Marin Fine Scale Vegetation Map

Final Report

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1. Executive Summary

This report documents the methods and results of the fine-scale, countywide vegetation map of Marin County, CA. The map represents the state of the landscape in summer, 2018, when the high-resolution imagery for the county was collected.

The Tamalpais Lands Collaborative (One Tam; https://www.onetam.org/), the network of organizations that manage lands on Mount Tamalpais in Marin County, initiated the countywide mapping project with their interest in creating a seamless, comprehensive map depicting vegetation communities across the landscape. With support from their non-profit partner the Golden Gate National Parks Conservancy (https://www.parksconservancy.org/) One Tam was able to build a consortium to fund and implement the countywide fine scale vegetation map.

Over a 3-year period, the project, collectively referred to as the "Marin Veg Map," has produced numerous environmental map products including countywide lidar data, 1-foot contours, orthophotography, stream centerlines, watershed boundaries, and other land cover maps. A 107-class fine-scale vegetation map was completed in May 2021 that details vegetation communities and agricultural land cover types, including forests, grasslands, riparian vegetation, wetlands, and croplands. The environmental data products from the Marin Veg Map are foundational and can be used by organizations and government departments for a wide range of purposes, including planning, conservation, and to track changes over time to Marin County's habitats and natural resources.

Development of the Marin fine-scale vegetation map was managed by the Golden Gate National Parks Conservancy and staffed by personnel from Tukman Geospatial (https://tukmangeospatial.com/) Aerial Information Systems (AIS; http://www.aisgis.com/), and Kass Green and Associates. The fine-scale vegetation map effort included field surveys by a team of trained botanists. Data from these surveys, combined with older surveys from previous efforts, were analyzed by the California Native Plant Society (CNPS) Vegetation Program (https://www.cnps.org/vegetation) with support from the California Department of Fish and Wildlife Vegetation Classification and Mapping Program (VegCAMP; https://wildlife.ca.gov/Data/VegCAMP) to develop a Marin County-specific vegetation classification. For more information on the field sampling and vegetation classification work refer to the final report (https://drive.google.com/file/d/1XldHB-JKpYkku912TqiZzR2fO02L2aNJ/view?usp=sharing) issued by CNPS and corresponding floristic descriptions (https://drive.google.com/file/d/1yTJ4f39rzlKVQh5MUVuUIicYlFcUJU9-/view?usp=sharing).

High density lidar data was obtained countywide in the early winter of 2019 to support the project. The lidar point cloud, and many of its derivatives, were used extensively during the process of developing the fine-scale vegetation and habitat map. The lidar data was used in conjunction with optical data. Optical data used throughout the project included 6-inch resolution airborne 4-band imagery collected in the summer of 2018, as well as 6-inch imagery from 2014 and various dates of National Agriculture Imagery Program (NAIP) imagery.

In 2019, a 26-class lifeform map was produced which serves as the foundation for the much more floristically detailed fine-scale vegetation and habitat map. The lifeform map was developed using expert systems rulesets in Trimble Ecognition®, followed by manual editing.

In 2019, Tukman Geospatial staff and partners conducted countywide reconnaissance field work to support fine-scale mapping. Field-collected data were used to train automated machine learning algorithms, which produced a fully automated countywide fine-scale vegetation and habitat map. Throughout 2020, AIS manually edited the fine-scale maps, and Tukman Geospatial and AIS went to the field for validation trips to inform and improve the manual editing process. In the spring of 2021, draft maps were distributed and reviewed by Marin County's community of land managers and by the funders of the project. Input from these groups was used to further refine the map. The countywide fine-scale vegetation map and related data products were made public in June 2021. In total, 107 vegetation classes were mapped with a minimum mapping size of one fifth to one acre, varying by class.

Accuracy assessment plot data were collected in 2019, 2020, and 2021. Accuracy assessment results were compiled and analyzed in the summer of 2021. Overall accuracy of the lifeform map is 95%. Overall accuracy of the fine-scale vegetation map is 77%, with an overall 'fuzzy' accuracy of 81%.

The Marin County fine-scale vegetation map was designed for a broad audience for use at many floristic and spatial scales. At its most floristically resolute scale, the fine-scale vegetation map depicts the landscape at the National Vegetation Classification alliance level – which characterizes stands of vegetation generally by the dominant species present. This product is useful to managers interested in specific information about vegetation composition. For those interested in general land use and land cover, the lifeform map may be more appropriate. To make the information contained in the map accessible to the most users, the vegetation map is published as a suite of GIS deliverables available in a number of formats. Map products are being made available wherever possible by the project stakeholders, including the regional data portal Pacific Veg Map (http://pacificvegmap.org/data-downloads).

In addition to the numerous data products, the fine-scale vegetation map contains several attributes that provide utility to the end user beyond vegetation type information. The map contains lidar-derived information about stand height, stand canopy cover, and the percent of impervious cover in each vegetation and habitat map polygon.

The fine scale vegetation map also provides a suite of attributes relevant to forest health (https://www.onetam.org/our-work/forest-health-resiliency). The data products delivered in this project will provide information about canopy mortality (percent standing dead by forested stand in 2019) and canopy gaps. These attributes apply to all forested stands and include the density of standing dead vegetation and the percent of the stand that is a canopy gap formed between 2010 and 2019. these products will be useful for tracking the spread of pathogens such as sudden oak death and pitch pine canker in Marin's forests and woodlands.

Another data product developed during the countywide fine scale vegetation map effort is the Standardized 2004-2014 County Parks/Marin Water Vegetation Map, which is a fine scale vegetation map for 47,334 acres of public lands in Marin County, combined from 4 earlier mapping efforts. The older fine scale maps exist in several different GIS datasets; this effort unifies them into a single dataset with a standardized set of attributes. This data product is meant to be used to understand vegetation conditions and how they changed between 2004 and 2014 for this subset of public lands in Marin County. The new 2018 countywide fine scale vegetation map should be used for analysis and mapping of post-2014 vegetation conditions. Section 3.8 details the methods used to create the Standardized 2004-2014 County Parks/Marin Water Vegetation Map.

This report details the methods used to develop the fine-scale vegetation map and its derivative products. Methods used to collect the lidar data and derived elevation products are detailed in a separate technical report (https://vegmap.press/quantum_marin_lidar_report).

This report is organized into the following sections:

- **Section 2. Acknowledgements**
- **Section 3. Mapping Methods** – details methods used to create the final map classes and rules, the lifeform map, and the fine-scale vegetation and habitat maps
- **Section 4. Accuracy Assessment Methods and Results** – provides information on the accuracy of the vegetation map overall, the accuracy by map class, and discussion of the major sources of confusion.
- **Section 5. Vegetation Map Data Products** – provides a list of the vegetation map data products, instructions for obtaining the data products and specifications of the map products including minimum mapping units.
- **Section 6. Discussion of the Veg Map and the State Standard** – provides a short discussion on how the Marin fine scale vegetation map differs from the California Department of Fish and Wildlife's state standard for vegetation mapping.
- **Section 7. References**
- **Section 8. Fine-scale Map Class Descriptions** – provides a page for each fine-scale map class that describes the map class, its composition, and its acreage mapped.

2. Acknowledgements

The Marin County fine scale vegetation map was a multi-year effort made possible with support from the following agencies and organizations:

- California Department of Parks and Recreation
- California Department of Fish and Wildlife
- California Native Plant Society
- County of Marin
- Golden Gate National Parks Conservancy
- Golden Gate National Recreation Area
- Greater Farallones Association
- Greater Farallones National Marine Sanctuary
- Marin Agricultural Land Trust
- Marin County Parks
- Marin County Resource Conservation District
- Marin Municipal Water District
- MarinMap
- One Tam
- Point Blue Conservation Science
- Point Reyes National Seashore
- San Francisco Bay Area Network of National Parks
- San Francisco Bay National Estuarine Research Reserve
- United States Geological Survey

In addition to providing monetary support for the project, One Tam provided guidance on the details of the classification, vegetation sampling priorities, and the specifications of the fine scale vegetation map and related data products. Input was provided through a committee of natural resource professionals representing public land managing agencies in Marin County.

We would like to extend our gratitude to those private landowners who provided access to their land for field work. Thanks also to Marin Water, the National Park Service, Marin County Parks, and California State Parks for providing full access to their properties for field crews as well as access to existing vegetation information.

3. Mapping Methods

3.1. Introduction

As summarized by Green, Congalton, & Tukman (2017), using remotely sensed data and ancillary information to map vegetation type is effective because there is a high correlation between variation in the imagery and ancillary data and variation in vegetation as specified by the classification scheme. In other words, when the vegetation on the ground changes, the spectral response of the imagery and/or the classes of ancillary data also change. Using remotely sensed data and ancillary information to map land cover and land use requires an understanding of the factors that cause variation on the ground and how the imagery and ancillary information represent those variations. Therefore, vegetation mapping requires completion of three basic steps:

- Developing a classification scheme to specify the type of land cover and land use characteristics to be detected and mapped
- Controlling variation in the imagery and ancillary information that is not related to variation in the classification scheme
- Capturing the variation in the imagery and ancillary data that is related to the variation in the classification scheme.

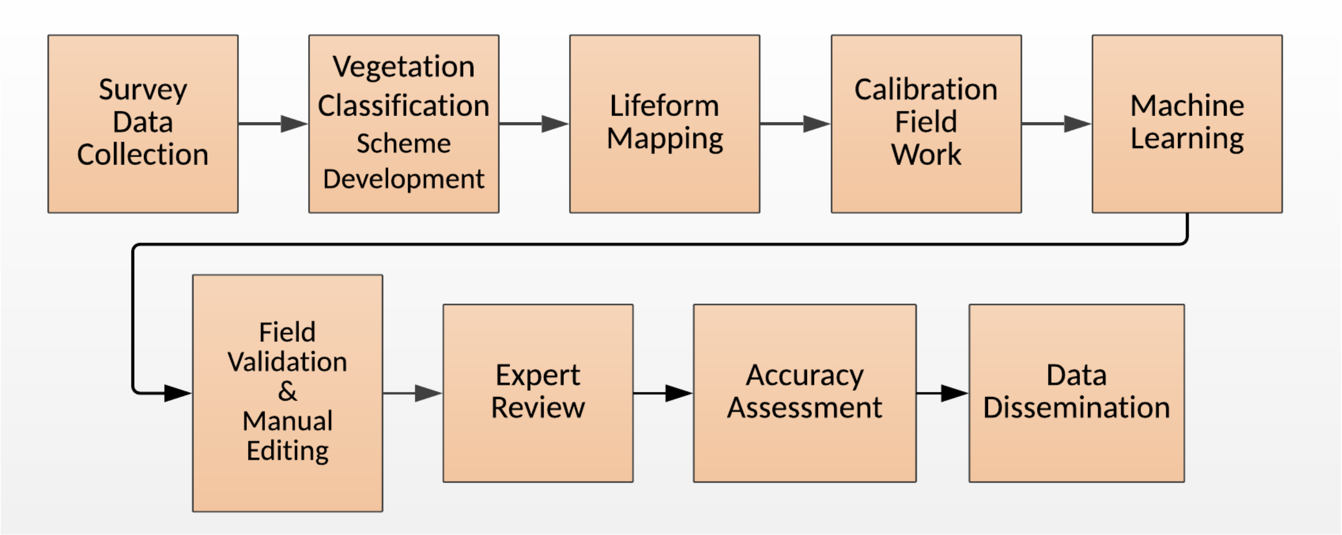
Since the early 1900s, these steps have been completed through the manual interpretation of remotely sensed data to delineate and identify vegetation using seven indicators of vegetation type; color, tone, texture, location, context, height, and shape of the feature of interest (Spurr, 1960). While a mainstay for decades, manual interpretation can be extremely time consuming, costly, and inconsistent. Semi-automated classification involves machine learning to establish relationships between the imagery, ancillary information, and features on the ground. Semi-automated methods can be more cost effective and consistent than manual interpretation by allowing computer data analysis to label the easily identified features, thereby focusing the skilled remote sensing analysts' efforts on difficult and complex features. This project employed semi-automated techniques.

Innovations over the last decade have resulted in the development of the semi-automated classification method of object-oriented classification. Object-oriented image classification classifies image objects (image segments) instead of single pixels, allowing for the incorporation of not only texture, tone, and color, but also shape and context into the creation of vegetation data. Object-oriented classification closely mimics manual interpretation by creating vegetation polygons yet brings substantial increase to the speed of map production, consistency, accuracy, and detail. While powerful in the classification of medium resolution data (e.g., Landsat), object-oriented classification is pivotal for semi-automated classification of high-resolution airborne imagery because of the mixture of shadow and illuminated features in the imagery and the need to group pixels together to map vegetation classes instead of vegetation features such as individual trees.

This project's semi-automated techniques combine the computer automation of object-oriented image segmentation and machine learning with the human work of field data collection, vegetation classification development, manual image interpretation and editing to create Marin County's vegetation map products.

This section provides an overview of the methods – both automated and non-automated – and data used to make the fine-scale vegetation and habitat map. There were nine overall steps in the mapping team's methods (see Figure 1).

Figure 1. *Fine-scale mapping steps*



3.2. Plot Data Collection and Classification Development

The fine-scale mapping effort began with countywide vegetation survey data collection by a team of trained botanists. These data were combined with surveys from previous efforts by the California Native Plant Society (CNPS). The collective body of new and older surveys was analyzed by CNPS to create a comprehensive classification, a dichotomous key that provides decision rules for labeling fine-scale vegetation classes, and vegetation descriptions for each fine-fine-scale vegetation class in Marin County (see Table 1). These products follow the same standards, framework, and hierarchy used by both the Manual of California Vegetation (Sawyer, Keeler-Wolf, & Evens, 2009) and the National Vegetation Classification System.

Table 1. *Table of classification related data products*

Data Product	**Description**	**Download URL**
CNPS Vegetation Classification of Alliances and Associations	Main body of classification document	https://drive.google.com/file/d/1XldHB-JKpYkku912TqiZzR2fO02L2aNJ/view?usp=sharing
Alliance and Associations Vegetation Descriptions	Appendix D of classification document (detailed descriptions of alliances)	https://drive.google.com/file/d/1yTJ4f39rzlKVQh5MUVuUIicYlFcUJU9-/view?usp=sharing

Data Product	Description	Download URL
Marin County Fine-scale Mapping Key	Key used for lifeform mapping and fine-scale vegetation mapping	https://vegmap.press/mapping_key

During the classification development phase, minimum mapping units (MMUs) were established for the vegetation mapping project. An MMU is the smallest area to be mapped on the ground. Many mapping projects have a single MMU; for this project the mapping team chose to map different features at different MMUs. For example, riparian vegetation had a smaller MMU than upland vegetation types because riparian vegetation is a sensitive habitat, is relatively uncommon on the landscape, and very important from a land manager's perspective. Table 2 shows the MMUs for the various features mapped in the Marin fine scale vegetation map.

Table 2. *Minimum mapping units by feature type*

Feature Type	Minimum Mapping Unit
Agricultural Classes	1/4 Acre
Woody Upland Classes	1/2 acre for contrasting lifeforms (e.g., forest surrounded by non-forest); 1 acre for different alliances in the same lifeform
Woody Riparian Classes	1/4 acre for contrasting lifeforms; 1 acre for different alliances in the same lifeform
Upland Herbaceous Classes	1/2 acre for contrasting lifeforms; 1 acre for different alliances in the same lifeform
Wetland Herbaceous Classes	1/4 acre for contrasting lifeforms; 1 acre for different alliances in the same lifeform
Bare Land	1/2 Acre
Impervious Features (in the impervious surfaces map)	1000 square feet; 200 square feet for buildings*
Developed (in the vegetation and habitat map)	1/5 Acre
Water	400 square feet

*These numbers apply to the Marin impervious surfaces map, which is referenced in this report but is not a vegetation map product. The lifeform map and fine-scale vegetation map show major road polygons and impervious features that have contiguous impervious areas (not including roads) of .2 acres or more.

3.3. Lifeform Mapping

3.3.1. Lifeform Mapping Overview

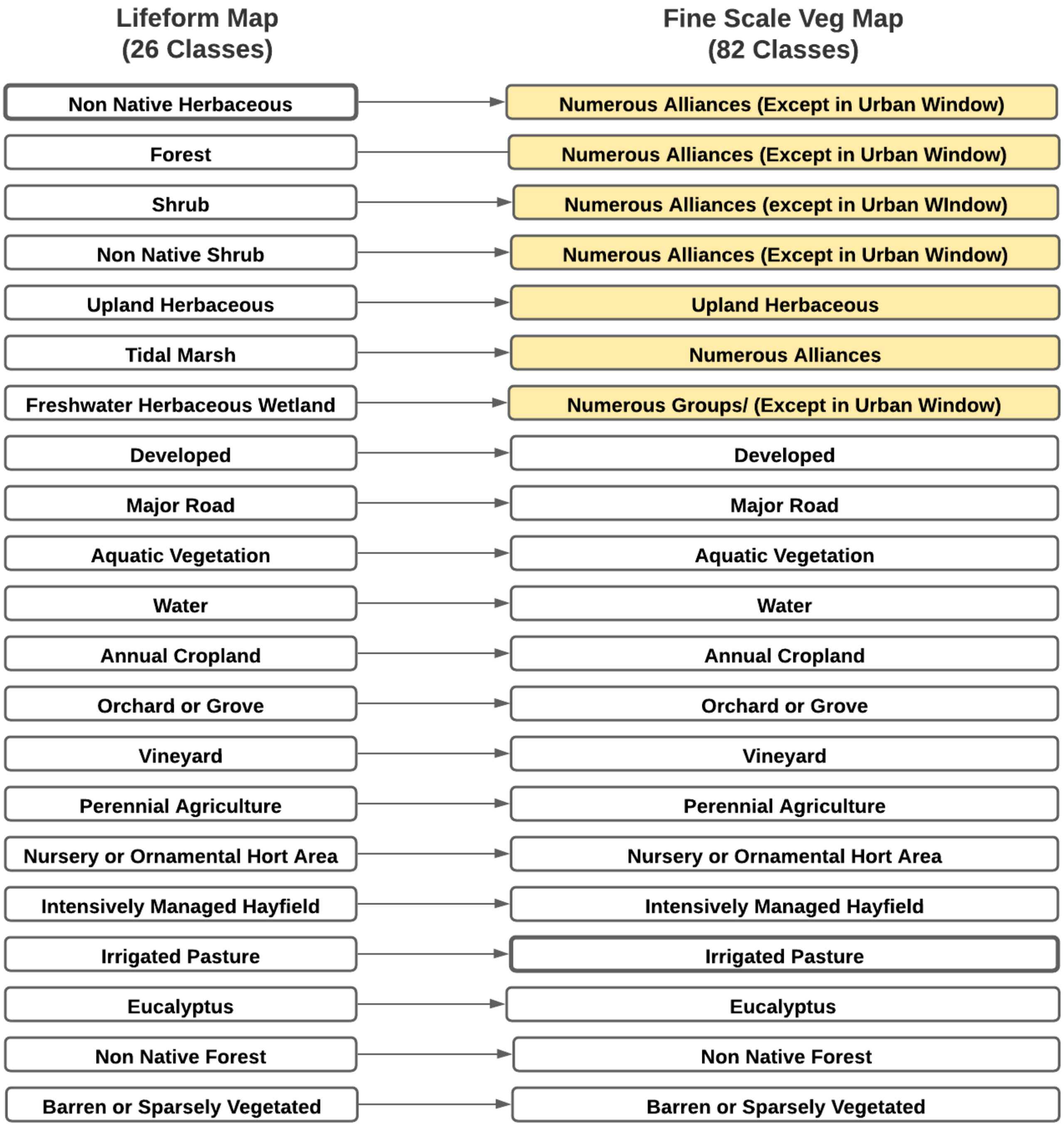
The lifeform and the enhanced lifeform maps depict land cover in a floristically general way and serve as the foundation for subsequent fine-scale mapping. This section describes the creation of the lifeform and enhanced lifeform maps, the methods used to map the built and agriculture lifeform classes, and the process of manually editing the lifeform and enhanced lifeform maps.

The mapping process begins with lifeform mapping, which is conducted using Trimble® Ecognition® followed by manual image interpretation. Lifeform mapping results in a map of very general lifeform classes. The lifeform map serves as the foundation for the fine scale vegetation map. The lifeform mapping process combines fine scale segmentation in Trimble® Ecognition® with machine learning and manual image interpretation. The lifeform map is produced and published as an interim draft map while the mapping team creates the final, fine scale vegetation map. Figure 2 illustrates the hierarchical nature of the lifeform and fine scale mapping classes.

Figure 3 illustrates the concept of lifeform mapping and how it fits into the workflow. The top right of the of the figure shows a lifeform polygon classified as 'Forest'. The fine scale map class phase of mapping result in the subdivision of lifeform polygons and the fine scale mapping of these polygons. In this example, the native forest lifeform polygon is subdivided into a number of forest polygons classified in this case as Douglas fir, redwood, and valley oak, blue oak and madrone forest.

A description of lifeform classes and the final acreage of each class in Marin County, is shown in Table 3.

Figure 2. *Hierarchical classifications – lifeform, and fine scale vegetation map classes for Marin*



Lifeform Map (26 Classes)	Fine Scale Veg Map (82 Classes)
Non Native Herbaceous	Numerous Alliances (Except in Urban Window)
Forest	Numerous Alliances (Except in Urban Window)
Shrub	Numerous Alliances (except in Urban WIndow)
Non Native Shrub	Numerous Alliances (Except in Urban Window)
Upland Herbaceous	Upland Herbaceous
Tidal Marsh	Numerous Alliances
Freshwater Herbaceous Wetland	Numerous Groups/ (Except in Urban Window)
Developed	Developed
Major Road	Major Road
Aquatic Vegetation	Aquatic Vegetation
Water	Water
Annual Cropland	Annual Cropland
Orchard or Grove	Orchard or Grove
Vineyard	Vineyard
Perennial Agriculture	Perennial Agriculture
Nursery or Ornamental Hort Area	Nursery or Ornamental Hort Area
Intensively Managed Hayfield	Intensively Managed Hayfield
Irrigated Pasture	Irrigated Pasture
Eucalyptus	Eucalyptus
Non Native Forest	Non Native Forest
Barren or Sparsely Vegetated	Barren or Sparsely Vegetated

Figure 3. *Lifeform mapping, fine scale segmentation and fine scale vegetation mapping workflow*

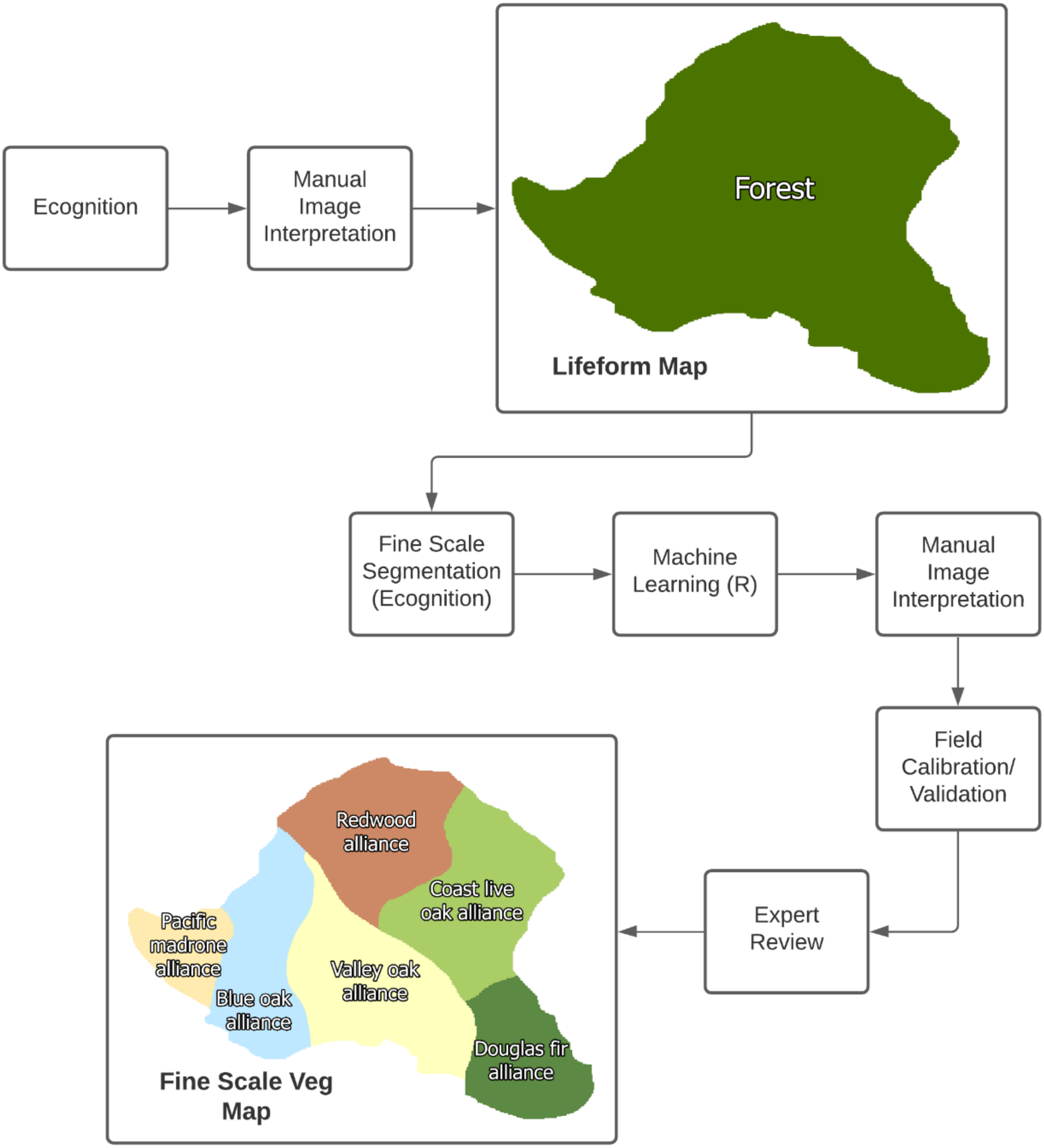


Table 3. *Lifeform classes and acreages, Marin County*

Lifeform Class	Description	Acres
Annual Cropland	Area is an irrigated annual cropland (e.g., vegetable crops)	173
Aquaculture	Area where aquaculture is present (e.g., oyster beds)	80
Aquatic Vegetation	Area is covered by aquatic vegetation	32
Barren	Areas where shrub, forest, and herbaceous cover are each less than 10% absolute cover and the area is best characterized as bare land	1,776
Channel	Channels within tidal marsh areas	98
Developed	Manmade developed areas greater than 0.2 acres	25,629
Eel Grass	Areas where eel grass is dominant	1,540
Forest Fragment	Small forested polygon (< 1 acre) surrounded by non-forest; woody vegetation >15 feet is at least 10% absolute cover	943
Freshwater Wetland	Areas of herbaceous wetland vegetation	4,949
Herbaceous	Areas where upland herbaceous vegetation is at least 10% absolute cover; absolute tree and shrub cover is less than 10%	107,628
Intensively Managed Hayfield	Area is an intensively managed hayfield that is mechanically turned over every year	2,721
Irrigated Pasture	Area is an irrigated pasture	404
Major Road	Area is a major road	1,629
Mudflat	Areas of mudflat (<10% vegetated cover) in the intertidal zone of salt marshes	3,982
Native Forest	Areas where woody vegetation >15 feet is at least 10% absolute cover; native trees dominate the tree stratum	117,857
Native Shrub	Area where native woody shrubs are at least 10% absolute cover	55,613
Non-native Forest	Areas where woody vegetation >15 feet is at least 10% absolute cover; tree cover dominated by ornamental non-native species (>50% relative tree cover)	4,408
Non-native Herbaceous	Areas where non-native herbaceous vegetation is at least 10% absolute cover; non-native herbaceous species dominate the herbaceous stratum; absolute tree and shrub cover is less than 10%.	1,889
Non-native Shrub	Areas where non-native, ornamental, or landscaping woody shrubs are at least 10% absolute cover; absolute tree and shrub cover is less than 10%	861
Nursery or Ornamental Horticulture Area	Nursery or horticultural area	12
Orchard or Grove	Area is an orchard or grove of fruit or nut trees	115

Lifeform Class	Description	Acres
Perennial Cropland	Area is a perennial cropland (e.g., lavender, berries, Christmas trees, rhododendron)	6
Shrub Fragment	Small shrub polygon (< 1 acre) surrounded by non-shrub; woody vegetation >15 feet is less than 10% absolute cover, and shrub cover is greater than or equal to 10%	1,164
Tidal Wetland	Area that has salt-water tolerant wetland species within the tidal zone	5,676
Vineyard	Area is a vineyard	197
Water	Water covers the area	26,904
	Total:	322,289

3.3.2. Trimble® Ecognition® for Lifeform

The lifeform map is created using Trimble® Ecognition® followed by manual image interpretation. The initial lifeform map is created using an Ecognition® rule set that combines automated image segmentation with object-based image classification. The rule set is developed heuristically based on the knowledge of experienced image analysts and is based on rulesets used in previous mapping efforts.

After Ecognition is run, an automated, countywide lifeform map is created. The automated countywide map is edited by image interpreters.

Key data sets used in the lifeform and the enhanced lifeform mapping process include high resolution aerial imagery for 2018, the LiDAR-derived Canopy Height Model (CHM), and several other LiDAR-derived raster and vector datasets. Table 4 provides a summary of the datasets used in lifeform mapping.

Table 4. *Imagery and ancillary datasets used in lifeform and mapping*

Layer	Roles in Lifeform Mapping	Source
Summer 2018 Orthoimagery	Used as the primary spectral input for lifeform mapping in Ecognition®.	Quantum Geospatial
2014 NAIP Imagery	Used as a second source of spectral information.	USDA
NDVI from Summer 2018	Used in Ecognition® decision rules for discriminating between vegetated and non-vegetated areas.	Tukman Geospatial/Quantum Spatial
2018 LiDAR Derived Canopy Height Model (CHM)	Represents height of vegetation. The CHM will be used widely as an input to the Ecognition® rule set, especially for mapping the natural lifeform classes.	Tukman Geospatial/Quantum Spatial

Layer	Roles in Lifeform Mapping	Source
Road Centerlines	The Marin County Road Centerlines dataset will be used to include major roads in the lifeform map.	Marin County
Hydrologic Breaklines	Used to represent large water bodies in the lifeform map.	Quantum Geospatial
LiDAR-derived DEM, Slope and Aspect	Used for various Ecognition® decision rules.	Quantum Geospatial
SFEI BAARI Wetlands Data	Used as a preliminary source of tidal salt marsh delineations.	San Francisco Estuary Institute
Building Footprints	Used as an input to the classification of developed areas in Ecognition®.	County of Marin
Wetlands Layer & Giacomini Wetland Map	Used to inform mapping of herbaceous wetlands in Point Reyes National Seashore	Lorraine Parsons, NPS

3.3.3. Lifeform Map - Built Classes

While the natural classes in the lifeform map are mapped by Ecognition® using rules developed solely from the imagery and the LiDAR data (with the exception of wetlands, which are discussed below), classes depicting the built landscape are mapped by Ecognition® using additional data sources and workflows. This section describes how the built classes will be mapped.

Developed areas – such as rural residential developments – are assigned the 'developed' class. Developed areas are included in the lifeform map if they exceed 0.2 acres in size and contain significant man-made impervious cover or are highly altered by man. Existing datasets of Marin County's building footprints were used to inform developed area mapping.

Major paved road polygons (highways and some major arterial roads) are included in the lifeform map and the fine-scale map as major roads, but minor paved roads and dirt roads are not included. Tukman Geospatial has worked with Marin County stakeholders to determine the list of major roads to be integrated in the lifeform map and subsequent map products. These roads are:

- Bear Valley Road
- Platform Bridge Road
- Chileno Valley Rd
- Panoramic Hwy
- E Hwy 37
- Pt Reyes Petaluma Rd
- E Hwy 37 Ramp
- Shoreline Hwy
- Limantour Rd
- Sir Francis Drake Blvd
- Limantour Spit Rd
- Tiburon Blvd
- Lucas Valley Rd
- Tomales Petaluma Rd

- Redwood Hwy
- E Hwy 580
- S Hwy 101
- E Sir Francis Drake Blvd
- S Novato Blvd
- Fallon Two Rock Rd
- Sears Point Rd
- Hicks Valley Rd
- Marshall Petaluma Rd
- W Hwy 37
- N Hwy 101
- W Hwy 37 Ramp
- Nicasio Valley Rd
- W Hwy 580
- Novato Blvd
- Wilson Hill Rd

Minor roads and individual building footprints are omitted from both the lifeform and fine-scale vegetation maps intentionally since these maps are meant to focus on the natural landscape. A separate product - the impervious surfaces map - includes polygons for all vehicle roads (paved and dirt), as well as all impervious surfaces down to a 400 square feet MMU (200 square meters for buildings). It should be noted that the fine-scale vegetation map contains attributes for each polygon about percent imperviousness by impervious cover type (e.g., % paved road, % other impervious). As such, the fine-scale detail regarding the built environment that exists in the impervious map is embedded in the fine-scale map polygons. The work to embed information about imperviousness into the fine scale vegetation map will occurred during final processing (see section 15).

3.3.4. The 'Urban Window'

The 'urban window' layer represents large, contiguous areas of urban landscape. This class was modeled after the approach used for Northern Sierra Nevada Foothills Mapping Project (Menke et al., 2011).

Inside of the urban window, vegetation was generally mapped to the 26 lifeform classes (see Table 3 for a list of classes), not to the fine scale vegetation map classes. There were two exceptions to this – 1) tidal wetlands were mapped to their fine scale map class even if inside the urban window and 2) areas of native forest were mapped to three 'enhanced lifeform' classes – 'Deciduous Hardwoods', 'Evergreen Hardwoods', and 'Conifer.' For example, a 1- acre patch of *Quercus agrifolia* within the urban core of San Rafael will receive a 'Evergreen Hardwood' map class and will not be mapped to the *Quercus agrifolia* Alliance, its fine scale map class.

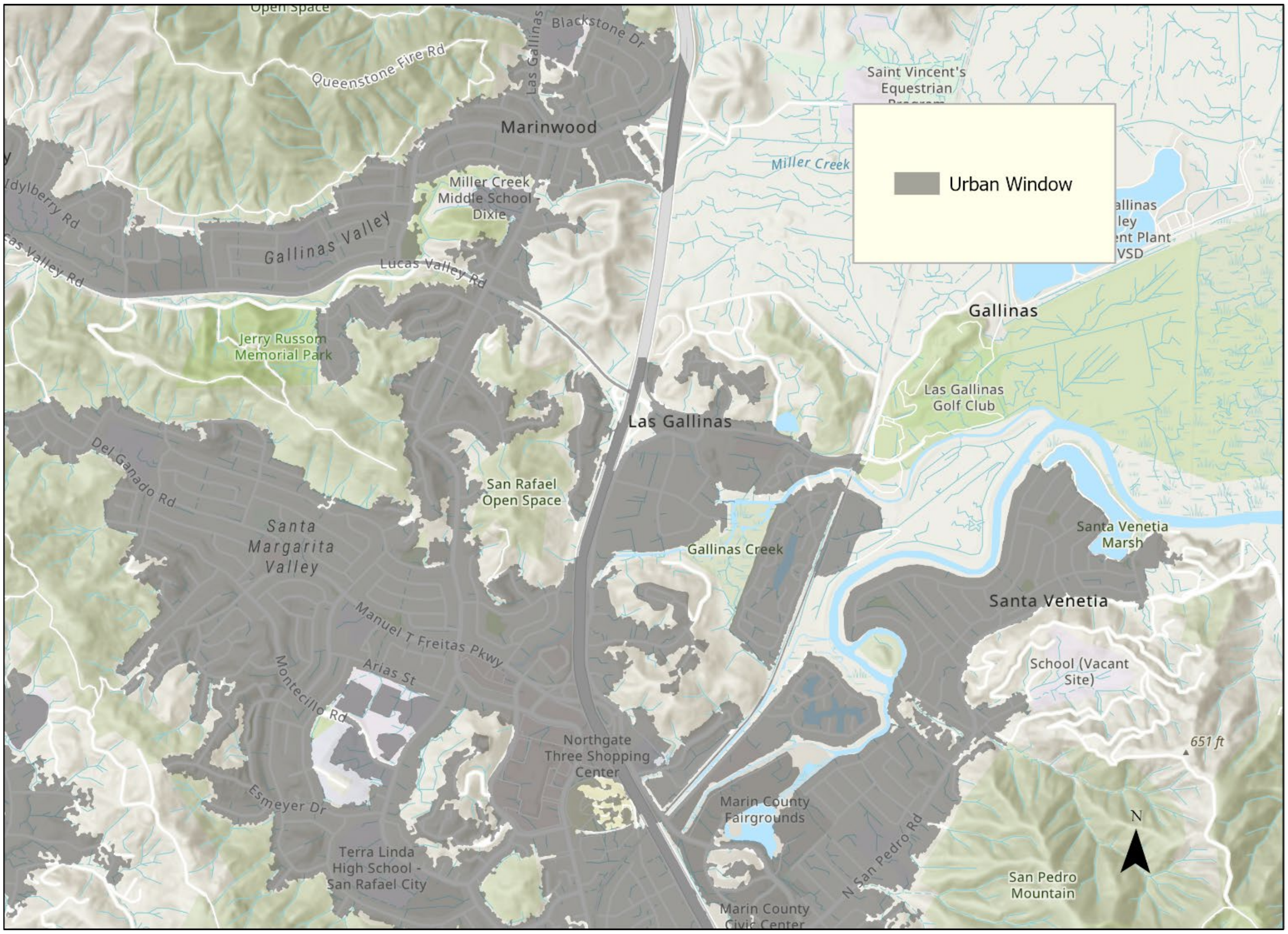
The following criteria were used to create the 'urban window' area:

1. The urban window represents contiguous and adjacent developed and/or major roads areas larger than approximately one square mile.
2. The urban window can finger out into adjacent natural areas if it has >30% impervious coverage.

3. Natural areas (e.g., riparian corridors) can extend into the urban window.
4. “Islands” of predominately natural land cover surrounded by urban core areas are mapped as part of the urban window if they are less than 10 acres. The MMU for natural vegetation within the urban core is 10 acres. If a natural area is greater than 10 acres (e.g., a large urban park), it is not considered part of the urban window and is mapped as natural vegetation.
5. Agriculture islands that exceed ¼ acre (the minimum mapping unit for agriculture) are preserved with their respective agricultural label inside the urban window.
6. Golf courses and playing fields are considered urban land cover and included as part of the urban window.
7. Forested riparian stands are mapped as natural vegetation within the urban window if they exceed 1/4 acre.

Figure 4 show an example of the urban window for an area of East central Marin County.

Figure 4. *The urban window in east central Marin County*



3.3.5. Agriculture

Agriculture was mapped in the lifeform map as several classes, at a ¼ acre minimum mapping unit. Agriculture classes included annual cropland, intensively managed hayfield, irrigated pasture, perennial cropland, orchard or grove, and vineyard. Agriculture fields were not mapped using Ecognition®, but entirely by manual editing.

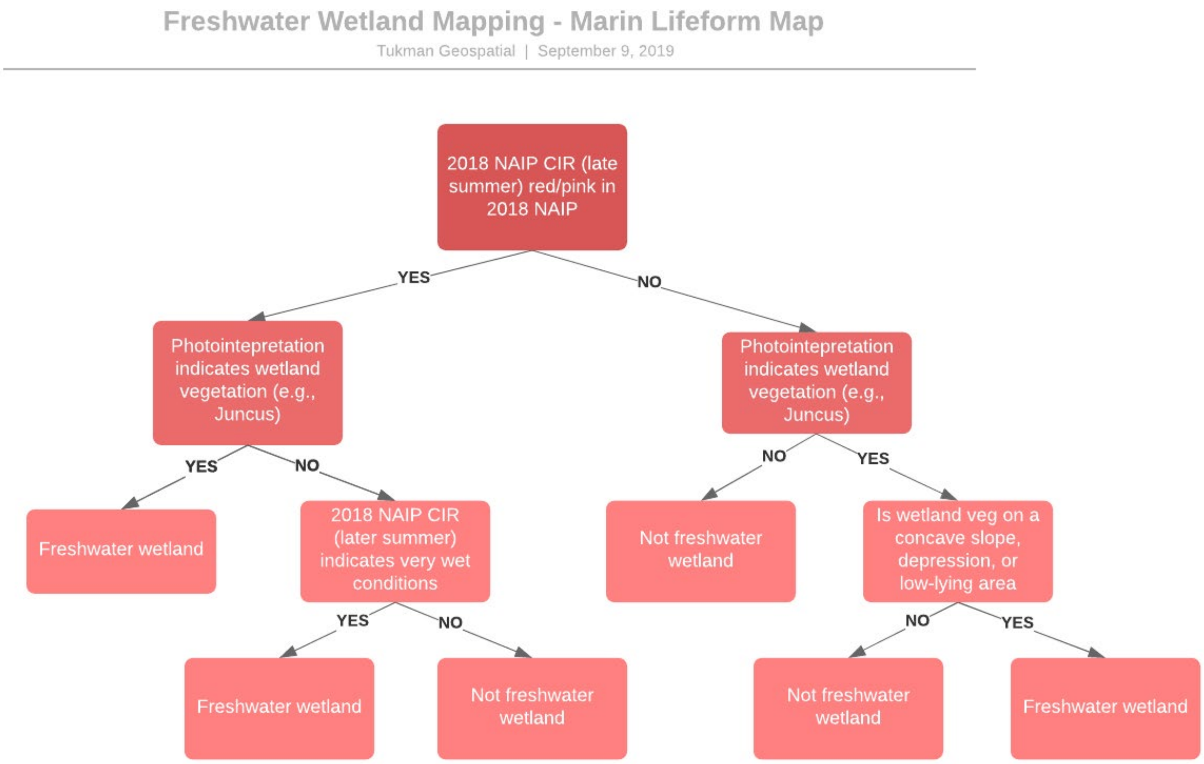
3.3.6. Tidal and Freshwater Wetlands

Tidal and freshwater wetlands are mapped initially in the lifeform map and refined during fine scale map editing. Tidal marshes are extracted from the SFEI’s BAARI Baylands dataset where the class label in that dataset is 'Tidal Vegetation'. These representative polygons were integrated into the lifeform dataset during the Ecognition processing. During lifeform manual editing, the tidal marsh polygons integrated from SFEI were assessed and edited. Additional tidal marsh (that was not included in SFEI’s layer) was added manually through photointerpretation. In the fine scale vegetation map, tidal marsh areas were mapped to the alliance level. See section 3.4.7 for details.

Freshwater wetlands were identified and delineated manually during lifeform mapping; existing freshwater wetlands datasets were not of high enough accuracy for direct integration into the map. Lifeform editors used the decision rules shown in Figure 5 for manually editing freshwater wetlands into the enhanced lifeform map. The rules are based on the appearance of the 2018 countywide orthoimagery, while viewed in color infrared (CIR). Freshwater wetlands were further refined during fine scale map editing.

Existing freshwater wetland layers provided by the National Park Service for Pt. Reyes National Seashore were used to inform herbaceous wetland mapping during manual editing of the lifeform map.

Figure 5. *Rules for editing freshwater wetlands in the lifeform map*



3.3.7. Lifeform Map Manual Editing

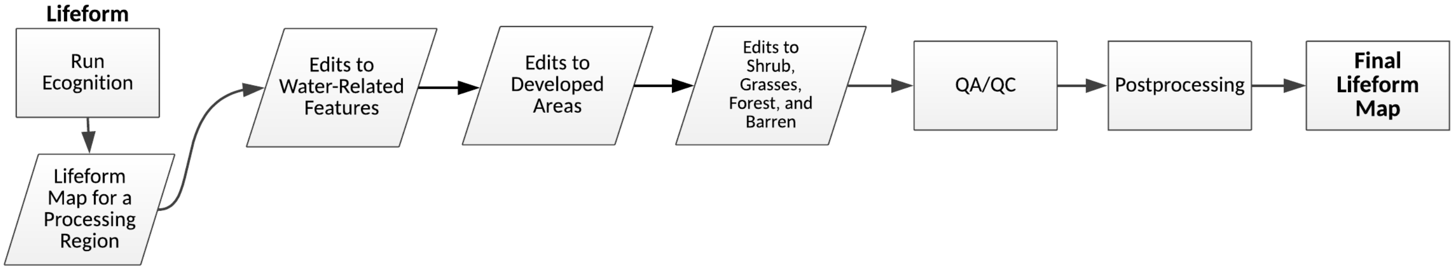
After it was produced using Ecognition®, the preliminary lifeform map was manually edited by photo-interpreters. Edits were made to accomplish the following:

- Splitting of map polygons that are not compositionally homogenous as per the lifeform mapping rules
- Addition of non-native forest and non-native shrub polygons where appropriate
- Edits to the lifeform label (e.g., changes from a forested lifeform to a shrub lifeform)

Manual editing was conducted using ArcMap tile by 250-acre tile. For each tile, the editors would conduct manual edits. A first pass of editing addressed errors related to water. A second pass of editing focused on the developed classes and the urban window. The final editing pass focused on the natural landscape. Once manual editing was complete for all tiles in the county, an additional QA/QC pass occurred at a zoomed-out scale to check for seamlines and other errors.

Figure 6 shows a schematic of the lifeform editing workflow.

Figure 6. *Lifeform editing workflow*

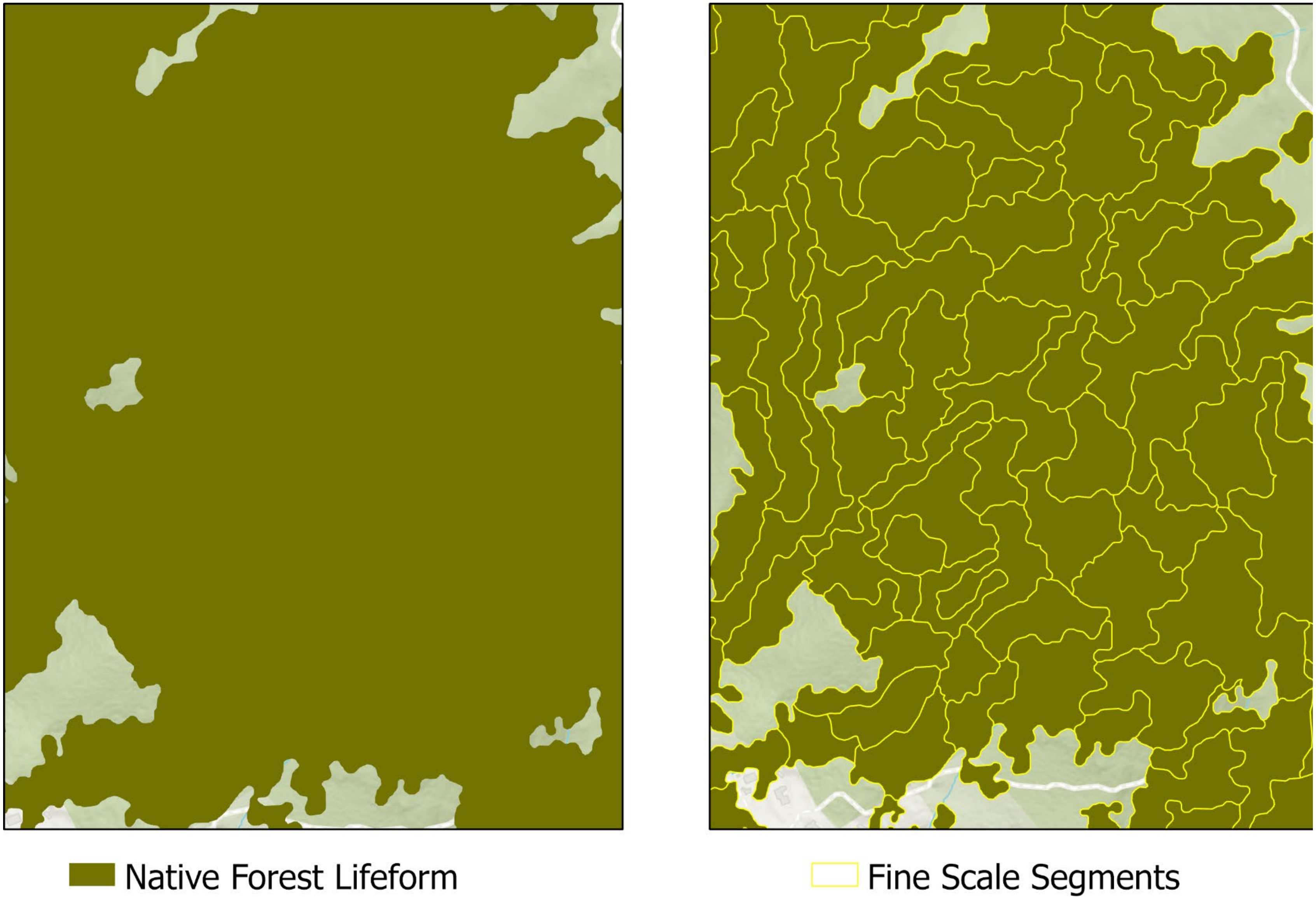


3.4. Fine Scale Mapping

3.4.1. Fine Scale Segmentation

After the lifeform map was completed, a second round of image segmentation was performed to divide the broad 'Native Forest' and 'Native Shrub' classes into smaller forested segments that are spectrally and structurally homogenous. Fine-scale segmentation divides the large and floristically broad native forest and shrub areas into much smaller image segments suitable for fine-scale mapping. Fine-scale segmentation was conducted using Trimble Ecognition® and will relied on summer 2018 high resolution imagery, the 2019 LiDAR-derived canopy height model, and a suite of spectral indices derived from the high-resolution imagery. Fine scale segments were created so that they had spectral homogeneity (from the high-resolution imagery) but also had structural homogeneity, meaning relatively uniform within-segment canopy height and canopy density. Figure 7 shows an example of the fine scale segments versus the much larger polygons of the lifeform map.

Figure 7. *Native forest polygon in lifeform map (left) and same area showing fine scale segments fine-scale segments (right)*



3.4.2. Fine-scale Map Calibration Field Work

Calibration field work is a critical step in the mapping workflow, providing training data for machine learning (see section 3.4.2) as well as visual reference for analysts conducting manual editing of the fine-scale vegetation map. The objectives of calibration field work are 1) to collect observations of all fine scale map classes (as defined in the Marin County fine scale mapping key) across their range of structural and compositional conditions and 2) to collect observations across the entire geography of the county, providing mappers with on-the-ground knowledge of the distribution of, and variation within, the fine scale map classes.

Calibration field data began in June 2019 with a kick-off meeting to review methods and protocols and to calibrate optical percent cover estimates to ensure that different field crews consistently assigned fine-scale map classes.

Teams from Tukman Geospatial and AIS collected calibration field data. Existing and new field survey data collected for floristic classification was also used for map calibration.

Tukman Geospatial developed a Marin County Veg Map Field Book that contains comprehensive information about identifying and keying out map classes, field data collection protocols, and detailed vegetation summaries for the fine-scale map classes. The field book was used by field data collection teams to standardize data collection and apply fine scale map class labels consistently in the field.

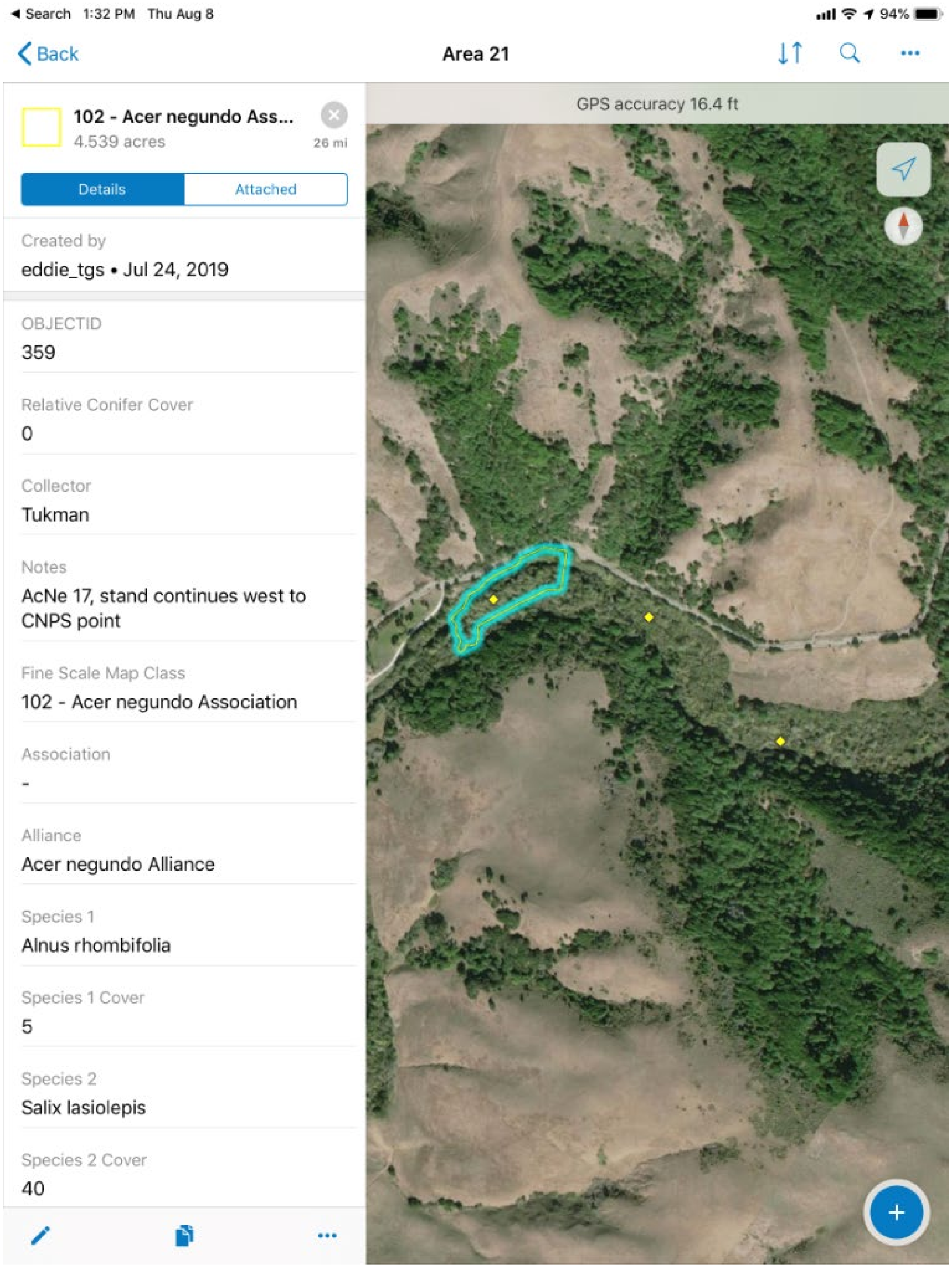
Calibration data collection teams use tablets running ESRI's Collector App (see Figure 8) to delineate and attribute polygons (or label image segments) representing shrub, forest and herbaceous stands observed in the field. The Collector App uses an ArcGIS Online web map with syncable feature services.

Data collected by field crews was synced up at the end of each day and once during the day depending on available cell service and WiFi. Field crews assigned the following to each of the field-collected calibration sites:

- Vegetation map class (from the fine scale mapping key)
- Field team names
- Notes
- Species and species cover for the 10 highest cover species in the stand
- Photos (as feature attachments)

Calibration field work resulted in hundreds of sites labeled countywide with their field-verified fine-scale map class. GPS-tagged photos were also taken at many locations for reference. After field visits, analysts reviewed the field-validated calibration sites with the dual aims of correcting data entry errors and performing QA/QC on field classifications. Data entry errors included assignment of incorrect map classes from the pick lists (usually this was the mis-assignment of the class falling before or after the intended class in the pick list). QA/QC resulted in throwing out or modifying field validated sites where in-office review showed inconsistencies between the field crew's map class assignment and what aerial imagery showed. When field labeled sites could not be reconciled with labels based on aerial imagery interpretation, they were removed as calibration candidates.

Figure 8. *Collector App for field calibration data collection*



102 - Acer negundo Ass...

4.539 acres

Created by

eddie_tgs • Jul 24, 2019

OBJECTID

359

Relative Conifer Cover

0

Collector

Tukman

Notes

AcNe 17, stand continues west to CNPS point

Fine Scale Map Class

102 - Acer negundo Association

Association

-

Alliance

Acer negundo Alliance

Species 1

Alnus rhombifolia

Species 1 Cover

5

Species 2

Salix lasiolepis

Species 2 Cover

40

3.4.3. Fine-scale Map Machine Learning

3.4.3.1. Overview

The Marin Veg Map Team utilized a type of algorithmic data modeling known as machine learning to automate the classification of fine-scale segments into one of Marin County's 107 fine-scale map classes. A form of supervised machine learning was adopted, whereby areas of known classification (training sites) are used to predict the map class for unknown areas through modeling techniques.

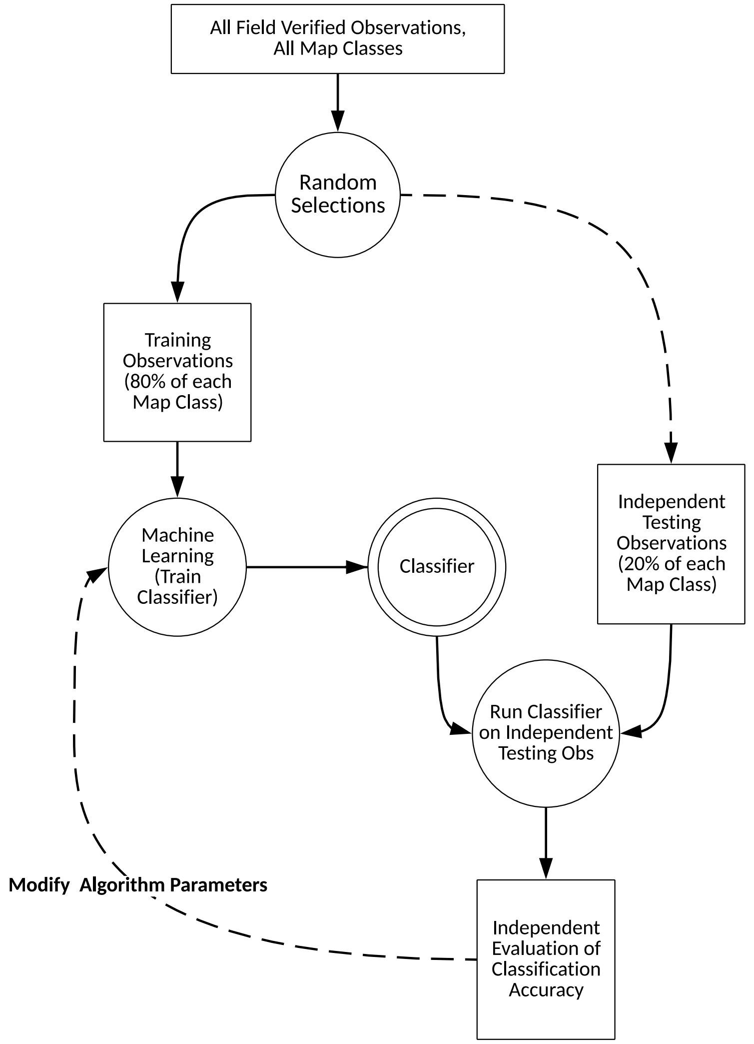
Field-calibrated sites discussed in the previous section were used as training data for machine learning, with their fine scale map class label serving as the dependent variable. The independent variables (referred to in this discussion as *predictor variables*) number over 300 and include variables that characterize the physical landscape and a wide variety of remotely sensed data to represent spectral reflectance of vegetation and forest structure. The predictor variables are discussed in detail in the next section.

Based on a review of the current literature and input from the Vegetation Mapping and Remote Sensing Advisory Committee, two machine learning algorithms were chosen to predict fine-scale vegetation class:

- Random Forests (Breiman, 2001) (section 3.5.2.1)
- Support Vector Machines (Meyer at al., 2018) (section 3.5.2.2)

Machine learning is an iterative process that requires trial and error to fine-tune algorithm parameters and inputs to maximize model accuracy. The Marin Veg Map team employed the workflow shown in Figure 9. At the beginning of the machine learning process, 22% (approximately 103) of the calibration sites were randomly selected for use as independent testing observations. These sites were not used to train the algorithm. The machine learning algorithms (random forests and support vector machines) were run on the remaining 78% (approximately 372) of the calibration sites to create the classifying model. The classifying model was then applied to the calibration sites reserved for independent testing, resulting in map class predictions for those segments. The predicted map class for each site was compared to the field-verified map class and accuracy numbers were generated. Changes to parameters and training sites were applied, and each change was evaluated in the context of its effect on the model accuracy of the independent testing group of segments. The final parameters chosen for both random forests and support vector machines were those that maximized model accuracy for the independent testing group.

Figure 9. *Workflow for machine learning*



3.4.3.2. Random Forests and Support Vector Machines

Random forests and support vector machines (SVMs) were used in tandem in an ensemble approach. The two algorithms were implemented as a script using the R statistical computing package (R Core Team, 2013). Dr. Matt Clark, professor at Sonoma State University, wrote the script. The script was originally used for the Sonoma Veg Map and adapted for use in Marin.

The ensemble approach uses random forests and SVMs so that both algorithms predict fine-scale map class labels for each unlabeled fine scale segment across the landscape. The script then compares the predictions against each other – if the prediction from the two algorithms is the same, the segment is labeled with that fine-scale map class. If the predictions are different, the fine-scale map class from the algorithm with the higher confidence is used (both random forest and SVMs provide metrics for confidence or probability of correctness). Both algorithms produced a primary fine-scale map class label – the algorithm's first choice for a segment – and a secondary class label – the algorithm's second choice. These primary and secondary labels and their associated confidence values were used by manual editors as reference information.

In addition to predicting fine-scale map class for each segment, machine learning was also used to predict relative hardwood versus conifer cover. This was done using relative cover calibration sites collected during calibration field work and supplemented by photo interpreted sites.

3.4.3.3. Random Forests

Random forests "mines" the field-labeled training data and a "stack" of independent predictor variables and builds rules (if-then statements) in a decision tree to predict the fine-scale map class for all unlabeled segments across landscape. Random forest is a powerful modeling approach because:

- it can accept both continuous and categorical data inputs,
- the results are easy to interpret,
- unlike a maximum likelihood classifier, no assumptions are required concerning the distributions of the independent variables,
- it identifies simple and complex relationships between variables that other techniques might not uncover, and
- it forces consistency and analytical rigor into the segment labeling process.

Dr. Clark's R code included several analytical tools that were helpful in interpreting the results of the random forest model and in providing information to help refine and improve model results. These items included – for each run of random forests – an importance matrix for assessing predictor variable importance (as an example, Table 6 in section 3.4.3.5 shows the importance matrix for the *Pseudotsuga menziesii – (Notholithocarpus densiflorus – Arbutus menziesii)* Alliance. In addition, Dr. Clark's code automatically created error matrixes for each run of random forests, providing user's accuracy, producer's accuracy, and overall accuracy for the independent testing sites. Lastly, for each fine scale segment on the landscape, the R code provided two votes – a first vote and a second vote. For both the first and second votes, Dr. Clark's R code provided a confidence value (0 to 1) for its fine-scale vegetation class prediction for the segment. Random forests bases its confidence values on the percentage of individual trees (i.e., set of rules) that predict the class.

For random forests, analysts did not do any predictor variable selection or winnowing – the entire stack of predictor variables was used for each run and the model assessed their importance.

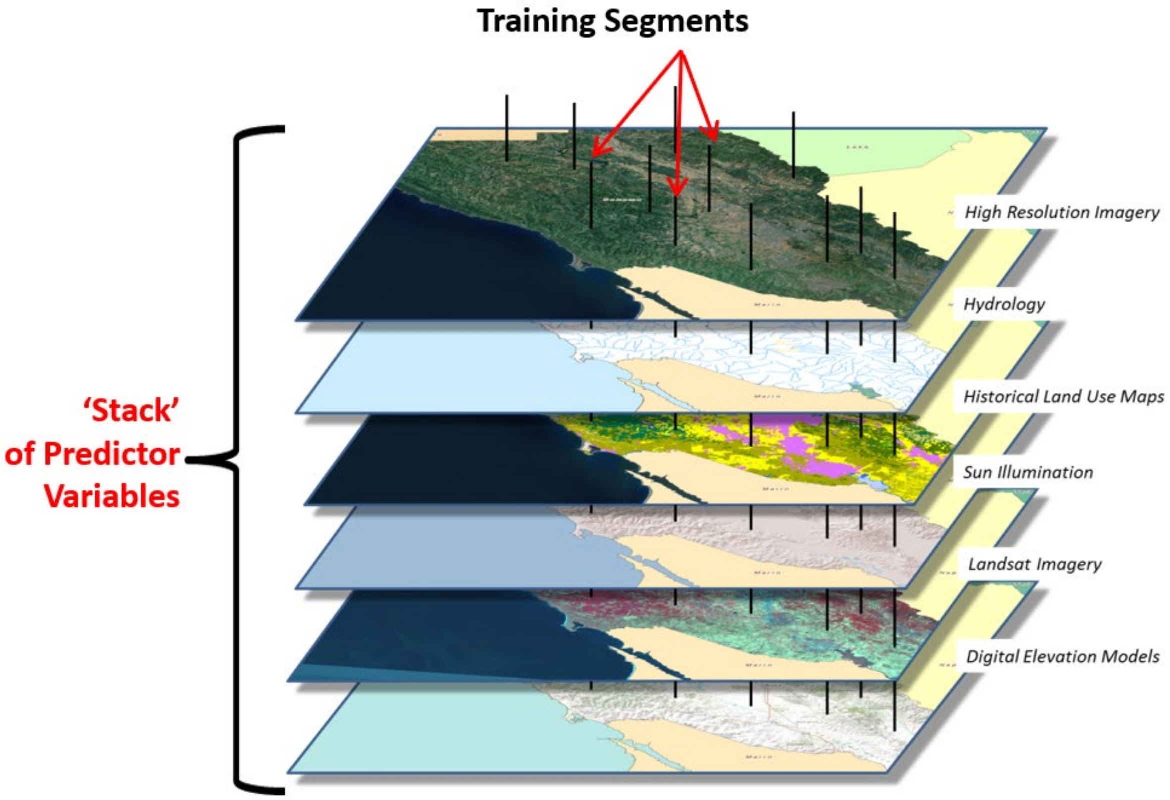
3.4.3.4. Support Vector Machines

Like Random Forests, SVMs are nonparametric supervised classifiers (Congalton, 2010). SVMs perform very well as a machine learning algorithm for vegetation mapping and have been widely adopted in the past few years. Like random forests, SVMs were used to assign each segment a predicted fine-scale map label, as well as a second label with lower confidence. As was done for random forests, Dr. Clark's R code provided error matrixes for SVMs' predictions for the independent testing sites.

3.4.3.5. Independent Variables

Both random forests and support vector machines require a "stack" of predictor variables for each training site and for each fine scale segment. Figure 10 illustrates the concept of the predictor variable stack. The stack of predictor variables was created by running ESRI's zonal statistics tool iteratively in a python script to create a table with the rows representing the training sites or fine scale segments and the columns representing the predictor variables.

Figure 10. *The concept of the "stack" of machine learning predictor variables*



Over 300 predictor variables were used, including high and medium resolution spectral information, spectral and hyperspectral indices derived from AVIRIS data from Dr. Clark, landscape characteristics such as slope, and other variables. Table 5 shows the list of predictor variables. Note that the Sentinel-derived variables at the bottom of the table represent over 100 individual predictor variables, and other rows in Table 5 represent more than one individual variable.

Table 5. *Predictor variables used in machine learning*

Machine Learning Predictor Variable	Data Source
% canopy density in the 15 to 60 foot range	2019 QL1 countywide lidar
% canopy density in the 60 to 100 foot range	2019 QL1 countywide lidar
% canopy density in the 100 to 150 foot range	2019 QL1 countywide lidar
% canopy density in the 150 to 200 foot range	2019 QL1 countywide lidar
% canopy density in the 200 to 250 foot range	2019 QL1 countywide lidar
Average lidar height from lascanopy	2019 QL1 countywide lidar
Lidar kurtosis for height from lascanopy	2019 QL1 countywide lidar
Lidar quadratic average height from lascanopy	2019 QL1 countywide lidar
Lidar skewness for height from lascanopy	2019 QL1 countywide lidar
% lidar returns between 0-4 meters above ground	2019 QL1 countywide lidar
% lidar returns between 4-8 meters above ground	2019 QL1 countywide lidar
Absolute canopy cover	2019 QL1 countywide lidar
Relative cover of trees taller than 60 feet	2019 QL1 countywide lidar
Lidar 5th percentile height from lascanopy	2019 QL1 countywide lidar
Lidar 10th percentile height from lascanopy	2019 QL1 countywide lidar
Lidar 25th percentile height from lascanopy	2019 QL1 countywide lidar
Lidar 50th percentile height from lascanopy	2019 QL1 countywide lidar
Lidar 75th percentile height from lascanopy	2019 QL1 countywide lidar
Lidar 90th percentile height from lascanopy	2019 QL1 countywide lidar
Lidar canopy height from lascanopy	2019 QL1 countywide lidar
Lidar intensity	2019 QL1 countywide lidar
Terrain slope (from bare earth DEM)	2019 QL1 countywide lidar
Canopy slope (slope derived from the canopy height model)	2019 QL1 countywide lidar
Canopy height model (a.k.a. normalized digital surface model)	2019 QL1 countywide lidar
2018 image indices (DVI, GDVI, GNDVI, VARI)	2018 6-inch countywide imagery
2018 high resolution imagery bands (Red, Green, Blue, Near Infrared)	2018 6-inch countywide imagery
Ratio of NDVI between 2014 and 2018	2014 and 2018 6-inch countywide imagery
Ecognition brightness	2018 6-inch countywide imagery

Machine Learning Predictor Variable	Data Source
Ecognition green index	2018 6-inch countywide imagery
Percentage of stand’s canopy classified as high NDVI (not including non-veg areas)	2018 6-inch countywide imagery
Percentage of stand’s canopy that is low NDVI (not including non-veg areas)	2018 6-inch countywide imagery
Loudon Index: (green band*2)/(red band + blue band) from NAIP 2009	USDA Farm Service Agency (NAIP)
2018 NAIP bands (Red, Green, Blue, Near Infrared)	USDA Farm Service Agency (NAIP)
AVIRIS indexes (EWT_AV, NDWI_AV, Wtr1AbAr_AV)	Dr. Matthew Clark, NASA
Sentinel 2018 bands (Red, Green, Blue, NIR, Red-Edge) for multiple months (Jan, Feb, Mar, July, Oct)	The European Space Agency, Google Earth Engine
Sentinel 2018, band differences (Red, Green, Blue, NIR, Red-Edge), between months (Jan, Feb, Mar, July, Oct)	The European Space Agency, Google Earth Engine
Sentinel 2018, indices (DVI, GNDVI, GRVI, VARI, NDVI) for multiple months (Jan, Feb, Mar, July, Oct)	The European Space Agency, Google Earth Engine
Sentinel 2018 index differences (DVI, GNDVI, GRVI, VARI, NDVI), between months (Jan, Feb, Mar, July, Oct)	The European Space Agency, Google Earth Engine
Distance from coast	Tukman Geospatial
Distance from nearest water body over 1 acre	Tukman Geospatial (lifeform map)
Average annual precipitation	PRISM, Oregon State University
Summer fog frequency	The Pacific Coast Fog Project, USGS
Mean annual maximum temperature, 1981-2010	Basin Characterization Model, USGS
Climatic water deficit, 1981 - 2010	Basin Characterization Model, USGS
Evapotranspiration, 1981 - 2010	Basin Characterization Model, USGS

To illustrate how predictor variables are used by the machine learning algorithms, Table 6 shows an importance matrix from random forests for the *Pseudotsuga menziesii – (Notholithocarpus densiflorus – Arbutus menziesii)* Alliance. Table 6 shows that canopy slope and the mean value of the green band were the most important variables for random forests for classifying the *Pseudotsuga menziesii – (Notholithocarpus densiflorus – Arbutus menziesii)* Alliance. Other important predictors for the *Pseudotsuga menziesii – (Notholithocarpus densiflorus – Arbutus menziesii)* Alliance are terrain slope, the Visual Atmospheric Resistance Index (VARI) derived from the 2018 6-inch orthoimagery, and the percent of lidar returns between 100 and 150 feet above the ground.

Table 6. *Top 10 most important predictor variables for the Pseudotsuga menziesii – (Notholithocarpus densiflorus – Arbutus menziesii) Alliance*

Predictor Variable Importance Rank	**Description of Predictor Variable**	**Data Source**
1	Mean 'canopy slope,' a slope raster derived from the lidar derived canopy height model	2019 QL1 countywide lidar
2	Mean July green band (canopy pixels only)	2019 Sentinel
3	Mean lidar derived slope (slope of the terrain)	2019 QL1 countywide lidar
4	Mean July green band	2019 Sentinel
5	Mean July Visual Atmospheric Resistance Index (VARI) value (canopy pixels only)	2019 Sentinel
6	Mean July VARI value in stand	2019 Sentinel
7	Mean July blue band value (canopy pixels only)	2019 Sentinel
8	Mean July VARI minus March VARI (canopy pixels only)	2019 Sentinel
9	Mean July blue band value	2019 Sentinel
10	Mean 100-150ft. Profile Value in Canopy Only	2019 QL1 countywide lidar

3.4.4. Fine-scale Manual Editing & Map Field Validation

3.4.4.1. Fine-scale Map Manual Editing

Manual editing allowed experts to improve the detail and accuracy of machine learning model predictions. Editors used a variety of supporting datasets and best practice protocols to standardize and maintain high quality edits.

Editing is an individual endeavor, and because of the difficulty of precisely interpreting vegetation type and cover from imagery, different humans may assign different labels to the same segment. To minimize inconsistencies among the numerous editors working on the map, protocols were followed to standardize the editing approach. All members of the mapping team worked with the same map document format, loaded with the same image and ancillary datasets.

Editors were assigned specific production modules based on the USGS topographic quadrangle boundaries. Fine-scale map class edits were conducted at Various scales, depending upon the complexity of the boundary adjustments; for example, discerning differences between intermixing shrub species requires a different level of scrutiny than boundaries between grass and forest lands. Editors worked module-by-module, completing one module and moving on to the next, edge matching the data across boundaries to ensure the seamless continuity of information. Edits resulted in the following types of changes to the fine-scale map:

- Changes to fine-scale map class where the editor noted a different map class than what was assigned by machine learning
- Changes to polygon shapes where a polygon wasn't compositionally homogenous
- Changes to relative hardwood versus conifer class

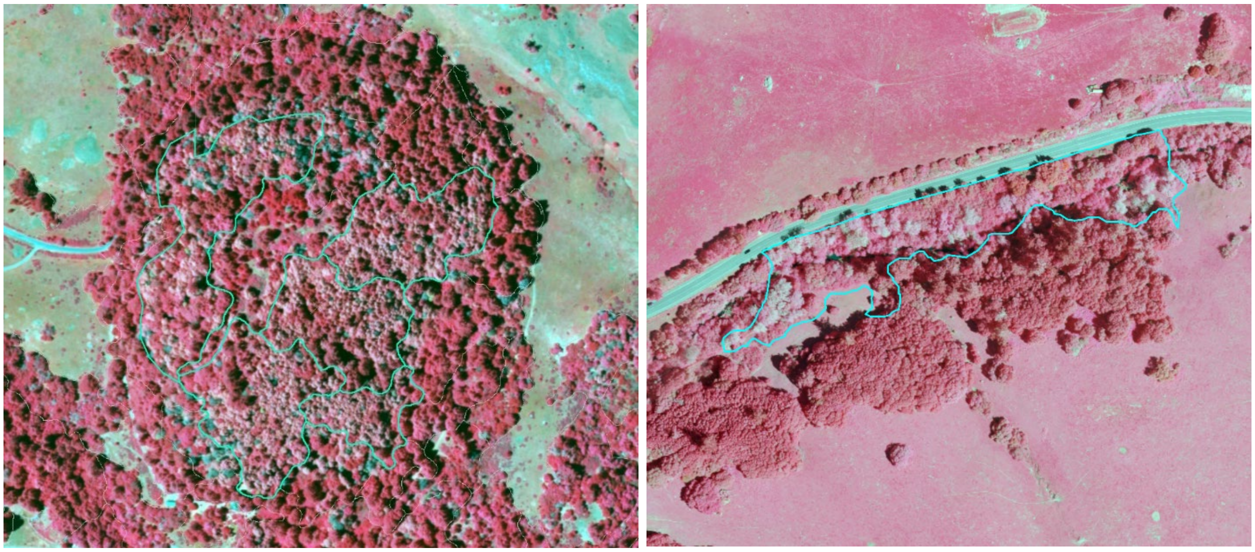
Editors relied on a wide variety of imagery and other data sources during editing (see Table 7). High resolution imagery was the most important dataset for editing, but different imagery or combinations of imagery were used to interpret different types of vegetation.

Table 7. *Datasets used as reference in fine-scale map class manual editing*

Raster Datasets	**Vector Datasets**
2009, 2012, 2016 and 2018 NAIP imagery, displayed as an RGB and CIR composite	Production modules (editing units) for tracking editing progress
2018 Marin County imagery (6-inch, 4-band), displayed as an RGB and CIR composite	Roads and trails
2014 Marin County imagery (6-inch, 4-band), displayed as an RGB and CIR composite	Field photos
2019 lidar derived bare earth DEM	CNPS survey points
2019 lidar derived bare earth hillshade	Field calibration polygons
2019 lidar derived canopy height	Geology (USGS)
USGS 7.5-minute topography	Soils (NRCS)
N/A	Ultramafic layer (CNPS)
N/A	Serpentine mask
N/A	Existing vegetation maps
N/A	Fire history
N/A	Field survey data from past vegetation mapping projects

For example, the 2009 NAIP imagery – when viewed in color infrared – showed *Notholithocarpus densiflorus* clearly, whereas other dates of imagery did not. To further illustrate how each image dataset was key for discriminating specific map classes, the *Umbellaria californica* alliance was very difficult to discern from other types of hardwoods (and even conifers in certain conditions) using many available image datasets. But in the 2009 and 2012 NAIP imagery displayed in true color, *Umbellaria* was clearly discernable.

Figure 11. *Notholithocarpus densiflorus (white crowns) in 2009 imagery displayed in infrared (left); Vancouverian riparian deciduous forest (bright pink) in 2011 imagery displayed in infrared (right)*



Online image sources, such as Google and Google Earth (GE) were also used to assist the editors. Winter imagery was used to help discern deciduous tree and shrub species, as the vegetation was in "leaf-off" condition, making it easier to distinguish between evergreen and deciduous types. On some GE imagery, it was possible to see vegetation in bloom, providing a good correlation to species signature on the base imagery. For example, Ulex europaeus was blooming in GE February 2018 imagery and broom species in the April 2013 GE images.

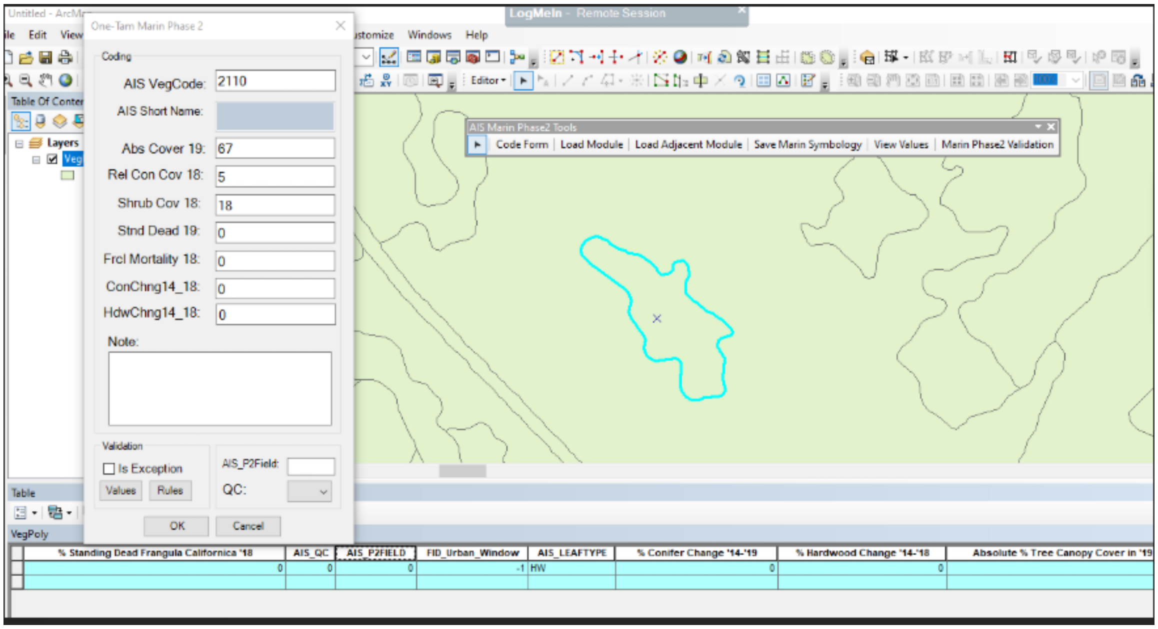
Environmental factors, such as slope, aspect, elevation, soils, and geology, were also assessed by the analysts. "Mental" models correlating the environmental factors to vegetation types were developed based on known correlations in the county. These proved useful, especially where the imagery did not provide sufficient information to discern the vegetation type.

In addition to the pre-loaded raster and vector datasets, the map document contained a project specific coding menu to facilitate consistent fine-scale map class editing among the team of analysts working on the map. The map document contained the following:

- Labels that show the polygon's map class with a unique numeric code assignment and associated attributes, such as cover class and relative conifer cover
- For edited polygons, dynamically rendered symbology to inform the editor that they have already been edited
- The coding menu displayed error flags that automatically turned on if the relative cover was incompatible with the map class (e.g., if a redwood classified polygon was assigned very low conifer relative cover)

- The coding menu displayed error flags that automatically turned on if an invalid vegetation type was assigned.

Figure 12. *Fine scale editing in ArcMap*



AIS VegCode: 2110
AIS Short Name:
Abs Cover 19: 67
Rel Con Cov 18: 5
Shrub Cov 18: 18
Stnd Dead 19: 0
Frcl Mortality 18: 0
ConChng14_18: 0
HdwChng14_18: 0
Note:
☐ Is Exception
AIS_P2Field:
QC:

% Standing Dead Frangula Californica '18	AIS_QC	AIS_P2FIELD	FID_Urban_Window	AIS_LEAFTYPE	% Conifer Change '14-'19	% Hardwood Change '14-'18	Absolute % Tree Canopy Cover in '19
0	0	0	-1	HW	0	0	

Map editors had weekly calls to review challenging areas. Areas that were difficult to map were labeled by group consensus or prioritized for field review.

3.4.5. Validation Field Work

Validation field work occurred during 2020 and in early 2021. Validation field work provided the mapping team with an opportunity to review the manually edited map in the field and perform quality control on the map. The mapping team also relied on field validation for difficult-to-map areas to inform additional map refinement and manual editing.

During manual editing, analysts targeted areas where uncertainty in the fine-scale map class was high. These areas were prioritized and visited by field crews where access was possible. Validation field work – like calibration field work – results in field verified fine-scale map class labels for all areas visited. During validation field work, polygons were labeled with their fine-scale map class using ESRI's collector app running on iPads by field teams in vehicles and on foot. See section 3.4.2 for more on how crews conducted this type of field work.

3.4.6. Notes on Other Existing Map Products

The Point Reyes National Seashore/Golden Gate National Recreation Area vegetation map (https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=18209&inline), which was created in the 1990s, was not directly integrated into the new countywide 2018 fine scale vegetation map because it is over 20 years old and was created before modern high-resolution imagery was available. However, the Point Reyes National Seashore/Golden Gate National Recreation Area map contains a wealth of information and was used extensively for reference during map creation and manual editing.

Other existing fine scale map efforts were used as reference to inform the 2018 countywide fine scale vegetation map. These include the following:

- Fine scale grasslands maps created by Shelly Benson for portions of Marin County Open Space District Lands
- Oak tree mapping conducted by Eric Wrubel (NPS) for a portion of the Marin Headlands
- A vegetation map in the floor of Tennessee Valley
- A vegetation map created for the parking lot area of Muir Woods
- A fine scale wetlands map of Giacomini wetlands at the south end of Tomales Bay
- Photointerpreted wetlands across Point Reyes National Seashore

3.4.7. Tidal Wetlands Mapping

Most fine scale vegetation maps map tidal wetlands only to the macrogroup level, which results in a map of tidal wetlands as a single class. For this project, the stakeholders were interested in a floristically more detailed map of tidal wetlands. As a result, the mapping team conducted alliance level mapping for the tidal wetlands. The result is that tidal wetlands in the fine scale vegetation map include the following alliances and associations in areas of tidal wetlands, each one mapped as its own fine scale map class:

- *Bolboschoenus maritimus* Alliance
- *Distichlis spicata* Alliance
- Sarcocornia pacifica (*Salicornia depressa*) Alliance
- *Triglochin maritima* Association
- *Grindelia stricta* Provisional Association
- *Spartina foliosa* Association
- *Atriplex prostrata – Cotula coronopifolia* Semi-Natural Alliance
- Mudflat/Dry Pond Bottom Mapping Unit
- Unvegetated Salt Marsh Channels (map as ‘Channel’)

These alliances and associations were mapped in a separate workflow from the rest of the vegetation map. Field calibration data was collected in the tidal wetlands, and fine scale segmentation was conducted with separate setting than for the rest of the vegetation map. Fine scale segments in the tidal wetlands were allowed to be much smaller than for upland and freshwater wetlands, with some fine scale segments in the tidal wetlands as small as a few hundred square feet. This allowed for the very fine scale delineations required to pick up very narrow features such as mud bottomed channels, gumplant (*Grindelia stricta*) polygons along the channels, and long linear areas of cord grass (*Spartina foliosa*) and saltgrass (*Distichlis spicata*) at interfaces between different areas of the tidal wetlands. Machine learning was run using the salt marsh calibration sites and the smaller salt marsh fine scale segments. Like the rest of the map, the resulting automated map was manually edited and reviewed in the field during validation trips. A round of expert review provided significant guidance for improving the tidal wetlands before final delivery of the fine scale vegetation map.

Accuracy was not assessed for the individual tidal wetland alliances and associations. However, accuracies are likely lower for the tidal wetland map classes are likely significantly lower than for many of the non-salt marsh fine scale map classes. The difficulty of mapping the tidal marsh herbaceous communities at high accuracy results from many factors. The following bullets includes some of the primary factors that drive the confusion between tidal marsh classes:

- **The tidal marsh alliances/associations have a wide range of appearances on the imagery**. For example, young pickleweed is very reflective of near infrared light, but older pickleweed doesn't reflect near infrared light as readily.
- **The alliances/associations mix and intergrade in ways that are difficult to interpret in the imagery**. For example, pickleweed (*Sarcocornia pacifica*) and salt grass (*Distichlis spicata*) often occur in nearly the same percent cover, making it hard to assign the correct class. These two alliances also can appear nearly the same in the high resolution 4-band imagery.
- **Non-native herbaceous and ruderal species intermix in the tidal marsh, further confounding interpretation of the tidal marsh alliance/association**.
- **The appearance in the imagery of the tidal marsh alliances and associations varies across space and time in unpredictable ways.** These variations are driven by many factors including salinity, inundation, mortality, and a wide range of other factors.
- **The salt marsh alliances and associations often occur in very narrow, linear patches that are inherently difficult to map due to their shape.**

3.5. Fine-scale Map Expert Review

After the fine-scale vegetation map was manually edited and field validation work was completed, the fine-scale vegetation map was distributed to dozens of Marin County land managers, ecologist, and interested parties. The vegetation map was also submitted to the California Native Plant Society's Vegetation Program and the Department of Fish and Wildlife's

Vegetation Classification and Mapping Program (VegCAMP). The purposes of expert map review were as follows:

1. For land managers who are intimately familiar with a parcel or set of parcels to impart their local knowledge into the vegetation and habitat map.
2. For local land managers, ecologists, botanists, and the map's end users to provide comments on geographic areas that they are familiar with or suggestions on ways to improve the map for their end uses.

Input from land managers was obtained through a publicly shared webmap, where stakeholders dropped points and entered for each point text about the issue or concern associated with that location. Other reviewers chose not to use the webmap but instead provided standalone spatial data (points and polygons) of the issues that they observed. After the input period ended, Tukman Geospatial compiled the collected input and provided it to AIS. AIS reviewed the input and took appropriate action to refine the map. If AIS had questions about a reviewer's concern, Tukman Geospatial and/or AIS contacted the reviewer to discuss the question.

3.6. Post-processing

After final review and a final round of manual editing was completed, post-processing was conducted to prepare the fine-scale vegetation map for publishing. Post-processing included the following steps:

- *Topology Checks*: Topology checks and topology edits ensure that there are no gaps and no overlaps in the fine scale vegetation map.
- *Adding the suite of attributes for percent imperviousness, carbon & biomass, and forest structure* (see section 6.4 for a complete list of all fine-scale map attributes).
- *QA/QC to ensure valid and complete data:* This step entailed review of all vegetation map polygons to ensure that each map polygon had complete and valid data. For example, each attribute of each polygon was checked for missing data, out-of-range or inappropriate values, etc.

Attributes delivered in the final, countywide map are shown in Section 6.4, Table 15.

3.7. Forest Health Mapping (standing dead and canopy gaps)

For forested areas, Tukman Geospatial mapped standing dead vegetation and canopy gaps and included this information as attributes in the fine scale vegetation map. Standing dead was mapped as a percentage of the woody canopy over 7 feet tall that appeared to be dead in the 2018 imagery. Canopy gaps represent forest gaps that formed between 2010 and 2019. Standing dead areas were mapped in Trimble® Ecognition® using a combination of high resolution imagery from 2014 and 2018, as well as countywide 2019 lidar data. The discussion below provides more detail on standing dead and canopy gap mapping.

3.7.1. Standing Dead

The mapping team mapped standing dead vegetation over 7 feet for all areas of Marin County. Countywide standing dead vegetation was be mapped using semi-automated techniques that combine automated object-based image analysis with manual photointerpretation. Standing dead forest areas were mapped using 2018 high resolution countywide imagery and the 2019 lidar data. Object based image analysis resulted in a 1-meter raster of living v. dead areas. The resulting map of standing dead was integrated into the forested stands of the fine scale vegetation map, and each forested stand was assigned a value representing the percentage of the woody canopy over 7 feet tall that was standing dead in 2018. AIS manually edited the percent dead assignments up or down based on image interpretation, adjusting the attribute upward where automated techniques underestimated standing dead and adjusting the attribute downward where automated techniques overestimated standing dead area. This product reflects the state of the landscape in June 2018. Some qualifications and specifications for the standing dead data product are listed below:

- Standing dead mortality applies to woody vegetation greater than or equal to 7 feet in height. Standing dead areas include entire tree crowns and parts of tree crowns that have died back.
- Each vegetation map polygon receives a percent of the polygon that is standing dead. This number was calculated as the area of the polygon over 7 feet in height that is dead, divided by the total area of the polygon over 7 feet in height.
- Living v. dead is defined by the presence of green leaves as viewed from above in the summer, 2018 high resolution imagery. It is possible that some areas mapped as dead could be trees defoliated by insects or fire in 2018 that regrew their leaves in the summer 2019 growing season.
- Note that this product does not provide species-specific mortality information. In a stand with 5% mortality labeled Sequoia sempervirens alliance in the vegetation map, for example, the dead trees may include a mix of hardwoods and this product does not include details on the species of the dead trees.

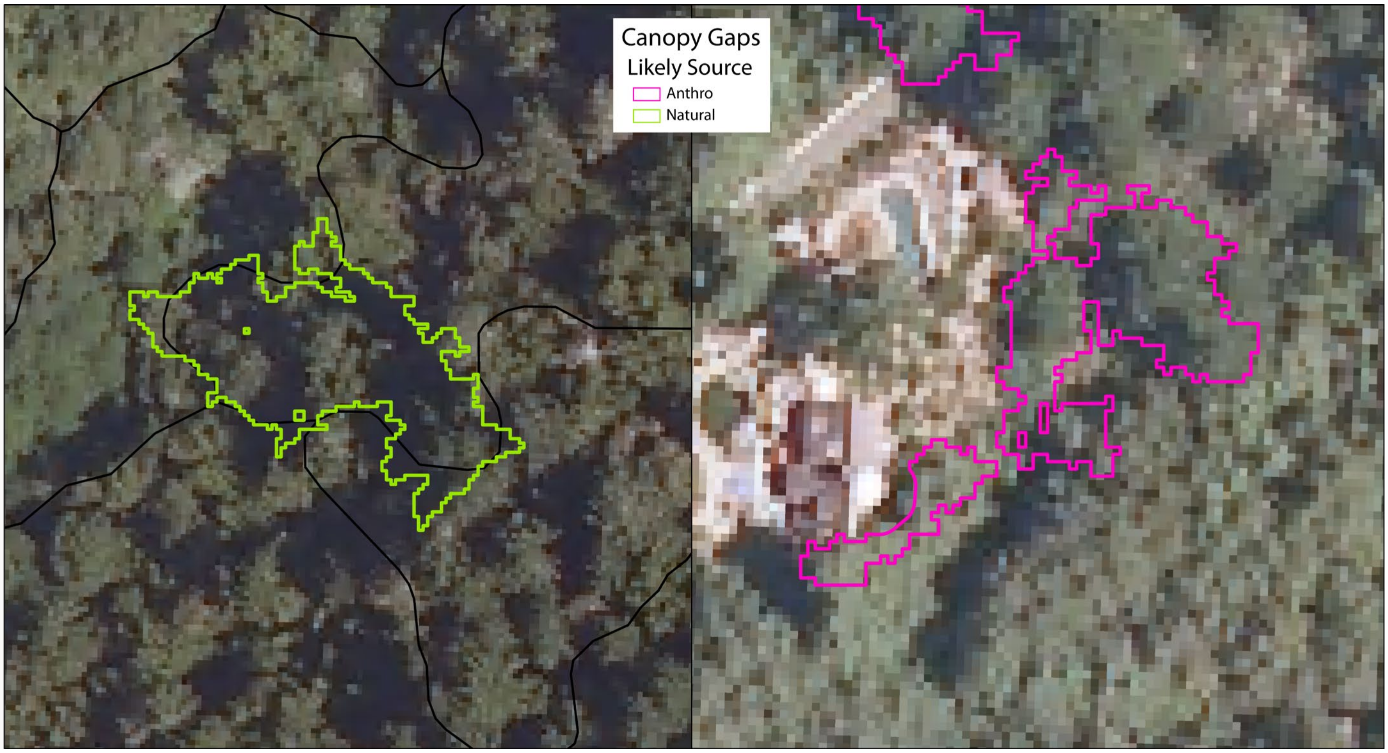
3.7.2. Canopy Gaps

Canopy gap analysis was conducted using Canopy Height Model (CHM) differencing, where analysts calculated the difference between the CHM value in 2019 minus the CHM value in 2010. This analysis was performed in Trimble® Ecogntion®, where the lidar CHM differencing was followed by noise removal to remove anomolous gaps. Very small gaps (<40 square feet) were also removed to reduce 'noise' in the gap analysis. The resulting canopy gaps were reviewed by analysts, who removed 'false positive' gaps along the coast and in urban areas. The final canopy gap dataset was integrated into the vegetation map, where each stand was assigned an attribute for the percent of its woody canopy over 7 ft. that was a gap formed between '10-'19. A second attribute provides information for the area of each forested stand's largest contiguous gap.

- Areas were considered canopy gaps and mapped as such if their canopy height changed in one of the following ways between 2010 and 2019 at the 1-meter raster scale:
    - **Low Gap**: Areas greater than or equal to 7 ft. in height in 2010 and less than 2 ft. in 2019 that lost more than 7 feet of canopy height between 2010 and 2019.
    - **Medium Gap**: Areas greater than or equal to 12 ft. in height in 2010 and less than 7 ft. In height in 2019.
    - **High Gap**: Areas greater than or equal to 15 ft. in height in 2010 that lost greater than 40 % of their total height between 2010 and 2019
    - **Very High Gap**: Areas greater than or equal to 100 ft. in height in 2010 that lost greater than 25% of their total height between 2010 and 2019.

Figure 13 illustrates the canopy gaps for areas near Inverness.

Figure 13. *Canopy gaps formed between 2010 and 2014 – top image shows the 2010 imagery, bottom image shows the 2019 imagery. Gaps are shown in magenta and green outlines.*



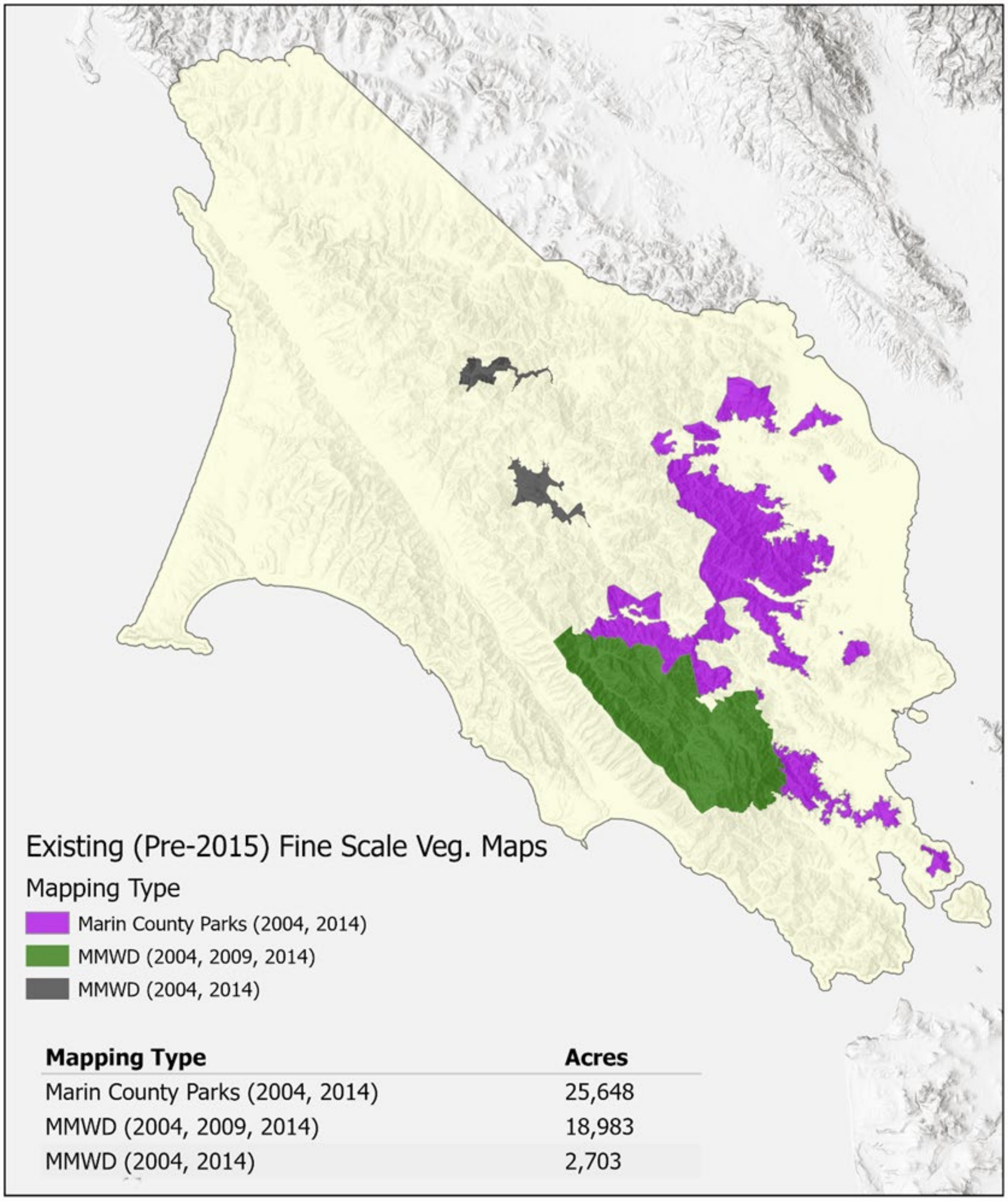
3.7.3. Shrub Percentage Cover

Percent shrub cover was be mapped for all non-forested, non-developed, and non-water vegetation map stands in Marin. Countywide shrub cover was mapped using semi-automated techniques that combined automated object-based image analysis with manual photointerpretation. In addition, AIS assigned % mortality in all *Frangula californica* stands in the fine scale vegetation map (regardless of stand height). This attribute was assigned based on aerial image interpretation.

3.8. Standardized 2004-2014 County Parks/Marin Water Vegetation Map

Standardized 2004-2014 County Parks/Marin Water Vegetation Map is a synthesized, standardized product that combines mapping efforts on Marin Municipal Water District and Marin County Parks lands that occurred between 2004 and 2014. Figure 14 shows the areas represented in this map, which represents 47,339 acres of the county. For more information on this data product, and to access it, go to this product datasheet: https://vegmap.press/marin_standardized_04_14_datasheet.

Figure 14. *Existing maps that were standardized and combined in the 2004-2014 standardized county lands map*



Mapping Type	Acres
Marin County Parks (2004, 2014)	25,648
MMWD (2004, 2009, 2014)	18,983
MMWD (2004, 2014)	2,703

4. ACCURACY ASSESSMENT

Accuracy assessment entails collecting representative samples of the map and comparing the reference label of the sample to its map label. The reference labels are assumed to be the “true” label and are usually derived from a source of higher accuracy than the map (e.g., field plot samples). This section of the report reviews the accuracy assessment methods and results for the lifeform map and the fine-scale vegetation map. The first section describes how the accuracy assessment samples were selected and labeled. Next, analysis procedures are explained and the resulting error matrices are presented. The last section details the causes of the most significant confusion in the maps.

4.1. Sample Design

Final draft map polygons, as well as field crew created calibration polygons were used as the spatial units for assessing map accuracy. Sample polygons were constrained so that only those greater than the project minimum map units were used to avoid sampling sub-minimum mapping unit islands of vegetation.

Two types of samples were collected:

- Manual labelling of sites from the imagery for assessment of classes other than shrub and native forest
- Field verification of sites for assessment of the shrub and forest fine-scale vegetation map and lifeform classes

4.1.1. Manually Interpreted Samples

Lifeform map accuracy was assessed using both the lifeform map class assigned to field-verified samples (see below) and the lifeform map class manually interpreted from imagery. Unlike fine-scale vegetation labels, non-shrub and non-native forest lifeform classes are easy to interpret from imagery and do not require field verification. Therefore, accuracy assessment reference samples for the non-native forest and non-shrub lifeforms were labeled using manual image interpretation in the office. One other fine-scale classes (North American Pacific Coastal Salt Marsh Macrogroup) were also assessed using manual interpretation because it is similarly readily identifiable on the imagery. For the manually interpreted sites, a random number generator was used to select approximately 30 sample segments for each class in the final draft fine scale vegetation map. Not all lifeform classes were assessed for accuracy. For example, the agricultural lifeform classes were not assessed because there were too few sites for a reasonable sample size. The urban window and major road classes were not assessed because 1) they were developed from very high accuracy inputs (road centerlines, building footprints, and the impervious surface map) and 2) the build landscape is not the primary focus of this project.

4.1.2. Field-Verified Samples

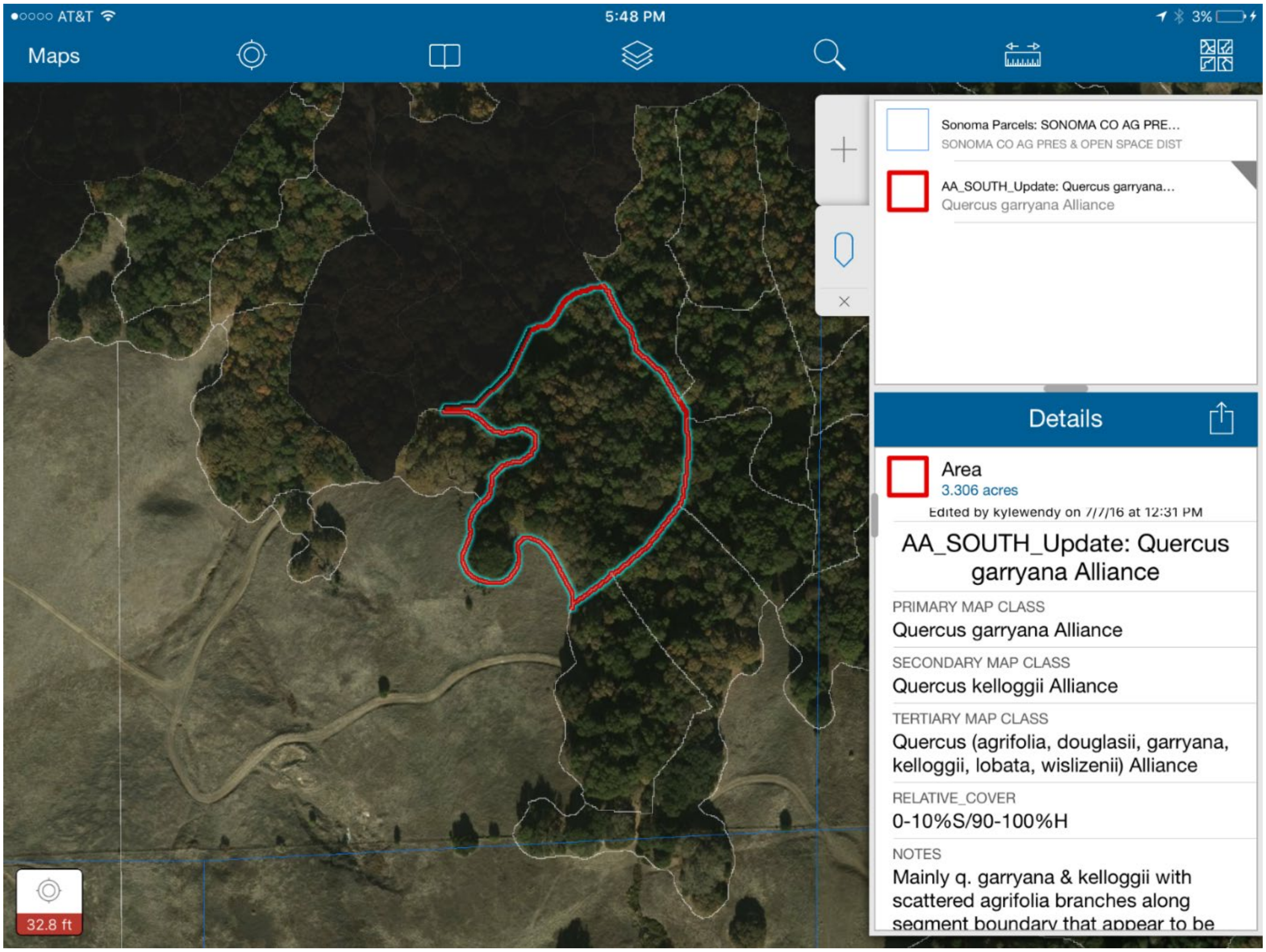
Two sources were used for field-verified accuracy assessment samples – field-collected calibration sites (see section 3.4.2) that were not used in the development of the lifeform and fine-scale vegetation maps, and newly established field sites that were chosen using a combined stratified random/cluster sampling approach. To select the new field sites, all access-restricted areas were masked out of the map, which focused the field sampling on public lands, conservation lands, and private lands whose landowners were willing to provide access. Next, areas with difficult access were masked out. These 'high travel cost' areas were defined by a cost surface that identified areas far from accessible roads and trails, as well as areas inaccessible due to steep terrain. Within the remaining areas, fine-scale map stands were randomly selected per fine-scale map class to serve as the feasible set of field-verified accuracy assessment samples. To ensure that samples were not spatially autocorrelated, a minimum distance of 2,500 feet between targeted stands of the same map class was required. Random allocations were performed to target stands for accuracy assessment sampling such that:

- 25 accuracy assessment samples were targeted for collected for fine scale map classes in the draft map that encompassed more than 2,500 acres
- 10 accuracy assessment samples were targeted for collected for fine scale map classes in the draft map that encompassed more than 500 acres and less than 2,500 acres
- 5 accuracy assessment samples were targeted for collected for fine scale map classes in the draft map that encompassed more than 500 acres and less than 2,500 acres

Field crews were made up of experienced botanists who had no role in creating or editing the fine scale map. Crews visited the randomly selected target sample stands with no indication of the stand's mapped label. To reduce travel costs, field personnel were encouraged to choose and collect AA data for two additional stands that were adjacent or nearby the randomly selected target sample stand but *with different fine-scale map classes than the randomly selected target sample stand*. At the selected target sample stand, field personnel viewed the entire area before assigning a reference map class for the stand. If the entire target sample stand was not visible from a vantage point, the crew walked or drove through the remaining area of the stand. Following inspection of the target sample stand, field personnel completed the accuracy assessment form on an iPad (see Figure 15). Field personnel estimated the percent cover of each vegetative species visible in the imagery and used the mapping key to label the stand with its appropriate fine scale map class. Estimates of cover by species were determined through manual interpretation of the imagery to ensure that estimates were made from above, rather than below the canopy.

A total of 696 total accuracy assessment samples were collected for 49 of the 107 fine-scale map classes. Those 49 classes represent 95% of the area mapped. Some classes were not sampled or lightly sampled because the class was extremely rare. Other classes were not assessed because there were an insufficient number of accessible areas representing the class to sample.

Figure 15. *Accuracy assessment form on iPad (ESRI Collector App)*



Sonoma Parcels: SONOMA CO AG PRE…
SONOMA CO AG PRES & OPEN SPACE DIST

AA_SOUTH_Update: Quercus garryana…
Quercus garryana Alliance

Area
3.306 acres
Edited by kylewendy on 7/7/16 at 12:31 PM

AA_SOUTH_Update: Quercus garryana Alliance

PRIMARY MAP CLASS
Quercus garryana Alliance

SECONDARY MAP CLASS
Quercus kelloggii Alliance

TERTIARY MAP CLASS
Quercus (agrifolia, douglasii, garryana, kelloggii, lobata, wislizenii) Alliance

RELATIVE_COVER
0-10%S/90-100%H

NOTES
Mainly q. garryana & kelloggii with scattered agrifolia branches along segment boundary that appear to be

4.2. Analysis

Once the accuracy assessment reference data were collected, the map labels (assigned during the mapping process) for each sample were compared to the reference labels (assigned from manual interpretation or field validated samples). Extensive quality control was performed to ensure that reference labels and map labels were accurate, and that spatial autocorrelation did not exist between sample segments. As a result, 44 map sample segments were removed from the data set for one or more of the following reasons:

- The reference sample received more than one map label because the map polygon delineations were more refined than many of the reference sample polygons.
- Two or more adjacent samples received the same reference label and map label, indicating that they were spatially autocorrelated. In these circumstances, all but one of the adjacent samples were removed from the assessment

Following quality control, the error matrices were created, and analysis was performed. The matrices can be found in Tables 8 (lifeform) and 12 (fine-scale vegetation). Error matrices provide a wealth of information about the map by indicating how many samples have agreement between the reference and map labels, and what classes are confused with one another. Samples with matching reference and map labels fall along the diagonal of the matrices, with cells shaded in green.

Two types of accuracy assessment analysis are typically done – deterministic and fuzzy (Green and Congalton, 2019). Overall deterministic accuracy is calculated by dividing the total number of samples on the diagonal by the total number of samples in the matrix. Samples off the diagonal indicate confusion between the map and the reference labels. Confused samples indicate not only that error exists in the map, but which classes are confused with one another. Several samples falling in an off-diagonal cell indicated a pattern of confusion which may exist throughout the map.

Useful additional measures for each class are the user's and producer's accuracies because they measure the proportion of errors of commission and omission in each class, respectively. User's accuracy is the total number of samples in agreement divided by the number of map samples in a class and provides an indication of the errors of commission in each class. Producer's accuracy is the total number of samples in agreement divided by the number of reference samples in a class and indicates the level of errors of omission of each class.

Map producers and users have long recognized that there is a certain amount of "fuzziness" in vegetation mapping because:

- Humans are incapable of precisely estimating percent cover, resulting in an average variance in estimates of +/- 10% (Congalton and Green, 2019). While this will have little impact in a simple map such as the lifeform map, it can have significant impact on a map as detailed as the fine-scale map, with numerous classes that are often distinguished from one another in the key based on small species percent cover differences.

- Classification schemes impose boundaries between vegetation types. However, vegetation usually exists along a continuum of vegetation cover. If the composition of a sample meets the condition for two or even more different map classes, then those labels should be considered acceptable. For example, a sample could receive a primary label of Quercus (*agrifolia, douglasii, garryana, kelloggii, lobata, wislizenii*) Alliance and a secondary label of *Quercus garryana* Alliance based on the field personnel's uncertainty regarding the proportion *Quercus garryana* cover verses that of other oak species.

Many map users and producers implement fuzzy accuracy assessment to deal with the ambiguity in a map. Usually this is implemented when the reference sample is being assessed by choosing a second acceptable reference label for a sample if the person collecting the data believes that more than one label would be acceptable (Congalton and Green, 2019). Rather than evaluating every sample for variation in interpretation, an alternative approach has been adopted by the California Department of Fish and Wildlife that applies a ruleset to the entire sample dataset as defined in Table 10. (CDFW & Aerial Information Systems, 2013; Menke et al., 2011). This is the form of fuzzy analysis chosen for the Marin County fine scale vegetation map assessment.

4.3. Results

4.3.1. Lifeform Map AA Results

Table 8 is the error matrix for the lifeform map. Lifeform classes are relatively simple to discern and are also homogeneous, which greatly reduces any ambiguity in labeling. Overall lifeform accuracy is 95 percent, indicating that there is minimal confusion in the lifeform map. The majority of the confusion is between the shrub and forest classes which typically occurs with shrub stands of low tree density. Table 9 shows user's and producer's accuracies for the lifeform map.

Table 8. *Lifeform error matrix with deterministic accuracy along the diagonal and user's accuracy (errors of commission) and producer's accuracy (errors of omission) along the vertical and horizontal axes.*

	REFERENCE													
MAP	Aquatic/Fresh Water Vegetation	Barren	Developed	Herbaceous	Native Forest	Native Shrub	Non-native Forest	Non-native Herbaceous	Non-native Shrub	Tidal Wetland	Water	Grand Total	User's Accuracy	
Aquatic/Fresh Water Vegetation	15			1		1		1		1		19	79%	
Barren		24									1	25	96%	
Developed			26									26	100%	
Herbaceous	1			30		5		1				37	81%	
Native Forest					263	5				1		269	98%	
Native Shrub					8	178		3				189	94%	
Non-native Forest							22					22	100%	
Non-native Herbaceous						2		12				14	86%	
Non-native Shrub						1			2			3	67%	
Tidal Wetland										23	1	24	96%	
Water											25	25	100%	
Grand Total	16	24	26	31	271	192	22	17	2	25	27	653		
Producer's Accuracy	94%	100%	100%	97%	97%	93%	100%	71%	100%	92%	93%		95%	Overall Accuracy

Table 9. *Lifeform user's and producer's accuracies*

Lifeform	**User's Accuracy**	**Producer's Accuracy**
Developed	100%	100%
Non-native Forest	100%	100%
Barren	96%	100%
Native Forest	98%	97%
Water	100%	93%
Tidal Wetland	96%	92%
Native Shrub	94%	93%
Herbaceous	81%	97%
Aquatic/Fresh Water Vegetation	79%	94%
Non-native Shrub	67%	100%
Non-native Herbaceous	86%	71%

4.3.2. Fine Scale Vegetation Map AA Results

The error matrix in Table 12 (fine-scale vegetation) is a deterministic accuracy matrix (it does not implement fuzzy accuracy assessment) developed using the approach suggested by Congalton and Green (2019) in their widely accepted accuracy assessment textbook.

Table 12 can be interpreted as follows:

- Classes with map and primary reference labels in agreement fall on the diagonal with cells shaded in green.
- Confused classes fall off the diagonal.

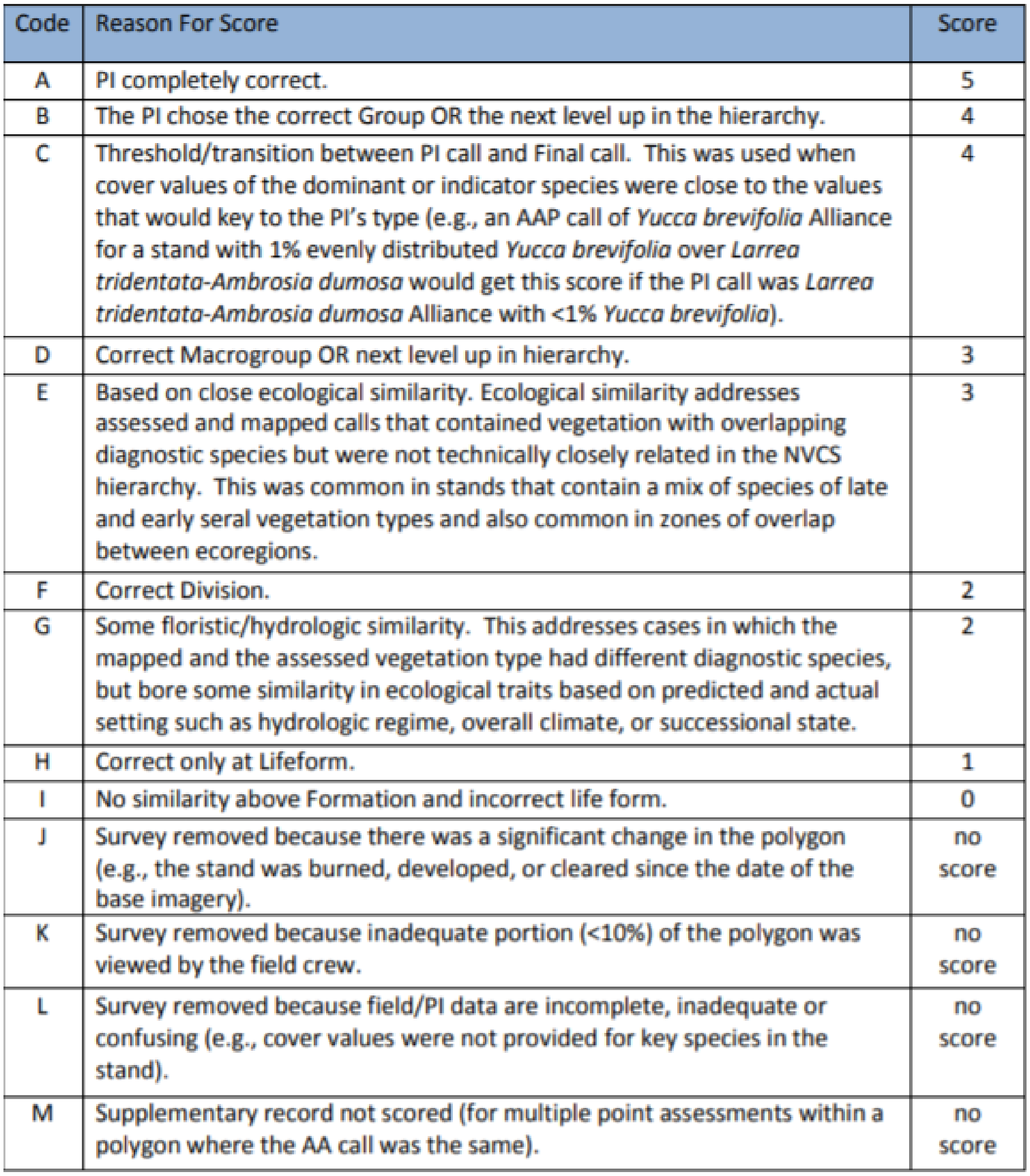
Overall deterministic accuracy of the fine-scale vegetation map is 77%.

Fuzzy accuracy assessment for the fine scale vegetation map was implemented as per state of California standards. The state standard was developed by the California Department of Fish and Wildlife in several mapping projects (CDFW & Aerial Information Systems, 2013; Menke et al., 2011). The CDFW state standard approach to fine scale vegetation map accuracy assessment applies a set of evaluation criteria to the entire accuracy assessment sample dataset. For accuracy assessment samples where the reference label is similar but not identical to the map label, partial credit is given. The criteria for partial credit are shown in Table 10.

Applying this approach to the Marin County fine scale vegetation map results in an **overall fuzzy accuracy of 81%.**

Table 11 summarizes the user's accuracy, producer's accuracy, and fuzzy accuracies for all map classes that had greater than or equal to one accuracy assessment stand collected by field crews.

Table 10. *CDFW evaluation criteria for fuzzy accuracy assessment*



Code	Reason For Score	Score
A	PI completely correct.	5
B	The PI chose the correct Group OR the next level up in the hierarchy.	4
C	Threshold/transition between PI call and Final call. This was used when cover values of the dominant or indicator species were close to the values that would key to the PI's type (e.g., an AAP call of *Yucca brevifolia* Alliance for a stand with 1% evenly distributed *Yucca brevifolia* over *Larrea tridentata-Ambrosia dumosa* would get this score if the PI call was *Larrea tridentata-Ambrosia dumosa* Alliance with <1% *Yucca brevifolia*).	4
D	Correct Macrogroup OR next level up in hierarchy.	3
E	Based on close ecological similarity. Ecological similarity addresses assessed and mapped calls that contained vegetation with overlapping diagnostic species but were not technically closely related in the NVCS hierarchy. This was common in stands that contain a mix of species of late and early seral vegetation types and also common in zones of overlap between ecoregions.	3
F	Correct Division.	2
G	Some floristic/hydrologic similarity. This addresses cases in which the mapped and the assessed vegetation type had different diagnostic species, but bore some similarity in ecological traits based on predicted and actual setting such as hydrologic regime, overall climate, or successional state.	2
H	Correct only at Lifeform.	1
I	No similarity above Formation and incorrect life form.	0
J	Survey removed because there was a significant change in the polygon (e.g., the stand was burned, developed, or cleared since the date of the base imagery).	no score
K	Survey removed because inadequate portion (<10%) of the polygon was viewed by the field crew.	no score
L	Survey removed because field/PI data are incomplete, inadequate or confusing (e.g., cover values were not provided for key species in the stand).	no score
M	Supplementary record not scored (for multiple point assessments within a polygon where the AA call was the same).	no score

Table 11. *Producer's and user's accuracies for the fine-scale vegetation map*

Fine Scale Map Class	Acres in Veg Map	# of Map Sites	User Accuracy	Fuzzy User Accuracy	# of Reference Sites	Producer Accuracy	Fuzzy Producer Accuracy
Californian Annual & Perennial Grassland Mapping Unit	106,994	37	81%	81%	32	94%	94%
Umbellularia californica Alliance	48,450	43	70%	81%	41	73%	85%
Baccharis pilularis Alliance	34,693	59	81%	87%	60	80%	86%
Water	26,904	25	100%	100%	26	96%	96%
Pseudotsuga menziesii – (Notholithocarpus densiflorus – Arbutus menziesii) Alliance	26,245	26	92%	92%	28	86%	89%
Developed	25,629	26	100%	100%	26	100%	100%
Quercus agrifolia Alliance	14,379	35	69%	86%	31	77%	87%
Sequoia sempervirens Alliance	11,265	36	86%	91%	34	91%	93%
North American Pacific Coastal Salt Marsh Macrogroup	5,771	24	96%	96%	24	96%	96%
Pinus muricata – Pinus radiata Alliance	4,668	30	90%	95%	28	96%	96%
Toxicodendron diversilobum – (Baccharis pilularis) Association	4,569	13	54%	77%	11	64%	82%
Vancouverian Freshwater Wet Meadow & Marsh Group	3,825	7	29%	40%	5	40%	48%
Quercus lobata Alliance	2,892	18	78%	91%	22	64%	87%
Salix lasiolepis Alliance	2,875	26	81%	82%	25	84%	84%
Arbutus menziesii Alliance	2,759	26	73%	78%	24	79%	83%
Lupinus arboreus Alliance	2,446	12	83%	88%	14	71%	73%
Ceanothus thyrsiflorus Alliance	2,139	11	91%	91%	10	100%	100%
Eucalyptus (globulus, camaldulensis) Provisional Semi-Natural Assocation	2,100	14	100%	100%	14	100%	100%
Acer macrophyllum – Alnus rubra Alliance	1,852	22	91%	92%	27	74%	81%
Adenostoma fasciculatum Alliance	1,822	18	61%	82%	16	69%	90%
Barren and Sparsely Vegetated	1,771	25	100%	100%	25	100%	100%
Arctostaphylos glandulosa Alliance	1,621	9	33%	73%	8	38%	83%
Non-native Forest	1,439	2	100%	100%	2	100%	100%
Quercus garryana Alliance	1,405	6	33%	73%	7	29%	71%
Artemisia californica – (Salvia leucophylla) Alliance	1,316	9	89%	96%	15	53%	71%
Shrub Fragment	1,164	4	75%	75%	4	75%	75%
Forest Fragment	943	3	67%	67%	3	67%	67%
Quercus douglasii Alliance	839	14	21%	80%	4	75%	95%
Mesembryanthemum spp. – Carpobrotus spp. Semi-Natural Alliance	707	7	86%	91%	7	86%	91%
Arctostaphylos (bakeri, montana) Alliance	704	12	58%	88%	8	88%	98%
Ammophila arenaria Semi-Natural Alliance	612	4	100%	100%	5	80%	88%
Frangula californica ssp. californica – Baccharis pilularis / Scrophularia californica Assoc	592	2	50%	60%	9	11%	27%
Arid West Freshwater Marsh Group	548	7	86%	91%	11	55%	62%
Urban Window Deciduous Hardwood	477	3	100%	100%	4	75%	80%
Hesperocyparis macrocarpa Ruderal Provisional Semi-Natural Association	431	4	100%	100%	4	100%	100%
Lupinus chamissonis – Ericameria ericoides Alliance	397	2	50%	70%	2	50%	70%
Arctostaphylos (nummularia, sensitiva) – Chrysolepis chrysophylla Alliance	352	0	0%	0%	1	0%	60%
Hesperocyparis sargentii / Ceanothus jepsonii – Arctostaphylos spp. Association	345	1	100%	100%	1	100%	100%
Conium maculatum – Foeniculum vulgare Semi-Natural Alliance	276	2	50%	50%	3	33%	47%
Ulex europaeus Provisional Semi-Natural Association	196	2	100%	100%	2	100%	100%
Alnus rhombifolia Alliance	181	3	67%	67%	3	67%	67%
Rubus spectabilis – Morella californica Alliance	175	2	0%	20%	2	0%	20%
Corylus cornuta / Polystichum munitum Association	118	2	50%	60%	1	100%	100%
Acer macrophyllum Association	98	0	0%	0%	2	0%	20%
Quercus durata Alliance	77	0	0%	0%	1	0%	60%
Aesculus californica Alliance	45	0	0%	0%	2	0%	80%
Ceanothus cuneatus Alliance	43	0	0%	0%	2	0%	80%
Notholithocarpus densiflorus Alliance	43	0	0%	0%	1	0%	20%
Quercus (agrifolia, douglasii, garryana, kelloggii, lobata, wislizeni) Alliance	39	0	0%	0%	10	0%	78%
Western North American Freshwater Aquatic Vegetation Macrogroup	32	5	20%	20%	1	100%	100%
Arctostaphylos (canescens, manzanita, stanfordiana) Alliance	31	0	0%	0%	4	0%	45%
Rhododendron columbianum - Gaultheria shallon / Carex obnupta Association	2	0	0%	0%	1	0%	20%

Table 12. *Fine-scale deterministic map error matrix. (See https://vegmap.press/marin_error_matrix for a larger-scale version of the error matrix)*

	REFERENCE LABELS																																																							
MAP LABELS	Acer macrophyllum – Alnus rubra Alliance	Acer macrophyllum Association	Adenostoma fasciculatum Alliance	Aesculus californica Alliance	Alnus rhombifolia Alliance	Ammophila arenaria Semi-Natural Alliance	Arbutus menziesii Alliance	Arctostaphylos (bakeri, montana) Alliance	Arctostaphylos (canescens, manzanita, stanfordiana) Alliance	Arctostaphylos (nummularia, sensitiva) – Chrysolepis chrysophylla Alliance	Arctostaphylos glandulosa Alliance	Arid West Freshwater Marsh Group	Artemisia californica – (Salvia leucophylla) Alliance	Baccharis pilularis Alliance	Barren and Sparsely Vegetated	Californian Annual & Perennial Grassland Mapping Unit	Ceanothus cuneatus Alliance	Ceanothus thyrsiflorus Alliance	Conium maculatum – Foeniculum vulgare Semi-Natural Alliance	Corylus cornuta / Polystichum munitum Association	Developed	Eucalyptus (globulus, camaldulensis) Provisional Semi-Natural Assocation	Frangula californica ssp. californica – Baccharis pilularis / Scrophularia californica Association	Hesperocyparis macrocarpa Ruderal Provisional Semi-Natural Association	Hesperocyparis sargentii / Ceanothus jepsonii – Arctostaphylos spp. Association	Lupinus arboreus Alliance	Lupinus chamissonis – Ericameria ericoides Alliance	Mesembryanthemum spp. – Carpobrotus spp. Semi-Natural Alliance	Non-native Forest	North American Pacific Coastal Salt Marsh Macrogroup	Notholithocarpus densiflorus Alliance	Pinus muricata – Pinus radiata Alliance	Pseudotsuga menziesii – (Notholithocarpus densiflorus – Arbutus menziesii) Alliance	Quercus (agrifolia, douglasii, garryana, kelloggii, lobata, wislizeni) Alliance	Quercus agrifolia Alliance	Quercus douglasii Alliance	Quercus durata Alliance	Quercus garryana Alliance	Quercus lobata Alliance	Rhododendron columbianum - Gaultheria shallon / Carex obnupta Association	Rubus spectabilis – Morella californica Alliance	Salix lasiolepis Alliance	Sequoia sempervirens Alliance	Toxicodendron diversilobum – (Baccharis pilularis) Association	Ulex europaeus Provisional Semi-Natural Association	Umbellularia californica Alliance	Urban Window Deciduous Hardwood	Forest Fragment	Shrub Fragment	Vancouverian Freshwater Wet Meadow & Marsh Group	Water	Western North American Freshwater Aquatic Vegetation M	(blank)	Total	User's Accuracy	
Acer macrophyllum – Alnus rubra Alliance	🟩																																						1			1												22	91%	
Acer negundo / (Rubus ursinus) Association	1																																																					1	0%	
Adenostoma fasciculatum Alliance			🟩					1			1		2	2			1																																					18	61%	
Alnus rhombifolia Alliance					🟩																																					1												3	67%	
Ammophila arenaria Semi-Natural Alliance						🟩																																																4	100%	
Arbutus menziesii Alliance							🟩																												3											4								26	76%	
Arctostaphylos (bakeri, montana) Alliance			2					🟩			1						1																				1																	12	58%	
Arctostaphylos glandulosa Alliance			3						2	1	🟩																																											9	33%	
Arid West Freshwater Marsh Group												🟩																																						1				7	86%	
Artemisia californica – (Salvia leucophylla) Alliance													🟩	1																																								9	89%	
Baccharis pilularis Alliance													3	🟩									5			1																		2		1								59	81%	
Barren and Sparsely Vegetated															🟩																																							25	100%	
Californian Annual & Perennial Grassland Mapping Unit													1	1		🟩			1							3																								1				37	81%	
Ceanothus thyrsiflorus Alliance																		🟩														1																						11	91%	
Conium maculatum – Foeniculum vulgare Semi-Natural Alliance													1						🟩																																			2	50%	
Corylus cornuta / Polystichum munitum Association																				🟩																				1														2	50%	
Developed																					🟩																																	26	100%	
Eucalyptus (globulus, camaldulensis) Provisional Semi-Natural Assocation																						🟩																																14	100%	
Frangula californica ssp. californica – Baccharis pilularis / Scrophularia californica Association														1									🟩																															2	50%	
Gaultheria shallon – Rubus (ursinus) Alliance														1					1																						1			1										4	0%	
Hesperocyparis macrocarpa Ruderal Provisional Semi-Natural Association																								🟩																														4	100%	
Hesperocyparis sargentii / Ceanothus jepsonii – Arctostaphylos spp. Association																									🟩																													1	100%	
Lupinus arboreus Alliance						1								1												🟩																												12	83%	
Lupinus chamissonis – Ericameria ericoides Alliance																											🟩	1																										2	50%	
Mesembryanthemum spp. – Carpobrotus spp. Semi-Natural Alliance																											1	🟩																										7	86%	
Non-native Forest																													🟩																									2	100%	
North American Pacific Coastal Salt Marsh Macrogroup																														🟩																					1			24	96%	
Pinus muricata – Pinus radiata Alliance																																🟩			1								1			1								30	90%	
Pseudotsuga menziesii – (Notholithocarpus densiflorus – Arbutus menziesii) Alliance																																	🟩		1							1												26	85%	
Quercus agrifolia Alliance							3		1																									2	🟩	1			2							2								35	69%	
Quercus douglasii Alliance																																		6		🟩		3	2															14	21%	
Quercus garryana Alliance																																		1				🟩	3															6	33%	
Quercus kelloggii Alliance																																		1				1																2	0%	
Quercus lobata Alliance																																						1	🟩				1			2								18	78%	
Quercus wislizeni – Quercus chrysolepis (shrub) Alliance									1		3																																											4	0%	
Rubus armeniacus Semi-Natural Association																							1																															1	0%	
Rubus spectabilis – Morella californica Alliance														2																																								2	0%	
Salix lasiolepis Alliance	3				1																																					🟩		1										26	81%	
Salix lucida ssp. lasiandra Association	1																																									1												2	0%	
Sequoia sempervirens Alliance		1																															3										🟩			1								36	86%	
Toxicodendron diversilobum – (Baccharis pilularis) Association														3									2																		1			🟩										13	54%	
Ulex europaeus Provisional Semi-Natural Association																																													🟩									2	100%	
Umbellularia californica Alliance	2	1		2			2																							1	1		1		2								1			🟩								43	70%	
Urban Window Deciduous Hardwood																																															🟩							3	100%	
Urban Window Evergreen Hardwood																																															1							1	0%	
Forest Fragment																																																🟩	1					3	67%	
Shrub Fragment																																																1	🟩					4	75%	
Vancouverian Freshwater Wet Meadow & Marsh Group												2		1		2																																		🟩				7	29%	
Water																																																			🟩			25	100%	
Western North American Freshwater Aquatic Vegetation Macrogroup												3																																						1		🟩		5	25%	
(blank)																																																								
Total	27	2	16	2	3	5	24	8	4	1	8	11	15	60	25	32	2	10	3	1	26	14	9	4	1	14	2	7	2	24	1	28	28	10	31	4	1	7	22	1	2	25	34	11	2	41	4	3	4	5	26	1	0	653		
Producer's Accuracy	74%	0%	69%	0%	67%	80%	79%	88%	0%	0%	38%	60%	53%	78%	100%	94%	0%	1%	33%	100%	100%	100%	13%	100%	100%	71%	50%	86%	100%	96%	0%	100%	85%	0%	77%	75%	0%	29%	64%	0%	0%	84%	91%	64%	100%	75%	75%	67%	75%	40%	100%	100%				
																																																						Overall Accuracy		77%

4.4. Discussion

As indicated by the lifeform error matrix, there is very little confusion in the lifeform map. Some confusion between shrub and native forest occurs, which often occurs for areas on the margins of those two classes. Only two non-native lifeform classes have user or producer accuracies below 80%.

Most of the confusion in the fine-scale vegetation map error matrix consists of scattered confusion of 1 or 2 sites in various cells across the matrix. When confusion does occur it is typically within lifeform and tends to be between map classes that commonly occur together. For example, the *Umbellularia californica*, *Quercus agrifolia*, and *Arbutus menziesii* Alliances, which often occur intermixed across the landscape, all show some errors of commission and omission with one another, even though all their producer's and user's accuracies are relatively high.

However, there are several patterns of agreement and confusion that are more noteworthy and warrant understanding by both map users and producers:

- 17 map classes representing 58% of the county acreage have both producer's and user's accuracies above 80%.
- 10 samples confused the *Quercus* (*agrifolia*, *douglasii*, *garryana*, *kelloggii*, *lobata*, *wislizenii*) Alliance with the alliances of the species which comprise it. The confusion is composed entirely of omission errors, indicating that the map has under mapped the mixed oak class. It is only the proportion of the mixture of oak species that divides the mixed oak alliance from the purer oak species alliances. The confusion is an excellent example of how a complex landscape is not easily divided into discrete map classes.
- *Quercus garryana* and *Quercus lobata* also have multiple errors of commission to other *Quercus* alliances and are probably also under mapped.
- Baccharis is ubiquitous throughout Marin County comprising almost 10% of the county and, therefore, is heavily sampled. Even though the Baccharis has high producer's (78%) and user's (81%) accuracies, there are 10 errors of commission to it. Most of the errors of commission are to classes that contain *Baccharis pilularis* such as the *Toxicodendron diversilobum* – (*Baccharis pilularis*) Association, *Artemisia californica* – (*Salvia leucophylla*) Alliance, or the *Frangula californica* ssp. *californica – Baccharis pilularis / Scrophularia californica* Association. There are 13 errors of omission in the *Baccharis pilularis* Alliance, again, mostly to classes that commonly contain *Baccharis pilularis*.
- Besides the *Baccharis* map class, there is considerable confusion within the shrub map classes. For example, the *Adenostoma fasciculatum* Alliance has 5 errors of commission to *Arctostaphylos* alliances, and 7 errors of omission with the several of the other shrub alliances, confusion between the *Arctostaphylos* map classes is also common. Shrub confusion is expected, as shrub species often mix in a stand and it is often more difficult to identify individual species of shrubs from aerial imagery than it is for trees.

- As can be expected, there is some confusion between the *Pseudotsuga menziesii* Mapping Unit and the *Sequoia sempervirens* Alliance. Both species can occur in each class, and the rules separating them from one another depend on very small percentages of Sequoia.
- The freshwater wetland groups and macrogroups are commonly confused with one another, but rarely with any other map classes. These wetland herbaceous communities are often difficult to distinguish using remotely sensed methods.

5. The Marin Fine Scale Vegetation Map and the State Standard

The Marin fine scale vegetation map specifications were designed to meet the needs of the project funders and stakeholders within the available project budget. Though similar to the fine scale vegetation maps produced by the Department of Fish and Wildlife's Vegetation Mapping Program standards (https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=102342&inline) there are several important differences. CDFW VegCAMP (https://wildlife.ca.gov/Data/VegCAMP) reviewed the final Marin Fine Scale Vegetation Map, and key differences are summarized below:

> **Marin fine scale vegetation map stands are not aggregated by California Wildlife Habitat Relationship (CWHR) System cover classes**: The result is a map that is more finely segmented. The justification for keeping it this way is that the cover values in the map are very accurately derived from lidar and some people might find the fine divisions useful.
>
> *CDFW Assessment:* Stands of the same community type are broken out by cover in a way that we would consider ecologically insignificant. However, the information is all there to collapse by cover classes if the desired. There is no "loss" of information here but the user would need GIS skills to simplify the map to state standard which most users do not have.
>
> **Tree cover is really "vegetation cover that is taller than 15 feet"**: Tall shrub stands (greater than 15 feet) will have high cover for this attribute and emergent tree cover would not be noted**. Shrub cover** is estimated using our standards. The process for deriving tree cover is based solely on vegetation height above 15 feet rather than lifeform.
>
> *CDFW Assessment*: We are losing some information on habitat value with this approach by losing the ability to easily identify stands where there is emergent tree cover (an important wildlife habitat feature). In addition, this will make attribution for FVeg difficult because for CalFire standards, if trees are dominant (10% or more) then the tree cover should be based on the *tree cover* only. VegCAMP suggests future mapping efforts to consider breaking the height into 2 categories: 15-25 feet for tall shrub/low trees and >25 feet for emergent trees to better capture the tree vs. shrub strata.

Herbaceous cover is not estimated, and shrub cover is not estimated for forested stands:

CDFW Assessment: CDFW VegCAMP recommends estimating shrub, herbaceous cover, and non-native species (exotics) cover to support habitat conservation and restoration planning. For future maps we suggest estimating shrub and herbaceous cover in broad cover classes as we define in our standards: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=102342&inline.

Herbaceous classification is very broad:

CDFW Assessment: Coastal prairie vs. CA annual grassland could generally be derived by users by doing a spatial analysis on herb polygons by applying distance from coast, fog, etc. (Note: this was considered by the Marin stakeholders, who ultimately determined that doing so would introduce inconsistency within the map.) this is an acceptable limitation of the map given the additional time and effort it would require to accurately differentiate these types.

6. Marin County Vegetation Map Data Products

6.1. Introduction

One of the aims of this program is to provide well-documented fine-scale vegetation data to the public in a way that makes the data easily accessible and easy to use. This section provides an overview of the data products. Section 6.2 provides an overview of obtaining the data products and section 6.3 provides the datasheets for each of the data products.

6.2. Obtaining Data Products

The vegetation map and related products are available for download from https://pacificvegmap.org. There are numerous ways of obtaining the data products from the web site. Table 13 provides an overview of available formats for each data product. The formats for the available products are listed and described as follows:

- **Feature Service**: Streaming data from ArcGIS Online to GIS software or webmaps. Feature services are queryable (attributes are exposed to the end user) and their symbology can be changed.
- **Tile Service**: Streaming data layer from ArcGIS Online where the polygons are turned into vector tiles that draw quickly and use less bandwidth than a feature service. Tile services are not queryable and their symbology is immutable to the end user.
- **File Geodatabase**: ESRI proprietary data format containing feature classes, for use with ArcGIS Desktop products (ArcMap and ArcGIS Pro). File geodatabases are also readable by open-source mapping software packages like QGIS.
- **Layer File**: ESRI proprietary file type which can be applied to a specific layer in a map and will apply pre-defined symbology and labels to that layer.
- **Datasheet**: Text descriptions of a data product.

Table 13. *Available formats for vegetation map data products from pacficvegmap.org*

Data Product	**Feature Service**	**Tile Service**	**Countywide Geodatabase**	**Countywide Layer Package**	**Layer File**	**Datasheet**
Marin County Fine-Scale Veg Map	✓	✓	✓	✓	✓	✓
Marin County Lifeform Map		✓	✓			✓
Marin County Forest Lifeform Map			✓			✓
Marin County Impervious Surfaces	✓	✓	✓			✓
Marin County Standardized County Lands Map			✓			✓

6.3. Data Product Specifications (Datasheets)

In addition to metadata for each spatial data product, datasheets were created and made available for each of the Marin Veg Map data products. Links to the datasheets for the vegetation map and its derivatives are provided in Table 14.

Table 14. *Datasheets for vegetation map products*

Product	Datasheet Link
Marin County Fine Scale Vegetation Map	https://vegmap.press/marin_vegmap_datasheet
Marin County Lifeform Map	https://vegmap.press/marin_lifeform_datasheet
Marin County Forest Lifeform Map	https://vegmap.press/marin_forest_lifeform_datasheet
Marin County Impervious Surfaces Map	https://vegmap.press/marin_impervious_datasheet
Standardized 2004-2014 County Parks/Marin Water Vegetation Map	https://vegmap.press/marin_standardized_04_14_datasheet

6.4. Attributes of the Fine-scale Vegetation Map

The fine-scale vegetation map has 96,638 polygons countywide. Each polygon includes its fine-scale map class and a suite of information about the polygon. Information is included in the form of numerous attributes that characterize the polygon's forest structure, its impervious composition, its relative hardwood versus conifer cover, and its carbon & biomass content. Table 15 includes a list and description of the numerous fine-scale vegetation map attributes.

Table 15. *Fine-scale vegetation map attributes*

Fine Scale Map Attributes (Name/Alias)	**Description**
OID_COPY/ OID_COPY	Unique index for internal use.
MAP_CLASS_18/Fine Scale Map Class in '18	National Vegetation Classification (NVCS) map class label for all stands, as defined in Marin's fine scale mapping key.
ABBRV/Fine Scale Map Class Abbreviation	Map class abbreviations for use in cartography and visualization. A key to abbreviations is available here: https://vegmap.press/marin_vegmap_abbrevs
LIFEFORM_18/Lifeform in '18	26-class lifeform label for all stands. Labels are floristically more general than the fine scale map class and forest lifeform.
FOREST_LIFEFORM_18/Forest Lifeform in '18	30-class lifeform label for all stands. Labels are floristically more general than the fine scale map class.
ABS_COVER_19/Absolute % Tree Canopy Cover in '19	Absolute cover of trees greater than 15 feet in height. Derived from 2019 lidar data.
REL_CON_COV_18/Relative % Conifer Cover in '18	Relative conifer cover, estimating the percent of tree canopy >= 15 ft. is conifer. Derived from manual image interpretation of '18 imagery.
REL_HDW_COV_18/Relative % Hardwood Cover in '18	Relative hardwood cover, estimating the percent of tree canopy >= 15 ft. is hardwood. Derived from manual image interpretation of '18 imagery.
HDW_COVER_18/Absolute % Hardwood Cover in '18	Absolute hardwood cover, derived as: ((relative % hardwood cover/100) x (absolute % hardwood/100)) * 100
CON_COVER_18/Absolute % Conifer Cover in '18	Absolute conifer cover, derived as: ((relative % conifer cover/100) x (absolute % cover/100)) * 100
SHB_COVER_18/Absolute % Shrub Cover in '18	Absolute shrub cover for herbaceous and shrub stands. Derived from manual image interpretation of '18 imagery.
STAND_HT_MN_19/Mean LiDAR Stand Height in '19 (ft.)	Mean stand height from LiDAR-derived canopy height model (CHM).
STAND_HT_MX_19/Maximum LiDAR Stand Height in '19 (ft.)	Maximum stand height from LiDAR-derived canopy height model (CHM).
STAND_HT_SD_19/Standard Deviation LiDAR Stand Height in '19 (ft.)	Standard deviation stand height from LiDAR-derived canopy height model (CHM).
STANDING_DEAD_19/% Standing Dead 2019	Estimate of percent standing dead vegetation in forested stands. Estimates the percent of the woody canopy > 7 feet tall that did not have a living crown in late 2018/early 2019.

Fine Scale Map Attributes (Name/Alias)	**Description**
FRACAL_MORTALITY_18/% Standing Dead Frangula Californica '18	Estimate of the % standing dead cover of *Frangula Californica* in mapped coffeeberry stands. Estimate is relative to total coffeeberry cover in the stand.
CANOPY_GAP_10_19/% Canopy Gap formed '10-'19	% of stand that is a canopy gap that formed between 2010 and 2019.
LARGEST_GAP_10_19/Sq. Feet of Largest '10-'19 Gap	Largest canopy gap that formed between 2010 and 2019 in square feet.
CON_CHANGE_14_18/% Conifer Change '14-'18	% conifer cover change between 2014 and 2018. Only applies to Marin County Parks and Marin Water lands.
HDW_CHANGE_14_18/% Hardwood Change '14-'18	% hardwood cover change between 2014 and 2018. Only applies to Marin County Parks and Marin Water lands.
AGL_BIOM_2017_RATE/ Mean Aboveground Live Biomass Tons per Hectare 2017 (LEMMA)	Aboveground live biomass in tons per hectare for forestlands. Data integrated from 2017 LEMMA (https://lemmadownload.forestry.oregonstate.edu/) using the zonal statistics function.
AGL_BIOM_2017_TOT/ Total Aboveground Live Biomass Tons 2017 (LEMMA)	Aboveground live biomass in tons for forestlands. Data integrated from 2017 LEMMA (https://lemmadownload.forestry.oregonstate.edu/) using the zonal statistics function.
MEAN_LADDER_FUELS/Mean Ladder Fuels 1-4 Meters (0-1)	Mean lidar derived 'ladder fuels' for forested stands. Represents density of lidar returns between 1-4 meters above ground. Integrated from the 2019 lidar derived ladder fuels raster (https://vegmap.press/ladder_datasheet) using the zonal statistics function. The ladder fuel metric is a 0-1 metric; 0 is lowest, 1 is highest.
SLOPE_MEAN/Mean Slope Degrees	Mean slope degrees, derived from the 2019 lidar data.
SLOPE_STD/Standard Deviation Slope Degrees	Standard deviation slope degrees, derived from the 2019 lidar data.
SLOPE_MAX/Maximum Slope Degrees	Maximum slope degrees, derived from the 2019 lidar data.
Orig_Map_Class/Original Map Class	Map class from the 2004-2014 fine scale mapping efforts.
WOODWARD_FIRE_SEVERITY/ Burn Severity for Woodward Fire	Burn severity classes (from WERT burn severity data) for stands within the footprint of the 2020 Woodward fire.
ACRES/ Acres	Acres of land encompassed by the stand.
DIRT_RD_18/% Dirt and Gravel Road in '18	Percent of stand that was dirt or gravel road in 2018. Integrated from the Marin County impervious surface map.

Fine Scale Map Attributes (Name/Alias)	**Description**
OTHER_PAVED_18/% Other Paved in '18	Percent of stand that was a paved, non-road surface (such as a paved parking lot) in 2018. Integrated from the Marin County impervious surface map.
BUILDING_18/% Buildings in '18	Percent of stand that was a building in 2018. Integrated from the Marin County impervious surface map.
OTHER_DIRT_18/% Other Dirt and Gravel in '18	Percent of stand that was an unpaved, non-road impervious surface (such as a gravel parking lot) in 2018. Integrated from the Marin County impervious surface map.
PAVED_RD_18/% Paved Road in '18	Percent of stand that was paved road in 2018. Integrated from the Marin County impervious surface map.
IMPERVIOUS_18/% Impervious in '18	Percent of stand that was impervious in 2018. Integrated from the Marin County impervious surface map.
PERVIOUS_18/% Pervious in '18	Percent of stand that was pervious in 2018. Integrated from the Marin County impervious surface map.

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8. Appendix: Fine-scale Map Class Descriptions

The following pages include a one-page summary for each of the 107 map classes in the fine-scale vegetation map. The one-page summaries detail the following information for each fine-scale map class:

Photos: Two photos are provided – a ground photo taken in the field and an aerial view from imagery.

Description: Descriptions are pulled from the California Native Plant Society (CNPS) report entitled *Classification of the Vegetation Alliances and Associations of Marin County, California Volume 2 of 2 – Vegetation Descriptions* (2021). The full CNPS descriptions are available here: https://drive.google.com/file/d/1yTJ4f39rzlKVQh5MUVuUIicYlFcUJU9-/view.

The CNPS report on floristic classification methods used in Marin can be found here: https://drive.google.com/file/d/1XldHB-JKpYkku912TqiZzR2fO02L2aNJ/view?usp=sharing.

For map classes that are above the alliance level of the National Vegetation Classification (e.g., riparian groups), the descriptions are adapted from the fine-scale mapping key, which is available at this URL: https://vegmap.press/mapping_key

Most Abundant Species: The most abundant species for the map class are listed.

Membership Rules: Membership rules are included for each fine scale map class.

Acres Mapped: The number of acres of the fine-scale map class mapped countywide.