Ketchikan Misty Fjords Vegetation Map Project

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Cover: Photo of Gravina Island, Alaska from Phocena Bay. Photo taken during a 2022 field sampling trip.

Dangerfield, C.; Johnson, J.; Bellante, G.; Goetz, W.; Foss, J.; Johnson, T.; Sheets, M.; Heutte, T.; Homan, K.; Wittwer, D.; Miller, S.; Ryerson, D.; Megown, K.; Moody, R.; Vernier, M.; 2023. Ketchikan Misty Fjords Existing Vegetation Map Project. GTAC-10272-RPT1. Salt Lake City, UT. U.S. Department of Agriculture, Forest Service, Geospatial Technology and Applications Center. 49 p.

Abstract

An existing vegetation map was prepared in a collaborative effort between the Tongass National Forest, the 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 Ketchikan Misty Fjords Ranger District. The final map products comprise ten distinct, integrated feature layers: 1) vegetation type, 2) tree canopy cover, 3) biomass (Mg) for trees ≥2” diameter at breast height (DBH), 4) gross board feet (GBF), 5) quadratic mean diameter (QMD) for trees ≥2” DBH, 6) quadratic mean diameter for trees ≥9” DBH, 7) stand density index (SDI) for trees ≥9” DBH, 8) trees per acre (TPA) for trees ≥1’ tall, 9) trees per acre for trees ≥6” DBH, and 10) thematic tree size. The vegetation type map consists of 28 classes, including 23 vegetation dominance types and five other land cover types. Forest structure metrics including tree canopy cover, biomass, GBF, QMD, SDI, TPA, and thematic tree size were developed for areas that were classified as *forest* on the final vegetation type map layer. 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 in the field and used to characterize the 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 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 the Ketchikan Misty Fjords Project Area 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.

Authors

Cody Dangerfield is a Remote Sensing Analyst employed by RedCastle Resources, Inc. at the Geospatial Technology and Applications Center (GTAC).

Joni Johnson was the Ecologist for the Tongass National Forest.

Gabriel Bellante is a Project Manager employed by RedCastle Resources, Inc. at GTAC.

Wendy Goetz is a Remote Sensing Analyst employed by RedCastle Resources, Inc. at GTAC.

Jacqueline Foss is the Soil, Ecology & Botany Program Manager for the Tongass National Forest.

Tanner Johnson is a Remote Sensing Analyst employed by RedCastle Resources, Inc. at GTAC.

Mike (Robert) Sheets is the Silviculturist for the Tongass National Forest.

Thomas Heutte is the GIS Program Manager for the Tongass National Forest.

Kim Homan is the Geospatial Program Manager for the USDA Forest Service Alaska Region, Ecosystem Planning and Information Management Office.

Dustin Wittwer is the Remote Sensing Coordinator for the USDA Forest Service Alaska Region, Ecosystem Planning and Information Management Office.

Susan C. Miller is the Regional Ecologist for the USDA Forest Service Alaska Region, Natural Resources Staff Group

Dan Ryerson is a Program Assistant for the Resource Inventory Monitoring and Mapping (RMIM) program at GTAC.

Kevin Megown is the Program Leader for the RMIM program at GTAC.

Rowan Moody is a Remote Sensing Analyst employed by RedCastle Resources, Inc. at GTAC.

Matt Vernier is a Remote Sensing Analyst employed by RedCastle Resources, Inc. at GTAC.

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 thank the Metlakatla Alaska Native Community and the Bureau of Indian Affairs for their support in sharing field data for the mapping of Annette Island. We would like to thank Valeria Cancino Hernandez and Adam Caster who provided expertise and coordination for field collection. We also wish to express our appreciation to Katie Baer, who coordinated and analyzed Forest Inventory and Analysis (FIA) data used for reference. Additional thanks to the Tongass National Forest field crews for their invaluable contributions in collecting the empirical field data: Ann Beeman, Lupin Conway, Kaito Lopez, Lara Grevstad, Dennis Landwehr, Mark Eldridge, Sheila Spores, Jenny Richter, Abby Lund, Tim Barry, and Nathan Mooers.

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Introduction

Existing vegetation maps support resource managers by informing project- and landscape-level planning efforts by providing vegetation data that can be used in numerous applications and future management activities. The United States Department of Agriculture (USDA) Forest Service's mission requires existing vegetation information for Forest planning, ecological assessment, forest health monitoring, vegetation management projects, and wildlife habitat management. Existing vegetation maps are commonly used 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, map products from the Prince of Wales Existing Vegetation Map Project were used to search for cedar trees suitable for cultural uses. On the Chugach National Forest, existing vegetation maps were used to monitor dusky Canada geese (*Branta canadensis occidentalis*), northern goshawk (*Accipiter gentilis*), and moose (*Alces alces*) habitat on the Kenai peninsula and Copper River Delta (Bellante et al., 2013, 2020). During the Swan Lake Fire in 2019, existing vegetation data products were used for fuels information and fire behavior modeling on the Kenai Peninsula. These products are also being used to monitor habitat for mountain goats (*Oreamnos americanus*), Kittlitz's Murrelets (*Brachyramphus brevirostris*), Marbled Murrelets (B*rachyramphus marmoratus*), and other prevalent species throughout Coastal Alaska.

The Ketchikan Misty Fjords Existing Vegetation Map Project is one in a series of mapping efforts that is being conducted across the Tongass and Chugach National Forests. These projects implement contemporary methodologies and use empirical data to develop defensible map products that are validated with an accuracy assessment. 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 Ketchikan Misty Fjords Vegetation Map Project was provided by the Tongass National Forest and the USDA Forest Service 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 Ketchikan Misty Fjords Ranger District.

Project Area

The Ketchikan Misty Fjords project area is located in Southeastern Alaska (Figure 1) and consists of two ecoregions, the Alexander Archipelago and Boundary Ranges, and is characterized by lakes, rivers, low wetlands and bogs, coastal rainforest, and glaciated mountains (Nowacki et al., 2001). This periglacial maritime landscape is characterized by rugged mountains and dense forest and provides critical habitat for migratory birds along the Pacific Flyway, large mammals such as moose and bears, and anadromous fisheries. The project area encompasses ~4.6 million acres and includes the Cleveland Peninsula, the Misty Fjords National Monument Wilderness, and several islands including Revillagigedo, Gravina, Annette, and Duke Islands. This landscape contains a matrix of productive temperate rainforest and less productive forest characterized by poorly drained soils.

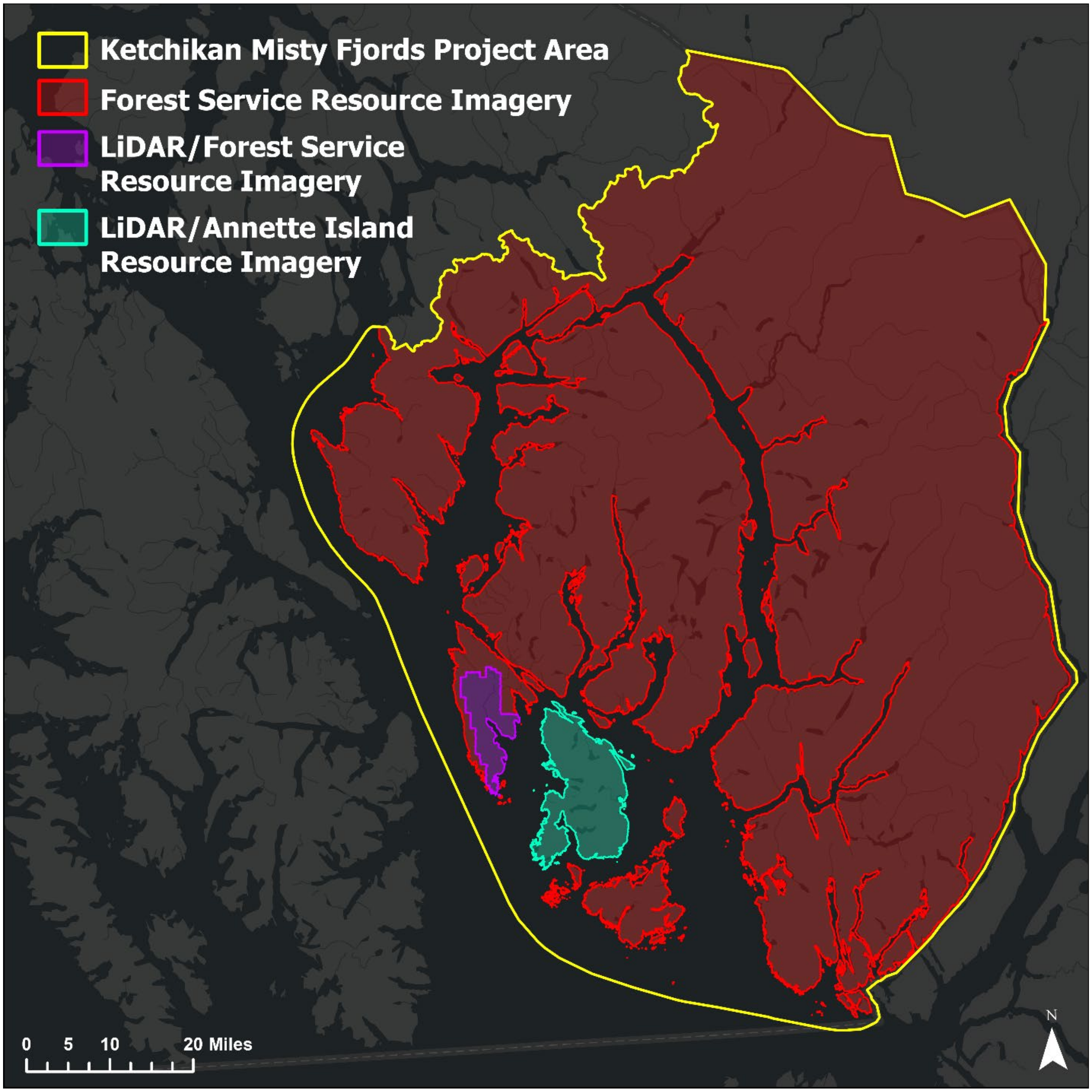

Figure 1.—Map extent of the Ketchikan Misty Fjords Existing Vegetation Map Project Area. The map depicts the three distinct data extents that were used during modeling. Areas that had 2019 Forest Service resource imagery are red and purple. Areas that contained LiDAR data from the Prince of Wales 2017—2018 acquisition are in purple and green. Annette Islands Reserve (green area) was not included in the 2019 imagery acquisition but had a separate imagery acquisition in 2016 that was leveraged during mapping. Annette Island Reserve also overlapped with the 2018 LiDAR acquisition.

Project Planning

In 2019, staff of the Forest Service met with partners to outline a strategy and prepare a project plan for the Ketchikan Misty Fjords Existing Vegetation Map Project. This partnership discussed map unit design and developed a vegetation classification system that was both ecologically meaningful and realistic with respect to technology and the available data 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 established the rules that defined the map classes found in the Ketchikan Misty Fjords Vegetation Type Classification Key (Appendix A). This dichotomous key established 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 ambiguity in their respective definitions, 3) contain classes that are capable of being mapped with the available data, and 4) be consistent with respect to the scale and scope of the project. One of the overarching goals for this project was to contribute to a regionally cohesive map product. Therefore, efforts were made to ensure that the spatial and thematic characteristics of the products would fulfill data requirements across the Tongass National Forest and be congruent with previous mapping projects, including the Prince of Wales Existing Vegetation Project (Bellante et al., 2020).

Existing vegetation consists of the present-day plant cover, or floristic composition and vegetation structure, occurring at a given location (Nelson et al., 2015). Vegetation types and structure classes were identified to address the information needs for the Alaska Regional Office (Region 10) and the Tongass National Forest. GTAC was tasked to develop a set of mid-level existing vegetation maps for the project area. Vegetation type classes were developed to depict taxonomic or technical groups that provide information to support resource allocation and management activities. The vegetation dominance types were designed to describe vegetation functional groups that occupy the Ketchikan Misty Fjords 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 type classes were a combination of species that describe a vegetation community (e.g., *Wet Herbaceous*) while others identified specific species (e.g., *Sitka Spruce*). Vegetation type classes are defined by the Ketchikan Misty Fjords 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 inability to differentiate certain classes. Ultimately, there was a total of 28 vegetation type classes—23 vegetated classes and five non-vegetated classes (Table 1). Additionally, nine structure map products are included with the deliverables—tree canopy cover, biomass (Mg) for trees ≥6” diameter at breast height (DBH), gross board feet (GBF) for trees ≥9” DBH, quadratic mean diameter (QMD) for trees ≥2” DBH, QMD for trees ≥9” DBH, stand density index (SDI) for trees ≥9” DBH, trees per acre (TPA) for trees ≥1’ tall, TPA for trees ≥6” DBH, and thematic tree size (Table 2).

These products were developed to provide up-to-date, comprehensive information about the vegetation communities and their structure across the project area. In doing so, over 4.5 million acres, including federal, state, local, native, and private land inholdings, were mapped. It is important to remember that the vegetation characteristics being depicted in the products are captured using remotely sensed data that is from an overhead, bird’s-eye perspective (Figure 2). Therefore, vegetation type and structure are based on what is visible in the overstory and does not depict understory vegetation.

Table 1.—List of Vegetation Type and Map Group classes for Ketchikan Misty Fjords Existing Vegetation Map Project. Vegetation Type Codes are the abbreviations used for the accuracy assessment in the confusion matrices (Appendix B & C).

Map Group	Vegetation Type	Vegetation Type Code
Conifer Forest	Sitka Spruce	SS
	Sitka Spruce-Western Hemlock	SS-WH
	Western Hemlock	WH
	Mountain Hemlock Mix	MHmix
	Mixed Conifer	MC
	Red Cedar	RC
	Yellow Cedar	YC
	Forested Peatland	FP
	Subalpine Mountain Hemlock Mix	SA-MHmix
	Subalpine Yellow Cedar	SA-YC
Broadleaf Forest	Black Cottonwood	BC
	Red Alder	RA
Mixed Forest	Sitka Spruce-Black Cottonwood	SS-BC
	Sitka Spruce-Red Alder	SS-RA
Shrub	Alder Shrub	AS
	Willow Shrub	WS
	Tall Shrub Mix	TSmix
	Ericaceous Shrub	ES
Herbaceous	Aquatic Herbaceous	AHB
	Saltwater Herbaceous	SWHB
	Wet Herbaceous	WHB
	Mesic Herbaceous	MHB
	Sedge Peatland	SP
Non-Vegetated	Sparse Vegetation	SV
	Barren	BR
	Water	WA
	Snow/Ice	S/I
	Developed	DEV

Table 2.—Thematic vegetation structure metrics produced for the Ketchikan Misty Fjords Existing Vegetation Map Project.

Thematic Structure Metrics	Thematic Structure Classes
Tree Canopy Cover	Woodland (10–24%)
	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)

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.

Methods

The map products for this project were developed using remotely sensed multispectral imagery, Light Detection and Ranging (LiDAR) and topographic Interferometric Synthetic Aperture Radar (IfSAR) data, field and photo-interpreted reference sites, and object-based 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 (Breiman, 2001) was then used to characterize these modeling units and assign map class labels, which ultimately produced the final vegetation maps for Ketchikan Misty Fjords. The major mapping phases that 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 had a unique set of qualities that, along with the imaging geometry, determined the spectral, spatial, and radiometric resolutions of the data that was collected. Multiple sources of geospatial data were acquired for this project to use the unique information afforded to different sensors and to maximize the range of data used in the computational modeling.

High-resolution imagery was a critical data source for several steps in the mapping process. The resolution of the imagery allows an analyst to evaluate and modify model outputs and was instrumental for developing relatively fine-scaled segments for a mapping project. Specifically, three data sources of high-resolution imagery were used including two sets of aerial imagery, Forest Service resource imagery and Annette Island Reserve imagery, and one set of satellite imagery from Maxar (Table 3). The Forest Service resource imagery was acquired during the summer of 2019 for most of the project area except for the Annette Island Reserve. Separate imagery for Annette Island was acquired in 2016. Maxar satellite imagery covered the entire project area and was collected from 2010–2020.

Other image mosaics and composites were created from Landsat 8, Landsat 9, and Sentinel-2. Specifically, seasonal composites were created for spring, summer, and fall from Sentinel-2 image archives. These composites were created to capture variations in vegetation floristics and phenology between the mapping classes during the early growing season, the height of the growing season, and plant senescence at the end of the growing season. Seasonal composites were created by collecting multiple scenes that had a cloud probability of less than 10 percent from 2017–2022 within a given seasonal window. A cloud masking workflow was then applied to each scene within the collection to remove any clouds present in each scene. Imagery for the composites were collected from May 1–June 30 for spring, July 1–August 31 for summer, and September 1–October 15 for fall. Following cloud masking, each composite was created by extracting the median value of each band from the resultant cloud-masked image collection.

For Landsat 8, a growing season composite was created using a similar workflow. Imagery for the Landsat 8 composite was collected from June 1–September 15 from 2014–2022. A larger collection window was used for Landsat 8 because it has a longer return interval than Sentinel-2. Consequently, a larger collection of imagery was necessary to create a cloud-free composite for the project area. Lastly, a mosaic of Landsat 9 was created using three separate dates from 2022: June 26, July 1, and July 3. Individual dates were used for the Landsat 9 mosaic due to a lack of imagery available to create a cloud-free composite because of the recency of the Landsat 9 satellite launch. Individual scenes were processed together in Google Earth Engine to create the final imagery datasets of the project area. For each set of imagery, a variety of indices were created to provide ancillary data. A Normalized Difference Vegetation Index (NDVI), Normalized Difference Moisture Index (NDMI), Normalized Difference Snow Index (NDSI), and Normalized Burn Ratio (NBR) were produced. A Tasseled-Cap Transformation was also performed on each set of imagery to create wetness, greenness, brightness layers (Crist & Cicone, 1984).

Elevation data for the project came from LiDAR and IfSAR data sources. The available LiDAR data was part of a larger acquisition that mainly covered Prince of Wales and was collected in 2017 and 2018. The mission was funded by the Forest Service and additional partners, including The Nature Conservancy, Sealaska Corporation, and a matching grant from the United States Geological Survey (USGS) 3D Elevation Program. These LiDAR data acquisitions were flown by Quantum Spatial and designated to meet USGS base specification quality level 1 with an accuracy of 10.0 cm root mean square error in z (RMSEz) and a density of 8 pulses per square meter (pls/m^2) (Heidemann, 2014). This acquisition only covered a portion of the Ketchikan Misty Fjords project area, which included Annette Islands Reserve and a section of Gravina Island (Figure 1). Where LiDAR data was not available, IfSAR data was used as the topographic input data for vegetation and structure prediction. The IfSAR data had three 5 m resolution components: 1) a digital terrain model (DTM), derived from the P-band, which penetrates through vegetation to provide a bare-earth approximation; 2) a digital surface model (DSM) derived from the X-band, which reflects higher canopy vegetation and provides an estimate of canopy surface elevation; and 3) a canopy height model (CHM), which is an approximation of vegetation height by taking the elevation difference between the DSM and DTM. Topographic derivatives including slope, aspect, heat load, topographic position index (TPI), and topographic wetness index (TWI) were produced from the IfSAR DTM.

Other ancillary data, including climate, disturbance detection data, and management spatial layers from Forest Service Activity Tracking System (FACTS) and Annette Islands Reserve were also used in the mapping process. Landscape Change Monitoring System (LCMS) and management layers were used to identify areas that were previously harvested. Actively managed areas were further reviewed to refine and accurately delineate harvest boundaries. Areas of recent harvest were modeled independently because of their distinct spectral properties, which warranted special consideration to limit error and class confusion.

Climate data developed from the USDA Forest Service Forest Health Assessment & Applied Sciences Team (FHAAST) served as additional predictor variables during the modeling process (Ellenwood et al., 2015). 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 Table 3.

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

Geospatial Data Source		Product Description	Spatial Resolution	Purpose
Spectral Data	**Forest Service Resource Imagery (2019)**	Bands: Red, Green, Blue, NIR Indices: NDVI, Principal Components (PC) 1, PC2, PC3, PC4	30 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
	Annette Island Imagery (2016)	Bands: Red, Green, Blue, NIR Indices: NDVI, Principal Components (PC) 1, PC2, PC3, PC4	30 cm	Segmentation, Vegetation Type & Structure Modeling, Image interpretation
	Sentinel-2 Composites (2017–2022) • **Spring** (May 1–June 30) • **Summer** (July 1–August 31) • **Fall** (September 1–October 15)	Bands: Blue, Green, Red, NIR Indices: NDVI	10 m	Segmentation, Vegetation Type & Structure Modeling
	Sentinel-2 Composites (2017–2022) • **Spring** (May 1–June 30) • **Summer** (July 1–August 31) **Fall** (September 1–October 15)	Bands: Red Edge (RE) 1, RE 2, RE 3, Shortwave Infrared (SWIR) 1, SWIR 2 Indices: NDVI, NDMI, NDSI, NBR, Tasseled Cap Transformation (brightness, greenness, wetness)	20 m	Vegetation Type & Structure Modeling
	Landsat 8 Composite (2014–2022) • June 1–September 15)	Bands: Blue, Green, Red, NIR, SWIR 1, SWIR 2, temp Indices: NDVI, NDMI, NDSI, NBR, Tasseled Cap Transformation (brightness, greenness, wetness)	30 m	Vegetation Type & Structure Modeling

Geospatial Data Source		Product Description	Spatial Resolution	Purpose
	Landsat 9 Mosaic • June 26, 2022 • July 01, 2022 • July 03, 2022	Bands: Blue, Green, Red, NIR, SWIR 1, SWIR 2, temp Indices: NDVI, NDMI, NDSI, NBR, Tasseled Cap Transformation (brightness, greenness, wetness)	30 m	Vegetation Type & Structure Modeling
Topographic Data	**LiDAR (2018)** • USGS Quality Level 1 (QL1) 8 pls/m^2	Digital Terrain Model (DTM) Digital Surface Model (DSM) Canopy Height Model (CHM)	1 m	Segmentation, Vegetation Type & Structure Modeling, Reference Data
Topographic Data	**LiDAR (2018)** • USGS Quality Level 1 (QL1) 8 pls/m2	First Order Metrics, point cloud height statistics (87 metrics)	30 m	Structure Modeling
Topographic Data	**IfSAR (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
Topographic Data	**Sentinel 1 (2021–2022)**	C-Band Polarizations: VV (ascending), VV (descending), VH (ascending), VH (descending) VV ascending/descending average, VH ascending/descending average Ratios: VV to VH (ascending), VV to VH (descending) *V=Vertical; H=Horizontal	10 m	Vegetation Type & Structure Modeling
Ancillary Data	**FHAAST Climate data (30-year mean)**	Growing season degree days Annual Moisture Index Mean Annual Temperature Mean Annual Precipitation Average temperature of the coldest month Average temperature of the warmest month	30 m	Vegetation Type & Structure Modeling

Geospatial Data Source		Product Description	Spatial Resolution	Purpose
	Landscape Change Monitoring System (LCMS)	Slow loss Fast loss Gain	30 m	Defining Harvest Areas
	Harvest layers	FACTS & Annette Islands Reserve harvest data	GIS Vector Data	Defining Harvest Areas

Image Segmentation

Image segmentation is the process of partitioning digital imagery and other geospatial data into spatially cohesive modeling units that represent discrete areas or objects on a landscape (Ryherd & Woodcock, 1996). The goal of image segmentation is to develop homogeneous segments or mapping polygons that delineate vegetation of similar physiognomic, floristic, and structural characteristics to serve as the fundamental modeling units (Nelson et al., 2015). High-resolution imagery (Forest Service and Annette Island Reserve resource imagery and Maxar satellite imagery) along with the Sentinel-2 imagery, LiDAR, and IfSAR topographic layers were used to generate the final segments for Ketchikan Misty Fjords (Table 3). High-resolution imagery exceled at portraying vegetation patterns across the landscape during the segmentation process, such as delineating forest boundaries or isolating patches of shrub. As such, the Forest Service and Annette Island resource imagery were the most important data sources for generating the final segments. While the Maxar imagery was another high-resolution imagery data source, it was less consistent than the aerial imagery. The Maxar imagery was collected over several years and during different seasons, which resulted in vegetated areas appearing different, being covered in snow, or having clouds present. As a result of the artifacts present in the Maxar imagery, we did not rely on it as consistently as the other high-resolution datasets for generating segments. The LiDAR data was also a critical data source as it detected changes in vegetation structure across the landscape. However, since the LiDAR data only covered a small portion of the study area, it was only leveraged when developing the segments for Annette Island and portions of Gravina Island (Figure 1) in conjunction with the other imagery data sources.

Despite the coarser spatial resolution of Sentinel-2, it was also used in the segmentation process since it contains a broader spectral resolution than the high-resolution imagery. Therefore, these data were useful for capturing the spectral variation of the vegetation types within Ketchikan Misty Fjords. Prior to segmentation, all imagery was resampled to 5 meters to make data processing more efficient and avoid over-segmentation of the complex landscape. This workflow avoided creating convoluted segments that follow minute changes in the imagery, such as canopy gaps, rather than capturing forest stands or other larger vegetation patterns.

Development of the segments was an iterative process that used a variety of algorithms and a combination of data sources that were structured into a ruleset within the Trimble eCognition Developer 10 software suite (Trimble Germany GmbH, 2021). 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 had an average size of 3.2 acres. Median segment size was 1.7 acres since large bodies of water and areas of glacial ice were classified and merged during the segmentation process, creating 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. This size limit prevented segments from capturing landscape features too small to adequately model using the available predictor data. The final segmentation yielded over 1.4 million segments that served as the modeling units for the project (Figure 3).

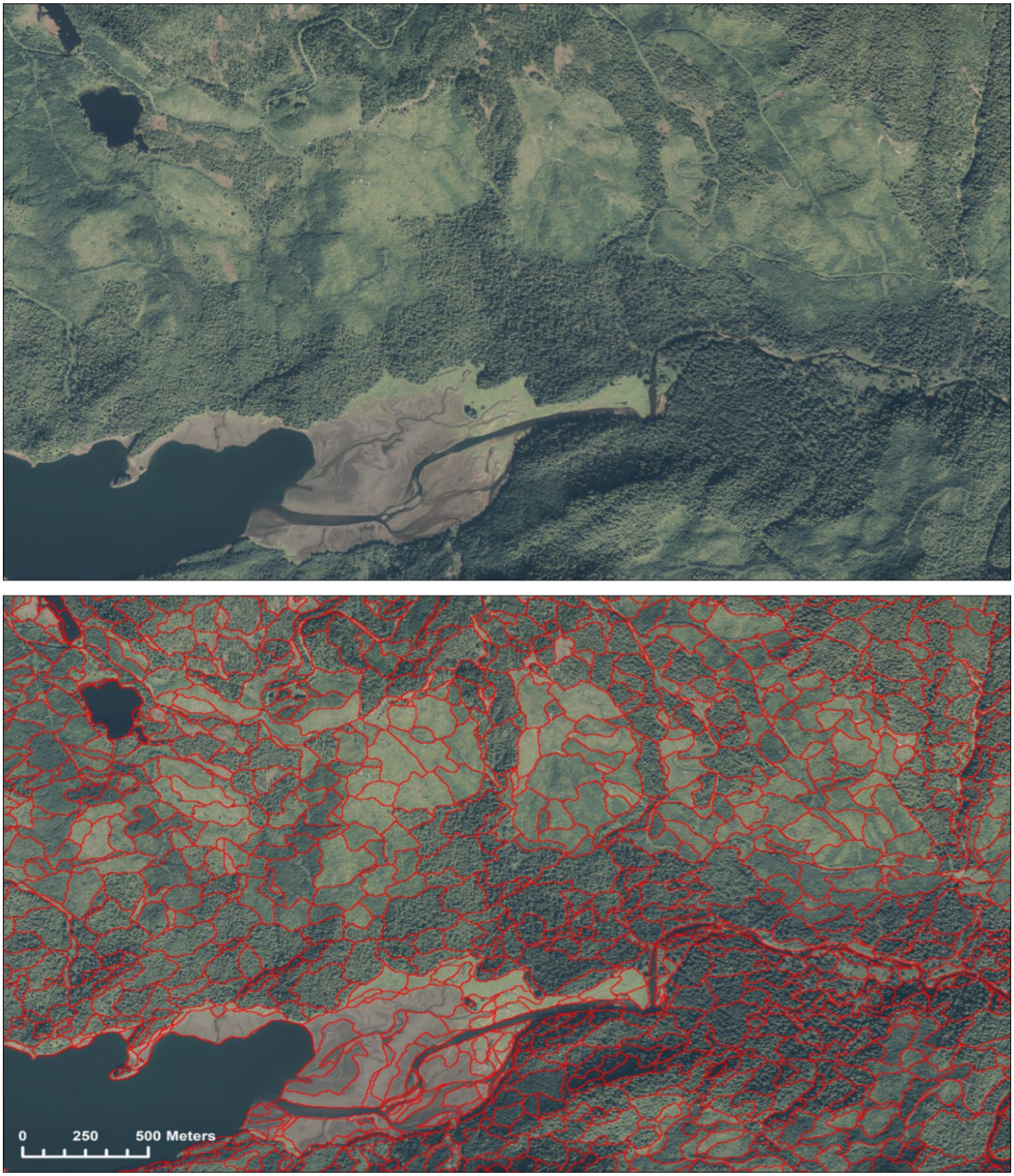

Figure 3.—An example of the final segments generated for the mapping project using Trimble eCognition. This is a snapshot of the Forest Service resource imagery in Traitors Cove with and without the overlayed final segments.

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 Ketchikan Misty Fjords. Alaska Regional and Tongass National Forest staff developed the Ketchikan Misty Fjords Vegetation Type 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) Forest Service field crews collecting vegetation information specific to this project, 2) Young Growth Inventory data, 3) legacy data from previous Forest Service survey plots and the Forest Inventory and Analysis (FIA) program, 4) field data from Annette Island supplied by the Bureau of Indian Affairs, and 5) image interpretation (Figure 4). Tongass National Forest personnel collected most of the ground data that was targeted for this mapping effort using a variety of means--helicopter, floatplane, boat, or by foot from existing trail and road infrastructure--to collect samples that capture the diversity of vegetation across the project area. The Young Growth Inventory information was leveraged as reference data for actively managed forest stands. These data were a result of the Challenge Cost Share Agreement between the Tongass National Forest and State of Alaska Division of Forestry. The legacy, FIA, and Annette Island data were all cross-referenced with the classification key (Appendix A) to label each systematic plot with a vegetation type class. Reference data was consolidated into a single database and reviewed within the context of their corresponding segment using high-resolution imagery. The final reference database included 2,811 sites—586 Forest Service ground, 565 legacy, 122 FIA, 97 Annette Island, and 1,441 Young Growth Inventory sites.

Following field collection, sites were added by GTAC personnel using image interpretation techniques to bolster reference datasets and improve map model performance. However, the more abundant vegetation and structure types were inevitably sampled at a higher frequency. It can be difficult to obtain an adequate sample for rarer classes or discern certain vegetation classes from one another. As a result, the following vegetation types from the classification key were dropped or consolidated into another vegetation type: *Shore pine peatland, Yellow cedar peatland, Red cedar peatland, Subalpine mountain hemlock-Sitka spruce, Subalpine mountain hemlock-yellow cedar, Subalpine mixed conifer, Other mixed conifer- broadleaf, Shrub peatland,* and any “*swamp*” conifer class (Appendix A). This is not to indicate that these vegetation types are absent from the landscape, but rather are not commensurate with this project’s scale and scope. Consequently, these types are not depicted on the final map products.

Ground Data

A total of 586 ground sites were collected by Tongass Forest Service personnel during the 2019−2022 field seasons. These sites were primarily pre-selected and were confined to areas accessible with respect to ownership, terrain, existing infrastructure—such as roads and trails—and ease of access. Additional sites were placed in remote areas that field crews could access via boat or floatplane. 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 segments for homogeneity and representativeness.

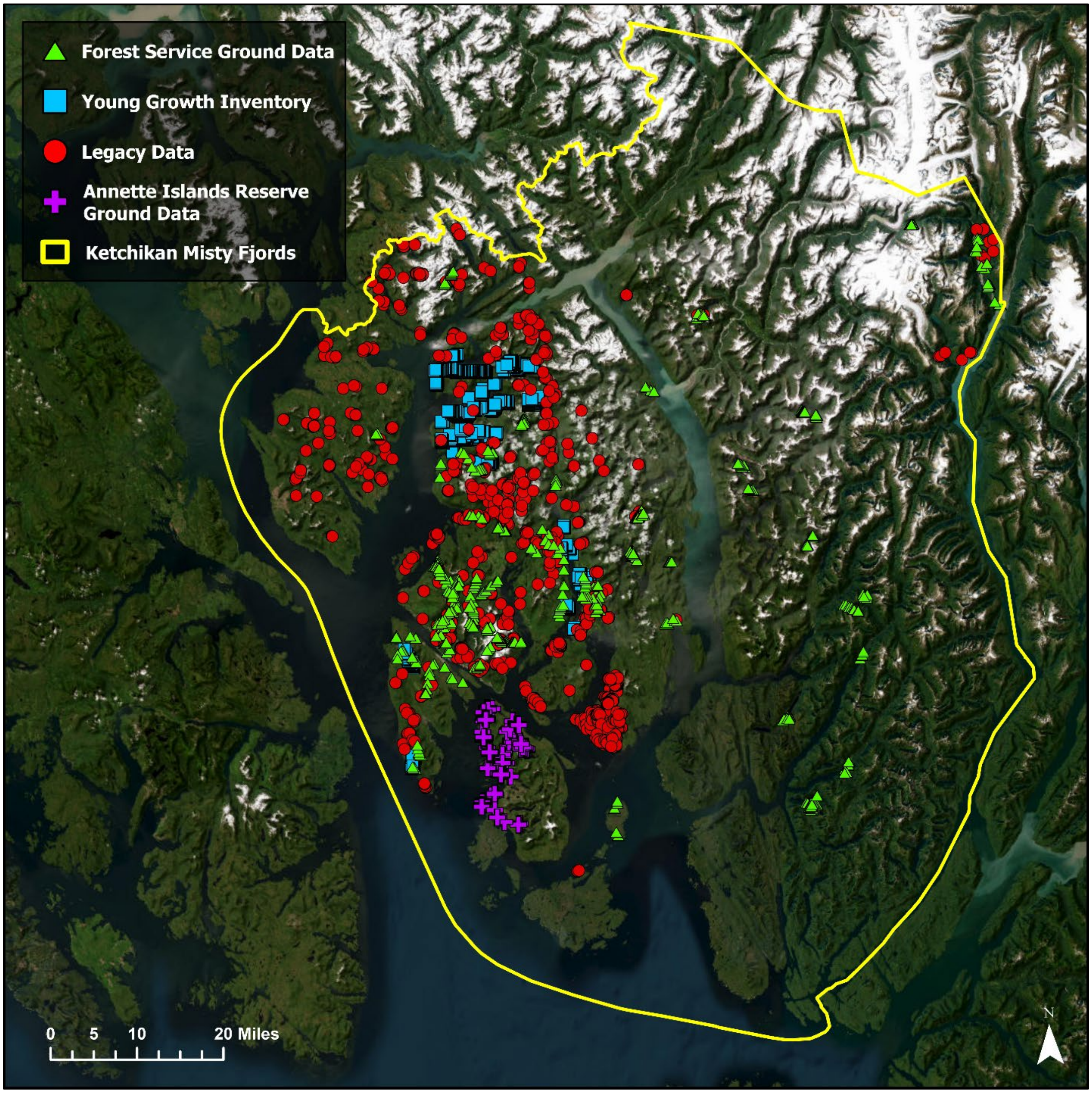

Figure 4.—Map showing the distribution of reference data (colored symbols) across the Ketchikan Misty Fjords project area.

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 contained highly detailed vegetation information on species composition and structure. In comparison, 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 for the dominant species, including visual estimates of vegetation cover by stratum and by species, as well as height information for tall shrubs and trees. Additionally, tree diameters were measured at 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 Ketchikan Misty Fjords Vegetation Type Classification Key (Appendix A).

Young Growth Inventory Data

The Tongass National Forest completed a young growth inventory to evaluate the current status of previously harvested stands on Forest Service lands, as the agency transitions from focusing harvest activities from young growth stands as opposed to old growth timber. Plots were placed using systematic design at a density of one plot for every 2.5 acres and were concentrated in stands 40+ years old at the time of inventory. Therefore, these data are not fully representative of all young growth. There were 2,365 young growth plots that fell within the Ketchikan Misty Fjords project area and were intersected with the segments. Data from these prism cruising (variable-radius) plots were translated to relative tree canopy cover by species using diameter and tree count as proxy variables. These plots were used to assign vegetation type labels to the corresponding segments according to the definitions set forth in the classification key. In cases where multiple plots intersect a single segment, the plot data was combined and summarized to a single segment. Following quality checks for homogeneity and representatives, a total of 1,441 reference sites were used in the vegetation type classification models.

Legacy Data

Additional reference sites were derived from field data sources, collected previously for other Forest Service projects. A total of 565 plots, comprised mostly of ecology and soils plots, were crosswalked to the vegetation classification system used for this mapping effort and image interpreted to determine if each site accurately represented vegetation within the corresponding segment. Data collected as part of the FIA program are often used in vegetation mapping projects because of the program's statistically robust, systematic random sampling design, which utilizes fixed-radius plots to inventory forest resources across all ownerships. This project classified 122 FIA plots according to the classification key (Appendix A) definitions and were utilized as reference in the prediction modeling.

All legacy data underwent a rigorous quality assurance/quality control process using high-resolution imagery and topographic data. Each site was reviewed for adequate representation and homogeneity within the context of the segments. If a site contained relatively uniform vegetation characteristics and the vegetation type map unit could accurately be ascertained, then it was utilized as a reference or validation site in the mapping process.

Image Interpreted Data

GTAC used image interpretation to bolster the training data and improve the vegetation type and tree size models. Segments were evaluated using the most contemporary high-resolution imagery available to assign vegetation classes and structure values. Resource aerial imagery collected in 2019 for the Tongass National Forest and Maxar imagery acquired between 2010 and 2020 were the primary data sources for image interpretation. Both image sources contain 4 bands (Red, Green, Blue, and Near Infrared) and have a spatial resolution of 30 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, insect defoliation, localized flooding, landslides, and wind events. Notably, the Tongass National Forest experienced two widespread defoliating events at the time of mapping Ketchikan Misty Fjords. A hemlock sawfly (*Neodiprion tsugae* Middleton) outbreak occurred from 2018-2020 followed by a black-headed budworm (*Acleris gloverana* Walsingham) outbreak that occurred from 2020-2022 (Graham, 2022, 2023). These outbreaks mainly impacted Western Hemlock dominated areas and may have affected modeling results as the acquisitions dates for the Forest Service (2019), Maxar (2010-2020) and Sentinel-2 (2017-2022) imagery either overlapped or coincided with these outbreaks.

Classification and Regression

Random forest was the machine learning technique used to predict and assign vegetation attributes to the segments (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 Table 3. For each of those datasets, we calculated a variety of zonal statistics including minimum, maximum, range, standard deviation, mean, and median for the segments. This equated to over 450 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 segments were then used to predict and characterize vegetation across Ketchikan Misty Fjords. Once models were finalized, vegetation masks were implemented to integrate the structure attributes with the appropriate vegetation types according to the lifeform definitions of the Ketchikan Misty Fjords Classification Key (e.g., tree canopy cover values were only applied to areas that were classified as *forest* on the final vegetation 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. Following the modeling process, neighboring segments with the same vegetation type and structure attributes were dissolved into the final map features (Nelson et al., 2015).

To model vegetation type and forest structure, we developed separate modeling extents based on the best available data for a given area. Because the aerial imagery and LiDAR data only had partial coverage of the project area but were important model drivers, we developed separate modeling extents for vegetation type and forest structure. For vegetation type, we developed two modeling extents based on the availability of high-resolution aerial imagery (Figure 1). Since Annette Island was not included in the 2019 Forest Service resource imagery acquisition, vegetation type was modeled separately using aerial imagery acquired in 2016 along with other data sources that covered the entire project area e.g., Sentinel-2, IfSAR data, etc. (Table 3). The rest of the project area leveraged the 2019 Forest Service resource imagery along with the other full-coverage data sources to model vegetation type.

Forest structure was modeled based on the availability of LiDAR data. Where LiDAR data were available, first order LiDAR metrics were calculated directly from the point cloud and were subsequently used to derive second order grid metrics (biomass, trees per acre, etc.) using linear regression equations developed by The Nature Conservancy (TNC). The first and second order grid metrics were then extrapolated across the full project extent to generate wall-to-wall vegetation structure products. The first order grid metrics were developed using the *lidR* R package (Roussel et al., 2020; Roussel & Auty, 2020). One of the first order metrics, the all-returns proportion above 2 meters, was used as a proxy for continuous tree canopy cover. For the second order structure metrics, TNC used a Pearson's correlation analysis to optimize a selection of first order LiDAR metrics that were then used as explanatory variables to calculate second order grid metrics using linear regression (Reynolds, 2019). The grid metrics were developed at a 30 m resolution and were summarized to the segments using a zonal mean for this project. After the forest metrics were generated for the LiDAR extent, a random sample of 10,000 sites were extracted and used to train random forest regression models and extrapolate the LiDAR-generated metrics to the remaining project area (Forest Service resource imagery only; Figure 1) using the zonal statistics derived from the other geospatial data sources (Table 3). Training data were stratified across Gravina and areas of Prince of Wales that had LiDAR coverage and coincident geospatial data including the 2019 resource imagery. Sites from Prince of Wales were included in the modeling effort to bolster our training dataset and sample across a wider distribution of forest structure than what would have been afforded if we limited our sample to just Gravina. In total, 2000 sites were sampled from Gravina Island and 8,000 sites were sampled from Prince of Wales. While Annette Island also had LiDAR coverage, it was excluded from sampling due to the lack of 2019 resource imagery.

Vegetation Type

Vegetation modeling was conducted in hierarchical stages in which vegetation types were iteratively 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 initially and classified further down 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. 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. Model outputs were evaluated and optimized using image interpretation at each stage of the mapping hierarchy to reduce misclassification 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.

Tree Canopy Cover

Tree canopy cover was derived from the LiDAR data by calculating the proportion of all-returns above 2 meters at a 30 m resolution:

$$all\text{-}return\ proportion = \frac{\#\ all\ returns\ >\ 2m}{\#\ all\ returns\ (total)}$$

Canopy cover values were then summarized to the segments that were within the LiDAR extent using a zonal mean. Canopy cover was then extrapolated to the rest of the project area that did not have LiDAR coverage using a random forest regression model. Following modeling, continuous tree canopy cover values were assigned to the map polygons classified as *forest* (*conifer*, *broadleaf*, or *mixed forest*) on the final vegetation type map. *Forest* was defined by the Ketchikan Misty Fjords 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 in Region 10 (Bellante et al., 2020, 2021; Dangerfield et al., 2022; Day et al., 2022) and maintain compatibility between those projects in order to generate a regionally cohesive map product in the future. The final products contain both a continuous and thematic attribute depicting tree canopy cover for the project area.

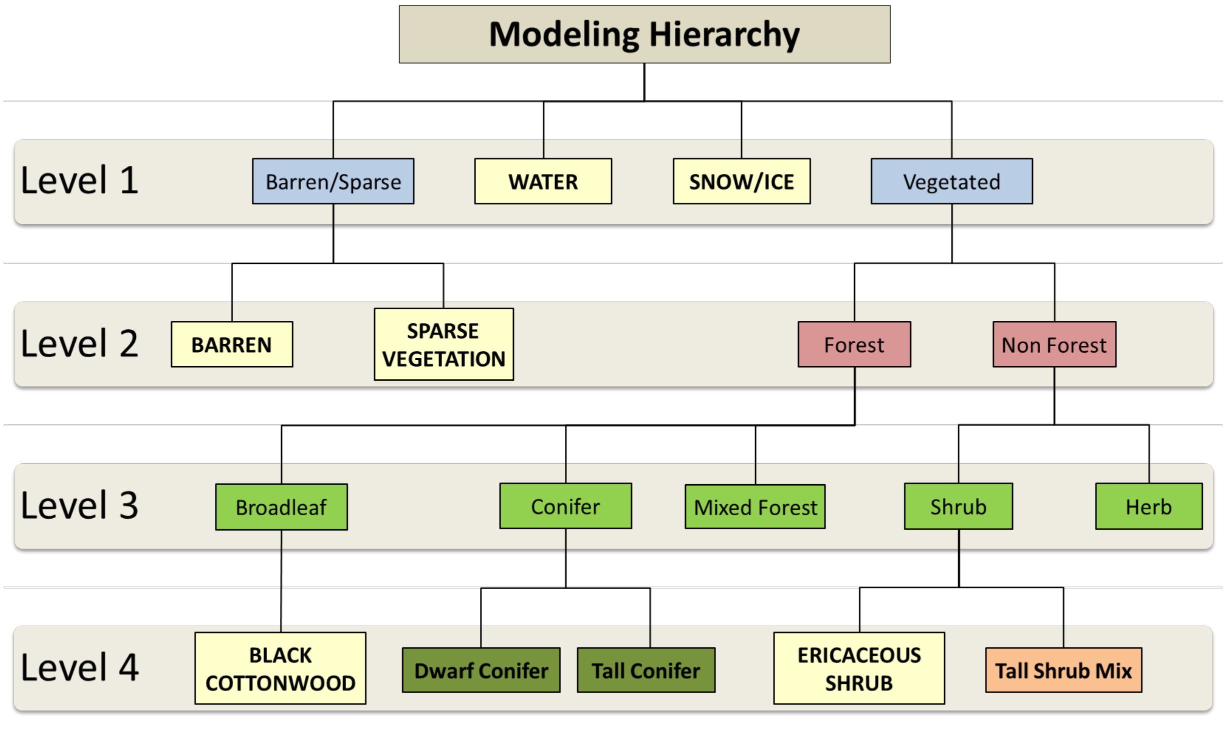

Figure 5.—A diagram showing examples of the highest levels of the vegetation type modeling hierarchy for the Ketchikan Misty Fjords Existing Vegetation Map Project. Individual classification models were developed for every node within the levels of the modeling hierarchy. For example, two independent 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. Note, not all vegetation type classes are depicted in the diagram.

Biomass

Biomass and other second order LiDAR metrics were derived from LiDAR data using calibration plots and linear regression equations developed by TNC as mentioned above. Below we provide the linear equations used for each metric, but for a more in-depth description of the linear regression equations used for this project see Reynolds (2019). Biomass was based on the equations from Standish et al. (1985) and was measured as the oven-dry Megagrams (metric tons) per acre. The first order LiDAR metrics used to develop the biomass linear regression equations included: (1) percentage of first returns above 2 meters and (2) 50th percentile height (elev_p50):

$$Biomass = e^{7.184811 + (0.025362 * Percentage\_first\_returns\_above\_2.00) + (0.765194 * \ln(elev\_p50))}$$

Gross Board Feet

A board foot is a unit of volume representing a theoretical, 12” X 12” X 1” board. It is predominantly used in evaluating timber for harvest. TNC used separate DBH thresholds for softwood and hardwood species when calculating GBF for each field plot. The equations used for softwoods are for Scribner scale, to a 6-inch top, using 32-foot lengths, with a 9-inch minimum DBH. For hardwoods, TNC only included red alder (*Alnus rubra*) for their field plots and used Scribner equations to an 8-inch top, using 32’ lengths, with an 11-inch minimum DBH. Equations were referenced from Zhou (2010). The first order metrics used to derive GBF included (1) percentage of first returns above 2 meters and (2) 70th percentile height (elev_p70):

$$GBF = (-19.14563 + (0.08404 * Percentage\_first\_returns\_above\_2) + (8.80670 * sqrt(elev\_p70)))^{3}$$

Quadratic Mean Diameter

Quadratic Mean Diameter (QMD) is a measure of central tendency for characterizing a group of trees that have been measured and is a proxy for tree size and volume in an area. QMD was calculated for all trees greater than or equal to two inches in diameter at breast height (≥2” DBH) and for merchantable timber greater than or equal to nine inches in diameter at breast height (≥9” DBH). The first order metrics used to calculate QMD ≥2” DBH included the percentage of all returns above mean height and the 50th percentile height (elev_p50) in the following equation:

$$\text{QMD } (\geq 2\text{” DBH}) = e^{(0.44478 + (-0.01236 * Percent\_all\_return\_above\_mean) + (0.094337 * \ln(elev\_p50)))}$$

QMD ≥9” DBH was calculated using the percentage of all returns above mean height and the 75% percentile (elev_p75) as the final predictors in the following equation:

$$\text{QMD } (\geq 9\text{” DBH}) = e^{(1.76810 + (-0.00320 * Percent\_all\_returns\_above\_mean) + (0.27402 * sqrt(elev\_p75)))}$$

Stand Density Index

Stand Density Index (SDI) is a forest density metric based on trees per acre and mean diameter (Reineke, 1933). This metric provides valuable information specific to the volume class and structure of the stand. The first order LiDAR metrics used to generate the linear equations for SDI from the LiDAR data included: (1) percentage first returns above mean height and (2) 50th percentile height:

$$SDI = (-5.33286 + (0.10458 * Percent\_first\_returns\_above\_mean) + (5.92987 * \ln(elev\_p50)))^{2}$$

Trees Per Acre

The forest metric, Trees Per Acre (TPA), is a good approximation for the number of trees that meet a certain size requirement within a given area. Regions with a relatively high TPA, often indicate a high number of small trees such as saplings, whereas a treed area with a low TPA indicates a low density of large trees. TPA was calculated under two conditions, the first included TPA for all trees greater than or equal to 1-foot tall (≥1’ tall) and the second included TPA for all trees greater than or equal to six inches in diameter at breast height (≥6” DBH). Using first order LiDAR metrics, the following equation was used to calculate TPA ≥1’ tall:

$$TPA\ (> 1'tall) = e^{(9.002736 + (0.013568 * Percent\_first\_returns\_above\_2) + (-1.544788 * \ln(elev\_p20)))}$$

For larger trees, where TPA ≥6” DBH, the following equation was used:

$$TPA\ (\geq 6"\ dbh) = (6.18864 + (0.19670 * Percent\_first\_returns\_above\_mean) + (4.06816 * \ln(elev\_cv)))^2$$

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 1,869 reference sites from various sources were used to model tree size. Few reference samples were available for the pole and large tree size classes, so sites were added to these classes using expert knowledge, topographic data, and image interpretation techniques. The tree size product was validated with 30 samples (120 total) that were randomly withheld from each class. This provides 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 (<5" DBH)*, 2) *TS2 Pole (5–8.9" DBH)*, 3) *TS3 Medium (9–20.9" DBH)*, and 4) *TS4 Large (≥21" DBH).*

Two random forest models were generated because Annette Island was not included in the 2019 Forest Service resource imagery acquisition which was used to model the rest of the project area (Figure 7). Annette Island tree size was modeled using all of the reference data but excluded the predictive covariates derived from the 2019 Forest Service resource imagery. Conversely, the remaining project area was modeled using a subset of the reference data, which excluded the legacy data from Annette Island but included the Forest Service resource imagery covariates. This workflow was adopted so that resource imagery could be used in modeling the bulk of the project area. Both models performed similarly, and the validation dataset included points from both modeling extents.

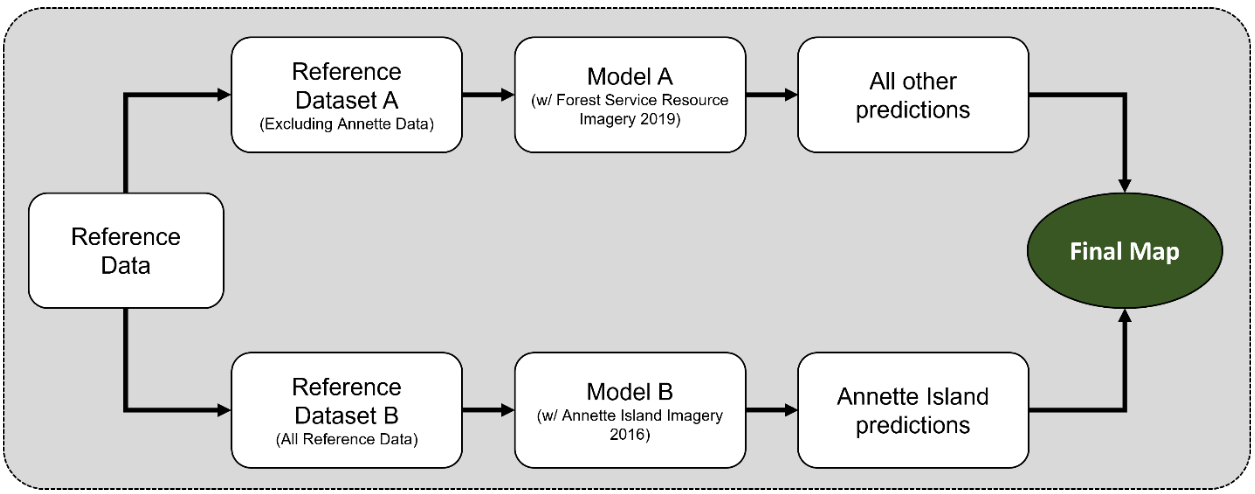

Figure 6.—Ketchikan Misty Fjords Tree Size modeling workflow. Two modeling pathways were developed to model Tree Size depending on the availability of high-resolution imagery.

Draft Map Review

After the initial models were reviewed and optimized by GTAC personnel, a draft version was created for each map layer. These layers were provided to local and regional experts for review within a web application where edits and feedback could be submitted. An additional review was conducted concurrently by GTAC personnel where the map products were systematically checked for classification error.

Upon completion of the draft map review, the edits and comments were compiled and used by GTAC to revise the draft products. Areas of misclassification were addressed by incorporating manual edits directly into the map including areas of known confusion, such as areas with persistent shadow or along shorelines. 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 the vegetation type of a segment from *nonforested* class to a *forested* class, the vegetation mask would have been removed and the modeled output for tree canopy cover would be reattributed back to the segment.

Results/Discussion

Vegetation Type

The final vegetation type map consisted of 28 classes and eight map groups: 10 *conifer forest* types, two *broadleaf forest* types, two *mixed forest* types, four *shrub* types, five *herbaceous* types, and five *non-vegetated* types (Table 4). *Forest* encompasses approximately 82% of the vegetated area within the Ketchikan Misty Fjords project area, while *shrub* covers about 16% and *herbaceous* covers about 2%. A full list of the vegetation type classes with their acreage is reported in Table 4 and their spatial distributions across Ketchikan Misty Fjords is depicted in Figure 7. A large portion of the Ketchikan Misty Fjords project area traverses the heavily glaciated mountains, so the higher altitudes consist of large swaths of *Barren* rock and *Snow/Ice* particularly on the mainland in the Misty Fjords National Monument Wilderness. The landscape transitions to vegetated areas below the mountain peaks and receding glaciers, where *Ericaceous Shrub* and *Mesic Herbaceous* species would start to colonize and become the predominant vegetation classes in the high-altitude areas. Further down the elevation gradient, vegetation typically transitions to areas of *tall shrub* just above the tree line and in avalanche chutes. A matrix of subalpine conifer types, rolling bogs, *tall shrubs,* and *herbaceous* classes would start to become more prevalent below the tree line before mixes of *Mountain Hemlock* and *Sitka Spruce-Western Hemlock* would begin to dominate the lower mountain slopes. *Sitka Spruce* and *Black Cottonwood* would frequently occupy the upper canopies of the valley bottoms along the mainland rivers in pure stands and in mixes (*Sitka Spruce-Black Cottonwood*) with different *tall shrub* and *herbaceous* classes occupying the canopy openings. Areas of *Yellow* and *Red Cedar, Mixed Conifer,* and *Western Hemlock* would often become the predominant vegetation types on south facing slopes and would often intermix with *Forested Peatlands* in areas with low elevation and poor soil drainage. For the islands of Ketchikan Misty Fjords, the vegetation composition was similar, but with *Red Alder* becoming the predominate broadleaf species in riparian corridors instead of *Black Cottonwood*.

Vegetation Type Accuracy Assessment

Accuracy assessments for vegetation type and their corresponding map group were conducted using image interpreted data. To collect sites for interpretation, a stratified random sample was performed on the vegetation map and a total of 840 sites were selected (30 per class). This approach, although justified given the resource limitations common to most accuracy assessments, inherently biases the sample. This bias occurs because it is based on the mapped extent of each class and consequently, relies on the error of commission of the map. The error of omission is then disproportionately impacted in the accuracy assessment using this approach since a truly random statistical sample could not be obtained. However, without this approach, the assessment would prevent the analysis of rarer classes without an unreasonably large sample size.

Each validation site was assessed by three independent image interpreters, one from GTAC and two from the Tongass National Forest. These interpreters were asked to assign a primary call on the vegetation type for each site. Determining a vegetation type could be difficult for some sites, especially when vegetation cover approaches 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 allowed us to use two separate methods to assess the accuracy of the vegetation type map. The first method contrasted the modeled vegetation classes of the 840 sites against the primary calls of the three interpreters. In this assessment, a site was considered correctly classified if its modeled class matched *any of the interpreter's primary calls*. If none of the primary calls matched the modeled mapped class, the process looked to see if there was a majority between the three primary calls to show which vegetation classes were getting confused in the error matrix. If a majority did not exist, the assessment used the primary of the GTAC interpreter for the error matrix (Appendix B).

The second method used the secondary call, in conjunction with the primary call, to produce an additional more 'fuzzed' assessment where both the primary and secondary calls were considered correct. A site was 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 error matrix. If a majority did not exist between calls, the assessment used the primary call of the GTAC interpreter. The fuzzed assessment allows the interpreters to acknowledge the uncertainty 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. This increases accuracy because it allows more chances for the mapped classes to match the image interpreted reference data.

Overall accuracy for the final vegetation type map was 74% using primary calls (Appendix B) and 81% using the fuzzed assessment (Appendix C). Between the three interpreters, there was a 25% agreement for their primary calls (Figure 8). The overall accuracy between each interpreter's primary call varied: the primary calls from Interpreter 1 matched the mapped classes 57% of the time (475/840), the primary calls from Interpreter 2 matched the mapped classes 52% of the time (434/840), and the primary calls from Interpreter 3 matched the mapped classes 34% of the time (285/840). These accuracy discrepancies demonstrate the variability inherent to the interpretation process, especially when evaluating a complicated landscape using a relatively complex classification system. This result also emphasizes the importance of not solely relying on the individual accuracy of each class, but rather being able to utilize the error matrix to extract additional information and gain a deeper understanding of how the classes are interacting on the map (Appendix B).

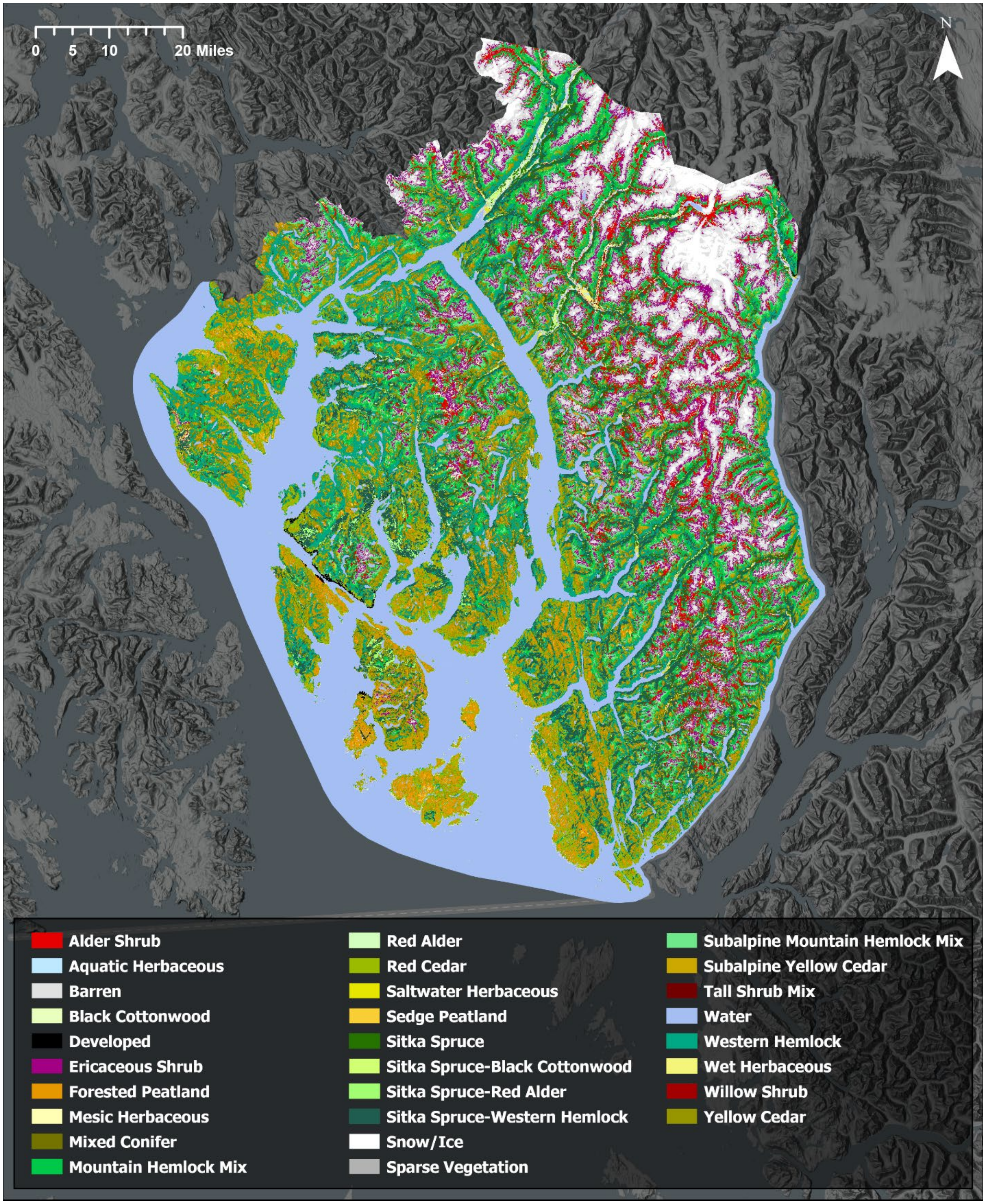

Figure 7 .—Vegetation classes across the project area.

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

Map Group	Vegetation Type	Acres	Percent of Study Area	Percent of Vegetated Area
Conifer Forest	Sitka Spruce	97,730	2.13%	3.37%
	Sitka Spruce-Western Hemlock	282,541	6.17%	9.73%
	Western Hemlock	479,231	10.47%	16.50%
	Mountain Hemlock Mix	415,157	9.07%	14.30%
	Mixed Conifer	116,516	2.55%	4.01%
	Red Cedar	216,182	4.72%	7.44%
	Yellow Cedar	291,243	6.36%	10.03%
	Forested Peatland	193,193	4.22%	6.65%
	Subalpine Mountain Hemlock Mix	208,637	4.56%	7.18%
	Subalpine Yellow Cedar	45,749	1.00%	1.58%
Broadleaf Forest	Black Cottonwood	7,580	0.17%	0.26%
	Red Alder	11,129	0.24%	0.38%
Mixed Forest	Sitka Spruce-Black Cottonwood	4,018	0.09%	0.14%
	Sitka Spruce-Red Alder	16,535	0.36%	0.57%
Shrub	Alder Shrub	257,168	5.62%	8.86%
	Willow Shrub	7,622	0.17%	0.26%
	Tall Shrub Mix	641	0.01%	0.02%
	Ericaceous Shrub	192,415	4.20%	6.63%
Herbaceous	Aquatic Herbaceous	1,095	0.02%	0.04%
	Saltwater Herbaceous	5,078	0.11%	0.17%
	Wet Herbaceous	10,428	0.23%	0.36%
	Mesic Herbaceous	21,421	0.47%	0.74%
	Sedge Peatland	22,763	0.50%	0.78%
TOTAL VEGETATED AREA		**2,904,072**	**63.43%**	**100%**
Non-Vegetated	Sparse Vegetation	99,150	2.17%	
	Barren	276,627	6.04%	
	Water	1,199,088	26.19%	
	Snow/Ice	94,180	2.06%	
	Developed	5,000	0.11%	
TOTAL AREA		**4,578,117**	**100%**	

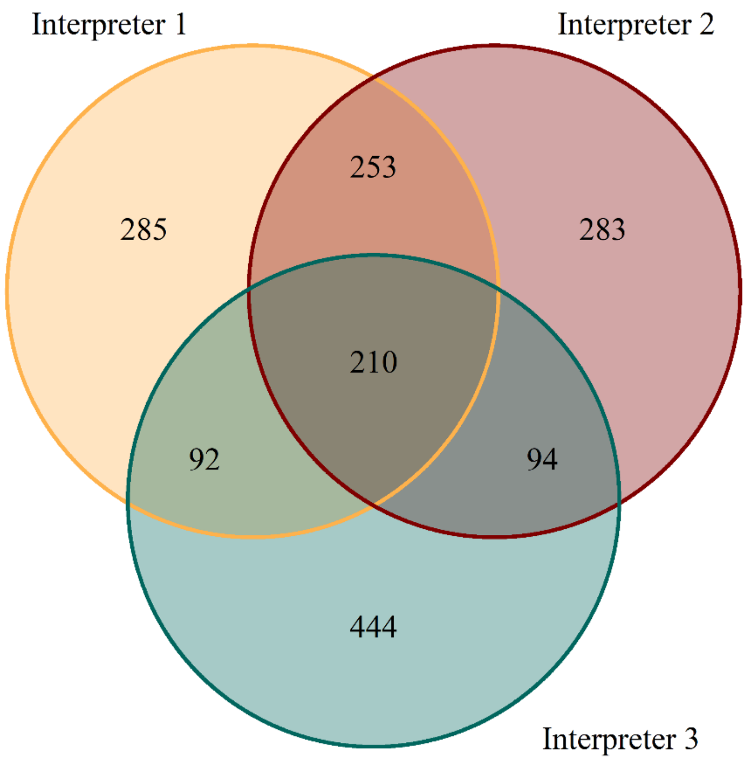

Figure 8.—Primary vegetation type call agreement between Image Interpreters (n = 840 per interpreter).

A total of 28 vegetation type classes were evaluated in the accuracy assessment. These vegetation types are nested into six lifeform map groups: *Conifer Forest, Broadleaf Forest, Mixed Forest, Shrub, Herbaceous,* and *Non-Vegetated.* Using the primary calls from the image interpreted validation data, the accuracy assessment resulted in an overall accuracy of 89% at the map group-level. Overall area-weighted accuracies were calculated for both vegetation type and map group as well. Area-weighted accuracy considers the relative proportion that each vegetation type class occupies on the map to reflect a more accurate estimate of overall map accuracy for the project area. For vegetation type, the area-weighted accuracy was 82% for primary calls and 87% for the accuracy assessment that used both primary and secondary calls. Map group-levels achieved an area-weighted accuracy of 97% (Table 6).

Table 5.—Error matrix of the Ketchikan Misty Fjords Existing Vegetation Map at the map group-level.

Map Group Accuracy Assessment		Reference Data						User's Accuracy	Commission Error
		Conifer Forest	Broadleaf Forest	Mixed Forest	Shrub	Herbaceous	Non-Vegetated		
Map Data	Conifer Forest	296	0	0	0	2	2	99%	1%
	Broadleaf Forest	6	39	6	8	1	0	65%	35%
	Mixed Forest	13	4	42	1	0	0	70%	30%
	Shrub	5	4	1	104	2	4	87%	13%
	Herbaceous	15	1	0	8	123	3	82%	18%
	Non-Vegetated	0	0	0	3	0	147	98%	2%
Producer's Accuracy		88%	81%	86%	84%	96%	94%	Kappa	0.86
Omission Error		12%	19%	14%	16%	4%	6%	Overall Accuracy	89%
								Area-Weighted Accuracy	97%

LiDAR Structure Metrics

Eight forest structure metrics were derived using LiDAR data and linear regression equations developed by TNC: tree canopy cover, biomass, GBF, two QMD metrics, SDI, and two TPA metrics. For areas where LiDAR data was not acquired, each structure metric was extrapolated to the remainder of the project area using a random forest regression model trained with 10,000 segments randomly selected from the LiDAR extent on Gravina and Prince of Wales Islands. Each forest metric was then validated by randomly selecting an additional 500 segments from Gravina Island that were not included in the training dataset to compare the predicted values from the random forest model with the LiDAR derived metric value (Figure 9). Note that because metrics derived from LiDAR data are known to be reliable, these values were considered truth, “observed values”, to evaluate model performance outside of the LiDAR extent.

To determine tree canopy cover within the LiDAR extent, a first order metric—the proportion of all-returns above 2 meters—was used as a proxy. The first order LiDAR metric was calculated directly from the LiDAR data without using additional models or inputs. Whereas the other desired forest metrics are second order metrics, which were calculated using a combination of first order metrics and linear regression equations developed by the TNC (Reynolds, 2019). Comparisons between the LiDAR derived canopy cover and the random forest modeled values showed an R^2 of 0.94 and an RMSE of 6.74% (Table 7; Figure 9). Project-wide acreage summaries for each canopy cover class are provided in Table 8. 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 is the threshold that distinguished *forest* classes from other vegetation types. The remaining second order LiDAR metrics were derived using linear regression equations developed by the TNC (Reynolds, 2019). The corresponding R^2 and RMSE values for each LiDAR structure metric are also reported in Table 7.

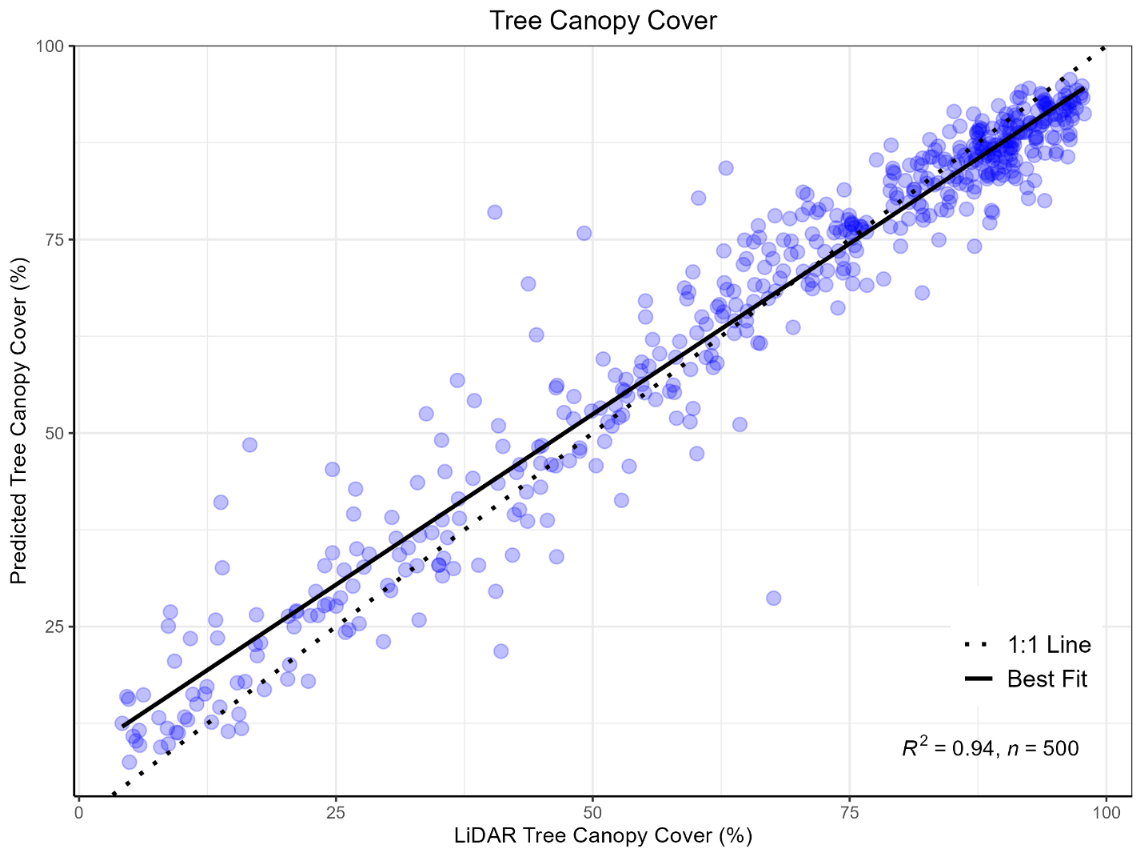

Figure 9.—Scatterplot (blue dots) of LiDAR derived tree canopy cover percent values (x-axis) vs. predicted tree canopy cover percent values (y-axis).

Table 6.—LiDAR forest structure metrics validation. R^2 *and RMSE values for each random forest model.*

Forest Metric	R^2	RMSE
Tree Canopy Cover (%)	0.94	6.74
Biomass (Mg/acre)	0.88	21.34
Gross Board Feet	0.83	7899.12
QMD ≥2” DBH	0.83	1.85
QMD ≥9” DBH	0.84	1.82
SDI ≥9” DBH	0.87	43.60
TPA ≥1' tall	0.78	410.18
TPA ≥6” DBH	0.89	14.44

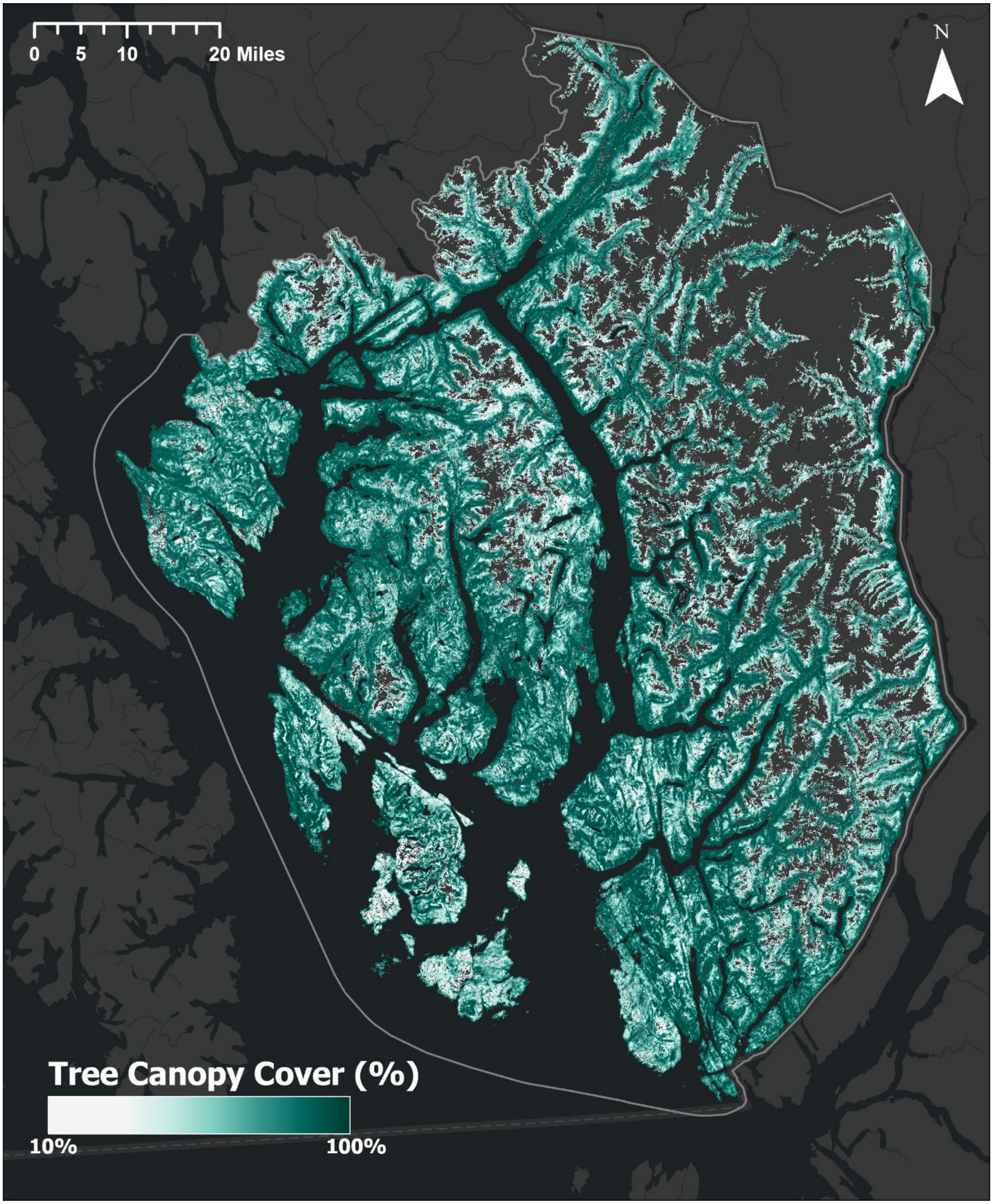

Figure 10.—Tree canopy cover across Ketchikan Misty Fjords.

Table 7.—Tree canopy cover acreage summary.

Tree Canopy Cover Class	Acres	Percent of Forested Area
Closed (60−100%)	1,396,239	58.53%
Open (25−59%)	726,911	30.47%
Woodland (10−24%)	262,292	11.00%
Total	2,385,441	100%

Tree Size

The final tree size map for Ketchikan Misty Fjords was generated using all areas classified as *forest* (Figure 11). Tree size was defined as the plurality diameter class forming the uppermost canopy layer when viewed from above, discounting over-topped trees. 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 are overtopped by larger trees are not counted in the diameter class plurality determination. Acreage summaries of the tree size classes are provided in Table 9.

The tree size product was validated with 30 samples (120 total) that were randomly withheld from each of the four tree size classes. The overall accuracy for *tree size* was 76% with an area-weighted accuracy of 70% (Table 10). Ultimately, the final tree size map (Figure 11) used all reference data, meaning that data withheld for accuracy assessment were reintroduced to create the most accurate *tree size* map.

Table 8.—Tree size acreage summary.

Tree Size Class	Acres	Percent of Forested Area
TS1 (<5" DBH)	518,350	21.7%
TS2 (5−8.9” DBH)	157,309	6.6%
TS3 (9−20.9” DBH)	1,481,262	62.1%
TS4 (≥21” DBH)	228,520	9.6%
Total	2,385,441	100%

Table 9.—Error matrix for thematic tree size.

Tree Size Class		**Reference Data**				User's Accuracy	Commission Error
		TS1 (<5" DBH)	TS2 (5–8.9" DBH)	TS3 (9–20.9" DBH)	TS4 (≥21" DBH)		
Map Data	TS1 (<5" DBH)	24	1	0	0	96%	4%
	TS2 (5–8.9" DBH)	4	23	1	0	82%	18%
	TS3 (9–20.9" DBH)	2	6	28	14	56%	44%
	TS4 (≥21" DBH)	0	0	1	16	94%	6%
Producer's Accuracy		80%	77%	93%	53%	Kappa	0.70
Omission Error		20%	23%	7%	47%	Overall Accuracy	76%
						Area-Weighted Accuracy	70%

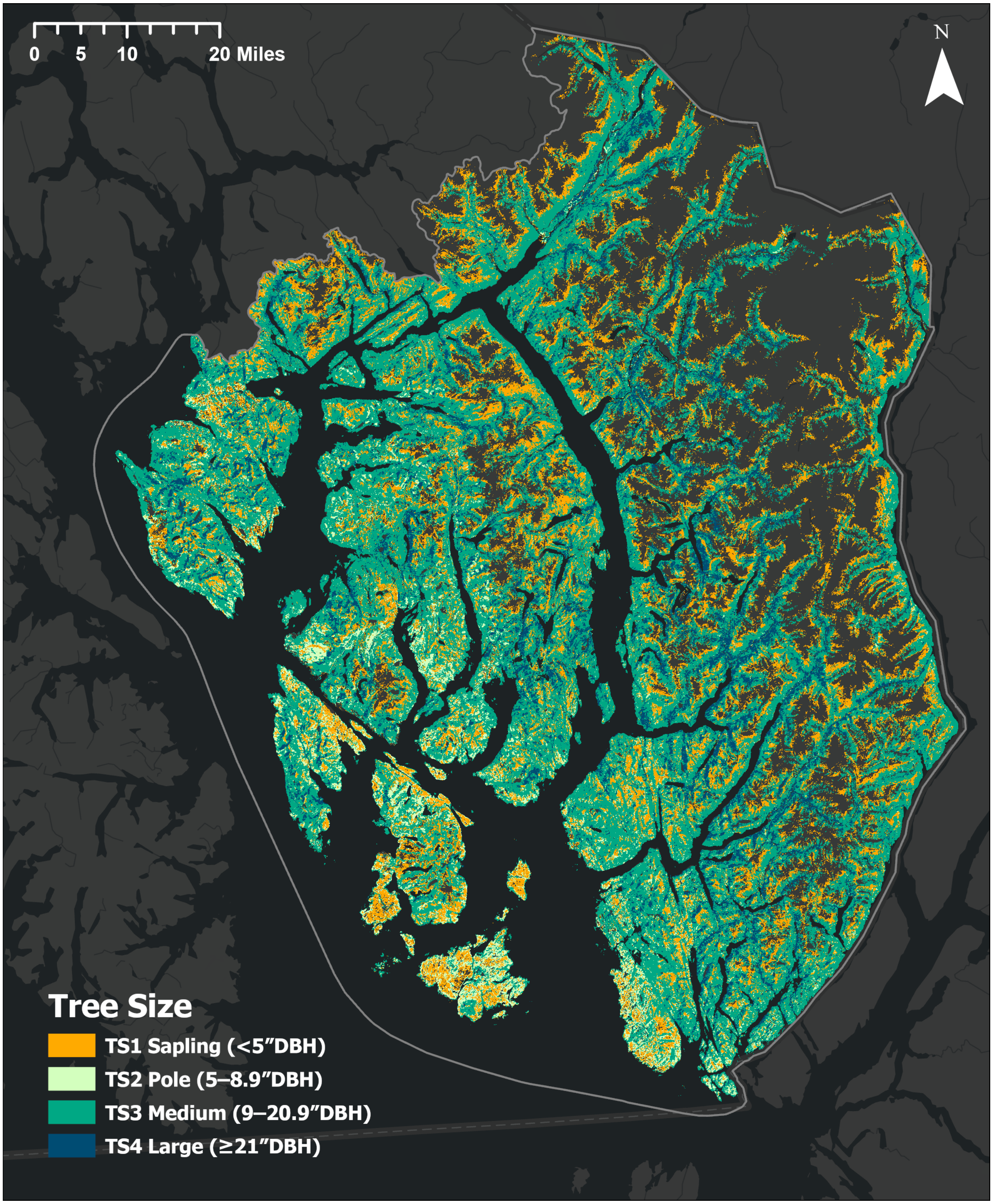

Figure 11.—Tree size across Ketchikan Misty Fjords.

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 available data. Map accuracy has an inverse relationship with classification complexity, meaning that with each additional class, there is an increased likelihood in class confusion. Considering this, the overall vegetation type class accuracy was 74% using primary calls from the interpreters (Appendix B). This level of accuracy is consistent with results from other mid-level vegetation mapping projects (Bellante et al., 2013, 2015, 2020, 2021; Dangerfield et al., 2022; Day et al., 2022) and is reasonable with the final map depicting 28 unique vegetation types. The compilation of the various vegetation structure outputs for each of the different modeling scenarios results in seamless data products that depict vegetation structure patterns across the Ketchikan Misty Fjords project area. Even though localized structure model accuracy may vary depending on the source data used (i.e., LiDAR vs. IfSAR), the overall forest structure patterns were captured effectively, and the accuracy of each metric is consistent with previous project areas (Bellante et al., 2020, 2021; Dangerfield et al., 2022; Day et al., 2022).

Individual class accuracies were computed within map group, vegetation type, and tree size. There are two ways to analyze individual class accuracy: 1) producer's accuracy, which is the proportion of sites correctly mapped for a class relative to the total number of sites for 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 a class relative 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 represents what is on the ground. For example, *Sitka Spruce-Western Hemlock* had a producer's accuracy of 49% 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 *Sitka Spruce-Western Hemlock confusion* came at the expense of two other *Conifer Forest* classes— *Sitka Spruce* and *Western Hemlock* (Appendix B). This type of confusion is intuitive since *Sitka Spruce-Western Hemlock* 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. Confusion between various *Conifer Forest* types that are comprised of similar species (such as *Sitka Spruce*, *Hemlock*, and *Sitka Spruce-Western Hemlock* types) indicates a lower error severity as compared to confusion between different lifeforms, such as *Conifer Forest* with *Herbaceous* types.

The assessment discussed in the previous paragraph used samples selected using a stratification of the map or ground data that was set aside. Both sample techniques have biases. The map stratification biases the error of omission in the map validation, while the ground data is biased by accessibility. Since the true distribution of each vegetation type cannot be known, stratification using the map is the best method to obtain a sample for accuracy assessment. However, the distribution of validation sites may not correspond to the relative proportions of the cover types found across the project area, meaning that overall map validation could be disproportionately influenced by rarer classes or by more accessible classes. To account for this bias, 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), multiplying by the proportion of the relative area that each class occupies on the final map (the area weight factor), and summating across every mapped class. Calculating an area-weighted accuracy that considers the relative proportion, or abundance, of the mapped classes provides a more representative measure of overall map quality. 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.

When studying the error matrices, even classes with relatively low accuracies may still provide important spatial information regarding vegetation assemblages of interest. Vegetation occurs along a continuum across the landscape and rarely conforms to a discrete boundary. Analyzing the error matrices allows a user to apply what they know about species' ecology to discriminate between errors caused by erroneous model associations (*e.g.,* a shadow classified as a water body) and errors from logical confusions. For example, if a segment was misclassified as *Yellow Cedar* when in the field it is *Red Cedar,* it does not mean that the segment does not also contain *Yellow Cedar*. Both vegetation types occupy similar niches on the landscape and are likely to overlap especially within transition zones along the elevational gradient where the predominant cedar species transitions from Red Cedar at lower elevations to Yellow Cedar at higher elevations (Caouette et al., 2016). By the key's definition, the *Red Cedar* class (Red cedar with ≥40% relative canopy cover) can contain a matrixed group of vegetation and likely consists of a mix of Red Cedar (*Thuja plicata*) and other conifer species like Yellow Cedar (*Callitropsis nootkatensis*), Shore pine (*Pinus contorta* subsp. *contorta*), and Western Hemlock (*Tsuga heterophylla*). Therefore, depending on the user's needs, valuable information can be extracted from classes that have lower accuracy, but it does require some interpretation of the error matrix. Interpretations from the accuracy information and knowledge of the landscape may be necessary to gain a comprehensive understanding of class relationships since individual class accuracy numbers—when taken by themselves—do not tell the whole story.

Conclusion

Existing vegetation for this project was mapped through a partnership with the Tongass National Forest, the Alaska Regional Office (Region 10), and GTAC. The final products comprises ten distinct, integrated feature layers: 1) vegetation type, 2) tree canopy cover, 3) biomass (Mg) for trees ≥6" DBH, 4) GBF for trees ≥9" DBH, 5) QMD for trees ≥2" DBH, 6) QMD for trees ≥9" DBH, 7) SDI for trees ≥9" DBH, 8) TPA for trees ≥1' tall, 9) TPA ≥6" DBH, and 10) thematic tree size. The vegetation type map consists of a total of 28 classes, including 23 vegetation classes and five classes encompassing other land cover types. The remaining forest structure metrics were generated for areas classified as *forest*. 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 Ketchikan Misty Fjords.

This project used an image object-based approach, and therefore, relied on a semi-automated segmentation process to develop segments 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 from image interpretation were intersected with the corresponding segments to extract associated statistics and to produce the predictive classification models. Most of the reference information was collected during the growing season of 2022 and consequently the maps are considered indicative of the existing vegetation conditions found in Ketchikan Misty Fjords during the summer of 2022.

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 limits the amount of light energy reflected by earth objects for detection by remote sensing instruments. The climate of Southeast Alaska makes obtaining cloud-free imagery difficult, especially when data acquisition has seasonal constraints and imaging sensors have infrequent revisit schedules. Despite these challenges, data sources were strategically used 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 89% and 74% accuracy when only using primary calls. The fuzzed assessment using primary and secondary calls for vegetation type showed an overall accuracy of 81%. The accuracy assessment for thematic tree size showed that it was mapped with a 76% 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 97% for map group, 82% for vegetation type (when using primary calls), 97% for the fuzzed assessment, and 70% for tree size. Lastly, the LiDAR derived structure products also showed strong agreement between modeled values and the LiDAR derived values (Table 7). Collectively, these accuracies show that final existing vegetation map products effectively capture the vegetation and forest composition patterns across Ketchikan Misty Fjords.

These products can be used in numerous ways to assist resource specialists and land managers. Existing vegetation maps can inform further project-level investigations, vegetation management, fire behavior, wildlife habitat modeling, and provide region-wide estimates of resource availability and status. This project was made possible through a dedicated collaborative team effort over a span of several years. Different mapping methods were employed based on the available data, desired map classes, and mapping objectives. These methods used the best available science and will inform future mapping efforts to make regionally consistent maps across coastal Alaska. This project is part of a larger mapping effort to create existing vegetation datasets across the Tongass National Forest and Region 10. As of this publication, six existing vegetation mapping projects, including Ketchikan Misty Fjords, have been completed across Region 10: Yakutat Forelands, Copper River Delta, Kenai Peninsula, Prince of Wales, and Cordova Existing Vegetation Map Projects (Bellante et al., 2013, 2015, 2020, 2021; Dangerfield et al., 2022; Day et al., 2022). The Glacier Existing Vegetation Map Project is in the finalization steps, which will be the last area needed to complete the forest-wide existing vegetation map for the Chugach National Forest. Two additional project areas (Northern and Central Tongass) are currently being mapped to complete the Tongass National Forest Existing Vegetation Map. Once the Tongass National Forest has been mapped, the vegetation types will be crosswalked to a common vegetation type classification key to create a Tongass-wide cohesive map product (Appendix D). The crosswalk will convert the vegetation types from the Prince of Wales project to match the remaining Tongass project areas (Ketchikan Misty Fjords, Central, and Northern Tongass). The crosswalk is necessary because the vegetation type classification key for the Tongass was not completed when Prince of Wales was being mapped. Notable differences between the Prince of Wales and Ketchikan Misty Fjords Existing Vegetation Map products and how they will be crosswalked are outlined in Appendix D. 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.

For more information please refer to the Alaska Region, Managing the Land, Resource Management, Plant Sciences and Ecology website for links to the Ketchikan Misty Fjords Existing Vegetation Map 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.

References

Bellante, G., Boucher, T., Homan, K., Schrader, B., Wittwer, D., Charnon, B., Schulz, B., Goetz, W., Pan, C., Megown, K., & Pugh, N. (2020). *Kenai Peninsula Existing Vegetation Map Project*. GTAC-10209-RPT1

Bellante, G., Goetz, W., Maus, P., Develice, R., Riley, M., & Megown, K. (2013). *Copper River Delta Existing Vegetation Map Project*. RSAC-10075-RPT1

Bellante, G., Goetz, W., Maus, P., Riley, M., Wittwer, D., Schrader, B., Johnson, E., & Megown, K. (2015). *Yakutat Foreland Existing Vegetation Map Project*. RSAC-10106-RPT1

Bellante, G., Pan, C., Day, T., Dillman, K., Homan, K., Krosse, P., Schrader, B., Wittwer, D., Goetz, W., Pugh, N., Megown, K., & Sheets, R. (2021). *Prince of Wales Existing Vegetation Map Project*. GTAC-10230- RPT1

Breiman, L. (2001). Random Forests. *Machine Learning*, *45*, 5–32. https://doi.org/10.1023/A:1010933404324

Caouette, J. P., Steel, E. A., Hennon, P. E., Cunningham, P. G., Pohl, C. A., & Schrader, B. A. (2016). *Influence of elevation and site productivity on conifer distributions across Alaskan temperate rainforests*. *261*(October 2010), 249–261.

Congalton, R. G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment*, *37*(1), 35–46. https://doi.org/10.1016/0034-4257(91)90048-B

Crist, E. P., & Cicone, R. C. (1984). A Physically-Based Transformation of Thematic Mapper Data---The TM Tasseled Cap. *IEEE Transactions on Geoscience and Remote Sensing*, *GE-22*(3), 256–263. https://doi.org/10.1109/TGRS.1984.350619

Cutler, D. R., Edwards, T. C., Beard, K. H., Cutler, A., Hess, K. T., Gibson, J., & Lawler, J. J. (2007). Random Forest for Classification in Ecology. *Ecology*, *88*(11), 2783–2792. https://doi.org/10.1890/07-0539.1

Dangerfield, C., Bellante, G., Day, T., Mohatt, K., Boucher, T., Homan, K., Wittwer, D., Pugh, N., Goetz, W., & Megown, K. (2022). *Cordova Existing Vegetation Map Project*. GTAC-10265-RPT1

Day, T., Bellante, G., Pugh, N., Homan, K., Boucher, T., Mohatt, K., Wittwer, D., Dangerfield, C., Goetz, W., & Megown, K. (2022). *Copper River Delta Vegetation Structure 2021 Map Project Report*. GTAC-10255-RPT1

Ellenwood, J. R., Krist, F. J. J., & Romero, S. A. (2015). *National Individual Tree Species Atlas* (FHTET-15-0). U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team.

FGDC. (2008). *National vegetation classification standard. Version 2.0.* (Issue February). U.S. Geological Survey Committee, Federal Geographic Data Committee (FGDC), Vegetation Subcommittee.

http://www.ncbi.nlm.nih.gov/pubmed/12180183

Graham, E. (2022). *Hemlock Sawfly: Current Status in Alaska (2022 Update)*. https://www.fs.usda.gov/detailfull/r10/forest-grasslandhealth/?cid=FSEPRD568804&width=full

Graham, E. (2023). *Western Blackheaded Budworm: Current Status in Alaska (2023 Update)*. https://www.fs.usda.gov/detailfull/r10/forest-grasslandhealth/?cid=FSEPRD646066&width=full

Heidemann, H. K. (2014). Lidar Base Specification. In *Collection and Delineation of Spatial Data* (Issue November). U.S. Geological Survey Standards. https://pubs.usgs.gov/tm/11b4/Version1.2/tm11-B4.pdf

Nelson, M. L., Brewer, K. C., & Solem, S. J. (2015). Existing Vegetation Classification, Mapping, and Inventory Technical Guide Version 2.0. *United States Department of Agriculture*, 1–212.

Nowacki, G. J., Spencer, P., Fleming, M., Brock, T., & Jorgenson, T. (2001). Unified Ecoregions of Alaska: 2001. In *Open-File Report*. https://doi.org/10.3133/ofr2002297

Reineke, L. H. (1933). Perfection a stand-density index for even-aged forest. *Journal of Agricultural Research*, *46*(7), 627–638. https://www.fs.usda.gov/research/treesearch/60134

Reynolds, C. (2019). *LiDAR-derived forest metric models for Prince of Wales Island, Alaska*. *November*.

Roussel, J.-R., & Auty, D. (2020). *lidR: Airborne LiDAR Data Manipulation and Visualization for Forestry Applications*. https://cran.r-project.org/package=lidR

Roussel, J.-R., Auty, D., Coops, N. C., Tompalski, P., Goodbody, T. R. H., Meador, A. S., Bourdon, J.-F., de Boissieu, F., & Achim, A. (2020). lidR: An R package for analysis of Airborne Laser Scanning (ALS) data. *Remote Sensing of Environment*, *251*(February), 112061. https://doi.org/10.1016/j.rse.2020.112061

Ryherd, S., & Woodcock, C. (1996). Combining spectral and texture data in the segmentation of remotely sensed images. *Photogrammetric Engineering and Remote Sensing*, *62*(2), 181–194.

Standish, J. T., Manning, G. H., & Demaerschalk, J. P. (1985). *Development of biomass equations for British Columbia tree species*. Canadian Forestry Service Pacific Foresl Research Centre.

Trimble Germany GmbH. (2021). *Trimble Documentation eCognition Developer 10.1 Reference Book*. Trimble Germany GmbH.

Zhou, X., & Hemstrom, M. A. (2010). *Timber Volume and Aboveground Live Tree Biomass Estimations for Landscape Analyses in the Pacific Northwest* (Issue Gen. Tech. Rep. PNW-GTR-819).

Appendix A: Vegetation Type Key

Master Key

1a. Total ***absolute*** tree cover is ≥10% 2
1b. Total ***absolute*** tree cover is <10% 4

2a. Tree ***relative*** cover of conifer species is ≥75% of tree species .... **Conifer Key**
2b. Tree ***relative*** cover is <75% conifer species 3

3a. Tree ***relative*** cover of broadleaf species is ≥75% of tree species .... **Broadleaf Key**
3b. Tree ***relative*** cover of broadleaf species is <75% of tree species .... **Mixed Broadleaf/Conifer Key**

4a. Shrub ***absolute*** cover is ≥25% .... **Shrub Key**
4b. Shrub ***absolute*** cover is <25% 5

5a. ***Absolute*** cover of herbaceous species is ≥25% (includes graminoids and/or forbs) .... **Herbaceous Key**
5b. ***Absolute*** cover of herbaceous species is <25% .... **Nonvascular/Sparse/Barren Key**

Vegetation Type Key

Conifer Forest

1a. Peatland forest (wetland indicators include stunted trees, cottongrass and tufted clubrush, Labrador tea and bog rosemary; open tree canopy typical). Sphagnum seen from above at least 25% cover 2
1b. Forest not in peatland habitat 4

2a. Shore pine ≥60% relative canopy cover .... **Shore pine peatland**
2b. Shore pine <60% relative canopy cover..........3

3a. Yellow cedar ≥40% relative canopy cover and stunted, peatland habitat .... **Yellow cedar peatland**
3b. Red cedar ≥40% relative canopy cover and stunted, peatland habitat .... **Red cedar peatland**
3c. Yellow cedar <40% relative canopy cover and most trees stunted, peatland habitat .... **Mixed conifer peatland**
(woodland and low percent cover, or the low productivity forest)

4a. High elevation forest <5 meter in height. Site productivity may be variable; however, average tree height within the segment is stunted (copperbush and heather may be present as indicators; canopy cover is typically open) …… 5
4b. Forest otherwise…… 6

5a. Yellow cedar ≥40% relative canopy cover and stunted………………………………… **Subalpine yellow cedar**
5b. Yellow cedar <40%, mountain hemlock with ≥75% relative canopy cover…………………………………………
……… **Subalpine mountain hemlock**
5c. Mountain hemlock <75% relative canopy cover, codominant with at least 15% Sitka spruce ……………
……………………………………………………………………………………… **Subalpine mountain hemlock – Sitka spruce**
5d. Mountain hemlock <75% relative canopy cover, codominant with at least 15% yellow cedar…………….
……………………………………………………………………………………… **Subalpine mountain hemlock – yellow cedar**
5e. If forested stand is not as above and multiple tree species are present …….. **Subalpine mixed conifer**

6a. Sitka spruce with ≥60% relative canopy cover; broadleaf trees or tall shrubs with <30% relative canopy cover…… **Sitka spruce**
6b. Sitka spruce with ≥60% relative canopy cover, broadleaf trees or tall shrubs with ≥30% relative canopy cover…………………………………………………………………………………………………… **Conifer-Broadleaf key**
6c. Sitka spruce with <60% relative canopy cover, no broadleaf trees present…………………………………………8

7a. Sitka spruce and Western hemlock combined are ≥90% total relative canopy cover; Sitka spruce at least 15% relative cover. Trees are codominant in the canopy …………………………………… **Spruce - Hemlock**
7b. Combined Sitka spruce and Western hemlock are < 90% total relative canopy cover……………………… 9

8a. Mountain hemlock with ≥75% relative canopy cover………………………………………… **Mountain hemlock**
8b. Mountain hemlock with <75% canopy cover ………………………………………………………………………………10

9a. Mountain hemlock present with <75% relative canopy cover, Sitka spruce is ≥15% relative cover and is co-dominant (combined canopy cover ≥90%) ……………………………… **Sitka spruce – Mountain hemlock**
9b. Mountain hemlock, if present, is <75% relative canopy cover; Sitka spruce is not present or if present not codominant ……11

10a. Subalpine or Pacific silver fir with ≥40% relative canopy cover …………………………………………………. **Fir**
10b. Subalpine or Pacific silver fir with <40% relative canopy cover …………………………………………………… 12

11a. Red ***or*** yellow cedar relative canopy cover is ≥40 …………………………………………………………………………13
11b. Red and yellow cedar are growing together and the combined relative canopy cover is ≥40%...........
……… 15

11c. Red or yellow cedar growing together or as a single species is <40% relative canopy cover………………. ……… 16

12. Red cedar with ≥40% relative canopy cover. Somewhat poorly drained soils with skunk cabbage >3% absolute cover …………………………………………………………………………………………………… **Red cedar swamp**
12b. Red cedar with ≥40% relative canopy cover; Skunk cabbage sparse to absent, moderately well drained soil ……… **Red cedar**
12c. Red cedar with <40% relative canopy cover ………………………………………………………………………… 14

13a. Yellow cedar ≥40% relative canopy cover, most trees not stunted; Somewhat poorly drained soils with skunk cabbage >3% absolute cover …………………………………………………………………**Yellow cedar swamp**
13b. Yellow cedar ≥40% relative canopy cover, most trees not stunted; Skunk cabbage sparse to absent, moderately well drained soil……………………………………………………………………………………… **Yellow cedar**

14a. Red and yellow cedar growing in somewhat poorly drained soils with skunk cabbage >3% absolute cover ……….. **Cedar swamp**
14b. Red and yellow cedar combined relative cover ≥40%, skunk cabbage sparse to absent, moderately well drained soils …….. **Cedar**

15a. Western hemlock with ≥60% relative canopy cover; Somewhat poorly drained soils with skunk cabbage >3% absolute cover……………………………………………………………………….. **Western hemlock swamp**
15b. Western hemlock with ≥60% relative canopy cover; Skunk cabbage sparse to absent, moderately well drained soil……………………………………………………………………………………………………… **Western hemlock**
15c. Western Hemlock with <60% relative canopy cover………………………………………………………………… 16

16a. Somewhat poorly drained soils with skunk cabbage >3% absolute cover; western hemlock always combined with other species in various relative canopy covers. Stand is mid to late-seral. ……**Mixed conifer swamp**
16b. Skunk cabbage sparse to absent, moderately well drained soil; western hemlock always combined with other species in various relative canopy covers. ……………………………………………………… **Mixed conifer**

Broadleaf Forest

1a. Red alder present with ≥75% ***relative*** cover ………………………………………………………………….. **Red alder**
1b. Black cottonwood present with ≥75% ***relative*** cover …………………………………………. **Black cottonwood**

Mix Conifer/Broadleaf Forest

1a. Black cottonwood with ≥25% ***relative*** cover and together with Sitka spruce comprise ≥75% ***relative*** cover ………………………………………………………………………………………… **Sitka spruce – Black cottonwood**

1b. Red alder with ≥25% ***relative*** cover and together with Sitka spruce comprise ≥75% ***relative*** cover …… **Sitka spruce – Red alder**
1c. Not as above. ……………………………………………………………………………… **Other mixed conifer - broadleaf**

Shrub

1a. Relative canopy cover of Sitka alder is ≥75% ………………………………………………………… **Alder shrub**

1b. Relative canopy cover of Sitka alder is <75% ……………………………………………………………………… 2

2a. Relative canopy cover of willow is ≥75% ……………………………………………………………… **Willow shrub**

2b. Relative canopy cover of willow is <75% ……………………………………………………………………………… 3

3b. Combined canopy cover of combined taller shrubs (≥1.5m) such as willow, spirea, copperbush, crabapple, elderberry, sweet gale, Sitka alder, salmonberry, devil's club, blueberry, etc. >25% ……… **Tall shrub**

3c. Combined tall shrub species <25%…………………………………………………………………………………… 4

4a. Peatland with shrubs <1.5 m (indicators include sphagnum peat, bog blueberry, bog cranberry, Labrador tea, bog laurel, or crowberry, etc. Other indicators include sedges, sundew, deer cabbage) …… **Shrub peatland**
4b. Not a peatland with shrubs <1.5 m (typically high elevation, mesic sites) …… **Ericaceous shrub**

Herbaceous

1a. Site is tidally influenced, vegetation is dominated by salt-tolerant species (e.g. *Carex lyngbei*) …………………………………………………………………………………………………… **Saltwater herbaceous**
1b. Site not tidally influenced, vegetation not dominated by salt-tolerant species ……………………………….2

2a. Site has permanent standing water with <25% emergent vegetation (rooting below the water). Dominant vegetation is aquatic or floating on the water surface …………………………… **Aquatic herbaceous**
2b. Site otherwise …….3

3a. Site a peatland with sedges such as cottongrass, tufted clubrush and scattered forbs (includes bog and poor fens) ………………………………………………………………………………………… **Sedge peatland**
3b. Site otherwise…… 4

4a. Site with fluctuating water table, soils are saturated, frequently with shallow standing water and dominated by mixed forbs and graminoids (includes rich fens, marshes, wet meadows) ……………………….. ……**Wet herbaceous**

4b. Site does not contain higher water table or seasonal standing water; Soils dry to mesic; mixed forbs and graminoids present (e.g. *Leymus* beach berms or subalpine/alpine shallow soils) ………**Mesic herbaceous**

Nonvascular/Sparse/Barren

1a. Total nonvascular vegetation cover is ≥25% ……………………………………………………………… **Nonvascular**

1b. Total nonvascular vegetation cover is <25% ……………………………………………………………………………… 2

2a. Total vascular vegetation ***absolute*** cover is ≥10% and <25% ……………………………… **Sparse vegetation**

2b. Total vascular vegetation ***absolute*** cover is <10% ……………………………………………………………………… 3

3a. Area is open water or a confined water course……………………………………………………………………… **Water**

3b. Not as above ……… 4

4a. Area is developed for urban, residential or administrative sites as well as rock pits, roads, marine access points, etc. ……………………………………………………………………………………………………… **Developed**

4b. Not as above ……… **5**

5a. Area is snowfield/ice covered ……………………………………………………………………………………… **Snow/Ice**

5b. Not as above …… **Barren**

Appendix B: Vegetation Type Error Matrix (Primary Calls)

Accuracy Assessment		Reference Data																												User's Accuracy	Commission Error
		SS	SS-WH	WH	MHmix	MC	RC	YC	FP	SA-MHmix	SA-YC	BC	RA	SS-BC	SS-RA	AS	WS	TSmix	ES	AHB	SWHB	WHB	MHB	SP	SV	BR	WA	S/I	DEV		
Map Data	SS	18	7	2	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60%	40%
	SS-WH	0	27	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	90%	10%
	WH	0	5	21	2	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70%	30%
	MHmix	0	1	0	25	0	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	83%	17%
	MC	2	2	8	2	14	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	47%	53%
	RC	0	1	0	0	3	25	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	83%	17%
	YC	0	1	3	2	7	3	10	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33%	67%
	FP	0	0	0	0	0	0	0	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	97%	3%
	SA-MHmix	0	0	0	1	0	0	0	1	22	4	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	73%	27%
	SA-YC	0	1	0	0	0	0	1	2	3	19	0	0	0	0	1	0	0	1	0	0	0	0	2	0	0	0	0	0	63%	37%
	BC	0	0	0	0	0	0	0	0	0	0	23	1	4	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	77%	23%
	RA	2	1	0	0	0	1	1	0	1	0	3	11	0	3	2	2	2	0	0	0	1	0	0	0	0	0	0	0	37%	63%
	SS-BC	4	0	0	0	0	0	0	0	0	0	1	0	21	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70%	30%
	SS-RA	1	7	1	0	0	0	0	0	0	0	0	4	0	16	1	0	0	0	0	0	0	0	0	0	0	0	0	0	53%	47%
	AS	0	0	0	2	0	0	0	0	4	0	0	0	0	0	21	0	0	1	0	0	0	1	0	1	0	0	0	0	70%	30%
	WS	0	0	0	1	0	1	0	0	0	0	0	0	0	0	8	19	1	0	0	0	0	0	0	0	0	0	0	0	63%	37%
	TSmix	1	0	0	0	0	0	0	0	0	0	3	2	0	1	0	6	14	0	0	0	1	0	0	2	0	0	0	0	47%	53%
	ES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29	0	0	0	0	0	1	0	0	0	0	97%	3%
	AHB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	0	1	0	0	0	0	1	0	0	93%	7%
	SWHB	2	0	0	0	0	4	0	1	0	0	0	0	0	0	0	0	0	0	1	21	0	0	0	1	0	0	0	0	70%	30%
	WHB	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	2	3	0	0	0	19	1	2	1	0	0	0	0	63%	37%
	MHB	0	2	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	24	1	0	0	0	0	0	80%	20%
	SP	0	0	0	1	0	0	0	2	0	2	0	1	0	0	0	0	0	0	0	0	1	0	23	0	0	0	0	0	77%	23%
	SV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	26	0	0	0	0	87%	13%
	BR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	28	0	0	0	93%	7%
	WA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	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	0	0	0	0	0	0	0	30	0	100%	0%
	DEV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	100%	0%
Producer's Accuracy		60%	49%	57%	69%	58%	68%	71%	76%	61%	76%	77%	58%	84%	59%	54%	66%	70%	81%	97%	100%	83%	89%	79%	74%	100%	97%	100%	100%	Kappa	0.7321
Omission Error		40%	51%	43%	31%	42%	32%	29%	24%	39%	24%	23%	42%	16%	41%	46%	34%	30%	19%	3%	0%	17%	11%	21%	26%	0%	3%	0%	0%	Overall Accuracy	74%
																														Area-Weighted Accuracy	82%

Appendix C: Vegetation Type Error Matrix (Primary & Secondary Calls)

Accuracy Assessment		Reference Data																												User's Accuracy	Commission Error
		SS	SS-WH	WH	MHmix	MC	RC	YC	FP	SA-MHmix	SA-YC	BC	RA	SS-BC	SS-RA	AS	WS	TSmix	ES	AHB	SWHB	WHB	MHB	SP	SV	BR	WA	S/I	DEV		
Map Data	SS	22	4	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	73%	27%
	SS-WH	0	28	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	93%	7%
	WH	0	4	24	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	80%	20%
	MHmix	0	1	0	26	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	87%	13%
	MC	2	2	5	1	19	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	63%	37%
	RC	0	0	0	0	3	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90%	10%
	YC	0	2	2	1	5	1	14	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	47%	53%
	FP	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100%	0%
	SA-MHmix	0	0	0	1	0	0	0	1	26	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	87%	13%
	SA-YC	0	1	0	0	0	0	1	3	2	21	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	70%	30%
	BC	0	0	0	0	0	0	0	0	0	0	26	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	87%	13%
	RA	2	2	0	0	0	1	1	0	1	0	2	15	0	2	1	1	1	0	0	0	1	0	0	0	0	0	0	0	50%	50%
	SS-BC	4	0	0	0	0	0	0	0	0	0	1	0	24	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	80%	20%
	SS-RA	1	5	2	0	0	0	0	0	0	0	0	2	0	19	1	0	0	0	0	0	0	0	0	0	0	0	0	0	63%	37%
	AS	0	0	0	2	0	0	0	0	2	0	0	0	0	0	21	0	0	2	0	0	0	1	0	2	0	0	0	0	70%	30%
	WS	0	0	0	1	0	1	0	0	0	0	0	0	0	0	3	24	1	0	0	0	0	0	0	0	0	0	0	0	80%	20%
	TSmix	1	1	0	0	0	0	0	0	0	0	3	1	0	0	0	3	19	0	0	0	0	0	0	2	0	0	0	0	63%	37%
	ES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	100%	0%
	AHB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29	0	0	0	0	0	0	1	0	0	97%	3%
	SWHB	1	2	0	0	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	0	0	1	0	0	73%	27%
	WHB	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	3	2	0	0	0	19	1	2	1	0	0	0	0	63%	37%
	MHB	0	2	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	24	1	0	0	0	0	0	80%	20%
	SP	0	0	0	1	0	0	0	2	1	1	0	1	0	0	0	0	0	0	0	0	1	0	23	0	0	0	0	0	77%	23%
	SV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	100%	0%
	BR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	29	0	0	0	97%	3%
	WA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	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	0	0	0	0	0	0	0	30	0	100%	0%
	DEV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	100%	0%
Producer's Accuracy		67%	52%	65%	72%	70%	79%	82%	73%	70%	95%	81%	79%	89%	86%	66%	77%	83%	88%	100%	100%	90%	92%	85%	83%	100%	94%	100%	100%	Kappa	0.8037
Omission Error		33%	48%	35%	28%	30%	21%	18%	27%	30%	5%	19%	21%	11%	14%	34%	23%	17%	12%	0%	0%	10%	8%	15%	17%	0%	6%	0%	0%	Overall Accuracy	81%
																														Area-Weighted Accuracy	87%

Appendix D: Tongass National Forest Dominance Type Crosswalk

Map Group	Dominance Type	Prince of Wales Map Unit	Ketchikan Misty Fjords Map Unit
Conifer Forest	Sitka Spruce	Sitka Spruce	Sitka Spruce
	Western Hemlock	Western Hemlock	Western Hemlock
	Western Hemlock Swamp (not in Prince of Wales key)		
	Spruce-Hemlock	Spruce-Hemlock	Sitka Spruce-Western Hemlock
	Cedar	Cedar	Red Cedar or Yellow Cedar
	Cedar Swamp (not in PoW key)		
	Red Cedar (not in PoW key)		Red Cedar
	Red Cedar Swamp (not in PoW key)		
	Yellow Cedar (not in PoW key)		Yellow Cedar
	Yellow Cedar Swamp (not in PoW key)		
	Shorepine	Mixed Conifer	Mixed Conifer
	Mixed Conifer		
	Mixed Conifer Swamp (not in PoW key)		
	Mountain Hemlock	Mountain Hemlock Mix	Mountain Hemlock Mix
	Sitka Spruce-Mountain Hemlock (Sitka Spruce/Mountain Hemlock on PoW)		
	Fir (Subalpine Fir on PoW)		
	Subalpine Mountain Hemlock		Subalpine Mountain Hemlock Mix
	Subalpine Mountain Hemlock-Sitka Spruce		
	Subalpine Mountain Hemlock-Yellow Cedar		
	Subalpine Mixed Conifer		
	Subalpine Yellow Cedar	NA	Subalpine Yellow Cedar
	Shorepine Peatland (Dwarf Shorepine on PoW)	Dwarf Conifer	Forested Peatland
	Dwarf Conifer		
	Yellow Cedar Peatland (Dwarf Yellow Cedar on PoW)		
	Red Cedar Peatland		
	Mixed Conifer Peatland		
	Mixed Species (PoW only)	Mixed Species	NA
Broadleaf Forest	Red Alder (Alder on PoW)	Red Alder	Red Alder
	Black Cottonwood (Cottonwood on PoW)	NA	Black Cottonwood
Mixed Forest	Sitka Spruce-Red Alder	Sitka Spruce-Red Alder	Sitka Spruce-Red Alder
	Sitka Spruce-Black Cottonwood	NA	Sitka Spruce-Black Cottonwood
Tall Shrub	Alder Shrub	Alder Shrub	Alder Shrub
	Willow Shrub	NA	Willow Shrub
	Tall Shrub Mix (Tall Shrub on PoW)	Tall Shrub	Tall Shrub Mix
Low Shrub	Low Shrubs (PoW only)	Low Shrubs	Ericaceous Shrub
	Ericaceous Shrub	Low Shrubs	
	Shrub Peatland	Low Shrubs	Sedge Peatland
Herbaceous	Aquatic Herbaceous	Aquatic Herbaceous	Aquatic Herbaceous
	Saltwater Herbaceous	Wet Herbaceous	Saltwater Herbaceous
	Wet Herbaceous		Wet Herbaceous
	Mesic Herbaceous		Mesic Herbaceous
	Sedge Peatland (not in PoW key)	NA	Sedge Peatland
Non-Vegetated	Sparse Vegetation	Barren/Sparse Vegetation	Sparse Vegetation
	Barren		Barren
	Water	Water	Water
	Snow/Ice (not in PoW key)	NA	Snow/Ice
	Developed	Developed	Developed