshwater pond with aquatic vascular bed
PUB3H	Freshwater pond with unconsolidated mud bottom
PUS2C	Seasonally flooded, unconsolidated sand shore of freshwater pond
PRB1H	Freshwater pond with rock bottom
R1UB1V	Riverine, unconsolidated cobble or gravel bed, permanently flooded with fresh water yet experiences tidal influence
R2UB1H	Riverine, lower perennial unconsolidated cobble or gravel bed, permanently flooded with fresh water
R3UB1H	Riverine, upper perennial unconsolidated cobble or gravel bed, permanently flooded with fresh water
R4SB3J	Riverine, streambed of unconsolidated cobble or gravel, intermittently flooded with fresh water

Descriptions of Deepwater and Wetland Types:

M1UBL - Marine subtidal with unconsolidated bottom

Marine deepwater habitat includes all land that is permanently flooded by salt water. This deepwater type is exposed to the waves and currents of the open ocean and salinities exceed 30 ppt, with little or no dilution except outside the mouths of estuaries. We used the marine subtidal with unconsolidated bottom (M1UBL) as the default assignment for ocean waters (Figure 4). Training data was placed to capture all surface conditions of the open ocean including wave-broken, wind-disturbed, calm, and fog shrouded (Figure 5). As a result, marine subtidal habitat was well predicted by the model and did not require manual revision.

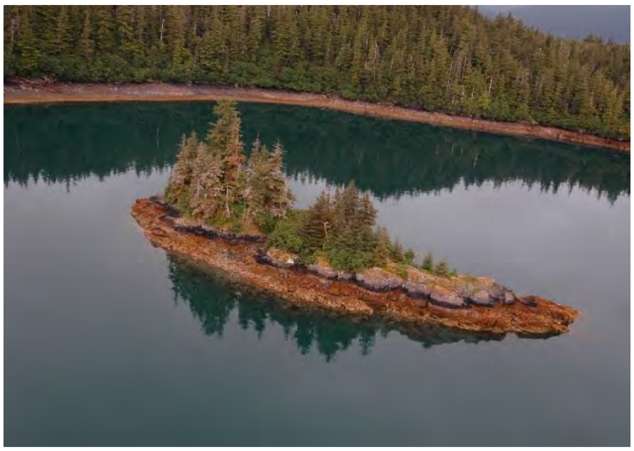

Figure 4. Representative photograph of marine subtidal with unconsolidated bottom (M1UBL); Iktua Bay, Evans Island (image from Shorezone).

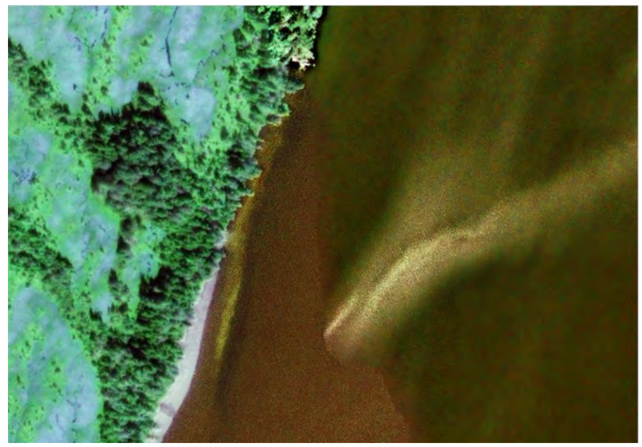

Figure 5. Maxar imagery showing different surface conditions of marine subtidal with unconsolidated bottom (M1UBL), owing in part to different capture dates for the image mosaic; east shore of Bainbridge Island, 1:1,600 scale.

M1AB1L– Marine subtidal with algal aquatic bed

Marine deepwater habitat supporting algal beds with at least 30% cover were assigned the marine subtidal with algal aquatic bed (M1AB1L) class (Figure 6). In the study area, this type is comprised of bull kelp (*Nereocystis luetkeana*) and typically forms along exposed coastlines with strong currents and bedrock substrate (Lindeberg and Lindstrom 2010). In imagery, these kelp beds appear as black-brown patches in coastal waters punctuated by areas of lighter color, which are the kelp blades floating on the surface (Figure 7). Kelp beds are distinguished from a wave-disturbed surface by their spatial concentration, which is different than the regular frequency and even distributions of waves. Training data captured most occurrences of bull kelp beds in the study area. As a result, the type was well predicted by the model and did not require manual revision.

Figure 6. Representative photograph of marine subtidal with algal aquatic bed habitat (M1AB1L); air plot 24, Elrington Island.

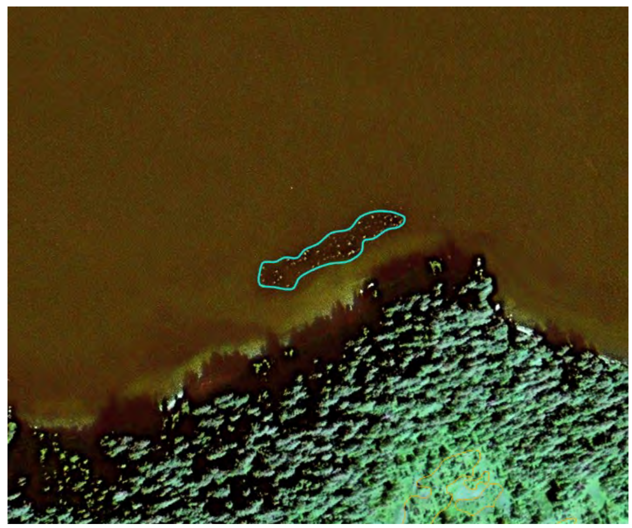

Figure 7. Maxar imagery showing a training polygon delineating marine subtidal with algal aquatic bed habitat (M1AB1L); west shore of Evans Island, 1:1,600 scale.

M2AB1M – Lower intertidal marine algal aquatic bed with irregular exposure

Intertidal marine wetlands are exposed at least once daily during the cycle of oceanic tides and supporting at least 30% cover of aquatic algal vegetation were assigned the marine lower intertidal with aquatic bed class (M2AB1M). These lower intertidal types transition seaward to subtidal ocean waters and inland to upper intertidal habitats where the substrate is regularly exposed by the ebb of tidal waters. In the project area, lower intertidal marine algal aquatic beds develop as linear coastal types along rubble beaches and bedrock where brown kelps are the dominant species (Figure 8). Lower intertidal algal beds are typically underwater in imagery, appearing as a yellow-green band upgradient from darker, subtidal waters (Figure 9). This type was moderately well predicted by the model and required limited manual revision.

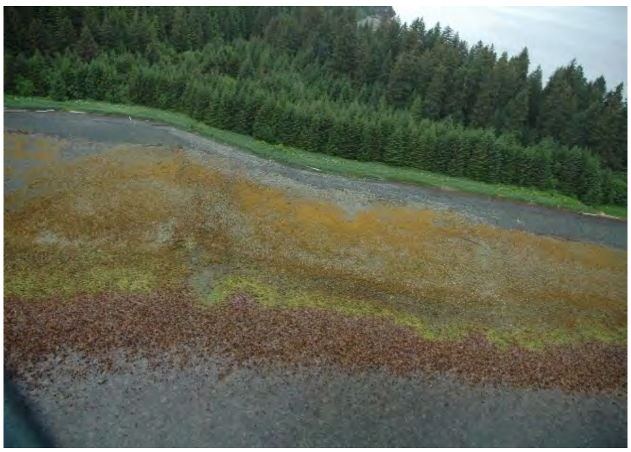

Figure 8. Representative photograph showing the transition from lower intertidal marine algal aquatic bed with irregular exposure (brown kelps - M2AB1M) to upper intertidal marine algal aquatic bed with regular exposure (golden-brown rockweed - M2AB1N); photo taken at low tide on Elrington Island (image from ShoreZone).

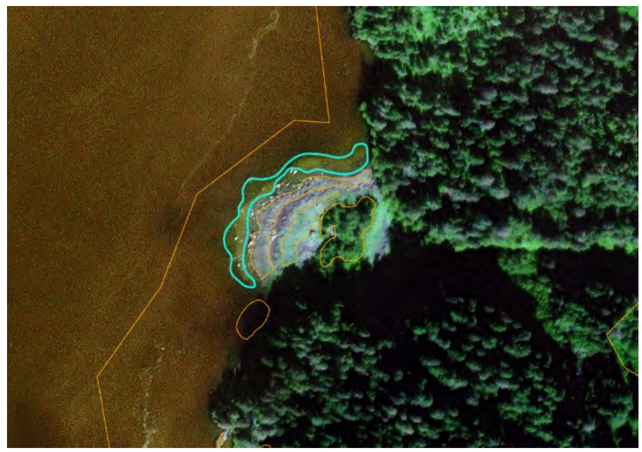

Figure 9. Maxar imagery showing a training polygon delineating lower intertidal marine algal aquatic bed with irregular exposure (M2AB1M); west shore of Bainbridge Island, 1:1,600 scale.

M2AB1N – Upper intertidal marine aquatic bed with regular flooding

The upper intertidal marine algal aquatic bed (M2AB1M) is a coastal linear type developing on rubble beaches and bedrock where rockweed (*Fucus distichus*) is the dominant species (Figures 10, 11). Rockweed has high tolerance for fresh water and freezing temperatures and defines the reach of regular tidal inundation (Lindberg and Lindstrom 2010). On gravel-cobble substrates, rockweed beds typically form above the brown kelp lower intertidal zone (Figure 9). Where these gravel-cobble beaches transition to bedrock cliffs, a band of black marine lichen (*Verrucaria maura*) indicating the wave break zone, may form above the rockweed beds (Figure 10). In the study area, the upper intertidal type is typically above water in imagery and appears as beach habitat with hint of darker vegetation (Figure 11). The inland extent of upper intertidal marine aquatic bed was restricted, in part, by the elevation of mean high tidal water, which we manually delineated. This type was moderately well predicted by the model and required limited manual revision.

Figure 10. Representative photo showing bands (listed in order from upland to subtidal) of upland Sitka spruce and coastal herbaceous meadow, intertidal rocky bedrock shore (M2RS1N), upper intertidal marine algal bed, which includes both the black marine lichen belt and rockweed beds, and below water, the lower intertidal brown kelp beds (M2AB1M); Sawmill Bay, Evans Island (image from ShoreZone).

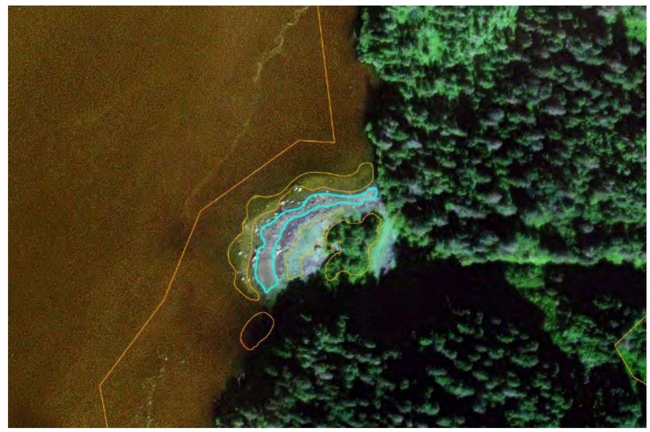

Figure 11. Maxar imagery showing a training polygon delineating upper intertidal marine algal aquatic bed with regular flooding (M2AB1N); west shore of Bainbridge Island, 1:1,600 scale.

M2RS1N – Intertidal, rocky shore bedrock with regular flooding

The upper intertidal marine rocky shore (M2RS1N) is a coastal linear type developing on fractured bedrock or rubble associated with rocky promontories, headlands, and cliffs (Figures 12). Rocky shores are common in the project area and typically occur above the bands of rockweed (*Fucus distichus*) and black marine lichen (*Verrucaria maura*). This upper intertidal type is typically above water in imagery and appears as bright, unvegetated rock (Figure 13). The inland extent of upper intertidal marine rocky shore was restricted, in part, by the elevation of mean high tidal water, which we manually delineated. This type was moderately well predicted by the model and required limited manual revision.

Figure 13. Representative photograph of intertidal rocky shore bedrock with regular flooding (M2RS1N). Note the rockweed band is not included in this type, south shore of Danger Island showing the same promontory as Figure 14 (image from ShoreZone).

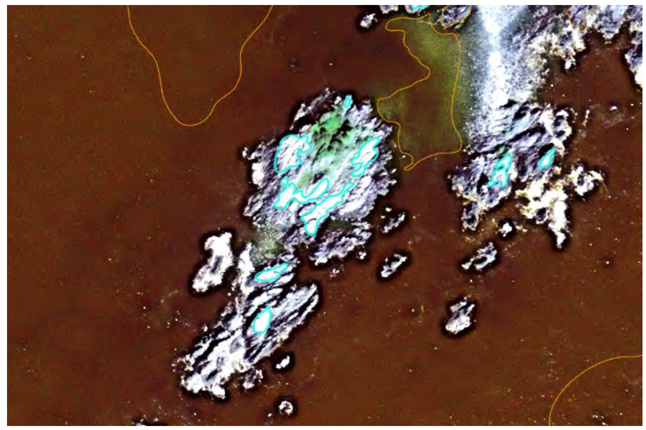

Figure 12. Maxar imagery showing a training polygon delineating intertidal rocky shore bedrock with regular flooding (M2RS1N); south shore of Danger Island, 1:1,600 scale.

M2US1N - Intertidal unconsolidated cobble-gravel shore with regular flooding

The intertidal unconsolidated cobble-gravel shore (M2US1N) is beach habitat occupying the zone of daily tidal influence. The barren to sparsely-vegetated condition of these beaches relates to both the uplift experienced by the region during the 1964 Good Friday Earthquake, which raised unvegetated substrates out of the ocean, as well as the generally high exposure and energy of the coastline, which precludes the retention of finer sediment that facilitates the establishment of vascular plants and some marine alga (Figure 14). In the study area, this type is typically above water in imagery and appears as a highly reflective, white substrate (Figure 15). This type was well predicted by the model and required very limited manual revision.

Figure 14. Representative photographs of intertidal unconsolidated cobble-gravel shore with regular flooding (M2US1N); Ground Plot 3, west shore Latouche Island (left) and Air Plot 20, east shore Bainbridge Island (right).

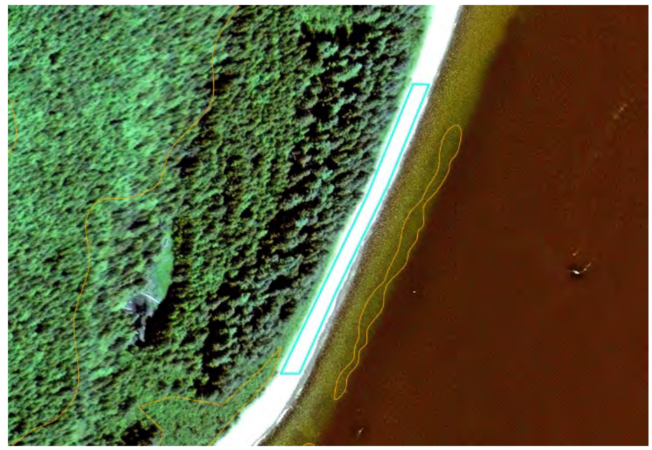

Figure 15. Maxar imagery showing a training polygon delineating intertidal unconsolidated cobble-gravel shore with regular flooding (M2US1N); east shore of Latouche Island, 1:1,600 scale.

E2EM1P - Intertidal estuarine emergent, persistent vegetation with irregular flooding

Estuarine environments develop along semi-protected coastlines where ocean water is occasionally diluted by freshwater runoff from the land. In the project area, estuarine wetlands typically develop on the fine sediments of protected beaches in the supratidal zone, which are only inundated once daily or during the highest of tides (Figure 16). Vegetation is dominated by (listed in decreasing order of salt tolerance from ocean to land): *Puccinellia nootkatensis* and *Honckenya peploides* with *Glaux maritima* and *Plantago maritima* making minor contributions. In imagery, this type appears as a deep green color that is contextually identified by its occurrence upgradient from grey sand or mud flats, yet downgradient from mint green coastal herbaceous meadows (Figure 17). Because estuarine wetlands are uncommon, manifest as a narrow type, and are in part defined by salinity (a trait not interpretable from remotely sensed data), we manually digitized all occurrences of E2EM1P.

Figure 17. Representative photograph of intertidal estuarine emergent, persistent vegetation with irregular flooding (E2EM1P); Chenega ground plot 10, mainland, west side of Bainbridge Passage.

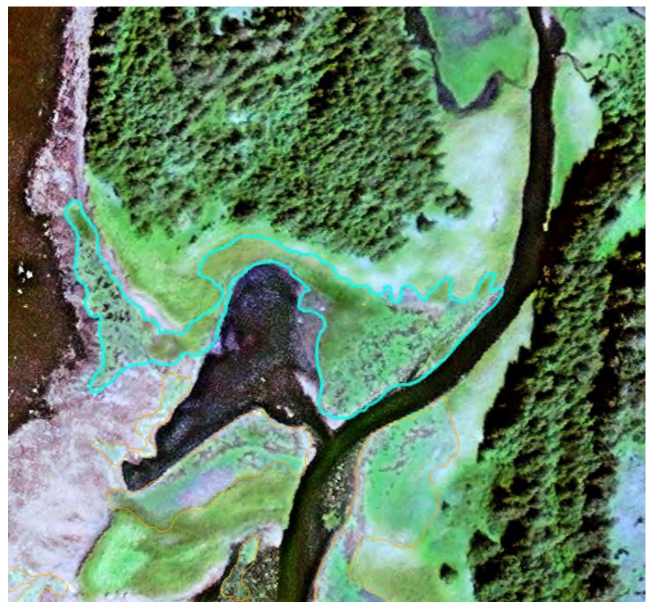

Figure 16. Maxar imagery showing a polygon delineating intertidal estuarine emergent, persistent vegetation with irregular flooding (E2EM1P); west shore of Latouche Island, 1:1,600 scale.

R1UB1V – Riverine, unconsolidated cobble or gravel bed, permanently flooded with fresh water yet experiences tidal influence

Riverine habitat includes all wetlands and deepwater habitats contained within a channel. Where rivers and streams meet the ocean, a portion of the reach can be affected by the tides. As the Chenega region is characterized by steep terrain, tidally influenced riparian habitat is uncommon. Where tidal rivers do occur, the gradient is low, and water level fluctuates under tidal influence (Figure 18). We found that the bank transition from beach rye grass (*Leymus mollis*) to blue joint reed grass (*Calamagrostis canadensis*) or Sitka spruce (*Picea sitchensis)* served as a reliable proxy for the upstream extent of tidal influence (Figure 19, 20). Due to the limited extent of tidally influenced rivers in the project area, we manually digitized all occurrences of R1UB1V.

Figure 19. Representative photograph of riverine, unconsolidated cobble or gravel bed, permanently flooded with fresh water, experiencing tidal influence (R1UB1V). Chenega air plot 63, mainland, west of Point Countess.

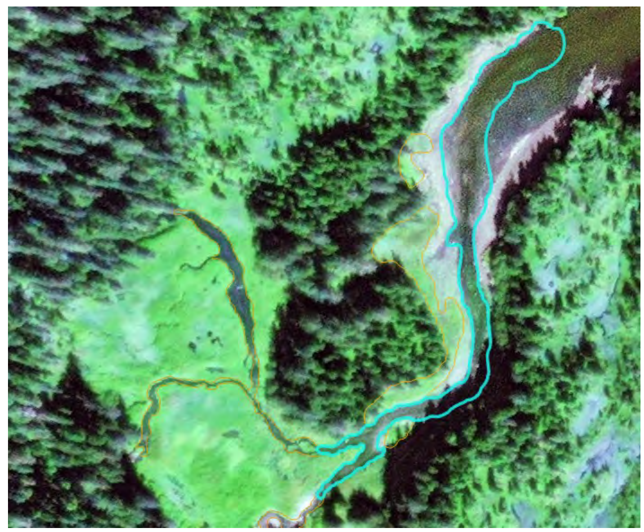

Figure 18. Maxar imagery showing a polygon delineating riverine, unconsolidated cobble or gravel bed, permanently flooded with fresh water experiencing tidal influence (R1UB1V); Chenega air plot 63, mainland, west of Point Countess, 1:1,600 scale.

Figure 20. Photograph showing transition from salt tolerant Leymus mollis (gray-green grass downstream on far bank) to salt-intolerant Calamagrostis canadensis (green grass upstream on far bank); Shelter Bay, Evans Island.

R2UB1H – Riverine, lower perennial unconsolidated cobble or gravel bed, permanently flooded with fresh water

In the project area, lower perennial rivers and streams occupy the reach between tidally-influenced and upper perennial habitat along which the gradient is low and flow is relatively slow and without obvious riffles (Figure 21). Although lower perennial rivers represent some of the slowest flowing waters in the project area, gradients preclude extensive floodplain development. Due to the limited extent and narrow width of lower perennial riverine habitat, we manually digitized all occurrences of R2UB1H with an average width of 4.5 m (15ft) or greater between confluences (Figure 22). The course of a river or stream was inferred from topography where overhanging vegetation obscured the water surface in imagery.

Figure 21. Representative photograph of riverine, lower perennial unconsolidated cobble or gravel bed, permanently flooded with fresh water (R2UB1H); Chenega air plot 02, Latouche Island.

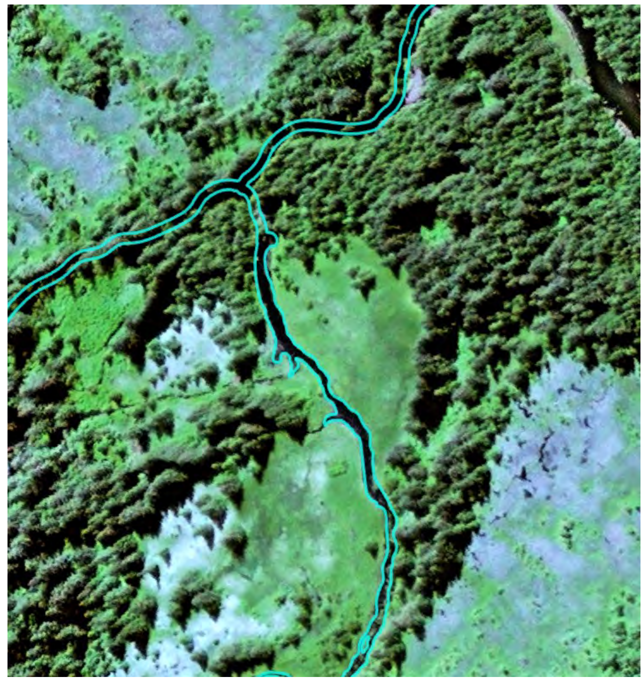

Figure 22. Maxar imagery showing a polygon delineating riverine, lower perennial unconsolidated cobble or gravel bed, permanently flooded with fresh water (R2UB1H); Chenega air plot 02, Latouche Island, 1:1,600 scale.

R3UB1H – Riverine, upper perennial unconsolidated cobble or gravel bed, permanently flooded with fresh water

In the project area, upper perennial streams occupy the reach between lower perennial and intermittent stream habitat along which the gradient is high, and flow is fast with obvious riffles. Floodplains can develop in alpine basins where the slope is low and melt-driven flows can be seasonally high (Figure 23). Due to the limited extent and narrow width of upper perennial riverine habitat in the project area, we manually digitized all occurrences of R3UB1H with an average width of 4.5 m (15ft) or greater between confluences (Figure 24). As upper perennial streams typically occur higher in the watershed, at or beyond tree line, their course is rarely obscured by overhanging vegetation.

Figure 23. Representative photograph of riverine, upper perennial unconsolidated cobble or gravel bed, permanently flooded with fresh water (R3UB1H); Chenega ground plot 15, Bainbridge Island.

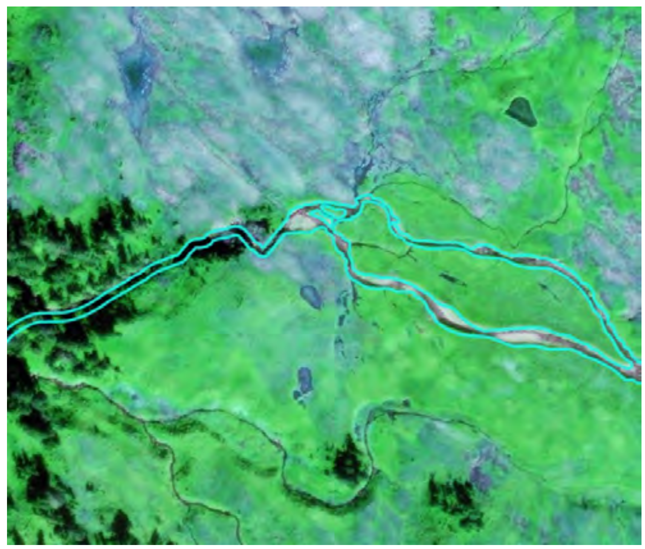

Figure 24. Maxar imagery showing a polygon delineating riverine, upper perennial unconsolidated cobble or gravel bed, permanently flooded with fresh water (R3UB1H); Chenega ground plot 15, Bainbridge Island, 1:1,600 scale.

R4SB3J – Riverine streambed of unconsolidated cobble or gravel, intermittently flooded with fresh water

In the project area, intermittent streams occupy the highest elevation, and steepest gradient reaches of the watershed (Figure 25). Water flows only part of the year and is sourced from snow melt, seeps, or direct precipitation. The downgradient transition from intermittent streambed to upper perennial stream is typically marked by an inflection in terrain slope, for example at the transition from alpine headwall to basin. Owing to their limited extent and narrow width, we manually digitized all occurrences of R4SB3J (Figure 26). As intermittent streambeds exclusively occur at or beyond tree line, their course is rarely obscured by overhanging vegetation and easily interpreted from topography.

Figure 25. Representative photograph an intermittently-flooded riverine streambed (R4SB3J; Chenega air plot 13, Bainbridge Island.

Figure 26. Maxar imagery showing a polygon delineating an intermittently-flooded riverine streambed, (R4SB3J); Bainbridge Island, 1:1,600 scale.

LUB3H – Freshwater lake with unconsolidated mud bottom

Lacustrine habitat type includes wetlands and deepwater habitats that are situated in a topographic depression, lack vegetation, and have a total area of at least 8 ha (20 ac). Only five lakes occur in the project area; four are natural and one is a reservoir above the Village of Chenega on Evans Island. All are permanently flooded with freshwater (Figure 27). Lake habitat was well-predicted by the model; minimal manual revision was required along lake shores that were obscured by trees or tree shadow (Figure 28).

Figure 27. Representative photograph of a freshwater lake with unconsolidated bottom (LUB3H); Chenega air plot 55, Evans Island.

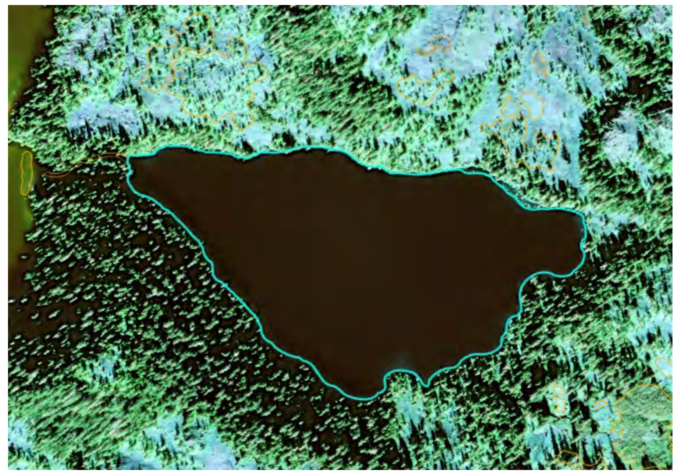

Figure 28. Maxar imagery showing a training polygon delineating a freshwater lake with unconsolidated bottom (LUB3H); Chenega air plot 55, Evans Island, 1:3,000 scale.

PAB3H - Freshwater pond with aquatic vascular bed

Palustrine habitat includes, in part, small, shallow, permanent, freshwater bodies, occupying less than 8 ha (20 ac). Where aquatic vegetation comprises at least 30% cover, this habitat is classified as freshwater pond with aquatic bed. In the project area, the most common aquatic rooted vascular species are pond lily (*Nuphar lutea),* and buckbean (*Menyanthes trifoliata*) (Figure 29). This type was well predicted by the model; minimal manual revision was required along pond shores that were obscured by trees or tree shadow (Figure 30).

Figure 30. Representative photograph of a freshwater pond with aquatic vascular bed (PAB3H); buckbean with white flowers in foreground, pond lily in center; Chenega ground plot 07, Latouche Island.

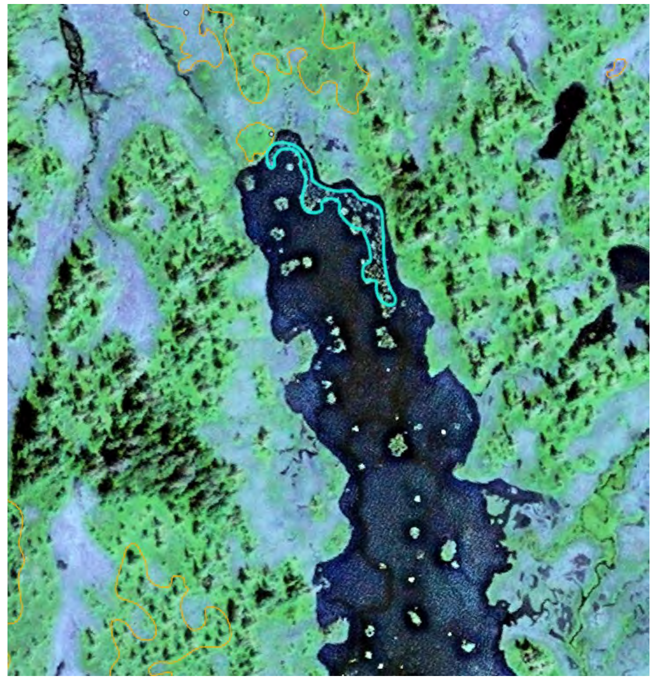

Figure 29. Maxar imagery showing a training polygon delineating the aquatic vascular bed of a freshwater pond (PAB3H); Chenega ground plot 07, Latouche Island, 1:1,600 scale.

PUB3H - Freshwater pond with unconsolidated mud bottom

Palustrine habitat includes, in part, small, shallow, permanent, freshwater bodies occupying less than 8 ha (20 ac). Where aquatic vegetation contributes less than 30% cover this habitat is classified with respect to its substrate. Most freshwater ponds in the project area are characterized by an unconsolidated mud bottom (Figure 31). This type was well predicted by the model; minimal manual revision was required along pond shores that were obscured by trees or tree shadow (Figure 32).

Figure 31. Representative photograph of a freshwater pond with unconsolidated mud bottom (PUB3H); Chenega air plot 51, Evans Island.

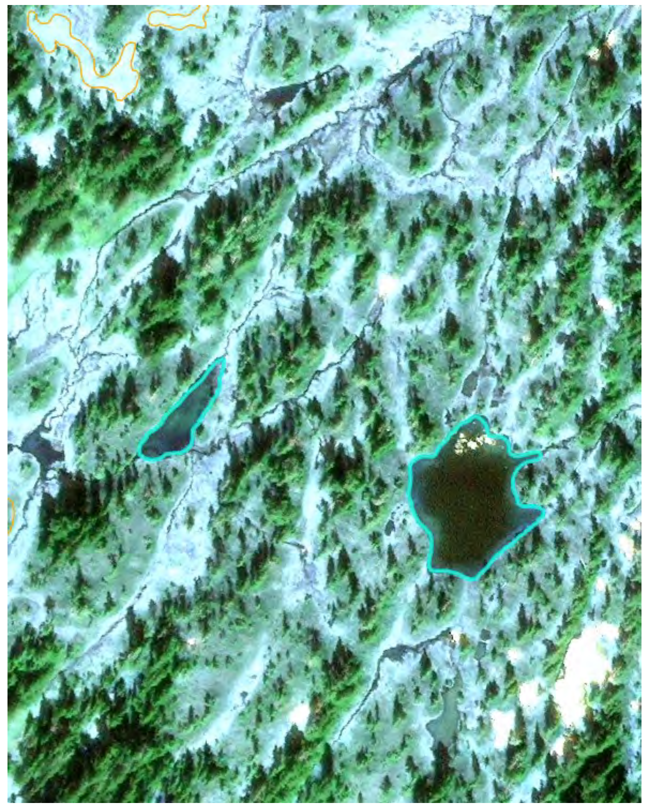

Figure 32. Maxar imagery showing two training polygons delineating freshwater ponds with unconsolidated mud bottoms (PUB3H); Chenega air plot 51, Evans Island, 1:1,600 scale.

PRB1H – Freshwater pond with rock bottom

Palustrine habitat includes, in part, small, shallow, permanent, freshwater bodies occupying less than 8 ha (20 ac). Where aquatic vegetation contributes less than 30% cover this habitat is classified with respect to its substrate. A portion of freshwater ponds in the alpine sections of the project area are perched on bedrock (Figure 33). As freshwater ponds with rock bottoms are uncommon in the project area, all occurrences of PRB1H were manually digitized (Figure 34).

Figure 33. Representative photograph of a freshwater pond with rock bottom (PRB1H); Chenega air plot 62, mainland, south of Sober Point.

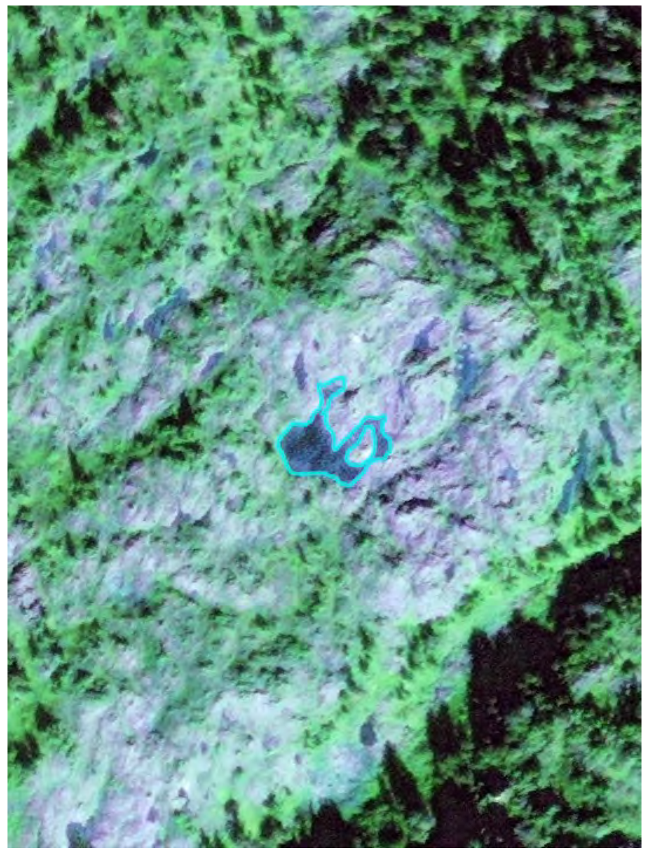

Figure 34. Maxar imagery showing a polygon delineating a freshwater pond with rock bottom (PRB1H); Chenega air plot 62, mainland, south of Sober Point, 1:1,600 scale.

PEM1C – Palustrine emergent wetlands with seasonal flooding

Palustrine habitat includes, in part, all freshwater wetlands dominated by persistent, emergent plants. In the project area, seasonally flooded palustrine emergent wetlands develop along shorelines of lakes, ponds and streams or within alpine floodplains where flooding likely occurs due to snowmelt (spring) and direct precipitation (fall) (Figure 35). Vegetation appears to be largely herbaceous and forb rich. Species documented early in the growing season included deercabbage (*Nephrophyllidium crista-galli*), white marsh marigold (*Caltha leptosepala*), marsh violet (*Viola epipsila*), tufted bulrush (*Trichophorum caespitosum*), longawn sedge (*Carex macrochaeta*), *Sphagnum* mosses, and dwarf fireweed (*Chamanerion latifolium*) (Figure 36). A more extensive study of eighteen alpine swales conducted in the mountains above Anchorage, Alaska found the following species, listed in decreasing order of dominance, to be associated with wetland habitat in the alpine: mountain heather (*Harrimanella stelleriana*) and partridge foot (*Leutkea pectinata*), longawn sedge (*Carex microchaeta*), alpine clubmoss (*Diphasiastrum alpinum*), Altai fescue (*Festuca altaica*), small flowered woodrush (*Luzula parviflora*), and Canadian burnet (*Sanguisorba canadensis*) (Johnson et al. 2022). As both wetland and alpine vegetation tends to be azonal, we expect these species to be characteristic of similar habitat in the Chenega region. In imagery, PEM1C appears as green-grey graminoid meadow (Figure 36). As this type is defined by proximity to waterbodies experiencing seasonal flooding (a temporal-spatial characteristic that is difficult to interpret from point-in-time remote imagery), its occurrence was poorly predicted by the model and required extensive manual revision.

Figure 36. Representative photograph of a palustrine emergent wetland with seasonal flooding (PEM1C) developing in an alpine floodplain; Chenega ground plot 15, central Bainbridge Island.

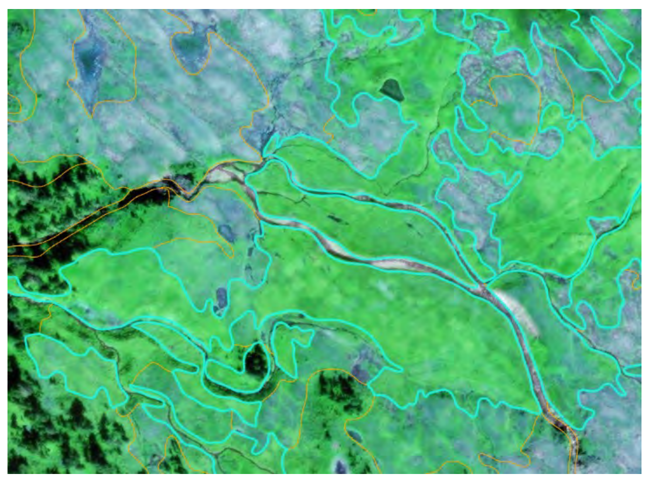

Figure 35. Maxar imagery showing polygons delineating palustrine emergent wetlands with seasonal flooding (PEM1C) developing in an alpine floodplain; Chenega ground plot 15, central Bainbridge Island, 1:1,600 scale.

PEM1D - Palustrine emergent wetland with continuous saturation

Palustrine habitat includes, in part, freshwater wetlands dominated by persistent, emergent plants. In the project area, continually saturated palustrine emergent wetlands develop on flat to gently sloping terrain where shallow bedrock and abundant precipitation maintain saturation throughout the growing season. This is a widespread type dominated by deercabbage (*Nephrophyllidium crista-galli*) and tufted bulrush (*Trichophorum caespitosum*) with minor contributions of long-awned sedge (*Carex macrochaeta*), and *Sphagnum* species. Drier microsites support dwarf shrubs such as crowberry (*Empetrum nigrum*) whereas wetter microsites include the emergent sedge tall cottongrass (*Eriophorum angustifolium*) and carnivorous species such as roundleaf sundew (*Drosera rotundifolia*) and common butterwort (*Pinguicula vulgaris*). Small upland inclusions of mountain hemlock (*Tsuga mertensiana*) skirted by low shrubs (*Vaccinium ovalifolium, Menziesia ferruginea, Sorbus sitchensis*) are common. In imagery, this type appears as evenly textured, bluish-purple meadows with minimal expression of surface water (Figure 38). This type was well-predicted by the model and required very limited manual revision.

Figure 37. Representative photograph of a palustrine emergent wetland with continuous saturation (PEM1D); Chenega ground plot 01, south Latouche Island.

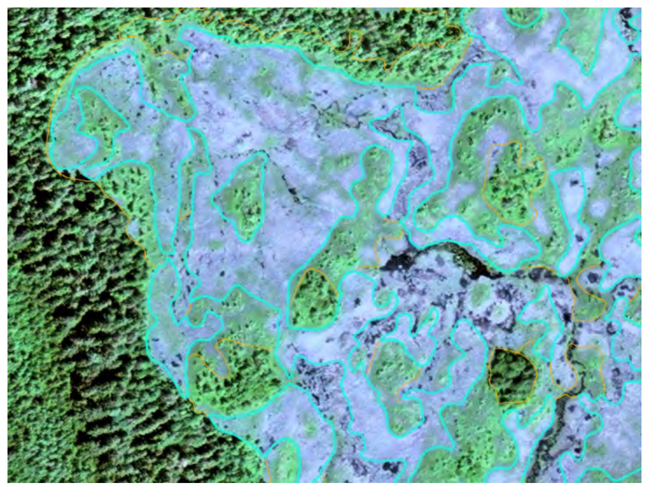

Figure 38. Maxar imagery showing polygons delineating palustrine emergent wetlands with continuous saturation (PEM1D); Chenega ground plot 01, south Latouche Island, 1:1,600 scale.

PEM1E - Palustrine emergent wetland with seasonal flooding or saturation

Palustrine habitat includes, in part, freshwater wetlands dominated by persistent, emergent plants. In the project area, seasonally flooded or saturated palustrine emergent wetlands develop on flat to gently sloping terrain where shallow bedrock and abundant precipitation cause seasonal flooding or saturation. This is a widespread type that similar to PEM1D, is dominated by deercabbage (*Nephrophyllidium crista-galli*), tufted bulrush (*Trichophorum caespitosum*), and tall cottongrass (*Eriophorum angustifolium*) with minor contributions of long-awned sedge (*Carex macrochaeta*), *Sphagnum* species, and carnivorous species such as roundleaf sundew (*Drosera rotundifolia*) and common butterwort (*Pinguicula vulgaris*) (Figure 39). In imagery, this type appears as evenly textured, purplish-blue meadows with more than 30% cover of surface water (Figure 40); PEM1E and PEM1D are often mosaicked. This type was well-predicted by the model and required very limited manual revision.

Figure 39. Representative photograph of a palustrine emergent wetland with seasonal flooding or saturation (PEM1E); Chenega ground plot 01, south Latouche Island.

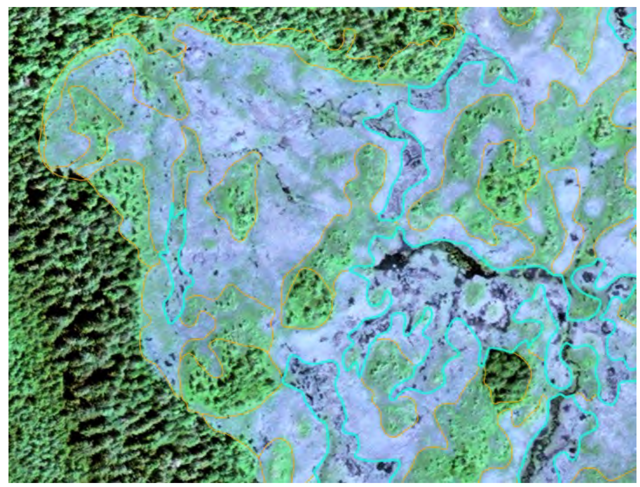

Figure 40. Maxar imagery showing polygons delineating palustrine emergent wetlands with seasonal flooding or saturation (PEM1E); Chenega ground plot 01, south Latouche Island, 1:1,600 scale.

PSS1C - Palustrine deciduous shrub wetland with seasonal flooding

Palustrine habitat includes, in part, freshwater wetlands where woody plants less than 6 m (20 ft) tall are the dominant life form. The 'shrub' life form includes true shrubs, young specimens of tree species that have not yet reached 6 m in height, and woody plants (including tree species) that are stunted because of adverse growing conditions. In the project area, palustrine deciduous shrub develops along the margins of lakes, ponds, rivers, and streams experiencing seasonal flooding due to snow melt (spring) and direct precipitation (fall) (Figure 41). Thickets are dominated by willows (*Salix sitchensis* and *Salix barclayi)* with a rich understory of salmonberry (*Rubus spectabilis*), cow parsnip (*Heracleum maximum*), field horsetail (*Equisetum arvense)*, woolly geranium (*Geranium erianthum*), Sitka valerian (*Valeriana sitchensis*), twisted stalk (*Streptopus amplexifolius*), marsh violet (*Viola epipsila*), and lady fern (*Athyrium filix-femina*). In imagery, this type appears as a rough-textured, grey-green thicket (Figure 42). As the extent of this type is geographically limited and of limited area, all occurrences of PSS1C were manually digitized.

Figure 41. Representative photograph of a palustrine deciduous shrub wetland with seasonal flooding (PSS1C); Chenega air plot 56, west central Evans Island.

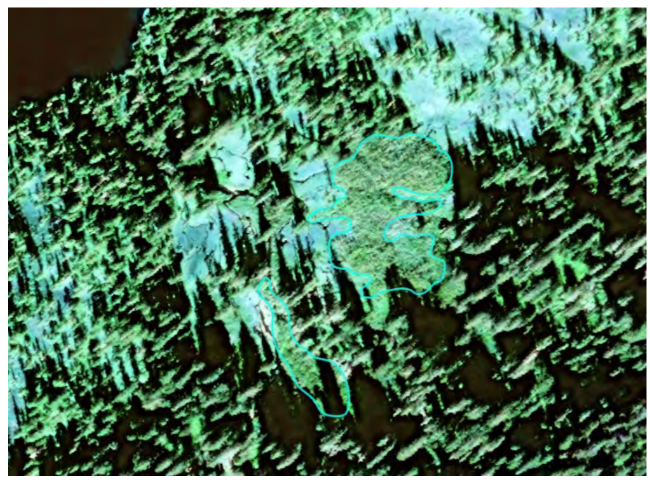

Figure 42. Maxar imagery showing two polygons delineating palustrine deciduous shrub wetlands with seasonal flooding (PSS1C); Chenega air plot 56, west central Evans Island.

PSS4B - Palustrine needleleaf shrub wetland with seasonal saturation

Palustrine habitat includes, in part, freshwater wetlands where woody plants less than 6 m (20 ft) tall are the dominant life form. The 'shrub' life form includes true shrubs, young specimens of tree species that have not yet reached 6 m in height, and woody plants (including tree species) that are stunted because of adverse growing conditions. In the project area, palustrine needleleaf shrub wetlands develop at the transition from saturated, herbaceous wetlands to upland forest, as drier inclusions in herbaceous wetlands, or as wetter inclusions in upland forest. Needleleaf shrub wetlands can occur on surprisingly steep slopes (up to 30^{o}, Boggs et al. 2008). Despite the drainage afforded by terrain, saturation is maintained by abundant precipitation and shallow bedrock, which retards infiltration. The needleleaf shrub component of the vegetation community is predominantly dwarf mountain hemlock (*Tsuga mertensiana*) with minor contributions of Sitka spruce (*Picea sitchensis*). Low shrubs such as copperbush (*Elliottia pyroliflora*), rusty menziesia (*Menziesia ferruginea*), and oval-leafed blueberry (*Vaccinium ovalifolium*) skirt the stands of trees. Herbaceous patches, codominated by deercabbage (*Nephrophyllidium crista-galli*) and tufted bulrush (*Trichophorum caespitosum*) may be interspersed (Figure 43). In imagery, this coniferous woodland appears as dark, conical trees separated by lighter green shrub cover (Figure 44). This type was well-predicted by the model and required very limited manual revision.

Figure 43. Representative photograph of a palustrine needleleaf shrub wetland with seasonal saturation (PSS4B); Chenega ground plot 05, central Latouche Island.

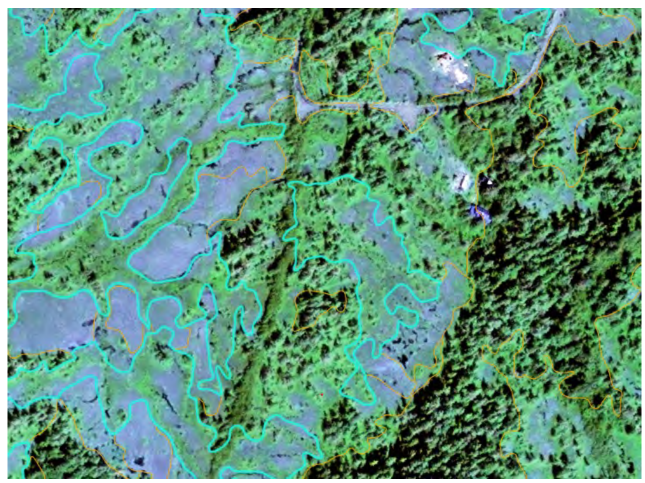

Figure 44. Maxar imagery showing polygons delineating palustrine needleleaf shrub wetlands with seasonal saturation (PSS4B); Chenega ground plot 05, central Latouche Island.

PFO4B - Palustrine needleleaf forested wetland with seasonal saturation

Palustrine habitat includes, in part, freshwater wetlands where woody plants greater than 6 m (20 ft) tall are the dominant life form. The 'tree' life form is defined as woody plants more than 6 m in height. In the project area, palustrine needleleaf forested wetlands develop at the transition from shrub or herbaceous wetlands to upland forest, as drier inclusions in shrub wetlands, or as wetter inclusions in upland forest. Forested stands range from open to closed and are dominated by mature mountain hemlock (*Tsuga mertensiana*). Open stands are common and similar in species composition to PSS4B. Open stands occur on a variety of landforms, including slopes up to 30° (Boggs et al. 2008), where abundant precipitation and shallow bedrock maintain saturation (Figure 45). Closed stands are uncommon, developing only on the most stable lowlands. While tree and shrub composition in the closed stands are similar to PSS4B (i.e., a canopy dominated by *Tsuga mertensiana* and shrub understory codominated by *Vaccinium ovalifolium* and *Elliottia pyroliflora*), lower strata are dominated by ferns and non-vascular species. Spreading woodfern (*Dryopteris expansa*), northern oakfern (*Gymnocarpium dryopteris*), five-leafed bramble (*Rubus pedatus*), and bunchberry dogwood (*Cornus canadensis*) are common in the lowest herbaceous stratum with the feathermosses, *Hylocomium splendens* and *Rhytidiadelphus loreus,* the leafy moss *Rhizomnium glabrescens*, and *Sphagnum* species, carpeting the ground. American skunkcabbage (*Lysichiton americanus*) occurs in pockets of standing water. In imagery, forested wetlands appear as dark, conical trees (often casting shadows due to their greater height), separated by a lighter green cover of shrubs. In more open stands, bluish-purple patches of deercabbage (*Nephrophyllidium crista-galli*) and tufted bulrush (*Trichophorum caespitosum*) may be interspersed (Figure 46). This type was well-predicted by the model and required very limited manual revision.

Figure 46. Representative photograph of a palustrine needleleaf forested wetland with seasonal saturation (PFO4B); Chenega air plot 12, west Bainbridge Island.

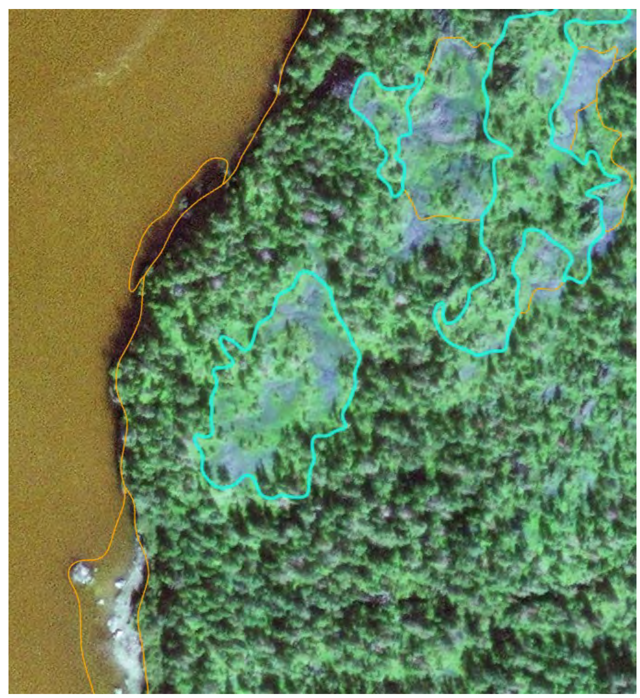

Figure 45. Maxar imagery showing polygons delineating palustrine needleleaf forested wetlands with seasonal saturation (PFO4B); Chenega air plot 12, west Bainbridge Island.

Special Mapping Conventions and/or Unique Wetland Codes:

No unique wetland codes were used for this project. Special mapping conventions were employed to the least extent possible. Situations bearing mention include our separation of marine and estuarine deepwater habitat, delineation of streams obscured by vegetation, and our treatment of subalpine swales and alpine floodplains.

Salinity data ranged from 25 ppm to 1.85 ppt at the four ground sites that were tested in the project area. We suspect that salinity measurements were low owing to the high input of fresh water from tidal glaciers within Prince William Sound and because our sampling was restricted to the shoreline. Despite salinity readings of less than 0.5 ppt, we elected to classify ocean waters exclusively as marine deepwater due to the unprotected nature of most coastlines.

Rivers and streams were mapped to capture both their surface expression in satellite imagery as well as their hydrologic connectivity. Hydrologic connectivity was important for assignment of the lotic landscape position attribute to lakes and ponds that were intersected by riverine polygons. Occasionally we were forced to infer the course of a river or stream from topography where the reach was obscured by overhanging vegetation or terrain shadow. In these cases, we were unable to confirm an average width of the watercourse between confluences and as a result may have mapped features less than 4.5 m (15 ft) wide.

Subalpine swales are a small patch and rare type restricted to exposed bedrock knobs and slopes at treeline. Vegetation is composed of mountain hemlock (*Tsuga mertensiana*), dwarf shrubs such as Alaska bellheather (*Harrimanella stelleriana*) and partridgefoot (*Luetkea pectinata*), and lichens in the *Cladonia* genus (*C. stellaris, arbuscula, rangiferina*). Owing to exposure, trees adopt a krummholz form and lower vegetation establishes in protected microsites. While protected swales may represent pockets of wetland habitat, their spatial extent rarely approaches the target mapping unit of 0.125 ac.

Alpine floodplains were captured as the PEM1C type. Because our fieldwork occurred early in the growing season and did not accommodate a second visit, it was difficult to determine if hydrophytic vegetation was indeed dominant and flooding was indeed seasonal in the few alpine basins we visited. Further, our model did not predict PEM1C habitat well, which resulted in considerable manual delineation. As a result, there is uncertainty associated with the extent of alpine floodplains in the project area.

While not a special mapping consideration *per se*, the occurrence of the following species served as useful indicators of upland and wetland habitat:

- Sitka spruce (*Picea sitchensis*) occurs exclusively in uplands along the coastal rim and in early successional sites due to tolerance to salt spray and unstable mineral soils.
- Sitka alder (*Alnus viridis* ssp. *sinuata*) occurs exclusively in uplands
- *Cladonia* lichens indicate uplands when present at approximately more than 20% cover
- American dunegrass (*Leymus mollis*) indicates supratidal uplands
- Sea sandwort (*Honckenya peploides*) indicates intertidal wetlands
- Rockweed (*Fucus distichus*) indicates the intertidal range
- Bull kelp (*Nereocystis luetkeana*) indicates subtidal waters

Wetland Plant List:

See Appendix 2. for a list of plant taxa and wetland indicator status documented in the Chenega region, Prince William Sound Alaska.

Discussion

We implemented a semi-automated approach for wetland mapping that retains advantages of automation while enabling a wetland ecologist to focus on providing the contextual information necessary to assign wetland and deepwater classes. Advantages of automation include consistency over large extents, repeatability to integrate updates and alterations, and integration of multi-parameter attributes such as indices of vegetation, moisture, topography, and hydrology. Although a formal assessment accuracy is not a standard requirement of NWI mapping, an automated approach provides an opportunity for a statistically robust accuracy assessment. Further, once the model is built, the automated approach can provide cost efficiency for large regions.

The chief disadvantage of a semi-automated approach is the time required to develop a training dataset. Training data should represent all habitat types and cover 10-15% of the total project area. Depending on the topographic complexity of the project area and the diversity of habitats represented, the time required for the wetland ecologist to build a training dataset can be significant. Similarly, additional time is required for the manual digitization of habitats and/or boundaries that are either geographically uncommon, of small extent, narrow, or defined by characteristics that are not interpretable from remotely sensed data. Specific to our project area, the lack of an accurate, tidally-referenced coastline required us to manually digitize the extent of mean high tide. Common to automated and manual approaches is the reliance on imperfect datasets, for example, phenological and snow cover variation among image tiles, distortion of imagery due to parallax, areas of no data due to terrain and cloud shadow, all of which can result in model or digitizing error.

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Appendices

Appendix 1. Textural, spectral, and topographic covariates used in modeling workflow for the prediction of wetland and deepwater conditions in the Chenega region, Prince William Sound Alaska.

The following table lists mapping covariates used in the automated portion of the workflow. Remote sensing indicators are listed by number as follows:

1. Image segmentation
2. Wetland and deepwater types

The following conventions are used to denote additional clarifying characteristics pertaining to one or more datasets:

Ϯ Growing season median composite 2015-2021
ǂ 40-day median composites representing mid-June, late July, mid-August, and mid-September 2019-2022
§ Derived from USGS 3DEP IFSAR Digital Terrain Model
¶ Derived from manual delineation

Type	Dataset (name abbreviation)	Original Resolution	Use
Segment Mean	Sentinel-1 SAR Vertical-Vertical polarization (s1_vv)Ϯ	10 × 10 m	2
Segment Mean	Sentinel-1 SAR Vertical-Horizontal polarization (s1_vh)Ϯ	10 × 10 m	2
Segment Mean	Sentinel-2 Band 2: Blue (s2_mm_02_blue)ǂ	10 × 10 m	2
Segment Mean	Sentinel-2 Band 3: Green (s2_mm_03_green)ǂ	10 × 10 m	2
Segment Mean	Sentinel-2 Band 4: Red (s2_mm_04_red)ǂ	10 × 10 m	2
Segment Mean	Sentinel-2 Band 5: Red Edge 1 (s2_mm_05_rededge1)ǂ	20 × 20 m	2
Segment Mean	Sentinel-2 Band 6: Red Edge 2 (s2_mm_06_rededge2)ǂ	20 × 20 m	2
Segment Mean	Sentinel-2 Band 7: Red Edge 3 (s2_mm_07_rededge3)ǂ	20 × 20 m	2
Segment Mean	Sentinel-2 Band 8: Near Infrared (s2_mm_08_nearir)ǂ	10 × 10 m	2
Segment Mean	Sentinel-2 Band 8a: Red Edge 4 (s2_mm_08a_rededge4)ǂ	20 × 20 m	2
Segment Mean	Sentinel-2 Band 11: Shortwave Infrared 1 (s2_mm_11_shortir1)ǂ	20 × 20 m	2
Segment Mean	Sentinel-2 Band 12: Shortwave Infrared 2 (s2_mm_12_shortir2)ǂ	20 × 20 m	2
Segment Mean	Sentinel-2 Modified Enhanced Vegetation Index-2 (s2_mm_evi2)ǂ	10 × 10 m	2
Segment Mean	Sentinel-2 Normalized Burn Index (s2_mm_nbr)ǂ	20 × 20 m	2
Segment Mean	Sentinel-2 Normalized Difference Moisture Index (s2_mm_ndmi)ǂ	20 × 20 m	2
Segment Mean	Sentinel-2 Normalized Difference Snow Index (s2_mm_ndsi)ǂ	20 × 20 m	2
Segment Mean	Sentinel-2 Normalized Difference Vegetation Index (s2_mm_ndvi)ǂ	10 × 10 m	2

Type	Dataset (name abbreviation)	Original Resolution	Use
Segment Mean	Sentinel-2 Normalized Difference Water Index (s2_mm_ndwi)[‡]	10 × 10 m	2
Gridded	AHRI 2020 Composite Blue	1 × 1 m	1
Segment Mean	AHRI 2020 Composite Blue (ahri_01_blue)	1 × 1 m	2
Segment Std. Dev.	AHRI 2020 Composite Blue (ahri_01_blue_std)	1 × 1 m	2
Segment Range	AHRI 2020 Composite Blue (ahri_01_blue_rng)	1 × 1 m	2
Gridded	AHRI 2020 Composite Green	1 × 1 m	1
Segment Mean	AHRI 2020 Composite Green (ahri_02_green)	1 × 1 m	2
Segment Std. Dev.	AHRI 2020 Composite Green (ahri_02_green_std)	1 × 1 m	2
Segment Range	AHRI 2020 Composite Green (ahri_01_green_rng)	1 × 1 m	2
Gridded	AHRI 2020 Composite Red	1 × 1 m	1
Segment Mean	AHRI 2020 Composite Red (ahri_03_red)	1 × 1 m	2
Segment Std. Dev.	AHRI 2020 Composite Red (ahri_03_red_std)	1 × 1 m	2
Segment Range	AHRI 2020 Composite Red (ahri_01_red_rng)	1 × 1 m	2
Gridded	AHRI 2020 Composite Near Infrared	1 × 1 m	1
Segment Mean	AHRI 2020 Composite Near Infrared (ahri_04_nir)	1 × 1 m	2
Segment Std. Dev.	AHRI 2020 Composite Near Infrared (ahri_04_nir_std)	1 × 1 m	2
Segment Range	AHRI 2020 Composite Near Infrared (ahri_01_nir_rng)	1 × 1 m	2
Gridded	AHRI 2020 Composite Modified Enhanced Vegetation Index-2	1 × 1 m	1
Segment Mean	AHRI 2020 Composite Modified Enhanced Vegetation Index-2 (ahri_evi2)	1 × 1 m	2
Segment Std. Dev.	AHRI 2020 Composite Modified Enhanced Vegetation Index-2 (ahri_evi2_std)	1 × 1 m	2
Segment Range	AHRI 2020 Composite Modified Enhanced Vegetation Index-2 (ahri_01_evi2_rng)	1 × 1 m	2
Gridded	AHRI 2020 Composite Normalized Difference Vegetation Index	1 × 1 m	1
Segment Mean	AHRI 2020 Composite Normalized Difference Vegetation Index (ahri_ndvi)	1 × 1 m	2
Segment Std. Dev.	AHRI 2020 Composite Normalized Difference Vegetation Index (ahri_ndvi_std)	1 × 1 m	2
Segment Range	AHRI 2020 Composite Normalized Difference Vegetation Index (ahri_01_ndvi_rng)	1 × 1 m	2
Gridded	AHRI 2020 Composite Normalized Difference Water Index	1 × 1 m	1
Segment Mean	AHRI 2020 Composite Normalized Difference Water Index (ahri_ndwi)	1 × 1 m	2
Segment Std. Dev.	AHRI 2020 Composite Normalized Difference Water Index	1 × 1 m	2

Type	Dataset (name abbreviation)	Original Resolution	Use
	(ahri_ndwi_std)		
Segment Range	AHRI 2020 Composite Normalized Difference Water Index (ahri_ndwi_rng)	1 × 1 m	2
Segment Mean	Topography – Aspect (top_aspect)§	5 × 5 m	3
Segment Mean	Topography – Elevation (top_elevation)§	5 × 5 m	3
Segment Mean	Topography – Exposure (top_exposure)§	5 × 5 m	3
Segment Mean	Topography – Heat Load Index (top_heat_load)§	5 × 5 m	3
Segment Mean	Topography – Position (top_position)§	5 × 5 m	3
Segment Mean	Topography – Radiation (top_radiation)§	5 × 5 m	3
Segment Mean	Topography – Roughness (top_roughness)§	5 × 5 m	3
Segment Mean	Topography – Slope (top_slope)§	5 × 5 m	3
Segment Mean	Topography – Surface Area (top_surface_area)§	5 × 5 m	3
Segment Mean	Topography – Surface Relief (top_surface_relief)§	5 × 5 m	3
Segment Mean	Topography – Wetness Index (top_wetness)§	5 × 5 m	3
Segment Mean	Hydrography – Distance from Coast or Estuary (hyd_estuary_dist)¶	1 × 1 m	1-2

Appendix 2. List of plant taxa and wetland indicator status documented in the Chenega region, Prince William Sound Alaska.

Habit	Scientific Name	Common Name	Species Code	Wetland Indicator Status
tree	*Picea sitchensis*	Sitka spruce	PISI	FAC
	Tsuga mertensiana	mountain hemlock	TSME	FAC
shrub	*Alnus viridis* ssp. *sinuata*	Sitka alder	ALVIS	FAC
	Andromeda polifolia	bog rosemary	ANPO	FACW
	Elliottia pyroliflora	copperbush	ELPY	FAC
	Empetrum nigrum	black crowberry	EMNI	FAC
	Harrimanella stelleriana	Alaska bellheather	HAST3	FACU
	Menziesia ferruginea	rusty menziesia	MEFE	FACU
	Oplopanax horridus	devilsclub	OPHO	FAC
	Rubus spectabilis	salmonberry	RUSP	FAC
	Salix barclayi	Barclay's willow	SABA3	FAC
	Salix sitchensis	Sitka willow	SASI2	FAC
	Sambucus racemosa	red elderberry	SARA2	FACU
	Sorbus sitchensis	western mountain ash	SOSI2	FAC
	Vaccinium cespitosum	dwarf bilberry	VACE	FAC
	Vaccinium ovalifolium	oval-leaf blueberry	VAOV	FAC
	Vaccinium oxycoccus	small cranberry	VAOX	OBL
	Vaccinium uliginosum	bog blueberry	VAUL	FAC
	Vaccinium vitis-idaea	lingonberry	VAVI	FAC
forb	*Achillea millefolium* var. *borealis*	boreal yarrow	ACMIB	FACU
	Anemone richardsonii	yellow thimbleweed	ANRI	FAC
	Angelica lucida	seacoast angelica	ANLU	FAC
	Aquilegia formosa	western columbine	AQFO	FACU
	Argentina anserina	silverweed cinquefoil	ARAN7	FAC
	Aruncus dioicus	bride's feathers	ARDI8	FACU
	Boschniakia rossica	northern groundcone	BORO	FACU
	Caltha leptosepela	white marsh marigold	CALE4	OBL
	Chamerion angustifolium	tall fireweed	CHAN9	FACU
	Chamerion latifolium	dwarf fireweed	CHLA13	FAC
	Circea alpina	small enchanter's nightshade	CIAL	FAC
	Claytonia sibirica	Siberian springbeauty	CLSI2	FAC
	Cochlearia groenlandica	Danish scurvygrass	COGR6	FACW
	Conioselinum chinense	hemlockparsley	COGM	FACW
	Coptis asplenifolia	fernleaf goldthread	COAS	FAC
	Cornus canadensis	bunchberry dogwood	COCA13	FAC
	Cornus suecica	Lapland cornel	COSU4	FAC
	Dodecatheon jeffreyii	Sierra shootingstar	DOJE	FACW
	Drosera rotundifolia	roundleaf sundew	DRRO	OBL
	Erigeron peregrinus	subalpine fleabane	ERPE3	FACW
	Frittilaria camschatcensis	Kamchatka fritillary	FRCA5	FAC
	Galium aparine	stickywilly	GAAP2	FACU
	Geranium erianthum	woolly geranium	GEER2	FACU
	Geum calthifolium	calthaleaf avens	GECA6	FACW

Habit	Scientific Name	Common Name	Species Code	Wetland Indicator Status
	Heracleum maximum	common cowparsnip	HEMA80	FAC
	Honckenya peploides	seaside sandplant	HOPE	FACU
	Iris setosa	beachhead iris	IRSE	FAC
	Lathyrus japonicus	beach pea	LAJA	FAC
	Ligusticum scoticum	Scottish licorice-root	LISC3	FAC
	Loiseleuria procumbens	alpine azalea	LOPR	FACU
	Lupinus nootkatensis	Nootka lupine	LUNO	FACU
	Lysichiton americanus	American skunkcabbage	LYAM3	OBL
	Maianthemum dilatatum	false lily of the valley	MADI	FAC
	Menyanthes trifoliata	buckbean	METR3	OBL
	Microseris borealis	northern microseris	MIBO	OBL
	Mimulus guttatus	seep monkeyflower	MIGU	OBL
	Mitella pitandra	fivestamen miterwort	MIPE	FACW
	Neprophyllidium crista-galli	deercabbage	NECR2	OBL
	Nuphar lutea	Rocky Mountain pond-lily	NULUP	OBL
	Pedicularis parviflora	smallflower lousewort	PEPA4	FACW
	Petasites frigidus	arctic sweet coltsfoot	PEFR5	FAC
	Pinguicula vulgaris	common butterwort	PIVU	OBL
	Platanthera stricta	slender bog orchid	PLST4	FACW
	Polemonium acutiflorum	tall Jacob's-ladder	POAC	FAC
	Potamogeton sp.	pondweed	POTAM	OBL
	Prenanthes alata	western rattlesnakeroot	PRAL	na
	Pyrola asarifolia	liverleaf wintergreen	PYAS	FAC
	Rubus chamaemorus	cloudberry	RUCH	FACW
	Rubus pedatus	strawberryleaf raspberry	RUPE	FAC
	Rumex salicifolius	willow dock	RUSAT4	FACW
	Sanguisorba canadensis	Canadian burnet	SACA14	FACW
	Sanguisorba sitchensis	Sitka willow	SASI2	FAC
	Saxifraga nelsoniana	heartleaf saxifrage	SANE3	FAC
	Saxifraga nudicaulis	nutty saw-wort	SANU	FAC
	Senecio psuedoarnica	seaside ragwort	SEPS	FACU
	Senecio triangularis	arrowleaf ragwort	SETR	FACW
	Spergularia canadensis	Canadian sandspurry	SPCA3	FACW
	Spiranthes romanzoffiana	hooded lady's tresses	SPRO	FACW
	Stellaria calycantha	northern starwort	STCA	FACW
	Streptopus amplexifolius	claspleaf twistedstalk	STAM2	FAC
	Tiarella trifoliata	threeleaf foamflower	TITR	FAC
	Triantha glutinosa	sticky tofieldia	TRGL5	FACW
	Trientalis europaea	arctic starflower	TREU	FAC
	Valeriana sitchensis	Sitka valerian	VASI	FAC
	Veratrum viride	green false hellebore	VEVI	FAC
	Viola epipsila	dwarf marsh violet	VIEP	na
	Viola langsdorfii	Aleutian violet	VILA6	FACW
graminoid	*Calamagrostis nutkaensis*	Pacific reedgrass	CANU	FACW
	Carex limosa	mud sedge	CALI7	OBL
	Carex lyngbyei	Lyngbye's sedge	CALY3	OBL
	Carex macrochaeta	longawn sedge	CAMA11	FACW

Habit	Scientific Name	Common Name	Species Code	Wetland Indicator Status
	Deschampsia cespitosa	tufted hairgrass	DECE	FAC
	Eriophorum angustifolium	tall cottongrass	ERAN6	OBL
	Festuca rubra	red fescue	FERU2	FAC
	Hordeum brachyantherum	meadow barley	HOBR2	FAC
	Leymus mollis	American dunegrass	LEMO8	FAC
	Puccinellia nutkaensis	Nootka alkaligrass	PUNU	FACW
	Trichophorum cespitosum	tufted bulrush	TRCE3	OBL
fern and allies	*Equisetum arvense*	field horsetail	EQAR	FAC
	Lycopodium annotinum	stiff clubmoss	LYAN2	FACU
	Selaginella selaginoides	club spikemoss	SESE	FACU
	Athyrium felix-femina	common ladyfern	ATFI	FAC
	Blechnum spicant	deer fern	BLSP	FAC
	Gymnocarpium dryopteris	western oakfern	GYDR	FAC
bryophyte	*Bryum pseudotriquetrum*	common green bryum moss	BRPS70	na
	Dicranum sp.	dicranum moss	DICRA8	na
	Hylocomium splendens	splendid feather moss	HYSP70	na
	Pleurozium schreberi	Schreber's big red stem moss	PLSC70	na
	Racomitrium lanuginosum	racomitrium moss	RALA70	na
	Rhizomnium glabrescens	rhizomnium moss	RHGL70	na
	Rhytidiadelphus loreus	goose neck moss	RHLO70	na
	Sphagnum spp.	sphagnum	SPHAG2	na
	Sphagnum squarrosum	sphagnum	SPSQ70	na
	Tomentypnum nitens	tomentypnum moss	TONI70	na
lichen	*Cladina arbuscula*	reindeer lichen	CLAR60	na
	Siphula ceratites	whitefingers lichen	SICE60	na
algae	*Fucus distichus*	rockweed	FUDI	na

Appendix 3. Metadata collected for ground plots in the Chenega region of Prince William Sound, Alaska.

Plot	Survey Date (MM/DD/YYYY)	Latitude (DD.dddddd)	Longitude (DD.dddddd)	Elevation (m)	Slope (%)	Aspect (degrees)	Land Cover Type (Detailed)	Wetland Code
CHE_GRN_001	7/11/2022	59.943430	-148.037718	13	7	322	Palustrine emergent, continuously saturated	PEM1D
CHE_GRN_002	7/11/2022	59.944714	-148.037495	19	4	290	Hemlock-Sitka spruce forest	UPL
CHE_GRN_003	7/11/2022	59.978651	-148.016815	2	1	275	Coastal herbaceous	UPL
CHE_GRN_004	7/12/2022	60.050618	-147.909651	0	18	272	Estuarine intertidal algal aquatic bed, regularly flooded	E2AB1N
CHE_GRN_005	7/12/2022	60.042920	-147.907633	33	12	232	Palustrine needleleaf forest/emergent, seasonally saturated	PSS4/EM1B
CHE_GRN_006	7/12/2022	60.039424	-147.903419	72	9	134	Palustrine emergent, continuously saturated	PEM1D
CHE_GRN_007	7/12/2022	60.038399	-147.902589	76	0	na	Lacustrine limnetic, unconsolidated bottom, permanently flooded	L1UB4H
CHE_GRN_008	7/12/2022	60.039964	-147.904057	70	8	230	Palustrine emergent, continuously saturated	PEM1D
CHE_GRN_009	7/13/2022	60.041541	-147.906353	60	25	315	Hemlock-Sitka spruce forest	UPL
CHE_GRN_010	7/13/2022	60.145669	-148.168694	0	2	120	Estuarine intertidal algal aquatic bed, regularly flooded	E2AB1N
CHE_GRN_011	7/13/2022	60.145736	-148.168807	10	10	140	Hemlock-Sitka spruce forest/Sitka Alder-Salmonberry side slope shrubland	UPL
CHE_GRN_012	7/13/2022	60.112671	-148.155311	116	4	150	Riverine lower perennial unconsolidated cobble-gravel bottom, permanently flooded	R2UB1H
CHE_GRN_013	7/13/2022	60.113522	-148.155335	111	0	na	Subalpine herbaceous meadow	UPL
CHE_GRN_014	7/13/2022	60.113376	-148.154222	109	0	na	Willow riparian shrub	UPL
CHE_GRN_015	7/13/2022	60.105316	-148.145981	284	4	290	Palustrine emergent, temporarily flooded	PEM1A
CHE_GRN_016	7/13/2022	59.991858	-148.137741	194	8	270	Palustrine emergent, continuously saturated	PEM1D
CHE_GRN_017	7/14/2022	59.992440	-148.137613	189	8	270	Palustrine needleleaf forest/emergent, seasonally saturated	PSS4/EM1B
CHE_GRN_018	7/14/2022	60.125148	-148.123604	3	2	150	Estuarine intertidal emergent, irregularly flooded	E2EM1P

Appendix 4. Metadata collected for air plots in the Chenega region of Prince William Sound, Alaska.

Plot	Survey Date (MM/DD/YYYY)	Latitude (DD.dddddd)	Longitude (DD.dddddd)	Land Cover Type (Coarse)	Wetland Code
CHE_AIR_001	7/11/2022	60.013720	-147.956687	scrub-shrub wetland	PSS4/EM1B
CHE_AIR_002	7/11/2022	59.979996	-148.011394	graminoid meadow	PEM1C
CHE_AIR_003	7/11/2022	59.951159	-148.032770	freshwater	PAB3H
CHE_AIR_004	7/11/2022	59.997343	-147.981413	estuarine intertidal	E2EM1P
CHE_AIR_005	7/13/2022	60.082142	-148.068026	estuarine intertidal	E2AB1N
CHE_AIR_006	7/13/2022	60.099240	-148.044328	scrub-shrub wetland	PSS4/EM1B
CHE_AIR_007	7/13/2022	60.120625	-148.035257	estuarine intertidal	E2RS1N
CHE_AIR_008	7/13/2022	60.184901	-148.121877	estuarine intertidal	E2AB1N
CHE_AIR_009	7/13/2022	60.187957	-148.133355	estuarine intertidal	E2AB1M
CHE_AIR_010	7/13/2022	60.185024	-148.154823	freshwater	PRB1H
CHE_AIR_011	7/13/2022	60.165246	-148.135014	coniferous forest	PFO4/SS1B
CHE_AIR_012	7/13/2022	60.141060	-148.155962	coniferous forest	PFO4/SS1B
CHE_AIR_013	7/13/2022	60.114819	-148.158338	subalpine shrub	UPL
CHE_AIR_014	7/13/2022	60.109125	-148.160205	forb meadow	PEM1A
CHE_AIR_015	7/13/2022	60.106700	-148.143375	alpine herbaceous	PEM1A
CHE_AIR_016	7/13/2022	60.131971	-148.098558	scrub-shrub wetland	PSS4/EM1B
CHE_AIR_017	7/13/2022	60.158181	-148.086564	coniferous forest	UPL
CHE_AIR_018	7/13/2022	60.178183	-148.078550	coniferous woodland	UPL
CHE_AIR_019	7/13/2022	60.197580	-148.059360	coniferous forest	UPL
CHE_AIR_020	7/13/2022	60.149290	-148.063235	coniferous forest/coastal herbaceous non-tidal	UPL
CHE_AIR_021	7/13/2022	60.119255	-148.097941	coniferous woodland	UPL
CHE_AIR_022	7/13/2022	60.049387	-148.116138	scrub-shrub wetland	PSS4/EM1B
CHE_AIR_023	7/14/2022	59.978984	-148.194687	scrub-shrub wetland	PSS4/EM1B
CHE_AIR_024	7/14/2022	59.980663	-148.203376	estuarine subtidal	E1AB1L
CHE_AIR_025	7/14/2022	59.951454	-148.202018	coniferous forest/subalpine shrub	UPL
CHE_AIR_026	7/14/2022	59.938359	-148.190950	freshwater	PAB3H
CHE_AIR_027	7/14/2022	59.931051	-148.197742	estuarine subtidal	E1AB1L
CHE_AIR_028	7/14/2022	59.949104	-148.116129	coniferous forest/subalpine shrub	UPL
CHE_AIR_029	7/14/2022	59.986335	-148.046730	freshwater	PAB3H
CHE_AIR_030	7/14/2022	59.990475	-148.035387	coniferous woodland/coastal herbaceous non-tidal	UPL
CHE_AIR_031	7/14/2022	60.026327	-148.025408	scrub-shrub wetland	PSS4/EM1B
CHE_AIR_032	7/14/2022	59.971789	-148.105649	sedge peatland	PEM1E
CHE_AIR_033	7/14/2022	59.968150	-148.112511	coastal barren	E2US1N
CHE_AIR_034	7/14/2022	59.967791	-148.082758	scrub-shrub wetland	PSS4/EM1B
CHE_AIR_035	7/14/2022	59.961591	-148.000199	alpine herbaceous	PEM1A
CHE_AIR_036	7/14/2022	59.960551	-147.996837	alpine herbaceous	UPL
CHE_AIR_037	7/14/2022	60.018806	-147.940324	freshwater	R1RB2V
CHE_AIR_038	7/14/2022	60.117064	-147.897647	freshwater	PEM1C
CHE_AIR_039	7/14/2022	60.061462	-147.818177	estuarine intertidal	E2AB1M
CHE_AIR_040	7/14/2022	60.031202	-147.844321	coniferous forest	PFO4B
CHE_AIR_041	7/14/2022	60.012486	-147.862932	coniferous forest	UPL

Plot	Survey Date (MM/DD/YYYY)	Latitude (DD.dddddd)	Longitude (DD.dddddd)	Land Cover Type (Coarse)	Wetland Code
CHE_AIR_042	7/14/2022	59.995659	-147.876442	scrub-shrub wetland	PSS4B
CHE_AIR_043	7/14/2022	59.998069	-147.887175	subalpine shrub	UPL
CHE_AIR_044	7/14/2022	59.973553	-147.907977	sparse	UPL
CHE_AIR_045	7/14/2022	59.994306	-147.872188	coniferous forest	UPL
CHE_AIR_046	7/14/2022	60.043647	-147.840313	freshwater	PUB3H
CHE_AIR_047	7/14/2022	60.123250	-147.907190	coniferous forest	UPL
CHE_AIR_048	7/14/2022	60.124008	-147.923981	estuarine intertidal	E2AB1N
CHE_AIR_049	7/14/2022	60.111661	-147.926530	forb meadow	PEM1C
CHE_AIR_050	7/14/2022	60.115209	-147.929678	coniferous forest	UPL
CHE_AIR_051	7/14/2022	60.146563	-147.970626	scrub-shrub wetland	PEM1/SS4B
CHE_AIR_052	7/14/2022	60.107676	-147.997838	sedge peatland	PEM1D
CHE_AIR_053	7/14/2022	60.085991	-148.024113	alpine herbaceous	PEM1A
CHE_AIR_054	7/14/2022	60.082778	-148.016669	alpine herbaceous	PEM1A
CHE_AIR_055	7/14/2022	60.089574	-148.044220	freshwater	L1UB3H
CHE_AIR_056	7/14/2022	60.087615	-148.038649	scrub-shrub wetland	PSS1C
CHE_AIR_057	7/14/2022	60.107289	-148.091711	sedge peatland	PEM1D
CHE_AIR_058	7/14/2022	60.195403	-148.043758	estuarine subtidal	E1UB1L
CHE_AIR_059	7/14/2022	60.195930	-148.057101	coniferous forest	UPL
CHE_AIR_060	7/14/2022	60.136446	-148.105697	scrub-shrub wetland	PSS4/EM1B
CHE_AIR_061	7/15/2022	60.209706	-148.127024	alpine herbaceous	UPL
CHE_AIR_062	7/14/2022	60.215176	-148.133335	freshwater	PRB1H
CHE_AIR_063	7/14/2022	60.217670	-148.119424	freshwater	R1RB2V
CHE_AIR_064	7/14/2022	60.218162	-148.121212	forb meadow	PEM1C
CHE_AIR_065	7/14/2022	60.219866	-148.085897	estuarine subtidal	E1UBL
CHE_AIR_066	8/25/2022	59.997617	-147.982163	riverine intertidal	R1AB3M

Appendix 5. Percent top cover by categories of ground cover for ground plots in the Chenega region of Prince William Sound, Alaska.

Plot	Standing Dead	Water	Dead and Downed Wood	Litter	Bedrock	Biotic	Gravel	Stone	Cobble	Boulder
CHE_GRN_001	1	2	0	0	0	97	0	0	0	0
CHE_GRN_002	0	0	15	0	0	85	0	0	0	0
CHE_GRN_003	0	0	5	2	0	83	0	7	3	0
CHE_GRN_004	0	0	0	0	50	50	0	0	0	0
CHE_GRN_005	2	0	2	0	0	96	0	0	0	0
CHE_GRN_006	0	0	0	0	0	100	0	0	0	0
CHE_GRN_007	0	86	0	0	0	14	0	0	0	0
CHE_GRN_008	0	0	0	0	0	100	0	0	0	0
CHE_GRN_009	3	0	0	0	0	97	0	0	0	0
CHE_GRN_010	0	0	2	0	0	30	3	30	30	5
CHE_GRN_011	0	0	0	0	0	98	0	0	2	0
CHE_GRN_012	0	0	2	4	0	54	5	15	20	0
CHE_GRN_013	0	0	0	0	0	100	0	0	0	0
CHE_GRN_014	0	0	4	12	0	84	0	0	0	0
CHE_GRN_015	0	15	0	0	0	80	5	0	0	0
CHE_GRN_016	0	4	0	2	0	94	0	0	0	0
CHE_GRN_017	5	0	0	0	0	95	0	0	0	0
CHE_GRN_018	0	0	0	2	0	96	0	0	0	2

Appendix 6. Percent foliar cover by categories of vegetation for ground plots in the Chenega region of Prince William Sound, Alaska; average height in meters of woody species provided parenthetically.

Plot	Needleleaf Tree	Tall Shrub	Low Shrub	Dwarf Shrub	Grasses	Sedges and Rushes	Forbs	Aquatics and Algae	Sphagnum	Feathermoss	Other Bryophytes	Light Colored Macrolichens	Ferns and Allies	Average Tree Height (m)	Average Shrub Height (m)
CHE_GRN_001	8	0	6	20	4	30	6	1	10	2	1	10	2	2	0
CHE_GRN_002	70	0	10	0	0	0	5	0	0	10	5	0	0	17.5	1.6
CHE_GRN_003	0	0	0	0	45	0	40	0	0	0	0	0	0	0	0
CHE_GRN_004	0	0	0	0	0	0	0	50	0	0	0	0	0	0	0
CHE_GRN_005	30	0	30	2	37	0	0	0	0	1	0	0	0	2.25	0
CHE_GRN_006	0	0	0	5	0	2	94	0	2	1	0	0	1	0	0
CHE_GRN_007	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0
CHE_GRN_008	0	0	0	5	70	0	15	0	10	0	0	0	0	0	0
CHE_GRN_009	80	5	15	0	0	0	0	0	0	0	0	0	0	8	1.8
CHE_GRN_010	0	0	0	0	0	0	25	5	0	0	0	0	0	0	0
CHE_GRN_011	30	45	16	0	0	0	2	0	0	5	0	0	2	16	3.75
CHE_GRN_012	0	0	35	0	5	3	25	0	0	0	15	0	5	0	0
CHE_GRN_013	0	0	2	0	1	1	70	0	0	26	0	0	0	0	0
CHE_GRN_014	0	75	5	0	0	0	20	0	0	0	0	0	0	0	2.7
CHE_GRN_015	0	0	0	0	0	10	50	0	10	10	0	0	0	0	0
CHE_GRN_016	0	0	0	4	0	64	20	0	12	0	0	0	0	0	0
CHE_GRN_017	33	0	0	2	0	8	54	0	2	1	0	0	0	3.5	0
CHE_GRN_018	0	0	0	0	30	15	55	0	0	0	0	0	0	0	0

Appendix 7. Percent foliar cover of taxa recorded on ground plots in the Chenega region of Prince William Sound, Alaska; average height in meters of woody species provided parenthetically.

Species	**CHE_GRN_001**	**CHE_GRN_002**	**CHE_GRN_003**	**CHE_GRN_004**	**CHE_GRN_005**	**CHE_GRN_006**	**CHE_GRN_007**	**CHE_GRN_008**	**CHE_GRN_009**	**CHE_GRN_010**	**CHE_GRN_011**	**CHE_GRN_012**	**CHE_GRN_013**	**CHE_GRN_014**	**CHE_GRN_015**	**CHE_GRN_016**	**CHE_GRN_017**	**CHE_GRN_018**
Achillea millefolium var. *borealis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20
Alnus viridus ssp. *sinuata*	0	0	0	0	0	0	0	0	0	0	45 (5.0)	3	0	0	1	0	0	0
Andromeda polifolia	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
Anemone richardsonii	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Angelica lucida	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aquilegia formosa	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Argentina anserina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24
Aruncus dioicus	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0
Athyrium filix-femina	0	0	0	0	0	0	0	0	0	0	1	0	0	8	1	0	0	0
Blechnum spicant	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Boschniakia rossica	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Bryum psuedotriquetrum	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0
Calamagrostis nutkatensis	0	0	0	0	1	1	0	0	0	0	0	8	0	0	0	0	0	6
Caltha leptosepela	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Carex limosa	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	6	1	0
Carex lyngbyaei	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Carex macrochaeta	0	0	0	0	0	0	0	0	0	0	0	1	3	0	1	0	0	0
Carex pauciflora	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Chamerion angustifolium	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Chamerion latifolium	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0
Circaea alpina	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Claytonia sibiricus	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Cochlearia groenlandica	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0
Conioselinum chinense	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Coptis asplenifolia	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
Coptis trifoliata	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Cornus canadensis	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cornus suecica	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	1	0
Deschampsia cespitosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Dicranum sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Dodecatheon jeffreyi	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0

Species	CHE_GRN_001	CHE_GRN_002	CHE_GRN_003	CHE_GRN_004	CHE_GRN_005	CHE_GRN_006	CHE_GRN_007	CHE_GRN_008	CHE_GRN_009	CHE_GRN_010	CHE_GRN_011	CHE_GRN_012	CHE_GRN_013	CHE_GRN_014	CHE_GRN_015	CHE_GRN_016	CHE_GRN_017	CHE_GRN_018
Drosera rotundifolia	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	8	1	0
Elliottia pyroliflora	0	0	0	0	10	0	0	0	3	0	0	0	0	0	0	0	0	0
Empetrum nigrum	0	0	0	0	2	5	0	0	0	0	0	0	0	0	0	1	3	0
Equisetum arvense	0	0	0	0	0	1	0	0	0	0	0	3	0	1	0	0	0	0
Erigeron peregrinus	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Eriophorum angustifolium	0	0	0	0	0	1	0	20	0	0	0	0	0	0	0	2	0	0
Festuca rubra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
Fritillaria camschatcensis	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0
Fucus distichus	0	0	0	50	0	0	0	0	0	5	0	0	0	0	0	0	0	0
Galium aparine	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geranium erianthum	0	0	0	0	0	0	0	0	0	0	0	1	2	1	0	0	0	0
Geum calthifolium	0	0	0	0	0	10	0	1	0	0	0	1	0	0	0	26	1	0
Gymnocarpium dryopteris	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Harrimanella stelleriana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Heracleum maximum	0	0	0	0	0	0	0	0	0	0	0	1	2	8	0	0	0	0
Honkenya peploides	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hylocomium splendens	0	70	0	0	8	0	0	0	10	0	1	0	0	0	0	0	0	0
Iris setosa	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Lathyrus japonicus	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leymus mollis	0	0	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ligusticum scoticum	0	0	1	0	0	0	0	0	0	0	0	1	2	1	0	0	0	2
Lupinus nootkatensis	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
Lysichiton americanus	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Maianthemum dilatatum	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Menyanthes trifoliata	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Menziesia ferruginea	0	50 (1.7)	0	0	20	0	0	0	2	0	0	0	0	0	0	0	0	0
Mimulus guttatus	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Mitella pentandra	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Nephrophyllidum crista-galli	0	0	0	0	60	70	0	2	0	0	0	0	0	1	15	6	40	0
Nuphar lutea	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0
Oplopanax horridus	0	0	0	0	0	0	0	0	0	0	2 (2.5)	0	0	0	0	0	0	0
Pedicularis parviflora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Petasites frigidus	0	0	0	0	0	0	0	0	0	0	0	4	8	0	2	0	0	0

Species	CHE_GRN_001	CHE_GRN_002	CHE_GRN_003	CHE_GRN_004	CHE_GRN_005	CHE_GRN_006	CHE_GRN_007	CHE_GRN_008	CHE_GRN_009	CHE_GRN_010	CHE_GRN_011	CHE_GRN_012	CHE_GRN_013	CHE_GRN_014	CHE_GRN_015	CHE_GRN_016	CHE_GRN_017	CHE_GRN_018
Picea sitchensis	25 (10)	40 (35)	0	0	3 (5)	0	0	0	20 (5)	0	0	1	0	0	0	0	0	0
Pinguicula vulgaris	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0
Plananthera stricta	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Plantago maritima	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
Pleurozium schrebii	0	0	0	0	4	1	0	0	0	0	0	0	20	0	0	0	0	0
Polemonium acutiflorum	0	0	0	0	0	1	0	0	0	0	0	1	1	1	0	0	0	0
Potamageton sp.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Prenanthes alata	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Puccinellia nutkaensis	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
Pyrola asarifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Rhizomnium glabrescens	0	1	0	0	0	0	0	0	2	0	1	0	0	0	20	0	0	0
Rhytidiadephus loreus	0	10	0	0	2	0	0	0	75	0	5	0	0	0	0	0	0	0
Rubus pedatus	0	1	0	0	6	0	0	0	1	0	0	0	0	0	0	0	0	0
Rubus spectabilis	0	1	0	0	0	0	0	0	0	0	10	0	1	5	0	0	0	0
Rumex salicifolius var. *transitorius*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Salix barclayi	0	0	0	0	0	0	0	0	0	0	0	0	0	45 (2.8)	0	0	0	0
Salix sitchensis	0	0	0	0	0	0	0	0	0	0	0	20	0	30 (2.6)	0	0	0	0
Sambucus racemosa	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Sanguisorba canadensis	0	0	0	0	0	1	0	0	0	0	0	0	5	0	5	0	0	0
Saxifraga nelsoniana	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
Saxifrage nudicaulis	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Selaginella selaginoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Senecio pseudoarnica	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Senecio triangularis	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0
Sorbus sitchensis	0	0	0	0	1	0	0	0	0	0	0	4	0	0	0	0	0	0
Spergularia canadensis	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Sphagnum sp.	0	0	0	0	0	1	0	10	10	0	0	0	0	0	0	12	0	0
Sphagnum squarosum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0
Stellaria calycantha	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Streptopus amplexifolius	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
Tiarella trifoliata	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Triantha glutinosa	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Tricophorum cespitosum	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	60	8	0

Species	CHE_GRN_001	CHE_GRN_002	CHE_GRN_003	CHE_GRN_004	CHE_GRN_005	CHE_GRN_006	CHE_GRN_007	CHE_GRN_008	CHE_GRN_009	CHE_GRN_010	CHE_GRN_011	CHE_GRN_012	CHE_GRN_013	CHE_GRN_014	CHE_GRN_015	CHE_GRN_016	CHE_GRN_017	CHE_GRN_018
Trientalis europaea	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0
Tsuga mertensiana	20 (6)	45 (35)	0	0	30 (12)	0	0	0	60 (30)	0	30 (20)	0	0	0	0	0	25 (10)	0
Vaccinium caespitosum	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0
Vaccinium ovalifolium	0	30 (1.6)	0	0	6 (1.8)	0	0	0	75 (1.8)	0	0	0	0	0	0	0	0	0
Vaccinium oxycoccos	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Vaccinium ulignosum	0	0	0	0	4	2	0	5	0	0	0	0	0	0	0	1	2	0
Valeriana sitchensis	0	0	0	0	0	0	0	0	0	0	0	0	0	2	10	0	0	0
Veratrum viride	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Viola epipsela	0	0	0	0	0	0	0	0	0	0	0	0	3	6	0	0	0	0
Viola langsdorffii	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 8. Background Data Preparation for assignment of LLWW codes to wetland and deepwater polygons, Chenega region, Prince William Sound, Alaska.

Elevation Data - Slope

1. Extract 5-meter digital elevation model dataset (DEM) from USGS – National Elevation Dataset (NED), which is available for download from a number of websites including the National Map program.
2. Aggregate 5-meter raster resolution to 10-meter resolution
    a. *Save 5-meter DEM as a 10-meter raster file*
3. Calculate slope in percent
    a. *Use Slope tool in ArcGIS, select output type as 'Percent Rise'*
4. Convert percent slope dataset to integer values
5. Apply slope percent value to each wetland polygon
    a. *Use Zonal Statistics as Table tool in ArcGIS*
    b. *Input feature zone dataset is wetlands polygon layer*
    c. *Zone Field is ObjectID, which provides a unique identifier for each polygon*
    d. *Input value raster is slope dataset*
    e. *Output table is LLWW slope, use statistics type = MEAN*
    f. *Join LLWW slope table to LLWW wetlands feature attribute table using OBJECTID as join field*

Elevation Data – Geomorphic Landforms

1. Use Geomorphon Landforms Tools for ArcGIS Pro to calculate 10 landform types: flat, peak, ridge, shoulder, spur, slope, hollow, footslope, valley, and pit (Jasiewicz and Stepiski, 2012).
2. Generate a Landforms dataset at a neighborhood radius appropriate for the landscape. We chose a 50-meter distance so that each cell is compared to the ten neighboring cells in each direction within that radius, this captured large features such as deeply incised alpine ridges and valleys while ignoring smaller features
3. Convert the raster landforms dataset to vector-based polygon dataset
4. Use the Eliminate tool in ArcGIS Pro to dissolve polygons smaller than 100 square meters

Appendix 9. Assignment of LLWW codes to wetland and deepwater polygons, Chenega region, Prince William Sound, Alaska.

Coding for Waterbodies:

Waterbody and Wetland Type Codes:

Pond (PD), Lake (LK), Stream (ST), Estuary (ES), Ocean (OB), Terrene (TE)

Ocean

1) Waterbody is permanently flooded, saline, and topographically unprotected.
    a. *Select by attribute from the NWI feature class where ATTRIBUTE begins with 'M' Marine*
    b. *Calculate Waterbody Type as 'OB' for Ocean*

Estuary

1) Waterbody is permanently flooded, intermediate between fresh and saline, and topographically protected.
    a. *Select by attribute from the NWI feature class where ATTRIBUTE begins with 'E' Estuarine*
    b. *Calculate Waterbody Type as 'ES' for Estuary*

Pond

1) Waterbody is permanently flooded standing water with a surface area of <20 acres.
    a. *Select by attribute from the NWI feature class where WETLAND_TYPE = 'Freshwater Pond' or 'Other'.*
    b. *Calculate Waterbody Type as 'PD' for Pond*

Lake

1) Waterbody is permanently flooded standing water with a surface area of ≥20 acres.
    a. *Select by attribute from the NWI feature class where WETLAND_TYPE = 'Lake'*
    b. *Calculate Waterbody Type as 'LK' for Lake*

Stream

1) Waterbody has flowing water with an average width greater than 15 feet. Note we considered all flowing waterbodies to be streams within the project area.
    a. *Select by attribute from the NWI feature class where WETLAND_TYPE = 'Riverine'*
    b. *Calculate Waterbody Type field as 'ST' for Stream*

Terrene

1) Wetlands that are not waterbodies (i.e., lakes, ponds, streams, estuaries or ocean) and not directly connected (adjacent) to any of those wetland types are considered Terrene.
    a. *Select by attribute from the LLWW feature class where Waterbody Type is NULL*
    b. *Calculate Waterbody Type field as 'TE' for Terrene*

Landscape Position Codes:

Marine (MA), Estuarine (ES), Lentic (LE), Lotic (LO), and Terrene (TE)

Marine

1) All Marine waterbodies are assigned a Marine landscape position.
    a. *Select by attribute from the NWI feature class where ATTIBUTE begins with 'M'*
    b. *Calculate Landscape Position as 'MA' for Marine*

Estuarine

1) All Estuary waterbodies are assigned an Estuarine landscape position.
    a. *Select by attribute from the NWI feature class where ATTIBUTE begins with 'E'*
    b. *Calculate Landscape Position as 'ES' for Estuarine*

Lentic

Note: no ponds met the following criteria as there were no large lakes (>500 acres) in the study area.

1) Ponds that are located in a basin formed and influenced by a large lake are assigned a Lentic landscape position.
    a. *Select by attribute from the NWI feature class where lake area > 2.02 square kilometers (>500 acres)*
    b. *Select by attribute from the LLWW feature class where Waterbody Type = PD and Landscape Position = NULL*
    c. *Select by location from the selection made in step b, pond polygons within 1 mile of the selection made in step a*
    d. *From this final selection of ponds within 1 mile of large lakes, calculate Landscape Position as 'LE' for Lentic*

Lotic

1) All streams are assigned a Lotic landscape position.
    a. *Select by attribute from the LLWW feature class where Waterbody Type = 'ST'*
    b. *Calculate Landscape Position as 'LO' for Lotic*
2) Lakes and ponds that are intersected by flowing waters are assigned a Lotic landscape position.
    a. *Select by attribute from the LLWW feature class where Waterbody Type = 'LK' or 'PD'*
    b. *From the selection made in step a, select by location the lake and pond polygons that intersect riverine polygons in the NWI feature class*
    c. *For this final selection, calculate Landscape Position as 'LO' for Lotic*
    d. *Select by attribute from the LLWW feature class where Waterbody Type = 'LK' or 'PD'*
    e. *Select by attributes from the NHD Flowline feature class where Ftype = 'StreamRiver'or 'Artificial Path'*
    f. *Select by Location LLWW features that Intersect Selecting Features NHD Flowline – Selection Type 'Select subset from the current selection'*
    g. *Assign selection a Landscape Position of "LO" for Lotic*
3) Waterbodies that are adjacent to Lotic wetlands are assigned a Lotic landscape position.
    a. *Select by attribute from the LLWW feature class where Landscape Position is NULL*
    b. *Using a second iteration of the LLWW dataset, select by attributes where Landscape Position has already been assigned 'LO'*

   c. *Select by location from the selection made in step a, wetland polygons that are adjacent to the lotic polygons selected in step b*
   d. *For this final selection, calculate Landscape Position as 'LO' for Lotic*

Terrene

1) Waterbodies that are neither Marine, Estuarine, Lentic, nor Lotic are assigned a Terrene (TE) landscape position.
   a. *Select by attribute from the LLWW feature class where Landscape Position is NULL*
   b. *For this selection, calculate Landscape Position as 'TE' for Terrene*

Flow Path Codes:

Bidirectional-tidal (BT), Outflow (OU), Throughflow (TH), and Vertical Flow (VR). Note: artificial flow codes, including Bidirectional Non-tidal, were not considered for the largely pristine study area. Inflow, where water enters a waterbody but does not exit, is not a flow type present in the study area.

Bidirectional Tidal

1) Estuarine and Marine waterbodies are assigned a Bidirectional Tidal (BT) flow path
   a. *Select by attribute from the LLWW feature class where Waterbody Type = 'ES' or 'OB'*
   b. *For the selection, calculate Flow Path as 'BT' for Bidirectional Tidal*

Through Flow

1) All streams are assigned a Through Flow (TH) flow path.
   a. *Select by attribute from the LLWW feature class where Waterbody Type = 'ST'*
   b. *For the selection, calculate Flow Path as 'TH' for Through Flow*
2) Lakes, ponds and wetlands that are connected to flowing waters (i.e., streams) are assigned a Through Flow (TH) flow path
   a. *Select by attribute from the LLWW feature class where Flow Path is NULL*
   b. *From the selection made in step a, select by location the lake, pond and wetland polygons that intersect riverine polygons in the NWI feature class*
   c. *For the final selection, calculate Flow Path as 'TH' for Through Flow*
3) Lakes, ponds and wetlands that are adjacent to wetlands that were previously assigned a Through Flow are also considered to experience Through Flow based on their presumed direct surface or subsurface hydrologic connection to that system.
   a. *Select by attribute from the LLWW feature class where Flow Path = 'NULL'*
   b. *Select by attribute in a second instance of the LLWW feature class where Flow Path = 'TH'*
   c. *Select by location from the selection made in step a, polygons that are within a distance of 2m of the selection made in step b*
   d. *From this final selection, calculate Flow Path as 'TH' for Through Flow*

Out Flow

1) Lakes, ponds and wetlands are assigned an Out Flow (OU) flow path if they are located at the top of a drainage system with no observable inflow.
   a. *Candidate polygons were manually attributed as 'OU' using the NWI feature class coupled with high resolution elevation and remotely sensed imagery*

Vertical Flow

Note: no wetland polygons in the project area met the following criteria, thus none were assigned a vertical flow regime.

1) Waterbodies and wetlands lacking a dominant surface water connection with a stream that are not otherwise categorized as tidal, through flow, or out flow are assigned a vertical flow (VR) path.
    a. *Select by attribute from the LLWW feature class where Flow Path is NULL*
    b. *Calculate Flow Path as 'VR' for Vertical Flow*

Landform Codes:

Basin (BA), Flat (FL), Fringe (FR), Slope (SL). Note: floodplain and island landforms do not occur within the project area. Peatlands, defined as a wetland formed by an accumulation of peat, is a concept that is not mutually exclusive with basin, flat, or slope landforms, and for this reason was not employed in our classification of LLWW. Similarly, pond and lake are concepts that are not mutually exclusive of the basin landform and for this reason, the pond and lake landforms were not used in our classification of LLWW.

Fringe

Wetland occurs within the banks of a stream or along the shoreline of a pond, lake, estuarine or marine waterbody

1) Lotic, Lentic, and Terrene waterbodies and wetlands intersected by flowing waters are assigned a Fringe (FR) landform.
    a. *Select by attribute from the LLWW feature class where Landscape Position = 'LO' 'LE' or 'TE'*
    b. *Select by location polygons that intersect stream polygons delineated in the NWI feature class*
    c. *For the final selection, calculate Landform as 'FR' for fringe*
2) Lotic, Lentic, and Terrene waterbodies and wetlands adjacent to open water are assigned a Fringe (FR) landform.
    a. *Select by attribute from the 'OU' LLWW feature class where Waterbody Type = 'LO' 'LE' or 'TE'*
    b. *Select by attribute from a second instance of the LLWW feature class where Waterbody Type = 'PD' 'LK' 'ES' or 'OB'*
    c. *Select by location from the selection made in step a, lotic, lentic or terrene polygons that are adjacent to the waterbodies selected in step b*
    d. *For the final selection, calculate Landform as 'FR' for Fringe*

Flat

Note: no wetland polygons in the project area met the following criteria, thus none were assigned a flat landform code.
Wetland occurs in a relatively level area and is fed primarily by precipitation

1) Terrene wetlands that have an average slope of less than 2% are assigned a Flat (FL) landform code.
    a. *Select by attribute from the LLWW feature class where Waterbody Type = 'TE'*
    b. *Calculate zonal statistics for the selection using the slope dataset as the input value raster*
    c. *Select by attributes from the selection made in step a, terrene polygons with slopes less than 2%*
    d. *For the final selection, calculate Landform as 'FL' for Flat*

Slope

Wetland occurs on a noticeable slope and hydrology is largely influenced by groundwater discharging to the surface.

1) Terrene wetlands that have an average slope of more than 2% are assigned a Slope (SL) landform code.
    a. *Select by attribute from the LLWW feature class where Waterbody Type = 'TE'*
    b. *Calculate zonal statistics for the selection using the slope dataset as the input value raster*
    c. *Select by attributes from the selection made in step a, terrene polygons with slopes greater than 2%*
    d. *For the final selection, calculate Landform as 'SL' for Slope*

Basin

Note: no wetland polygons in the project area met the following criteria, thus none were assigned a basin landform.
Wetland exists in a distinct depression

1) Lotic, Lentic, and Terrene waterbodies and wetlands not adjacent to flowing or open water are assigned a Basin (BA) landform code.
    a. *Select by attribute from the LLWW feature class where Waterbody Type = 'LO' 'LE' or 'TE' and Landform is NULL*
    b. *For the selection, calculate Landform as 'BA' for Basin*