United States Department of Agriculture

GTAC-10209-RPT1

May 29, 2020

Kenai Peninsula Existing Vegetation Map Project

Bellante, G.; Boucher, T.; Charnon, B.; Goetz, W.; Homan, K.; Pan, C.; Pugh, N.; Megown, K; Schrader, B.; Schulz, B.; Wittwer, D. 2020. Kenai Peninsula Existing Vegetation Map Project. GTAC-10209-RPT1. Salt Lake City, UT: U.S. Department of Agriculture, Forest Service, Geospatial Technology and Applications Center. 39 p.

Abstract

An existing vegetation map was prepared in a collaborative effort between the Forest Service and multiple agency partners. 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 of the Kenai Peninsula. The final map comprises four distinct, integrated feature layers: 1) dominance type; 2) tree canopy cover; 3) tree size; and 4) tall shrub canopy cover. The dominance type map consists of 33 classes, including 28 vegetation classes and 5 other land cover types. Continuous canopy cover products were developed for areas classified as *forest* and *tall shrub*. Additionally, a thematic layer depicting tree diameter class categories was generated for areas classified as *forest*. Geospatial data, including remotely sensed imagery, topographic data, and climate information, were assembled to classify vegetation and produce the map. A semi-automated image segmentation process was used to develop the modeling units (mapping polygons), which delineate homogeneous areas of land cover. Land cover class determinations were made for field sites, collected on the ground or from above in a helicopter, in order to characterize associated mapping polygons. Subsequently, this reference data was used to develop the predictive random forest models that ultimately produced the final map products. Important model drivers included Sentinel 2 and Landsat 8 satellite imagery for dominance type prediction, while vegetation structure models relied heavily on Light Detection and Ranging (LiDAR) and Interferometric Synthetic Aperture Radar (IfSAR) data sources. The mapping process utilized various Forest Service Enterprise software, adopting the most contemporary methods and technology. Most of the reference information and geospatial data were collected in the summer of 2017, and therefore, the final map can be considered indicative of the existing vegetation conditions found on the Kenai Peninsula at that time. Once the final map was produced, an accuracy assessment was conducted to reveal individual class confusion and provide additional insight into the reliability of the final map for resource applications.

Authors

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

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

Kim Homan is the Geospatial Program Manager for the USFS Alaska region, Engineering and Information office in Juneau, AK.

Barb Schrader is the Regional Ecologist for the USFS Alaska region, Landscape and Vegetation Ecology Program in Juneau, AK.

Dustin Wittwer is the Remote Sensing Coordinator for the USFS Alaska region, Engineering and Information office in Juneau, AK.

Betty Charnon is the Invasive Species Coordinator for State and Private Forestry in Anchorage, AK.

Bethany Schulz (retired) is a Research Ecologist for USDA-FS Pacific Northwest Research Station in Anchorage, AK.

Wendy Goetz is a Vegetation Mapping Team Leader employed by RedCastle Resources, Inc. at the GTAC in Salt Lake City, UT.

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

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

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

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 auxiliary data sets, along with draft map and other product reviews. Peter Davis, now an employee of the US Forest Service, contributed invaluable mapping expertise and was instrumental in modeling portions of the Kenai Peninsula. We are also indebted to Mark Laker and John Morton, US Fish and Wildlife Service, for collection of high-resolution imagery during the summer of 2016, which provided the foundational image layer used in segmentation for non-Forest Service lands and was critical for photo interpretation. Sue Rodman with Alaska Department of Fish and Game provided valuable insight, leadership, and support during the project. Additionally, a special thanks to Dan Fehringer of Ducks Unlimited for his expertise of the local Alaska flora and organization of the helicopter reference data collection campaign.

We would like to thank the following contributing team members who provided expertise throughout the length of the project:

Katie Baer, Brandon Bornemann, Kate Mohatt, Erik Jackson, Sean Cahoon, Jason Herreman, Parker Martyn, Beth Koltun, Mitch Michaud, Timothy Mullet, Dawn Magness, Elizabeth Camarata, Melinda Lamb, Holly Russon, Kelsey Aho, Amy Miller, Bobbi Lay, Paul Maus, Tom Thompson

We thank you all.

Partnerships

Our partners played a vital role in providing large datasets, resources toward classification and analysis, field crews and field surveys, mapping needs and product uses, expertise in legacy data, designing and testing applications, training, review of draft maps and subject matter expertise in the development of the key. These partnerships are critical to ensure the highest level of integrity, objectivity, and usefulness for internal uses and for external consumption.

Federal Partners:

USDA Forest Service

- Alaska Regional Office
- Chugach National Forest
- State & Private Forestry
- Inventory & Monitoring Program
- Fire & Fuels Management
- Geospatial Technology & Applications Center (GTAC)
- Forest Inventory and Analysis (FIA)

U.S. Fish & Wildlife Service

- Kenai National Wildlife Refuge

National Park Service

- Alaska Regional Office
- Kenai Fjords National Park

State of Alaska Partners:

- Alaska Geospatial Council - Vegetation Working Group
- Alaska Department of Fish & Game

Private Partners:

- Ducks Unlimited

Local Partners:

- Kenai Peninsula All Lands/All Hands Partnership
- Kenai Peninsula Borough
- Kenai Watershed Forum

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Introduction

Maps of existing vegetation support resource managers by informing project- and landscape-level planning efforts with vegetation data that can be used in numerous applications. Use of existing vegetation maps can save time and money by eliminating work redundancies and informing a multitude of future management activities. Mission-critical Forest Service goals necessitate existing vegetation information for Forest planning, ecological assessment, forest health monitoring, and wildlife habitat management. Additionally, existing vegetation maps are commonly employed for fire risk assessment, natural resource inventories, silviculture, rare and sensitive species monitoring, invasive species modeling, recreation management, disturbance susceptibility evaluations, and climate change analyses. This project implemented consistent methodologies, which used empirical data leveraging technological advancement, to develop defensible map products that utilized the best available science. The resultant map establishes a baseline of landscape ecological condition through the depiction of vegetation dominance types, tree size, and canopy cover distributions.

Authority and funding for the Kenai Peninsula (from henceforth referred to as the Kenai) existing mapping project was provided by the Chugach National Forest, the USFS Alaska Regional Office including State and Private Forestry Fire and Fuels program, Kenai National Wildlife Refuge, and the Alaska Department Fish and Game. The Geospatial Technology and Applications Center (GTAC) produced this existing vegetation map using contemporary mapping methods, 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 a vegetation map to inform planning and management decisions pertinent to the Kenai.

Project Area

The Kenai mapping project is located in Southcentral Alaska and encompasses over 5.7 million acres. This periglacial maritime landscape provides critical habitat for migratory birds along the Pacific Flyway, large mammals such as moose and bears, and anadromous fisheries. The mapping extent consists of lands administered by federal, state, Kenai Borough, Alaska Native Corporation lands, and private entities. The entire Seward Ranger District and the northwestern portion of the Glacier Ranger District of the Chugach National Forest were mapped as part of this effort. The Kenai spans three ecoregions—1) Cook Inlet Basin; 2) Gulf of Alaska Coast; and 3) Chugach-St. Elias Mountains—and is characterized by lakes, rivers, low wetlands and bogs, coastal rainforest, and glaciated mountains (Nowacki et al. 2001). The terrain ranges from sea-level to over 6,600 ft in elevation. Between the stark topography and the rain-shadow of the Kenai Mountains, a wide assortment of vegetation communities occurs on the Kenai. Recently, periods of drought have culminated with rampant spruce beetle infestations and extensive, human-caused and naturally ignited fires that have had significant impacts, especially on the west side of the Kenai (Burr and Hutton 2017).

Project Planning

In 2016, staff of the USDA Forest Service met with partners to outline a strategy and prepare a project plan for the Kenai existing vegetation mapping project (see the full list of project partners in the Partnerships section above). This multi-agency partnership discussed map unit design in order to develop a vegetation classification system that was both ecologically meaningful and realistic with respect to technology and the data available for the area. Vegetation map units share a common definition based on their physiognomic, floristic, or structural characteristics. The map unit design process establishes the rules that define the map classes found in the classification key (Appendix A). This dichotomous key establishes the discrete absolute and relative vegetation cover percentages, as well as the height definitions that distinctly classify every vegetation community encountered on the ground. Although class assignment in the field may be difficult, especially when threshold cover and height determinations are approached, the class definitions themselves 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 are to be mapped; 2) be mutually exclusive to contain classes with no overlap or have any ambiguity in their respective definitions; 3) describe vegetation that is readily observed in the field; and 4) contain classes that are capable of being mapped and are consistent with the scale and scope of the project.

For this project, vegetation dominance types and structure classes were identified to address the information needs of the land management agency partners. GTAC was tasked to develop a set of mid-level existing vegetation maps for the entire Kenai. Existing vegetation is the plant cover, or floristic composition and vegetation structure, occurring at a given location at the current time (Nelson et al. 2015). Some dominance types are a combination of species which describe a vegetation community (e.g. Wet Herbaceous) while others identify specific species (e.g., Sitka Alder). Vegetation dominance type classes are defined by the *Kenai Peninsula dominance type key,* however several types were collapsed or removed due to the lack of available reference data, limited occurrence on the landscape, or the inability to differentiate certain classes. Ultimately, there were a total of 33 dominance type classes—28 vegetation types and 5 non-vegetated cover types; 3 binned canopy cover classes for both tree and tall shrub; and 5 tree size classes (Table 1). Changes to the original dominance type classes are listed below, in Table 2.

One of the overarching goals for this project was to provide a regionally cohesive map product, therefore efforts were made to ensure that the spatial and thematic characteristics of the maps would fulfill data requirements across the various agency partners. These products were developed to provide up-to-date, comprehensive information about the vegetation communities, and their structure, across the Kenai. Over 5.7 million acres (including other federal, state, local, native, and private land inholdings) were mapped. It is important to remember that the vegetation characteristics being described on the final maps is from a synoptic, overhead, bird's-eye perspective (Figure 1). Therefore, understory vegetation that is not visible from above, is <u>not</u> being depicted.

Table 1. List of vegetation types and structure classes for the Kenai existing vegetation map project—(a) Dominance types; (b) Tree canopy cover; (c) Tree size; and (d) Tall shrub canopy cover.

(a)

Map Group	Dominance Types	Map Unit Abbreviation
Needleleaf Forest	Black Spruce	BS
	Black Spruce Peatland	BSP
	Mountain Hemlock	MH
	Mountain Hemlock-Lutz Spruce	MH-LS
	Mountain Hemlock-Sitka Spruce	MH-SS
	Sitka Spruce	SS
	White/Lutz Spruce	W/LS
Broadleaf Forest	Alaska Paper Birch (and Kenai Birch)	B
	Black Cottonwood (and Balsam Poplar)	C
	Quaking Aspen	QA
Mixed Forest	Black Spruce-Broadleaf	BS-B
	White/Lutz Spruce-Birch	W/LS-B
	White/Lutz Spruce-Cottonwood	W/LS-C
	White/Lutz Spruce-Aspen	W/LS-A
Tall Shrub	Alder	A
	Willow	W
	Alder-Willow	A-W
Low Shrub	Low Shrub Peatland	LSP
	Low Shrub Willow-Dwarf Birch	LSW-DB
	Wet Willow (Sweetgale)	WW
Dwarf Shrub	Dryas Dwarf Shrub	DDS
	Dwarf Shrub-Lichen	DS-L
	Ericaceous Dwarf Shrub	EDS
Herbaceous	Sedge Peatland	SP
	Aquatic Herbaceous	AHB
	Dry Herbaceous	DHB
	Mesic Herbaceous	MHB
	Wet Herbaceous	WHB
Other	Sparse Vegetation	SV
	Barren	BR
	Water	WA
	Snow/Ice	S/I
	Developed	DEV

(b)

Tree Canopy Cover Classes
Woodland (10 - 24%)
Open (25 - 59%)
Closed (60 - 100%)

(c)

Tree Size Classes (Diameter at Breast Height)
TS1 (0 - 1.9" dbh)
TS2 (2 - 4.9" dbh)
TS3 (5 - 11.9" dbh)
TS4 (12 - 17.9" dbh)
TS5 (≥ 18”dbh)

(d)

Tall Shrub Canopy Cover Classes
Sparse (9 - 24%)
Open (25 - 59%)
Closed (60 - 100%)

Table 2. A list of changes to the original dominance type classes that are described in the classification key (Appendix A).

Original Map Class	Action	Comments
Dwarf Mountain Hemlock	Drop	Spectrally similar to Mountain Hemlock class
Black Spruce - White (Lutz Spruce)	Drop	Inadequate sample
Lutz Spruce	Merge	Merged with White Spruce into White/Lutz Spruce class
Mixed Broadleaf	Drop	Inadequate sample
Mountain Hemlock - Birch	Drop	Inadequate sample
Sitka Spruce - Cottonwood	Drop	Inadequate sample
White Spruce - Birch	Merge	Merged with Lutz Spruce - Birch
White Spruce - Quaking Aspen	Merge	Merged with Lutz Spruce - Quaking Aspen
White Spruce - Cottonwood	Merge	Merged with Lutz Spruce - Cottonwood
White Spruce - Mixed Broadleaf	Drop	Inadequate sample
Lutz Spruce - Mixed Broadleaf	Drop	Inadequate sample
Salmonberry	Drop	Inadequate sample
Willow Dwarf Shrub	Drop	Inadequate sample
Lichen	Merge	Merged with Dwarf Shrub - Lichen

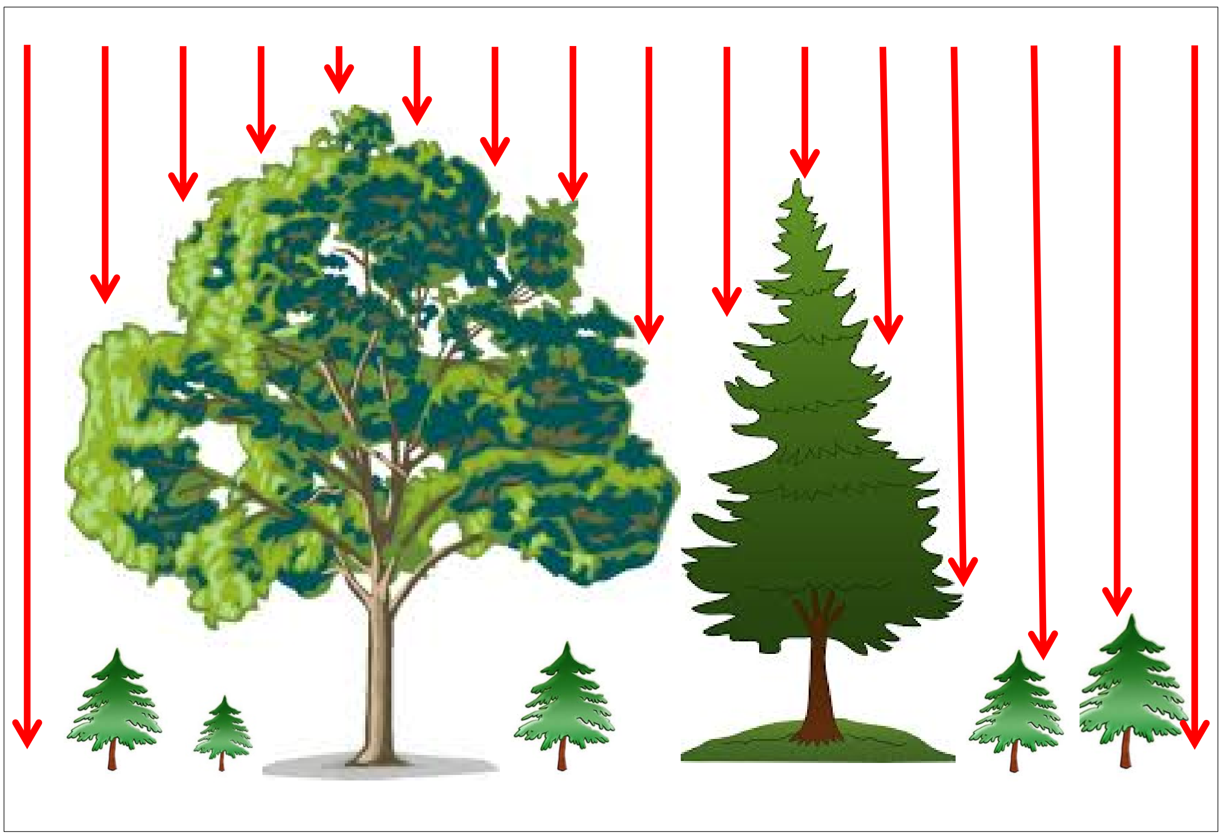


Figure 1. An example of the synoptic remote sensing perspective when viewing the landscape from above. The red arrows illustrate the vegetation that would be detected from an overhead sensor.

Mapping Methods

The map products for this project were developed using remotely sensed multispectral imagery, topographic LIDAR and IfSAR data, field and photo-interpreted reference sites, and object-oriented classification models. The modeling units (segments) were produced using a semi-automated image segmentation process that considers the shape, size, and spectral content of spatially contiguous pixels across the landscape. Random Forest, an ensemble classifier, was then used to characterize these modeling units and assign map class labels, which ultimately produced the final vegetation maps for the Kenai.

The major mapping phases, which are discussed in more depth below, include: geospatial data acquisition; image segmentation; reference data collection; classification; final map development; and accuracy assessment.

Geospatial Data Acquisition

This project utilized remotely sensed imagery acquired from various sensors on both satellite and airborne platforms. Each image sensor has a unique set of qualities that, along with the imaging geometry, determines the spectral, spatial, and radiometric resolutions of the data that is collected. Multiple sources of imagery were acquired for this project in order to utilize the unique information afforded different sensors and to maximize the range of data used in the computational modeling. Image mosaics were developed from SPOT 5, Landsat 8, and Sentinel 2 satellite image archives. The SPOT 5 Level 1A image scenes were collected between 2010 and 2016 by the Statewide Digital Mapping Initiative (University of Alaska, Fairbanks). Landsat 8 and Sentinel 2 images were reviewed and prioritized in order to reflect current ground conditions, limit cloud obscurity, and capture variations in vegetation phenology. Individual scenes were ultimately mosaicked together in Google Earth Engine to remove clouds and aggregate adjacent image swaths for the purpose of developing seamless image mosaics of the entire project area for each sensor. Independent image mosaics are ideally generated for the spring, summer, and fall seasons in order to depict phenological conditions throughout the growing season to better distinguish vegetation types. Ultimately, the prevalence of clouds allowed for only a single Sentinel 2 mosaic and two Landsat 8 mosaics to be developed for this project. The single Sentinel 2 mosaic represented maximum vegetation development during the height of summer, while both a summer and fall mosaic were developed for Landsat 8. A Normalized Difference Vegetation Index (NDVI) and Normalized Difference Moisture Index (NDMI) were produced for each image mosaic. Also, a Tasseled-Cap Transformation was developed for each Landsat 8 mosaic (Crist and Cicone 1984), while Principal Component Analysis (PCA) was performed on the Sentinel 2 image mosaic.

High-resolution imagery is critical for photo interpretation, which allows an analyst to evaluate and modify model outputs and is instrumental for developing relatively fine-scaled segments for a mapping project. Resource imagery that covered lands administered by the Chugach National Forest, located in the northeast portion of the Kenai, was acquired in 2009. This imagery includes 4-spectral bands (red, green, blue, and near infrared) and has a 60 cm resolution. Additional high-resolution imagery was acquired by the US Fish & Wildlife Service during the summer and fall of 2016 using a fixed-wing aircraft. It features 4 bands (red, green, blue, and near-infrared), has a spatial resolution of 75 cm, and covers approximately 4 million acres or 66% of the project area. Only the distant southern tip of the Kenai Peninsula, about 12% of the project area, lacked high-resolution imagery coverage.

Elevation data for the project area came from LiDAR and IfSAR data sources. The LiDAR data were collected in 2010 to USGS contract specifications for the western lowlands, as well as for an east-west corridor across the mountainous region of the Kenai. The total LiDAR coverage area is 3 million acres, over half of the project area. The acquisition specifications differed from Forest Service standards and resulted in low point densities (less than 1 point per square meter), high maximum scan angles, and low flight line overlap. These issues led to artificial banding between flight lines, which were visible in some height and canopy metrics. Despite these limitations, the LiDAR data remained the strongest and most important data source for modeling vegetation structure for this project. Canopy cover for *forest* and *tall shrub* areas within the LiDAR data extent was derived using a discrete threshold of the canopy height model (CHM) and the 1st-return proportion metric. Additional vegetation structure metrics were also derived from the LiDAR point cloud to model tree size. IfSAR data covered the full extent of the Kenai and 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 CHM, which is the difference between the DSM and DTM. Topographic derivatives including slope, aspect, heat load, topographic index, and a topographic wetness index were produced from the IfSAR DTM.

Ancillary data, including climate and ownership spatial layers, were also used in the mapping process. Climate data, especially the continentality layer, were instrumental in determining Lutz versus Sitka Spruce dominance type extents on the final maps. The ownership layer assisted in the development of an access layer that was used for field reference site placement. All final data layers were co-registered and projected to Universal Transverse Mercator (UTM), NAD83, Zone 6 North. The data were resampled to 5 meters to maintain consistency in spatial resolution across all data layers. A complete list of geospatial data used in the project can be found in Table 3.

Image Segmentation

Image segmentation is the process of partitioning digital imagery into spatially cohesive modeling units (mapping polygons) that represent discrete areas or objects on a landscape (Ryherd and Woodcock 1996). The goal is to develop homogenous segments that delineate vegetation of similar physiognomic, floristic, and structural characteristics to serve as the fundamental modeling units. High-resolution aerial imagery collected in 2009 and 2016, along with satellite imagery collected in 2017, were used to generate the final segments. High-resolution imagery collected by the US Fish & Wildlife Service was histogram-matched and mosaicked with Resource Imagery covering the Chugach National Forest portion of the Kenai. This mosaic covered approximately 88% of the mapping project area—all but the very southern portion of the Peninsula as indicated earlier. Fine spatial resolution imagery excels at portraying vegetation patterns across the landscape during the segmentation process, such as delineating forest edges or isolating patches of shrub, and therefore, this mosaic was the most important data source for generating the final segments. Additionally, SPOT-5 and Sentinel-2 satellite

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

	Geospatial Data Source	Bands/Native Resolution	Purpose
Spectral Data	Landsat 8 OLI • Fall Mosaic September 2016 & October 2017 • Summer Mosaic June 2015, July 2016, & August 2017 • Summer Composite (July-August 2013-2017)	• Blue, Green, Red, Near Infrared (NIR), Shortwave Infared (SWIR) 1, SWIR 2 – 30m • Panchromatic – 15m	Dominance Type & Structure Modeling
	Sentinel 2	• Blue, Green, Red, NIR – 10m • Red Edge 1, Red Edge 2, Red Edge 3, SWIR 1, SWIR 2 – 20m	Segmentation, Dominance Type & Structure Modeling
	SPOT 5	• Green, Red, NIR - 5m • SWIR - 20m • Panchromatic - 2.5m	Segmentation, Dominance Type & Structure Modeling
	Fish & Wildlife Service Imagery	• Blue, Green, Red, NIR - 75cm	Segmentation & Evaluation/Interpretation
	Chugach National Forest Resource Imagery	• Blue, Green, Red, NIR - 60cm	Segmentation & Evaluation/Interpretation
Topographic Data	LiDAR	Approximately 1 pulse per square meter	Structure Modeling & Reference for non-LiDAR areas
	IfSAR	5m	Structure Modeling
Ancillary Data	Daymet Climate Data	1km	Lutz versus Sitka Spruce extent determination, Dominance Type & Structure Modeling
	Ownership	GIS Vector Data	Reference/Validation Site Placement & Access
	Transportation (Roads & Trails)	GIS Vector Data	Reference/Validation Site Placement & Access

imagery were particularly important in segmenting the Southern Peninsula, where the high-resolution mosaic lacked coverage. All imagery was resampled to 5 meters to make data processing more efficient and avoid over-segmentation of the complex landscape of the Kenai.

Development of the Kenai segments was an iterative process which utilized a variety of algorithms and a combination of data sources structured into a ruleset within the Trimble eCognition software suite. Coarse segments were initially generated to classify large waterbodies, glacial ice, and tidal area. Subsequently, the segments were incrementally refined to further delineate landscape features until the final segments were achieved and were commensurate with the scale and scope of the project.

Segments were on average 2.77 acres in size. Median segment size was 1.66 acres since large bodies of water and areas of glacial ice were classified and merged during the segmentation process, creating very large segments that increased the mean as compared to the median. The final segments were filtered and smoothed to ensure that the smallest segment was 0.25 acres or greater in size in order to prevent segments from capturing landscape features too small to adequately model with the available predictor data. The final segmentation yielded over 2 million mapping segments that served as the elemental modeling units for the project (Figure 2).

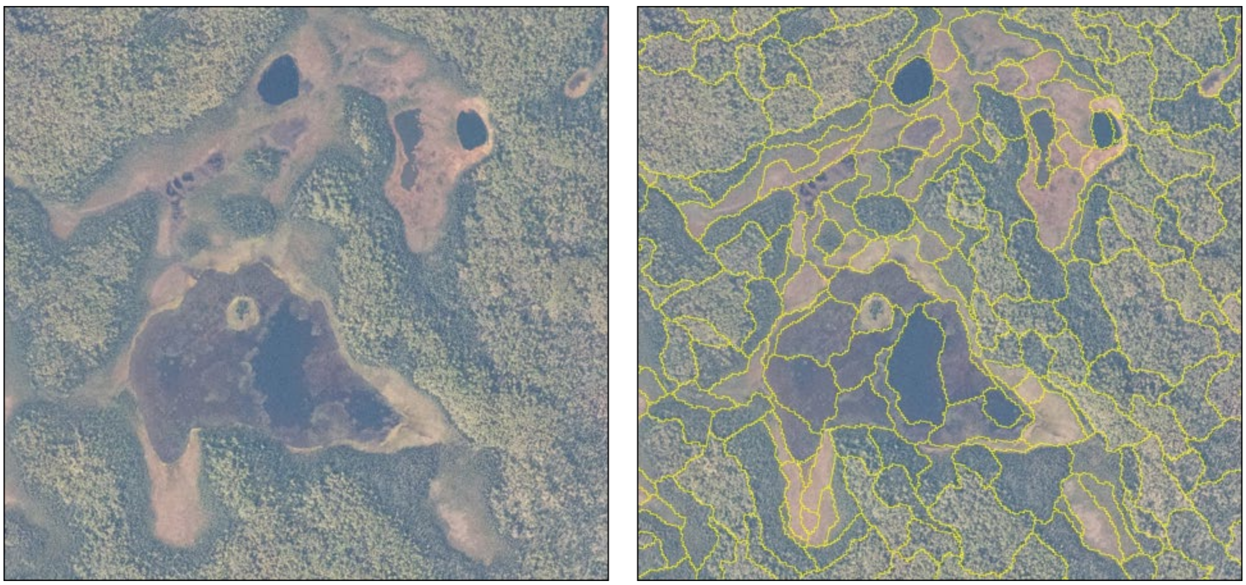


Figure 2. Example of the final segments generated as the fundamental modeling units for the mapping project using Trimble eCognition. This is a snapshot of the 75 cm Fish & Wildlife Service Imagery from the western lowlands of the Kenai (left) and overlaid with the final segments (right). Scale 1:10,000

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 the diverse landscape of the Kenai. Chugach National Forest staff and partners prepared the Kenai classification system (Appendix A) and identified the desired map units (map classes) to be depicted.

Reference data for this project came from numerous sources, including: 1) ground; 2) helicopter; 3) the Forest Inventory and Analysis (FIA) program; 4) legacy data from the National Park Service; and 5) photo interpretation (Figure 3). Federal and State field personnel collected the ground data, while Ducks Unlimited and GTAC contractors collected the helicopter data.

All of the reference data from the various sources was consolidated into a single database and reviewed within the context of their corresponding map segment using high-resolution imagery. The final reference database included 2,750 sites. Inevitably, the more abundant vegetation and structure types were sampled at a higher frequency. It can be difficult to obtain an adequate sample for rarer classes and some of the dominance types were dropped as a result.

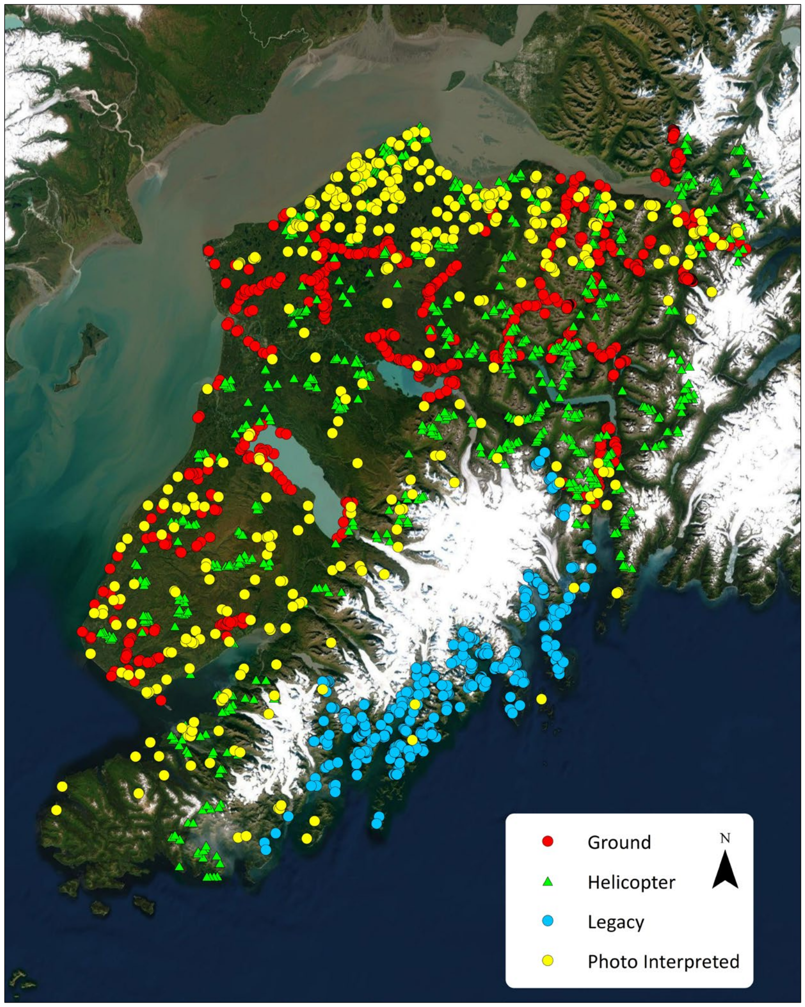


Figure 3. Illustration showing the distribution of reference data, from various sources, across the Kenai project area.

Ground Data

A total of 747 sites were collected on the ground by Forest Service, US Fish & Wildlife Service, and Alaska Department of Fish & Game personnel during the summer of 2017. These sites were primarily pre-selected using an image stratification of a Landsat 8 summer mosaic to help distribute the sites equally across the full-range of vegetation conditions in the project area. This stratification was confined within the bounds of an access layer that identified areas accessible with respect to ownership, terrain slope, avoiding dangerous river or stream crossings, and remoteness. This approach was developed to maximize sampling efficiency and to sample across the full-range of ground conditions within the accessible areas of the Kenai. Pre-selected sites targeted for ground sampling were reviewed within the context of their associated larger mapping segments for homogeneity and representativeness.

Two types of field sites were collected by field crews—descriptive and observation. A 50-foot radius plot was evaluated at each sampled location. Descriptive sites contain highly detailed, comprehensive plot information on species and structure, whereas an observational plot is a quick method by which a field crew can make dominance type and structure determinations without collecting discrete plot data. For descriptive plots, detailed plant cover information was collected, including ocular estimates of vegetation cover by species, along with height and diameter information for tall shrubs and trees, respectively. Total absolute cover equaled 100 percent for every reference plot. After vegetation cover, tree diameter, and shrub heights were measured, final dominance type and structure determinations were made using the dichotomous key (see Appendix A). For observational plots, dominance type and associated structure determinations were made after a brief assessment. Estimates were made from a 'bird's-eye' perspective in order to mimic that of a remote sensing instrument from above, discounting vegetation that is overtopped. Field crews noted a secondary dominance type in situations where class assignment was ambiguous. Approximately 20% of the total number of plots collected on the ground were the observational type.

Helicopter Data

During July and August of 2017, a total of 837 vegetation reference sites were collected from a helicopter by GTAC and Ducks Unlimited contractors. A single sample, or reference site, consisted of a single mapping segment. The segments were pre-selected using a stratified random sample across the entire study area, since helicopter sampling is not constrained by access. Over a 16-day period, the weather allowed for 14 days of data collection from the helicopter. Three separate staging areas were used to optimize sampling across the Kenai: 1. Cooper Landing; 2. Soldotna; and 3. Homer. Trip planning was strategized to maximize the amount of data collected at each location.

Ocular estimates of canopy cover were recorded for every species observed from the encircling helicopter. Cover was always assessed from the synoptic perspective—as viewed from above, thereby discounting understory vegetation. Average tree diameter and shrub height was also recorded for *forest* and *tall shrub* sites. If tree diameter or shrub height determinations were ambiguous, then structure determinations were not assigned. Upon completion of a site, class labels were assigned using the definitions described in the *Kenai Peninsula Dominance Type Classification Key* (Appendix A). When the opportunity arose to touch down, the helicopter was grounded to allow for closer inspection of the vegetation to ensure the correct identification of species from the air. Figure 4 is a picture taken on a slope above an adjacent fjord on the southern portion of the Peninsula during the 2017 helicopter campaign.

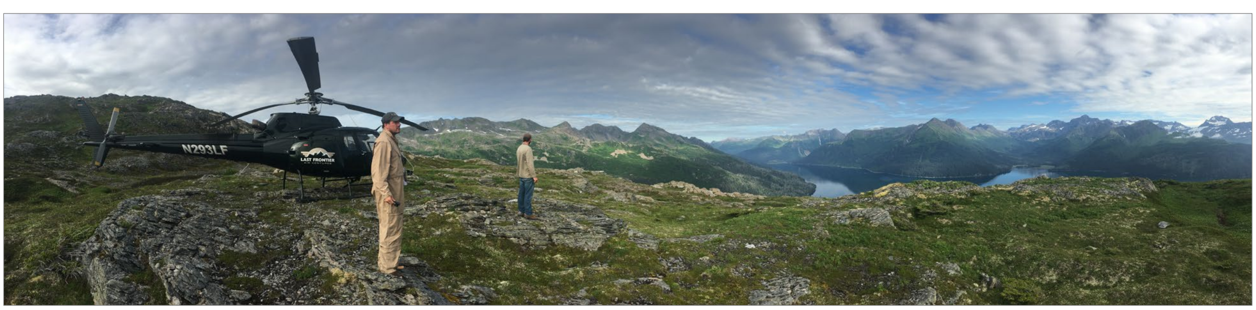


Figure 4. Dan Fehringer (front) of Ducks Unlimited and the pilot, Levi Meyer (back) of the Last Frontier Aviation Group, look out from a high perch on the Kenai during the helicopter data collection campaign.

Legacy Data

Additional reference data were obtained from the National Park Service and the FIA program, including a total of 586 sites that were collected by the Kenai Fjords National Park and 111 sites that were systematically collected by FIA field crews. Given that these data were collected for other projects, each site had to be cross-walked to the vegetation classification system used for this mapping effort and photo interpreted to determine if the site represented the mapping segment it was located in.

Photo Interpreted Data

Ducks Unlimited reviewed and photo interpreted 469 field plots, collected for a previous project, within the context of the segments. The most contemporary imagery was used to evaluate the field information and make a dominance type determination. If a plot location was in a disturbed area or the vegetation label could not be corroborated against the current imagery, then the site was not used in the modeling effort. GTAC photo interpreted over 1,500 sites, however these were not always applied at the final map class-level but instead used in interim map models that split coarser vegetation groupings. These photo interpreted sites did not include any ground verification information, thereby requiring an analyst to be more conservative with class assignment. Multiple imagery datasets were used for the purpose of interpretation. Resource imagery collected in 2009 for the Chugach National Forest and imagery acquired in 2016 by the US Fish & Wildlife Service were the most frequently utilized data sources. Both image sources contain 4 bands (Red, Green, Blue, and Near Infrared) and have a spatial resolution of 60 cm and 75 cm, respectively.

Classification and Regression

Random forest was the data mining technique used to predict and assign vegetation attributes to the mapping polygons (Breiman 2001, Cutler et al. 2007). It is an ensemble classifier that uses the plurality vote in the case of classification, or the average of continuous predictions in the case of regression, for the multitude of individual decision trees that make up the ‘forest’ to determine final class assignment or regression output.

The predictor layers used in the classification were the satellite imagery, topographic data, and climate information (Figure 5). Zonal statistics, including: minimum; maximum; range; standard deviation; mean; and median, were generated for the mapping segments using these layers. This equated to over 400 statistics being generated for each of the 2 million plus mapping segments. Subsequently, these statistics were compiled into a single dataset to be used in the computational modeling. Zonal statistics associated with the reference mapping segments can then be used to predict and characterize vegetation across the Kenai. Additionally, both the IfSAR and LiDAR data sources were collected in 2010, therefore they would not adequately depict current vegetation structural condition in areas that have experienced recent change. In response to this, we leveraged contemporary satellite imagery to model current vegetation dominance types across the Kenai according to the definitions outlined in the classification key. Vegetation masks were implemented to adapt individual structural models to specific lifeforms. This would help mitigate misclassification in areas that experienced drastic changes since 2010, which was common on the western side of the Kenai where beetle infestations and fire have been common.

Predictor Layers

LiDAR
- CHM
- DTM
- 1st Order metrics (87)

Sentinel 2
- Nine bands
- NDMI
- NDVI
- Principal components (3)

Spot 5
- Four bands
- NDVI
- Principal components (3)

IfSAR
- CHM
- DTM
- Heat load
- Slope & aspect
- Topographic position index
- Topographic wetness index

Landsat 8

Composite, fall, summer
- Six bands
- NDVI
- Panchromatic
- NDMI
- Tasseled cap (3)

Climate 30-yr mean daily
- Ave pp. water vapor
- Max temperature
- Min temperature
- Ave temperature
- Total precipitation
- Continentality

Figure 5. List of geospatial data layers that were used to generate the zonal statistics utilized by the random forest classification models.

Dominance Type

A separability analysis was performed to indicate which classes were most readily discernible. This informed a mapping hierarchy that grouped classes based on data similarity. The mapping hierarchy determined the sequence in which models were run. Spectrally distinct classes were mapped first, while classes that were more difficult to distinguish were grouped together and subsequently modeled further down the hierarchy (Figure 6). 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 32 dominance types are sufficiently modeled. Model outputs were evaluated and optimized using photo interpretation at each stage of the mapping hierarchy to reduce model confusion and improve overall map accuracy. Note, the *Developed* class was added to the map manually since 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. There are distinct advantages to using this hierarchical modeling approach because it enables a targeted review of map outputs at each level, where conspicuous errors can be addressed.

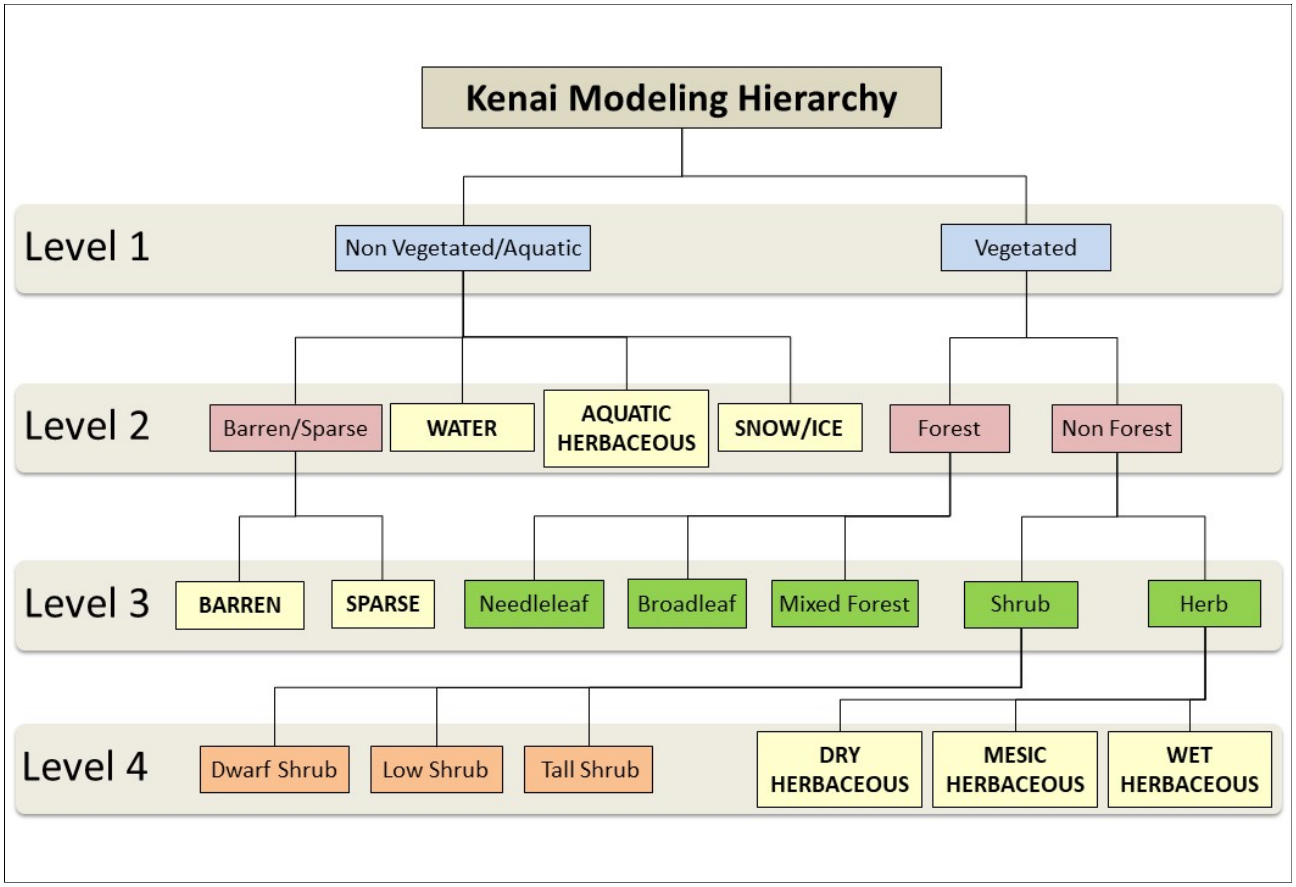


Figure 6. A diagram of the highest levels of the dominance type modeling hierarchy for the Kenai existing vegetation mapping project. An independent classification model was developed at every node within each level of the modeling hierarchy. For example, three independent classification models were developed for level 3—1. Differentiating barren from sparse; 2. Discerning between three types of forest; and 3. Distinguishing shrub from herb. Note, Yellow highlighted boxes with emboldened class names in all caps indicate final classes. Other colored boxes indicate similar groupings of vegetation that are further refined at subsequent modeling levels.

Tree Canopy Cover

Tree canopy cover was modeled continuously, from 0-100%, using a random forest regression model. Continuous tree canopy cover values were then assigned to map polygons classified as *forest* on the final dominance type map. *Forest* is defined by the dominance type key as any area containing at least 10% tree cover when viewed from above, discounting over-topped trees.

Modeling canopy cover with LiDAR was significantly more challenging as compared to tree size because of inconsistencies and artifacts found within the LiDAR canopy cover metrics. The structure metrics used to model tree size were less plagued by these issues. Traditionally, tree canopy cover is modeled using LiDAR data with a variety of modeling approaches, including: 1) thresholding the CHM to derive a binary canopy cover layer; 2) the all-return proportion (Equation 1); or 3) the 1st-return proportion (Equation 2) (Arumäe and Lang 2018, Hopkinson and Chasmer 2009, van Leeuwen and Nieuwenhuis 2010, Smith et al. 2009, Wasser et al. 2013). For tree canopy cover, all three of these methods were explored with the CHM thresholding and 1st-return proportion approaches being utilized to derive the final canopy cover products. Additionally, a height threshold must be identified that best differentiates tree and shrub lifeforms given that *forest* areas require a tree canopy cover value, excluding *tall shrub* cover, and vice versa. An inverse relationship exists between canopy cover and threshold height. As threshold height increases, canopy cover decreases due to a smaller proportion of total returns, or cells, within a given segment occurring above the identified threshold value and therefore less are classified as canopy (Figure 7). A 2-meter height threshold was chosen to best make this distinction, however, inevitably some *tall shrubs* were counted and some stunted trees were missed in mixed polygons mapped as *forest*.

The 1st-return proportion metric, obtained from the LiDAR point cloud, was found to be the best method for determining tree canopy cover within the LiDAR data extent. Counter to the all-returns approach, which utilizes all of the returns above and below a specified height threshold, the 1st-return proportion considers only the 1st-return of each beam, disregarding all subsequent reflections as the beam passes through the canopy and approaches the surface of the earth. Area A was the one exception, where it was found that deriving continuous tree canopy cover directly from the CHM was found to most accurately reflect conditions on the ground (Figure 8). This approach quantifies canopy cover as the percentage of CHM cells within a segment above the 2-meter predefined height value.

Tree canopy cover values derived from the LiDAR data for ten thousand randomly selected mapping segments were used as reference for a random forest model to predict continuous canopy cover outside the LiDAR data extent. This model relied on zonal statistics from IfSAR and satellite imagery as predictors. Results were mosaicked together to create a seamless, continuous (0-100%) tree canopy cover product for the entire Kenai.

Equation 1.

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

Equation 2.

$$\text{1st-return proportion} = \frac{\#\, 1st\ returns > 2m}{\#\, 1st\ returns\ (total)}$$

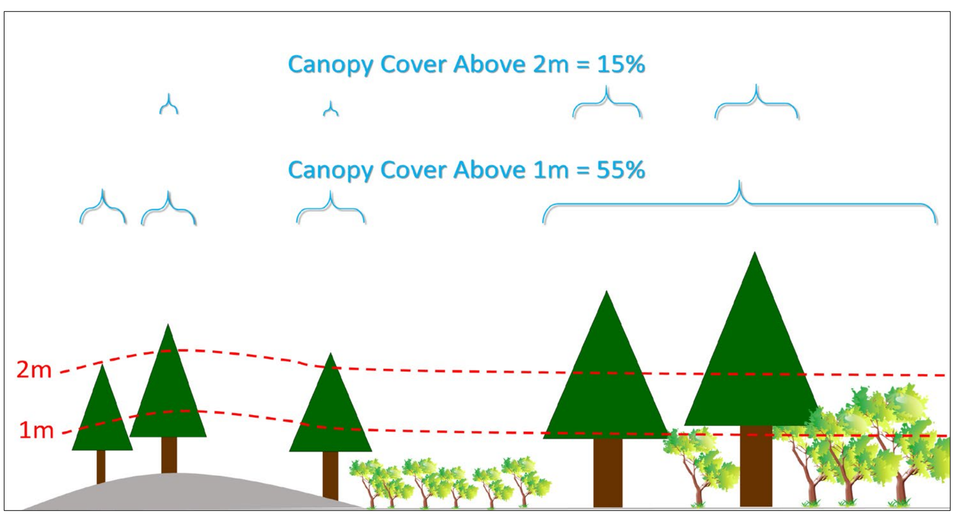


Figure 7. The top brackets represent areas considered cover as estimated by a 2-meter CHM threshold (top dashed line). The bottom set of brackets represent areas considered cover as estimated by a 1-meter CHM threshold (bottom dashed line).

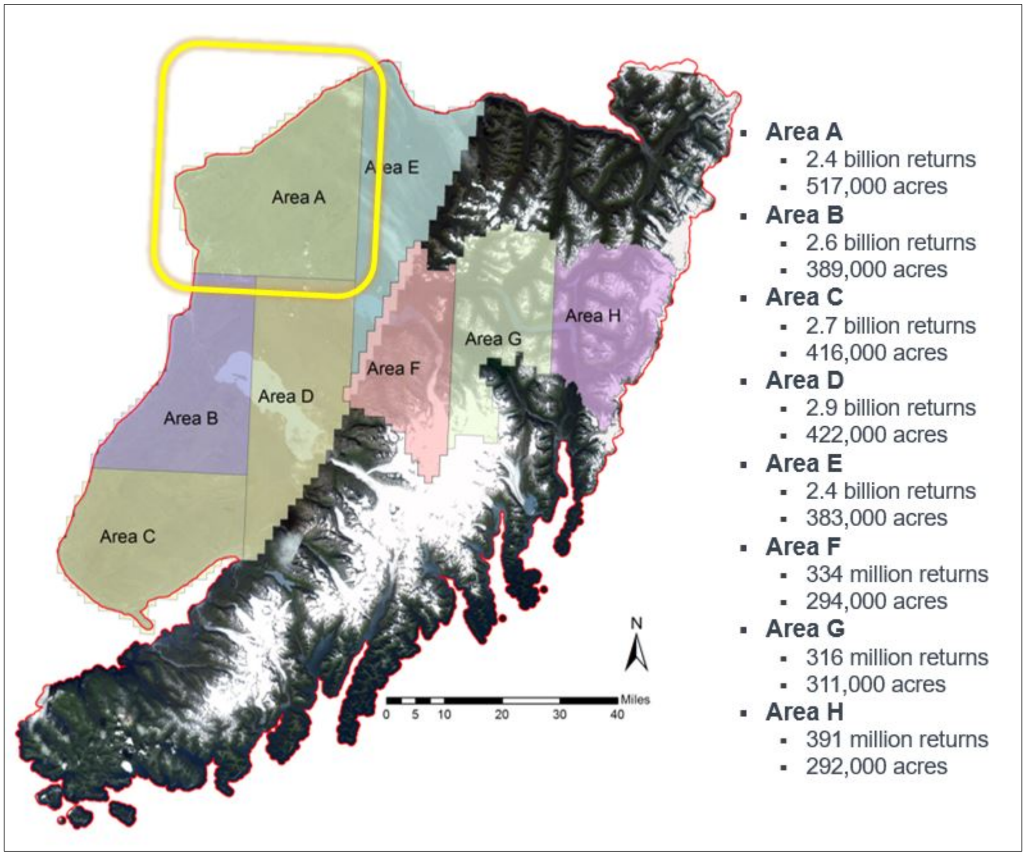


Figure 8. Areas A-H represent the various zones where LiDAR data was collected on the Kenai in 2010. Area A is the area in which the LiDAR data was especially tarnished by a striping artifact, which introduced noise at the flight line boundaries.

Tree Size

Tree size classes were assigned to mapping polygons classified as *forest* on the final dominance 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 ground.

Random forest was the classifier used to predict the five tree size classes. Where LiDAR data was available, over 80 LiDAR metrics and the associated tree size reference data, collected on the ground or by helicopter, were used to develop the classification models. The 1st order metrics were developed using FUSION LiDAR processing software (McGaughey 2009). These covariates were summarized as zonal statistics for mapping segments that were coincident to the LiDAR extent. LiDAR tree size model results for ten thousand randomly selected sites were used as reference to model areas outside of the LiDAR extent—similar to the tree canopy cover workflow. Zonal statistics derived from the IfSAR and spectral data were the model predictors. Results inside and outside the LiDAR data extent were subsequently mosaicked together to create a seamless thematic tree size product for the project area.

Tall Shrub Canopy Cover

Continuous canopy cover was assigned to areas classified as *tall shrub* on the dominance type map. *Tall shrub* is defined by the dominance type key as any area containing at least 25% shrub cover, with an abundance of shrubs being taller than 1.5 meters, when viewed from above. The LiDAR CHM was used to calculate tall shrub canopy values, similar to the method that modeled tree canopy cover for Area A, for areas within the LiDAR extent. The 1.5-meter height threshold was used since this is the height that differentiates *tall* from *low shrub*. The LiDAR modeling results were subsequently used as training data in a random forest model, leveraging IfSAR and spectral data as predictor layers, to assign canopy cover values to polygons outside of the LiDAR extent. Tall shrub canopy cover values from a stratified random sample of ten thousand mapping polygons selected from areas classified as *tall shrub* were used as reference for areas outside the LiDAR data extent. Results were mosaicked together to create a seamless continuous (0-100%) tall shrub canopy cover product for the entire project area.

For more information on the methods used to generate the final vegetation structure products for the Kenai, please refer to the [*2018 Chugach National Forest Structure Mapping Pilot Report*].

Final Map Products

After initial models were reviewed and optimized by GTAC personnel, draft versions of the four map layers were created: 1) dominance type; 2) tree canopy cover; 3) tree size; and 4) tall shrub canopy cover. These layers were provided to local and regional experts for review within a web application that provided a platform by which edits and feedback could be submitted.

Upon completion of the draft map review, all of the edits and comments were compiled and used by GTAC to revise the draft map products. Areas of misclassification were either: remodeled with additional reference sites; remodeled using different predictor data; or by incorporating manual edits directly into the map. The dominance type map product was manually edited in known areas of confusion, such as within areas of persistent shadow or along shorelines, whereas the canopy cover products were remodeled using different prediction metrics. Review of the tree canopy cover results found that the 1st-return proportion (Equation 2) was the superior metric to model tree canopy cover using the LiDAR data, as opposed to the all-return proportion (Equation 1). It was also identified that modeled tall shrub canopy cover values were consistently low across the entire product area. Further investigation revealed that deriving tall shrub canopy cover using the LiDAR CHM threshold method generate higher values that better reflect ground conditions relative to the return proportion metrics. Therefore, this method was employed to raise the global average of *tall shrub* canopy cover significantly. Subsequently, the updated LiDAR modeled results were used to remodel areas outside the LiDAR data extent using the previously selected ten thousand sites for reference. The tree size product was not altered from its draft form because the distribution of large and small trees was determined to reflect patterns of forest basal area across the Peninsula.

Dominance Type

The final dominance type map consisted of 33 land cover classes contained within 8 map groups: 7 *needleleaf forest* types; 3 *broadleaf forest* types; 4 *mixed forest* types; 3 *tall shrub* types; 3 *low shrub* types; 3 *dwarf shrub* types; 5 *herbaceous* types; and 5 *other* types (Appendix B). Depiction of the collapsed *map groups* across the Kenai project extent is shown in Figure 9. *Forest* encompasses 45% of the vegetation on the Kenai Peninsula, while *shrub* covers 43% and *herbaceous* types cover 12% of the vegetated area. A list of the dominance type map classes with their associated areal extent across the Kenai Peninsula is tabulated in Table 4.

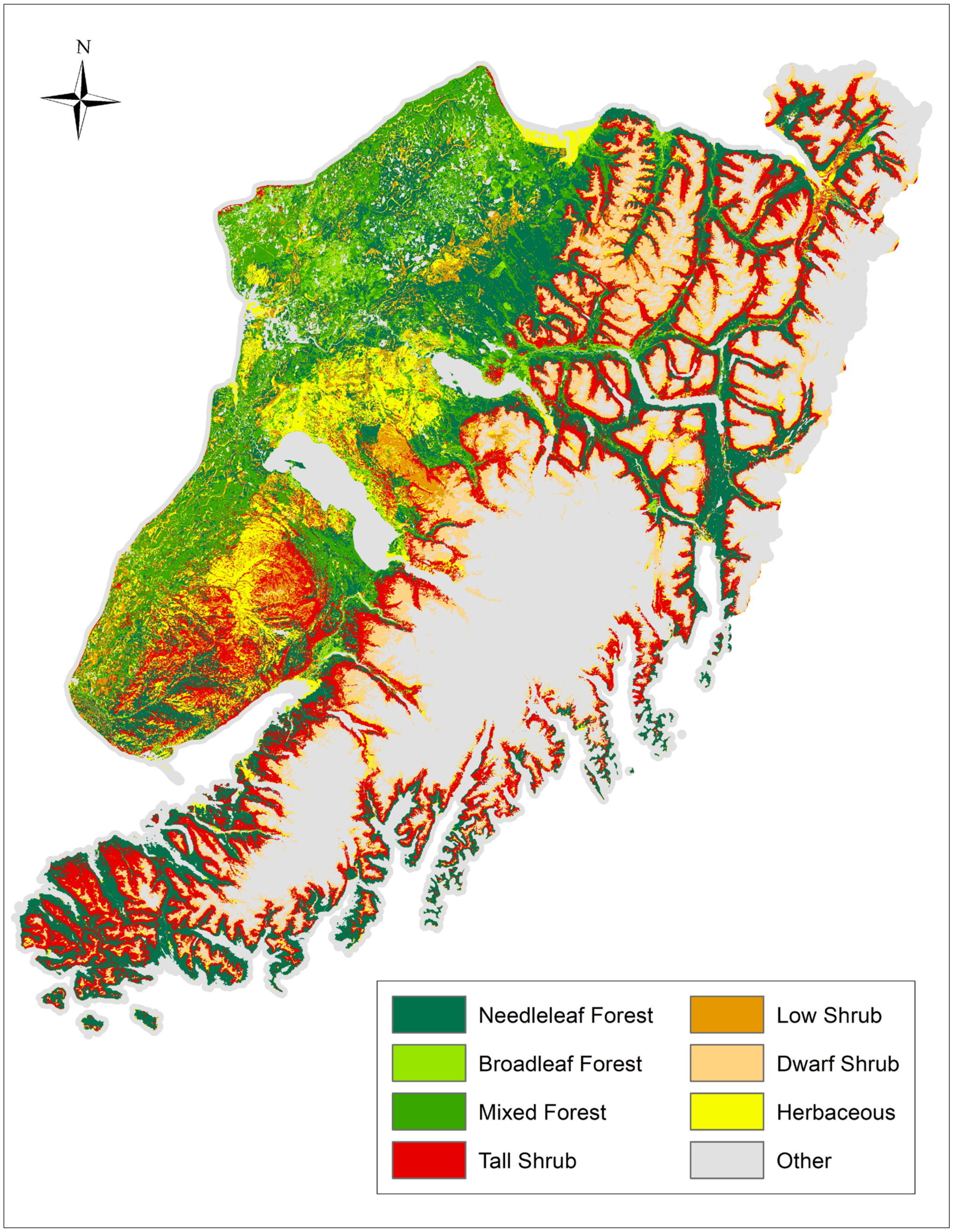


Figure 9. Map of map groups across the Kenai.

Table 4. Map group and dominance type acreage summary for the Kenai existing vegetation map.

Map Group	Area (ac)	% Area	Dominance Type Class	Area (ac)	% Area
Needleleaf Forest	1,052,638	18.25%	Black Spruce	232,512	4.03%
			Black Spruce Peatland	86,595	1.50%
			Mountain Hemlock	206,799	3.59%
			Mountain Hemlock-Lutz Spruce	36,830	0.64%
			Mountain Hemlock-Sitka Spruce	75,049	1.30%
			Sitka Spruce	207,325	3.59%
			White/Lutz Spruce	207,528	3.60%
Broadleaf Forest	153,352	2.66%	Alaska Paper Birch (and Kenai Birch)	101,391	1.76%
			Black Cottonwood (and Balsam Poplar)	28,226	0.49%
			Quaking Aspen	23,735	0.41%
Mixed Forest	506,055	8.77%	Black Spruce-Broadleaf	54,168	0.94%
			White/Lutz Spruce-Birch	422,000	7.32%
			White/Lutz Spruce-Cottonwood	16,500	0.29%
			White/Lutz Spruce-Aspen	13,387	0.23%
Tall Shrub	899,669	15.60%	Alder	756,649	13.12%
			Willow	125,727	2.18%
			Alder-Willow	17,293	0.30%
Low Shrub	247,042	4.28%	Low Shrub Peatland	122,052	2.12%
			Low Shrub Willow-Dwarf Birch	83,150	1.44%
			Wet Willow (Sweetgale)	41,840	0.73%
Dwarf Shrub	483,065	8.38%	Dryas Dwarf Shrub	10,074	0.17%
			Dwarf Shrub-Lichen	119,150	2.07%
			Ericaceous Dwarf Shrub	353,841	6.14%
Herbaceous	469,115	8.13%	Sedge Peatland	65,066	1.13%
			Aquatic Herbaceous	8,203	0.14%
			Dry Herbaceous	1,877	0.03%
			Mesic Herbaceous	334,361	5.80%
			Wet Herbaceous	59,608	1.03%
Other	1,956,370	33.92%	Sparse Vegetation	24,054	0.42%
			Barren	507,075	8.79%
			Water	635,641	11.02%
			Snow/Ice	762,344	13.22%
			Developed	27,256	0.47%
Total	5,767,306	100.00%	Total	5,767,306	100.00%

Tree Canopy Cover

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

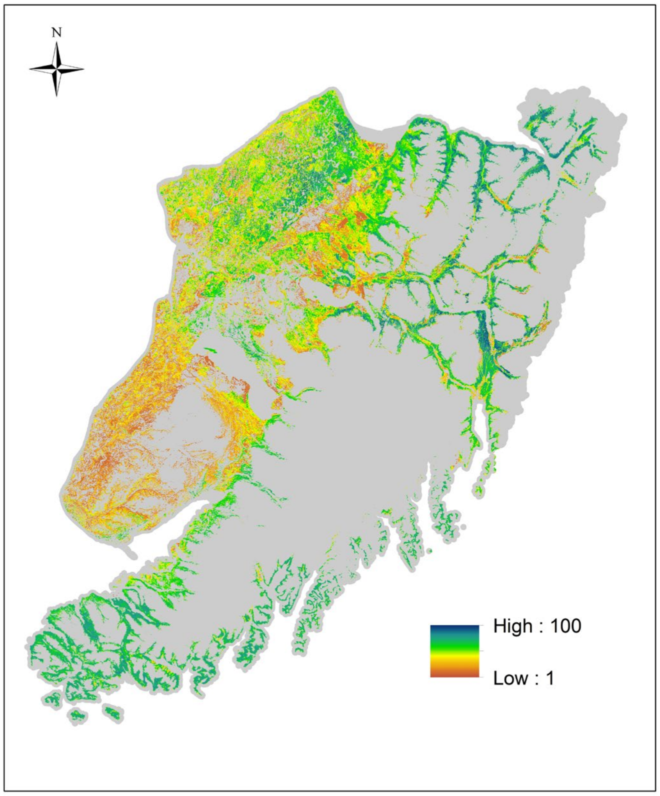


Figure 10. Tree canopy cover across the Kenai.

Table 5. Tree canopy cover acreage summary for the Kenai existing vegetation map.

Tree Canopy Cover Class	Area (ac)	% Forest Area
Woodland (10 - 24%)	297,757	17.39%
Open (25 - 59%)	845,702	49.40%
Closed (60 - 100%)	568,585	33.21%
Total	1,712,044	100.00%

Tree Size

The final tree size map for the Kenai was generated for all areas classified as *forest* on the final dominance type map, similar to tree canopy cover (Figure 11). Tree size class is determined as the diameter class containing the plurality of cover within a given area or mapping polygon. Seedlings less than 4.5 feet tall are included in the smallest tree diameter class (*Tree Size 1*). 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 obstructed from the synoptic perspective by larger trees are ignored and not counted in the diameter class estimate. Peninsula-wide acreage summaries of the tree size classes are provided in Table 6.

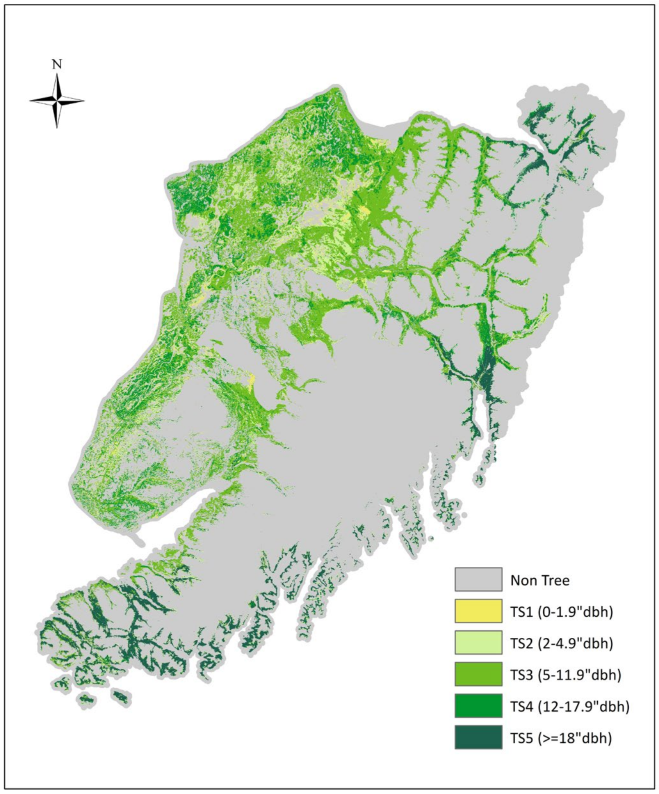


Figure 11. Tree size across the Kenai.

Table 6. Tree size acreage summary for the Kenai existing vegetation map.

Tree Size Class (Diameter at Breast Height)	Area (ac)	% Forest Area
TS1 (0 - 1.9" dbh)	37,067	2.17%
TS2 (2 - 4.9" dbh)	229,215	13.39%
TS3 (5 - 11.9" dbh)	915,796	53.49%
TS4 (12 - 17.9" dbh)	300,678	17.56%
TS5 (≥ 18”dbh)	229,289	13.39%
Total	1,712,045	100.00%

Tall Shrub Canopy Cover

An additional structure product was produced to depict canopy cover for *tall shrubs* greater than 1.5m in height. These areas were classified as *tall shrub*, as defined by the *'Kenai Peninsula Vegetation Dominance Type Key'*, and include 3 dominance types—*Alder*, *Alder-Willow*, and *Willow*. This product illustrates continuous *tall shrub* canopy cover with values ranging from 1 to 100% (Figure 12). *Tall shrub* is defined as any area with at least 25% total shrub cover and is dominated by shrubs that are taller than 1.5 meters in height. In instances where *tall shrub* cover does not equal or exceed 25%, other shrubs may be present but are shorter than or equal to the 1.5-meter height threshold. Note that this map does not include canopy cover for areas mapped as *low* or *dwarf shrub*. Table 7 provides a Peninsula-wide acreage summary for the same cover categories that were used to summarize tree canopy cover. It is worth noting that because of the fine-level of discernment required to distinguish *tall*- from *low*- or *dwarf*- shrubs we acknowledge this product is reaching the limits of what the data are capable of providing given the resolution and age of the data.

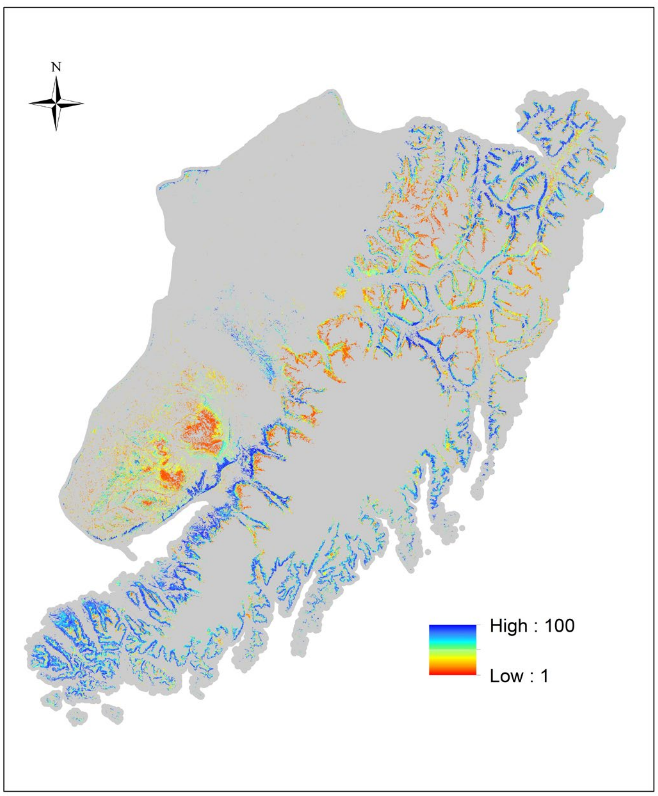


Figure 12. Tall shrub canopy cover across the Kenai.

Table 7. Tall shrub acreage summary for the Kenai existing vegetation map.

Tall Shrub Canopy Cover Class	Area (ac)	% Forest Area
Sparse (9 - 24%)	184,177	20.47%
Open (25 - 59%)	252,842	28.10%
Closed (60 - 100%)	462,649	51.43%
Total	899,668	100.00%

Accuracy Assessment

An accuracy assessment was conducted to validate the final map and reveal details of individual class confusion. The fundamental modeling units for this project were the segments (mapping polygons), therefore that is the unit by which the map was validated. Two methods were employed to conduct the accuracy assessment in order to best leverage the data available and evaluate the map products from a couple different perspectives. There are strengths and weaknesses to both approaches but each provides information that can shed light on the utility of the final map products. A purely photo interpreted assessment of map groups, which are broader groupings of similar dominance types, was an approach to ensure an equitable sample that was spatially balanced and unbiased. Even though photo interpretation was difficult in some circumstances, it allowed for a statistically robust and impartial assessment of the existing vegetation types at the map group-level. Alternatively, the assessments of final dominance type, tree canopy cover, and tall shrub canopy cover map products were evaluated using a combination of photo interpreted and ground collected data. Although some of these detailed classes could be adequately photo interpreted, many of these vegetation attributes could not and had to rely on field verification. There are obvious advantages to field verification, however accessibility limitations due to the remote landscape of the Kenai biased the ground data used in the accuracy assessment. Sampling was confined to areas with close proximity to roadways, railroads, and easily accessed foot trails. All validation information was collected blindly—no map products were available to photo interpreters or field crews participating—in order to limit human bias and keep this validation independent.

Map Group

The map groups were assessed using photo interpretation methods. Fifty mapping polygons were randomly selected for each of the 8 map groups, resulting in a total of 400 sites selected for photo interpretation. Each of the selected polygons were evaluated across their entire extent in order to assign the appropriate map group, as defined by the *Kenai Peninsula Dominance Type Key*. New assessment polygons had to be produced for areas mapped as *water* and *snow/ice* (within the *other* map group). During the initial segmentation process, these areas were classified and merged to more accurately delineate large water bodies (lakes and portions of the Gulf of Alaska) and glaciers (e.g., like the Harding Icefield). This resulted in extremely large polygons that could be thousands of acres in size. To produce reasonable areas to photo interpret, randomly selected points that intersected *water* and *snow/ice* areas were buffered 100 meters instead of extracting the associated polygon for interpretation. All other accuracy assessment sites were evaluated using the original mapping polygons.

Because of the uncertainty associated with photo interpreted data as compared to ground verified data, five independent reviewers were tasked with interpreting the 400 selected sites. Ultimately, a single map group label was assigned using the plurality vote or majority designation. The various high-resolution data sources used to photo interpret the accuracy assessment sites are listed in Table 8. The sites were then intersected with the final Kenai map to obtain the associated map group labels. The map labels for the accuracy assessment sites were then cross-referenced with the photo interpretation calls to produce the final map group error matrix (Table 9). Overall accuracy was 80% at the map group-level.

Table 8. List of available data sources for the photo interpretation accuracy assessment.

Data Source	Spatial Resolution	# of Bands
Chugach NF Resource Imagery (DOQQ)	60 cm	4 (r, g, b, nir)
US Fish and Wildlife Service Imagery	75 cm	4 (r, g, b, nir)
SPOT5 Imagery	2.5 m	4 (r, g, b, nir)
LiDAR	5 m	dtm, dsm, chm
IfSAR	5 m	dtm, dsm, chm
Continentality	1 km	na

Table 9. Error matrix of the Kenai existing vegetation map at the map group-level.

Map Group		Reference Data								User's Accuracy	Commission Error
		Needle-leaf	Broad-leaf	Mixed Forest	Tall Shrub	Low Shrub	Dwarf Shrub	Herb	Other		
Map Data	Needleleaf Forest	**48**	0	2	0	0	0	0	0	96%	4%
	Broadleaf Forest	0	**40**	5	2	0	0	3	0	80%	20%
	Mixed Forest	5	1	**44**	0	0	0	0	0	88%	12%
	Tall Shrub	1	0	1	**37**	4	4	2	1	74%	26%
	Low Shrub	4	1	2	0	**27**	2	14	0	54%	46%
	Dwarf Shrub	0	0	0	0	0	**43**	1	6	86%	14%
	Herbaceous	0	4	0	3	5	2	**34**	2	68%	32%
	Other	0	0	0	0	0	2	0	**48**	96%	4%
Producer's Accuracy		83%	87%	81%	88%	75%	81%	63%	84%	Kappa	0.77
Omission Error		17%	13%	19%	12%	25%	19%	37%	16%	Overall Accuracy	80.3%
										Area-Weighted Accuracy	86.53%

Dominance Type

During the photo interpretation process to assess the map groups, interpreters were asked to make a dominance type determination for each site, when possible. Additionally, interpreters provided a *high*, *medium*, or *low* confidence rating associated with each dominance type label assignment. Subsequently, the confidence ratings were analyzed to understand the variability of the dominance type assignments and shed light on which classes could be adequately photo interpreted.

Given the classification complexity for this project, ground collected data was required to bolster the photo interpretation effort to obtain an adequate sample to validate most of the final dominance type classes. Hundreds of accuracy assessment sites were collected on the ground for the purpose of validating the dominance type, tree size, tree canopy cover, and tall shrub canopy cover map products.

Ground data collection was limited to close proximity of existing infrastructure, and therefore, these sites are biased and are not a true sample of map accuracy.

Photo interpreted sites with dominance type assignments and an associated *high*, or *medium*, -level of confidence were used in conjunction with field data for the validation of the final dominance types. All 33 dominance types were validated, except: *dryas dwarf shrub*; *dry herbaceous*; *sparse vegetation*; and *developed* because these classes had less than 10 samples. Additionally, the *developed* class was not evaluated because this class was inherently subjective and the major roadways and urban centers were manually edited into the final map. A total of 871 sites were used in the validation and to develop the dominance type error matrix (See Appendix C).

Tree Canopy Cover

In addition to the map group and dominance type labels, photo interpreted sites that fell within the *forest* map groups—*needleleaf*, *broadleaf*, and *mixed forest*—were also assigned a continuous tree canopy cover value. Interpretations of continuous canopy cover utilized the Chugach National Forest resource and US Fish and Wildlife Service high-resolution image sources. The final continuous canopy cover values used in the validation were the average of the estimates made by multiple interpreters. The scatter plot containing the modeled versus predicted continuous tree canopy cover values with associated r and R^2 statistics can be seen in Figure 13.

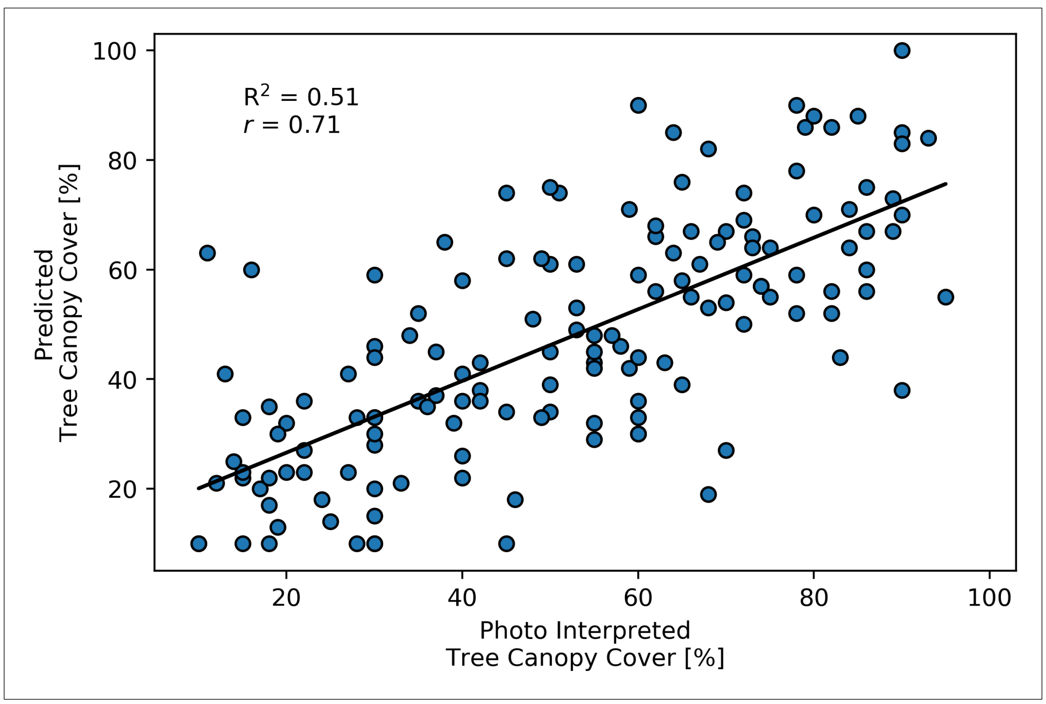


Figure 13. Plot of predicted versus photo interpreted values for the tree canopy cover product.

In order to further understand tree canopy cover map accuracy, mean photo interpreted continuous canopy cover values were binned into thematic *woodland*, *open*, and *closed* tree canopy cover classes for use in an error matrix evaluation. Photo interpreted sites were then combined with sites collected in the field to create the final thematic validation dataset. A total of 906 sites were used in the development of the final error matrix for thematic tree canopy cover (Table 10). It is notable that the *woodland* class had a low producer's and user's accuracy. Relatively small sample sizes can adversely impact class accuracy, with model outputs preferentially swayed towards prediction of more prevalent classes. Additionally, this class contained the narrowest range of values (10 – 24%) that consequently would make the distinction from *non tree* and *open* tree canopy cover classes more difficult.

Table 10 Error matrix of thematic tree canopy cover for the Kenai existing vegetation mapping project.

Tree Canopy Cover		Reference Data				User's Accuracy	Commission Error
		TC1	TC2	TC3	Non Tree		
Map Data	TC1 (Woodland 10 – 24%)	**22**	25	6	6	37%	63%
	TC2 (Open 25 – 59%)	12	**158**	51	5	70%	30%
	TC3 (Closed 60 – 100%)	1	53	**115**	1	68%	32%
	Non Tree	15	11	4	**421**	93%	7%
Producer's Accuracy		44%	64%	65%	97%	Kappa	0.68
Omission Error		56%	36%	35%	3%	Overall Accuracy	79.03%
						Area-Weighted Accuracy	84.39%

Tree Size

Since there is no way to accurately photo interpret tree size, validation had to completely rely on the ground collected validation data. A total of 768 sites were used to generate the final tree size error matrix (Table 11). Note that there were only 8 sites used to validate the TS1 (0 – 1.9" dbh) class. This sample is not adequate to validate this class. The relatively small sample is due to the overall rare occurrence of this tree size across the landscape given that this class encompasses a short seral stage that includes seedlings that quickly transition to larger diameter classes.

Table 11 Error matrix of tree size for the Kenai existing vegetation mapping project.

		Reference Data						User's Accuracy	Commission Error
		TS1	TS2	TS3	TS4	TS5	Non Tree		
Map Data	TS1 (0 - 1.9" dbh)	**1**	0	0	0	0	1	50%	50%
	TS2 (2 - 4.9" dbh)	3	**9**	9	2	0	2	36%	64%
	TS3 (5 - 11.9" dbh)	0	14	**114**	46	6	6	61%	39%
	TS4 (12 - 17.9" dbh)	0	1	9	**20**	4	1	57%	43%
	TS5 (≥ 18"dbh)	0	0	9	35	**28**	2	38%	62%
	Non Tree	4	6	10	5	0	**421**	94%	6%
Producer's Accuracy		13%	30%	75%	19%	74%	97%	Kappa	0.63
Omission Error		88%	70%	25%	81%	26%	3%	Overall Accuracy	77.21%
								Area-weighted Accuracy	82.21%

Tall Shrub Canopy Cover

It was not possible to photo interpret continuous tall shrub canopy cover since the discrimination of shrubs taller than 1.5 meters in height from surrounding vegetation is too fine a distinction to be made remotely. However, interpreters were comfortable with making a thematic call using the same groupings applied to the continuous tree canopy cover product. Therefore, a combination of photo interpreted and ground collected data were used to assess the accuracy of the tall shrub canopy cover product. A total of 917 sites were used to evaluate tall shrub canopy cover thematic accuracy and generate the final error matrix (Table 12). Note that the *sparse* thematic tall shrub canopy cover class contained only 4 samples, which is inadequate to validate any map class.

Table 12 Error matrix of thematic tall shrub canopy cover for the Kenai existing vegetation mapping project.

Tall Shrub Canopy Cover		Reference Data				User's Accuracy	Commission Error
		TSC1	TSC2	TSC3	Non Tall Shrub		
Map Data	TSC1 (Sparse 10 – 24%)	**3**	12	14	28	5%	95%
	TSC2 (Open 25 – 59%)	0	**9**	16	20	20%	80%
	TSC3 (Closed 60 – 100%)	0	10	**30**	11	59%	41%
	Non Tall Shrub	1	2	9	**752**	98%	2%
	Producer's Accuracy	75%	27%	43%	93%	Kappa	0.48
	Omission Error	25%	73%	57%	7%	Overall Accuracy	86.59%
						Area-Weighted Accuracy	88.73%

Accuracy Assessment Discussion

Overall accuracy is the most comprehensive statistic when it comes to understanding the underlying reliability of a map product. It is calculated by taking the proportion of sites classified correctly divided by the total number of sites assessed for each product. Numerous factors impact classification accuracy, including: 1) classification complexity; 2) landscape complexity; and 3) quality of the data that is available. Map accuracy has an inverse relationship with classification complexity, meaning that the more classes you have the less accurate your classification output will be. Considering this, the overall dominance type class accuracy was 63 percent (Appendix C). This level of accuracy is consistent with results from other mid-level vegetation mapping projects and is reasonable since the final map depicts 33 unique dominance types. The conglomeration of the various vegetation structure outputs for each of the different modeling scenarios resulted in seamless data products that depicted vegetation structure patterns across the entirety of the Kenai. Even though localized structure model accuracy may vary depending on the source data used, the overall pattern of tree canopy cover, tree size, and tall shrub canopy cover was captured effectively.

Individual class accuracies were computed for each of the map products. There are two ways to analyze individual class accuracy: 1) producer's accuracy, which is the proportion of sites correctly mapped for that class to the total number of sites of that class as determined by the reference data (i.e., the column total); and 2) user's accuracy, which is the proportion of sites correctly mapped for that class to the total number of sites assigned that particular class (i.e., the row total) (Congalton 1991). Producer's accuracy provides a measure of omission error that describes the probability that an area on the ground is mapped correctly. User's accuracy provides a measure of commission error that describes the probability that a mapped class actually represents what is on the ground. For example, *alder* had a producer's accuracy of 83 percent, but had a user's accuracy of 49 percent. This indicates that this class was over-mapped. Most of the *alder* confusion came at the expense of the other *tall shrub* classes—*alder–willow* and *willow* (Appendix C). This is intuitive, since all three of these classes belong to the *tall shrub* map group. 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.

Calculating an area-weighted accuracy that takes into account the relative proportion, or abundance, of the individual classes that comprise the maps provides a more representative measure of overall map quality. The assessment discussed in the previous paragraph utilized a sample that was either stratified, in order to adequately sample each cover type, or biased by accessibility, and therefore the distribution of assessment sites did not correspond to the relative proportions of the cover types found across the project area. This means that overall accuracy could be disproportionately influenced by rarer classes or by classes more easily accessed. To account for this, overall area-weighted accuracies were calculated by taking the proportion of correctly classified accuracy assessment sites for each class (the individual class user's accuracies) and multiplying them by the proportion of the total area that the class occupies on the final map (the area weight factor) and summating across every mapped class. Although the true relative abundance of each class across the mapped area cannot be known, the user's accuracy is the best proxy to approximate the distributions of the various classes. Both overall accuracy measures were reported since the area-weighted measure is going to be comparatively inflated since the most common classes are usually modeled more accurately and don't necessarily contain vegetation, such as *water* and *snow/ice*. For example, the overall area-weighted accuracy was 75 percent at the dominance type-level and 87 percent at the map group-level, as opposed to 63 percent and 80 percent, respectively (Appendix C and Table 9).

When studying the error matrices, even classes with relatively low accuracies may still provide important spatial information regarding vegetation assemblages of interest. Correct interpretation of the error matrices allows a user to apply expert knowledge of known plant associations in order to discriminate between errors caused by completely erroneous model associations and those that were logical confusions. For example, a site misclassified as *white/lutz spruce-birch* when in reality it was *white/lutz spruce-cottonwood* does not mean that the site does not contain birch. Local ecology informs us that *white/lutz spruce-cottonwood* forests commonly contain some component of birch, it is just less abundant. Therefore, depending on the user's needs, there may be valuable information contained within those classes that have low accuracy. Such confusion is common when discrete decision rules are applied to a continuous landscape. Although critical thinking may be necessary to tease out meaningful information and gain a comprehensive understanding of class relationships, individual class accuracy numbers, when taken by themselves, do not tell the whole story.

Conclusion

Existing vegetation was mapped through a partnership with the Chugach National Forest, Alaska Regional Office (Region 10), State & Private Forestry, Inventory & Monitoring Program, Fire & Fuels Management, Kenai National Wildlife Refuge, Alaska Department of Fish and Game, Kenai Fjords National Park, Alaska Geospatial Council, Ducks Unlimited, and the Geospatial Applications and Technology Center (GTAC). The final map comprises four distinct, inter-related feature layers: 1) dominance type; 2) tree canopy cover; 3) tree size; and 4) tall shrub canopy cover. The dominance type map consists of a total of 33 classes, including 28 vegetation classes and 5 classes encompassing other land cover types. Continuous tree canopy cover and thematic tree diameter class categories were generated for areas classified as *forest*. Tall shrub canopy cover was also modeled continuously and then subsequently binned for accuracy assessment purposes. 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 of the Kenai. The final Kenai existing vegetation map products provide a spatial depiction of vegetation floristics and structure in 2017. These products can be used in numerous ways to assist resource specialists and land managers. Existing vegetation maps can inform further project-level investigations, timber management, fire behavior, wildlife habitat modeling, and provide region-wide estimations of resource availability and status. This project was made possible through a collaborative team effort that took dedicated work over a span of several years. Different mapping methods were employed based on the available data, desired map classes, and mapping objectives. These methods utilized the best available science and will inform future mapping efforts to make regionally consistent maps across coastal Alaska.

This project used an image object-oriented approach, and therefore, relied on a semi-automated segmentation process to develop the mapping polygons to be used as the fundamental modeling units. Predictor data including remotely sensed imagery, topographic data, and climate information, were summarized as zonal statistics to these segments. Subsequently, reference data collected in the field or photo interpreted were intersected with the corresponding segments to extract associated statistics and to produce the predictive classification models. Random forest, a data mining technique, was used to assign land cover and vegetation structure attributes and produce the final map products. Sentinel 2 and Landsat 8 satellite imagery were the most important model drivers for dominance type prediction, while vegetation structure models relied most heavily on LiDAR and IfSAR data sources. Most of the geospatial data and all of the reference information was collected during the growing season of 2017 and consequently the maps are considered to be indicative of the existing vegetation conditions found on the Kenai during the summer of 2017. The Kenai existing vegetation map products precision and spatial resolution exceed prior mapping efforts. 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 Southcentral Alaska makes obtaining cloud-free imagery difficult, especially when data acquisition has seasonal constraints and imaging sensors have infrequent revisit schedules. Despite these challenges, disparate data sources were strategically utilized to best leverage the available data and achieve high-resolution products. The final existing vegetation map products provided a reasonable portrayal of vegetation patterns across the entirety of the Kenai. Overall accuracies, which evaluated each mapped class with all of the available validation data regardless of extent on the landscape, were: 80% for map group; 63% for dominance type; 79% for tree canopy cover; 77% for tree size and 87% for tall shrub canopy cover. Overall area-weighted accuracy, which accounts for the extent of each class on the final map and weights them proportionally, was estimated to be: 87% for map group; 75% for dominance type; 84% for tree canopy cover; 82% for tree size; and 89% for tall shrub canopy cover.

For more information please refer to the Alaska Region, Plants and Animals, Alaska Region Vegetation Mapping and Ecology website for links to the Kenai Vegetation Mapping ArcGIS StoryMap.
This Story Map 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, the 2016 Fish & Wildlife Service imagery, reference data, and final map products.

Currently, more mapping projects are being conducted within Coastal Alaska. Ongoing projects include mapping existing vegetation on Prince of Wales Island on the Tongass National Forest and the interior portion of the Cordova Ranger District on the Chugach National Forest. Additionally, the Alaska Regional office is working with the individual National Forests and other land management agency partners to plan future mapping work for lands in and around the Ketchikan-Misty Fiord Ranger District on the Tongass and Prince William Sound on the Chugach. Project objectives and strategies are being discussed in order to adequately map these ecologically important areas.

References

Arumäe, T.; Lang, M. 2018. Estimation of canopy cover in dense mixed-species forests using airborne LiDAR data. *European Journal of Remote Sensing*. 51(2): 132-131.

Bellante, G.; Davis, P.; Bogren, W.; Russon, H.; Pugh, N.; Goetz, W.; Maus, P. 2019. Chugach National Forest Structure Mapping Pilot Project Report. *Geospatial Technology and Applications Center*. pp.1-17.

Breiman, L. 2001. Random Forests. *Machine Learning*. 45(1): 5-32.

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.; Cincone, R.C. 1984. A physically-based transformation of thematic mapper data—The TM tasseled cap. *IEE Transactions on Geoscience and Remote Sensing*. 108(4): 422-435.

Cutler, D.R.; Edwards, T.C.; Beard, K.H.; Cutler, A.; Hess, K.T.; Gibson, J.; Lawler, J.J. 2007. Random forests for classification in ecology. *Ecology.* 88(11): 2783-2797.

Burr, S.; Hutten, K., eds. 2017. Forest health conditions in Alaska—2017. Forest Health Protection Report R10-PR-43. U.S. Department of Agriculture, Forest Service, State and Private Forestry, Alaska Region, Anchorage, AK. 64 p.

Hopkinson, C.; Chasmer, L. 2009. Testing LiDAR models of fractional cover across multiple forest ecozones. *Remote Sensing of Environment*. 113(1): 275-288. http://dx.doi.org/10.1016/j.rse.2008.09.012

van Leeuwen, M.; Nieuwenhuis, M. 2010. Retrieval of forest structural parameters using LiDAR remote sensing. *European Journal of Forest Research*. 129(4): 749-770.

McGaughey, R. J. 2009. FUSION/LDV: Software for LiDAR data analysis and visualization. *U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station*. http://forsys.cfr.washington.edu/FUSION/fusionlatest.html

McGuire, A.D.; Melillo, J.M.; Joyce, L.A.; Kicklighter, D.W.; Grace, A.L.; Moore III, B.; Vorosmarty, C.J. 1992. Interactions between carbon and nitrogen dynamics in estimating net primary productivity for potential vegetation in North America. *Global Biogeochemical Cycles*. 6(2): 101-124.

Nelson, M.L.; Brewer, C.K.; Solem, S.L., eds. 2015. Existing vegetation classification, mapping, and inventory technical guide, version 2.0 Gen. Tech. Rep. WO-90. Washington, DC: *U.S. Department of Agriculture, Forest Service, Ecosystem Management Coordination Staff*. 210 p.

Nowacki, G.; Spencer, P.; Brock, T.; Fleming, M.; & Jorgenson, T. 2001. Ecoregions of Alaska and neighboring territory (map). *U.S. Geological Survey*. http://www.adfg.alaska.gov/index.cfm?adfg=ecosystems.ecoregions#prettyPhoto/0/

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

Smith, A.M.; Falkowski, M.J.; Hudak, A.T.; Evans, J.S.; Robinson; A.P.; Steele, C.M. 2009. A cross-comparison of field, spectral, and LiDAR estimates of forest canopy cover. *Canadian Journal of Remote Sensing.* 35(5): 447-459.

Wasser, L.; Day, R.; Chasmer, L.; Taylor, A. 2013. Influence of vegetation structure on LiDAR-derived canopy height and fractional cover in forested riparian buffers during leaf-off and leaf-on conditions. *PLOS One*. 8(1). https://doi.org/10.1371/journal.pone.0054776

Appendix A: Dichotomous Key Containing the Class Definitions for the Kenai Peninsula

Dominance Type Master Key

Step 1 – Vegetation types

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

1b. Tree cover less than 10% 2
2a. At least 25 percent cover is erect to decumbent shrubs 3
3a. shrubs taller than 1.5 m (5 ft) dominate ....**Tall Shrub Key**
3b. shrubs 20 cm (8 in) to 1.5 m in height dominate ....**Low Shrub Key**
3c. shrubs <20cm dominate ....**Dwarf Shrub Key**

3a. Herbaceous vegetation at least 25% ....**Herbaceous Key**

3b. Herbaceous vegetation less than 25% ....**Non-vascular/Non-vegetated/Sparse Vegetation Key**

(After selection, go to indicated Key)

Forest Type Key

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

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

1c. 25-75% total tree cover broadleaf and needleleaf ….**Mixed Broadleaf-Needleleaf Forest Key**

(Go to appropriate forest growth form…)

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

1a. Total tree cover is at least 15% mountain hemlock ……………………………………………………..2

2a. At least 15% of total tree cover is spruce ……………………………………………………………3

3a Spruce species is Sitka ………………………………**Mountain Hemlock – Sitka Spruce**

3b. Spruce species is Lutz ……………………………….**Mountain Hemlock – Lutz Spruce**

2b. Less than 15% total tree cover is sitka, lutz, or white ……………….**Mountain Hemlock**

2c. Dominant tree cover is dwarf mountain hemlock …………….**Dwarf Mountain Hemlock**

1b. Total tree cover is less than 15% mountain hemlock ………………………………………………….4

4a. At least 25% of total tree cover is black spruce, other spruce less than 15% total tree cover………5

5a. trees not stunted ……………………………………………………………**Black Spruce**

5b. trees stunted black spruce, sphagnum moss present ….**Black Spruce Peatland**

4b. At least 25% of total tree cover is black Spruce, and at least 25% total tree cover is white or lutz spruce but no one species dominates ….**Black spruce – White (Lutz) Spruce**

4c. Less than 25% total tree cover is black spruce and least 25% total tree cover is sitka or lutz or white spruce ……………………………………………………………………………………….6

6a. At least 15% total tree cover is sitka spruce ……………………………**Sitka Spruce**

6b. At least 15% total tree cover is lutz spruce ……………………………….**Lutz Spruce**

6c. At least 15% total tree cover is white spruce ………………………….**White Spruce**

Broadleaf Forest Key (At least 75% of total tree cover broadleaf)

1a. At least 50% of total tree cover is aspen ……………………………………….**Quaking Aspen**

1b. At least 50% of total tree cover is black cottonwood and/or balsam poplar ……………………………………………………………….**Black Cottonwood (and Balsam Poplar)**

1c. At least 50% of total tree cover is birch ……………**Alaska Paper Birch (and Kenai Birch)**

1d No single species has 50% total tree cover …………………………………..**Mixed Broadleaf**

Mixed Broadleaf-Needleleaf Forest Key (25-75% total tree cover broadleaf and needleleaf)

1. At least 25% total tree cover is mountain hemlock ....**Mountain Hemlock – Birch**

2. At least 25% total tree cover is black spruce ....**Black spruce – Mixed Broadleaf**

3. At least 25% total tree cover is sitka spruce ....**Sitka Spruce –Cottonwood**

4. At least 25 % total tree cover is white spruce

    4a. At least 25% total tree cover is birch ....**White Spruce – Birch**

    4b. At least 25% total tree cover is aspen ....**White Spruce – Quaking Aspen**

    4c. At least 25% total tree cover is cottonwood ....**White Spruce – Cottonwood**

    4d. No one broadleaf tree is dominant ....**White Spruce – Mixed Broadleaf**

5. At least 25% total tree cover is Lutz spruce.

    5a. At least 25% total tree cover is birch ....**Lutz Spruce – Birch**

    5b. At least 25% total tree cover is aspen ....**Lutz Spruce – Quaking Aspen**

    5c. At least 25% total tree cover is black cottonwood ...**Lutz Spruce –Cottonwood**

    5d. No one broadleaf tree is dominant.....................**Lutz Spruce – Mixed Broadleaf**

Forest Canopy Closure Key

1a. Total tree cover at least 10 percent, but less than 25% ....**TC1 (Woodland)**

1b. Total tree cover greater than 25% but less than 60% ....**TC2 (Open)**

1c. Total tree cover is at least 60 percent ....**TC3 (Closed)**

Tree Size Class Key (Tree diameter at breast height class determined by plurality of cover using tree size form found on page 6)

TS1 = 0 - 1.9”dbh
TS2 = 2 - 4.9”dbh
TS3 = 5 - 11.9”dbh
TS4 = 12 - 17.9”dbh
TS5 = ≥18”dbh
NT = Non Tree

Tall Shrub Key (shrubs taller than 5 ft (1.5 m) dominate)

1. At least 50% total shrub cover salmonberry ……………………………………….. **Salmonberry**

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

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

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

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

1c. (Not as above) Other tall shrubs (Mt ash, Malus, Devils club, etc.) provide at least 50% total cover ……………………………………………………..**Other Tall Shrub** (describe in notes)

Low Shrub Key (shrubs 8 in (20 cm) to 1.5 m in height dominate)

1a. Standing water, sphagnum, or wetland indicators present ……..……………………….…2

2a. At least 15% Sweet gale and/or Willow …………………..**Wet Willow (Sweetgale)**

2b. Not as above, peatland/wetland indicators present …….. **Low Shrub Peatland**

1b. Wetland indicators not present ……………………………………………………………..……..3

3a. Shrubs are dominated by willows and/or dwarf birch …….**Low Shrub Willow – Dwarf Birch**

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

Dwarf Shrub Key

1a. At least 25% lichen ……………………………………………..……… **<u>Dwarf Shrub - Lichen</u>** (mesic)

1b. Dryas dominant; less than 25% Lichen ……… **<u>Dryas Dwarf Shrub</u>** (limited distribution)

1c. Ericaceous or crowberry dominant; less than 25% lichen …….**<u>Ericaceous Dwarf Shrub</u>** (mesic)

1d. Dwarf willow dominant; less than 25% lichen ……………..…………**<u>Willow Dwarf Shrub</u>**

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

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

2a. Dry soils (beach rye, fescue, hairgrass) ……………………………….**<u>Dry Herbaceous</u>**

2b. Moderate moisture (bluejoint, fireweed, mixed forb) ……...**<u>Mesic Herbaceous</u>**

2c. Wet (marsh, rich fen, sedges, cottongrass, water often present) ………………………….……………………………………………………………….**<u>Wet Herbaceous</u>**

2d. Wet peatland, bog, or poor fen (sphagnum dominates, sedges, bull rush, cottongrass, Andromeda, Oxycoccus) …………………………………..…..**<u>Sedge Peatland</u>**

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

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

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

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

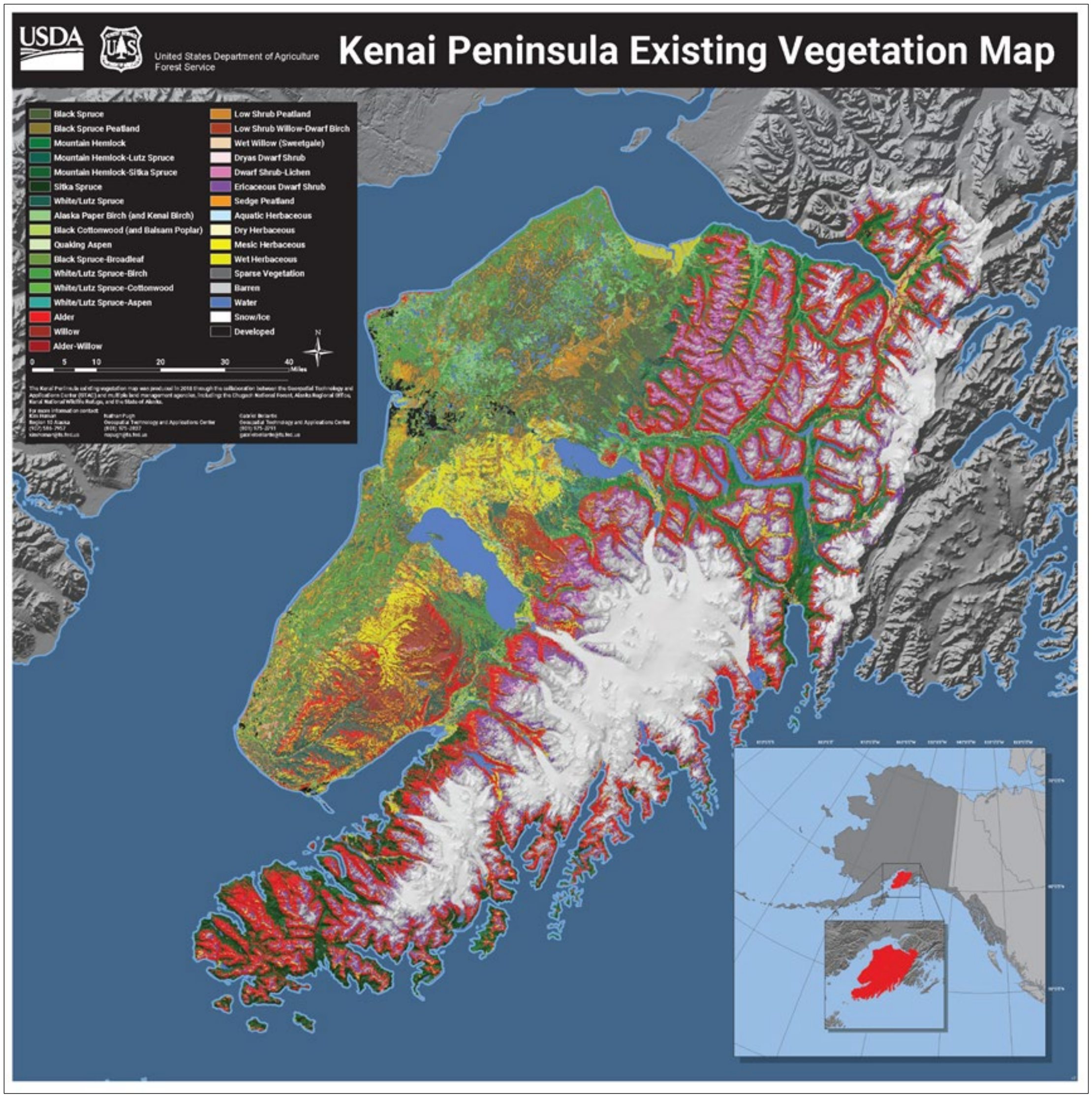
1c. Area is dominated by open water or a confined watercourse …………………………**<u>Water</u>**

1d. Area is dominated by snow and ice ……………………………………………………….**<u>Snow/Ice</u>**

1e. Less than 25% vascular vegetation ……………………………………………**<u>Sparse Vegetation</u>**

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

Appendix B: Kenai Peninsula Dominance Type Map



Download a high resolution poster (36x36) of the Kenai Peninsula Existing Vegetation Map.

Appendix C: Kenai Peninsula Dominance Type Error Matrix

Reference Data

Map Data	Black Spruce	Black Spruce Peatland	Mountain Hemlock	Mountain Hemlock-Lutz Spruce	Mountain Hemlock-Sitka Spruce	Sitka Spruce	White/Lutz Spruce	Alaska Paper Birch (and Kenai Birch)	Black Cottonwood (and Balsam Poplar)	Quaking Aspen	Black Spruce-Broadleaf	White/Lutz Spruce-Birch	White/Lutz Spruce-Cottonwood	White/Lutz Spruce-Aspen	Alder	Willow	Alder-Willow	Low Shrub Peatland	Low Shrub Willow-Dwarf Birch	Wet Willow (Sweetgale)	Dwarf Shrub-Lichen	Ericaceous Dwarf Shrub	Sedge Peatland	Aquatic Herbaceous	Mesic Herbaceous	Wet Herbaceous	Barren	Water	Snow	User's Accuracy	Commission Error
Black Spruce	**19**	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90%	10%
Black Spruce Peatland	3	**11**	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	65%	35%
Mountain Hemlock	0	0	**30**	7	2	3	3	0	1	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	61%	39%
Mountain Hemlock-Lutz Spruce	0	0	4	**16**	1	1	6	0	0	0	0	3	2	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	46%	54%
Mountain Hemlock-Sitka Spruce	0	0	2	0	**19**	15	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50%	50%
Sitka Spruce	0	0	1	0	2	**10**	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	67%	33%
White/Lutz Spruce	1	1	0	0	0	0	**17**	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	71%	29%
Alaska Paper Birch (and Kenai Birch)	0	0	0	0	0	0	0	**39**	3	2	1	6	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	72%	28%
Black Cottonwood (and Balsam Poplar)	0	0	0	0	0	0	0	1	**25**	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	83%	17%
Quaking Aspen	0	0	0	0	0	0	0	7	0	**10**	1	5	1	4	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	33%	67%
Black Spruce-Broadleaf	1	0	0	0	0	0	1	0	0	0	**2**	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20%	80%
White/Lutz Spruce-Birch	1	1	1	0	0	0	1	2	0	2	9	**60**	10	7	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	63%	37%
White/Lutz Spruce-Cottonwood	0	0	0	0	0	0	1	0	3	0	0	5	**6**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40%	60%
White/Lutz Spruce-Aspen	0	0	0	0	0	0	0	0	0	0	0	3	0	**2**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40%	60%
Alder	0	5	2	0	0	0	0	0	2	1	0	4	0	0	**50**	9	6	1	0	2	0	8	1	1	9	2	0	0	0	49%	51%
Willow	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	**11**	2	0	3	1	0	2	0	0	0	0	0	0	0	50%	50%
Alder-Willow	0	0	0	0	0	0	1	1	4	0	0	1	2	0	2	1	**11**	0	0	3	0	0	0	1	0	1	0	0	0	39%	61%
Low Shrub Peatland	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**9**	0	0	0	0	5	0	1	0	0	0	0	56%	44%
Low Shrub Willow-Dwarf Birch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**7**	0	0	2	1	0	0	1	0	0	0	58%	42%
Wet Willow (Sweetgale)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	1	**13**	0	0	0	0	1	2	0	0	0	65%	35%
Dwarf Shrub-Lichen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**26**	4	0	0	1	0	0	0	0	84%	16%
Ericaceous Dwarf Shrub	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	**34**	0	0	1	0	2	0	0	76%	24%
Sedge Peatland	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	2	0	0	**10**	0	0	0	0	0	0	45%	55%
Aquatic Herbaceous	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**4**	0	0	0	2	0	67%	33%
Mesic Herbaceous	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	1	1	0	1	0	0	**28**	3	0	0	0	76%	24%
Wet Herbaceous	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	3	0	0	1	2	0	**25**	0	0	0	76%	24%
Barren	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	**16**	0	0	94%	6%
Water	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**22**	0	96%	4%
Snow/Ice	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	0	**18**	100%	0%
Producer's Accuracy	76%	50%	75%	70%	79%	34%	52%	76%	61%	63%	13%	61%	25%	13%	83%	46%	52%	41%	58%	52%	76%	67%	56%	40%	67%	69%	89%	92%	100%	Kappa	0.61
Omission Error	24%	50%	25%	30%	21%	66%	48%	24%	39%	38%	87%	39%	75%	87%	17%	54%	48%	59%	42%	48%	24%	33%	44%	60%	33%	31%	11%	8%	0%	Overall Accuracy	63.15%
																														Overall Area-Weighted Accuracy	74.61%