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Cordova Existing Vegetation Map Project

Cover image: Overlook of the Columbia Bay, Columbia Glacier, and the surrounding vegetation. Photo taken from a helicopter during the 2021 helicopter field sampling trip.

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Authors

Cody Dangerfield is a Remote Sensing Analyst employed by RedCastle Resources, Inc. at the Geospatial Technology & Applications Center (GTAC) in Salt Lake City, UT.

Gabriel Bellante is a Geospatial Project Manager and Remote Sensing Analyst employed by RedCastle Resources, Inc. at GTAC in Salt Lake City, UT.

Thomas Day is a Remote Sensing Analyst employed by RedCastle Resources, Inc. at GTAC in Salt Lake City, UT.

Kate Mohatt was the Prince William Sound Zone Ecologist and is now the Vegetation Program Manager for the Chugach National Forest in Girdwood, AK.

Tina Boucher was the Vegetation Program Manager for the Chugach National Forest, USFS Alaska region in Anchorage, AK.

Kim Homan is the Geospatial Program Manager for the USFS Alaska region, Ecosystem Planning and Information Management Office in Juneau, AK.

Dustin Wittwer is the Remote Sensing Coordinator for the USFS Alaska region, Ecosystem Planning and Information Management Office in Juneau, AK.

Nathan Pugh is an Assistant Program Leader for the Resource Inventory Monitoring and Mapping (RMIM) program at GTAC in Salt Lake City, UT

Wendy Goetz is a Contract Manager employed by RedCastle Resources, Inc. at GTAC in Salt Lake City, UT.

Kevin Megown is the Program Leader for the Resource Inventory Monitoring and Mapping (RMIM) program at GTAC in Salt Lake City, UT.

Abstract

An existing vegetation map was prepared in a collaborative effort between the Chugach National Forest, Alaska Regional Office (Region 10), and the Geospatial Applications and Technology Center (GTAC). This map was designed to be consistent with the standards established in the Existing Vegetation Classification and Technical Guide (Nelson et al. 2015), and to provide baseline information to support project planning and inform land management for the Cordova Ranger District. The final map products comprise four distinct, integrated feature layers: 1) vegetation type, 2) tree canopy cover, 3) tree size, and 4) tall shrub canopy cover. The vegetation type map consists of 22 classes, including 17 vegetation dominance types and five other land cover types. Continuous canopy cover products were developed for areas classified as *forest* and *tall shrub*. Additionally, a thematic layer depicting tree diameter class categories was generated for areas classified as *forest*. Geospatial data, including remotely sensed imagery, topographic data, and climate information, were assembled to classify vegetation and produce the data products. A semi-automated image segmentation process was used to develop the modeling units (mapping polygons), which delineate homogeneous areas of land cover. Land cover class determinations were made for field sites, collected on the ground or from above in a helicopter, in order to characterize associated mapping polygons. Subsequently, these reference data were used to train and develop the predictive random forest models that ultimately produced the final map products. The mapping process used various Forest Service Enterprise software, adopting contemporary methods and technology. Most recent reference data was collected in the summer of 2021, and therefore, the final map can be considered indicative of the existing vegetation conditions found in Cordova at that time. Once the data products were finalized, an accuracy assessment was conducted to reveal individual class confusion and provide additional insight into the reliability of these products for real-world resource applications.

Acknowledgements

We would like to acknowledge our partners for their indispensable contributions to this effort. These contributions consisted of financial and in-kind support, identification of mapping needs, field data collection, and assembly of auxiliary data sets, along with draft map and other product reviews. Inclusion of neighboring lands expanded the utility and accuracy of this map, and we would like to acknowledge the Native Village of Eyak, the Tatitlek Corporation, and the State of Alaska for permission to collect vegetation data on their lands. USFS personnel critical in collecting ground data for this project included Elizabeth Camarata, Daniel Schmalzer, Sean Meade, and James Ianni. Special thanks to Dan Fehringer of Ducks Unlimited for his expertise of the local Alaska flora and organization of the helicopter reference data collection campaign. We also wish to express our appreciation to Katie Baer, who coordinated and analyzed Forest Inventory and Analysis (FIA) data used for reference, as well as Barb Schrader, the former regional ecologist now retired, who provided leadership and guidance throughout this project.

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Introduction

Maps of existing vegetation support resource managers by informing project- and landscape-level planning efforts with vegetation data that can be used in numerous applications. The use of existing vegetation maps can save time and money by eliminating work redundancies and informing a multitude of future management activities. Mission-critical Forest Service goals necessitate existing vegetation information for Forest planning, ecological assessment, forest health monitoring, and wildlife habitat management. Existing vegetation maps are commonly employed for fire risk assessment, natural resource inventories, silviculture, rare and sensitive species monitoring, invasive species modeling, recreation management, disturbance susceptibility evaluations, and climate change analyses. For example, on the Chugach National Forest, existing vegetation maps from other project areas (see Bellante et al., 2013, 2020) have been used to monitor Dusky Canada Geese (*Branta canadensis occidentalis*), Northern Goshawk (*Accipiter gentilis*), and moose habitat on the Kenai peninsula and Copper River Delta. During the Swan Lake Fire in 2019, the existing vegetation data products were used for fuels information and fire behavior modeling on the Kenai Peninsula. These products are also expected to be used to monitor mountain goat, Kittlitz's Murrelet (*Brachyramphus brevirostris*), Marbled Murrelet (*Brachyramphus marmoratus*), and other prevalent wildlife habitat on the Forest.

This project implemented contemporary methodologies and used empirical data to develop defensible map products. The resultant data products establish a baseline of landscape ecological condition through the depiction of vegetation dominance types, tree size, and canopy cover distributions. Authority and funding for the Cordova Existing Mapping Project was provided by the Chugach National Forest and the United States Department of Agriculture, Forest Service (USFS) Alaska Regional Office. The Geospatial Technology and Applications Center (GTAC) developed these existing vegetation map products using national guidelines, adhering to the standards established in the Existing Vegetation Classification, Mapping, and Inventory Technical Guide (Nelson et al., 2015) and using the most current data available. This project provides land managers with data layers to inform planning and management decisions pertinent to the Cordova Ranger District.

Project Area

The mapping project area is located in Southcentral Alaska near the Gulf of Alaska, and in this report is referred to hereafter as the Cordova project area (figure 1). It encompasses an area of 3 million acres, and traverses a diverse landscape including portions of Prince Williams Sound, the Chugach Mountains, and the Copper River. The project area consists of two ecoregions, the Gulf of Alaska Coast and Chugach-St. Elias Mountains, and is characterized by lakes, rivers, low wetlands and bogs, coastal rainforest, and glaciated mountains (Nowacki et al. 2001). This periglacial maritime landscape provides critical habitat for migratory birds along the Pacific Flyway, large mammals such as moose and bears, and anadromous fisheries. The mapping extent consists of lands administered by federal, state, Eyak and Tatitlek Native Corporations, and private entities. The project area contains a majority of the USFS Cordova Ranger District and the northeastern portion of the Glacier Ranger District, which includes the Columbia Bay and Columbia Glacier. The portion of the Cordova Ranger District that contains the Copper River Delta was excluded from this project as its vegetation dominance types and associated forest structure products were previously mapped in 2013 and 2021, respectively (Bellante et al., 2013; Day et al., 2022).

Project Planning

In 2018, staff of the USDA Forest Service met with partners to outline a strategy and prepare a project plan for the Cordova Existing Mapping Project. This partnership discussed map unit design in order to develop a vegetation classification system that was both ecologically meaningful and realistic with respect to technology and the data available for the area. Vegetation map units share a common definition based on their physiognomic, floristic, or structural characteristics (Nelson et al., 2015). The map unit design process establishes the rules that define the map classes found in the Cordova Vegetation Type Classification Key (Appendix A). This dichotomous key establishes the discrete, absolute, and relative vegetation cover percentages, as well as the height definitions that distinctly classify the vegetation communities encountered on the ground. Although class assignment in the field may be difficult, especially near cover and height thresholds, their definitions must be clear and unambiguous. The classification key had to meet these critical standards: 1) be exhaustive to describe the full range of environmental conditions that could be encountered on the ground, 2) be mutually exclusive to contain classes with no overlap or have any ambiguity in their respective definitions, 3) contain classes that are capable of being mapped with the available data, and 4) be consistent with the scale and scope of the project.

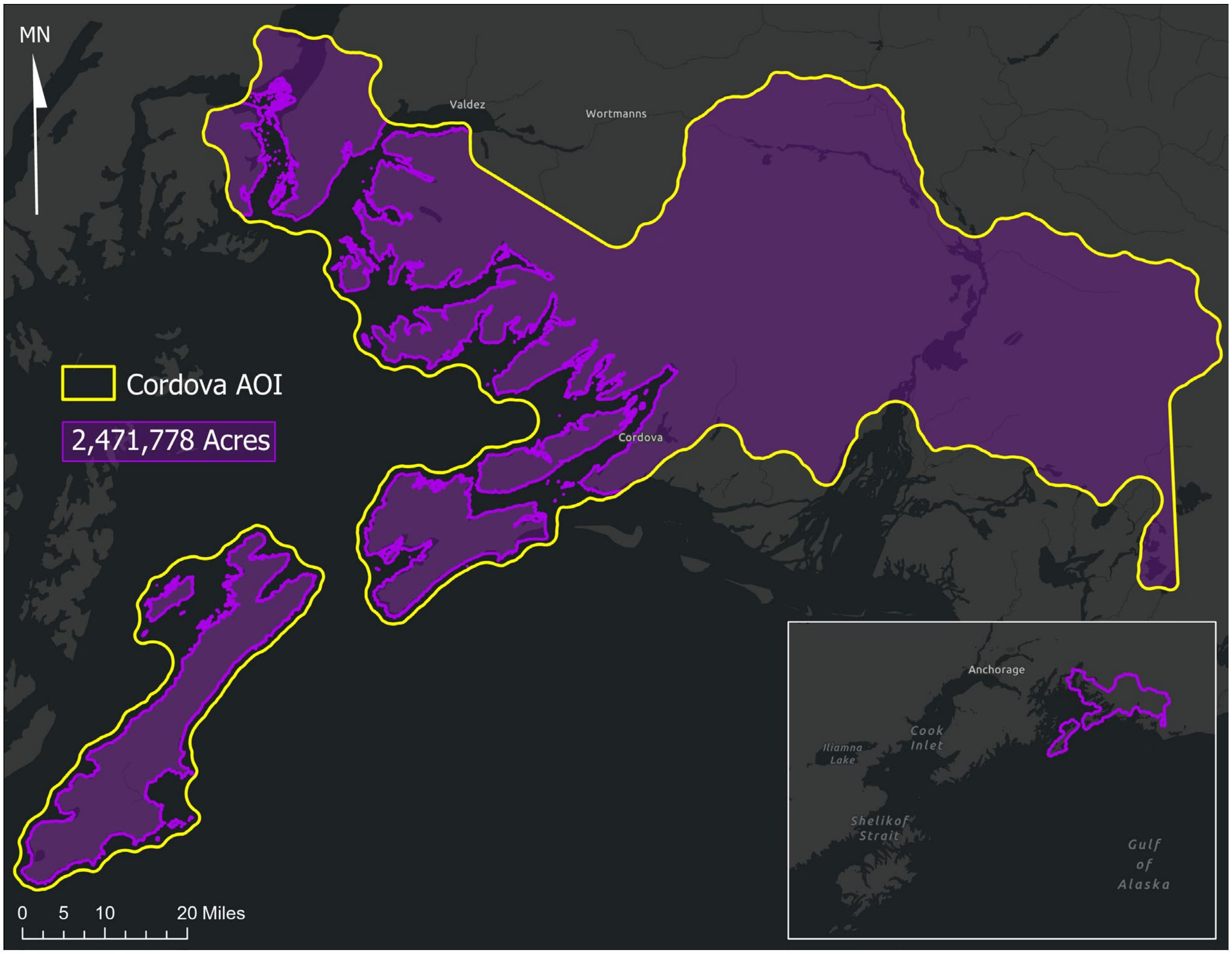

Figure 1.— Map extent of the Cordova Existing Vegetation Map area of interest (AOI). The project boundary is depicted in yellow. The terrestrial areas and inland waterbodies are depicted in purple and encompass ~2.5 million acres.

Vegetation types and structure classes were identified to address the information needs of the Alaska Region and Chugach National Forest. GTAC was tasked to develop a set of mid-level existing vegetation maps for the project area. Existing vegetation consists of the plant cover, or floristic composition and vegetation structure, occurring at a given location at the current time (Nelson et al. 2015). Vegetation type classes were developed to depict taxonomic or technical groups that provide information that supports resource allocation and activities. The vegetation dominance types, also known as mapping units, were designed to describe vegetation functional groups that occupy the Cordova landscape, meet the Forest Service business requirements for planning and monitoring purposes consistent with the mid- to base-level scale, and be compatible with the National Vegetation Classification (NVC) hierarchy (FGDC, 2008; Nelson et al., 2015). Some vegetation types were a combination of species which describe a vegetation community (e.g., *Wet Herbaceous*) while others identified specific species (e.g., *Sitka Spruce*). Vegetation type classes are defined by the Cordova Vegetation Type Classification Key (Appendix A).

Prior to modeling, several classes were collapsed or removed due to the lack of available reference data, limited occurrence on the landscape, or the inability to differentiate certain classes. Ultimately, there were a total of 22 vegetation type classes – 17 vegetated classes and five non-vegetated classes (table 1), three binned canopy cover classes for both tree and tall shrubs, and four tree size classes (table 2).

Table 1.— List of classifications for Map Group and Vegetation Type classifications from the Cordova Existing Vegetation Key (Appendix A).

Map Group	Vegetation Type	Vegetation Type Code
Needleleaf Forest	Sitka Spruce	SS
	Hemlock	H
	Hemlock-Sitka Spruce	H-SS
	Hemlock-Yellow Cedar	H-YC
	Dwarf Mountain Hemlock	DMH
	Forested Peatland	FP
Broadleaf Forest	Black Cottonwood	BC
Mixed Forest	Sitka Spruce-Black Cottonwood	SS-BC
Tall Shrub	Alder	A
	Alder-Willow	A-W
Low Shrub	Sweetgale	SG
Dwarf Shrub	Ericaceous Dwarf Shrub	EDS
Herbaceous	Sedge Peatland	SP
	Aquatic Herbaceous	AHB
	Wet Herbaceous	WHB
	Mesic Herbaceous	MHB
	Dry Herbaceous	DHB
Non-Vegetated	Sparse Vegetation	SV
	Barren	BR
	Water	WA
	Snow/Ice	S/I
	Developed	DEV

Table 2.—Thematic vegetation structure metrics produced for the Cordova Existing Vegetation Map Project.

Structure Metrics	Thematic Structure Classes
Tree Canopy Cover	Woodland (10-24%)
	Open (25 - 59%)
	Closed (60 - 100%)
Tall Shrub Canopy Cover	Sparse (9-24%)
	Open (25 - 59%)
	Closed (60 - 100%)
Tree Size	TS1 Sapling (<5” DBH)
	TS2 Pole (5–8.9” DBH)
	TS3 Medium (9–20.9” DBH)
	TS4 Large (≥21” DBH)
	Non-Tree

One of the overarching goals for this project was to provide a regionally cohesive map product; therefore, efforts were made to ensure that the spatial and thematic characteristics of the maps would fulfill data requirements across the Chugach National Forest and be congruent with previous mapping projects on the Forest (Bellante et al., 2013, 2020; Day et al., 2022). These products were developed to provide up-to-date, comprehensive information about the vegetation communities and their structure across Cordova. Over 3 million acres (including other federal, state, local, native, and private land inholdings) were mapped. It is important to remember that the vegetation characteristics being described on the final maps are captured from an overhead, bird’s-eye perspective (figure 2). Therefore, understory vegetation that is not visible from above is not being depicted; vegetation dominance types and structure are based on what is visible in the overstory.

Figure 2.— An example of the remote sensing perspective when viewing the landscape from above. The arrows illustrate the vegetation that would be detected from an overhead sensor.

Mapping Methods

The map products for this project were developed using remotely sensed multispectral imagery, topographic Interferometric Synthetic Aperture Radar (IfSAR) data, field and photo-interpreted reference sites, and object-oriented classification models. The modeling units (segments) were produced using a semi-automated image segmentation process that considers the shape, size, and spectral content of spatially contiguous pixels across the landscape. Random Forest, an ensemble classifier, was then used to characterize these modeling units and assign map class labels, which ultimately produced the final vegetation maps for Cordova. The major mapping phases, which are discussed in more depth below, include: geospatial data acquisition, image segmentation, reference data collection, classification, final map development, and accuracy assessment.

Geospatial Data

This project used remotely sensed imagery acquired from various sensors on both satellite and airborne platforms (table 3). Each image sensor has a unique set of qualities that, along with the imaging geometry, determines the spectral, spatial, and radiometric resolutions of the data that is collected. Multiple sources of imagery were acquired for this project to utilize the unique information afforded to different sensors and to maximize the range of data used in the computational modeling. Medium resolution image mosaics were acquired from satellite platforms including SPOT 5, Landsat 8, and Sentinel 2. The SPOT 5 Level 1A image scenes were collected between 2010 and 2016 by the Statewide Digital Mapping Initiative (University of Alaska, Fairbanks).

Landsat 8 and Sentinel 2 images were reviewed and prioritized in order to reflect current ground conditions, limit cloud obscurity, and capture variations in vegetation phenology. Individual scenes were ultimately mosaicked together in Google Earth Engine to remove clouds and aggregate adjacent image swaths for the purpose of developing seamless image mosaics of the entire project area for each sensor. Independent image mosaics are ideally generated for the spring, summer, and fall seasons in order to depict phenological conditions throughout the growing season to better distinguish vegetation types. Ultimately, the prevalence of clouds allowed for only a single Sentinel 2 mosaic, but three seasonal mosaics (spring, summer, and fall) were generated from Landsat 8. The single Sentinel 2 mosaic was obtained from imagery taken from September 12–13th, 2020, while spring, summer, and fall mosaics were developed from Landsat 8. The spring mosaic is meant to capture the early growing season, summer captures the height of the growing season, and fall captures the end of the growing season, during vegetation senescence. A Normalized Difference Vegetation Index (NDVI) and Normalized Difference Moisture Index (NDMI) were produced for each image mosaic. A Tasseled-Cap Transformation was also performed on each Sentinel 2 and Landsat 8 mosaic (Crist & Cicone, 1984).

High-resolution imagery was critical for image interpretation, which allowed an analyst to evaluate and modify model outputs and was instrumental for developing relatively fine-scaled segments for the project. Resource orthoimagery that covered lands administered by the Chugach National Forest within the Cordova project area was acquired from July 09, 2010 – September 16, 2010. This imagery included 4 spectral bands (red, green, blue, and near infrared) and had a 60 cm resolution. We also used Maxar high-resolution imagery for image interpretation, segmentation, and modeling. This imagery was acquired from 2010-2020, featured 4 bands (red, green, blue, and near infrared), and had a spatial resolution of 50 cm. Principal Component Analysis was conducted for the imagery resulting in four principal components for each dataset.

Elevation information for the project came from data collected by an IfSAR instrument, collected by Fugro between 2010 and 2012. IfSAR data covered the full extent of the project area and contained a digital terrain model (DTM) and a digital surface model (DSM) that were used to derive several other geospatial modeling inputs. The DTM was derived from the P-band, which penetrates through vegetation to provide a bare-earth elevation approximation, and the DSM was derived from the X-band (Kampes et al., 2011), which reflects higher canopy vegetation and provides an estimate of canopy surface elevation. Using the DTM and DSM, a canopy height model (CHM) was produced by calculating the difference between the two layers. Other topographic derivatives including slope, aspect (cosine and sine transformations), heat load, topographic position index (TPI), and a topographic wetness index (TWI) were produced from the DTM. Sentinel 1 synthetic-aperture radar (SAR) data was also acquired for the project area and used as predictor data for modeling.

Other ancillary data, including climate and ownership spatial layers, were also used in the mapping process. The ownership layer assisted in the development of an access layer that was used for field reference site placement, and the climate data served as predictor variables during the modeling process. All final data layers were co-registered and projected to Universal Transverse Mercator (UTM), NAD83, Zone 6 North. The data were resampled to 5 meters to maintain consistency in spatial resolution across all data layers. A complete list of geospatial data used in the project can be found in tables 3a, 3b, and 3c.

Table 3a.— List of spectral data sources with native resolutions and how they were used in the mapping process.

Geospatial Data Source	Product Description	Spatial Resolution	Purpose
Resource Imagery (2010)	Bands: Red, Green, Blue, NIR Indices: NDVI, Principal Components (PC) 1, PC2, PC3, PC4	60 cm	Segmentation, Vegetation Type & Structure Modeling, Image Interpretation
Maxar Imagery (2010-2020)	Bands: Red, Green, Blue, NIR Indices: NDVI, Principal Components (PC) 1, PC2, PC3, PC4	50 cm	Segmentation, Vegetation Type & Structure Modeling, Image Interpretation
SPOT 5 (2011-2016)	Bands: Green, Red, NIR Indices: NDVI, PC1, PC2, PC3	Pansharpened 2.5 m (Native Resolution 5 m)	Vegetation Type & Structure Modeling
Sentinel 2 (2020) • Sep. 12-13, 2020	Bands: Blue, Green, Red, NIR Indices: NDVI	10 m	Segmentation, Vegetation Type & Structure Modeling
	Bands: Red Edge (RE) 1, RE 2, RE 3, Shortwave Infrared (SWIR) 1, SWIR 2 Indices: Normalized Difference Moisture Index (NDMI), Tasseled Cap Transformation (brightness, greenness, wetness)	20 m	
Landsat 8 (2013-2018) • Spring May 13, 2016 May 30, 2017 • Summer Aug. 25, 2013 July 02, 2014 July 05, 2015 July 12, 2017 • Fall Sep. 02, 2016 Sep. 08, 2018 Oct. 08, 2018	Bands: Blue, Green, Red, NIR, SWIR 1, SWIR 2 Indices: NDVI, NDMI, Tasseled Cap Transformation (brightness, greenness, wetness)	30 m	Vegetation Type & Structure Modeling

Table 3b.— List of topographic data sources with native resolutions and how they were used in the mapping process.

Geospatial Data Source	Product Description	Spatial Resolution	Purpose
IfSAR (2010-2012)	Digital Terrain Model (DTM) Digital Surface Model (DSM) Canopy Height Model (CHM) Topographic Position Index (TPI) Topographic Wetness Index (TWI) Heatload Cosine Aspect Transformation Sine Aspect Transformation	5 m	Vegetation Type & Structure Modeling
Sentinel 1 (2018)	C-Band Polarizations: VV (ascending), VV (descending), VH (ascending), VH (descending) Indices: VV to VH (ascending), VV to VH (descending) *V=Vertical; H=Horizontal	10 m	Vegetation Type & Structure Modeling

Table 3c.— List of ancillary data sources with native resolutions and how they were used in the mapping process.

Geospatial Data Source	Product Description	Spatial Resolution	Purpose
Daymet Climate Data (30-year mean)	Annual Precipitation Continentally Solar Radiation Max Temperature Min Temperature Water Vapor Pressure	1 km	Vegetation Type & Structure Modeling
Ownership	Landownership covering Cordova	GIS Vector Data	Reference/Validation Site Placement & Access

Image Segmentation

Image segmentation is the process of partitioning digital imagery into spatially cohesive modeling units (mapping polygons) that represent discrete areas or objects on a landscape (Ryherd & Woodcock, 1996). The goal is to develop homogenous segments that delineate vegetation of similar physiognomic, floristic, and structural characteristics to serve as the fundamental modeling units. High-resolution imagery, including the Resource and Maxar imagery, along with the Sentinel 2 imagery and IfSAR topographic layers were used to generate the final segments (tables 3a, 3b). High-resolution imagery excels at portraying vegetation patterns across the landscape during the segmentation process, such as delineating forest boundaries or isolating patches of shrub. As such, the Resource and Maxar imagery were the most important data sources for generating the final segments. However, there were notable limitations and artifacts in the high-resolution imagery which presented challenges during segmentation, requiring different datasets to be strategically leveraged to create accurate segments. For example, the Resource imagery was collected nearly a decade before project began, consequently creating contemporary segments that captured the current vegetation patterns of Cordova's dynamic landscape would not have been possible without leveraging more recent imagery from Maxar and Sentinel 2. The Resource imagery was also not as spectrally dynamic, meaning that it could not differentiate between different vegetation types as readily as other imagery. While the Maxar imagery was more current and spectrally dynamic than the Resource imagery, it was also less consistent as it was collected over several years and during different seasons, which resulted in vegetated areas appearing different or being covered in snow. The Maxar imagery also contained more shadow than the Resource imagery, so the Resource imagery was able to capture landscape patterns in areas where the Maxar imagery could not. Although Sentinel 2 had a coarser spatial resolution, its relatively broad spectral resolution and contemporary temporal resolution helped mitigate these issues during segmentation. All of these datasets presented separate challenges for segmentation and were leveraged to maximize their strengths while mitigating their limitations to create the most accurate segments possible. Prior to segmentation, all imagery was resampled to 5 meters to make data processing more efficient and avoid over-segmentation of the complex landscape i.e., avoid creating convoluted segments that follow minute changes in the imagery such as canopy gaps, rather than capturing forest stands or larger vegetation patterns.

Development of the Cordova segments was an iterative process which used a variety of algorithms and a combination of data sources that were structured into a segmentation ruleset within the Trimble eCognition Developer 10 software suite. Coarse segments were initially generated to classify waterbodies, barren rock, glacial ice, and shoreline. Subsequently, the segments were incrementally refined to further delineate vegetation and landscape features, commensurate with the scale and scope of the project, until the final segments were achieved.

Segments were on average 3.44 acres in size. Median segment size was 1.6 acres since large bodies of water and areas of glacial ice were classified and merged during the segmentation process, creating very large segments that increased the mean as compared to the median. The final segments were filtered and smoothed to ensure that the smallest segment was 0.25 acres or greater in size to prevent segments from capturing landscape features too small to adequately model with the available predictor data. The final segmentation yielded approximately 900,000 mapping segments that served as the modeling units for the project (figure 3).

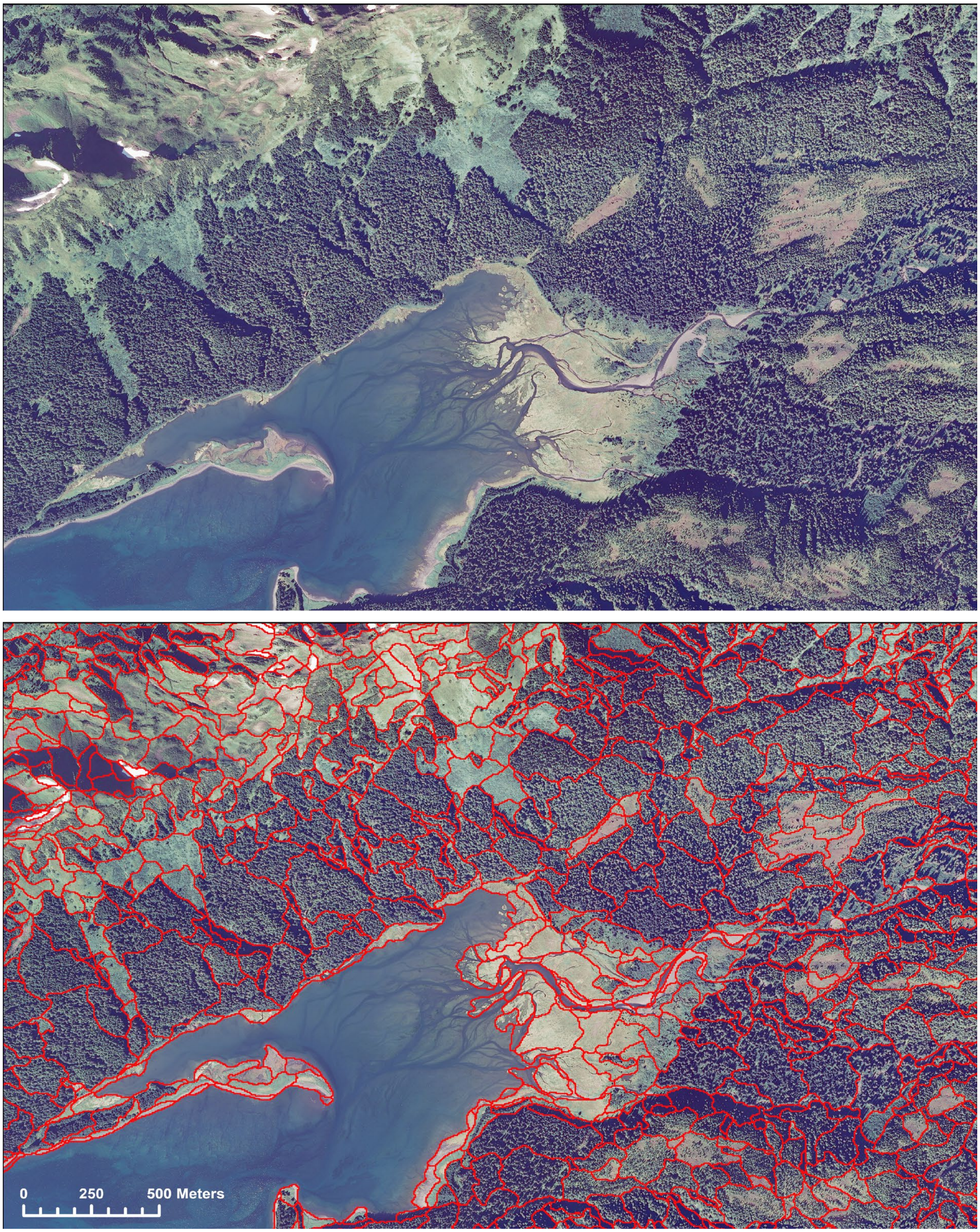

Figure 3.— An example of the final segments generated for the mapping project using Trimble eCognition. This is a snapshot of the Resource Imagery on Hinchinbrook Island with and without the overlayed final segments.

Reference Data Collection

Consistent and precise reference information is imperative to successfully map existing vegetation. GTAC worked with project partners to identify and collect the reference data required for modeling vegetation across Cordova. Alaska Regional and Chugach National Forest staff developed the classification key (Appendix A) and identified the desired classes to be collected in the field and depicted on the final map products.

Reference data for this project came from numerous sources including: 1) ground, 2) helicopter, 3) the Forest Inventory and Analysis (FIA) program, and 4) image interpretation (figure 4). Forest Service field personnel collected the ground data, while Ducks Unlimited and GTAC contractors collected the helicopter data. Reference data from the various sources was consolidated into a single database and reviewed within the context of their corresponding mapping segment using high-resolution imagery. The final reference database included 985 field sites – 687 sites collected on the ground and 298 sites collected from a helicopter. Following field collection, sites were added by GTAC and Ducks Unlimited personnel using image interpretation techniques to bolster reference datasets and improve map model performance. Inevitably, the more abundant vegetation and structure types were sampled at a higher frequency. It can be difficult to obtain an adequate sample for rarer classes and some of the vegetation types were dropped as a result. The following eight dominance types were dropped: *Tall Willow*, *Copperbush*, *Salmonberry*, *Low Willow*, *Willow Dwarf Shrub*, *Dwarf Shrub Peatland*, *Dwarf Shrub/Lichen*, and *Lichen*. This does not mean that these vegetation types don't occur but rather are not discernible for this project's scale and scope. Consequently, these types are not depicted on the final map products. The *Hemlock-Yellow Cedar* class was retained, even with its minimal distribution, since it has particular ecological relevance as yellow cedar (*Callitropsis nootkatensis*) reaches its most northern extent in Prince Williams Sound (Hennon & Trummer, 2001). Known occurrences from legacy reference information and observations in the field were used to intersect corresponding mapping polygons and manually map this class's extent.

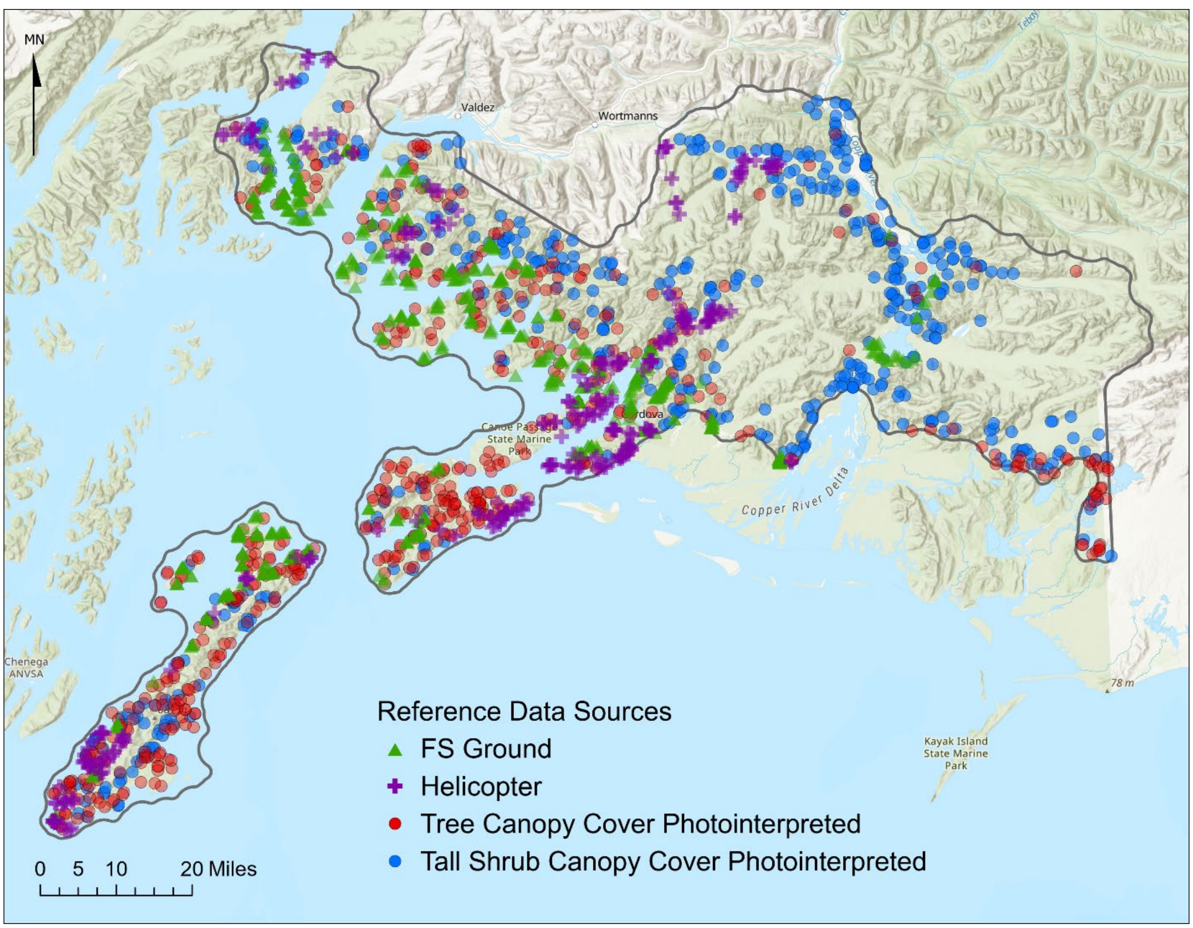

Figure 4.—Map showing the distribution of reference data (colored symbols) across the Cordova project (dark outline).

Ground Data

A total of 687 sites were collected on the ground by Chugach Forest Service personnel during the 2019 and 2020 field season. These sites were primarily pre-selected using a cluster analysis of the Sentinel 2 image mosaic that was stratified by elevation in an attempt to distribute the sites equally across the full range of vegetation conditions in the project area. Site selection was confined to areas accessible with respect to ownership, terrain slope, existing infrastructure (i.e., roads and trails), and ease of access. Most ground sampling was conducted from accessing the shoreline since so little infrastructure (roads and trails) exist within the project area, while some sampling was done from a boat because areas could be assessed from a distance on the water. Special consideration was also made to place multiple sites near one another to maximize sampling efficiency. Pre-selected sites targeted for ground sampling were reviewed within the context of their associated larger mapping segments for homogeneity and representativeness.

Two types of field sites were collected by field crews – descriptive and observational. A 50-foot radius plot was evaluated at each sampled location. Descriptive sites contain highly detailed vegetation information on species composition and structure, whereas an observational plot was a quick method by which a field crew could make vegetation type and structure determinations without collecting descriptive vegetation plot data. For descriptive plots, detailed plant cover information was collected, including visual estimates of vegetation cover by species, along with height information for tall shrubs and trees. Additionally, tree diameters were measured at breast height (dbh) to determine the most abundant diameter class for forested plots. For observational plots, vegetation type and associated structure determinations were made after a brief assessment. The slope and aspect for descriptive and observational plots were also recorded in addition to plot photos. Cover estimates were evaluated from the remote sensing perspective, meaning vegetation composition was calculated for what was visible from above. Discounting overtopped vegetation, absolute cover was summated to 100% for every reference plot and used to determine the final vegetation type and structure classes using the dichotomous Cordova Vegetation Type Classification Key (see Appendix A).

Helicopter Data

During August of 2021, a total of 298 reference sites were collected from a helicopter by GTAC and Ducks Unlimited contractors. A single sample, or reference site, consisted of a single mapping segment and served as the unit for evaluation. The segments were pre-selected using a stratified random sample across the entire study area, since helicopter sampling is not constrained by infrastructure. Identified helicopter avoidance areas, primarily seabird colonies and Forest Service cabins, were not sampled to prevent disturbing wildlife and recreationalists. The helicopter effort coincided with a stretch of inclement weather characterized by extensive periods of rain and widespread low-lying fog that limited flight opportunities. Most flights were restricted to lower elevations and were dictated by the distribution of low-lying clouds. Higher elevations were only accessed during a few flights when weather conditions allowed. Over a 10-day period, weather allowed for 7 days of data collection from the helicopter and required the crew to be flexible and ready at a moment's notice given the narrow time windows that were conducive for flying. The helicopter work was staged from the Cordova Municipal Airport for 6 ½ days and from the Valdez Municipal Airport for 3 ½ days with an additional remote fueling location on Hanning Bay of Montague Island. Trip planning was strategized to maximize the amount of data collected at each location and to limit transit time.

Visual estimates of canopy cover were recorded for every species observed from the encircling helicopter. Cover was always assessed from above the canopy, thereby discounting understory vegetation. Average tree diameter and shrub height was also recorded for *forest* and *tall shrub* sites. If tree diameter or shrub height determinations were ambiguous, then structure determinations were not assigned. Upon completion of a site, class labels were assigned using the definitions described in the Cordova Vegetation Type Classification Key (Appendix A).

Image Interpreted Data

Ducks Unlimited image interpreted 400 additional reference sites to supplement the reference data used to model the vegetation types, focusing on under-sampled classes. GTAC also used image interpretation to bolster the training data used in the predictive models. Numerous sites were interpreted to improve the vegetation type models and generate the training data used to develop the structure products. A total of 1,000 sites were evaluated by analysts for continuous canopy cover to provide the reference information used to develop and validate the models for *forest* and *tall shrub* areas. Supplemental reference data was also interpreted for stands of small (*0–4.9"dbh*) and large (*≥21"dbh*) trees to improve the thematic tree size results by providing a more balanced dataset that better reflects these rarer seral stages across the project area.

To assign vegetation classes and structure values to each segment, the vegetation was evaluated using the most contemporary high-resolution imagery available. Resource imagery collected in 2009 and 2010 for the Chugach National Forest and Maxar imagery acquired between 2010 and 2020 were the primary data sources for image interpretation. Both image sources contained 4 bands (red, green, blue, and near infrared) and had a spatial resolution of 60 cm and 50 cm, respectively. Vegetation class assignments and structure values interpreted from the high-resolution imagery were then cross-evaluated with the Sentinel 2 imagery to ensure that the designations had not changed since the high-resolution imagery was acquired. Primary drivers of recent vegetation changes for the project area included glacier recession, erosion, timber harvest activity, localized flooding, landslides, and wind events.

Tree and tall shrub canopy cover was modeled and validated using reference data that was image interpreted. For each product, 500 sites were randomly selected using a stratification based on the *forest* and *tall shrub* extents of an early iteration of the vegetation type product. Each reference site, consisting of a single mapping segment, was assigned an absolute canopy cover value for the particular lifeform being assessed – tree canopy cover was evaluated for *forest* segments while tall shrub cover was assigned to sites mapped as *tall shrub*. Image interpreters assigned a canopy cover value of 0–100% for each evaluated site. To reduce bias, canopy cover was estimated independently for each segment by two analysts. A third analyst evaluated a subset of 50 segments from each reference dataset. The interpreted values of each analyst were then cross-validated with one another to confirm similar results. If disagreement between the analysts was greater than an absolute value of 10 percent (±10%), the site was reevaluated and reconciled to determine an appropriate final canopy cover value. The analysts also assigned a confidence-level rating of "low", "medium", or "high" to help determine the later application or removal of sites. In some cases, canopy cover could not be reliably assessed – usually due to shadows or clouds which precluded estimation of canopy cover. In these situations, the segment was given a "low" confidence rating and taken out of the reference dataset so that only "medium" and "high" quality segments were used for the modeling or validation effort. The "low" confidence sites were replaced using the same random stratification method until a total of 500 sites with "medium" and "high" confidence ratings were reached for each canopy cover product. Final canopy cover values were calculated by taking the average of the estimates made by multiple interpreters.

Classification and Regression

Random forest was the machine learning technique used to predict and assign vegetation attributes to the mapping polygons (Breiman, 2001; Cutler et al., 2007). It is an ensemble classifier that uses the majority vote in the case of classification, or the average value in the case of regression, of the individual decision trees that make up the 'forest' to determine final class assignment or regression output. The predictor layers used in the classification and regression consisted of the imagery, topographic data, and climate data outlined in tables 3a, 3b, and 3c. For each of those datasets, we calculated zonal statistics including minimum, maximum, range, standard deviation, mean, and median for the mapping segments. This equated to 360 statistics being calculated for every segment. Subsequently, these statistics were compiled into a single dataset to be used in the computational modeling. Zonal statistics associated with the reference mapping segments were then used to predict and characterize vegetation across Cordova. Once models were finalized, vegetation masks were implemented to integrate the structure attributes with the appropriate dominance types according to the lifeform definitions of the Cordova Classification Key (e.g., tree canopy cover values were only applied to areas that were classified as *forest* on the final dominance type layer). This minimizes confusion for the end user by ensuring that there is consistency between the various modeled products and that the structure products conform to the definitions established in the classification key. Additionally, this step removes noise in the final products.

Vegetation Type

Vegetation modeling was conducted in hierarchical stages in which vegetation types were separated into different groups based on their characteristics, e.g., *forest* vs. *non-forest* (figure 5). The mapping hierarchy determined the sequence in which models were run. Spectrally distinct classes were mapped first, while classes that were more difficult to distinguish were grouped together and classified further down in the hierarchy. This iterative process of evaluating and rerunning classification models at each level of the mapping hierarchy is a sequential operation in which broad vegetation groupings are subsequently further divided until all vegetation types are sufficiently mapped. There were three classes that were not a part of the modeling process and were added to the map manually using legacy reference information, observations from the field, and image interpretation. The *Developed* class was added manually because permanent infrastructure is mostly confined to the urban centers and anthropogenic sprawl is difficult to adequately delineate with segmentation in a project of this scale. The *Hemlock-Yellow Cedar* and *Sitka Spruce-Black Cottonwood* classes were also added to the map manually because we did not have sufficient reference data in order to map the classes accurately via modeling. Model outputs were evaluated and optimized using image interpretation at each stage of the mapping hierarchy to reduce model confusion and improve overall map accuracy. The distinct advantage of using this hierarchical modeling approach is that it enables a targeted review of map outputs at each level, where conspicuous errors can be addressed.

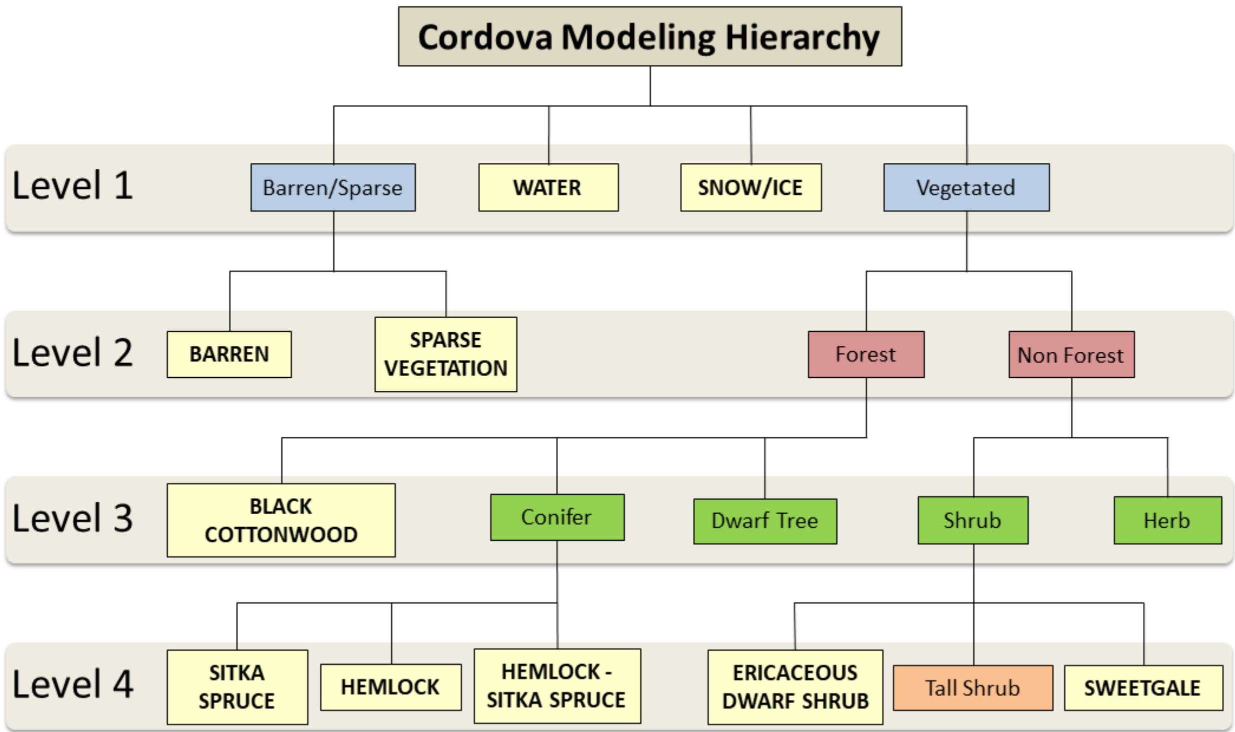

Figure 5.— A diagram showing examples of the highest levels of the vegetation type modeling hierarchy for the Cordova Existing Vegetation Mapping Project. Individual classification models were developed for every node within the levels of the modeling hierarchy. Note, not all vegetation type classes are depicted in the diagram. For example, two independent classification models were developed for Level 2: 1) Differentiating Barren from Sparse Vegetation; 2) Grouping vegetated areas into forest and non-forested areas. Yellow highlighted boxes with emboldened class names in all caps indicate final classes. Other colored boxes indicate similar groupings of vegetation that are further refined at subsequent modeling levels.

Tree Canopy Cover

Tree canopy cover was modeled continuously, from 0–100%, using random forest regression models. An initial random forest model was trained and validated using a total of 500 reference sites that were image interpreted, 450 of which were used for training and the other 50 were randomly withheld from modeling for validation. The tree canopy cover results were assessed using linear regression in which we compared the withheld reference sites to the predicted tree canopy cover values. Following validation, the withheld data were reincorporated into the training dataset and a separate random forest model was trained using the full reference dataset to produce the final tree canopy cover map.

Continuous tree canopy cover values were assigned to the map polygons classified as *forest* (*needleleaf*, *broadleaf*, or *mixed forest*) on the final vegetation type map. *Forest* was defined by the Cordova Existing Vegetation Classification Key as any area containing at least 10% total tree canopy cover when viewed from above, discounting over-topped trees. If a modeled continuous tree canopy cover value was less than 10% for a segment classified as forest, it was inflated to meet the minimum tree cover threshold that defines *forest* in the classification key. To generate acreage summaries and allow users to interpret tree canopy cover patterns at broader landscape-level scale, segments were assigned to one of three categories based on their numerical canopy cover value: 1) *Woodland (10–24%)*, 2) *Open (25–59%)*, and 3) *Closed (60–100%)*. These categories are consistent with previous mapping projects on Chugach National Forest (Bellante et al., 2013; Day et al., 2022) and maintain compatibly between those projects in order to generate a regionally cohesive map product for the Chugach National Forest in the future. The final products contain both a continuous and thematic attribute depicting tree canopy cover for the project area.

Tree Size

Thematic tree size was assigned to mapping polygons classified as *forest* on the final vegetation type map. Tree size is defined as the plurality diameter class forming the uppermost canopy layer when viewed from above, discounting over-topped trees. Tree diameter was measured at breast height (dbh), 4.5 feet above the root crown. A total of 757 reference sites from various sources were used to model tree size. Few samples were available for the small and large tree size classes, so sites were added to these classes using expert knowledge, topographic data, and image interpretation techniques. Given the limited sample size afforded these classes, the tree size product was validated with 10 samples (40 total) that were randomly withheld from each class. Although this is an insubstantial validation sample, it does provide some insight into the statistical accuracy and overall reliability of the tree size product. After the accuracy assessment, these withheld data were reinserted into the reference dataset and the model was rerun to generate the final map product. This ensured the best map of tree size was produced. Random forest was the classifier used to predict the four thematic tree size classes (*TS*) across the entire project area: 1) *TS1 Seedling/Sapling (0–4.9”dbh)*, 2) *TS2 Pole (5–8.9”dbh)*, 3) *TS3 Medium (9–20.9”dbh)*, 4) *TS4 Large (≥21”dbh),* and 5) *Non Tree*.

Tall Shrub Canopy Cover

Similar to tree canopy cover, tall shrub canopy cover was modeled continuously, from 0–100%, using random forest regression models. The initial random forest model for tall shrub canopy cover was trained and validated using 500 reference sites that were image interpreted, 450 of which were used for training and the other 50 were randomly selected and withheld from modeling for validation. The tall shrub canopy cover results were assessed using linear regression in which the withheld reference sites were compared to the predicted tree canopy cover values. Following validation, the withheld data were reincorporated into the training dataset and a separate random forest model was trained using the full reference dataset to produce the final tall shrub canopy cover map.

Continuous tall shrub canopy cover values were assigned to the map polygons classified as *tall shrub* (*Alder* or *Alder-Willow*) on the vegetation type map. *Tall shrub* was defined by the vegetation type key as any area containing at least 25% total shrub cover when viewed from above and is dominated by shrubs that are taller than 1.5 meters in height. In instances where tall shrub cover does not equal or exceed 25%, other shrubs may be present but are shorter than or equal to the 1.5 meter height threshold. To be consistent with other regional projects, tall shrub canopy cover values were inflated to 9% if a segment was classified as *tall shrub* and its modeled continuous tall shrub canopy cover value was less than 9% (Bellante et al., 2013; Day et al., 2022). This 9% threshold was selected because theoretically it is the lowest amount of canopy cover that *tall shrubs* could occupy in a segment while still being the predominate map group and being classified as *tall shrub*. For example, a segment could contain exactly 25% total shrub canopy cover while containing 9% *tall shrub*, 8% *low shrub*, and 8% *dwarf shrub*. After being modeled continuously, segments were assigned to one of three categories based on their numerical canopy cover value in order to generate acreage summaries and allow users to interpret tall shrub canopy cover patterns at broader, landscape level scales: 1) *Sparse (9–24%)*, 2) *Open (25–59%)*, and 3) *Closed (60–100%)*. These categories are also compatible with previous mapping projects on Chugach National Forest (Bellante et al., 2013; Day et al., 2022). The final products contain both a continuous and thematic attribute depicting tall shrub canopy cover for the project area.

Draft Map Review

After the initial models were reviewed and optimized by GTAC personnel, draft versions of the four map layers were created: 1) vegetation type, 2) tree canopy cover, 3) tree size, and 4) tall shrub canopy cover. These layers were provided to local and regional experts for review within a web application that provided a platform by which edits and feedback could be submitted. An additional review was conducted concurrently by GTAC personnel in which the project was systematically checked for classification errors using an overlaid grid with 10 km^2 cells that spanned the full extent of the project area.

Upon completion of the draft map review, all of the edits and comments were compiled and used by GTAC to revise the draft map products. Areas of misclassification were addressed by incorporating manual edits directly into the map including areas of known confusion, such as areas along shorelines or with persistent shadow. Following vegetation type edits, the vegetation masks were reapplied to the structure products if the lifeform of the segment changed due to a manual edit. For example, if a manual edit changed an *herbaceous* segment to a *tall shrub* segment, the vegetation mask would have been removed and the modeled output for tall shrub canopy cover was then reattributed back to the segment.

Results/Discussion

Vegetation Type

The final vegetation type map consisted of 22 land cover classes contained within eight map groups: six *needleleaf forest* types, one *broadleaf forest* type, one *mixed forest* type, two *tall shrub* types, one *low shrub* type, one *dwarf shrub* type, five *herbaceous* types, and five *non vegetated* types (table 4). *Forest* encompasses 43.43% of the vegetation in Cordova, while *shrub* covers 46.32% and *herbaceous* types cover 10.26% of the vegetated area. A full list of the vegetation type classes with their acreage is tabulated in table 4 and their spatial distributions across Cordova is depicted in figure 6. A large portion of the Cordova project area traverses the heavily glaciated Chugach Mountains, so the higher altitudes of Cordova consisted of large swaths of *Barren* rock and *Snow/Ice*. The landscape would transition to vegetated areas below the mountain peaks and receding glaciers, where *Ericaceous Dwarf Shrub* and *Mesic Herbaceous* species would start to colonize and become the predominate vegetation classes in the high-altitude areas. Vegetation would then typically transition to areas of *tall shrub* just above the tree line and in avalanche chutes. A matrix of *Dwarf Mountain Hemlock*, *tall shrubs,* and *herbaceous* classes would start to become prevalent below the tree line before mixes of *Hemlock* and *Hemlock-Sitka Spruce* began to dominate the lower mountain slopes. *Sitka Spruce* and *Black Cottonwood* would frequently occupy the upper canopies of the valley bottoms along the braided rivers in pure stands and in mixes (*Sitka Spruce-Black Cottonwood*) with different *tall shrub* and *herbaceous* classes occupying the canopy openings. Moving closer to the coastline, the vegetation composition was similar, but with *Wet Herbaceous*, *Sweetgale*, *Forested Peatlands,* and *Sedge Peatlands* becoming increasingly more dominant in the areas with relatively flat topography and poor drainage. This coastal influence was especially prevalent on Montague, Hinchinbrook, and Hawkins Islands.

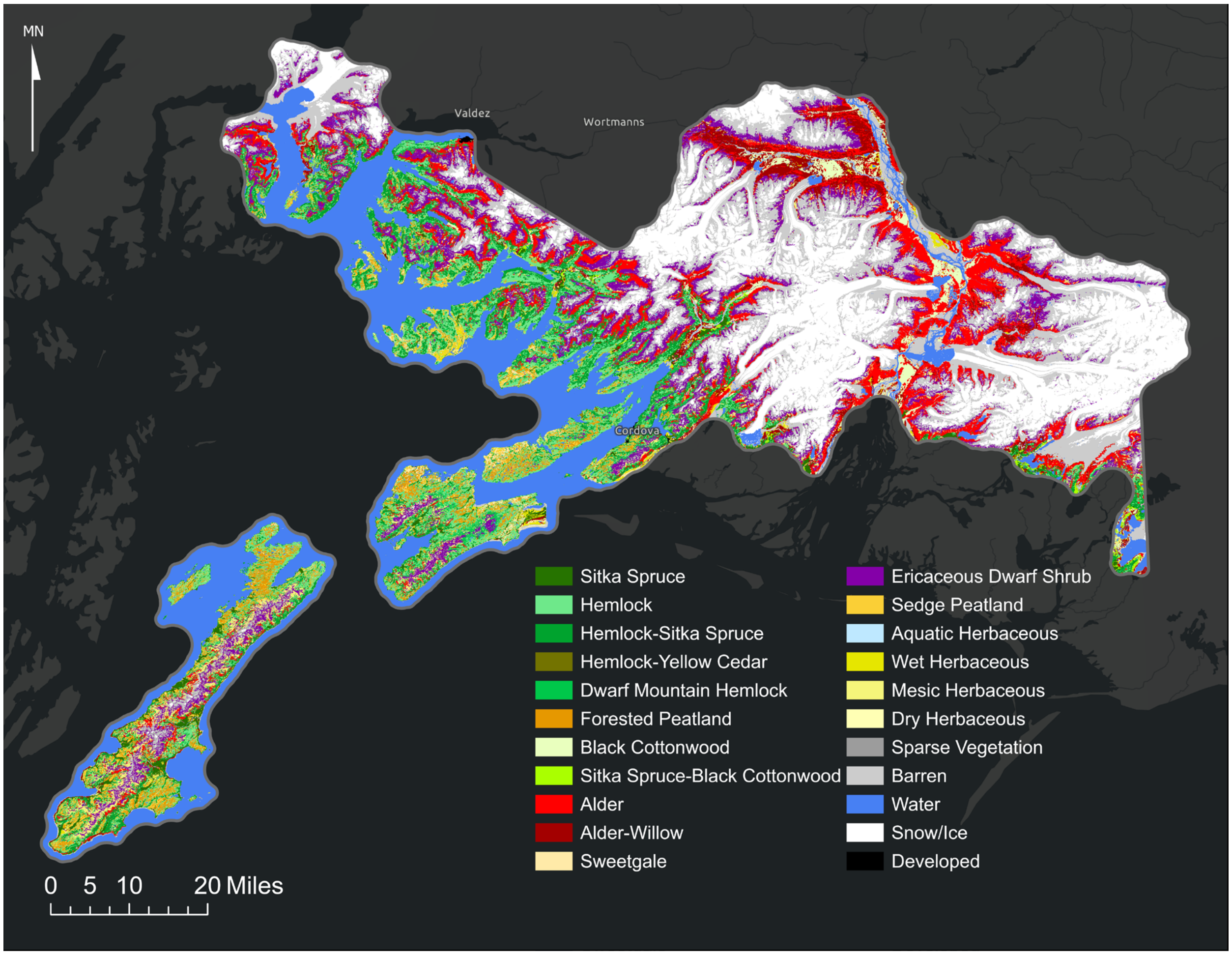

Figure 6.—Vegetation classes across the project area. Note, the legend is only applicable to the mapped project area and the space outside Cordova should not be considered Developed.

Table 4.— Map group and vegetation type acreage summary for the vegetation map.

Map Group	Vegetation Type	Acres	Percent of Study Area
Needleleaf Forest	Sitka Spruce	34,267	1.14%
	Hemlock	204,853	6.82%
	Hemlock-Sitka Spruce	151,643	5.05%
	Hemlock-Yellow Cedar	280	0.01%
	Dwarf Mountain Hemlock	66,538	2.22%
	Forested Peatland	67,467	2.25%
Broadleaf Forest	Black Cottonwood	34,025	1.13%
Mixed Forest	Sitka Spruce-Black Cottonwood	6,827	0.23%
Tall Shrub	Alder	248,552	8.28%
	Alder-Willow	83,124	2.77%
Low Shrub	Sweetgale	19,244	0.64%
Dwarf Shrub	Ericaceous Dwarf Shrub	252,663	8.41%
Herbaceous	Sedge Peatland	38,309	1.28%
	Aquatic Herbaceous	1,895	0.06%
	Wet Herbaceous	19,212	0.64%
	Mesic Herbaceous	71,091	2.37%
	Dry Herbaceous	3,278	0.11%
TOTAL VEGETATED AREA		**1,303,268**	**43.40%**
Non-Vegetated	Sparse Vegetation	52,729	1.76%
	Barren	490,423	16.33%
	Water	595,020	19.81%
	Snow/Ice	560,205	18.65%
	Developed	1,482	0.05%
TOTAL NON-VEGETATED AREA		**1,699,859**	**56.60%**

Tree Canopy Cover

The final tree canopy cover map was generated for all areas classified as *forest,* as defined by the Cordova Vegetation Type Classification Key (Appendix A), on the final vegetation type map (figure 7). Tree canopy cover was assessed as the total tree cover as viewed from above, discounting overtopped trees. Project-wide acreage summaries for each canopy cover class are provided in table 5. Note that the tree canopy cover map itself depicts continuous tree canopy cover values from 10 to 100%, so there is highly detailed information on the map that is not included in the thematic acreage summary provided below. All areas containing less than 10% tree canopy cover were not assigned a value because this was the threshold that distinguished *forest* classes from other vegetation types.

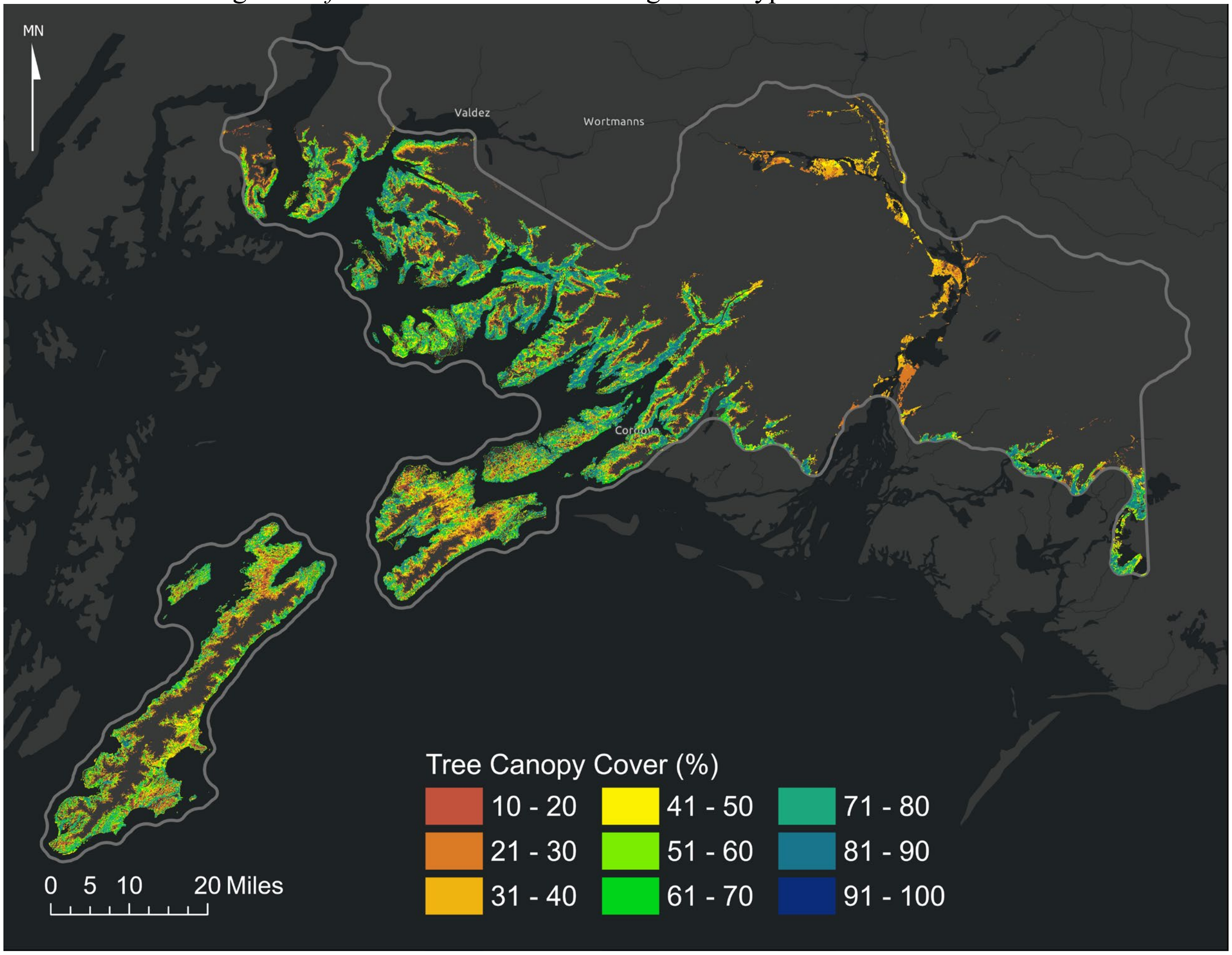

Figure 7.— Tree canopy cover across Cordova.

Table 5.—Tree canopy cover acreage summary.

Tree Canopy Cover Class	Area (ac)	% Forest Area
Closed (60 - 100%)	272,881	48.91%
Open (25 - 59%)	239,951	42.23%
Woodland (10 - 24%)	53,068	8.86%
Total	565,900	100%

Tree Size

The final tree size map for Cordova was generated for all areas classified as *forest* on the final vegetation type map (figure 8). Tree size class was determined as the diameter class containing the plurality of cover within a given area or mapping polygon. Plurality of cover is determined by comparing the areal tree cover of individual diameter classes when viewed from above – discounting overtopped trees. For example, smaller trees that were overtopped by larger trees were ignored and not counted in the diameter class estimate. Acreage summaries of the tree size classes are provided in table 7.

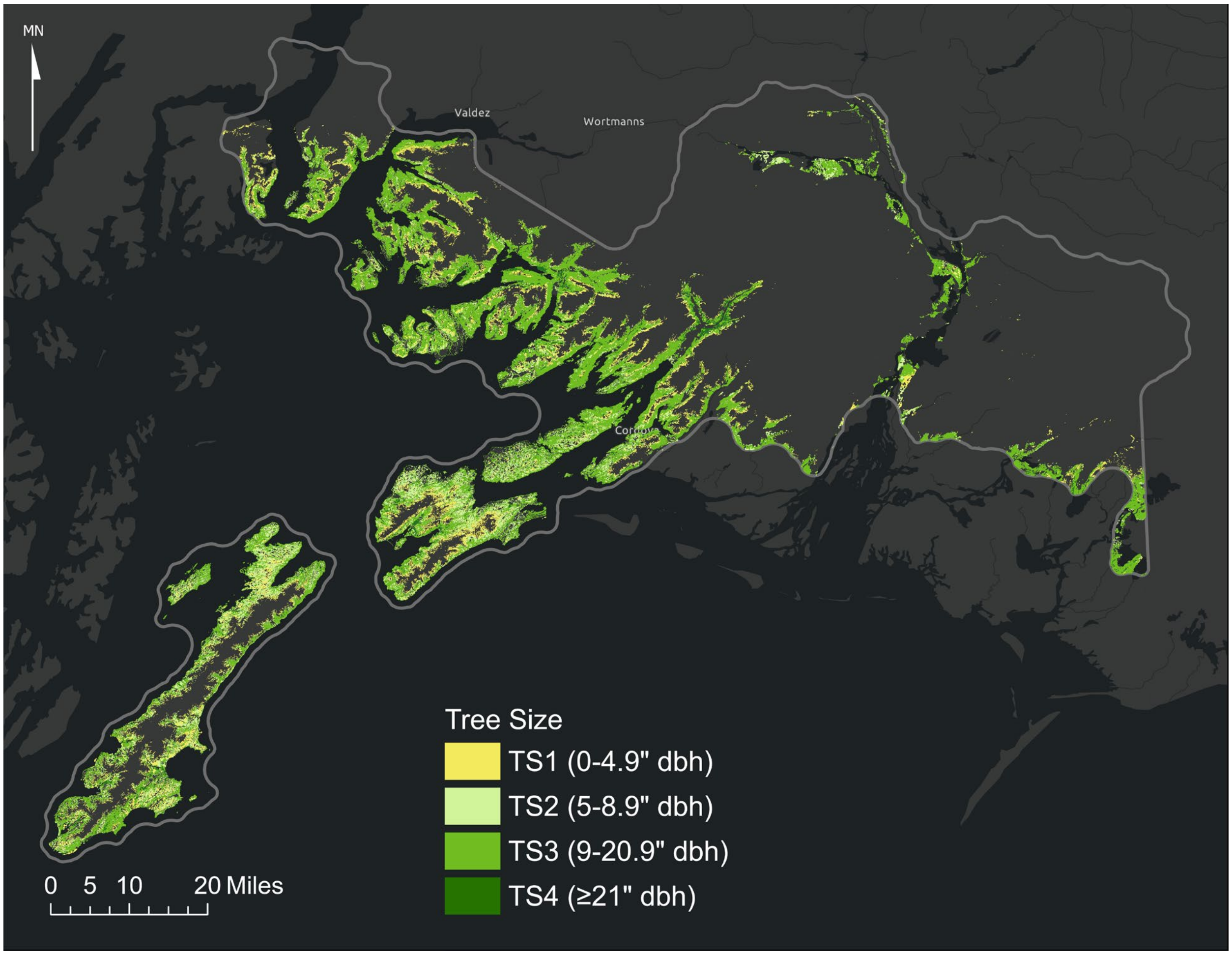

Figure 8.—Tree size across Cordova.

Table 6.—Tree size acreage summary.

Tree Size Class	Area (acres)	% Forest Area
TS1 (0-4.9” dbh)	89,905	15.89%
TS2 (5-8.9” dbh)	109,981	19.43%
TS3 (9-20.9” dbh)	348,849	61.65%
TS4 (≥21” dbh)	17,164	3.03%
Total	565,900	100.00%

Tall Shrub Canopy Cover

Tall shrub canopy cover was produced to depict the cover of tall shrubs greater than 1.5 meters in height. These areas were classified as *tall shrub*, as defined by the Cordova Vegetation Type Classification Key (Appendix A) and includes 2 vegetation types – *Alder* and *Alder-Willow*. This product illustrates continuous *tall shrub* canopy cover with values ranging from 9 to 100% (figure 9). *Tall shrub* was defined as any area with at least 25% total shrub cover and is dominated by shrubs that are taller than 1.5 meters in height. Note that this map does not include canopy cover for areas mapped as *low* or *dwarf shrub*. Table 7 provides an acreage summary for the thematic canopy cover categories. It is worth noting that because of the fine-level of discernment required to distinguish *tall*- from *low*- or *dwarf*- shrubs, we acknowledge this product is reaching the limits of what the data are capable of providing given the resolution and age of the data.

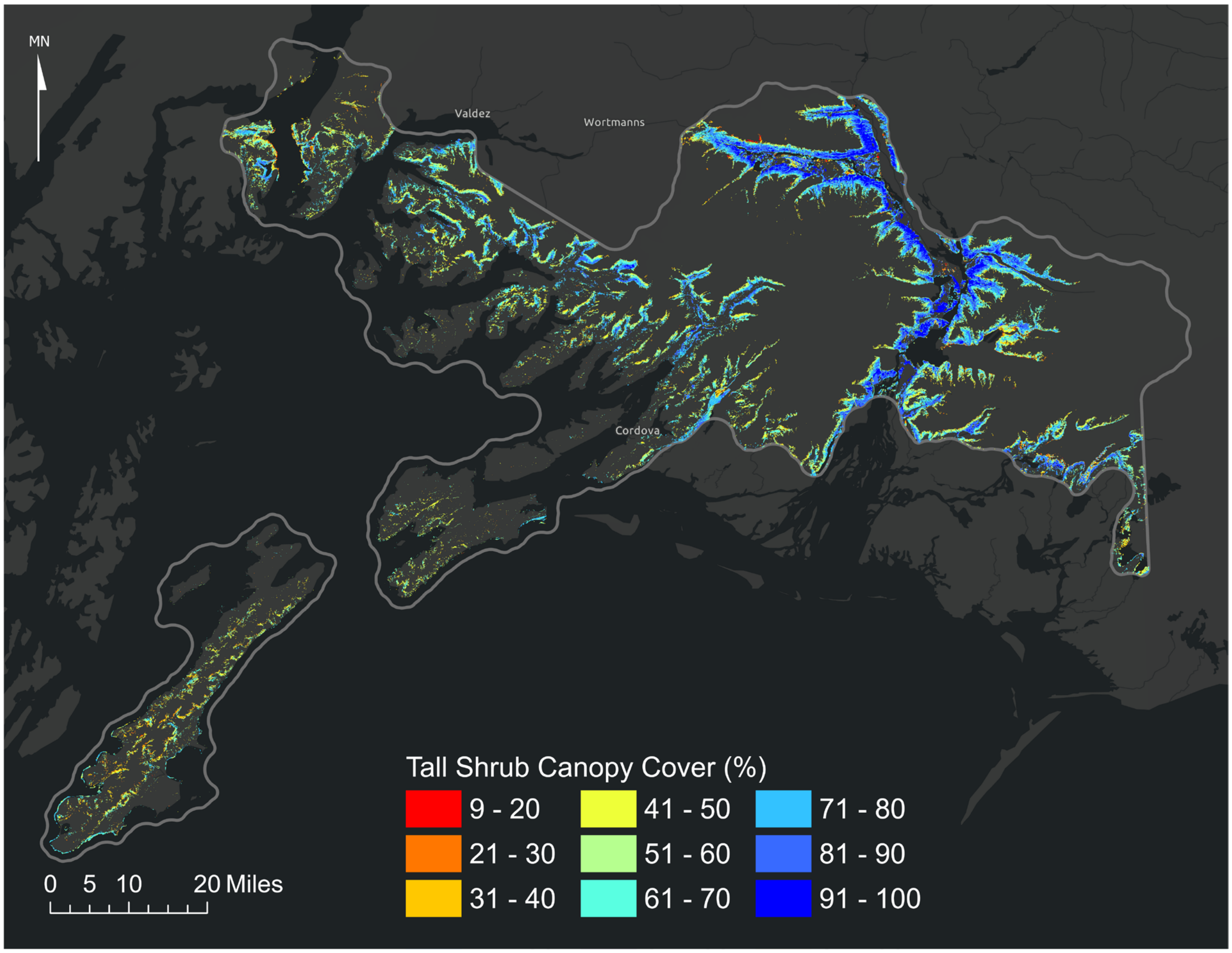

Figure 9.— Tall shrub canopy cover across Cordova.

Table 7.— Tall shrub canopy cover acreage summary.

Tall Shrub Canopy Cover Class	Area (acres)	% Tall Shrub Area
Closed (60 - 100%)	217,737	65.65%
Open (25 - 59%)	111,312	33.56%
Sparse (9 - 24%)	2,628	0.79%
Total	331,677	100%

Accuracy Assessment

Accuracy assessments were conducted to validate the final map products and reveal details of individual class confusion. The fundamental modeling units for this project were the segments (mapping polygons), therefore that is the unit by which the map was evaluated. The accuracy assessments for vegetation type, tree canopy cover, and tall shrub canopy cover were conducted using purely image interpreted reference data, and the accuracy assessment for tree size used a combination of image interpreted and ground collected data. Each method was chosen to best leverage the data available for each product while producing the most accurate models possible. There are strengths and weaknesses to using image interpreted data versus ground data. However, in some cases we could not withhold field data from the models, and both methodologies can provide information on the utility of the final map products. Although image interpretation was difficult in some circumstances, it allowed for a statistically robust and impartial assessment of the existing vegetation types. All validation information was collected blindly, and no map products were available to image interpreters or field crews participating in order to limit human bias and keep this validation independent.

Vegetation Type

Accuracy assessments for vegetation type and their corresponding map group were conducted using image interpreted reference data. To collect sites for interpretation, a stratified random sample was performed on the vegetation draft map and a total of 660 sites were selected. For each vegetation type, 30 sites were targeted for sampling; however, the stratification did not guarantee a balanced sample because sites were selected from a draft version of the map which was edited further before being finalized. This approach, although justified given the resource limitations common to most accuracy assessments, inherently biases the sample because it is based on the mapped extent of each class, relying indirectly on the user's accuracy and errors of commission of the draft map. Although impossible to quantify without a truly random sample, it is acknowledged that the accuracy assessment was impacted. Errors of omission and the producer's accuracy is disproportionately impacted since a statistical sample could not be obtained. Without this approach, the assessment would preclude the analysis of rarer classes without an unreasonably large sample size.

Validation sites were assessed via image interpretation by two independent interpreters, one from GTAC and another from the Chugach National Forest. During the validation process, interpreters were asked to assign a primary call on the vegetation type for each site. Determining a vegetation type could be difficult for some of the sites especially when the vegetation cover approached the thresholds that distinguish one class from another. To address this issue, interpreters could also assign a secondary call, if necessary, when the vegetation type was more ambiguous. The use of primary and secondary calls during image interpretation allowed us to use two separate methods to assess the accuracy of the vegetation map. The first method contrasted the modeled vegetation classes of the 660 sites against the primary calls of the two interpreters. In this assessment, a site was considered correctly classified if its modeled class matched *either of the interpreter's primary calls*. If neither of the primary calls matched the modeled mapped class, it looked to see if there was a majority between the two primary calls to show which vegetation classes were getting confused in the confusion matrix. If a majority did not exist, the assessment took the primary call of the GTAC interpreter for the confusion matrix (Appendix B). The second method used the secondary call in conjunction with the primary call designation to produce an additional 'fuzzed' assessment, where both the primary and secondary calls were considered correct i.e., a site considered correctly classified if its modeled class matched *any of the interpreter's primary or secondary calls.* If neither of the primary or secondary calls matched the mapped class, it looked to see if there was a majority between the primary and secondary calls for the confusion matrix. If a majority did not exist between calls, the assessment used the primary call of the GTAC interpreter to show which vegetation classes were getting confused. The fuzzed assessment allows the interpreters to acknowledge the variability of putting discrete labels on a continuous landscape. By accounting for the ambiguity that might exist within a segment and allowing secondary calls to also designate whether a site was classified correctly, it inherently inflates the accuracy in the fuzzed assessment because it allows more chances for the mapped classes to match the image interpreted reference data.

Overall accuracy for the final vegetation dominance type map was 71% using primary calls (Appendix B) and 81% using the fuzzed assessment (Appendix C). Between the two interpreters, there was a 59% agreement for their primary calls and a 37% agreement when both interpreters gave a secondary call (table 8). Again, secondary calls were optional, and the interpreters were not required to assign a secondary call for every site. The primary calls from the GTAC interpreter matched the mapped classes 63% of the time (417/660), and the primary calls from the Chugach National Forest interpreter matched the mapped classes 49% of the time (325/660). Of the sites in which the primary call of the GTAC interpreter did not match the mapped class (n = 243), there were 51 sites where the Chugach National Forest interpreter's primary call matched the mapped class which inflated the accuracy ~8% from the GTAC interpreter's primary calls to reach the reported overall accuracy of 71% (Appendix B). The reverse would be also true given that we considered either of the primary calls correct. Of the sites in which the primary call of the Chugach National Forest interpreter's primary call did not match the mapped class (335/660), there were 143 sites where the GTAC interpreter's primary calls matched the mapped class which in turn increased the accuracy ~22% from the Chugach National Forest interpreter's primary calls to reach the reported overall accuracy for primary calls, 71%. Theses discrepancies between interpreters demonstrate the previously mentioned ambiguity that can arise when discrete labels are assigned on a continuous landscape. This also emphasizes the importance of not solely relying on the individual accuracy of each class, but rather being able to utilize the confusion matrix to extract additional information and gain a deeper understanding of how the classes are interacting on the map (Appendix B).

Table 8.— Comparison between Image Interpreters.

Image Interpreter Comparison	GTAC Interpreter	Chugach National Forest Interpreter
Primary Calls (n)	660	660
Primary Call Agreement (%)	59% (389/660)	59% (389/660)
Secondary Calls (n)	343	169
Sites w/ a Single Secondary Call (n)	232	58
Sites w/ Two Secondary Calls (n)	111	111
Secondary Call Agreement (%)	37% (41/111)	37% (41/111)

A total of 21 vegetation type classes were evaluated in the accuracy assessment. The *Hemlock-Yellow Cedar* class was the only class not included in the accuracy assessment because it had a limited extent and was manually added to the map based on known locations. There was a total of eight lifeform map groups that were modeled for vegetation type: *Needleleaf Forest, Broadleaf Forest, Mixed Forest, Tall Shrub, Low Shrub, Dwarf Shrub, Herbaceous,* and *Non-Vegetated.* Using the primary calls from the image interpreted reference data, the accuracy assessment showed that there was an overall accuracy of 84% for the map group-level. Additional area-weighted overall accuracies were calculated for both vegetation type and map group. The area-weighted overall accuracy takes into account the relative proportion that each class occupies on the landscape. For vegetation type, the area-weighted overall accuracy was 83% for primary calls and 90% for the fuzzed assessment. Map group-levels achieved an area-weighted overall accuracy of 92% (table 9).

Table 9.— Error matrix of the Cordova Existing Vegetation Map at the map group-level.

Map Group Accuracy Assessment		Reference Data								User's Accuracy	Commission Error
		Needleleaf Forest	Broadleaf Forest	Mixed Forest	Tall Shrub	Low Shrub	Dwarf Shrub	Herba-ceous	Non-Vegetated		
Map Data	Needleleaf Forest	151	0	1	1	0	0	0	0	99%	1%
Map Data	Broadleaf Forest	0	28	0	3	0	0	0	0	90%	10%
Map Data	Mixed Forest	1	6	23	0	0	0	0	0	77%	23%
Map Data	Tall Shrub	5	0	1	78	0	1	2	2	88%	12%
Map Data	Low Shrub	4	0	0	1	17	0	6	0	61%	39%
Map Data	Dwarf Shrub	1	0	0	1	0	24	2	2	80%	20%
Map Data	Herbaceous	14	0	0	16	0	14	84	11	60%	40%
Map Data	Non-Vegetated	3	0	0	4	0	0	1	152	95%	5%
Producer's Accuracy		84%	82%	92%	75%	100%	62%	88%	91%	Kappa	0.81
Omission Error		16%	18%	8%	25%	0%	38%	12%	9%	Overall Accuracy	84%
										Area-Weighted Accuracy	92%

Tree Canopy Cover

To validate the tree canopy cover map, 50 image interpreted tree canopy cover reference sites were randomly selected and withheld to validate the model predictions. We assessed tree canopy cover results using linear regression and compared the image interpreted values to the predicted tree canopy cover values. Image interpretations of continuous canopy cover relied on the Chugach National Forest Resource imagery and Maxar imagery. The final continuous canopy cover values used in the validation were the average of the estimates made by multiple interpreters. Moderate agreement was observed between the independent and dependent variables ($n = 50$, $R^2 = 0.62$), meaning that the predicted tree canopy cover values captured much of the observed variation. The scatter plot containing the modeled versus predicted continuous tree canopy cover values can be seen in figure 10.

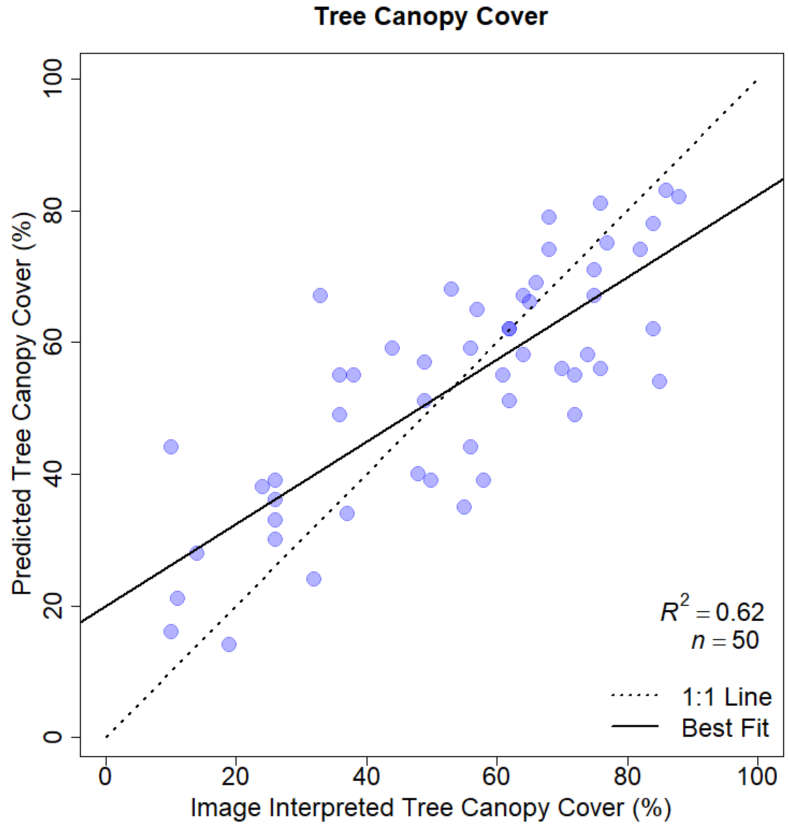

Figure 10.— Scatterplot (blue dots) of image interpreted tree canopy cover percent values (x-axis) vs. predicted tree canopy cover percent values (y-axis).

Tree Size

Thematic tree size was validated using reference data that contained a combination of image interpreted and ground data. Prior to modeling, a total of 40 sites (10 per class) were randomly selected and withheld from modeling. The accuracy assessment for tree size showed an overall accuracy of 78% and an area-weighted overall accuracy of 71% (table 10).

Table 10.—Error matrix for thematic tree size.

Tree Size Class		Reference Data				User's Accuracy	Commission Error
		TS1 (0-4.9" dbh)	TS2 (5-8.9" dbh)	TS3 (9-20.9" dbh)	TS4 (≥21" dbh)		
Map Data	TS1 (0-4.9" dbh)	9	1	0	0	90%	10%
	TS2 (5-8.9" dbh)	0	7	0	0	100%	0%
	TS3 (9-20.9" dbh)	1	2	10	5	56%	44%
	TS4 (≥21" dbh)	0	0	0	5	100%	0%
Producer's Accuracy		90%	70%	100%	50%	Kappa	0.7
Omission Error		10%	30%	0%	50%	Overall Accuracy	78%
						Area-Weighted Accuracy	71%

Tall Shrub Canopy Cover

Similar to tree canopy cover, tall shrub canopy cover was validated using 50 image interpreted sites that were randomly selected and withheld from modeling. To assess the accuracy of tall shrub canopy cover, we used linear regression and compared the image interpreted values to the predicted tall shrub canopy cover values. The interpretations of tall shrub canopy cover relied on the high-resolution imagery datasets, the Resource imagery and Maxar imagery. Moderate agreement was observed between the independent and dependent variables ($n = 50$, $R^2 = 0.74$), meaning that the predicted tall shrub canopy cover values captured much of the observed variation. The scatter plot containing the modeled versus predicted continuous tall shrub canopy cover values can be seen in figure 11.

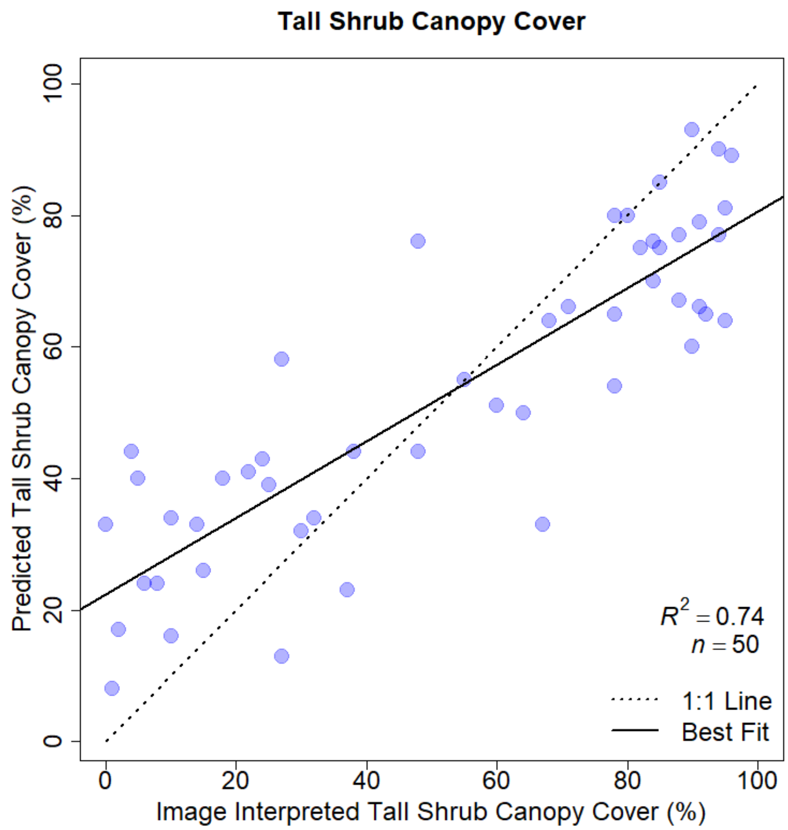

Figure 11.— Scatterplot (blue dots) of image interpreted tall shrub canopy cover percent values (x-axis) vs. predicted tall shrub canopy cover percent values (y-axis).

Accuracy Assessment Discussion

Overall accuracy is the most comprehensive statistic when it comes to understanding the underlying reliability of a map product. It is calculated by taking the proportion of sites classified correctly divided by the total number of sites assessed for each product. Numerous factors impact classification accuracy, including: 1) classification complexity; 2) landscape complexity; and 3) quality of the data that is available. Map accuracy has an inverse relationship with classification complexity, meaning that the more classes you have the less accurate your classification output will be. Considering this, the overall vegetation type class accuracy was 71% (Appendix B). This level of accuracy is consistent with results from other mid-level vegetation mapping projects and is reasonable since the final map depicts 22 unique vegetation types. The compilation of the various vegetation structure outputs for each of the different modeling scenarios resulted in seamless data products that depicted vegetation structure patterns across the Cordova project area. Even though localized structure model accuracy may vary depending on the source data used, the overall pattern of tree canopy cover, tree size, and tall shrub canopy cover was captured effectively.

Individual class accuracies were computed for each of the map products. There are two ways to analyze individual class accuracy: 1) producer's accuracy, which is the proportion of sites correctly mapped for that class to the total number of sites of that class as determined by the reference data (i.e., the column total); and 2) user's accuracy, which is the proportion of sites correctly mapped for that class to the total number of sites assigned that particular class (i.e., the row total) (Congalton, 1991). Producer's accuracy provides a measure of omission error that describes the probability that an area on the ground is mapped correctly. However, because the accuracy assessment was conducted using reference sites that were selected from a stratification of the draft map, the producer's accuracy or rate of omission may be biased. User's accuracy provides a measure of commission error that describes the probability that a mapped class actually represents what is on the ground. For example, *Hemlock-Sitka Spruce* had a producer's accuracy of 63%, but had a user's accuracy of 90%. This indicates that this class was under-mapped because of the relatively high omission error. Most of the *Hemlock-Sitka Spruce* confusion came at the expense of two other *Needleleaf Forest* classes – *Sitka Spruce* and *Hemlock* (Appendix C). This type of confusion is intuitive since *Hemlock-Sitka Spruce* is a matrixed class of the two other classes. This illustrates how studying the error matrices can provide insight not only into the reliability of an individual map class, but also into how and where confusion occurs. This type of confusion between various *Needleleaf Forest* types comprised of similar species (such as *Sika Spruce*, *Hemlock*, and *Hemlock-Sitka Spruce* types) indicates a lower error severity as compared to confusion between different lifeforms, such as *Needleleaf Forest* with *Dwarf Shrub* types.

Calculating an area-weighted accuracy that takes into account the relative proportion, or abundance, of the mapped classes provides a more representative measure of overall map quality. The assessment discussed in the previous paragraph utilized a sample that was either stratified, in order to adequately sample each cover type, or in the case of ground data, are biased by accessibility. Consequently, the distribution of assessment sites did not correspond to the relative proportions of the cover types found across the project area. This means that overall accuracy could be disproportionately influenced by rarer classes or by classes more easily accessed. To account for this, overall area-weighted accuracies were calculated by taking the proportion of correctly classified accuracy assessment sites for each class (the individual class user's accuracies) and multiplying them by the proportion of the total area that the class occupies on the final map (the area weight factor) and summating across every mapped class. Although the true relative abundance of each class across the mapped area cannot be known, the user's accuracy is the best proxy to estimate the distributions of the various classes. Both overall accuracy measures were reported since the area-weighted measure is going to be comparatively inflated since the most common classes are usually modeled more accurately and don't necessarily contain vegetation, such as *water* and *snow/ice*. For example, the overall area-weighted accuracy was 71% at the vegetation type-level using primary calls and 84% at the map group-level, as opposed to 83% and 92%, respectively (Appendix C and table 9).

When studying the error matrices, even classes with relatively low accuracies may still provide important spatial information regarding vegetation assemblages of interest. Correct interpretation of the error matrices allows a user to apply expert knowledge of known plant associations in order to discriminate between errors caused by completely erroneous model associations and those that were logical confusions. For example, if a site was misclassified as *Mesic Herbaceous* when in the field it was *Ericaceous Dwarf Shrub, it* does not mean that the site does not contain mesic herbaceous species. Local ecology informs us that in the upper elevations of Cordova, these two classes are both prevalent and areas of *Ericaceous Dwarf Shrub* are likely intermixed with herbaceous species and vice versa. Therefore, depending on the user's needs, there may be valuable information contained within those classes that have low accuracy, but it does require some interpretation of the confusion matrix. Such confusion is common when discrete decision rules are applied to a continuous landscape. Interpretations from the accuracy information and knowledge of the landscape may be necessary to tease out more meaningful information and gain a comprehensive understanding of class relationships, since individual class accuracy numbers do not tell the whole story when taken by themselves.

Conclusion

Existing vegetation was mapped through a partnership with the Chugach National Forest, Alaska Regional Office (Region 10), Ducks Unlimited, and the Geospatial Applications and Technology Center (GTAC). The final map comprises four distinct, inter-related feature layers: 1) vegetation type; 2) tree canopy cover; 3) tree size; and 4) tall shrub canopy cover. The vegetation type map consists of a total of 22 classes, including 17 vegetation classes and five classes encompassing other land cover types. Continuous tree canopy cover and thematic tree diameter class categories were generated for areas classified as *forest*. Tall shrub canopy cover was also modeled continuously and then subsequently binned for acreage summaries. This map was designed to be consistent with the standards established in the Existing Vegetation Classification and Technical Guide (Nelson et al., 2015) and to provide baseline information to support project planning and management in the Cordova Ranger District. The final Cordova existing vegetation map products provide a spatial depiction of vegetation floristics and structure in 2021. These products can be used in numerous ways to assist resource specialists and land managers. Existing vegetation maps can inform further project-level investigations, timber management, fire behavior, wildlife habitat modeling, and provide region-wide estimations of resource availability and status. This project was made possible through a collaborative team effort that took dedicated work over a span of several years. Different mapping methods were employed based on the available data, desired map classes, and mapping objectives. These methods utilized the best available science and will inform future mapping efforts to make regionally consistent maps across coastal Alaska.

This project used an image object-oriented approach, and therefore, relied on a semi-automated segmentation process to develop the mapping polygons to be used as the fundamental modeling units. Predictor data including remotely sensed imagery, topographic data, and climate information were summarized as zonal statistics to these segments. Subsequently, reference data collected in the field or image interpreted were intersected with the corresponding segments to extract associated statistics and to produce the predictive classification models. Random forest, a data mining technique, was used to assign land cover and vegetation structure attributes and produce the final map products. Most of the reference information was collected during the growing season of 2021 and consequently the maps are considered to be indicative of the existing vegetation conditions found in Cordova during the summer of 2021.

Although this map achieved relatively high accuracies, there were data limitations and other factors that made this project challenging. Low sun angles found in northern latitudes increase shadows and limit the amount of light energy reflected by earth objects for detection by remote sensing instruments. The climate of Southcentral Alaska makes obtaining cloud-free imagery difficult, especially when data acquisition has seasonal constraints and imaging sensors have infrequent revisit schedules. Despite these challenges, disparate data sources were strategically utilized to best leverage the available data and achieve high-resolution products. Overall accuracies, which evaluated each mapped class with all the available validation data regardless of extent on the landscape, showed that map group and vegetation type were mapped with 84% and 71% accuracy when only using primary calls. The fuzzed assessment for vegetation type showed an overall accuracy of 81%. The accuracy assessment for thematic tree size showed that it was mapped with a 78% overall accuracy. Overall area-weighted accuracy, which accounts for the extent of each class on the final map and weights them proportionally, was estimated to be 92% for map group, 83% for vegetation type when using primary calls, 90% for the fuzzed assessment, and 71% for tree size. Lastly, the canopy cover products showed strong agreement between modeled values and the image interpreted reference data as the R^2 values for tree and tall shrub canopy cover were 0.62 and 0.74, respectively. Collectively, these accuracies show that final existing vegetation map products effectively capture the vegetation and forest composition patterns across Cordova of the Chugach National Forest.

For more information please refer to the Alaska Region, Managing the Land, Resource Management, Plant Sciences and Ecology website for links to the Cordova Vegetation Mapping ArcGIS StoryMap.

This StoryMap contains interactive map applications, descriptions of the project, and links that enable the user to download associated project data. Downloadable data includes: the classification key, reference data, and final map products.

Currently, more mapping projects are being conducted within coastal Alaska. Ongoing projects include mapping existing vegetation for the Ketchikan-Misty Fjords Ranger District on the Tongass National Forest and the Glacier Ranger District on the Chugach National Forest. The Alaska Regional office is working with the individual National Forests and other land management agency partners to coordinate these mapping efforts. This collaboration is critical to the identification of project objectives and designing strategies for achieving those objectives, which are necessary steps to adequately map these ecologically important areas.

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Appendix A: Cordova Vegetation Type Classification Key

Vegetation Type Key:

1a. Total Tree cover 10-100% ....**Forest Type Key**

1b. Tree cover less than 10% 2

2a. At least 25 percent cover is erect to decumbent shrubs ……………….…….………….....……….3

3a. shrubs taller than 1.5 m (5 ft) are most abundant ……………..……………....**Tall Shrub Key**

3b. shrubs 20 cm (8 in) to 1.5 m in height are most abundant ..…………….……**Low Shrub Key**

3c. shrubs <20cm are most abundant ………………...………...……………...**Dwarf Shrub Key**

2b. Herbaceous vegetation at least 25% ……………………………….....…..................**Herbaceous Key**

2c. Herbaceous vegetation less than 25% ………..**Non-vascular/Non-vegetated/Sparse Vegetation Key**

(After selection, go to indicated Key)

Forest Type Key

1a.At least 75% of the total tree cover present is needleleaf ……………….…….…..**Needleleaf Forest Key**

1b. At least 75% of total tree cover broadleaf ……………………………….....……..….**Broadleaf Forest**

……………………………………………………….……….………...…**Black Cottonwood**

1c. Not as above …………………….……….………………….....**Mixed Broadleaf – Needleleaf Forest**

……………………………………………………......……**Sitka Spruce – Black Cottonwood**

Needleleaf Forest Key (At least 75% of the total tree cover present is needleleaf)

1a. Saturated peatlands with stunted trees. Wetland indicators include sphagnum peat, wetland sedges, tufted clubrush, cottongrass, bog rosemary (*Andromeda polifolia*), bog cranberry (*Vaccinium oxycoccus*) or sundew (*Drosera* spp.) tree canopy cover usually 10-35% ….…………….………....…..….. **Forested Peatland**

1b. Non-wetland …………….………...…………………………….……….….…….……………...2

2a. Total tree cover is at least 15% hemlock (mountain or western) ……...…….….….………...…...…...3

3a. At least 15% of total tree cover is spruce ….……………….......…...…**Hemlock – Sitka Spruce**

3b At least 15% of total tree cover is Yellow Cedar ………………….… **Hemlock – Yellow Cedar**

3c. Less than 15% total tree cover is Yellow Cedar or Sitka spruce, trees not Krumholtz ……………………………………….…....……….....……….….……………...**Hemlock**

3d. Dominant tree cover is dwarf mountain hemlock (usually upper elevation with krumholtz growth form), not wetland.…………...**Dwarf Mountain Hemlock**

2b. Total tree cover is less than 15% hemlock and At least 15% total tree cover is Sitka spruce …………………………………………………………….....……………...…………...**Sitka Spruce**

2c. Not as above ……………………………………………...…………………………**Other Conifer** (describe in notes)

Tall Shrub Key (shrubs taller than 5 ft (1.5 m) are most abundant)

1a. Alder and willow combined cover greater than 50% total shrub cover ……………..…..……….2

2a. Alder with greater than 75% of the combined cover of alder and willow …….………………………………………………………………………………..…**Alder**

2b. Willow with greater than 75% of the combined cover of alder and willow....….……………………………………….………………………..**Tall Willow**

3c. Neither alder nor willow make up 75% ....**Alder - Willow**

1b. (Not as above) Other tall shrubs (e.g., Mt. ash, Malus, Elderberry, Salmonberry, etc.) ……………………………………………………...…………………..…..…….**Other Tall Shrub (describe in notes)**

Low Shrub Key (shrubs 8 in (20 cm) to 1.5 m in height are most abundant)

1a. At least 15% Sweet gale…..……..…..…………………………….………………….**Sweetgale**

1b. At least 15% Willow …..…………………………………………………….……**Low Willow**

1c. At least 15% Copperbush.…………………..…………………………………..……**Copperbush**

1d. At least 15% Salmonberry....……………………………………….……………..**Salmonberry**

3b. Not as above ……………………..………………….................……….**Other Low Shrub (describe in notes)**

Dwarf Shrub Key

1a. At least 25% lichen, not wetland …………………………………….….…. **Dwarf Shrub / Lichen**

1b. Ericaceous dwarf shrubs or crowberry dominant……………………………………………………………..…………………...……2

2a. Wetland sites with sphagnum, sedges, or deer cabbage; other indicators may include bog rosemary (*Andromeda polifolia*), bog cranberry (*Vaccinium oxycoccus*) and sundew (*Drosera* spp.) ……………………………………..….... **Dwarf Shrub / Sedge peatland**

2b. Mesic sites, not peatlands…………………..……………....**Ericaceous Dwarf Shrub**

1c. Dwarf willow dominant; less than 25% lichen ……………………….…...**Willow Dwarf Shrub**

Herbaceous Key (Herbaceous vegetation at least 25% and shrub cover is less than 25%)

1a. Emergent or terrestrial herbaceous vegetation cover at least 25% …………..…......................2

2a. Dry soils (beach rye, fescue, hairgrass) …………………………..….**Dry Herbaceous**

2b. Moderate moisture (bluejoint, fireweed, umbels, mixed forb)…………………………………………………………………**Mesic Herbaceous**

2c. Wet sites often with standing water (marsh, rich fen, sedges, cottongrass, water often present)….……………………….………………………….....…**Wet Herbaceous**

2d. Saturated peatlands with wetland sedges, tufted clubrush, or cottongrass. Other indicators may include bog rosemary (*Andromeda polifolia*), bog cranberry (*Vaccinium oxycoccus*) and sundew (*Drosera* spp.)…………………………………………………………………………...**<u>Sedge Peatland</u>**

1b. Emergent or terrestrial herbaceous vegetation cover less than 25%. Dominant vegetation growing submerged in water or floating on the water surface……………………………………………………………………….**<u>Aquatic Herbaceous</u>**

Non-Vascular/Non-Vegetated/Sparse Vegetation Types (Herbaceous vascular vegetation is less than 25%)

1a. Lichen cover greater than 25% ....**<u>Lichen</u>**

1b. Area is currently developed for urban, residential, administrative use.……………..…**<u>Developed</u>**

1c. Area is dominated by open water or a confined watercourse……………………..…..….**<u>Water</u>**

1b. Vegetation cover 10-25%...**<u>Sparse vegetation</u>**

1d. Less than 10% vascular vegetation….……………………………………………………..**<u>Barren</u>**

Tree Canopy Cover Class Key

1a. Total tree cover at least 10 percent, but less than 25% ....**<u>Woodland (10-24%)</u>**

1b. Total tree cover greater than or equal to 25% but less than 60% ……….....…**<u>Open (25-59%)</u>**

1c. Total tree cover is at least 60 percent …………………...………………..…....**<u>Closed (60-100%)</u>**

Tree Size Class Key

TS1 (0 - 4.9" dbh)
TS2 (5 - 8.9" dbh)
TS3 (9 - 20.9" dbh)
TS4 (≥21" dbh)
NT Non Tree

Tall Shrub Canopy Cover Class Key

1a. Total tall shrub cover at least 9 percent, but less than 25% ....**<u>Sparse (9-24%)</u>**

1b. Total tall shrub cover greater than or equal to 25% but less than 60%..**<u>Open (25-59%)</u>**

1c. Total tall shrub cover is at least 60 percent……………………..................**<u>Closed (60-100%)</u>**

Appendix B: Cordova Vegetation Type Error Matrix (Primary Calls)

Primary Call Accuracy Assessment		Reference Data																					User's Accuracy	Commission Error
		SS	H	H-SS	DMH	FP	BC	SS-BC	A	A-W	SG	EDS	SP	AHB	WHB	MHB	DHB	SV	BR	WA	S/I	DEV		
Map Data	SS	**18**	1	7	0	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	58%	42%
	H	1	**21**	6	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	68%	32%
	H-SS	0	3	**26**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90%	10%
	DMH	2	4	1	**20**	2	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	65%	35%
	FP	0	0	0	0	**31**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100%	0%
	BC	0	0	0	0	0	**28**	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	90%	10%
	SS-BC	1	0	0	0	0	6	**23**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	77%	23%
	A	0	1	0	4	0	0	0	**44**	5	0	1	0	0	0	2	0	1	0	0	0	0	76%	24%
	A-W	0	0	0	0	0	0	1	16	**12**	0	1	0	0	0	0	0	0	0	1	0	0	39%	61%
	SG	0	0	0	0	4	0	0	0	1	**17**	0	5	0	1	0	0	0	0	0	0	0	61%	39%
	EDS	0	0	0	1	0	0	0	1	0	0	**24**	0	0	0	2	0	1	0	0	1	0	80%	20%
	SP	0	0	0	0	9	0	0	0	0	1	0	**20**	0	0	0	0	0	0	0	0	0	67%	33%
	AHB	1	0	0	0	0	0	0	0	1	0	0	0	**15**	2	1	0	0	0	1	0	0	71%	29%
	WHB	1	0	0	0	0	0	0	2	1	0	0	0	1	**16**	0	1	6	1	0	0	0	55%	45%
	MHB	0	0	0	2	0	0	0	2	0	0	14	1	0	0	**10**	0	2	0	0	0	0	32%	68%
	DHB	1	0	0	0	0	0	0	4	6	0	0	0	0	0	2	**14**	1	0	0	0	0	50%	50%
	SV	0	0	0	0	0	0	0	1	0	0	7	0	0	0	1	0	**14**	5	1	4	0	42%	58%
	BR	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	**27**	0	3	0	82%	18%
	WA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**33**	0	0	97%	3%
	S/I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**30**	0	100%	0%
	DEV	1	0	1	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	**25**	83%	17%
Producer's Accuracy		67%	70%	63%	71%	65%	82%	85%	56%	44%	94%	49%	77%	94%	80%	56%	93%	56%	79%	92%	79%	100%	Kappa	0.69
Omission Error		33%	30%	37%	29%	35%	18%	15%	44%	56%	6%	51%	23%	6%	20%	44%	7%	44%	21%	8%	21%	0%	Overall Accuracy	71%
																							Area-Weighted Accuracy	83%

Appendix C: Cordova Vegetation Type Error Matrix (Fuzzed)

Fuzzed Accuracy Assessment		Reference																					User's Accuracy	Commission Error
		SS	H	H-SS	DMH	FP	BC	SS-BC	A	A-W	SG	EDS	SP	AHB	WHB	MHB	DHB	SV	BR	WA	S/I	DEV		
Map Data	SS	**22**	1	4	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	71%	29%
	H	2	**24**	3	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	77%	23%
	H-SS	0	0	**29**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100%	0%
	DMH	1	2	3	**23**	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	74%	26%
	FP	0	0	0	0	**31**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100%	0%
	BC	0	0	0	0	0	**30**	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	97%	3%
	SS-BC	0	0	0	0	0	3	**27**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90%	10%
	A	0	1	0	2	0	0	0	**52**	0	0	1	0	0	0	1	0	1	0	0	0	0	90%	10%
	A-W	1	0	0	0	0	0	0	9	**20**	0	0	0	0	0	0	0	0	0	1	0	0	65%	35%
	SG	0	0	0	0	3	0	0	0	1	**21**	0	3	0	0	0	0	0	0	0	0	0	75%	25%
	EDS	0	0	0	0	0	0	0	1	0	0	**25**	0	0	0	2	0	0	1	0	1	0	83%	17%
	SP	0	0	0	0	3	0	0	0	0	0	0	**27**	0	0	0	0	0	0	0	0	0	90%	10%
	AHB	0	0	1	0	0	0	0	2	0	0	0	0	**16**	2	0	0	0	0	0	0	0	76%	24%
	WHB	1	0	0	0	0	0	0	2	1	0	0	0	0	**17**	0	1	6	1	0	0	0	59%	41%
	MHB	0	0	0	1	0	0	0	2	0	0	9	1	0	0	**15**	0	3	0	0	0	0	48%	52%
	DHB	1	0	0	0	0	0	0	0	10	0	0	0	0	0	0	**17**	0	0	0	0	0	61%	39%
	SV	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	**21**	4	1	5	0	64%	36%
	BR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**29**	1	2	0	88%	12%
	WA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**34**	0	0	100%	0%
	S/I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**30**	0	100%	0%
	DEV	1	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	**26**	87%	13%
Producer's Accuracy		76%	86%	71%	85%	78%	91%	93%	72%	61%	100%	69%	87%	100%	89%	79%	94%	66%	83%	92%	79%	100%	Kappa	0.80
Omission Error		24%	14%	29%	15%	23%	9%	7%	28%	39%	0%	31%	13%	0%	11%	21%	6%	34%	17%	8%	21%	0%	Overall Accuracy	81%
																							Area-Weighted Accuracy	90%